Low Temperature Physics Division
Fachverband Tiefe Temperaturen (TT)

Elke Scheer
University of Konstanz
Department of Physics
78457 Konstanz
dpg-fvtiefetemperaturen@uni-konstanz.de

Overview over the conference program of the Low Temperature Physics Division

(Lecture halls H 0104, H 2053, H 3005, H 3007, H 3010, and H 3025; Poster C and E)

Tutorial Organized by the Low Temperature Physics Division

Invited Talks of the Tutorial "Thermoelectricity - Fundamental Aspects, Materials, Applications" (joint session MA/TT)

TT 1.1	Sun	16:00–16:40	H 1058	**Transport properties of thermoelectric materials** — •Maria Ibáñez
TT 1.2	Sun	16:45–17:25	H 1058	**Thermoelectricity: basic concepts, and applications to nanoscale heat engines** — •Karol I. Wysokiński
TT 1.3	Sun	17:30–18:10	H 1058	**Novel thermoelectric materials: synthesis, characterization and application** — •Wenjie Xie

Plenary and Prize Talks Chaired by the Low Temperature Physics Division

PLV II	Mon	14:00–14:45	H 0105	**How to Rectify Supercurrents Using Electron Spin?** — •Christoph Strunk
PLV VI	Wed	14:00–14:45	H 0105	**Decoding and Steering Monitored Quantum Dynamics** — •Matthew Fisher
PRV III	Thu	13:15–13:45	H 0105	**Superconducting diode effect, magnetochiral anisotropy and other nonreciprocal effects in φ_0 Josephson junctions** — •Nicola Paradiso

Symposia Coorganized by the Low-Temperature Physics Division

Invited Talks of the Symposium SKM Dissertation Prize 2024 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	9:30–10:00	H 1012	**Nonequilibrium dynamics in constrained quantum many-body systems** — •Johannes Feldmeier
SYSD 1.2	Mon	10:00–10:30	H 1012	**Controlled Manipulation of Magnetic Skyrmions: Generation, Motion and Dynamics** — •Lisa-Marie Kern
SYSD 1.3	Mon	10:30–11:00	H 1012	**Interactions within and between cytoskeletal filaments** — •Charlotta Lorenz
SYSD 1.4	Mon	11:00–11:30	H 1012	**Field theories in nonequilibrium statistical mechanics: from molecules to galaxies** — •Michael te Vrugt
SYSD 1.5	Mon	11:30–12:00	H 1012	**Lightwave control of electrons in graphene** — •Tobias Weitz

Invited Talks of the Symposium "3D Nanostructures: From Magnetism to Superconductivity"

See SYMS for the full program of the symposium.

SYMS 1.1	Mon	9:30–10:00	H 0105	**3D Racetrack Memory** — •Stuart Parkin
SYMS 1.2	Mon	10:00–10:30	H 0105	**Curved electronics: geometry-induced effects at the nanoscale** — •Paola Gentile
SYMS 1.3	Mon	10:30–11:00	H 0105	**Curvilinear micromagnetism** — •Denys Makarov
SYMS 1.4	Mon	11:15–11:45	H 0105	**Study of 3D superconducting nanoarchitectures** — •Rosa Córdoba
SYMS 1.5	Mon	11:45–12:15	H 0105	**3D nanoarchitectures for superconductivity and magnonics** — •Oleksandr Dobrovolskiy

Invited Talks of the Symposium "Diversity and Equality in Physics"

See SYDE for the full program of the symposium.

SYDE 1.1	Tue	9:30–10:00	PTB HS HvHB	**Workplace cultures in physics as a game changer for equal opportunities** — •Martina Erlemann
SYDE 1.2	Tue	10:00–10:30	PTB HS HvHB	**Science on the Web: How networks bias academic communication online** — •Agnes Horvat
SYDE 1.3	Tue	10:30–11:00	PTB HS HvHB	**Citation inequity and gendered citation practices in contemporary physics** — •Erin Teich
SYDE 1.4	Tue	11:15–11:45	PTB HS HvHB	**The Diversity-Innovation Paradox in Science** — •Bas Hofstra
SYDE 1.5	Tue	11:45–12:15	PTB HS HvHB	**Gender and retention patterns among U.S. faculty** — •Aaron Clauset

Invited Talks of the Symposium "Emerging Materials for Renewable Energy Conversion"

See SYEM for the full program of the symposium.

SYEM 1.1	Wed	9:30–10:00	H 0105	**Non-critical Materials Production for a Green Energy Transition** — •Anke Weidenkaff
SYEM 1.2	Wed	10:00–10:30	H 0105	**Strategies for the morphological design of photoactive oxynitride particles and electrodes for solar water-splitting.** — •Simone Pokrant
SYEM 1.3	Wed	10:30–11:00	H 0105	**Computational workflows for an accelerated design of novel materials and interfaces** — •Ivano Eligio Castelli
SYEM 1.4	Wed	11:30–11:45	H 0105	**Autonomous composition control of emerging nitride materials for solar energy conversion** — •Andriy Zakutayev
SYEM 1.5	Wed	11:45–12:00	H 0105	**Understanding and tailoring the catalytic activity of spinel and perovskite surfaces from first principles calculations** — •Rossitza Pentcheva
SYEM 1.6	Wed	12:00–12:15	H 0105	**Mastering Compositional Complexity in High Entropy Materials for Energy Applications - Towards Accelerated Materials Discovery by Integration of High-throughput Experimentation, Simulation, and Materials Informatics** — •Alfred Ludwig

Invited Talks of the Symposium "Entanglement in Quantum Information, Condensed Matter and Gravity"

See SYQI for the full program of the symposium.

SYQI 1.1	Wed	15:00–15:30	H 0105	**The Quantum Internet: Concepts, Challenges and Progress** — •Ronald Hanson

SYQI 1.2	Wed	15:30–16:00	H 0105	**Strange metals - A platform to study entanglement in condensed matter?** — •Silke Paschen
SYQI 1.3	Wed	16:00–16:30	H 0105	**Quantum black holes may not have interiors** — •Vijay Balasubramanian
SYQI 1.4	Wed	16:30–17:00	H 0105	**Gauge Symmetry-Resolved Entanglement in Lattice Gauge Theories: A Tensor Network Approach** — •Moshe Goldstein
SYQI 1.5	Wed	17:00–17:30	H 0105	**Parameter estimation of gravitational waves with a quantum metropolis algorithm** — •Miguel Angel Martin - Delgado

Invited Talks of the Symposium "Quantum Communication: Promises or Reality?"

See SYQC for the full program of the symposium.

SYQC 1.1	Fri	9:30–10:00	H 0105	**Efficient Quantum Dot Micropillars for Quantum Networks** — •Ruth Oulton
SYQC 1.2	Fri	10:00–10:30	H 0105	**Superconducting Single Photon Detectors - Limited only by the laws of physics** — •Andreas Fognini
SYQC 1.3	Fri	10:45–11:15	H 0105	**Laser triggering of quantum light sources using engineered optical pulses** — •Kimberley Hall
SYQC 1.4	Fri	11:15–11:45	H 0105	**Quantum Networks and Technologies** — •Rob Thew

Focus Sessions Jointly Organized with Other Divisions

Invited Talks of the Focus Session "Quantum Interactive Dynamics" (joint session DY/TT)

TT 8.1	Mon	9:30–10:00	A 151	**Quantum information phases in space-time: measurement-induced entanglement and teleportation on a noisy quantum processor** — •Vedika Khemani
TT 8.2	Mon	10:00–10:30	A 151	**Measurement phase transitions and universality** — •Adam Nahum
TT 8.3	Mon	10:30–11:00	A 151	**Dual-unitary circuit dynamics** — •Pieter Claeys
TT 17.1	Mon	15:00–15:30	A 151	**Quantum Mechanics and Many Body Games** — •Shivaji Sondhi
TT 17.2	Mon	15:30–16:00	A 151	**Measurement induced phase transitions of fermions: from theory to observability** — •Sebastian Diehl

Invited Talks of the Focus Session "Frustrated Magnetism and Local Order" (joint session MA/TT)

TT 22.1	Tue	9:30–10:00	H 1058	**Neutron scattering studies of spin-freezing phenomena at quantum phase transitions** — •Christian Pfleiderer
TT 22.2	Tue	10:00–10:30	H 1058	**Frustrations, glassiness and complexity of spin systems with large spatial dimension** — •Mikhail Katsnelson
TT 22.3	Tue	10:30–11:00	H 1058	**Self-Induced Spin Glass Phase and Thermally Induced Order in dhcp Nd** — •Anders Bergman
TT 22.6	Tue	11:45–12:15	H 1058	**Frustrated Quantum Devices: Pathways to leverage exotic order in novel spintronic technologies** — •James Analytis
TT 22.9	Tue	12:45–13:15	H 1058	**New Frontiers in Artificial Spin Ice: Phase Transitions in Two and Three Dimensions** — •Gavin M. Macauley

Invited Talks of the Focus Session "Exploring Quantum Entanglement with Superconducting Qubits and Resonators" (joint session QI/TT)

TT 30.1	Tue	9:30–10:00	HFT-FT 131	**Loophole-free Bell Inequality Violation with Superconducting Circuits** — •Andreas Wallraff
TT 30.2	Tue	10:00–10:30	HFT-FT 131	**Microwave quantum networks** — •Kirill G. Fedorov
TT 30.6	Tue	11:30–12:00	HFT-FT 131	**Quantum sensing of axionic dark matter with a phase resolved haloscope** — •Audrey Cottet
TT 30.7	Tue	12:00–12:30	HFT-FT 131	**Demonstration of Quantum Advantage in Microwave Quantum Radar** — •Audrey Bienfait

Topical Talks of the Focus Session "Spin Phenomena in Chiral Molecular Systems" (joint session O/TT)

TT 32.1	Tue	10:30–11:00	MA 141	**The Electron's Spin and Chirality - a Miraculous Match** — •Ron Naaman
TT 32.3	Tue	11:30–12:00	MA 141	**Electrical Dipole Moment Governs Spin Polarization in Charge Transport in Single α-helical Peptides Junctions** — •Ismael Diez-Perez
TT 32.2	Tue	11:00–11:30	MA 141	**Electrons, Vibrations and Chirality** — •Martin B. Plenio
TT 32.7	Tue	12:45–13:15	MA 141	**First-principles approaches to chiral induced spin selectivity** — •Carmen Herrmann
TT 43.1	Wed	10:30–11:00	MA 141	**Chiral-induced Spin Selectivity in Hybrid Chiral Molecule/ Metal Systems** — •Angela Wittmann
TT 43.2	Wed	11:00–11:30	MA 141	**Chirality-induced spin selectivity at the single-molecule scale** — •Daniel Emil Bürgler

Invited Talks of the Focus Session "Recent progresses in criticality in the presence of boundaries and defects" (joint session DY/TT)

TT 40.1	Wed	9:30–10:00	A 151	**Boundary behavior at classical and quantum phase transitions** — •Max Metlitski
TT 40.6	Wed	11:15–11:45	A 151	**Criticality senses topology** — •Anna Maciolek
TT 56.1	Wed	15:00–15:30	A 151	**Conformal boundary conditions of symmetric quantum critical states** — •Long Zhang

Invited Talks of the Focus Session "Unconventional Thermoelectric Phenomena and Materials" (joint session MA/TT)

TT 48.1	Wed	15:00–15:30	H 1058	**Enhanced Nernst effect in van der Waals tellurides** — •H. Reichlova
TT 48.2	Wed	15:30–16:00	H 1058	**Hybrid transverse magneto-thermoelectric cooling in artificially tilted multilayers** — •Ken-ichi Uchida
TT 48.3	Wed	16:00–16:30	H 1058	**Nonlocal heat engines with hybrid quantum dot systems** — •Rafael Sánchez
TT 48.4	Wed	16:45–17:15	H 1058	**Large anomalous Nernst thermoelectric performance in $YbMnBi_2$** — •Yu Pan
TT 48.5	Wed	17:15–17:45	H 1058	**A path to suistainable and scalable production of high-performance thermoelectric materials** — •Maria Ibáñez

Invited Talks of the Focus Session “$SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor” (joint session KFM/MA/O/TT)

TT 62.1	Thu	9:30–10:00	H 0104	**Ferroelectricity and Superconductivity in $SrTiO_3$** — •Susanne Stemmer
TT 62.2	Thu	10:00–10:30	H 0104	**Dilute superconductivity in doped strontium titanate** — •Kamran Behnia
TT 62.3	Thu	10:30–11:00	H 0104	**Polarons and Excitons in quantum-paraelectric $SrTiO_3$** — •Cesare Franchini
TT 62.4	Thu	11:15–11:45	H 0104	**Controlling ferroelectrics with light** — •Andrea Cavalleri
TT 62.5	Thu	11:45–12:15	H 0104	**Terahertz electric field driven dynamical multiferroicity in $SrTiO_3$** — •Stefano Bonetti

Invited Talks of the Focus Session “Nanomechanical systems for classical and quantum sensing applications” (joint session HL/QI/TT)

TT 70.1	Thu	9:30–10:00	EW 202	**Quantum sensors and memories based on soft-clamped phononic membrane resonators** — •Albert Schliesser
TT 70.2	Thu	10:00–10:30	EW 202	**Quantum mechanics-free subsystem with mechanical oscillators** — •Laure Mercier de Lepinay
TT 70.3	Thu	10:30–11:00	EW 202	**Electrothermally tunable metal-graphene-siliconnitride membrane mechanical device** — •Elke Scheer
TT 70.4	Thu	11:15–11:45	EW 202	**From Nanomechanics to Spins** — •Christian Degen
TT 70.5	Thu	11:45–12:15	EW 202	**Enhanced cooling efficiency in nonlinear cavity optomechanics** — •Anja Metelmann

Invited Talks of the Focus Session “Emerging Magnetic Phenomena from Chiral Phonons” (joint session MA/TT)

TT 63.1	Thu	9:30–10:00	H 1058	**Giant effective magnetic fields from chiral phonons** — •Dominik M. Juraschek
TT 63.2	Thu	10:00–10:30	H 1058	**Chiral phonons in quantum materials revealed by the thermal Hall effect** — •Gael Grissonnanche
TT 63.3	Thu	10:30–11:00	H 1058	**Phonon chirality and thermal Hall transport** — •Benedetta Flebus
TT 63.4	Thu	11:15–11:45	H 1058	**Orbital magnetic moment of phonons in diamagnetic and paraelectric perovskites** — •Martina Basini
TT 63.5	Thu	11:45–12:15	H 1058	**Spin-lattice coupling in multiscale modeling** — •Markus Weissenhofer

Invited Talks of the Focus Session “Evolution of Topological Materials into Superconducting Nanodevices” (joint session HL/TT)

TT 89.1	Fri	9:30–10:00	EW 202	**Tunneling spectroscopy of a phase-tunable topological insulator Josephson junction** — •Jakob Schluck
TT 89.2	Fri	10:00–10:30	EW 202	**Robust Majorana modes in topological material-based nanoelectronic hybrid devices** — •Kristof Moors
TT 89.3	Fri	10:30–11:00	EW 202	**Thermal and electric response of superconducting topological materials; are Majorana states more widespread than expected?** — •Ewelina Hankiewicz
TT 89.4	Fri	11:15–11:45	EW 202	**Tunable Josephson coupling in HgTe nanodevices** — •Martin P. Stehno
TT 89.5	Fri	11:45–12:15	EW 202	**Superconducting proximity effect in topological Dirac materials** — •Chuan Li
TT 89.6	Fri	12:15–12:45	EW 202	**Exploring Josephson Junctions made of Topological Insulator Wires and Superconductors** — •Dieter Weiss

Focus Sessions of the Low Temperature Physics Division

Invited Talks of the Focus Session "Artificial Intelligence in Condensed Matter Physics"

TT 2.1	Mon	9:30–10:00	H 0104	**Exploring artificial intelligence for engineered quantum matter** — •Eliska Greplova
TT 2.2	Mon	10:00–10:30	H 0104	**Communicability as a criterion for interpretable representations** — •Renato Renner
TT 2.3	Mon	10:30–11:00	H 0104	**Disentangling Multiqubit States using Deep Reinforcement Learning** — •Marin Bukov
TT 2.4	Mon	11:15–11:45	H 0104	**Neural Quantum States For The Many-Electron Problem** — •Giuseppe Carleo
TT 2.5	Mon	11:45–12:15	H 0104	**Neural quantum states for strongly correlated systems: learning from data and Hamiltonians** — •Annabelle Bohrdt
TT 2.6	Mon	12:15–12:45	H 0104	**Towards an Artificial Muse for new Ideas in Quantum Physics** — •Mario Krenn

Invited Talks of the Focus Session "Anomalous Quantum Oscillations"

TT 9.1	Mon	15:00–15:30	H 0104	**Unusual Magnetic Oscillations in Kagome Mott Insulators** — •Lu Li
TT 9.2	Mon	15:30–16:00	H 0104	**Quantum oscillations in small-gap insulators** — •Nigel Cooper
TT 9.3	Mon	16:00–16:30	H 0104	**Quantum Oscillations of the Quasiparticle Lifetime in a Metal** — •Nico Huber
TT 9.4	Mon	16:45–17:15	H 0104	**Simplicity of quantum oscillations in CoSi from its hidden quasi-symmetry** — •Philip J.W. Moll
TT 9.5	Mon	17:15–17:45	H 0104	**Quantum oscillations of superconducting iron-chalcogenides $FeSe_{1-x}S_x$** — •Amalia Coldea

Invited Talks of the Focus Session "Strongly Disordered Superconductors"

TT 21.1	Tue	9:30–10:00	H 0104	**The fate of the superfluid density near the superconductor-insulator transition** — •Benjamin Sacepe
TT 21.2	Tue	10:00–10:30	H 0104	**Vortices in dirty superconducting films** — •Elio König
TT 21.3	Tue	10:30–11:00	H 0104	**Superfluid stiffness of a strongly disordered superconductor close to the superconductor-insulator transition** — •Alexander Weitzel
TT 21.4	Tue	11:15–11:45	H 0104	**Thermally enhanced superconductivity and photonic dissipation in Josephson junction arrays** — •Andrew P. Higginbotham
TT 21.5	Tue	11:45–12:15	H 0104	**Spectral Gap and Order Parameter Statistics in Disordered Superconducting Films** — •Matthias Stosiek

Invited Talks of the Focus Session "Dynamical Probes for Topological Magnetism"

TT 34.1	Wed	9:30–10:00	H 0104	**A phononic route to ultrafast control of magnetic order** — •Andrei Kirilyuk
TT 34.2	Wed	10:00–10:30	H 0104	**Spectroscopic signatures of spin dynamics in spin-orbit-coupled magnets: resolving quantum spin liquids versus magnetically ordered phases** — •Roser Valenti
TT 34.3	Wed	10:30–11:00	H 0104	**Probing spin dynamics by Hall effect and emergent inductance** — •Max Hirschberger
TT 34.4	Wed	11:15–11:45	H 0104	**Dissipative Spin-wave Diode and Nonreciprocal Magnonic Amplifier** — •Jelena Klinovaja
TT 34.5	Wed	11:45–12:15	H 0104	**Floquet magnons in a periodically-driven magnetic soliton** — •Helmut Schultheiss

Individual Invited Talks of the Low Temperature Physics Division

TT 4.1	Mon	9:30–10:00	H 3005	**Hyperfine interactions and nuclear-electronic quantum criticality in $PrOs_4Sb_{12}$** — •Alix McCollam
TT 3.5	Mon	10:30–11:00	H 2053	**Topological Thermal Hall Conductance of Even Denominator Fractional States** — •Moty Heiblum
TT 6.8	Mon	11:30–12:00	H 3010	**Theory of supercurrent diode effect and other spin-orbit-driven phenomena in superconducting magnetic junctions** — •Andreas Costa
TT 19.1	Mon	16:15–16:45	H 3025	**Quantum thermodynamics and its statistical mechanics: Facts, debatable issues and still unsolved problems** — •Peter Hänggi
TT 52.1	Wed	15:00–15:30	H 3010	**A tale of two kinds of superconducting nickelates** — •Frank Lechermann
TT 67.1	Thu	9:30–10:00	H 3007	**Giant lattice softening at a uniaxial-pressure-tuned Lifshitz transition in the unconventional superconductor Sr_2RuO_4** — •Hilary M. L. Noad
TT 85.1	Fri	9:30–10:00	H 3005	**Majorana bound states in artificial Kitaev chains** — •Srijit Goswami

All Sessions

TT 1.1–1.3	Sun	16:00–18:10	H 1058	**Tutorial: Thermoelectricity – Fundamental Aspects, Materials, Applications (joint session TT/TUT/MA)**
TT 2.1–2.8	Mon	9:30–13:15	H 0104	**Focus Session: Artificial Intelligence in Condensed Matter Physics I (joint session TT/DY)**
TT 3.1–3.12	Mon	9:30–13:00	H 2053	**Topology: Quantum Hall Systems**
TT 4.1–4.12	Mon	9:30–13:00	H 3005	**f-Electron Systems**
TT 5.1–5.14	Mon	9:30–13:15	H 3007	**Nickelates I**
TT 6.1–6.12	Mon	9:30–13:00	H 3010	**Superconductivity: Tunnelling and Josephson Junctions I**
TT 7.1–7.11	Mon	9:30–12:30	H 3025	**Correlated Electrons: Electronic Structure Calculations**
TT 8.1–8.10	Mon	9:30–12:45	A 151	**Focus Session: Quantum Interactive Dynamics I (joint session DY/TT)**
TT 9.1–9.7	Mon	15:00–18:15	H 0104	**Focus Session: Anomalous Quantum Oscillations**
TT 10.1–10.11	Mon	15:00–18:00	H 2053	**Topology: Majorana Physics I**
TT 11.1–11.9	Mon	15:00–17:30	H 3005	**Heavy Fermions**
TT 12.1–12.6	Mon	15:00–16:30	H 3007	**Fluctuations and Noise**
TT 13.1–13.12	Mon	15:00–18:15	H 3010	**Kagome Systems**
TT 14.1–14.4	Mon	15:00–16:00	H 3025	**Artificial Intelligence in Condensed Matter Physics II (joint session TT/DY)**
TT 15.1–15.11	Mon	15:00–18:00	EW 202	**Focus Session: Evolution of Topological Materials into Superconducting Nanodevices (joint session HL/TT)**
TT 16.1–16.10	Mon	15:00–17:30	MA 005	**2D Materials I: Electronic Structure (joint session O/TT)**
TT 17.1–17.9	Mon	15:00–18:00	A 151	**Focus Session: Quantum Interactive Dynamics II (joint session DY/TT)**
TT 18.1–18.71	Mon	15:00–18:00	Poster C	**Superconductivity: Poster**
TT 19.1–19.6	Mon	16:15–18:00	H 3025	**Quantum Coherence (joint session TT/DY)**
TT 20.1–20.6	Mon	16:45–18:15	H 3007	**Quantum Dots and Quantum Wires (joint session TT/HL)**
TT 21.1–21.7	Tue	9:30–12:45	H 0104	**Focus Session: Strongly Disordered Superconductors**
TT 22.1–22.9	Tue	9:30–13:15	H 1058	**Focus Session: Frustrated Magnetism and Local Order (joint session MA/TT)**
TT 23.1–23.13	Tue	9:30–13:00	H 2013	**Topological Insulators and Weyl Semimetals (joint session MA/TT)**
TT 24.1–24.14	Tue	9:30–13:15	H 2053	**Quantum-Critical Phenomena**
TT 25.1–25.13	Tue	9:30–13:00	H 3005	**Nonequilibrium Quantum Systems I (joint session TT/DY)**
TT 26.1–26.8	Tue	9:30–11:30	H 3007	**Nanotubes and Nanoribbons**
TT 27.1–27.13	Tue	9:30–13:00	H 3010	**Correlated Electrons: Other Materials**
TT 28.1–28.10	Tue	9:30–12:15	H 3025	**Topology: Other Topics**

TT 29.1–29.13	Tue	9:30–13:00	A 151	**Many-Body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)**
TT 30.1–30.11	Tue	9:30–13:30	HFT-FT 131	**Focus Session: Exploring Quantum Entanglement with Superconducting Qubits and Resonators (joint session QI/TT)**
TT 31.1–31.6	Tue	10:30–12:15	MA 005	**2D Materials II: Electronic Structure (joint session O/TT)**
TT 32.1–32.7	Tue	10:30–13:15	MA 141	**Focus Session: Spin Phenomena in Chiral Molecular Systems I (joint session O/TT)**
TT 33.1–33.5	Tue	11:45–13:00	H 3007	**Focus Session: Nanomechanical Systems for Classical and Quantum Sensing I (joint session TT/DY/HL/QI)**
TT 34.1–34.5	Wed	9:30–12:15	H 0104	**Focus Session: Dynamical Probes for Topological Magnetism**
TT 35.1–35.14	Wed	9:30–13:15	H 2053	**Superconducting Electronics: SQUIDs, Circuit QED**
TT 36.1–36.13	Wed	9:30–13:00	H 3005	**Superconductivity: Theory I**
TT 37.1–37.7	Wed	9:30–11:15	H 3007	**Graphene and 2D Materials (joint session TT/HL)**
TT 38.1–38.7	Wed	9:30–11:15	H 3010	**Topological Semimetals I**
TT 39.1–39.10	Wed	9:30–12:15	H 3025	**Correlated Electrons: Charge Order**
TT 40.1–40.9	Wed	9:30–12:30	A 151	**Focus Session: Recent Progresses in Criticality in the Presence of Boundaries and Defects I (joint session DY/TT)**
TT 41.1–41.14	Wed	9:30–13:15	HFT-FT 131	**Superconducting Qubits (joint session QI/TT)**
TT 42.1–42.10	Wed	10:30–13:00	MA 005	**2D Materials III: Electronic Structure (joint session O/TT)**
TT 43.1–43.6	Wed	10:30–12:30	MA 141	**Focus Session: Spin Phenomena in Chiral Molecular Systems II (joint session O/TT)**
TT 44.1–44.6	Wed	11:30–13:00	H 3007	**Twisted Materials / Systems**
TT 45.1–45.7	Wed	11:30–13:15	H 3010	**$PtBi_2$ and Weyl Superconductors**
TT 46.1–46.5	Wed	11:45–13:00	EW 202	**Focus Session: Evolution of Topological Materials into Superconducting Nanodevices (joint session HL/TT)**
TT 47.1–47.13	Wed	15:00–18:15	H 0104	**Superconducting Electronics: Qubits I (joint session TT/QI)**
TT 48.1–48.5	Wed	15:00–17:45	H 1058	**Focus Session: Unconventional Thermoelectric Phenomena and Materials (joint session MA/TT)**
TT 49.1–49.12	Wed	15:00–18:15	H 2053	**Frustrated Magnets: Strong Spin-Orbit Coupling I**
TT 50.1–50.11	Wed	15:00–18:00	H 3005	**Superconductivity: Theory II**
TT 51.1–51.8	Wed	15:00–17:00	H 3007	**Topological Semimetals II**
TT 52.1–52.4	Wed	15:00–16:15	H 3010	**Nickelates II**
TT 53.1–53.10	Wed	15:00–17:45	EW 202	**Focus Session: Nanomechanical Systems for Classical and Quantum Sensing II (joint session HL/DY/TT/QI)**
TT 54.1–54.11	Wed	15:00–18:00	MA 005	**2D Materials IV: Graphene (joint session O/TT)**
TT 55.1–55.11	Wed	15:00–17:45	HL 001	**Topology and Symmetry Protected Materials (joint session O/TT)**
TT 56.1–56.4	Wed	15:00–16:15	A 151	**Focus Session: Recent Progresses in Criticality in the Presence of Boundaries and Defects II (joint session DY/TT)**
TT 57.1–57.23	Wed	15:00–18:00	Poster E	**Topology: Poster**
TT 58.1–58.7	Wed	15:00–18:00	Poster E	**$SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor: Poster (joint session TT/KFM/MA/O)**
TT 59.1–59.19	Wed	15:00–18:00	Poster E	**Transport: Poster**
TT 60.1–60.7	Wed	16:00–17:45	H 3025	**Cryogenic Detectors and Sensors, Refrigeration and Thermometry**
TT 61.1–61.6	Wed	16:30–18:00	H 3010	**Correlated Electrons: 1D Theory**
TT 62.1–62.7	Thu	9:30–12:45	H 0104	**Focus Session: $SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor I (joint session TT/KFM/MA/O)**
TT 63.1–63.5	Thu	9:30–12:15	H 1058	**Focus Session: Emerging Magnetic Phenomena from Chiral Phonons I (joint session MA/TT)**
TT 64.1–64.12	Thu	9:30–12:45	H 2013	**Spin Transport and Orbitronics, Spin-Hall Effects I (joint session MA/TT)**
TT 65.1–65.13	Thu	9:30–13:00	H 2053	**Frustrated Magnets: General I**
TT 66.1–66.11	Thu	9:30–12:30	H 3005	**Superconductivity: Yu-Shiba-Rusinov and Andreev Physics**

TT 67.1–67.13	Thu	9:30–13:15	H 3007	**Unconventional Superconductors**
TT 68.1–68.14	Thu	9:30–13:15	H 3010	**Superconductivity: Properties and Electronic Structure**
TT 69.1–69.13	Thu	9:30–13:00	H 3025	**Nonequilibrium Quantum Systems II (joint session TT/DY)**
TT 70.1–70.8	Thu	9:30–13:00	EW 202	**Focus Session: Nanomechanical Systems for Classical and Quantum Sensing III (joint session HL/DY/TT/QI)**
TT 71.1–71.13	Thu	9:30–13:00	A 151	**Many-Body Quantum Dynamics I (joint session DY/TT)**
TT 72.1–72.11	Thu	15:00–18:00	H 0104	**$SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor II (joint session TT/KFM/MA/O)**
TT 73.1–73.5	Thu	15:00–16:15	H 2053	**Superconducting Electronics: Qubits II (joint session TT/QI)**
TT 74.1–74.11	Thu	15:00–18:00	H 3005	**Topological Insulators**
TT 75.1–75.10	Thu	15:00–17:45	H 3007	**Low Dimensional Systems**
TT 76.1–76.10	Thu	15:00–17:45	H 3010	**Superconductivity: Tunnelling and Josephson Junctions II**
TT 77.1–77.6	Thu	15:00–16:30	H 3025	**Frustrated Magnets: Strong Spin-Orbit Coupling II**
TT 78.1–78.4	Thu	15:00–16:00	EB 107	**Spin Transport and Orbitronics, Spin-Hall Effects II (joint session MA/TT)**
TT 79.1–79.10	Thu	15:00–17:45	A 151	**Quantum Chaos and Coherent Dynamics (joint session DY/TT)**
TT 80.1–80.59	Thu	15:00–18:00	Poster E	**Correlated Electrons: Poster**
TT 81.1–81.6	Thu	16:30–18:00	H 2053	**Frustrated Magnets: General II**
TT 82	Thu	18:05–19:30	H 3005	**Members' Assembly**
TT 83.1–83.11	Fri	9:30–12:30	H 0104	**$SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor III (joint session TT/KFM/MA/O)**
TT 84.1–84.8	Fri	9:30–11:30	H 1058	**Focus Session: Emerging Magnetic Phenomena from Chiral Phonons II (joint session MA/TT)**
TT 85.1–85.7	Fri	9:30–11:30	H 3005	**Topology: Majorana Physics II**
TT 86.1–86.14	Fri	9:30–13:15	H 3007	**Correlated Electrons: Method Development**
TT 87.1–87.14	Fri	9:30–13:15	H 3010	**Frustrated Magnets: Spin Liquids**
TT 88.1–88.9	Fri	9:30–12:15	EW 201	**2D Materials and Heterostuctures: (Twisted) Bilayers (joint session HL/TT)**
TT 89.1–89.6	Fri	9:30–12:45	EW 202	**Focus Session: Evolution of Topological Materials into Superconducting Nanodevices (joint session HL/TT)**
TT 90.1–90.4	Fri	9:30–10:30	A 151	**Many-Body Quantum Dynamics II (joint session DY/TT)**
TT 91.1–91.9	Fri	10:30–12:45	MA 005	**2D Materials VII: Heterostructures (joint session O/TT)**
TT 92.1–92.9	Fri	10:45–13:00	A 151	**Quantum Dynamics, Decoherence and Quantum Information (joint session DY/TT)**

Members' Assembly of the Low Temperature Physics Division

Thursday 18:05–19:30 H 3005

ALL members – group leaders, group members, professors, postdocs, doctoral candidates and students – are welcome to attend! Please feel free to send items to discuss in the topic "Miscellaneous" to the above-indicated e-mail address.

- Report on the current meeting
- Outlook 2024, 2025
- Miscellaneous

TT 1: Tutorial: Thermoelectricity – Fundamental Aspects, Materials, Applications (joint session TT/TUT/MA)

Thermoelectric effects have been discussed for several decades and have found widespread applications. Characteristic physical quantities are the efficiency, the figure of merit, ZT, and the power factor. In particular, increasing ZT has been the issue for many years. In recent developments, the focus has been on "unconventional" thermoelectric phenomena and materials: these include, in particular, transverse thermoelectric effects where the generated charge current is perpendicular to the temperature gradient, as can be observed, e.g., when applying a magnetic field (ordinary and anomalous Nernst effect). Transverse thermoelectricity can be found even without a magnetic field, e.g., in goniopolar materials (which have n- and p-type parts of the Fermi surface at the same time). – The Tutorial, jointly organized by the divisions MA and TT, will cover the basic physics of thermoelectricity, as well as discuss the question which materials are most useful for which applications, respectively. Attending the Tutorial thus will allow the non-experts in the field to fully appreciate the related presentations in the conference.

Organizers: Ulrich Eckern (University of Augsburg), Claudia Felser (MPI CPS Dresden), Anke Weidenkaff (TU Darmstadt & Fraunhofer IWKS)

Time: Sunday 16:00–18:10 Location: H 1058

Tutorial TT 1.1 Sun 16:00 H 1058
Transport properties of thermoelectric materials — •Maria Ibáñez — Institute of Science and Technology (ISTA), Klosterneuburg, Austria

Thermoelectricity is the phenomenon of converting heat directly into electricity and vice versa. As energy harvesters, thermoelectric devices can be used to partially recover large quantities of the waste heat to reduce our primary energy production or to run low-power devices, especially those that require autonomy, such as sensors and transmitters in remote or difficult-to-access locations. Furthermore, its reversible nature allows thermoelectric devices to be operated as precise coolers for small-scale temperature control. Such localized cooling is crucial in infrared detectors, microelectronics, and optoelectronics, among others, where space is limited, and heat dissipation is localized. This lecture will provide a comprehensive introduction to thermoelectricity. We will begin by giving a brief history of thermoelectrics, a description of the phenomenon, and its potential applications. Later on, we will introduce the fundamental principles of thermoelectricity, emphasizing the importance of material properties, in particular, those related to electronic and thermal transport. We will present the thermoelectric figure of merit and its significance as a metric for evaluating thermoelectric efficiency. ZT components, including electrical conductivity, Seebeck coefficient, and thermal conductivity, and their interplay in determining the overall performance will be deeply evaluated, and the different strategies to maximize performance will be presented using, as examples, traditional thermoelectric materials.

5 min. break

Tutorial TT 1.2 Sun 16:45 H 1058
Thermoelectricity: basic concepts, and applications to nanoscale heat engines — •Karol I. Wysokiński — Institute of Physics, M. Curie-Sklodowska University, Lublin, Poland

Thermoelectric power generators directly convert heat into electricity. These solid-state heat engines have no moving parts and are extremely reliable. Their performance is characterized by efficiency and power output, both of which depend on a single parameter called the thermoelectric figure of merit ZT, of which they are monotonically increasing functions. The dimensionless parameter ZT depends on the materials' transport coefficients: conductivity, thermal conductivity, Seebeck coefficient, and operating temperature. However, due to the coupling between conductivity and thermal conductivity quantified by the Wiedemann-Franz ratio obeyed by standard materials, the quest to increase ZT is a challenge for contemporary materials physics. Novel materials and structures have been proposed to overcome these difficulties on the way to achieve efficient waste heat harvesters with possible applications at large and small scales.

During the lecture, the above main ideas in the theory of thermoelectricity will be discussed, and their application in the nanoscale illustrated by the analysis of the devices consisting of a single or two quantum dots, tunnel coupled to two or more external electrodes. The electrodes may be simple metals, ferromagnets, or superconductors. The steady-state transport characteristics of the devices will be analysed. Special attention will be paid to the role of interactions between the carriers, and the non-linear effects prevalent in such structures.

5 min. break

Tutorial TT 1.3 Sun 17:30 H 1058
Novel thermoelectric materials: synthesis, characterization and application — •Wenjie Xie — Institute of Materials Science, Technical University of Darmstadt, Darmstadt, Germany — Fraunhofer IWKS, Alzenau, Germany

Thermoelectricity offers a direct and highly efficient approach for converting heat into electricity, relying on two key factors: Carnot efficiency and the materials-dependent property, ZT. Over the past two decades, significant progress has been made in pursuing high ZT thermoelectric materials, culminating in a bulk ZT surpassing 3. In this presentation, we offer a comprehensive review of the development of novel thermoelectric materials, categorized according to their application temperature ranges: low/room, medium, and high temperatures.

Within each temperature range, we will focus on the synthesis and characterization of one or two exemplary materials. For instance, the discussion will delve into materials such as Bi_2Te_3 for room temperature applications, SnSe/PbTe for medium temperature regimes, and the utilization of half-Heusler and oxide materials for high-temperature scenarios. Furthermore, the sustainable aspects of thermoelectric material synthesis will be explored.

Last, we will discuss the practical application of thermoelectric materials, examining their usage in real-world scenarios. The discussion will mainly focus on Bi_2Te_3, half-Heusler, and oxides, providing a comprehensive overview of the current landscape and future potential in the realm of thermoelectric cooling and power generation.

TT 2: Focus Session: Artificial Intelligence in Condensed Matter Physics I (joint session TT/DY)

While artificial intelligence leaves an ever growing footprint in our everyday lives, it has as well inspired various new approaches in the physical sciences; for instance, one of the outstanding success stories is the prediction of protein folding with unprecedented accuracy. But what role can AI play in condensed matter physics? This symposium aims to provide an overview and discussion of recent applications of modern machine learning and its prospects for the advancement of research in this field. The increasingly data-intensive experiments with high-dimensional observations call for the development of new tools for analysis matching known strengths of machine learning algorithms. Reinforcement learning agents can be employed to precisely manipulate many-body systems, which, among other use cases, is a pivotal ingredient for quantum technologies. On the computational side, ideas from deep learning and generative modeling inspire new building blocks to boost numerical simulations. One may even ask the question whether a machine can autonomously discover physical concepts such as effective degrees of freedom or equations of motion, and reveal them in an interpretable manner to human researchers.
Please note the second part of this session which will take place this afternoon, TT 14 (15:00 – 16:00) in the lecture Hall H3025.

Prof. Dr. Simon Trebst, Universität Köln
Prof. Dr. Florian Marquardt, Max-Planck-Institut Erlangen
Dr. Markus Schmitt, FZ Jülich

Time: Monday 9:30–13:15 Location: H 0104

Invited Talk TT 2.1 Mon 9:30 H 0104
Exploring artificial intelligence for engineered quantum matter — •Eliska Greplova — Kavli Institute of Nanoscience, Delft University of Technology, Netherlands

In research labs worldwide, quantum physics is making unprecedented strides. The realization of robust quantum systems holds tremendous promise for applications in secure communication and computing. Yet, as physicists, our most exciting pursuit lies in experimentally testing quantum phenomena predicted over the past century within highly controlled environments. In this talk, I will explore artificial intelligence approaches in the field of engineered quantum matter. Throughout the seminar, we will uncover how these approaches can be effectively deployed in contemporary quantum experiments. As one example, I will show how we can utilize generative models for parameter prediction of engineered topological systems known as Kitaev chains. Using this result and similar examples, I will discuss how we can use ML techniques to pave the way for advancing our control and understanding of real quantum experiments.

Invited Talk TT 2.2 Mon 10:00 H 0104
Communicability as a criterion for interpretable representations — •Renato Renner — ETH Zürich, Zürich, Switzerland

We propose an autoencoder architecture that can generate representations of data from physical experiments which are operationally meaningful and thus interpretable. The architecture is based on the paradigm of "communicability". Roughly, the idea is that the encoder orders the data into several parts that may be communicated separately to agents, whose task is to answer different questions about the data. The encoding is then optimised so that this communication is minimised, i.e., each agent receives precisely the information that is relevant to its task. Using some toy examples, including ones from quantum state tomography, we show that this approach leads to a separation of parameters, which can be regarded as a step towards interpretability.

Invited Talk TT 2.3 Mon 10:30 H 0104
Disentangling Multiqubit States using Deep Reinforcement Learning — •Marin Bukov — Max Planck Institute for the Physics of Complex Systems

Quantum entanglement plays a central role in modern quantum technologies. It is widely perceived as a proxy for the quantum nature of physical processes and phenomena involving more than one particle. In this talk, we will revisit the problem of disentangling 4-, 5-, and 6-qubit quantum states with the help of machine learning techniques. We use policy gradient algorithms to train a deep reinforcement learning agent which, given access to the pure state of a multiqubit system, has to find the shortest sequence of disentangling two-qubit gates that brings it to a product state. We leverage the agent's interpolation and extrapolation capabilities to learn (approximately) optimal strategies to disentangle Haar-random states that lack any obvious spatial entanglement structure in the computational basis. Analyzing the protocols found by the agent, we show that any 4-qubit state can be prepared using at most 11 CNOT gates. Last, we also demonstrate the robustness of our agent to various sources of stochasticity common for present-day NISQ devices.

15 min. break

Invited Talk TT 2.4 Mon 11:15 H 0104
Neural Quantum States For The Many-Electron Problem — •Giuseppe Carleo — EPFL, Lausanne, Switzerland

This presentation explores recent strides in using neural quantum states [1] to represent many-body fermionic quantum wave functions for the many-electron problem [2]. I will delve into a message-passing-neural-network-based Ansatz designed for simulating strongly interacting electrons in continuous space [3]. This approach achieves unprecedented accuracy in the electron gas problem, pushing the boundaries of system sizes previously inaccessible to neural network states. I will also discuss a Pfaffian-based neural-network quantum state for ultra-cold Fermi gases, outperforming traditional methods and enabling exploration of the BCS-BEC crossover region [4]. Finally, I will provide insight into ongoing work on the entanglement properties of Helium 4 and Helium 3, and discuss open problems in the field [5].
[1] Carleo and Troyer, Science 355, 602 (2017)
[2] Hermann et al., Nature Reviews Chemistry 7, 692 (2023)
[3] Pescia et al., arxiv:2305.07240 (2023)
[4] Kim et al., arxiv:2305.08831 (2023)
[5] Linteau et al., in preparation (2024).

Invited Talk TT 2.5 Mon 11:45 H 0104
Neural quantum states for strongly correlated systems: learning from data and Hamiltonians — •Annabelle Bohrdt[1], Hannah Lange[2], Schuyler Moss[3], Fabian Döschl[2], Felix Palm[2], Giulia Semeghini[4], Mikhail Lukin[4], Sepehr Ebadi[4], Tout Wang[4], Fabian Grusdt[2], Juan Carrasquilla[5], and Roger Melko[3] — [1]Universität Regensburg — [2]LMU München — [3]UWaterloo — [4]Harvard University — [5]Vector Institute

Neural quantum states have emerged as a new tool to efficiently represent quantum many-body states with two main use cases: 1.) efficiently reconstruct a quantum state by training on measured data. For states with a non-trivial sign structure, measurements in many different basis configurations are necessary. I will present an active learning scheme which adaptively chooses the next measurement basis in order to maximize the information gain. 2.) The second main application of neural quantum states is to apply variational Monte Carlo to find e.g. the ground state of a system. I will present some of our recent results on ground states of strongly correlated systems, such as t-J type systems and fractional quantum Hall states. Finally, we combine both approaches: by first training on experimental data from a Rydberg atom tweezer array, we initialize the neural quantum state closer to the ground state. By then switching to variational Monte Carlo to minimize the energy in the second stage of training, we find a speedup in convergence. This showcases how limited datasets from experiments can be combined with numerical methods in a hybrid approach to yield more accurate results than either could provide on their own.

Invited Talk TT 2.6 Mon 12:15 H 0104

Towards an Artificial Muse for new Ideas in Quantum Physics — •Mario Krenn — Max Planck Institute for the Science of Light, Erlangen, Germany

Artificial intelligence (AI) is a potentially disruptive tool for physics and science in general. One crucial question is how this technology can contribute at a conceptual level to help acquire new scientific understanding or inspire new surprising ideas. I will talk about how AI can be used as an artificial muse in quantum physics, which suggests surprising and unconventional ideas and techniques that the human scientist can interpret, understand and generalize to its fullest potential.

[1] Krenn et al., Phys. Rev. X 11 (2021) 031044.
[2] Krenn et al., Nat. Rev. Phys. 4 (2022) 761.
[3] Krenn et al., Nat. Mach. Intell. 5 (2023) 1326

TT 2.7 Mon 12:45 H 0104

Adversarial Hamiltonian learning of quantum dots in a minimal Kitaev chain — •Rouven Koch[1], David van Driel[2,3], Alberto Bordin[2,3], Jose L. Lado[1], and Eliska Greplova[3] — [1]Department of Applied Physics, Aalto University, Espoo, Finland — [2]QuTech, Delft University of Technology, Delft, The Netherlands — [3]Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands

Knowledge of the underlying Hamiltonian in quantum devices is key for tuning and controlling experimental quantum systems. Here we demonstrate an adversarial machine learning framework capable of Hamiltonian learning of a quantum dot chain from noisy experimental measurements. We train a convolutional conditional generative adversarial network with simulated data of the differential conductances based on a Kitaev chain model. The trained model is able to predict the parameters determining the sweet spot conditions of the two-quantum-dot system at which the predicted mid-gap bound state emerges. This gives us a fast and numerically efficient way to explore the phase diagram describing the transition between elastic co-tunning and Andreev reflection regimes and thus is suitable to assist the sweet-spot tuning of the Kitaev chains. The application of our methodology to experimental measurements in an InSb nanowire shows promising results in extracting Hamiltonians from measurements, potentially supporting the hard task of tuning quantum-dot systems into distinct Hamiltonian regimes.

TT 2.8 Mon 13:00 H 0104

Machine determination of a phase diagram with and without deep learning — •Burak Çivitcioğlu[1], Rudolf A. Römer[2], and Andreas J. Honecker[1] — [1]Laboratoire de Physique Théorique et Modélisation, CNRS UMR 8089, CY Cergy Paris Université, France — [2]University of Warwick, Coventry, UK

We study the performance of unsupervised learning in detecting phase transitions in the J_1-J_2 Ising model on the square lattice. We use variational auto encoders (VAE) and the reconstruction error, defined as the mean-squared error between two configurations, to explore the phase diagram of the system. Moreover, we propose as simple alternative method a direct spin comparison. The results of the spin comparison are contrasted with that of the VAEs. Our findings highlight that for certain systems, the simpler method can yield results comparable to a much more complex model, namely the VAE. This work contributes to the broader understanding of machine-learning applications in statistical physics and introduces an efficient approach to the detection of phase transitions using machine determination techniques.

TT 3: Topology: Quantum Hall Systems

Time: Monday 9:30–13:00 Location: H 2053

TT 3.1 Mon 9:30 H 2053

Current cross-correlations from an anyonic Mach-Zehnder interferometer — Sarthak Girdhar[1,2,3], Diksha Garg[2,3,4], •Thomas L. Schmidt[3], and Edvin G. Idrisov[3] — [1]Tata Institute of Fundamental Research, Bengaluru, India — [2]Indian Institute of Technology Bombay, Mumbai, India — [3]Department of Physics and Materials Science, University of Luxembourg, Luxembourg — [4]Bhabha Atomic Research Centre, Mumbai, India

Advances in hybrid mesoscopic devices have opened up new avenues for studying edge excitations in quantum Hall (QH) systems. Recent experimental breakthroughs have enabled the construction of anyonic colliders at both integer ($\nu = 2$) and fractional ($\nu = 1/3$) filling factors. Measurements of current cross-correlations and the generalized Fano factor at fractional fillings have demonstrated possible evidence of anyonic exclusion statistics for the constituent charge carriers. All these findings align with the theoretical predictions for the Laughlin state at $\nu = 1/3$.

In our work, we use the nonequilibrium bosonization technique to study the collision of two dilute beams of quasiparticles in chiral QH edge states at filling factors $\nu = 1/(2n + 1)$ in a Mach-Zehnder interferometer. The presence of two QPCs acting as beam splitters has some very interesting consequences, e.g., a modulation of the ordinary Aharonov-Bohm oscillations with the length difference between the two beam splitters in the chiral channels. We calculate the tunneling current, its zero frequency noise and the cross-correlation between the currents after scattering.

TT 3.2 Mon 9:45 H 2053

Nonlocal thermoelectric detection of interaction and correlations in edge states — Alessandro Braggio[1], Matteo Carrega[2], •Björn Sothmann[3], and Rafael Sánchez[4] — [1]NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, I-56127 Pisa, Italy — [2]SPIN-CNR, 16146 Genova, Italy — [3]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [4]Departamento de Física Teórica de la Materia Condensada, IFIMAC, and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain

We investigate nonequilibrium effects in the transport of interacting electrons in quantum conductors, proposing the nonlocal thermoelectric response as a direct indicator of the presence of interactions, nonthermal states and the effect of correlations. This is done by assuming a quantum Hall setup where two channels (connected to reservoirs at different temperatures) co-propagate for a finite distance, such that a thermoelectrical response is only expected if the electron-electron interaction mediates heat exchange between the channels. This way, the nonlocal Seebeck response measures the interaction strength. Considering zero-range interactions, we solve the charge and energy currents and noises of a non-equilibrium integrable interacting system, determining the universal interaction-dependent length scale of energy equilibration. Further, a setup with two controllable quantum point contacts allows thermoelectricity to monitor the interacting system thermalisation as well as the fundamental role of cross-correlations in the heat exchange at intermediate length scales.

TT 3.3 Mon 10:00 H 2053

Quantum Hall effect and current distribution in a 3D-topological insulator — •Stefan Hartl[1], Maximilian Kühn[2], Lukas Freund[2], Johannes Ziegler[1], Dmitriy Kozlov[1], Jürgen Weis[2], and Dieter Weiss[1] — [1]Universität Regensburg, Regensburg, Germany — [2]MPI für Festkörperforschung, Stuttgart, Germany

Strained 3D-HgTe, which is a strong topological insulator, exhibits a pronounced quantum Hall effect. This is despite the fact that the current is carried by electrons on the top and bottom surfaces as well as electrons in the bulk conduction band. Here we study the system by three experimental techniques: transport measurements, which include all charge carriers, magnetocapacitance which probes the topmost layer of charges, and Hall potential profile measurements using a scanning field-effect transistor to probe the current distribution in the quantum Hall regime. At small magnetic magnetic fields B, the carrier density reflected by the periodicity of the Shubnikov-de Haas and magnetocapacitance oscillations is strikingly different. This suggests the coexistence of different Landau fans for the three electron species. For large B, however, the capacitance and SdH oscillations reflect the same carrier density. This suggests that at sufficiently high B - due to the charge rearrangement - only one Landau fan survives. The current distribution in the quantum Hall regime shows that the Hall quantization results from the dissipationless Hall current flow in the incompressible bulk regions of the system, similar to the mechanism in conventional two-dimensional electron systems.

HgTe provided by N. Mikhailov and S. A. Dvoretsky, Novosibirsk.

TT 3.4 Mon 10:15 H 2053

Current distribution in the quantum Hall regime — •Serkan Sirt[1], Matthias Kamm[1], Afif Siddiki[2], Vladimir Umansky[3], and Stefan Ludwig[1] — [1]Paul-Drude-Inst. für Festkörperelektronik, Berlin — [2]Istanbul Atlas Univ., Turkey — [3]Weizmann Inst., Israel

The current distribution in the quantized Hall regime is of fundamental interest and important for applications. The widely appreciated Landauer-Büttiker picture (LBP) assumes chiral current flow along 1D, dissipation-less, compressible edge channels (EC). The screening theory [1] goes beyond the scope of the LBP by taking into account Coulomb interaction between electrons. It predicts dissipation-less current flow within incompressible strips (ICSs). The current-generating electric field is restricted to the Landau-gaped ICSs but fully screened elsewhere. As the magnetic field, B, is increased along a quantized Hall plateau, the ICSs move from the edge into the bulk of the Hall bar and thereby widen. Local potential measurements favor the screening theory [2] but direct current measurements are still missing.

Here, we present such direct current distribution measurements using a Hall bar including a small ohmic contact in its center, which does not disturb EC currents. Our measurements suggest EC current at the low B sides of the plateaus but clearly demonstrate bulk currents at higher B, while the Hall resistance remains quantized. Using multi-terminal measurements, we further confirm that both, edge and bulk currents, are chiral.

[1] R.R.Gerhardts, Phys. Stat. Sol. (b), **245** (2008) 378
[2] E. Ahlswede et al., Physica B **298** (2001) 562

Invited Talk TT 3.5 Mon 10:30 H 2053

Topological Thermal Hall Conductance of Even Denominator Fractional States — •Moty Heiblum — Weizmann Institute of Science Rehovot 76100, Israel

The even denominator fractional quantum Hall (FQH) states $\nu = 5/2$ and $\nu = 7/2$, have been long predicted to host non-abelian quasiparticles. The presence of energy-carrying neutral modes cripples customary conductance measurements and thus motivates thermal transport measurements, which already proved to be sensitive to all energy-carrying modes. Each state has a different capacity to carry quanta of heat - as expressed by the so-called: 'central charge' - identifying the state's topological order. While the 'two-terminal' thermal conductance measurements identified the topological orders of abelian and non-abelian QH states, they are prone to partial thermal equilibration among counter-propagating modes. Here, we report a 'four-terminal' thermal Hall conductance measurement, which separately measures the heat carried by the downstream and upstream chiral modes. This measurement is insensitive to thermal equilibration among modes. We verify that the $\nu = 5/2$ and $\nu = 7/2$ states are non-abelian, supporting a single upstream Majorana mode, thus obeying the Particle-Hole Pfaffian topological order. While current numerical works predict a different central charge, this contribution should motivate further theoretical work.

15 min. break

TT 3.6 Mon 11:15 H 2053

Fractional quantum Hall states with variational Projected Entangled-Pair States: a study of the bosonic Harper-Hofstadter model — •Erik Lennart Weerda and Matteo Rizzi — University of Cologne, Cologne, Germany

An important class of model Hamiltonians for investigation of topological phases of matter consists of mobile, interacting particles on a lattice subject to a semi-classical gauge field, as exemplified by the bosonic Harper-Hofstadter model. A unique method for investigations of two-dimensional quantum systems are the infinite projected-entangled pair states (iPEPS), as they avoid spurious finite size effects that can alter the phase structure. However, due to no-go theorems in related cases this was often conjectured to be impossible in the past. In this letter, we show that upon variational optimization the infinite projected-entangled pair states can be used to this end, by identifying fractional Hall states in the bosonic Harper-Hofstadter model. The obtained states are characterized by showing exponential decay of bulk correlations, as dictated by a bulk gap, as well as chiral edge modes via the entanglement spectrum.

TT 3.7 Mon 11:30 H 2053

Quantum chaos in a quantum optical simulation of a topological insulator — •Jacquelin Luneau[1,2], Tommaso Roscilde[2], Benoit Douçot[3], and David Carpentier[2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]ENSL, CNRS, Laboratoire de Physique, F-69342 Lyon, France — [3]LPTHE, UMR 7589, CNRS and Sorbonne Université, 75252 Paris Cedex 05, France

We consider a simple setup of two bosonic modes strongly coupled to a two-level system. In a regime of topological coupling, the dynamics in the space of number of quanta simulates the dynamics of a particle in a Chern insulator submitted to a weak electric field [1]. This analogy enables us to group the eigenstates of the system in three distinct families lying at the same energy scales. The first two families are associated to the bulk of the topologically trivial and non-trivial domain, while the last family corresponds to the edge domain. The family associated to a non-trivial topology is chaotic, while the one associated to a trivial topology is not chaotic. We show that the quantum signatures of chaos of the topological family of eigenstates are non-standard, corresponding to a system at the limit of the domain of application of Random Matrix Theory [2].

[1] J. Luneau, B. Douçot, D. Carpentier, arXiv:2211.13502 (2022).
[2] J. Luneau, T. Roscilde, B. Douçot, D. Carpentier, to be submitted.

TT 3.8 Mon 11:45 H 2053

Topological Phase Transitions of Interacting Phases in Commensurate Magnetic Flux — •Axel Fünfhaus[1], Marius Möller[1], Thilo Kopp[2], and Roser Valentí[1] — [1]Goethe Uni Frankfurt, Frankfurt am Main, Germany — [2]University of Augsburg, Augsburg, Germany

Lattice Hamiltonians in external magnetic fields provide a non-trivial magnetic translation algebra which results in Lieb-Schultz-Mattis (LSM) type theorems. The LSM theorems impose constraints on the topology of the system, in particuar on its Hall conductivity, and exclude trivial band insulating phases depending on the filling factor. We examine these constraints by taking into account the role of interaction driven spontaneous symmetry breaking of translation symmetry. Using exact diagonalization, we identify phase transitions from Hall insulating to topologically trivial charge density wave states for various flux quantum ratios and filling factors. Our findings demonstrate the importance of "conventional" phase transitions in the study of topological phases as they may provide loopholes for properties otherwise protected by no-go LSM-type theorems.

TT 3.9 Mon 12:00 H 2053

New evidence for protected helical Andreev hinge modes in a bismuth nanoring Josephson junction — •Alexandre Bernard[1], Yang Peng[2], Alik Kasumov[1], Richard Deblock[1], Meydi Ferrier[1], Franck Fortuna[3], Yuval Oreg[4], Felix von Oppen[5], Hélène Bouchiat[1], and Sophie Guéron[1] — [1]Laboratoire de Physique des Solides, France — [2]California State University, USA — [3]Institut des Sciences Moléculaires d'Orsay, France — [4]Weizmann Institute of Science, Israel — [5]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Germany

Second-order topological insulators are characterized by helical, non-spin-degenerate one-dimensional states running along opposite crystal hinges with no backscattering [1]. Injecting superconducting pairs therefore entails splitting Cooper pairs into two families of helical Andreev states of opposite helicity, one at each hinge. Here we provide new evidence for such separation via the measurement and analysis of the switching supercurrent statistics of a crystalline nanoring of bismuth connected to superconducting electrodes. Using a phenomenological model of two helical Andreev hinge modes, we identify an 'odd'

state in this long junction, and we find that pairs relax at a rate comparable to individual quasiparticles, in contrast to the much faster pair relaxation of non-topological systems [2].
The nanowire was made by Alik Kasumov, Vladimir Volkov and Yusif Kasumov in Chernogolovka.

[1] F. Schindler et al., Nat. Phys. 14 (2018) 918
[2] A. Bernard et al., Nat. Phys. 19 (2023) 358

TT 3.10 Mon 12:15 H 2053

Thermal robustness of the quantum spin Hall phase in monolayer WTe_2 from single-point first-principles simulations — •Antimo Marrazzo — Dipartimento di Fisica, Università di Trieste, Strada Costiera 11, Trieste I-34151, Italy

I will present first-principles simulations of the temperature effects on the electronic structure of monolayer 1T'-WTe_2 and consider the contributions of both thermal expansion and electron-phonon coupling [1]. First, I will show that thermal expansion is weak but tends to increase the indirect band gap. Then, I will discuss the effect of electron-phonon coupling on the band structure, which has been calculated with nonperturbative methods, observing a small reduction of the band inversion with increasing temperature. Notably, the topological phase and the presence of a finite gap are found to be particularly robust to thermal effects up to and above room temperature. Finally, I will introduce a single-point formula to calculate $\mathbb{Z}_2$ topological invariants in the supercell framework [2], where a single Hamiltonian diagonalisation is performed. Beyond disordered systems, our approach [2] is particularly useful to investigate the role of defects, to study topological alloys and in the context of *ab initio* molecular dynamics simulations at finite temperature.

[1] A. Marrazzo, Phys. Rev. Materials 7 (2023) L021201
2] R. Favata, A. Marrazzo, Electron. Struct. 5 (2023) 014005

TT 3.11 Mon 12:30 H 2053

Quantum kinetic equation and thermal conductivity tensor for bosons — •Léo Mangeolle[1,2,3], Lucile Savary[1,2], and Leon Balents[2] — [1]ENS de Lyon, CNRS, Laboratoire de Physique, 46 allée d'Italie, 69007 Lyon, France — [2]Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106 — [3]Technical University of Munich, School of Natural Sciences, Physics Department, 85748 Garching, Germany

We obtain a systematic derivation of the semi-classical kinetic equation for neutral bosons from their full quantum kinetic equation. It incorporates the semi-classical topological dynamics of wavepackets in the form of geometric properties of the energy eigenstates, such as the Berry phases and curvatures, generalized to phase space. This makes it possible to treat inhomogeneous systems, including boundaries, textures, etc., in a compact and natural manner. We compute the associated observable quantities, such as energy and current densities, away from equilibrium. In particular, the thermal conductivity tensor, which describes the energy current induced by a temperature gradient, is exactly obtained. This provides a self-contained and exact derivation of the intrinsic thermal Hall effect of neutral bosons such as phonons and magnons, in agreement with Kubo formula results while being considerably more intuitive, and naturally avoiding subtleties associated with magnetization currents. I will eventually present a few calculations using the derived quantum kinetic equation: - the local thermal Hall current of topological magnons in a collinear antiferromagnet, - the energy density and local currents in a skyrmion lattice.

TT 3.12 Mon 12:45 H 2053

Correlated two-Leviton states in the fractional quantum Hall regime — Bruno Bertin-Johannet[1], Alexandre Popoff[2], •Flavio Ronetti[1], Jérôme Rech[1], Thibaut Jonckheere[1], Laurent Raymond[1], Benoît Grémaud[1], and Thierry Martin[1] — [1]Aix-Marseille Univ, Université de Toulon, CNRS, CPT, Marseille, France — [2]Collège de Tipaerui, BP4557- 98713 Papeete, Tahiti, French Polynesia

The on-demand generation of single- and few-electron states in mesoscopic systems has opened the way to the fascinating field of electron quantum optics (EQO), where individual fermionic quantum states are manipulated with methods borrowed from photonic quantum-optical experiments. In this framework, a train of Lorentzian voltage pulses represents one of the most reliable experimental protocol to inject coherent single-electronic states, known as Levitons, into ballistic channels of meso-scale devices. These fascinating results open up the possibility of investigating the dynamics of single-electron states in one-dimensional systems. Indeed, it is well known that, in contrast with photons, electronic systems are drastically affected by electron-electron correlations. In this talk, we focus on two-Leviton states injected in a single period with a time separation Δt. We propose that an effective interaction between the two Levitons is induced by the strongly-correlated background which can be tuned by this time delay Δt. Evidence for this interaction between single-elctron wave-packets can be found in some quantum transport measurement and we support this statement by analytical and numerical calculations.

TT 4: f-Electron Systems

Time: Monday 9:30–13:00 Location: H 3005

Invited Talk TT 4.1 Mon 9:30 H 3005

Hyperfine interactions and nuclear-electronic quantum criticality in $PrOs_4Sb_{12}$ — •Alix McCollam — School of Physics, University College Cork, Ireland

Many strongly correlated electron systems develop ordered phases at low temperatures that can be well understood in terms of an electronic order parameter. At ultra-low temperatures, however, the hyperfine interaction becomes increasingly important, and we must consider how this affects ordered phases and phase transitions near $T = 0$.

$PrOs_4Sb_{12}$ is a superconductor below $T_C = 1.85$ K and $H_{C_2} = 2.2$ T, and develops antiferroquadrupolar (AFQ) order in magnetic fields between ~ 4 T and 14 T. The hyperfine constant of Pr is relatively large at 52 mK, and influences the Pr crystal electric field levels that are closely involved in both the superconducting and AFQ phases.

To explore this influence, we performed magnetic susceptibility measurements as a function of temperature and magnetic field to temperatures as low as 1 mK. We find that the phase boundaries in $PrOs_4Sb_{12}$ show anomalous behaviour down to ~ 5 mK: AFQ order is enhanced at low temperature, whereas superconductivity is suppressed.

We explain our results in terms of a ground state composed of hybrid nuclear-electronic states with novel low energy excitations. The low temperature quadrupole excitations develop from these nuclear-electronic states, and are considerably modified compared to their higher temperature counterparts. Our results indicate a novel type of nuclear-electronic quantum critical point at the AFQ transition.

TT 4.2 Mon 10:00 H 3005

Inelastic neutron scattering of single-crystal ErB_2 — Michal Stekiel[1], •Christoph Resch[2], Andreas Bauer[2], Karin Schmalzl[3], Jakob Lass[4], Astrid Schneidewind[1], and Christian Pfleiderer[2,5,6,7] — [1]Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, Lichtenbergstr. 1, 85747 Garching, Germany — [2]TUM School of Natural Sciences, Physik Department 85748 Garching, Germany — [3]Institut Laue-Langevin, 38042 Grenoble Cedex 9, France — [4]Paul Scherrer Institute, 5232 Villigen PSI, Switzerland — [5]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, D-85748 Garching, Germany — [6]Zentrum für Quantum Engineering (ZQE), Technische Universität München, D-85748 Garching, Germany — [7]Munich Center for Quantum Science and Technology (MCQST), Technische Universität München, D-85748 Garching, Germany

We present inelastic neutron scattering data on the hexagonal rare-earth diboride ErB_2. Previous neutron Laue and single-crystal diffraction together with measurements of the magnetic and electrical bulk properties consistently established the magnetic ground state to be an easy-plane ferromagnet with strong magnetocrystalline anisotropies [1]. We studied the magnetic excitation spectrum as a function of magnetic field by means of multiplexing triple-axis spectroscopy. We interpret the observed spectra to be consistent with a strong easy-plane ferromagnet. Additional anomalous features may be explained in the context of strong magnon-phonon-coupling.

[1] C. Resch, unpublished

TT 4.3 Mon 10:15 H 3005

Electronic structure, transport and magnetic properties of ErB_2 — •André Deyerling[1], Christoph Resch[1], Michal Stekiel[2], Christian Pfleiderer[1,3,4,5], and Marc A. Wilde[1,3] — [1]Physik Department, TUM School of Natural Sciences, Technische Universität München, Germany — [2]Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), Germany — [3]Zentrum für Quantum Engineering (ZQE), Technische Universität München, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Technische Universität München, Germany — [5]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, Germany

ErB_2 is a hexagonal easy plane ferromagnet exhibiting a large field-dependent anomalous Hall effect for magnetic fields along the hard axis. The magnetic excitation spectrum has features reminiscent of strong single-ion anisotropy and magnon-phonon coupling. We present density functional theory calculations of the magnetic anisotropy energies in and out of the hexagonal plane and calculate the Heisenberg exchange coupling constants via the spin spiral method. Further, we report the Berry curvature contribution of the electronic structure to the anomalous Hall effect when rotating the magnetization from the easy-plane to the hard axis.

TT 4.4 Mon 10:30 H 3005

Direct observation of spin-split electronic structures in antiferromagnet NdBi by micro-focused laser SARPES — •Rikako Yamamoto[1,2], Takeru Motoyama[3], Takuma Iwata[1,3], Yukimi Nishioka[3], Kazumasa Ideura[3], Towa Kousa[3], Masashi Arita[4], Shinichiro Ideta[4], Kenya Shimada[4], Koji Miyamoto[4], Taichi Okuda[4], Akio Kimura[1,3], Takahiro Onimaru[3], and Kenta Kuroda[1,3] — [1]WPI-SKCM[2], Hiroshima University, Higashi-Hiroshima, Japan — [2]MPI-CPfS, Dresden, Germany — [3]AdSE, Hiroshima University, Higashi-Hiroshima, Japan — [4]HiSOR, Hiroshima University, Higashi-Hiroshima, Japan

Recently, rare-earth monopnictides RX (R: rare earth, X: N, P, As, Sb, and Bi) have received renewed interest due to the topological electronic structure in both paramagnetic and antiferromagnetic ordered states. The antiferromagnet NdBi has surface states and band splitting associated with the multi-q magnetic structure has been reported below $T_N = 24$ K and its topological origin has been discussed. However, the information on the spin of the electronic structure has not been experimentally determined.

In this study, we have performed spin- and angle-resolved photoemission spectroscopy (SARPES) experiments using a micro-focused 6.4 eV laser at the Synchrotron Radiation Center, Hiroshima University (T. Iwata *et al.*, Sci. Rep. in press). Our laser-SARPES separates spatially mixed magnetic domains and observes anisotropic surface band dispersions appearing in $T < T_N$. We unambiguously reveal the lifting of spin degeneracy in the surface electronic structures.

TT 4.5 Mon 10:45 H 3005

Quantum Phase Transitions in Ferromagnetic $CeAgSb_2$ under Pressure — •Christian de Podesta[1], Oliver Squire[1], Jiasheng Chen[1], David Graf[2], Stanley Tozer[2], Patricia Alireza[1], and F. Malte Grosche[1] — [1]Cavendish Laboratory, University of Cambridge, UK — [2]National High Magnetic Field Laboratory, Tallahassee, Florida, USA

The Kondo lattice system $CeAgSb_2$ is ferromagnetic below 10 K. Under pressure, $CeAgSb_2$ displays a complex phase diagram, incorporating quantum phase transitions of both the ambient pressure ferromagnetism and a high-pressure antiferromagnetic phase. Becuase of this, single crystals of $CeAgSb_2$ are ideal for studying the ferromagnetic quantum phase transition and the corresponding changes to the Fermi surface under pressure.

Here we present transport measurements of the high-pressure phase diagram up to 70 kbar, down to 100 mK and in high magnetic fields. We discuss these findings in relation to the new magnetic phases and tricritical wing structures which emerge at quantum phase transitions in itinerant ferromagnets. At ambient pressure we resolve the entire Fermi surface from Shubnikov de Haas oscillations and find heavy quasi-particles persisting to high fields and long mean free paths, documenting the high quality of our crystals. We present preliminary results of extending these measurements to higher pressures using the tunnel diode oscillator technique in a diamond anvil cell.

TT 4.6 Mon 11:00 H 3005

Nonlinear Transport and Fluctuation Spectroscopy in antiferromagnetic EuT_2P_2 at the CMR transition. — •Marvin Kopp[1], Charu Garg[1], Sarah Krebber[1], Kristin Kliemt[1], Cornelius Krellner[1], Sudhaman Balguri[2], Fazel Tafti[2], and Jens Müller[1] — [1]Institute of Physics, Goethe-University Frankfurt, Frankfurt (Main), Germany — [2]Departments of Physics, Boston College, USA

The colossal magnetoresistance (CMR) effect has been a focal point of extensive research for decades, owing to its pivotal role in the physics of correlated electron systems and its potential applications. Unlike typical CMR compounds characterized by mixed valence, double exchange in manganites, or structural Jahn-Teller distortion and ferromagnetic ordering, our focus lies on EuT_2P_2 (X = Cd, Zn), with both compounds exhibiting a strikingly large negative MR significantly preceding their antiferromagnetic ordering temperature. Initial reports suggest that strong magnetic fluctuations could be responsible for the drastic change of resistance in the magnetic field [1]. In this work, we aim to investigate these fluctuations using higher harmonic resistance and resistance fluctuation (noise) spectroscopy. Higher harmonic measurements are sensitive to the small changes in magneto-electric coupling caused by the postulated forming of magnetic clusters (polarons), often hidden in standard resistance measurements. The dynamics of these magnetic clusters is studied using resistance noise spectroscopy as a function of temperature and magnetic field which can reveal further microscopic characteristics.

[1] Adv. Mat. 33 (2021) 2005755.

15 min. break

TT 4.7 Mon 11:30 H 3005

Low-temperature physical properties of the $R_2Ni_5C_3$ (R = La-Nd, Sm, Gd, Tb) "interstitial" carbides — •Volodymyr Levytskyi[1], Volodymyr Babizhetskyy[2], Olivier Isnard[3], and Roman Gumeniuk[1] — [1]Institut für Experimentelle Physik, TU Bergakademie Freiberg, Leipziger Str. 23, Freiberg 09596, Germany — [2]Department of Inorganic Chemistry, Ivan Franko National University of Lviv, Kyryla i Mefodia Str. 6, Lviv 79005, Ukraine — [3]Université Grenoble Alpes, Institut Néel, CNRS, 25 rue des Martyrs, BP166, Grenoble, Cédex 9 38042, France

$R_2Ni_5C_3$ (R = La-Nd, Sm, Gd, Tb) represent a family of the interstitial carbides with a chemical composition in between those of the so-called carbometalates and metal-rich carbides [i.e., $R_xT_yC_z$ are in the range of $2 \leq (x+y)/z \leq 4$, with R staying for a rare earth and T as a 3d-metal]. The $La_2Ni_5C_3$ structure prototype is a two-layered structure (space group $P4/mbm$) combining structure fragments of $CaTiO_3$- and AlB_2-types. The structural stability of the $R_2Ni_5C_3$ series until R = Tb is confirmed by of crystal structure refinements and electronic structure calculations. The low-temperature (1.8–300 K) dependencies of magnetization, specific heat, and thermoelectric characteristics (electrical resistivity, thermal conductivity, and thermopower) have been studied. Respective physical properties of $R_2Ni_5C_3$ metallic systems will be discussed in details.

[1] V. Levytskyi, V. Babizhetskyy, O. Isnard, R. Gumeniuk, J. Alloys Compd. **969** (2023) 172411.

TT 4.8 Mon 11:45 H 3005

Searching for the critical endpoint in the valence-fluctuating $Eu(Rh_{1-x}Co_x)_2Si_2$-system — •Franziska Walther, Alexej Kraiker, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt/Main, Germany

In ternary europium-based intermetallic compounds with the $ThCr_2Si_2$ structure valence fluctuations of the Eu ions and a coupling between lattice and electronic degrees of freedom lead to intriguing phenomena. Under variation of temperature and pressure, it is possible to enforce a valence transition from a magnetic Eu^{2+} to a non-magnetic Eu^{3+} state [1]. $EuRh_2Si_2$ orders antiferromagnetically below $T_N = 24$ K in a stable divalent state [2], whereas the isoelectronic compound $EuCo_2Si_2$ is nearly trivalent und indicates no magnetic ordering [1]. $EuRh_2Si_2$ can be shifted with pressure towards a first-order valence transition, which is expected to terminate in a second-order critical endpoint (CEP), where critical elasticity may occur [3]. In this study, we aim to approach the CEP by applying chemical pressure through substituting Rh with Co. It turned out, that the crystal growth process due to the high vapour pressure of europium is a real challenge, however, we successfully have grown first single crystals of this series. We report on the growth of $Eu(Rh_{1-x}Co_x)_2Si_2$ samples and investigated their physical properties.

[1] Y. Onuki et al., J. Phys. Soc. Jpn. **89**, 102001 (2020)
[2] S. Seiro, C. Geibel, J. Phys.: Condens. Matter **26**, 046002 (2014)
[3] F. Honda et al J. Phys. Soc. Jpn. **85**, 063701 (2016)

TT 4.9 Mon 12:00 H 3005

The valence and magnetism of Ce in $Mo_4Ce_4Al_7C_3$ nanolamellar ferromagnetic Kondo lattice — •Fabrice Wilhelm[1], Maxime Barbier[1,2], Thierry Ouisse[2], Daniel Braithwaite[3], Christine Opagiste[4], and Andrei Rogalev[1] — [1]ESRF, Grenoble, France — [2]LMGP, Grenoble, France — [3]IRIG-CEA, Grenoble, France — [4]CNRS, Grenoble, France

Rare-earth-based nanolaminates have attracted attention motivated by their potential as precursors for the synthesis of two-dimensional (2D) magnetic materials. Their intricate magnetism is governed by the strong interplay of the orbital and valence degrees of freedom that gives rise to a multitude of ground states. Herein we present the results of thorough study of the electronic and magnetic properties of $Mo_4Ce_4Al_7C_3$, exploiting X-ray absorption near edge spectroscopy and X-ray magnetic circular dichroism. This system orders ferromagnetically below 10.5 K [1] and allows for mechanical exfoliation being a derivative of the well-known MAX phases. The element-selective studies and magnetoresistance measurements under pressure evidenced that this mixed valent compound combines a Kondo lattice behavior with ferromagnetism [2]. We have shown that this unusual property is due to very different electronic and magnetic properties of the two non-equivalent Ce sites.

[1] Q. Tao et al., Phys. Rev. Mater. 2 (2018) 114401.
[2] M. Barbier et al., Phys. Rev. B 102 (2020) 155121

TT 4.10 Mon 12:15 H 3005

Valence-to-core RIXS at the uranium M_5 edge in UO_2 and UF_4 — •Ondrej Stejskal and Jindrich Kolorenc — Institute of Physics (FZU), Czech Academy of Sciences, Prague, Czech Republic

Motivated by a recent experimental study [1], we simulate the valence-to-core resonant inelastic x-ray scattering (RIXS) measured at the uranium M_5 edge in insulating compounds UO_2 and UF_4. To do so, we employ the Anderson impurity model from LDA+DMFT electronic-structure calculations [2]. We find that the feature experimentally observed at an energy loss of roughly 10 eV above the white line reflects the charge-transfer excitations from the uranium 5f to the ligand 2p states, in agreement with other closely related investigations [3]. We analyze how the intensity of this feature depends on the metal–ligand hybridization and discuss whether there is a direct link between the energy loss, at which the feature is observed, and the band gap as argued in [1].

[1] J. G. Tobin *et al.*, J. Phys.: Condens. Matter **34** (2022) 505601.
[2] J. Kolorenc, A. Shick, A. Lichtenstein, Phys. Rev. B **92** (2015) 085125.
[3] Kvashnina *et al.*, Chem. Commun. **54** (2018) 9757.

TT 4.11 Mon 12:30 H 3005

Signatures of hidden ocutpolar order from non-linear Hall effects — •Sopheak Sorn[1] and Adarsh S. Patri[2] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Massachusetts Institute of Technology, Boston, USA

Multipolar moments are locally anisotropic distribution of charge and magnetization of electronic wave function. They commonly arise from a combined effect of crystal electric field and strong spin-orbit interactions. In a variety of d-electron and f-electron compounds, dipolar moments are quenched, and higher-rank multipolar moments emerge as the dominant features. Due to their tensorial nature and their uncommon symmetry properties, their long-ranged orders has been challenging to directly detect. In this talk, we theoretically propose a transport-based detection of a ferroic ordering of ocutpolar moments in a metallic system. Using a minimal electron model coupled to the order parameter, we demonstrate that the onset of the octupolar order enables a non-zero third-order Hall response–rise of a transverse Hall voltage which scales cubically with the applied current. Its dissipationlessness, its anisotropy and its unusual dependence on the order parameter will be discussed. Our work provides the first example of using nonlinear transports to investigate multipolar long-ranged orders.

[1] S. Sorn and A. S. Patri, arXiv:2311.03435 (2023)

TT 4.12 Mon 12:45 H 3005

Magnetic behaviour of UNi_4B in high magnetic fields — •Philip Schröder[1], Jannis Willwater[1], Stefan Süllow[1], Manfred Reehuis[2], Hiroshi Amitsuka[3], Bachir Ouladdiaf[4], Romain Sibille[5], Milan Klicpera[6], Michael Vališka[6], Jiří Pospíšil[6], and Vladimír Sechovský[6] — [1]Institut für Physik der Kondensierten Materie, TU Braunschweig, Germany — [2]Helmholtz-Center Berlin for Materials and Energy, Berlin, Germany — [3]Department of Physics, Hokkaido University, Japan — [4]Institute Laue-Langevin, Grenoble, France — [5]Paul Scherrer Institut, Villingen, Switzerland — [6]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

UNi_4B is a rare example of an ising-like f-electron magnet with a highly unusual form of partial antiferromagnetic ordering at $T_N = 19.5\,K$. Only two thirds of the U-ions participate in long-range magnetic order and form a vortex-like magnetic structure in the pseudo-hexagonal plane. Measurements of the elastic constants verified a complex and highly anisotropic phase diagram, including a plethora of magnetic high field phases. Here we present a comprehensive study of the evolution of the ordered state of UNi_4B in its high field spin-reorienting phases III and III‘ on a microscopic level. We discuss the results of multiple elastic neutron scattering experiments on single crystalline UNi_4B in magnetic fields up to 10 T for H||b and in magnetic fields up to 12 T for H||c. This behaviour might indicate a spin-reorientation and a previously proposed quadrupolar contribution of the non ordering third of U-ions.

TT 5: Nickelates I

Time: Monday 9:30–13:15 Location: H 3007

TT 5.1 Mon 9:30 H 3007

Theory of magnetic excitations in bilayer nickelate superconductor $La_3Ni_2O_7$ — •Steffen Bötzel, Frank Lechermann, Jannik Gondolf, and Ilya Eremin — Ruhr-Universität Bochum, theoretische Physik III, Bochum, Germany

Motivated by the recent reports of high-T_c superconductivity in $La_3Ni_2O_7$ under pressure, we analyzed theoretically the magnetic excitations in the normal and the superconducting state in this compound, which can be measured by inelastic neutron scattering. We show that the bilayer structure of the spin response allows to elucidate the role of the interlayer interaction and the Cooper-pairing in a very efficient way. In particular, we demonstrate the key difference between the potential $s_\pm$ and d-wave gaps, discussed recently, by comparing the corresponding response in the even and odd channels of the spin susceptibility. We show that mostly interlayer driven $s_\pm$ Cooper-pairing produces a single large spin resonance peak in the odd channel near the X point whereas several resonances are predicted for the d-wave scenario.

TT 5.2 Mon 9:45 H 3007

Electronic correlations and superconducting instability in $La_3Ni_2O_7$ under high pressure — Frank Lechermann, •Jannik Gondolf, Steffen Bötzel, and Ilya M. Eremin — Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Motivated by the report of superconductivity in bilayer $La_3Ni_2O_7$ at high pressure, we examine the interacting electrons in this system. First-principles many-body theory is utilized to study the normal-state electronic properties. Below 100 K, a multi-orbital non-Fermi liquid state resulting from loss of Ni-ligand coherence within a flat-band dominated low-energy landscape is uncovered. The incoherent low-temperature Fermi surface displays strong mixing between Ni-d_{z^2} and Ni-$d_{x^2-y^2}$ orbital character. In a model-Hamiltonian picture, spin fluctuations originating mostly from the Ni-d_{z^2} orbital give rise to strong tendencies towards a superconducting instability with B_{1g} or B_{2g} order parameter. The dramatic enhancement of T_c in pressurized $La_3Ni_2O_7$ is due to stronger Ni-d_{z^2} correlations compared to those in the infinite-layer nickelates.

TT 5.3 Mon 10:00 H 3007

Superconductivity in high-pressure $La_3Ni_2O_7$ — •Pascal Reiss[1], Minu Kim[1], Runze Zhang[1], Pascal Puphal[1], Matthias Hepting[1], Keita Masaki[2], Kentaro Kitagawa[2], Bernhard Keimer[1], and Hidenori Takagi[1,2,3] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]Department of Physics, The University of Tokyo, Bunkyo, Tokyo, Japan — [3]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Germany

The recent observation of high-temperature superconductivity in $La_3Ni_2O_7$ under high pressures represents a remarkable discovery. However, superconductivity appears very fragile, and reports so far have differed greatly regarding the observation of a zero-resistance state, pressure range required, and the nature of the normal state.

In this talk, we will present our own high-pressure investigations of single crystal and powder $La_3Ni_2O_7$ samples and we will discuss several implications regarding the nature of the superconducting phase.

TT 5.4 Mon 10:15 H 3007

Investigation of Superconducting Phase in Polycrystalline $La_3Ni_2O_{7-\delta}$ — •Runze Zhang[1], Yuichiro Shiroki[1,2], Minu Kim[1], Pascal Reiss[1], and Hidenori Takagi[1,2,3] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]University of Tokyo, Tokyo 113-0033, Japan — [3]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany

The recent discovery of superconductivity in Ruddlesden-Popper (RP) nickelate $La_3Ni_2O_7$ under pressure has attracted significant research attention. However, the exact phase that facilitates this superconductivity remains unidentified, partly due to the complexities in managing RP stacking faults in single crystals. To address this issue, we present a comprehensive growth study focusing on identifying the potential superconducting phase using high-quality pure-phase polycrystalline $La_3Ni_2O_{7-\delta}$ samples. The implications on the critical role of oxygen deficiency will be discussed.

TT 5.5 Mon 10:30 H 3007

Correlated electronic structure of $La_3Ni_2O_7$ under pressure — •Viktor Christiansson[1], Francesco Petocchi[2], and Philipp Werner[1] — [1]University of Fribourg, Switzerland — [2]University of Geneva, Switzerland

The report of superconductivity with a record T_c for nickelates in bulk samples of bilayer $La_3Ni_2O_7$ (up to 78 K at pressures above 14 GPa) sets the stage for a continued interest in the nickelate superconductors. An important theoretical task is therefore to formulate a relevant model to describe this system, and to clarify its normal state properties. Here, we discuss the correlated electronic structure of the high-pressure phase for a minimal four-orbital low-energy subspace using different many-body approaches: GW, dynamical mean field theory (DMFT), extended DMFT (EDMFT), and GW+EDMFT.

We focus mainly on the nonlocal correlation and screening effects captured by GW+EDMFT which result in an instability towards the formation of charge stripes for the experimentally reported high-pressure $Fmmm$ structure, with the $3d_{z^2}$ as the main active orbital. While charge ordering has been found experimentally in the low-pressure phase, it is suppressed under application of pressure. We comment on this in relation to the crystal structure and possible rare-earth self-doping, since hole doping suppresses the ordering tendency in our model.

15 min. break

TT 5.6 Mon 11:00 H 3007

Critical role of interlayer dimer correlations in the superconductivity of $La_3Ni_2O_7$ — •Siheon Ryee[1], Niklas Witt[1,2], and Tim Wehling[1,2] — [1]Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germnay

The recent discovery of superconductivity in $La_3Ni_2O_7$ with $T_c \simeq 80\,K$ under high pressure opens up a new route to high-T_c superconductivity. This material realizes a bilayer square lattice model featuring a strong interlayer hybridization unlike many unconventional superconductors. A key question in this regard concerns how electronic correlations driven by the interlayer hybridization affect the low-energy electronic structure and the concomitant superconductivity. Here, we demonstrate using a cluster dynamical mean-field theory that the interlayer electronic correlations (IECs) induce a Lifshitz transition resulting in a change of Fermi surface topology. By solving an appropriate gap equation, we further show that the dominant pairing instability (intraorbital s-wave/interorbital $d_{x^2-y^2}$-wave) is enhanced by the IECs. The underlying mechanism is the quenching of a strong ferromagnetic channel, resulting from the Lifshitz transition driven by the IECs. Our finding establishes the role of IECs in $La_3Ni_2O_7$ and potentially paves the way to designing higher-T_c nickelates.

TT 5.7 Mon 11:15 H 3007

Synthesis of bulk Rare Earth Nickelates from infinite-layer to Ruddlesden-Popper — •Pascal Puphal[1], Vignesh Sundaramurthy[1], Valentin Zimmermann[1], Yu-Mi Wu[1], Y. Eren Suyolcu[1], Björn Wehinger[2], Masahiko Isobe[1], Bernhard Keimer[1], and Matthias Hepting[1] — [1]Max Planck Institut für Festkörperforschung, Heisenbergstraße 1, D-70569 Stuttgart, Germany — [2]European Synchrotron Radiation Facility, 71 Avenue des Martyrs, F-38043 Grenoble, France

Recently, rare-earth nickel oxides have emerged as a new class of unconventional superconductors. Where two types of structures have drawn particular interest. The first type comprises nickelates with the infinite-layer crystal structure which only exists via topochemical synthesis, such as $Nd_{0.8}Sr_{0.2}NiO_2$, showing superconducting transition temperatures T_c up to 20 K. The second type falls in to the Ruddlesden-Popper phase nickelates, where $La_3Ni_2O_7$ under hydrostatic pressure manifests a remarkably high Curie temperature T_C of 80 K. Despite these promising observations, the possibly distinct mechanisms driving the superconductivity in these two types of nickelates are not yet fully understood. In my talk I will show limitations in the doping and ways out of this issue via topochemistry for the first class of nickelates. We recently observed that the second class exhibits multiple crystallographic phases and a pronounced sensitivity to oxygen stoichiometry. Here, I will show how they affect their physical properties and superconducting mechanism.

TT 5.8 Mon 11:30 H 3007

Synthesis and characterization of electron-doped nickelate single crystals — •Vignesh Sundaramurthy, Pascal Puphal, Masahiko Isobe, Bernhard Keimer, and Matthias Hepting — Max-Planck-Institut für Festkörperforschung, Stuttgart, Deutschland

Transition metal oxides with their strong interplay between the lattice, spin and charge degrees of freedom exhibit a plethora of interesting properties. One example are perovskite rare-earth nickelates that show electronic and magnetic ground states, tunable via change of structural parameters and charge carrier doping. Substitution of the rare-earth site by tetravalent Ce ions serves this purpose, potentially leading to novel physical properties. However, the single crystal growth of these highly distorted and electron-doped nickelates is challenging [1], which will be elaborated in this talk. Furthermore, we will present initial results of topotactic reductions of Ce-substituted nickelates, aiming for the realization of single crystals with the infinite-layer structure that are isostructural and isoelectronic to superconducting cuprates.

[1] P. Puphal, V. Sundaramurthy et al., APL Mater. 11 2023) 081107

TT 5.9 Mon 11:45 H 3007

Orbital imaging of Ni3d states in the infinite-layer nickelate $LaNiO_2$ — •Edgar Abarca Morales[1], Vignesh Sundaramurthy[2], Georg Poelchen[1], Martin Sundermann[1,3], Hlynur Gretarsson[1,3], Pascal Phupal[2], Matthias Hepting[2], Hao Tjeng[1], and Berit Goodge[1] — [1]MPI for Chemical Physics of Solids, Dresden, DE — [2]MPI for Solid State Research, Stuttgart, DE — [3]DESY, Hamburg, DE

The motivation for comparing nickelates and cuprate high-T_c superconductors has been strongly justified by the discovery of superconductivity in doped infinite-layer $NdNiO_2$ [1], which is isostructural and with the same electron count ($3d^9$) as the cuprate analogue. However, apart from the considerable lower T_c in the nickelate, recent studies have shown that its electronic structure differs significantly from the cuprate [2-4]. Hence, direct observation of the nickelate electronic structure has become of central need. Orbital imaging through non-resonant inelastic x-ray scattering (sNIXS) has been recently used to directly probe the ground state of Ni in NiO [5]. Here we employ sNIXS to reveal the charge density around the Ni-site in $LaNiO_2$, proving that the 3d hole structure is compatible with having an e_g symmetry. Moreover, we show that sNIXS is ideal to probe the ground state of other nickelates if efforts are taken towards the synthesis of single-crystalline samples.

[1] D. Li et al., Nature 572 (2019) 624
[2] M. Hepting et al., Nat. Mater. 19 (2020) 381
[3] B.H. Goodge et al., PNAS 118 (2021) e2007683118
[4] H. Lu et al., Science 373 (2021) 213
[5] H. Yavas et al., Nat. Phys. 15 (2019) 559

TT 5.10 Mon 12:00 H 3007

Strong orbital- and momentum-dependent correlation effects in an infinite-layer $NdNiO_2$ — •Evgeny Stepanov[1], Matteo Vandelli[2], Alexander Lichtenstein[2], and Frank Lechermann[3] — [1]École polytechnique, France — [2]Universität Hamburg, Germany — [3]Ruhr-Universität Bochum, Germany

Layered nickel-oxide compounds have garnered significant attention since the discovery of superconductivity in this class of materials. The physical properties of layered nickelates originate from a complex interplay between strong local Coulomb correlations, spatial collective electronic fluctuations, orbital degrees of freedom, and a non-trivial band structure. Until now, even the most advanced numerical calculations could not account for all these important effects simultaneously.

In this talk we present results of accurate many-body D-TRILEX calculations for the layered $NdNiO_2$ compound at stoichiometry and upon hole doping [arXiv:2311.09983 (2023)] performed in the framework of an ab-initio three-orbital model. Our calculations demonstrate that both spatial collective electronic fluctuations and orbital degrees of freedom are equally important. Considering both these effects in a self-consistent manner results in a strong momentum- and orbital-dependent renormalization of the electronic spectral function. This renormalization favors the formation of the charge density wave ordering, which originates from the intraband correlations within the Ni-d_{z^2} orbital. We also find that the system displays strong antiferromagnetic fluctuations that stem from the Ni-$d_{x^2-y^2}$ orbital.

TT 5.11 Mon 12:15 H 3007

Charge-density wave in infinite-layer nickelates — Tharathep Plienbumrung[1], Jean-Baptiste Moree[2], Andrzej M. Oles[3], and •Maria Daghofer[1] — [1]FMQ, University of Stuttgart, Germany — [2]Waseda University, Tokyo, Japan — [3]Jagiellonian University, Kraków, Poland

We use the constrained random-phase approximation to derive a two-band model for infinite-layer nickelates. We find that a large variety of orbital wave functions lead to similar bands, but take particular care to arrive at a converged solution. The effective model then turns out to feature substantial long-range Coulomb interactions within and between bands. We next turn to the random-phase approximation and a variant of the variational cluster approach to investigate the effective model. In the variational cluster approach, interactions within the cluster are taken into account exactly, while those connecting clusters have to be decoupled in a mean-field approach. We find that the inclusion of inter-site Coulomb interactions tends to suppress long-range antiferromagnetism while favoring a charge-density wave. We find a charge pattern with periodicity of three sites, consistent with recent experimental results.

TT 5.12 Mon 12:30 H 3007

Feshbach resonances in cuprate and nickelate high-Tc superconductors — •Fabian Grusdt[1,2], Annabelle Bohrdt[2,3], Lukas Homeier[1,2], Hannah Lange[1,2,4], Henning Schloemer[1,2], Ulrich Schollwoeck[1,2], and Eugene Demler[5] — [1]Department of Physics and Arnold Sommerfeld Center for Theoretical Physics (ASC), Ludwig-Maximilians-Universität München, Theresienstr. 37, München D-80333, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany — [3]University of Regensburg, Universitätsstr. 31, Regensburg D-93053, Germany — [4]Max-Planck-Institute for Quantum Optics, Hans-Kopfermann-Str.1, Garching D-85748, Germany — [5]Institute for Theoretical Physics, ETH Zurich, 8093 Zürich, Switzerland

Experimental advances in solids, quantum simulators, and numerical techniques allow unprecedented microscopic studies of the structure of strongly correlated quantum matter. Taking advantage of these achievements, we present evidence for the existence of a Feshbach resonance in Hubbard and t-J models commonly used to model cuprate and nickelate compounds. In a 2d square lattice, we show that attractive d-wave interactions between magnetic-polaron charge carriers are mediated through coupling to a near-resonant bosonic paired state of two holes. We present a closely related Feshbach picture for the bilayer nickelate superconductors under pressure, described by a mixed-dimensional t-J model. As an outlook we describe how higher critical temperatures can be reached, including in ultracold atom experiments that have previously observed strong pairing mixed dimensions.

TT 5.13 Mon 12:45 H 3007

Probing the pairing symmetry of superconducting nickelates through electron irradiation induced disorder — •Abhishek Ranna[1], Michal Moravec[1,2], Romain Grasset[3], Kyuho Lee[4], Bai Yang Wang[4], Marcin Konczykowski[3], Harold Y. Hwang[4], Andrew P. Mackenzie[1,2], and Berit H. Goodge[1] — [1]Max Planck Institute for Chemical Physics of Solids, Germany — [2]University of St. Andrews, UK — [3]LSI, Ecole Polytechnique, France — [4]Stanford University, USA

Superconducting infinite-layer nickelates were experimentally realized two decades after their theoretical prediction, generating significant interest for being isoelectronic to the $3d^9$ superconducting cuprates. Despite similarities between their phase diagrams, key distinctions in electronic landscapes and hybridizations have been identified. Direct investigations to probe the fundamental superconducting properties using photoemission spectroscopy and single-particle tunneling experiments have so far proved challenging due to the thin film geometry and surface degradation caused during *ex situ* topotactic reduction. We employ high-energy electron irradiation to controllably and systematically induce disorder, thereby examining the impact of pair-breaking defects on the superconductivity which can help elucidate the nature of the superconducting gap symmetry. Here, we present our initial findings on the evolution of electronic properties such as the superconducting transition temperature and residual resistivity with increasing disorder to shed light on the pairing symmetry and electronic behaviour of the infinite-layer nickelates.

TT 5.14 Mon 13:00 H 3007

Strain engineering of superconducting infinite-layer nickelates — •Berit Goodge[1,2], Dan Ferenc Segedin[3], Grace Pan[3], Charles Brooks[3], Julia Mundy[3], and Lena Kourkoutis[1] — [1]Cornell University, Ithaca, USA — [2]Max Planck Institute CPfS, Dresden, Germany — [3]Harvard University, Cambridge, USA

The superconducting monovalent layered nickelates demonstrate a key example of successful materials prediction and design based on proximity to a related system, namely the superconducting cuprates. The metastable nickel valence corresponding to the requisite electronic configuration, however, results in a complex synthetic route to stabilize these compounds involving high-quality thin film synthesis of higher-valent nickelate epitaxial thin films followed by topotactic chemical reduction to the desired square-planar phase. This two-step processes introduces competing epitaxial strain states in the precursor and target phases, which present both immense challenges as well as unique possibilities to leverage these strain interactions for bespoke tuning of the resulting film structure. Here we discuss both the limits to and possibilities for strain engineering in superconducting nickelates.

TT 6: Superconductivity: Tunnelling and Josephson Junctions I

Time: Monday 9:30–13:00 Location: H 3010

TT 6.1 Mon 9:30 H 3010

Tailoring arbitrary energy-phase relationships using Josephson tunnel junctions — •A. Mert Bozkurt[1,2], Jasper Brookman[1], Valla Fatemi[3], and Anton Akhmerov[1] — [1]Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 4056, 2600 GA Delft, The Netherlands — [2]QuTech, Delft University of Technology, 2600 GA Delft, The Netherlands — [3]School of Applied and Engineering Physics, Cornell University, Ithaca, NY 14853 USA

Josephson tunnel junctions exhibit a simple current-phase relation, characterized by single harmonics. Conversely, high-transparency Josephson junctions feature multiple harmonics, with the specific harmonics depend on microscopic details of the junction, presenting a challenge for precise control. We find that when two Josephson tunnel junctions are connected in series, their energy-phase relationship is identical to a high-transparency Josephson junction. By connecting multiple arms in parallel and introducing a magnetic flux, we can systematically engineer specific current-phase relationships. As an example, we present a superconducting diode implementation with a high efficiency, a two-terminal device that controls supercurrent flow in one direction differently from the other. The resulting superconducting diode efficiency is robust against the imperfections in the design parameters, making it practical for real-world implementations. Beyond superconducting diodes, we showcase various other energy-phase relationships to demonstrate the versatility of the approach. This technique can be useful for engineering sophisticated energy-phase landscapes for advanced quantum computing systems.

TT 6.2 Mon 9:45 H 3010

Shaping quantized current steps in Josephson junctions using tailored drives — •Fabian Kaap, Christoph Kissling, Victor Gaydamachenko, Asen Georgiev, Lukas Grünhaupt, and Sergey Lotkhov — Physikalisch-Technische Bundesanstalt, Bundesallee 100 38116, Deutschland Braunschweig

Recent experiments have confirmed predictions made nearly four decades ago about the existence of quantized current steps in Josephson junctions and superconducting nanowires - referred to as dual Shapiro steps. These steps, separated by $2ef$, with e the elementary charge and f the frequency, hold potential for a novel current standard. To realize dual Shapiro steps, we embed a Al/AlO_x/Al dc-SQUID in a high-impedance environment made from granular aluminium and oxidized titanium. Demonstration of quantized current steps in the IV-curves is achieved with an external sinusoidal driving signal of frequencies up to 6 GHz, resulting in steps up to $I = n \times 2ef \approx n \times 2\,\text{nA}$. Using a sawtooth shaped driving signal instead, enhances the first dual Shapiro step at positive or negative currents while suppressing the opposite value step, contingent on the slope of the sawtooth signal. We compare the flatness of the enhanced current steps, as compared to the steps generated using the sinusoidal drive, by the peak values of the differential resistance $R_{\text{diff}} = \frac{dU}{dI}$ and find an improvement by a factor of ~ 2.

TT 6.3 Mon 10:00 H 3010

Magnetochiral vortex rachet effect in two-dimensional semiconductor-superconductor Josephson junction arrays — •Simon Reinhardt[1], Johanna Berger[1], Sergei Gronin[2], Geoffrey C. Gardner[2], Tyler Lindemann[2], Michael J. Manfra[2], Nicola Paradiso[1], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Purdue University, West Lafayette, Indiana 47907, USA

We study two-dimensional Josephson junction arrays in hybrid aluminum/InGaAs/InAs semiconductor-superconductor heterostructures. An out-of-plane magnetic field induces vortices, which form ordered patterns for commensurate values of the frustration parameter. We probe the symmetry of the intrinsic vortex pinning potential using critical current measurements. When applying in-plane magnetic fields we observe non-reciprocal vortex depinning currents, revealing a ratchet-like vortex pinning potential. We discuss how this novel effect can be linked to the anomalous Josephson effect, caused by the combination of Rashba spin-orbit coupling and Zeeman field [1,2,3].

[1] W. Mayer *et al.*, Nat. Commun. **11** (2020) 212
[2] C. Baumgartner *et al.*, Nat. Nanotechnol. **17** (2021) 39
[3] S. Reinhardt *et al.*, arXiv:2308.01061 (2023)

TT 6.4 Mon 10:15 H 3010

Experimental and simulated realization of magnetization-controlled critical current in a ferromagnetically constricted Josephson junction — •Lukas Kammermeier and Elke Scheer — Universität Konstanz

We present an experimental realization of a magnetization (M) controlled Josephson junction in a superconductor-ferromagnet S-S'-S (S'=S/F) hybrid structure, which allows for a post-manufacturing manipulation of the critical current I_c. We observe multiple and non-monotonic discrete jumps of $I_c(M)$ up to full supression depending on the magnetic history. In addition we reproduce the observed effects in micromagnetic simulations with MuMax3 [1] and a simple model of stray-field-mediated suppression of I_c. Resulting in a semi quantitaive microscopic explanation for the jumps in the $I_c(M)$ measurements.

[1] A. Vansteenkiste, AIP Advances 4 (2014) 107133

TT 6.5 Mon 10:30 H 3010

Equal-spin Cooper pairs across S/M interfaces with strongly polarized magnets — •Danilo Nikolic and Matthias Eschrig — Institut für Physik, Universität Greifswald, Felix-Hausdorff-Str. 6, 17489 Greifswald, Germany

Motivated by recent experiments on the proximity effect in the superconductor (S) - helimagnet (M) systems [1], we present a systematic theoretical study of such an effect in SM systems with strongly polarized M featuring different textures of magnetization. The theory is done in the framework of the quasiclassical Usadel Green's formalism. However, due to the large splitting between the spin bands, the standard Usadel approach [2] cannot be applied directly but a somewhat modified description is required [3]. Applying this approach, we account for equal-spin triplet correlations and investigate their influence on observables, e.g., the critical temperature of S. Moreover, due to the strong spin polarization of M, Josephson junctions involving it represent a promising platform for studying the novel superconducting diode effect. This effect can be explained through the coupling between the superconducting phase and the gauge field induced by the inhomogeneous magnetization in M [4].

[1] A. Spuri *et al.*, arXiv:2305.02216 (2023)
[2] A. I. Buzdin, Rev. Mod. Phys. **77** (2005) 935
[3] R. Grein *et al.*, Phys. Rev. Lett. **102** (2009) 227005
[4] A. B. Vorontsov *et al.*, Phys. Rev. Lett. **101** (2008) 127003; I. V. Bobkova *et al.*, Phys. Rev. B **96** (2017) 094506

TT 6.6 Mon 10:45 H 3010

Spin torque in a Josephson junction between two superconducting magnetic impurity states — •Fabian Ziesel[1], Ciprian Padurariu[1], Björn Kubala[2], and Joachim Ankerhold Ankerhold[1] — [1]ICQ and IQST, Ulm University, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

In this talk, we study a Josephson junction formed between two magnetic impurities. Such a junction was recently realized using a scanning tunneling microscope tip functionalized with a magnetic impurity that probes a second impurity on the sample [1]. We suggest that the Josephson effect can determine and also influence the relative magnetic orientation of the impurities due to a Josephson-induced exchange interaction that arises, similarly to Josephson junctions with two magnetic layers [2].

Our theoretical approach treats the Josephson and spin dynamics equally. We identify a key experimental signature of spin dynamics: a small d.c. bias results in excess d.c. current due to the coupling between spins and the Josephson phase. We also discuss spin control, exemplified by inducing a spin-flip of an impurity using an adiabatic voltage pulse, and provide a protocol for calculating the appropriate temporal area of the pulse.

[1] H. Huang *et al.*, Phys. Rev. Research **3** (2021) L032008
[2] X. Waintal *et al.*, Phys. Rev. B **65** (2002) 054407

TT 6.7 Mon 11:00 H 3010

Spectral and transport properties of spin-filter Josephson junctions — •Niklas L. Schulz, Anna-Izabella Levbarg,

Danilo Nikolic, and Matthias Eschrig — Institut für Physik, Universität Greifswald, D-17489 Greifswald, Germany

Recent experiments [1] showed that the supercurrent in spin-filter Josephson junctions [2], which incorporate a ferromagnetic insulating barrier (FI), strongly varies with the barrier's width and results in a temperature-induced incomplete $0-\pi$ transition. Motivated by this, we provide a full theoretical study of an S-FI-S junction within the quasi-classical Usadel theory [3] and investigate spectral and transport properties. We model the FI interface using a scattering matrix approach that effectively enters the quasi-classical theory as boundary conditions allowing to account for various effects arising from the interface [4]. We found temperature-induced $0-\pi$ transitions in S-FI-S junctions which depend on the barrier width. Moreover, self-consistent calculations show incomplete $0-\pi$ transitions. Finally, such systems represent an intermediate step towards S-FI-F-FI-S junctions, which are expected to exhibit the superconducting diode effect [5] and are subject of ongoing research.

[1] R. Caruso *et al*, Phys. Rev. Lett. **122**, 047002 (2019)
[2] K. Senapati *et al*, Nat. Mater. **10**, 849-852 (2011)
[3] K. D. Usadel, Phys. Rev. Lett. **25**, 507 (1970)
[4] M. Eschrig *et al*, New J. Phys. **17**, 083037 (2015)
[5] R. Grein *et al*, Phys. Rev. Lett. **102**, 227005 (2009)

15 min. break

Invited Talk TT 6.8 Mon 11:30 H 3010

Theory of supercurrent diode effect and other spin-orbit-driven phenomena in superconducting magnetic junctions — •Andreas Costa — University of Regensburg, Germany

Their extraordinary physical properties to tailor spin-polarized triplet supercurrents—exploiting, e.g., spin-orbit coupling (SOC)—make superconducting magnetic junctions a promising platform to implement quantum-computing concepts or explore topological effects.

The first part of this talk will give a more general overview of such junctions' SOC-driven transport anomalies, covering giant transport magnetoanisotropies that result from the triplet-current-inducing unconventional (spin-flip) Andreev-reflection process [1,2] and sizable transverse Hall supercurrents that originate from SOC-induced skew scattering of charge carriers [3].

In the second part of the talk, we will focus on our theoretical model developed to understand the supercurrent diode effect (SDE) in Al/InAs-based Josephson-junction arrays [4–6]. The competition between SOC and an appropriately aligned magnetic field imprints a strong polarity dependence on the critical Josephson currents with characteristic features, such as 0–π-like transitions and a possible reversal of the SDE, that we could further characterize with our model.

This work has been supported by DFG Grants 454646522 and 314695032 (SFB 1277), and by ENB IDK Topological Insulators.

1] Phys. Rev. Lett. **115** (2015) 116601
[2] Phys. Rev. B **95** (2017) 024514
[3] Phys. Rev. B **100** (2020) 060507(R)
[4] Nat. Nanotechnol. **17**(2022)39
[5] Nat. Nanotechnol. **18** (2023) 1266
[6] Phys. Rev. B **108** (2023) 054522

TT 6.9 Mon 12:00 H 3010

A diode effect in an Ising-superconductor Josephson junction — •Sourabh Patil[1], Gaomin Tang[2,3], and Wolfgang Belzig[1] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Graduate School of China Academy of Engineering Physics, 100193 Beijing, China — [3]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

Two Ising superconductors proximitized by ferromagnetic layers can be used to build a Josephson junction. This setup allows for tunable spin-triplet pairing correlations, letting us control charge and spin supercurrents through the in-plane magnetic exchange fields [1]. Recently, there has been significant interest in the study of the superconducting diode effect. A Josephson diode allows a greater dissipationless supercurrent to flow in one direction compared to the other [2].

Here, we study a new kind of Josephson diode that uses supercurrent interference. It is created through a Josephson junction, incorporating a small non-magnetic barrier with perfect transmission combined with a fully polarized ferromagnetic barrier in the tunneling limit. The superposition of the current-phase relations from these two barriers results in the diode effect in the junction. This unique design attains diode efficiencies of up to 20

[1] G. Tang et al., Phys. Rev. B 104 (2021) L241413
[2] R. Souto et al., Phys. Rev. Lett. 129 (2022) 267702

TT 6.10 Mon 12:15 H 3010

Performance study of gate-controlled superconducting currents in Nb devices — •Leon Ruf, Jennifer Koch, Elke Scheer, and Angelo Di Bernardo — University of Konstanz, Universitätsstraße 10, 78457 Konstanz, Germany

Gate controlled superconductivity (GCS) has recently attracted great attention. It was reported [1] that the superconducting state can be suppressed in gated nanoconstrictions by a gate voltage. The authors attribute their observation to an electric field induced perturbation of the superconducting state, giving the next milestone for future superconducting and CMOS compatible transistors. However, the mechanism for the GCS effect is strongly under debate. Other works report about different mechanism caused by a leakage current: high-energy quasiparticle injection [2], low-energy mediated phonon excitation [3] or hot-spot generation [4]. Here we are studying the performance of Nb Dayem bridges made by electron beam lithography and lift off. Our observations show the GCS effect also for relatively large bridges increasing the critical current. We observe a linear anticorrelation between the critical current and the amplitude of the gate leakage current. We discuss our findings in the light of the suggested mechanism [1-4].

[1] G. De Simoni et al., Nat. Nanotechnol. 13 (2018) 802
[2] L.D. Alegria et al., Nat. Nanotechnol. 16 (2021) 404
[3] M.F. Ritter et al. Nat. Electron. 5 (2022) 71
[4] J. Basset, et al. Phys. Rev. Research 3 (2021) 043169

TT 6.11 Mon 12:30 H 3010

Non-Hermitian phase-biased Josephson junctions — •Jorge Cayao[1] and Masatoshi Sato[2] — [1]Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden — [2]Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

We study non-Hermitian Josephson junctions formed by conventional superconductors with a finite phase difference under non-Hermiticity naturally appearing due to coupling to normal reservoirs. Depending on the structure of non-Hermiticity, the low-energy spectrum hosts topologically stable exceptional points either at zero or finite real energies as a function of the superconducting phase difference. Interestingly, we find that the corresponding phase-biased supercurrents acquire divergent profiles at such exceptional points, an instance that turns out to be a natural and unique non-Hermitian effect signalling a possible way to enhance the sensitivity of Josephson junctions.

TT 6.12 Mon 12:45 H 3010

Quantum size effects on Andreev transport in Josephson junctions — Gábor Csire[1], •Balázs Ujfalussy[2], and Nóra Kucska[2] — [1]Materials Center Leoben Forschung GmbH, Roseggerstraße 12, 8700 Leoben, Austria — [2]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary

Measurements of the critical current density, superconducting coherence length, and superconducting transition temperature in single-domain, epitaxially-grown Nb(110)/Au(111)/Nb(110) junctions show an oscillatory behavior as a function of the thickness of the Au layers. We apply the first principles-based microscopic theory of inhomogeneous relativistic superconductivity to understand both the fundamentals and the specifics of the underlying physical mechanism of this behavior. We study the effects of spin-orbit coupling, and the effect of confinement and show that they induce a complex structure of Andreev states in the superconducting state which in turn modifies the quasi-particle spectrum and the Josephson supercurrent. Our study reveals the coexistence of two superconducting phases in the gold layers, the usual intraband *s*-wave phase and an additional Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) phase stemming from interband pairing (without magnetic field). The results indicate the rich interplay between quantum size and proximity effects which suggests the possibility of modifying superconducting transport properties by exploiting thickness-dependent quantum size effects.

TT 7: Correlated Electrons: Electronic Structure Calculations

Time: Monday 9:30–12:30 Location: H 3025

TT 7.1 Mon 9:30 H 3025

Influence of the ionic coordination on the electronic structure of NiO and CoO calculated with a DFT+DMFT first principles many-body approach — •Daniel Mutter[1], Daniel F. Urban[1,2], Frank Lechermann[3], and Christian Elsässer[1,2] — [1]Fraunhofer IWM, 79108 Freiburg — [2]Freiburg Materials Research Center (FMF), Universität Freiburg — [3]Institut für Theoretische Physik III, Ruhr-Universität Bochum

The electronic structure of first-row transition-metal (TM) oxides is determined by strong electron correlation leading to interesting effects as, e.g., Mott-insulating behavior. Such effects can be related to the high energy excitation features in the spectral functions, which cannot be described by the quasi-particle density of states resulting from density-functional theory (DFT) calculations based on LDA or GGA exchange-correlation functionals. To derive the many-body spectral functions for the two TM oxides NiO and CoO, we applied a combination of DFT and dynamical mean field theory (DFT+DMFT). The influence of the crystal-field coordination of the TM cations by oxygen anions is studied by considering the two compounds in both rock-salt and zincblende structures. In addition to the electron correlation in the TM 3d orbitals, we account for the correlation in the oxygen 2p orbitals by augmenting DFT+DMFT with a self-interaction-correction pseudopotential scheme [1].

[1] F. Lechermann et al., Phys. Rev. B 100 (2019) 115125.

TT 7.2 Mon 9:45 H 3025

Bridging DFT+U and DFT+DMFT: Hartree-Fock approximation and Wannier Projectors — •Alberto Carta[1], Iurii Timrov[2], Peter Mlkvik[1], Alexander Hampel[3], and Claude Ederer[1] — [1]ETH Zurich, Zurich, Switzerland — [2]Paul Scherrer Institut, Villigen, Switzerland — [3]Flatiron Institute (CCQ), New York, USA

Materials exhibiting strong electron-electron interactions are effectively described by combining density functional theory and dynamical mean-field theory (DFT+DMFT), where electronic correlations are captured by mapping the system to a self-consistently determined impurity model.

By solving the impurity model within the Hartree-Fock approximation, the static-mean field limit of DMFT is recovered. In this contribution we show that DFT+DMFT with the Hartree-Fock approximation is equivalent to the well established DFT+U method.

We demonstrate this equivalence by benchmarking DFT+DMFT calculations against DFT+U for various example systems (MnO, NiO, and $LuNiO_3$), using the new integration of maximally localized Wannier functions as Hubbard projectors in DFT+U as implemented in Quantum ESPRESSO.

Finally, the flexibility of our implementation allows us to extend the application of DFT+U beyond the usual atomic-like orbitals. We explore the use of DFT+U on different basis sets, such as frontier orbitals in $LuNiO_3$ or a molecular orbital-like basis in VO_2, showcasing the versatility of our approach.

TT 7.3 Mon 10:00 H 3025

Parametrization of the Coulomb interaction matrix with point-group symmetry — •Coraline Letouzé, Guillaume Radtke, Benjamin Lenz, and Christian Brouder — Sorbonne Université, Muséum National d'Histoire Naturelle, UMR CNRS 7590, Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, IMPMC, 75005 Paris, France

In realistic (DFT+DMFT) calculations of correlated materials, the matrix of the partially-screened electron-electron Coulomb interaction is usually approximated in spherical symmetry and parameterized by Slater integrals (or, equivalently, Racah parameters). Few works have considered the real point-group symmetry of the Coulomb matrix.

Here, Coulomb integrals are analyzed by considering both the point-group symmetry of the site occupied by the atom in the crystal or molecule and the permutation symmetries of the orbitals in the integrals. Explicit formulas are provided to calculate all integrals of the interaction tensor in terms of a minimum set of independent ones. The effect of a symmetry breaking is also investigated by describing Coulomb integrals of a group in terms of those of one of its subgroups.

Possible applications of the presented framework include the calculation of solid-state and molecular spectroscopies via multiplet techniques, dynamical mean-field theory, or the *GW* approximation.

[1] Phys. Rev. B **108**, 115137

TT 7.4 Mon 10:15 H 3025

Single-site DFT+DMFT for vanadium dioxide using bond-centered orbitals — •Peter Mlkvik, Nicola A. Spaldin, and Claude Ederer — ETH Zurich, Zurich, Switzerland

We present a combined density-functional theory and single-site dynamical mean-field theory (DMFT) study of vanadium dioxide (VO_2) using an unconventional set of bond-centered orbitals as the basis of the correlated subspace. VO_2 is a prototypical material undergoing a metal-insulator transition (MIT), hosting both intriguing physical phenomena and the potential for industrial applications. With our choice of correlated subspace, we can investigate the interplay of structural dimerization and electronic correlation in VO_2 in a computationally cheaper way than other state-of-the-art methods, such as cluster DMFT. Our approach allows us to treat the rutile and M1 monoclinic VO_2 phases on an equal footing and to vary the dimerizing distortion continuously, exploring the energetics of the different phases. The choice of basis presented in this work hence offers a complementary view on the long-standing discussion on the MIT in VO_2 and suggests possible future extensions to other similar materials hosting molecular-orbital-like states.

TT 7.5 Mon 10:30 H 3025

Origin of transitions inversion in rare-earth vanadates — •Xuejing Zhang[1], Erik Koch[1,2], and Eva Pavarini[1,2] — [1]Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA High-Performance Computing, 52062 Aachen, Germany

The surprising inversion of orbital- and magnetic-order transition with increasing rare earth radius in the $ReVO_3$ series (with Re=La, Pr, Tb, Y and Lu) is poorly understood[1]. Here –using a combination of the LDA+DMFT method and irreducible tensors decomposition[2]– we show that this remarkable behavior results from the competition between rare-earth-specific super-exchange couplings and lattice distortions. For systems with small Re ionic radius, we find that electron-lattice interaction stabilize orbital ordering. Increasing the rare-earth radius modifies the active super-exchange couplings, leading to a strongly enhancement of orbital super-exchange effects and G-type anti-ferromagnetism.[3]

[1] S. Miyasaka, Y. Okimoto, M. Iwama, and Y. Tokura, Phys. Rev. B 68 (2003) 100406(R).
[2] X. J. Zhang, E. Koch, and E. Pavarini, Phys. Rev. B 105 (2022) 115104; Phys. Rev. B 106 (2022) 115110.
[3] X. J. Zhang, E. Koch, and E. Pavarini, Manuscript in preparation (2023).

TT 7.6 Mon 10:45 H 3025

Neural-network-boosted exact diagonalization: A new approach and a new community code — •Pavlo Bilous[1], Louis Thirion[2], and Philipp Hansmann[2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

The solution of quantum many-body systems (clusters) in truncated finite size Hilbert spaces presents a paradigm in many fields of research ranging from quantum chemistry to condensed matter physics. Whether the considered clusters are of real nature (atoms, molecules) or auxiliary (e.g. as used in dynamical mean-field theory), solving the eigenvalue equation for the Hamiltonian $\hat{H}\Psi = E\Psi$ with exact or numerical diagonalization procedures is severely limited due to the exponential growth of the Hilbert space dimension w. r. t. the single particle quantum numbers (orbitals/sites). However, it turns out that often only a small subset of basis states is sufficient to approximate expectation values of observables. The challenge is to identify this a priori unknown subset: In this talk we present an approach to converge observables like the ground state energy with successive basis extension and basis selection steps which are assisted by a neural-network (NN) classification scheme. Concrete examples show that the NN selection outperforms traditional truncation schemes dramatically and might push the boundaries of such calculations by an order of magnitude. The method is integrated in SOLAX: a new JAX-based parallelized GPU-accelerated Python code which we are currently developing.

15 min. break

TT 7.7 Mon 11:15 H 3025

Dynamical mean-field theory study of the spin-orbit insulator Ba_2IrO_4: Effective low-energy models from first principles — •Léo Gaspard[1], Francesco Cassol[2], Michele Casula[2], Benjamin Lenz[2], and Cyril Martins[1] — [1]Laboratoire de Chimie et Physique Quantiques, Université Toulouse III - Paul Sabatier , Toulouse, France — [2]Institut de Minéralogie de Physique des Matériaux et de Cosmochimie, Sorbonne Université, Paris, France

Iridium-based transition metal oxydes are generally described by a low-energy effective model based on $j_{\rm eff} = \frac{1}{2}$ and $\frac{3}{2}$ spin-orbitals. Among those, the most famous is the spin-orbit Mott insulator Sr_2IrO_4 for which it is possible to build a $j_{\rm eff}=\frac{1}{2}$ one band model, establishing a connection with the isostructural high-temperature superconductor copper oxydes. In Iridates, Coulomb interaction and spin-orbit coupling are of the same order of magnitude as the kinetic energy of the electrons. A model based on effective spin-orbitals thus treats spin-orbit coupling and electronic correlations at different levels of approximations. In this work, we carefully extract an effective Hubbard-Kanamori model for Ba_2IrO_4, a sister-compound of Sr_2IrO_4 which does not exhibit structural distortions. Starting from a DFT calculation, we use maximally localized Wannier functions and constrained Random Phase Approximation to parametrize the model. We then solve this model using Dynamical Mean Field Theory ,treating electronic correlations and spin-orbit coupling on equal footing. We will discuss the influence of the choice of the model space (full 5d manifold against t_{2g} manifold) on the computed observables.

TT 7.8 Mon 11:30 H 3025

Dynamical mean-field theory study of the spin-orbit insulator Ba_2IrO_4: the role of spin-orbit coupling in the Mott transition — •Francesco Cassol[1], Léo Gaspard[2], Michele Casula[1], Cyril Martins[2], and Benjamin Lenz[1] — [1]IMPMC, Sorbonne University - CNRS, Paris, France — [2]LCPQ, Université Paul Sabatier Toulouse III - CNRS, Toulouse, France

The discovery of the spin-orbit (SO) induced insulating ground state in Sr_2IrO_4 has triggered intense resarch efforts targeting materials with strong SO coupling. We focus here on Ba_2IrO_4, a sister compound of Sr_2IrO_4 with similar properties. In Ba_2IrO_4, the absence of structural distortions yields pseudo-spin states that are close in energy, casting doubts on the single band $j_{\rm eff} = 1/2$ picture invoked for Sr_2IrO_4. Its simple structure makes Ba_2IrO_4 also an ideal candidate to systematically study the interplay between SO coupling and Coulomb interactions in the metal-insulator transition. Based on an effective three-band model of Ba_2IrO_4, we investigate the evolution of the Mott transition within dynamical mean-field theory (DMFT). The corresponding phase diagram is studied with respect to the variation of the relevant couplings and temperature. We clarify the topological role of SO coupling and show that the paramagnetic insulating phase is recovered for realistic electron-electron interactions, thus establishing Ba_2IrO_4 as a SO-induced Mott insulator. Comparing our calculations with available angle-resolved photoemission spectra, we finally discuss the limitations of a single-site DMFT treatment and the role of antiferromagnetic fluctuations.

TT 7.9 Mon 11:45 H 3025

Formation of spin-orbital entangled 2D electron gas in layer delta-doped bilayer iridate $La_\delta Sr_3Ir_2O_7$ — •Amit Chauhan[1], Arijit Mandal[2], and B. R. K. Nanda[2] — [1]Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Condensed Matter Theory and Computational Lab, Department of Physics, IIT Madras, Chennai-36, India

The state-of-the-art doping techniques pave the way to engineer nontrivial exotic quantum transport in strongly spin-orbit coupled quantum materials. By performing DFT calculations and formulating a multi-orbital Hubbard model, we predict the formation of a sharply confined spin-orbital entangled two-dimensional electron gas (2DEG) on a δ-doped bi-layer iridate $La_\delta Sr_3Ir_2O_7$. It differs from the conventional way of forming the 2DEG out of polar oxide heterostructures. The electron doping in the otherwise half-filled $J_{eff} = 1/2$ states destroy the Neel state of the IrO_2 layers near to the δ-doped layer, leading to partially filled Ir upper-Hubbard sub-bands which host the spin-orbital entangled electron gas. The gas is confined by a potential well formed by the positively charged LaO layer. The estimated electrical conductivity is giant and is of the order of 10^{19} $Sm^{-1}s^{-1}$. Our study will encourage experimenters to grow δ-doped structures on a wide class of spin-orbit correlated materials to explore the formation of 2DEG which is crucial for future quantum technologies.

[1] A. Chauhan *et al.*, Phys. Rev. Materials **7** (2023) 114409.

TT 7.10 Mon 12:00 H 3025

On the cuprates' universal waterfall feature: evidence of a momentum-driven cross-over — Benjamin Bacq-Labreuil[1], Chafic Fawaz[2], Matteo d'Astuto[2], Silke Biermann[1,3], and •Benjamin Lenz[4] — [1]Ecole Polytechnique, Palaiseau, France — [2]Institut Néel, Grenoble, France — [3]Collège de France, Paris, France — [4]Sorbonne Université, Paris, France

We study two related universal anomalies of the spectral function of cuprates, so called waterfall and high-energy kink features, by a combined cellular dynamical mean-field theory and angle-resolved photoemission study for the oxychloride $Na_xCa_{2-x}CuO_2Cl_2$ (Na-CCOC). Tracing their origin back to an interplay of spin-polaron and local correlation effects both in undoped and hole-doped (Na-)CCOC, we establish them as a universal cross-over between regions differing in the *momentum*-dependence of the coupling and not necessarily in the energy of the related quasiparticles. The proposed scenario extends to doping levels coinciding with the cuprate's superconducting dome and motivates further investigations of the fate of spin-polarons in the superconducting phase.

TT 7.11 Mon 12:15 H 3025

Electron glass phase with resilient Zhang-Rice singlets in $LiCu_3O_3$ — •Armando Consiglio[1], Gianmarco Gatti[2], Edoardo Martino[2], Tobias Hofmann[1], Ronny Thomale[1], Giorgio Sangiovanni[1], Domenico Di Sante[3], Martin Greiter[1], Marco Grioni[2], and Simon Moser[2,4,5] — [1]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Germany — [2]Institute of Physics, Ecole Polytechnique Fédérale de Lausanne, Switzerland — [3]Department of Physics and Astronomy, University of Bologna, Italy — [4]Advanced Light Source, Berkeley, California 94720, USA — [5]Physikalisches Institut and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Germany

$LiCu_3O_3$ is an antiferromagnetic cuprate where Li substitution disrupts the native arrangement of edge-sharing Cu(II)O and Cu(I) ions. Utilizing angle-resolved photoemission spectroscopy (ARPES) and density functional theory (DFT), we reveal two distinct insulating electronic subsystems arising from Li-induced disorder. The first involves a Cu dz^2/O p_z valence band dispersing on the Cu(I) plane, while the second showcases a resilient Cu $3d_{x^2-y^2}$/O $2p_{x,y}$ derived Zhang-Rice singlet (ZRS) band on the Cu(II)O planes. Li's impact stabilizes the insulating ground state, also inducing a unique 2D electron glass behavior in charge transport, as observed through ARPES. This study underlines that, despite disorder, the Cu(II)-derived ZRS remains largely unaffected from impurity scattering and implies a local segregation of Li and Cu atoms.

TT 8: Focus Session: Quantum Interactive Dynamics I (joint session DY/TT)

Quantum many-body systems out of equilibrium represent a challenging frontier and have been shown to exhibit extremely rich phenomena. Recent experimental advances in building Noisy Intermediate-Scale Quantum (NISQ) devices have opened up a completely new territory in this context. The natural evolution implemented by NISQ devices is a quantum interactive dynamics generated by a combination of unitary gates and measurements. These platforms provide an opportunity to explore vastly larger parts of the Hilbert space and go beyond what can be realized in purely unitary systems. In pioneering works, an entanglement phase transition was identified in the dynamics of circuits of random unitary gates interleaved with local projective measurements. This phase transition separates a disentangling phase, obeying an area law, and an entangling phase obeying a volume law. Successively, it has been shown that additional phase transitions between different area phases can occur and new kinds of quantum phase transitions have been discovered. This session aims to give an overview of recent theoretical and experimental developments within this very active field and point towards the open questions.

Organized by Roderich Moesser (Dresden) and Frank Pollmann (München)

Time: Monday 9:30–12:45 Location: A 151

Invited Talk TT 8.1 Mon 9:30 A 151

Quantum information phases in space-time: measurement-induced entanglement and teleportation on a noisy quantum processor — •Vedika Khemani — Stanford University, USA

I will discuss the dynamics of monitored systems combining the ingredients of unitary evolution, measurements, and adaptive classical control. I will present various novel dynamical phases and phase transitions that arise in these systems, ranging from entanglement and teleportation phase transitions to "learnability" transitions in the ability to reconstruct quantum information from measurements. I will also discuss experimental realizations of these phenomena in noisy quantum processors.

Invited Talk TT 8.2 Mon 10:00 A 151

Measurement phase transitions and universality — •Adam Nahum — ENS Paris & CNRS

Repeated measurement can lead to a phase transition in quantum many-body dynamics. A subcritical rate of measurement allows complex, entangled states to evolve, while a supercritical measurement rate kills long-range entanglement. These phase transitions allow formal analogies with standard ordering transitions, but they are fundamentally different, partly as a result of the role played by quantum mechanical measurement randomness. Obtaining exact results for generic versions of the problem is challenging. I will sketch limits in which progress can be made (for example mean-field-like models, models in high dimensions, and noninteracting analogs).

Invited Talk TT 8.3 Mon 10:30 A 151

Dual-unitary circuit dynamics — •Pieter Claeys — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden

Dual-unitary circuits are minimal models of many-body quantum dynamics characterized by an underlying space-time duality. This duality makes them amenable to exact analysis, while remaining chaotic, and in recent years dual-unitary circuits have been used to study e.g. aspects of operator dynamics, quantum chaos, operator scrambling, entanglement dynamics, and the interplay between unitary dynamics and projective measurements. In this work I will give an overview of recent developments in dual-unitary circuits, focusing on the connection with many-body dynamics.

TT 8.4 Mon 11:00 A 151

Truncated Hilbert space approach for simulating dynamics in perturbed Ising chains — •Nico Albert[1] and Hong-Hao Tu[2] — [1]Technische Universität Dresden, Dresden, Germany — [2]Ludwig-Maximilians-Universität München, Munich, Germany

Simulating dynamics in interacting quantum many-body systems is a challenging problem. We develop a truncated Hilbert space approach (THSA) and apply it to the quantum Ising chain with both transverse and longitudinal fields for studying its spectrum and quench dynamics. We find that the characteristic features of this model, such as E_8 particles with universal mass ratios, are well captured in the truncated Hilbert space approach. We also use this new method to study the confinement dynamics of domain-wall bound states in the ferromagnetic phase.

TT 8.5 Mon 11:15 A 151

Entanglement Transitions in Unitary Circuit Games — •Raúl Morral-Yepes[1,2], Adam Smith[3], Shivaji L. Sondhi[4], and Frank Pollmann[1,2] — [1]Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]University of Nottingham, Nottingham, UK — [4]University of Oxford, Oxford, UK

Repeated projective measurements in unitary circuits can lead to an entanglement phase transition as the measurement rate is tuned. In this work, we consider a different setting in which the projective measurements are replaced by dynamically chosen unitary gates that minimize the entanglement. This can be seen as a one-dimensional unitary circuit game in which two players get to place unitary gates on randomly assigned bonds at different rates: The "entangler" applies a random local unitary gate with the aim of generating extensive (volume law) entanglement. The "disentangler", based on limited knowledge about the state, chooses a unitary gate to reduce the entanglement entropy on the assigned bond with the goal of limiting to only finite (area law) entanglement. In order to elucidate the resulting entanglement dynamics, we consider three different scenarios: (i) a classical discrete height model, (ii) a Clifford circuit, and (iii) a general $U(4)$ unitary circuit. We find that both the classical and Clifford circuit models exhibit phase transitions as a function of the rate that the disentangler places a gate. In contrast, the entangler always wins when using Haar random unitary gates and we observe extensive, volume law entanglement for all non-zero rates of entangling.

TT 8.6 Mon 11:30 A 151

Entanglement phases, localization and multifractality of monitored free fermions in two dimensions — •Karim Chahine and Michael Buchhold — Institut für Theoretische Physik, Universität zu Köln, D-50937 Cologne, Germany

We investigate the entanglement structure and wave function characteristics of continuously monitored free fermions with $U(1)$-symmetry in 2D. By deriving the fermion replica-Keldysh field theory and a bosonic effective long-wavelength action, we explore the similarities and differences between entanglement phase transitions in 2D monitored fermions and Anderson-type localization transitions in 3D. Using exact numerical simulations, we establish the phenomenology of entanglement transitions in 2D monitored fermions, examining entanglement entropy, mutual information, and inverse participation ratio. At weak monitoring, we observe characteristic $L \log L$ entanglement growth and multifractal dimension $D_q = 2$, resembling a metallic Fermi liquid. At strong monitoring, exponentially localized wave functions lead to saturation, following an area law for entanglement. In between, the critical point exhibits entanglement scaling consistent with emergent conformal invariance and strong multifractality. Our numerical findings align well with mean-field analysis and a one-loop renormalization group treatment of the field theory, shaping the understanding of a monitoring-induced metal-to-insulator transition in entanglement content. This establishes 2D monitored fermions as a unique platform to explore the connection between non-unitary quantum dynamics in D dimensions and quantum statistical mechanics in $D + 1$ dimensions.

TT 8.7 Mon 11:45 A 151

Temporal Entanglement in Dual-Unitary Clifford Circuits with Probabilistic Measurements — •Jiangtian Yao and Pieter Claeys — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We study temporal entanglement in dual-unitary Clifford circuits with probabilistic measurements preserving spatial unitarity. We present exact results on characterizing the temporal entanglement barrier in the measurement-free regime. In the finite-measurement-rate regime, we numerically study the interplay between measurement rate and bath size. We connect the initial diffusive growth of temporal entanglement with bath size to a persistent random walk model and present an exact transfer-matrix approach for understanding how the system approaches the perfect-dephaser limit.

TT 8.8 Mon 12:00 A 151

Universal correlations in mesoscopic many-body systems: Berry's Random Wave Model in Fock space — •Florian Schöppl[1,2], Rémy Dubertrand[2], Juan Diego Urbina[2], and Klaus Richter[2] — [1]Northumbria University, NE1 8ST Newcastle upon Tyne, United Kingdom — [2]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

A complete characterization of quantum signatures of (mean-field) chaos in interacting many-body systems requires, besides the widely used universality of spectral correlations, the analysis of the corresponding universality for eigenstate correlations in Fock space.

We lift the concepts and techniques that characterize this universality in first-quantized systems, introduced by Berry [1] into the realm of interacting bosonic fields in [2]. The existence of a classical (mean-field) limit allows us to use of many-body semiclassical methods [3].

We employ them to investigate the universal statistical features of eigenstate correlations in Bose-Hubbard models.

[1] M. V. Berry, ”Regular and irregular semiclassical wavefunctions”, Journal of Physics A: Mathematical and General 10, 2083 (1977). [2] R. Dubertrand, F. Schöppl, J. D. Urbina, K. Richter, ”Universal correlations in chaotic many-body quantum states: Fock space formulation of Berry*s random wave model”, preprint (2023). [3] K.Richter, J.D. Urbina, S. Tomsovic. ”Semiclassical roots of universality in many-body quantum chaos”,J. Phys. A: Math. Theor. 55 453001 (2022)

TT 8.9 Mon 12:15 A 151

Efficient Learning of Matrix Product States for Approximation of Purities in Quantum Many-Body Systems — •Dmytro Kolisnyk, Raimel Medina, and Maksym Serbyn — Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria

The defining feature of quantum many-body systems is an exponential scaling of the Hilbert space with the number of degrees of freedom. This exponential complexity naïvely renders the complete characterization of state, for instance via the complete set of bipartite Renyi entropies, a challenging task. Recently, the compact way of storing subregions' purities by encoding them as amplitudes of a fictitious quantum wave function, known as the entanglement feature (EF), was proposed. Matrix product state (MPS) encoding of such EF was obtained for Haar random states, however, the general applicability and practical usage of such encoding remained unclear. In this work, we demonstrate that EF can be efficiently learned using only polynomial amount of samples in the number of degrees of freedom through the so-called TTcross algorithm, assuming it is expressible as a finite bond dimension MPS. We benchmark this learning process on Haar and random MPS states, utilizing analytic insights. Additionally, we devise novel applications for the learned EF, such as quantifying the distance between different entanglement patterns and finding the optimal one-dimensional ordering of physical indices in a given state, highlighting the potential utility of proposed learning method in characterizing quantum many-body systems.

TT 8.10 Mon 12:30 A 151

Quantum complexity phase transitions in monitored random circuits — •Ryotaro Suzuki[1], Jonas Haferkamp[2], Jens Eisert[1], and Philippe Faist[1] — [1]Freie Universität Berlin — [2]Harvard University

Recently, the dynamics of quantum systems that involve both unitary evolution and quantum measurements have attracted attention due to the exotic phenomenon of measurement-induced phase transitions. At the same time, quantum complexity emerged as a key quantity for the identification of complex behaviour in quantum many-body dynamics. Quantum complexity of a quantum state is defined as the minimum number of unitary gates to generate the state by a quantum circuit. In this work, we investigate the dynamics of the quantum state complexity in monitored random circuits, where n qubits evolve according to a random unitary circuit and are individually measured with a fixed probability at each time step. We find that the growth behaviour of the exact quantum state complexity undergoes a phase transition when changing the measurement rate. Below a critical measurement rate, the complexity grows linearly in time until an exponential time in n. Above, the complexity does not grow more than polynomially in n. We lower bound the exact state complexity in the former regime using recently developed techniques based on algebraic geometry.

TT 9: Focus Session: Anomalous Quantum Oscillations

Quantum oscillation (QO) phenomena describe the periodic variation of thermodynamic and transport properties of materials as a function of magnetic field. Since their discovery almost a century ago, their observation has been taken as a definite sign for the presence of a Fermi surface (FS) in metals. The standard theory of Onsager connects the QO frequency with the momentum space area of FS orbits forming the basis of a well-established experimental procedure for determining the electronic structure of metals. However, recent developments have challenged this canonical description of QOs. New mechanisms have been proposed to explain anomalous QO observed in several materials ranging from twisted bilayer graphene to topological multifold-semimetals like CoSi and beyond. The proposed Focus Session aims to connect recent advances in the theoretical description of QO with specific experimental signatures in correlated metallic materials. The symposium will highlight the intimate connection between fluctuation contributions to QOs and the subtle experimental evidence for identifying the correct electronic structure.

Organizers: Johannes Knolle (TU Munich), Christian Pfleiderer (TU Munich)

Time: Monday 15:00–18:15 Location: H 0104

Invited Talk TT 9.1 Mon 15:00 H 0104

Unusual Magnetic Oscillations in Kagome Mott Insulators — •Lu Li — University of Michigan, Ann Arbor, MI 48109, US

The observations of the Landau Level quantizations in narrow-gapped correlated Kondo insulators raise intriguing questions on the origins [1]. However, none of the models suggest the phenomena existing in wide-gap insulators. Kagome lattice Mott insulator Herbertsmithite is a well-established Dirac fermion spin liquid candidate. Yet, our search for magnetic oscillations in Herbertsmithite yielded only a series of magnetic transitions [2], possibly due to the ion disorders on the Kagome lattice. This problem is resolved in the recently discovered sibling compound $YCu_3(OH)_{6.5}Br_{2.5}$ [3]. Using ultrasensitive magnetometry in 70 T intense fields, we observe both the 1/3-plateau and 1/9-plateau transitions. The magnetometry reveals strong oscillations in the magnetic torque. While the temperature dependence follows the Fermi liquid theory, the oscillations appear to be roughly periodic in the magnetic field B, opposite to the $1/B$ trend in conventional metals. Furthermore, a strong angular dependence is observed for the oscillation fields, which indicates the orbital effect. Separating orbital and Zeeman effect, we show that this magnetic oscillation pattern is consistent with a Dirac fermion existing near the 1/9 plateau, and the fermion's chemical potential is shifted by the Zeeman effect [4].

[1] Xiang, Li et al., Science 362, 65 (2018); Li et al., Nat. Rev. Phys. 2, 463 (2020); Xiang, Li et al., Nat. Phys. 17, 788 (2021).
[2] Asaba, Li et al., Phys. Rev. B 90, 064417(2014)
[3] Zeng et al., PRB 105, L121109 (2022)
[4] Zheng et al., arXiv:2310.07989 (2023)

Invited Talk TT 9.2 Mon 15:30 H 0104

Quantum oscillations in small-gap insulators — •Nigel Cooper — Cavendish Laboratory, University of Cambridge, United Kingdom

In recent years it has become understood that quantum oscillations of the magnetization as a function of magnetic field, long recognized as a phenomenon intrinsic to metals, can also manifest in insulating systems. Theory has shown that in certain narrow-gap band insulators, quantum oscillations can appear with a frequency set by the area traced out by the minimum gap in momentum space. I shall provide an overview of the theories of quantum oscillations in simple band insulators of this type, and discuss the relevance of these theories to experimental measurements on novel materials.

Invited Talk TT 9.3 Mon 16:00 H 0104

Quantum Oscillations of the Quasiparticle Lifetime in a Metal — •Nico Huber[1], Valentin Leeb[1,2], Andreas Bauer[1,4], Georg Benka[1], Johannes Knolle[1,2,3], Christian Pfleiderer[1,2,4], and Marc A. Wilde[1,4] — [1]Technical University of Munich (TUM) — [2]MCQST, Munich — [3]Blackett Laboratory, Imperial College London — [4]TUM Zentrum für QuantumEngineering (ZQE), Munich

The low-lying excitations of metals are remarkably well explained by effective single-particle theories. Yet, strong interactions are abundant in condensed matter systems. This raises the question for direct spectroscopic signatures of phenomena beyond effective single-particle behavior. Here, we report on such a signature in the quantum oscillations (QOs) of the topological semimetal CoSi [1]. Its surprisingly simple QO spectrum related to Fermi surface pockets around the R-point [2,3] allows us to identify a QO frequency which defies the standard description in two ways. First, the frequency corresponds to the difference of quasi-particle (QP) orbits of two bands although the composite orbit is semi-classically forbidden. Second, the oscillations exist up to 50 K - in contrast to its constituent frequencies, which already vanish above a few K. We show that our findings are in excellent agreement with QOs of the QP lifetime [4]. Since the only precondition for this effect is a non-linear coupling of two orbits, e.g., due to QP scattering on defects, such QOs of the QP lifetime are generic for any metal featuring Landau quantization.

[1] Huber *et al.*, Nature **621**, 276 (2023)
[2] Huber *et al.*, PRL **129**, 026401 (2022)
[3] Guo *et al.*, Nat. Phys. **18**, 813 (2022)
[4] Leeb, Knolle, PRB **108**, 054202 (2023)

15 min. break

Invited Talk TT 9.4 Mon 16:45 H 0104

Simplicity of quantum oscillations in CoSi from its hidden quasi-symmetry — •Philip J.W. Moll[1], Chunyu Guo[1], Lunhui Hu[2], Carsten Putzke[1], Jonas Diaz[3], Xiangwei Huang[3], Kaustuv Manna[4], Feng-Ren Fan[4], Yan Sun[4], Chandra Shekhar[4], Claudia Felser[4], Chaoxing Liu[2], and Andrei B Bernevig[5] — [1]MPI for the Structure & Dynamics of Matter — [2]The Pennsylvania State University — [3]EPFL — [4]MPI for Chemical Physics of Solids — [5]Princeton University

The crystal symmetry dictates the type of topological band structures it may host, hence it is the principle guiding the search for topological materials. Here we present a twist on this idea, materials in which approximate symmetries stabilize near-degeneracies of bands. Specifically, we coin quasi-symmetry as a term for an exact symmetry of a Hamiltonian to lower-order yet is broken by higher-order perturbation terms. This enforces finite but parametrically small gaps at low-symmetry k-points across the whole Brillouin zone, eliminating the need for fine-tuning as the sources of large Berry curvature will occur at any arbitrary chemical potentials. We demonstrate that in the eV-bandwidth semi-metal CoSi an internal quasi-symmetry stabilizes gaps below 2 meV on eight large near-degenerate planes (2D) [1]. These quasi-degeneracies connect continuously to thetrue, symmetry-protected topological ones in CoSi. Depending on spatial symmetry, these are easily gapped by weak strain which is evidenced by new magnetic breakdown orbits [2]. In contrast, the quasi-symmetry has no spatial character and thus is resilient to strain.

Invited Talk TT 9.5 Mon 17:15 H 0104

Quantum oscillations of superconducting iron-chalcogenides $FeSe_{1-x}S_x$ — •Amalia Coldea — Clarendon Laboratory, University of Oxford, Oxford, UK

Iron-chalcogenides superconductors display intertwined electronic nematic and spin-density wave phases and their role in superconducting pairing is difficult to assess. However, versatile tuning parameters, like applied pressure and chemical pressure [1,2], can be used to separate and explore their relative importance. I will present quantum oscillations studies in $FeSe_{1-x}S_x$ using magnetotransport and tunnel diode oscillator experiments tuned both by chemical and applied pressures [3,4,5,6]. I will discuss the evolution of the Fermi surface and the quasiparticle effective masses in the high-pressure phase of the tetragonal $FeSe_{1-x}S_x$ where superconductivity is enhanced. These findings will be compared with magnetotransport studies to understand the signatures of different competing phases with superconductivity [7].

[1] A. I. Coldea, Frontiers in Phys. 8, 594500 (2021)
[2] A. I. Coldea et al., npj Quantum Materials, 4, 2 (2019)
[3] P. Reiss et al, Nat. Phys. 16, 89 (2020)
[4] P. Reiss et al, Phys. Rev. Lett. 127, 246402 (2021)
[5] Z. Zajicek et al., A. I. Coldea, Phys. Rev. Res. 4, 043123 (2022)
[6] Z. Zajicek et al., A. I. Coldea, submitted (2023)
[7] P. Reiss et al., arXiv.2212.06824 (2022)

TT 9.6 Mon 17:45 H 0104

Interband scattering- and nematicity-induced quantum oscillation frequency in FeSe — •Valentin Leeb[1] and Johannes Knolle[1,2] — [1]Technical University of Munich, Germany — [2]Imperial College London, United Kingdom

Understanding the nematic phase observed in the iron-chalcogenide materials is crucial for describing their superconducting pairing. Experiments on $FeSe_{1-x}S_x$ showed that one of the slow Shubnikov–de Haas quantum oscillation frequencies disappears when tuning the material out of the nematic phase via chemical substitution or pressure, which has been interpreted as a Lifshitz transition [Coldea et al., npj Quant Mater 4, 2 (2019), Reiss et al., Nat. Phys. 16, 89-94 (2020)]. Here, we present a generic, alternative scenario for a nematicity-induced sharp quantum oscillation frequency which disappears in the tetragonal phase and is not connected to an underlying Fermi surface pocket. We show that different microscopic interband scattering mechanisms – for example, orbital-selective scattering – in conjunction with nematic order can give rise to this quantum oscillation frequency beyond the standard Onsager relation. We discuss implications for iron-chalcogenides and the interpretation of quantum oscillations in other correlated materials.

TT 9.7 Mon 18:00 H 0104

Interaction-induced quantum oscillations of the lifetime — •Przemyslaw Bieniek[1], Valentin Leeb[1], and Johannes Knolle[1,2] — [1]Technical University of Munich, Germany — [2]Imperial College London, United Kingdom

In the last few years, several deviations from the standard theory of quantum oscillations, as well as new theories, have been reported. Recently, it was demonstrated in CoSi that interband impurity scattering can lead to fundamentally new frequencies [Huber et al. Nature 2023; Leeb, Knolle PRB 2023]. Similar phenomena occur in 2D electron gases [Polyanovsky 1988]. However in all works, the effect of interactions was neglected completely. Here, we show that already simple Hubbard interactions lead to oscillations of the lifetime, eventually appearing as new quantum oscillation frequencies. We extend our analysis to more generic Coulomb interactions. Our results provide an alternative scenario for the microscopic scattering mechanism in CoSi.

TT 10: Topology: Majorana Physics I

Time: Monday 15:00–18:00 Location: H 2053

TT 10.1 Mon 15:00 H 2053

Characterization of Majorana bound states with Entanglement measures — •Vimalesh Vimal[1] and Jorge Cayao[2] — [1]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden — [2]Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden

We consider a pair of Majorana bound states coupled to quantum dots and investigate the dynamics of quantum correlations quantifying their entanglement. In particular, for an initial state with maximally entangled quantum dots, a maximally entangled state between Majorana states and one of the quantum dots can be created periodically in time which strongly dependent on the Majorana nonlocality. A similar result is also obtained for a separable initial state, but the dynamics then develop oscillations that have different local and global frequencies when Majorana states have finite energy. Therefore, the entanglement dynamics have the potential to identify the emergence of Majorana states and also show that topological systems can serve as a source of entanglement.

TT 10.2 Mon 15:15 H 2053

Autocorrelation times of Majorana Zero Modes at finite Temperature — •Niklas Tausendpfund[1,2], Matteo Rizzi[1,2], and Aditi Mitra[3] — [1]Peter Grünberg Institut 8, Forschungszentrum Jülich, Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Köln, Germany — [3]New York University

Majorana zero modes provide a promising platform for robust quantum information storage due to their topological nature. For the non-interacting Kitaev chain, it is known that information imprinted in the edge modes has an infinite lifetime at arbitrary temperatures. The situation changes drastically with the introduction of interactions, leading to a long, but finite, lifetime at infinite temperature. In this work we study the influence of temperature on the lifetime of information stored in interacting Majorana zero modes.

TT 10.3 Mon 15:30 H 2053

Transport-based fusion that distinguishes between Majorana and Andreev bound states — •Maximilian Nitsch[1], Rubén Seoane Souto[1,2], Stephanie Matern[1], and Martin Leijnse[1] — [1]Lund University, S-22100 Lund, Sweden — [2]Materials Science Institute of Madrid, Spanish Research Council (CSIC), 28049 Madrid, Spain.

It has proven difficult to distinguish between topological Majorana bound states and nontopological Andreev bound states and to measure the unique properties of the former. In this work, we aim to alleviate this problem by proposing and theoretically analyzing a new type of fusion protocol based on transport measurements in a Majorana box coupled to normal leads. The protocol is based on switching between different nanowire pairs being tunnel coupled to one of the leads. For a Majorana system, this leads to switching between different states associated with parity blockade. The charge being transmitted at each switch provides a measurement of the Majorana fusion rules. Importantly, the result is different for a system with nontopological Andreev bound states. The proposed protocol only requires measuring a DC current combined with fast gate-control of the tunnel couplings.

TT 10.4 Mon 15:45 H 2053

Braiding of Majorana box qubits in open quantum systems — •Kunmin Wu, Sadeq S. Kadijani, Johan Ekström, and Thomas Schmidt — Department of Physics and Materials Science, University of Luxembourg, 1511 Luxembourg, Luxembourg

We propose a braiding protocol in an open quantum system consisting of three coupled Majorana boxes harboring Majorana bound states (MBSs). Each MBS is coupled to a quantum dot placed in a Markovian bosonic bath. In the limit of weak coupling, the dissipation in the Majorana sector will be governed by a master equation of Lindblad form. The existence of a dark state subspace makes it possible to engineer nontrivial steady states by controlling the tunnel coupling between quantum dots and MBSs. Since braiding requires a degenerate ground state subspace with a given fermionic parity, we find that at least three Majorana boxes are needed. We start with a dark state stabilization protocol and subsequently propose a device geometry which allows the implementation of a braiding protocol. In this braiding process, the tunnel couplings are changed adiabatically and periodically, forcing the steady state to undergo a rotation on the Bloch sphere with a nontrivial winding number. Our proposal provides a template for performing braiding operations within decoherence-free subspaces in a fermionic system.

TT 10.5 Mon 16:00 H 2053

Exploring Vortex Dynamics in Superconductor-Ferromagnet Heterostructures: From Domain Wall Interactions to Adiabatic Braiding of Majorana Modes — •Jonas Nothhelfer[1], Sebastián A. Díaz[2], Stephan Kessler[3], Tobias Meng[4], Matteo Rizzi[5,6], Kjetil M. D. Hals[7], and Karin Everschor-Sitte[1] — [1]University of Duisburg-Essen — [2]University of Konstanz — [3]Johannes Gutenberg University of Mainz — [4]Technische Universität Dresden — [5]Forschungszentrum Jülich — [6]University of Cologne — [7]University of Agder, Norway

In superconductor-magnet heterostructures, interface-induced spin-orbit coupling can play a vital role in the dynamics of textures in the superconductor and the magnet. We show that magnetic textures like domain walls and skyrmions exhibit a rich interaction spectrum with superconducting vortices. We find that the Rashba spin-orbit coupling induces magnetoelectric interactions between vortices and domain walls, with the domain wall's helicity determining the interaction: Néel walls push or pull the vortices, and vortices glide along Bloch walls. Furthermore, we show that hybrid excitations of superconducting vortices and magnetic skyrmions can bind Majorana modes that enable quantum computing. By adiabatically braiding these hybrid topological structures, we explicitly confirm the non-Abelian statistics of Majorana zero modes through self-consistent numerical simulations. Our findings provide a crucial basis for controlling superconducting vortices and using them for quantum computing.

[1] Díaz et al. arXiv:2310.06866
[2] Nothhelfer et al. Phys. Rev. B 105 (2022) 224509

TT 10.6 Mon 16:15 H 2053

How symmetry and topology bring order into the mess of vortex core states — •Thomas Gozlinski[1,2], Qili Li[1], Rolf Heid[1], Ryohei Nemoto[3], Roland Willa[1], Toyo Kazu Yamada[3], Jörg Schmalian[1], and Wulf Wulfhekel[1] — [1]Karlsruhe Institute of Technology (KIT) — [2]Ludwig-Maximilians-Universität München (LMU) — [3]Chiba University, Japan

One popular approach of engineering Majorana bound states has been the combination of an s-wave superconductor and a topological insulator which is proposed to support Majorana zero modes in its vortex cores [1]. In principle, this state should be detectable as a zero bias conductance peak (ZBCP) in a scanning tunneling experiment. However, not every ZBCP is due to a Majorana bound state. In vortex cores, Caroli-de Gennes-Matricon (CdGM) states [2] are ubiquitous and can be mistaken for Majorana bound states. We use high-resolution scanning tunneling spectroscopy and semi-classical Eilenberger simulations to break down the complexity of the local density of states (LDOS) patterns these CdGM states can form [3]. We start from the simplest case of a single-flux-quantum vortex in an s-wave superconductor and successively increase the complexity through Fermi surface anisotropy, multi-band superconductivity and higher flux quantum numbers to understand the LDOS patterns observed in our experiment.

[1] L. Fu, C.L. Kane, Phys. Rev. Lett. **100** (2008) 096407
[2] C. Caroli, P.G. De Gennes, J. Matricon, Phys. Lett. **9** (1964) 307
[3] T. Gozlinski et al., Sci. Adv. **9** (2023) eadh9163

15 min. break

TT 10.7 Mon 16:45 H 2053

Hybrid light-matter states in topological superconductors coupled to cavity photons — •Olesia Dmytruk[1] and Marco Schirò[2] — [1]CPHT, CNRS, École polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France — [2]JEIP, UAR 3573 CNRS, Collège de France, PSL Research University, 11 Place Marcelin Berthelot, 75321 Paris Cedex 05, France

Using photonic cavities to probe and to control properties of the materials is a novel research direction of condensed matter physics. Topological materials play particularly important role in this direction due to their robustness and their possible application in quantum technologies. We study a topological superconductor that hosts Majorana bound states strongly coupled to cavity photons. We consider two models for topological behaviour: a prototype Kitaev chain and experimentally relevant semiconducting-superconducting nanowire. We find that the cavity photonic spectral function directly related to polariton spectrum of the hybrid system depends on the parity of the Majorana bound states in the topological phase. Moreover, we demonstrate that the peaks in cavity spectral function appear at different energy scales for the electronic chain in the trivial and topological phases. Therefore, cavity spectral function could be used to probe Majorana bound states in topological superconductors.

[1] O. Dmytruk, M. Schirò, arXiv:2310.01296

TT 10.8 Mon 17:00 H 2053

Quest for topological bands in magnetic chains on superconductors — •András Lászlóffy[1], Bendegúz Nyári[2], Nóra Kucska[1], László Szunyogh[2], and Balázs Újfalussy[1] — [1]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary — [2]Budapest University of Technology and Economics, Budapest, Hungary

In magnetic chains placed on superconductors, Shiba bands are formed within the superconducting gap. Spin-orbit coupling or a spin-spiral configuration can lead to the hybridization of Shiba bands which can open a topologically non-trivial gap around the Fermi energy. Simple models are suitable to understand which effects assist the formation of topological band structure, but provide no recipe how this works out in real situations. To have a quantitative and realistic description of these systems, we solve the Kohn-Sham-Dirac Bogoliubov-de Gennes equations within the Korringa-Kohn-Rostoker multiple scattering theory. We demonstrate that by scaling the magnetic moment in the spin spirals, several, however, narrow regions can be found where the system is topological. By adding a non-magnetic overlayer between the superconductor and the chain, we explore the topological properties of a large variety of systems in terms of changing the crystallographic direction of the chain and the magnetic configuration.

TT 10.9 Mon 17:15 H 2053

Manipulation of Majorana bound states – Stability, Topological fragmentation, and Braiding — •Balázs Ujfalussy[1], András Lászlóffy[1], Gábor Csire[2], Nóra Kucska[1], Bendegúz Nyári[3], and László Szunyogh[3] — [1]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary — [2]Materials Center Leoben Forschung GmbH, Roseggerstraße 12, 8700 Leoben, Austria — [3]Budapest University of Technology and Economics, Budapest, Hungary

In this talk, we provide a detailed and quantitative theoretical description of the effects of manipulating spins in an iron chain deposited on top of Au/Nb heterostructure in the superconducting state and hosting a Majorana Zero Mode by applying a first-principles computational approach. By studying the superconducting order parameter and the quasiparticle charge density of states (CDOS), we perform computational experiments in spin spiral chains that shed light on several concerns and difficulties during practical applications and add new aspects to the interpretation of recent experiments. We explore the stability of topological zero energy states, the formation of and distinction between topologically trivial and non-trivial zero energy edge states, the emergence of topological fragmentation, and the shift of Majorana Zero Modes along the superconducting nanowires These findings open avenues toward the implementation of a braiding operation.

TT 10.10 Mon 17:30 H 2053

Kitaev chain in an alternating quantum dot –– Andreev bound state array — •Sebastian Miles, David van Driel, Michael Wimmer, and Chun-Xiao Liu — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2600 GA, The Netherlands

We propose to implement a Kitaev chain based on an array of alternating normal and superconductor hybrid quantum dots embedded in semiconductors. In particular, the orbitals in the dot and the Andreev bound states in the hybrid are now on equal footing and both emerge as low-energy degrees of freedom in the Kitaev chain, with the couplings being induced by direct tunneling. Due to the electron and hole components in the Andreev bound state, this coupling is simultaneously of the normal and Andreev types, with their ratio being tunable by varying one or several of the experimentally accessible physical parameters, e.g., strength and direction of the Zeeman field, as well as changing proximity effect on the normal quantum dots. As such, it becomes feasible to realize a two-site Kitaev chain in a simple setup with only one normal quantum dot and one hybrid segment. Interestingly, when scaling up the system to a three-site Kitaev chain, next-nearest-neighbor couplings emerge as a result of high-order tunneling, lifting the Majorana zero energy at the sweet spot. This energy splitting is mitigated in a longer chain, approaching topological protection. Our proposal has two immediate advantages: obtaining a larger energy gap from direct tunneling and creating a Kitaev chain using a reduced number of quantum dots and hybrid segments.

TT 10.11 Mon 17:45 H 2053

Quantum scars and caustics in Majorana billiards — •Johanna Zijderveld[1], Mert Bozkurt[1,2], Michael Wimmer[1,2], and Inanç Adagideli[3,4] — [1]Kavli Institute of Nanoscience, Delft University of Technology, 2600 GA Delft, The Netherlands — [2]QuTech, Delft University of Technology, 2600 GA Delft, The Netherlands — [3]Faculty of Engineering and Natural Sciences, Sabanci University, Orhanli-Tuzla, Istanbul, Turkey — [4]MESA+ Institute for Nanotechnology, University of Twente, The Netherlands

Majorana billiards are finitely sized and arbitrarily shaped topological superconductors which feature fermion parity switches. We investigate the influence of the shape of a topological superconductor on the localization of Majorana wavefunctions. Examining both p-wave and s-wave topological superconductors, we confirm that Majorana wavefunction features shape-dependent effects such as quantum scarring and caustics from semiclassical physics. With chiral symmetry, we find a mapping between wavefunctions of a regular $p^2/2m$ Hamiltonian and Majorana wavefunctions, which offers insight into this existence of partially localized quantum scars in Majorana billiards. Furthermore, we examine how the Majorana wavefunction changes due to a local perturbation in a region of neglibible wavefunction amplitude. In topological superconductors without chiral symmetry, we observe that the convexity of the billiard determines caustic-like features in the Majorana wavefunctions.

TT 11: Heavy Fermions

Time: Monday 15:00–17:30 Location: H 3005

TT 11.1 Mon 15:00 H 3005

Controlling crystal-electric field levels through symmetry-breaking uniaxial pressure in a cubic super heavy fermion — •Elena Gati[1], Burkhard Schmidt[1], Sergey L. Bud'ko[2], Andrew P. Mackenzie[1,3], and Paul C. Canfield[2] — [1]MPI for Chemical Physics of Solids, 01187, Dresden, Germany — [2]Ames National Laboratory, US DOE, and Physics Dept., Iowa State University, Ames, IA, 50011, USA — [3]Scottish Universities Physics Alliance, School of Physics and Astronomy, University of St Andrews, UK

YbPtBi is one of the heavy-fermion systems with largest Sommerfeld coefficient γ and is thus classified as a 'super'-heavy fermion material. In this work, we resolve the long-debated question about the crystal-electric field (CEF) level scheme in YbPtBi, by deliberate breaking of its cubic symmetry through uniaxial pressure tuning. Through measurements of the novel a.c. elastocaloric effect and generic symmetry arguments, we identify an elastic level splitting under uniaxial pressure that is unambiguously associated with the symmetry-allowed splitting of a quartet CEF level at $\Delta/k_B \approx 1.6$ K. Our study shows the potential of the a.c. elastocaloric effect to control and quantify strain-induced changes of the CEF schemes, opening a different route to disentangle the CEF energy scales from other relevant energy scales in correlated quantum materials.

Work is supported by the DFG through TRR 288 (ID 422213477) and the SFB 1143 (ID 247310070).

[1] Gati *et al.*, npj Quant. Mat. **8** (2023) 69.

TT 11.2 Mon 15:15 H 3005

High-pressure Fermi surface studies in the Kondo lattice system YbPtBi — •Oliver Squire, Maximilian Daschner, Jiasheng Chen, Patricia Alireza, and Malte Grosche — Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United Kingdom

Quantum oscillation measurements provide valuable information about the electronic properties of heavy fermion materials. By performing these measurements under hydrostatic pressure, it is possible to detect the Fermi surface and quasiparticle mass enhancement at interesting points of the phase diagram, and to measure their evolution as the strengths of Kondo and magnetic interactions are varied.

Tunnel diode oscillator (TDO) circuits offer a technique to detect quantum oscillations in the skin depth and magnetisation of samples with high precision, and can be extended to high hydrostatic pressures using microcoils in anvil cells [1]. Using the TDO technique, we have performed a quantum oscillation study on the heavy fermion semimetal YbPtBi, measuring the variation of its Fermi surface properties as the material is tuned by pressure. We will discuss the role of f-electrons and the field dependence of the Fermi surface by comparing our results to electronic structure calculations and other RPtBi compounds.

[1] Semeniuk et al., PNAS 120 (2023) e2301456120.

TT 11.3 Mon 15:30 H 3005

Origin of the non-Fermi-liquid behavior in $CeRh_2As_2$ — •Pavlo Khanenko[1,2], Konstantin Semeniuk[1], Daniel Hafner[1], Jacintha Banda[1], Thomas Lühmann[1], Javier F. Landaeta[1], Florian Bärtl[3], Tommy Kotte[3], Joachim Wosnitza[2,3], Gertrud Zwicknagl[4], Christoph Geibel[1], Seunghyun Khim[1], Elena Hassinger[2], and Manuel Brando[1] — [1]Max Planck Institute for Chemical Physics of Solids, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence, Germany — [4]Institute for Mathematical Physics, Technische Universität Braunschweig, Germany

Unconventional superconductivity appears near magnetic quantum critical points (QCPs). This seems to be the case also for $CeRh_2As_2$ which is a multi-phase heavy-fermion superconductor ($T_c = 0.31$ K). Furthermore, another ordered state is observed below $T_0 \approx 0.48$ K whose nature is unclear, possibly a quadrupolar order. In addition, NQR/NMR experiments have detected an antiferromagnetic order below T_c. The presence of a QCP is indicated by the non-Fermi-liquid (NFL) behavior observed above the ordered states in both the specific heat, $C(T)/T \propto T^{-0.6}$, and the resistivity, $\rho(T) \propto \sqrt{T}$. Here, we present specific-heat measurements taken at a field applied at various angles α with respect to the crystallographic c axis. We observe that the NFL behavior depends very weakly on the field and on the angle α, a result that is at odds with that observed in standard magnetic QCPs. Possible origins for this unusual NFL behavior are discussed.

TT 11.4 Mon 15:45 H 3005

Low-temperature muon spin relaxation (μSR) studies on quality-improved $CeRh_2As_2$ single crystals — •Seunghyun Khim[1], Oliver Stockert[1], Manuel Brando[1], Christoph Geibel[1], Thomas J. Hickens[2], Christopher Baines[2], and Hubertus Luetkens[2] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Paul Scherrer Institute, Villigen, Switzerland

The unusual superconducting (SC) state ($T_c = 0.3$ K) of the heavy-fermion compound $CeRh_2As_2$ emerges from an unknown ordered state below $T_o = 0.55$ K, the precise nature of which has not been determined. Nuclear quadrupole/magnetic resonance (NQR/NMR) studies have revealed a clear signature of an antiferromagnetic order with a T_N very close to the T_c of the SC state. However, thermodynamic bulk measurements have not yet detected any anomalies associated with this T_N transition. To elucidate the multiple identified phases and their correlations, we conducted muon spin relaxation (μSR) studies of local magnetic properties in quality-improved $CeRh_2As_2$ single crystals at low temperatures. The experimental results will be discussed based on the unique characteristics of the Ce-4f moments and its intricate relation with superconductivity.

TT 11.5 Mon 16:00 H 3005

Characteristic energy scales in $CeRh_2As_2$ — •O. Stockert[1], M. M. Koza[2], and S. Khim[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany — [2]Institut Laue-Langevin, Grenoble, France

The heavy-fermion superconductor $CeRh_2As_2$ is located close to a quantum critical point and attracts a lot of attention due to its interplay of unconventional heavy-fermion superconductivity with $T_c \approx 0.25$ K and a possibly quadrupolar ordered state setting in above T_c. Recent measurements suggest the existence of antiferromagnetic order above the superconducting transition temperature. To better understand the unusual low-temperature properties of $CeRh_2As_2$, a knowledge of the relevant characteristic energy scales is important. We performed inelastic neutron scattering on $CeRh_2As_2$ powder to study the crystalline-electric-field (CEF) excitations and to look for the Kondo fluctuations. Our experiments reveal a low-lying excited CEF above the ground state doublet in addition to a Kondo enery scale of around 30 K. We will discuss our results in comparison to the previously suggested quadrupolar ground state and their implications for the ordered state.

15 min. break

TT 11.6 Mon 16:30 H 3005

Paradigm for the search of d-electron heavy fermions: the case of Cr-doped $CsFe_2As_2$ — •Matteo Crispino[1,2], Pablo Villar Arribi[1,3], Anmol Shukla[4], Frédéric Hardy[4], Amir-Abbas Haghighirad[4], Thomas Wolf[4], Rolf Heid[4], Christoph Meingast[4], Tommaso Gorni[1], Adolfo Avella[5], and Luca de' Medici[1] — [1]Laboratoire de Physique et Etude des Matériaux, UMR8213 CNRS/ESPCI/UPMC, Paris, France — [2]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany — [3]International School for Advanced Studies (SISSA), Via Bonomea 265, I-34136 Trieste, Italy — [4]Karlsruhe Institute of Technology, Institute for Quantum Materials and Technologies (IQMT), 76021 Karlsruhe, Germany — [5]Dipartimento di Fisica "E. R. Caianiello", Università degli Studi di Salerno, I-84084 Fisciano, Italy

We define a general strategy to find new heavy-fermion materials without rare-earth elements: doping towards half-filling a Hund metal with pronounced orbital-selective correlations. We argue that in general bandstructures a possible orbital-selective Mott transition is frustrated by inter-orbital hopping into a heavy-fermion behaviour - with d-orbitals providing both heavy and light electrons - which is enhanced by approaching half-filling. This phase ultimately breaks due to magnetic correlations, as in a standard Doniach diagram. Experimentally we have hole-doped the Hund metal CsFe2As2, and obtained a heavy-fermion state with the highest Sommerfeld coefficient for Fe-pnictides to date (270 mJ/mol K^2), before antiferromagnetism sets in.

TT 11.7 Mon 16:45 H 3005

Magnetic adatoms as a probe for topological surface states in SmB_6. — •Fabiola Neumann[1], Michael Turaev[1], and Johann Kroha[1,2] — [1]University of Bonn, DE — [2]University of St. Andrews, UK

Recent scanning tunneling spectroscopy (STS) experiments on the surface of the predicted topological Kondo insulator SmB_6 revealed that the peak in the local surface density of states (LDOS) is suppressed by a Gd impurity at the surface [1]. Surprisingly, this suppression extends spatially to a distance of several nm from the impurity, much larger than the range of the impurity potential. In the present work, we model the SmB_6 bulk-surface heavy-fermion system by a layered auxiliary boson mean-field theory at temperature $T = 0$, while the Gd impurity possesses a static spin $s = 7/2$ in the 4f shell and a spin $s = 1/2$ in the 5d shell. In particular, we investigate two possible scenarios for the LDOS suppression: (1) Coupling of the static Gd magnetic moment to the electron spin in the Dirac *surface* band by which the Dirac node acquires a gap [1], and (2) Local destruction of the SmB_6 *bulk* topological heavy-fermion band by the time-reversal-breaking impurity which consequently removes the topological surface band. The latter mechanism may explain the long-range nature of the LDOS suppression via the Kondo coherence length $\xi_K = v_F/T_K$ where v_F is the Fermi speed and T_K the Kondo temperature.

[1] L. Jiao *et al.*, Sci. Adv. **4** (2018) eaau4886.

TT 11.8 Mon 17:00 H 3005

Realization of heavy fermion phase diagram in van der Waals heterostructures — •Somesh Chandra Ganguli — Aalto University School of Science, Finland

The heavy fermion compounds host a rich playground for correlated quantum states. In these compounds, the itinerant electrons in s, p or d shells interact with the lattice of localized magnetic moments in f shell via Kondo effect giving rise to Kondo lattice, resulting in a large effective mass as well as a gap in the conduction electron spectra, known as heavy fermion hybridization gap, which upon chemical doping can host unconventional superconductivity and quantum criticality. Recently, we have been able to demonstrate that heavy fermionic behavior can be created artificially using vdW epitaxy, using heterostructure of 2 different phases of the same material TaS_2. Stacking 1H-TaS_2 hosting 2-D conduction electrons, and 1T-TaS_2 hosting localized magnetic moments gives rise to Kondo lattice and heavy-fermion hybridization gap. We also observe, that in vdW heterostructure of similar material $NbSe_2$, the Kondo coupling (JK) does not overcome the exchange coupling (JAF) between the localised magnetic moments. Furthermore, the chemical potential becomes site dependent, driving the 1T-$NbSe_2$/1H-$NbSe_2$ system into the doped Mott insulator regime with exotic charge order. These observations establish artificial vdW heterostructures as a versatile platform to navigate the heavy fermion phase diagram.

TT 11.9 Mon 17:15 H 3005

Kondo physics and magnetism with high-order Van Hove singularities — •Krzysztof P. Wójcik[1], Johann Kroha[2,3], and Peter Wahl[3,2] — [1]Institute of Molecular Physics, Polish Academy of Sciences, Poznań, Poland — [2]Physikalisches Institut, Universität Bonn, Germany — [3]SUPA, School of Physics and Astronomy, University of St Andrews, United Kingdom

Despite vast experimental progress in strongly-correlated electron research over last decades, a number of major puzzles remain unsolved. In particular, in some materials (e.g. strontium ruthenates) the nature of magnetic-field-driven quantum criticality has not been determined. It may be caused mainly by quantum fluctuations, or rather a second-order Van Hove singularity present near the Fermi level may play the major role [1]. To better understand the tension between these two mechanisms, an analysis of a simple impurity model is proposed, which can clarify the fate of the Kondo effect in the host exhibiting a spin-split Van Hove singularity.

The model is solved with numerical renormalization group. It is shown that the spin-splitting of the band stabilizes a novel strong-coupling partially polarized fixed point. Such splitting is seen experimentally in surface spectroscopy of $Sr_3Ru_2O_7$, even in the absence of external magnetic field [1]. The results concerning spin susceptibility and entropy will be presented, followed by the predictions of spectral properties and discussion of their significance for the correlated lattices.

[1] C. A. Marques *et al.*, Sci. Adv. **8** (2022) eabo7757.

TT 12: Fluctuations and Noise

Time: Monday 15:00–16:30 Location: H 3007

TT 12.1 Mon 15:00 H 3007

Full counting statistics of ultrafast quantum transport — •Matthias Hübler and Wolfgang Belzig — Universität Konstanz, D-78457 Konstanz, Germany

Quantum transport in the presence of time-dependent drives is dominated by quantum interference and many-body effects at low temperatures. For a periodic driving, the analysis of the full counting statistics revealed the elementary events that determine the statistical properties of the charge transport. However, so far only continuous wave excitations were considered, but recently transport by few-cycle light pulses were investigated [1] and the need for a statistical interpretation became eminent. We investigate the temporal dynamics of single- or few-cycle light pulses leaving traces in the charge transfer. The fingerprints of these time-dependent voltage pulses are imprinted in the full counting statistics of a coherent mesoscopic conductor at zero temperature. In addition, we identify the elementary processes that occur in the form of electron-hole pair creations, which can be investigated by the excess noise. We study the differential noise quantum oscillations induced by a wave packet consisting of an oscillating carrier modulated by a Gaussian- or a box-shaped envelope. As expected, the differential noise exhibits an oscillatory behavior with increasing amplitude. We find clear signature of the so-called carrier-envelope phase in the peak heights and positions of these quantum oscillations.

[1] T. Rybka, M. Ludwig, M. F. Schmalz, V. Knittel, D. Brida, A. Leitenstorfer, Nat. Photonics 10 (2016) 667.
[2] M. Hübler, W. Belzig; Appl. Phys. Lett. 17 (2023) 123 (3): 034006.

TT 12.2 Mon 15:15 H 3007

Noise calculations for transport through quantum dot systems and applications in charge sensing and nano thermodynamics — •Simon Wozny and Martin Leijnse — Division of Solid State Physics and NanoLund, Lund University, Box 118, S-22100 Lund, Sweden

Using full counting statistics we calculate the current and current noise through quantum dot (QD) systems. With this general framework making use of master equations we can investigate many different systems including electron-electron interactions and focus on different aspects. We have, for example, investigated the use of a parallel double QD as a charge sensor and show that it can outperform a single-dot charge sensor. We also explore the connection between the current noise and other thermodynamic quantities. Here relevant relations are for example fluctuation dissipation bounds or thermodynamic uncertainty relations.

TT 12.3 Mon 15:30 H 3007

Dark states versus blocking states in electronic transport: a Lee-Yang zero analysis of full counting statistics — •Johann Zöllner[1], Eric Kleinherbers[2], Philipp Stegmann[3], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, 47057 Duisburg, Germany — [2]Department of Physics and Astronomy, University of California, Los Angeles, California 90095, USA — [3]Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Electronic transport through nanostructures can be suppressed by coherent population trapping, in which quantum coherence leads to a dark state that decouples from the drain electrode. Finite transport, then, relies on decoherence of the dark state [1]. An alternative scenario for reduced transport is weak coupling of a state, referred to as a blocking state, to the drain [2]. This raises the question of whether and how these two scenarios can be distinguished in the transport features. For the example of electron transport through a carbon nanotube, we identify regimes, in which this distinction is possible by analyzing the full counting statistics in terms of Lee-Yang zeros and factorial cumulants [3].

[1] A. Donarini et al., Nat. Commun. 10 (2019) 381
[2] M.-C. Harabula et al., Phys. Rev. B 97 (2018) 115403.
[3] P. Stegmann et al., Phys. Rev. B 92 (2015) 155413

TT 12.4 Mon 15:45 H 3007

Strongly correlated radiation of a tunnel junction due to charge quantization — •Steven Kim and Fabian Hassler — Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany

A chaotic light source is characterized by the fact that many independent, identical emitters radiate with a random optical phase. For such light sources, the correlation of the photons, characterized by the second-order coherence, is always given by $g^{(2)}(0) = 2$. One might expect that a tunnel junction with many channels produces chaotic light as many independent channels contribute to the radiation. We study the radiation emitted by a tunnel junction embedded in a cavity at low temperatures. Surprisingly, we find that the radiation deviates from the prediction of chaotic light. In particular, we find strong correlations of the photons. These correlations originate from shot-noise, where a single electron traversing the junction emits multiple photons.

TT 12.5 Mon 16:00 H 3007

Heat Pulses in Electron Quantum Optics — •Pedro Vinicius de Castro Portugal, Fredrik Brange, and Christian Flindt — Department of Applied Physics, Aalto University, 00076, Finland

Electron quantum optics aims to realize ideas from the quantum theory of light with the role of photons being played by charge pulses in electronic conductors. Experimentally, the charge pulses are excited by time-dependent voltages, however, one could also generate heat pulses by heating and cooling an electrode [1,2]. Here, we explore this intriguing idea by formulating a Floquet scattering theory of heat pulses in mesoscopic conductors [3]. The adiabatic emission of heat pulses leads to a heat current that in linear response is given by the thermal conductance quantum. However, we also find a high-frequency component, which ensures that the fluctuation-dissipation theorem for heat currents, whose validity has been debated, is fulfilled. The heat pulses are uncharged, and we probe their electron-hole content by evaluating the partition noise in the outputs of a quantum point contact. We also employ a Hong–Ou–Mandel setup to examine if the pulses bunch or antibunch. Finally, to generate an electric current, we use a Mach–Zehnder interferometer that breaks the electron-hole symmetry and thereby enables a thermoelectric effect.

[1] P. Portugal, C. Flindt, N. Lo Gullo, Phys. Rev. B **104** (2021) 205420.
[2] P. Portugal, F. Brange, C. Flindt, Phys. Rev. Res. **4** (2022) 043112.
[3] P. Portugal, F. Brange, C. Flindt, arXiv:2311.16748

TT 12.6 Mon 16:15 H 3007

Noise measurements in four-terminal quantum wire interferometer — •Birkan Düzel[1], Olivio Chiatti[1], Christian Riha[1], Sven S. Buchholz[1], Dirk Reuter[2], Andreas D. Wieck[3], and Saskia F. Fischer[1,4] — [1]Novel Materials Group,Humboldt-Universität zu Berlin,10099 Berlin, Germany — [2]Optoelektronische Materialien undBauelemente, Universität Paderborn,33098 Paderborn, Germany — [3]Angewandte Festkörperphysik,Ruhr-Universität Bochum,44780 Bochum, Germany — [4]Center for the Science of Materials Berlin, 12489 Berlin, Germany

Quantum ring structures can be used to investigate interference effects of electrons as a result of phase-coherent transport. Voltage noise measurements are performed using the cross-correlation technique in an etched quantum ring structure based on $Al_{0.35}Ga_{0.65}As/GaAs$ at temperatures of 4.2 K. In thermal equilibrium the measured two-terminal voltage noise depends on the detail of the contact configuration in these multiply-connected quantum wire ring structures [1,2]. Here, we investigate and discuss all noise contributions in various contact configurations and compare these with the calculated thermal noise according to the Johnson-Nyquist formula $S_V = 4k_BTR$, as determined from the four-terminal conductance measurements of the respective contact configuration. Aharonov-Bohm magneto-resistance oscillations observed at 15 mK prove quantum interference in the ring structure.

[1] C. Riha *et al.*, Appl. Phys. Lett. **117**, 063102 (2020).
[2] B. Düzel *et al.*, accepted/to be published in 2023 International Conference on Noise and Fluctuations (ICNF), IEEE.

TT 13: Kagome Systems

Time: Monday 15:00–18:15 Location: H 3010

TT 13.1 Mon 15:00 H 3010

Investigation of the charge density wave in single crystal CsV_3Sb_5 under hydrostatic pressure — Fabian Stier[1], Amir Haghighirad[3], Tobias Ritschel[1], Chandra Shekhar[2], Claudia Felser[2], •Jochen Geck[1], and Matthieu Le Tacon[3] — [1]IFMP, TU Dresden, Germany — [2]MPI CPfS, Dresden, Germany — [3]IQMT, KIT, Karlsruhe, Germany

The kagome materials AV_3Sb_5 (A = K, Rb, Cs) show a nontrivial electronic topology, exhibit unconventional superconductivity (SC) and charge-density-wave (CDW) order. We investigated the CDW in two different sample batches of CsV_3Sb_5 using x-ray diffraction as a function of hydrostatic pressure and temperature at the ID15B Beamline at the ESRF. Samples from both batches were loaded in the same diamond anvil cell (DAC) to ensure equal experimental conditions. Near ambient pressure, both sample batches exhibit the previously reported 2x2x2 and 2x2x4 CDW. The order in which these phases occur with decreasing temperature is reversed in one sample batch with respect to the other. Increasing the pressure at low temperature yields a new CDW order, which is the same in both batches. The critical pressures at which this new CDW phase appears and finally vanishes again, correspond well to the previously reported anomalies in the pressure dependence of the SC transition temperature. At low temperature and higher pressures the samples show another transient transition from the hexagonal unit cell to a monoclinic cell. Using our experimental results in combination with DFT calculations we will discuss the pressure effects on the electronic structure and the superconductivity.

TT 13.2 Mon 15:15 H 3010

Unconventional superconductivity on the kagome lattice — •Brian Møller Andersen, Sofie Castro Holbeak, Morten Holm Christensen, and Andreas Kreisel — Niels Bohr Institute, University of Copenhagen, DK-2200 Copenhagen, Denmark

Recent developments have focussed research on unusual electronic orders on the kagome lattice. This is evident mainly from the discovery of CDW phases and superconductivity in the AV_3Sb_5 (A:K, Rb, Cs) metals. We discuss the general expected form of superconductivity on the kagome lattice from charge- and spin-fluctuations. Some discussion will also be included on the potential role of orbital -selective phonons on the nature of superconductivity in the specific AV_3Sb_5 compounds. The second part of the talk addresses disorder on the kagome lattice. Surprisingly, unconventional superconductivity with sign-changing order parameters are remarkable robust to point-like nonmagnetic disorder. We demonstrate this effect by explicit calculations of bound states and Tc-suppression rates. The origin of the robustness is tied to the particular sublattice interference present for the electronic states on the kagome lattice.

TT 13.3 Mon 15:30 H 3010

Non-equilibrium carrier dynamics of the CsV3Sb5 kagome metal — •Kai Frisch[1], Niklas Hofmann[1], Leonard Weigl[1], Johannes Gradl[1], Brenden Ortiz[2], Andrea Capa Salinas[3], Stephen Wilson[3], and Isabella Gierz[1] — [1]University of Regnsburg — [2]Oak Ridge national Lab — [3]University of California, Santa Barbara

The V planes in AV_3Sb_5 (A=K, Rb, Cs) form a kagome lattice, resulting in a peculiar electronic structure with coexisting Dirac cones and flat bands [1]. The compounds exhibit a possibly chiral CDW below ~ 90 K and become superconducting below ~ 3 K consistent with predictions from a kagome Hubbard model at van Hove filling [2]. We use time- and angle-resolved photoemission spectroscopy to study the non-equilibrium carrier dynamics of CsV_3Sb_5 in its metallic room temperature phase. We extract the transient electronic temperature of the carriers and interpret the cooling dynamics in terms of strongly coupled optical phonons. Our results shed light onto the coupling between electrons and phonons in kagome metals, relevant for unraveling the mechanism behind the different exotic ground states.

[1] Phys. Rev. Materials, 3 094407 (2019)
[2] Phys. Rev. B 86, 121105(R) (2012)

TT 13.4 Mon 15:45 H 3010

Order-by-disorder charge density wave condensation at $q = (\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$ in kagome metal ScV_6Sn_6 — •Alaska Subedi — CPHT, CNRS, Ecole Polytechnique, IP Paris, Palaiseau, France

The recent discovery of a charge density wave order at the wave vector P $(\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$ in the kagome metal ScV_6Sn_6 has created a mystery because subsequent theoretical and experimental studies show a dominant phonon instability instead at another wave vector H $(\frac{1}{3}, \frac{1}{3}, \frac{1}{2})$. Here, I discuss the results of first principles total energy calculations that were used to map out the landscape of the structural distortions due to the unstable phonon modes at H, L $(\frac{1}{2}, 0, \frac{1}{2})$, and P present in this material. In agreement with previous results, I find that the distortions due to the H instability cause the largest gain in energy relative to the parent structure, followed in order by the L and P instabilities. However, only two distinct structure occur due to this instability, which are separated by 6 meV/f.u. The instability at L results in three distinct structures separated in energy by 5 meV/f.u. In contrast, six different distorted structures are stabilized due to the instability at P, and they all lie within 2 meV/f.u. of each other. Hence, despite a lower energy gain, the condensation at P could be favorable due to a larger entropy gain associated with the fluctuations within a manifold with larger multiplicity via the order-by-disorder mechanism.

TT 13.5 Mon 16:00 H 3010

^{51}V Nuclear Magnetic Resonance as a Local Probe for the Charge Ordered Kagome System ScV_6Sn_6 — •Robin Guehne, Jonathan Noky, Chandra Shekhar, Maia G. Vergniory, Michael Baenitz, and Claudia Felser — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

Intermetallic compounds featuring Kagome lattice planes have lately attracted immense attention as platforms that provide the opportunity to study a diversity of topological features, like van Hove singularities, Dirac cones, and correlated flat bands. Some of these materials show long-range charge order. This is the case for the Vanadium based Kagome metal ScV_6Sn_6 that undergoes a charge density wave (CDW) transition around 96 K. The origin of this transition is still under debate, even more so the properties of the CDW phase, such as related to chirality of the charge order or hidden magnetism [1]. We use ^{51}V nuclear magnetic resonance (NMR) to investigate the CDW phase transition from a local point of view. Aided by density functional theory (DFT), NMR allows us to separate the chemistry from electronic properties and to identify the CDW fingerprint encoded in the NMR shift and relaxation amid the structural phase transition that manifests in the electric quadrupole interaction. In the presentation we will give an overview of the results and discuss potential implications.

[1] C. Yi, X. Feng, P. Yanda, S. Roychowdhury, C. Felser, C. Shekhar, arXiv:2305.04683 (2023)

TT 13.6 Mon 16:15 H 3010

Charge carrier dynamics of kagome metals $GdMn_6Sn_6$ and $TbMn_6Sn_6$ probed by transient reflectivity — •Marcos Vinicius Goncalves Faria[1,2], Alexej Pashkin[1], Stephan Winnerl[1], Hechang Lei[3], Qi Wang[3], Maxim Wenzel[4], Manfred Helm[1,2], and Ece Uykur[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf — [2]Technische Universität Dresden — [3]Renmin University of China — [4]Universität Stuttgart

In the present study, we use optical pump-probe spectroscopy in reflection geometry to unravel the dynamics of charge carriers in the magnetic kagome metals $GdMn_6Sn_6$ and $TbMn_6Sn_6$. The measured pump-probe traces reveal two exponential decay processes and a slow thermal relaxation, similarly to what has been observed in other kagome metals. The exponential decays occur on quite different time scales, and we ascribe them to the dynamics of different types of charge carriers present in the compounds. Additionally, a damped oscillation feature appears during the first 15-20 picoseconds. It can be explained in the context of acoustic strain waves, generated due to a thermal expansion at the sample's surface that is induced by the pump pulse. We also present temperature and pump fluence dependence for both compounds that helps to understand better the relaxation mechanisms.

15 min. break

TT 13.7 Mon 16:45 H 3010

Visualizing many body phases in a partially filled kagome flat band — Caiyun Chen, Jiangchang Zheng, Yuman He, Ruopeng Yu, Soumya Sankar, Kam Tuen Law, Hoi Chun Po, and •Berthold Jäck — HKUST, Department of Physics, Clear Water Bay, Kowloon, Hong Kong SAR, China

The kagome lattice with spin-orbit coupling exhibits a topologically non-trivial flat band in which the effect of Coulomb interactions between the localized charge carriers is believed to be strong. Hence, material realizations of the kagome lattice provide a promising platform to search for new quantum phases of matter at the confluence of topology and strong electronic correlations. We previously showed that the kagome metal CoSn exhibits a quasi-two-dimensional flat band whose occupied electronic states are strongly localised in real space [1].

Here, we study the low energy density of states of $Co_{1-x}Fe_xSn$ in which partial flat band fillings are realised by hole-doping with Fe. We will present results from temperature-dependent scanning tunnelling microscopy measurements on $Co_{1-x}Fe_xSn$. Combining high-resolution spectroscopy with spectroscopic imaging on samples with different doping levels x, we observe a rich sequence of states appearing at the Fermi energy that cannot be explained within a single-particle picture. We will discuss our findings in the context of electron-electron interaction induced many body states at partial flat band fillings.

We gratefully acknowledge support by the Hong Kong RGC and the Croucher Foundation.

[1] C. Chen et al., arXiv:2308.08976 (2023)

TT 13.8 Mon 17:00 H 3010

High-pressure infrared spectroscopy study on magnetic kagome metal Fe_3Sn_2 — •Ece Uykur[1,2], Maxim Wenzel[2], Francesco Capitani[3], Qi Wang[4], Hechang Lei[4], Stephan Winnerl[1], and Martin Dressel[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Inst. Ion Beam Phys. & Mat. Res., 01328 Dresden, Germany — [2]1. Physikalisches Institut, Universität Stuttgart, 70569, Stuttgart, Germany — [3]Synchrotron SOLEIL, 91192, Saint-Aubin, France — [4]Renmin University of China, 100872, Beijing, China

We present a high-pressure broadband optical study of ferromagnetic kagome metal Fe_3Sn_2 at room temperature up to 18 GPa. Different contributions to the optical spectra have been discussed and compared with the DFT calculations, which use the experimental high-pressure crystal structure. Infrared spectra reveal the signatures of conventional and unconventional charge carriers in the compound. While the low-energy spectral range reflects the response of the mobile charge carriers and is significantly modified with increasing pressure, the high energy range shows the modification of the interband transitions in the compound. We also observe the appearance of a sharp plasma edge at energies below 300 cm^{-1} that gradually shifts to the higher energy range in accordance with the appearance of a new Fermi surface under pressure.

TT 13.9 Mon 17:15 H 3010

Broadband optical investigations of the antiferromagnetic kagome metal FeGe — •Maxim Wenzel[1], Alexander A. Tsirlin[2], Sudip Pal[1], Renjith Mathew Roy[1], Chandra Shekhar[3], Claudia Felser[3], Ece Uykur[4], Artem V. Pronin[1], and Martin Dressel[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Germany — [2]Felix Bloch Institute for Solid-State Physics, Leipzig University, Germany — [3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [4]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Germany

Hexagonal FeGe is a two-dimensional kagome metal with the intricate coexistence of magnetism and charge-density-wave (CDW) order. Here, we present a broadband optical spectroscopy study of the antiferromagnetic compound down to 10 K. The contributions of itinerant and localized charge carriers to the optical spectra are comparatively discussed and signatures of the emerging CDW state below approximately 100 K are unveiled. Aided by DFT calculations, we show that the low-energy interband transitions are very sensitive to small changes of the Fermi level and uncover a delicate interplay between phonons, charge order, and localized carriers.

TT 13.10 Mon 17:30 H 3010

Unveiling a Kagome Metal Candidate with m-type Van Hove Singularity at Fermi Level: Theoretical Exploration and Electronic Features — •Anja Wenger — University of Würzburg, Germany

We embark on theoretically identifying universality classes of promising kagome metal candidate materials still to be realized in experiment. We intend to reach an electronic correlation strength still ensuring electronic itineracy. Conducting a free energy analysis of our proposed material candidate as a function of volume reveals a minimum at unstrained volume. This holds true even for the structural distortions exhibited by the material, i.e., a twisted and breathing kagome configuration. Remarkably, we generically obtain a mixed-type van Hove singularity in close proximity to the Fermi level. The results were obtained employing both, ab-initio calculations in the framework given by density functional theory (DFT), and crystal field analysis. Our proposed kagome material promises to exhibit exotic electronic features, opening new possibilities for exploring unprecedented quantum phenomena in kagome metals.

TT 13.11 Mon 17:45 H 3010

Spin-orbit coupling effects in a kagome scattering network — •Patrick Wittig[1], Fernando Dominguez[1], and Patrik Recher[1,2] — [1]Institute of Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Laboratory of Emerging Nanometrology, 38106 Braunschweig, Germany

Recently, scattering networks have gained a lot of attention, because they can model two-dimensional Dirac systems that are dominated by valley chiral modes. Here, we study the kagome scattering network that has been proposed in double-aligned graphene-hexagonal boron nitride [1,3] and periodically strained graphene [2]. By combining scattering matrices, we transform the kagome network to a triangular network with an energy-dependent scattering matrix and perform magnetotransport calculations. Additionally, due to the recent interest in proximity-induced spin-orbit effects in graphene, we include spin-orbit coupling in the scattering network model.

[1] C. Moulsdale et al., Phys. Rev. B 105 (2022) L201112.
[2] C. De Beule et al., Phys. Rev. B 107(2023) 045405.
[3] F. K. de Vries et al., arXiv: 2303.06403.

TT 13.12 Mon 18:00 H 3010

Magnetocrystalline and charge transport anisotropy in metallic Kagome ferromagnet Fe_3Sn — •Lilian Prodan[1], Vladimir Tsurkan[1,2], and Istvan Kezsmarki[1] — [1]Experimentalphysik V, Institute of Physics, Augsburg University, D-86159 Augsburg, Germany — [2]Institute of Applied Physics, Moldova State University, MD 2028, Chisinau, R. Moldova

Electron correlated Kagome magnets have recently been recognized as a versatile platform to investigate the interplay between the topology of the electronic band structure, magnetism and emergent novel topological states. Topological band effects were also invoked for explanation of the giant 'anomalous' anisotropy of the longitudinal conductivity and off-diagoanl Hall resistivity. Here we report the interplay of magnetocrystalline anisotropy (MAE) and charge transport in metallic Kagome ferromagnet Fe_3Sn. We revealed an 'anomalous' anisotropy of the longitudinal resistivity and anomalous Hall resistivity (AAHR). The linear scaling of AAHR with the MAE suggests that the anisotropic charge transport in Fe_3Sn is governed by the strong spin-orbit coupling. Our results provide new insight into elucidation of interplay of crystal structure, charge transport and magnetism in the iron-based Kagome metallic magnets.

TT 14: Artificial Intelligence in Condensed Matter Physics II (joint session TT/DY)

While artificial intelligence leaves an ever growing footprint in our everyday lives, it has as well inspired various new approaches in the physical sciences; for instance, one of the outstanding success stories is the prediction of protein folding with unprecedented accuracy. But what role can AI play in condensed matter physics? This symposium aims to provide an overview and discussion of recent applications of modern machine learning and its prospects for the advancement of research in this field. The increasingly data-intensive experiments with high-dimensional observations call for the development of new tools for analysis matching known strengths of machine learning algorithms. Reinforcement learning agents can be employed to precisely manipulate many-body systems, which, among other use cases, is a pivotal ingredient for quantum technologies. On the computational side, ideas from deep learning and generative modeling inspire new building blocks to boost numerical simulations. One may even ask the question whether a machine can autonomously discover physical concepts such as effective degrees of freedom or equations of motion, and reveal them in an interpretable manner to human researchers.

Prof. Dr. Simon Trebst, Universität Köln
Prof. Dr. Florian Marquardt, Max-Planck-Institut Erlangen
Dr. Markus Schmitt, FZ Jülich

Time: Monday 15:00–16:00 Location: H 3025

TT 14.1 Mon 15:00 H 3025

Uncertainty-aware active learning for interatomic potentials generation and its applications for spin dynamics — •Valerio Briganti and Alessandro Lunghi — School of Physics, AMBER and CRANN Institute, Trinity College, Dublin 2, Ireland

In the last decade, the materials science community has increasingly exploited the potential of AI for various applications, ranging from the discovery of new materials to the generation of interatomic potentials (IP). Developments in the latter have enabled to perform molecular dynamics simulations with unprecedented timescales, with the promise of successfully overcoming the computational costs required by ab initio methods keeping a sufficiently high accuracy. Two of the main challenges in this field are the design of models to allow greater transferability and the optimal selection of data to be included in the training set. In this contribution, I will show how a linear regression model based on SNAP [1] augmented with an uncertainty aware active learning procedure [2] can efficiently lead to the generation of accurate IPs able to simulate the dynamics of organic and open-shell compounds at room temperature. In addition to this, I will also present the performance of machine learning IPs for prediction of phonons and spin-phonon relaxation time.

[1] A.P. Thompson et al., J. of Comp. Phys., 285 (2015) 316.
[2] V. Briganti, A. Lunghi, Mach. Learn.: Sci. Technol. 4 (2023) 035005.

TT 14.2 Mon 15:15 H 3025

Transverse barrier and filament formation by electrical triggering of a metal-to-insulator or insulator-to-metal transition — •Lorenzo Fratino[1], Marcelo Rozenberg[2], Pavel Salev[3], Javier Del Valle[4], and Ivan K. Schuller[5] — [1]LPTM, CY Cergy Paris Université, Cergy-Pontoise — [2]LPS, Université Paris Saclay, Orsay — [3]University of Denver, USA — [4]University of Geneva, Switzerland — [5]University of California, San Diego, USA

By doing numerical simulations on Mott resistors network model, we were able to give a theoretical background to experimental observations on magnetotransport in ferromagnetic oxide (La,Sr)MnO_3 (LSMO) during electrical triggering of the intrinsic metal-insulator transition (MIT), which produces volatile resistive switching. This switching occurs in a characteristic spatial pattern, the formation of a paramagnetic insulating barrier perpendicular to the current flow, in contrast to the conventional filamentary percolation parallel to the current. This formation was also simulated in order to demonstrate that this process is triggered by nucleation at hotspots, with a subsequent expansion over several decades in time. By comparing three case studies (VO_2, V_3O_5, and V_2O_3), we identified the resistivity change across the transition as the crucial parameter governing this process. Our results provide a spatio-temporal characterisation of volatile resistive switching in Mott insulators, which is important for emerging technologies, such as optoelectronics and neuromorphic computing.

[1] Phys. Rev. B 108 (2023) 174434.
[2] Nat. Comm. 12 (2021) 1.
[3] Science 373 (2021) 907.

TT 14.3 Mon 15:30 H 3025

Autonomous bromine removal in scanning tunneling microscope — •Nian Wu[1], Markus Aapro[1], Alexander Ilin[2], Robert Drost[1], Joakim Jestilä[1], Zhijie He[2], Peter Lijeroth[1], and Adam S. Foster[1,3] — [1]Applied Physics, Aalto University, Helsinki, Finland — [2]Computer Science, Aalto University, Helsinki, Finland — [3]WPI Nano Life Science Institute, Kanazawa University, Kanazawa, Japan

More recent studies have even harnessed scanning probe microscopy (SPM) to control chemical reactions in on-surface molecular synthesis. In general, the SPM manipulations are predominantly controlled via parameters of the tip position, pulse voltages and tunneling conductance in scanning tunneling microscope (STM). However, the selection of proper parameters requires extensive domain knowledge, which is time-consuming and not necessarily transferable to new systems. Recent research has allowed the automation of a wide range of challenges, including lateral and vertical manipulation. However, the automation for breaking or forming covalent bonds, which is an indispensable step in chemical synthesis, is unexplored yet. To address this problem, we build on our deep reinforcement learning approach to automate the bromine removal from 5,15-bis(4-bromo-2,6-methyl-phenyl)porphyrin (Br_2Me_4DPP) through learning manipulation parameters in STM.

TT 14.4 Mon 15:45 H 3025

Neural quantum states for a two-leg Bose-Hubbard ladder under a magnetic field — •Kadir Çeven[1,2], Mehmet Özgür Oktel[2], and Ahmet Keleş[3] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, Germany — [2]Department of Physics, Bilkent University, Ankara, Turkey — [3]Department of Physics, Middle East Technical University, Ankara, Turkey

This work explores novel quantum phases in a two-leg Bose-Hubbard ladder, achieved using neural quantum states. The remarkable potential of quantum gas systems for analog quantum simulation of strongly correlated quantum matter is well-known; however, it is equally evident that new theoretical bases are urgently required to comprehend their intricacies fully. While simple one-dimensional models have served as valuable test cases, ladder models naturally emerge as the next step, enabling studying higher dimensional effects, including gauge fields. Using [Çeven et al., PRA 106, 063320 (2022)], this work investigates the application of neural quantum states to a two-leg Bose-Hubbard ladder in the presence of strong synthetic magnetic fields. This paper showcased the reliability of variational neural networks, such as restricted Boltzmann machines and feedforward neural networks, in accurately predicting the phase diagram exhibiting superfluid-Mott insulator phase transition under strong interaction. Moreover, the neural networks successfully identified other intriguing many-body phases in the weakly interacting regime. These exciting findings firmly designate a two-leg Bose-Hubbard ladder with magnetic flux as an ideal testbed for advancing the field of neural quantum states.

TT 15: Focus Session: Evolution of Topological Materials into Superconducting Nanodevices (joint session HL/TT)

The focus session intends to span the arc between topological materials and superconducting nanodevices, both experimentally and theoretically. Such structures are interesting for applications in future topological quantum circuits. In recent years, the number of topological materials and the knowledge about them has rapidly increased. As part of the focus session, material properties of layered systems made of topological materials, especially in combination with superconductors, are discussed. On the other hand, the special challenges in the nanofabrication of these materials for use in future topological quantum processors are addressed. Another focus is the quantum transport in nanoscale hybrid structures.

Organized by Thomas Schäpers, Philipp Rüßmann, and Peter Schüffelgen

Time: Monday 15:00–18:00 Location: EW 202

TT 15.1 Mon 15:00 EW 202

Transport studies in selectively grown topological insulator multiterminal Josphson junctions — •Gerrit Behner[1,2], Alina Rupp[1,2], Abdur Rehman Jalil[1,2], Kristof Moors[1,2], Dennis Heffels[1,2], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Jara-Fundamentals of Future Information Technology, Forschungszentrum Jülich and RWTH Aachen University, Germany

The combination of an ordinary s-type superconductor with three-dimensional topological insulators creates a promising platform for fault tolerant topological quantum computing circuits based on Majorana braiding. The backbone of the braiding mechanism are three terminal Josephson junctions. It is crucial to understand the transport in these devices for further use in quantum computing applications. We present low-temperature measurements of three-terminal $Bi_{0.8}Sb_{1.2}Te_3$ Josephson junctions fabricated, based on a combination of selective area growth and shadow mask evaporation. The transport properties of the junction are mapped out as a function of bias current and magnetic field. The bias current maps reveal a variety of transport phenomena, i.e. multiple Andreev reflections suggesting the successful fabrication of a fully coupled three-terminal junction. The junctions seem to be in good agreement with a resistively and capacitively shunted junction model, but also reveal the influence of intrinsic asymmetries and their effect on the transport in the junctions.

TT 15.2 Mon 15:15 EW 202

Quasparticle poisoning effects on electron transport through a Majorana wire — •Florinda Viñas Boström[1,2] and Patrik Recher[1,3] — [1]Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [2]Division of Solid State Physics and NanoLund, Lund University, Box 118, S-221 00 Lund, Sweden — [3]Laboratory of Emerging Nanometrology, D-38106 Braunschweig, Germany

Majorana bound states have been suggested as building blocks for fault-tolerant quantum computational devices. However, a problem for both Majorana based and other types of superconducting qubits, is quasi-particle poisoning, where an additional quasiparticle changes the parity of the superconducting condensate. In this work, we show how quasi-particle poisoning affects electron transport through a Majorana wire coupled to current leads on each side of the wire, using an open systems approach combining master equations with full counting statistics. To describe the correct low-energy physics for current and noise, we include sequential- and co-tunneling processes in our description. We believe that our study will be a guide both for future theoretical work, and to analyze transport experiments of such setups.

TT 15.3 Mon 15:30 EW 202

Andreev spectrum of Josephson junctions with topological insulator nanostructures — •Dennis Heffels, Peter Schüffelgen, Kristof Moors, and Detlev Grützmacher — Peter Grünberg Institute 9, Forschungszentrum Jülich, 52425 Jülich, Germany

Josephson junctions and the presence of Andreev bound states play an important role in quantum information and quantum materials research, forming an integral part of SQUIDs and superconducting qubits, for example. The bound states within a Josephson junction have a phase-dependent spectrum known as the Andreev spectrum. The investigation of this spectrum with phase-sensitive measurements can be used to characterize exotic types of superconductivity, such as topological superconductors with Majorana bound states. Here we present a method to efficiently calculate numerically detailed Andreev spectra, based on a scattering matrix method and (3D) tight binding, for different junction geometries, chemical potential and disorder profiles, etc. We apply this method to proximitized topological insulator (TI) nanostructure-based junctions in which Majorana bound states are expected upon application of an external magnetic field. In this setup, the spin-momentum-locked topological surface states give rise to highly unconventional Andreev spectra and corresponding current-phase relationships, both in the topologically trivial and nontrivial superconducting regimes.

TT 15.4 Mon 15:45 EW 202

Realistic modeling of proximitized magnetic topological insulator nanoribbons — •Eduárd Zsurka[1,2,3], Julian Legendre[3], Daniele Di Miceli[3,4], Llorenç Serra[4], Thomas Schmidt[3], and Kristof Moors[1,2] — [1]PGI-9, Forschungszentrum Jülich — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University — [3]Department of Physics and Materials Science, University of Luxembourg — [4]Department of Physics, University of the Balearic Islands

Proximitized magnetic topological insulator nanoribbons (PMTINRs) are a potential platform for the practical realization of the Majorana zero-energy mode (MZM) [1]. Here, we present a realistic description of PMTINRs and similar superconductor-topological insulator heterostructures. Both bulk and effective surface-state models are used to capture the low-energy electronic spectrum, with realistic parameters extracted from *ab initio* calculations. Using numerical simulations, we study in a tight-binding framework the properties of PMTINRs. Particular attention is given to the thin-film limit, where theoretical results have been conflicting on the topology of the hybridization gap. Magnetic and nonmagnetic disorder, as well as device imperfections, can all be detrimental to the formation of MZMs in PMTINRs. We aim to clarify what are the optimal conditions to obtain MZMs in PMTINRs, that are robust against such effects.

[1] C.-Z. Chen, Y.-M. Xie, J. Liu, P. A. Lee, and K. T. Law, Phys. Rev. B 97, 104504 (2018).

TT 15.5 Mon 16:00 EW 202

Transport in core/shell GaAs/InAs/Al half-shell nanowire-based hybrid devices — •Farah Basarić[1,2], Patrick Zellekens[3], Russell Deacon[3], Vladan Brajović[1,2], Alexander Pawlis[1,2], Gerrit Behner[1,2], Hans Lüth[1,2], Detlev Grützmacher[1,2], Koji Ishibashi[3], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany — [3]RIKEN Center for Emergent Matter Science and Advanced Device Laboratory, 351-0198 Saitama, Japan

Epitaxially grown core-shell GaAs/InAs nanowires provide a heterostructure with transport properties governed by the angular momentum states in the InAs shell. Besides conventional polymorphic GaAs/InAs nanowires, phase-pure core/shell nanowires featuring only wurtzite crystal structure along the axis were studied by magnetotransport measurements under an axial magnetic field. Transport regime analysis for both nanowire types indicates the presence of Aharonov-Bohm-type oscillations, while magnetotransport analysis suggests a strong effect of disorder reduction for phase-pure nanowires. This is manifested by the presence of the quasi-ballistic transport regime, indicating superior transport properties of the phase-pure nanowire. Combining phase-pure GaAs/InAs nanowires with an in-situ deposited superconducting Al half-shell, a gate-controlled Josephson junction was fabricated.

TT 15.6 Mon 16:15 EW 202

Van der Pauw measurements for the optimization of magnetic topological insulators — •Jan Karthein[1,3], Jonas Buchhorn[1,3], Kaycee Underwood[1,3], Abdur Reman Jalil[1,3], Peter Schüffelgen[1,3], Detlev Grützmacher[1,2,3], and Thomas Schäpers[1,3] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Peter Grünberg Institut (PGI-10), Forschungszentrum Jülich, 52425 Jülich, Germany — [3]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, 52425 Jülich, Germany

Quantum anomalous Hall insulators are proposed to be a platform for the realization of chiral Majorana edge modes when coupled to a superconductor by the proximity effect. The quantum anomalous Hall state has already been achieved in magnetic topological insulators but inducing superconductivity into these materials remains a challenge. We present a measurement scheme based on the van der Pauw method that allows to get fast insights into the electrical transport properties of thin films at low temperatures prepared by molecular beam epitaxy. On the example of Cr-doped $(Bi_xSb_{1-x})_2Te_3$ the effect of different growth parameters is investigated and compared to Hall bar measurements. The van der Pauw method enables a fast feedback loop between growth and transport measurements. This will help to establish a reliable epitaxial growth of quantum anomalous Hall insulator thin films and allow to systematically search for promising material compositions to induce superconductivity into magnetic topological insulators.

15 min. break

TT 15.7 Mon 16:45 EW 202

Topology of finite size magnetic topological insulator/superconductor heterostructures — •Julian Legendre[1], Eduárd Zsurka[1,2,3], Daniele Di Miceli[1,4], Llorenç Serra[4,5], Kristof Moors[2,3], and Thomas L. Schmidt[1] — [1]Department of Physics and Materials Science, University of Luxembourg — [2]PGI-9, Forschungszentrum Jülich — [3]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University — [4]Institute for Cross-Disciplinary Physics and Complex Systems IFISC (CSIC-UIB) — [5]Department of Physics, University of the Balearic Islands

Heterostructures of magnetic topological insulators (MTIs) and superconductors (SCs) in two-dimensional (2D) slab and one-dimensional (1D) nanoribbon geometries have been predicted to host chiral Majorana edge states or Majorana bound states (MBS), respectively. We study the topological properties of such MTI/SC heterostructures upon variation of the slab geometry from wide slabs to quasi-1D nanoribbon systems and as a function of the chemical potential, the magnetic doping, and the induced superconducting pairing potential. To do so, we construct effective symmetry-constrained low-energy $\mathbf{k}\cdot\mathbf{p}$ Hamiltonians accounting for the real-space confinement. Transitions between topological phases are then signalled by sign changes of the resulting gap magnitude at the Γ point. For confined slab geometries, as the chemical potential, the magnetic doping and/or the width of the slab are varied, we observe a periodic sign change of the bulk gap, which entails reentrant MBS at the ends of the nanoribbon.

TT 15.8 Mon 17:00 EW 202

Proximity induced superconducting gap in Bi-containing thin TI and highly ordered TI films grown on the Nb(110) surface — •Artem Odobesko, Felix Friedrich, Robin Boshuis, and Matthias Bode — Julius-Maximilians-Universität Würzburg,Physikalisches Institut, Experimentelle Physik II, Am Hubland, 97074 Würzburg, Germany

A superconductor (SC) in contact with a non-SC metal leads to a proximity effect, wherein Cooper pairs from the SC infiltrate the metal. The proximity effect has recently regained attention due to its potential for achieving topological superconductivity within heterostructures of 3D topological insulators (TI) combined with conventional s-wave SC. Theoretical predictions suggest the emergence of Majorana zero-energy modes within the vortices of such TI/SC heterostructures.

The magnitude of the proximity-induced gap is pivotal for the robustness of Majorana zero modes and in general distinct from proximity pairing correlations. The current experiments are aimed at examining the induced SC-gap on the exposed surface of thin Bi-containing slabs -Bi(111), Bi(110) and Bi_2Te_3 - grown on Nb(110) substrate. The characteristics of the induced SC-gap are not solely dependent on the thickness of the slab; they are also strongly influenced by the matching of Fermi surfaces between the SC and non-SC materials at their interfaces. The band structure correspondence and band bending at the interface, plays a crucial role in generating a robust proximity-induced SC-gap. It underscores the necessity to explore compatible pairs of SC and non-SC materials for effective band matching.

TT 15.9 Mon 17:15 EW 202

Selective growth of magnetic topological insulator nanostructures via molecular beam epitaxy — •Max Vassen-Carl, Peter Schüffelgen, and Detlev Grützmacher — Peter Grünberg Institute, Forschungszentrum Jülich, Jülich, Germany

Magnetic topological insulators (MTIs) have great potential for hosting Majorana zero modes [1]. To achieve this, MTI nanostructures are a promising candidate. In such devices, the chiral edge modes (CEM) of the MTI are predicted to hybridise [2]. To verify this prediction, other groups have etched MTI films into thin Hallbars [3]. This etching process is prone to damage the edge states.
In this work a new molecular beam epitaxy (MBE) technique is presented, which enables the selective growth of MTI structures for the first time. Transport measurements on such devices provide insights into the size dependence of CEM in MTIs.

[1] D. Burke et al., arXiv 2302.10982 (2023)
[2] Chen et al., Phys. Rev. B 97, 104504 (2018)
[3] Zhou et al., Phys. Rev. Lett. 130, 086201 (2023)

TT 15.10 Mon 17:30 EW 202

Conductance asymmetry in proximitized magnetic topological insulator junctions with Majorana modes — •Daniele Di Miceli[1,2], Eduárd Zsurka[2,3,4], Julian Legendre[2], Kristof Moors[3,4], Thomas Schmidt[2], and Llorenç Serra[1,5] — [1]Institute for Cross-Disciplinary Physics and Complex Systems IFISC (CSIC-UIB) — [2]Department of Physics and Materials Science, University of Luxembourg, 1511 Luxembourg, Luxembourg — [3]PGI-9, Forschungszentrum Jülich — [4]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University — [5]Department of Physics, University of the Balearic Islands

Magnetic topological insulators are outstanding candidates for the realization of topological 1D and 2D superconducting phases when coupled by proximity to ordinary s-wave superconductors. We study normal-superconductor-normal junctions made of narrow (wirelike) or wide (filmlike) magnetic topological insulator slabs with a central proximitized sector. Specifically, we investigate how the electronic transport depends on the topological phase of the central superconductor when the voltage bias is split asymmetrically between the two normal leads of the junction. The occurrence of charge-nonconserving Andreev processes entails a nonzero conductance related to an electric current flowing to ground from the proximitized sector of the junction. We show that topologically protected Majorana modes require an antisymmetry of this conductance with respect to the point of equally split bias across the junction.

TT 15.11 Mon 17:45 EW 202

Transport spectroscopy on $(Bi,Sb)_2Te_3$ nanoribbons proximitized by aluminum as parent superconductor — •Benedikt Frohn, Tobias W. Schmitt, Vanessa S. Bello, Dennis Heffels, Albert Hertel, Michael Schleenvoigt, Abdur R. Jalil, Kristof Moors, Peter Schüffelgen, and Detlev Grützmacher — Peter Grünberg Institut, Forschungszentrum Jülich & JARA Jülich-Aachen Research Alliance, D-52425 Jülich, Deutschland

One-dimensional topological insulator nanowires which are proximitized by an s-wave superconductor and are exposed to an in-plane magnetic field are predicted to become topological superconductors [1, 2]. So far, realizing a strong proximity effect in such structures has remained an experimental challenge. In this talk, I present transport spectroscopy results on $(Bi,Sb)_2Te_3$ nanowires with Al as parent superconductor. All materials are grown via molecular beam epitaxy in a single growth run consisting of six subsequent deposition steps. To prevent diffusion of Al into $(Bi,Sb)_2Te_3$ and creating a transparent interface, we employ a thin diffusion barrier made from Pt. These devices are fabricated using stencil lithography [3] and possess contacts with varying barrier strength made of AlOx. This enables us to study the density of states and therefore to search for topological features within the induced superconducting gap, of which we measure the dependences of different magnetic field directions as well as temperature.

[1] Cook et al., Phys. Rev. B 86, 155431 (2012)
[2] Heffels et al., Nanomaterials 13, 723 (2023)
[3] Schüffelgen et al., Nat. Nanotechnology 14, 825-831 (2019)

TT 16: 2D Materials I: Electronic Structure (joint session O/TT)

Time: Monday 15:00–17:30 Location: MA 005

TT 16.1 Mon 15:00 MA 005

Electronic and magnetic properties of single chalcogen vacancies in MoS_2/Au(111) — Sergey Trishin[1], •Christian Lotze[1], Nils Krane[2], and Katharina J. Franke[1] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]nanotech@surfaces Laboratory, Empa - Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland

Two-dimensional (2D) transition-metal dichalcogenides (TMDCs) are considered highly promising platforms for next-generation optoelectronic devices. Because of their 2D structure, the performance of potential devices is strongly impacted by defects. Nowadays a lot of research aims to optimize growth methods towards defect-free TMDCs. However, defect engineering has also gained a lot of attention, as it may allow for control and design of new properties of 2D materials.

Here, we create single S vacancies in a monolayer of MoS_2 that was grown on Au(111). Using combined scanning tunneling and atomic force microscopy, we show that these defects are negatively charged and give rise to a Kondo resonance. The latter reveals the presence of an unpaired electron spin that is exchange-coupled to the underlying metal substrate. The strength of the exchange coupling depends on the density of states at the Fermi level, which is modulated by the moiré structure of the MoS_2 lattice and the Au(111) substrate. We also show that in the absence of direct hybridization of MoS_2 with the metal substrate, the S vacancy remains charge-neutral. Our results suggest that defect engineering may be used to induce and tune magnetic properties of otherwise nonmagnetic materials.

TT 16.2 Mon 15:15 MA 005

Non-ambient Raman spectroscopy combined with ion bombardment — •André Maas, Joel Verlande, Leon Daniel, Lucia Skopinski, Lars Breuer, and Marika Schleberger — Universität Duisburg-Essen, Fakultät für Physik and CENIDE, Germany

Characterizing materials in non-ambient conditions poses a persistent challenge, particularly in understanding irradiation-induced defects and their effects on crystal structure and electronic/optoelectronic properties. While ambient conditions often saturate defects with adsorbates, investigating the influence of unsaturated defects remains crucial for a comprehensive understanding.

In the first part of this study, we focused on analyzing defect formation in CVD-grown WS_2 by irradiating it with low-energy Ar^+ ions ($E_{\mathrm{kin}} \leq 500$ eV) to create sulfur vacancies. Subsequent analysis via Raman and photoluminescence spectroscopy revealed insights into the nature of these defects. A custom-built cell was used enabling us to characterize the electrical and optical properties at a pressure of $p = 10^{-6}$ mbar, to study the effects of temperature (77 K to 600 K) and the presence of sulfur hexafluoride on the irradiated samples.

In a novel experiment, defects were induced in graphene using highly charged ions (Xe^{17+} - Xe^{40+} at around $E_{kin} = 200$ keV). In-situ optical measurements at ultra-high vacuum ($p = 10^{-9}$ mbar) allowed us to detect the influence of saturated defects on the properties of this important 2D material.

TT 16.3 Mon 15:30 MA 005

Local creation and manipulation of sulfur vacancies in two-dimensional MoS_2 — •Daniel Jansen[1], Tfyeche Tounsi[1], Jeison Fischer[1], Arkady Krasheninnikov[2], Thomas Michely[1], Hannu-Pekka Komsa[3], and Wouter Jolie[1] — [1]II. Physikalisches Institut, Universität zu Köln, Köln, Germany — [2]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [3]Faculty of Information Technology and Electrical Engineering, University of Oulu, Oulu, Finland

Point defects in two-dimensional semiconductors can exhibit spatially confined and electronically isolated quantum states in the band gap of their host material. A prerequisite for the use of such point defects in quantum applications is to gain control over defect creation and manipulation.

Here, we report on a new technique for the local creation of individual sulfur vacancies in two-dimensional MoS_2 involving the tip of a scanning tunneling microscope and single Fe adatoms that we utilize as chemical markers. We exemplify how this technique can be employed to tailor the in-gap states by the creation of a vacancy dimer, giving rise to hybrid orbitals. Additionally we show that the tip can also be used to manipulate the sulfur vacancy charge state through local gating. When negatively charged, two distinct Jahn-Teller distortions are observed and characterized using scanning tunneling spectroscopy and density functional theory.

TT 16.4 Mon 15:45 MA 005

Charge State-Dependent Symmetry Breaking of Atomic Defects in Transition Metal Dichalogenides — •Lysander Huberich[1], Feifei Xiang[1], Jonas Allerbeck[1], Preston A. Vargas[2], Riccardo Torsi[3], Anne Marie Tan[2], Pascal Ruffieux[1], Roman Fasel[1], Oliver Gröning[1], Yu-Chuan Lin[3], Richard Henning[2], Joshua Robinson[3], and Bruno Schuler[1] — [1]Empa - nanotech@surfaces Laboratory, 8600 Dübendorf, Switzerland — [2]University of Florida, Gainesville, FL, 32611, USA — [3]The Pennsylvania State University, University Park, PA, 16802, USA

The electronic properties of atomically thin 2D materials are strongly influenced by occuring atomic defects and their interaction with the host lattice. Here we report on the direct imaging of charge state-dependent symmetry breaking of single rhenium dopants (Re_{Mo}) and negatively charged sulfur vacancies ($Vac_S{}^-$) in mono- and bilayer MoS_2 by atomically-resolved STM and nc-AFM. While $Vac_S{}^-$ occur in both the symmetric and the symmetry-broken state, Re_{Mo} exhibit charge-dependent symmetry breaking stabilized by the difference in substrate workfunction. The local lattice distortions and symmetry-broken defect orbitals of $Vac_S{}^-$ as well as $Re_{Mo}{}^0$ and $Re_{Mo}{}^{-1}$ are attributed to the (pseudo-)Jahn-Teller effect. By mapping of electronic orbitals and geometric structures, we can disentangle effects of spatial averaging, charge multistability, configurational dynamics, and external perturbations that often mask the presence of local symmetry breaking. [Xiang, Huberich, et al., arXiv:2308.02201]

TT 16.5 Mon 16:00 MA 005

Tuning Intrinsic Transition Probabilities in CVD-Grown WS_2 through Introduction of Sulfur Vacancies — •Leon Daniel, Charleen Lintz, Osamah Kharsah, Andre Maas, Stephan Sleziona, and Marika Schleberger — Universität Duisburg-Essen

Monolayer transition metal dichalcogenides (TMDCs) like tungsten disulfide (WS_2) are highly interesting materials for optoelectronic and valleytronic applications. Although WS_2 has a significantly higher quantum efficiency compared to its MoS_2 counterparts, its intrinsic properties are much less studied. This study investigates the controlled creation of sulfur vacancies in chemical vapor deposition (CVD)-grown WS_2 by high-temperature annealing in vacuum conditions up to 627 K. Employing in-situ photoluminescence (PL) spectroscopy, we observe a selective reduction in the intensity of the A exciton, while the B exciton remains unaffected upon introduction of vacancies. This distinctive behavior provides valuable insights into intrinsic transition probabilities associated with deliberately induced defect levels in WS_2. Additionally, an increased trion emission was detected, indicating increased doping by selectively removing sulfur. Intriguingly, despite the vacancy introduction, no observable localized states are detected. Similar results are achieved through 100 eV argon ion irradiation, if the sample is annealed with high laser powers before PL measurements are conducted; we therefore attribute this to the desorption of adsorbates. Our findings suggest that low energy ion bombardment is a suitable option for selectively tailoring the material's optical properties.

TT 16.6 Mon 16:15 MA 005

Formation of complex CDW patterns in single-layer TiSe2 — •Wen Wan, Paul Dreher, Maria Gastiasoro, Fernando de Juan, and Miguel Ugeda — Donostia International Physics Center, San Sebastián, Spain

While the CDW in TiSe2 emerges naturally with a commensurate 2x2x2 symmetry below ~200 K, superconductivity only develops induced by pressure, doping, and intercalation. Interestingly, these external stimuli triggering superconductivity also induce a CDW phase transition from a commensurate (CCDW) to an incommensurate state (ICCDW). Therefore, it has been speculated that superconductivity in TiSe2 is triggered by the CCDW to ICCDW transition in an unprecedented, exotic mutual interplay.

In this work, we explore the CDW state of TiSe2 in the single-layer limit by means of low-temperature STM/STS measurements. nm-scale STM imaging reveals the presence of a CDW with a local 2x2 atomic periodicity as in bulk TiSe2 which, in contrast, is markedly inhomogeneous in space. On a larger scale, we find that such inhomogeneity is due to incommensuration of the CDW, which leads to the formation of complex 4-fold 2D matrix of CDW domains. Our high-resolution large-scale STM images allow us to spatially map the full complex CDW order parameter (amplitude and phase) with sub-nm precision. This analysis reveals that the CDW develops π-phase shifts at the domain walls. Lastly, while the matrix of CDW domains is unaffected by point defects in the Se layer, artificially introduced defects in the Ti plane pin the domain walls.

TT 16.7 Mon 16:30 MA 005

Unconventional charge-density-wave gap in monolayer NbS_2 — Timo Knispel[1], Jan Berges[2], Arne Schobert[3], Erik van Loon[4], Wouter Jolie[1], Tim Wehling[3], Thomas Michely[1], and •Jeison Fischer[1] — [1]II. Physikalisches Institut, Universität zu Köln, Köln — [2]Universität Bremen, Bremen — [3]I. Institut für Theoretische Physik, Universität Hamburg, Hamburg — [4]Lund University, Lund, Sweden

Here, we report scanning tunneling microscopy and spectroscopy measurements for a monolayer of H-NbS_2 grown by molecular beam epitaxy on graphene/Ir(111). We find that monolayer NbS_2 displays a 3×3 modulation superstructure due to a charge density wave (CDW), which is not present in bulk NbS_2. Evidence for the CDW is given by bias voltage contrast inversion and temperature suppression of the CDW signal. Our high-resolution differential conductance spectra display a pronounced gap of the order of 20 meV at the Fermi level. Within the gap low energy features are present. The gap structure with its low energy features is at variance with the expectation for a gap opening in the electronic band structure due to a static CDW distortion. Instead, comparison with ab initio calculations indicates that the observed gap structure is due to combined electron-phonon quasiparticles. The phonons in question are the elusive amplitude (Higgs) and phase (Goldstone) collective modes of the CDW transition [1].

[1] Knispel et al., arXiv:2307.13791.

TT 16.8 Mon 16:45 MA 005

Orbital character and ground-state electronic properties in van der Waals semiconductors VI3 and CrI3 — •Alessandro De Vita[1,2], Thao Nguyen[3], Roberto Sant[4], Gian Marco Pierantozzi[1], Danila Amoroso[5], Chiara Bigi[1,6], Vincent Polewczyk[1], Giovanni Vinai[1], Loi Nguyen[7], Tai Kong[7], Jun Fujii[1], Ivana Vobornik[1], Nicholas Brookes[4], Giorgio Rossi[1,2], Robert Cava[7], Federico Mazzola[1], Kunihiko Yamauchi[3], Silvia Picozzi[5], and Giancarlo Panaccione[1] — [1]IOM-CNR, Laboratorio TASC, Trieste, Italy — [2]Dipartimento di Fisica, Università di Milano, Italy — [3]ISIR, Osaka University, Japan — [4]ESRF, Grenoble, France — [5]CNR-SPIN c/o Università G. D'Annunzio, Chieti, Italy — [6]University of St Andrews, United Kingdom — [7]Department of Chemistry, Princeton University, NJ USA

Layered van der Waals magnetic semiconductors CrI3 and VI3 hold promise for novel electronic and spintronic 'few-layers' functionalities; however, detailed experimental information on the electronic structure, the interplay with relevant interactions (e.g. spin-orbit coupling), and the crossover of 3D vs 2D properties, is lacking. By combining X-ray electron spectroscopies and density functional theory calculations, we report a complete characterization of CrI3 and VI3 electronic ground states. We show that the transition metal-induced orbital filling drives the stabilization of distinct phases. X-ray absorption measurements on VI3 reveal that its electronic properties are strongly influenced by dimensionality effects. Our results have direct implications in band engineering and layer-dependent properties of two-dimensional systems.

TT 16.9 Mon 17:00 MA 005

Exchange splitting in the electronic structure of quasi-2D antiferromagnet CrSBr — •Matthew D. Watson[1], James Nunn[1,2], Swagata Acharya[3], Laxman Naga-Reddy[2], Dimitar Pashov[4], Malte Rösner[5], Mark van Schilfgaarde[3], Neil R. Wilson[2], and Cephise Cacho[1] — [1]Diamond Light Source Ltd, Harwell Science and Innovation Campus, Didcot, OX11 0DE, UK — [2]Department of Physics, University of Warwick, Coventry, CV4 7AL, UK — [3]National Renewable Energy Laboratory, Golden 80401 CO, USA — [4]Theory and Simulation of Condensed Matter, King's College London, The Strand, London WC2R2LS, UK — [5]Institute for Molecules and Materials, Radboud University, Heijendaalseweg 135, 6525AJ Nijmegen, The Netherlands

We present the evolution of the electronic structure of CrSBr from it's antiferromagnetic ground state to the paramagnetic phase above $T_N = 132$ K, in both experiment and theory. The ground state angle-resolved photoemission spectroscopy (ARPES) results, obtained using a novel method to overcome sample charging issues, are very well reproduced by our QSGW calculations including Bethe-Salpeter Equations (BSE) self-consistently. By tracing band positions as a function of temperature, we identify certain bands at the X points to be exchange-split pairs of states with mainly Br and S character, with the splitting disappearing above T_N. Our results lay firm foundations for the interpretation of the many other intriguing physical and optical properties of CrSBr.

TT 16.10 Mon 17:15 MA 005

Ultrafast momentum microscopy of hybrid exciton dynamics in homobilayer 2H-MoS$_2$ — •Paul Werner[1], Jan Philipp Bange[1], Wiebke Bennecke[1], David Schmitt[1], Giuseppe Meneghini[2], Anna Seiler[1], AbdulAziz AlMutairi[3], Marco Merboldt[1], Sabine Steil[1], Daniel Steil[1], Stephan Hofmann[3], G. S. Matthijs Jansen[1], Samuel Brem[2], R. Thomas Weitz[1], Ermin Malic[2], Marcel Reutzel[1], and Stefan Mathias[1] — [1]I. Physikalisches Institut, Georg-August Universität Göttingen, Germany — [2]Fachbereich Physik, Philipps-Universität Marburg, Germany — [3]Department of Engineering, University of Cambridge, United Kingdom

Transition-metal dichalcogenides (TMDs) monolayers host a rich landscape of excitonic states. If, in addition, these monolayers are stacked on top of each other, novel interlayer and hybrid excitonic states can form. Hybrid excitons, where either the excitons' hole or electron is layer-delocalized as a result of interlayer hopping, are responsible for efficient charge transfer between the layers [1, 2]. In homobilayer MoS$_2$, hybrid excitons are predicted to be the energetically most favorable excitonic state, making it an ideal system to study their properties. We employ time-resolved momentum microscopy to study the ultrafast exciton dynamics in H-stacked homobilayer MoS$_2$. By directly imaging the electron and hole contributions of the hybrid excitons, we are able to track their ultrafast dynamics.

[1] Schmitt *et al.*, Nature **608**, 499-503 (2022)
[2] Bange, Werner *et al.*, 2D Mater. *10* 035039 (2023)

TT 17: Focus Session: Quantum Interactive Dynamics II (joint session DY/TT)

Quantum many-body systems out of equilibrium represent a challenging frontier and have been shown to exhibit extremely rich phenomena. Recent experimental advances in building Noisy Intermediate-Scale Quantum (NISQ) devices have opened up a completely new territory in this context. The natural evolution implemented by NISQ devices is a quantum interactive dynamics generated by a combination of unitary gates and measurements. These platforms provide an opportunity to explore vastly larger parts of the Hilbert space and go beyond what can be realized in purely unitary systems. In pioneering works, an entanglement phase transition was identified in the dynamics of circuits of random unitary gates interleaved with local projective measurements. This phase transition separates a disentangling phase, obeying an area law, and an entangling phase obeying a volume law. Successively, it has been shown that additional phase transitions between different area phases can occur and new kinds of quantum phase transitions have been discovered. This session aims to give an overview of recent theoretical and experimental developments within this very active field and point towards the open questions.

Organized by Roderich Moesser (Dresden) and Frank Pollmann (München)

Time: Monday 15:00–18:00 Location: A 151

Invited Talk TT 17.1 Mon 15:00 A 151

Quantum Mechanics and Many Body Games — •Shivaji Sondhi — University of Oxford, UK

I will describe some work on the theme of exploring many body quantum mechanics by playing games with its help. I will primarily discuss a set of results that raise the possibility of classifying quantum states by asking whether they confer a quantum advantage in winning a particular game. I will comment briefly on other interesting directions encompassed by this general theme.

Invited Talk TT 17.2 Mon 15:30 A 151

Measurement induced phase transitions of fermions: from theory to observability — •Sebastian Diehl — University of Cologne

The quest for phases and phase transitions in general non-unitary quantum dynamics has been spotlighted by the recent discovery of measurement-induced phase transitions. They result from the competition of deterministic Schrödinger and random measurement dynamics, and surface in a qualitative change of the entanglement structure.

Here we first introduce instances of entanglement transitions in fermion systems, between a regime of logarithmic entanglement growth, and a quantum Zeno regime obeying an area law. We identify the relevant degrees of freedom driving the phase transition in terms of an effective field theory. This yields a physical picture in terms of a depinning from the measurement operator eigenstates induced by unitary dynamics, and places it into the BKT universality class.

In standard quantum mechanical observables however, these transitions are masked due to the degeneracy of measurement outcomes. We then point out a general route of gently breaking this degeneracy – preselection – which makes such transitions observable in state-of-the-art quantum platforms without modifying any of the universal properties. It reveals an intriguing connection to quantum absorbing state transitions.

Invited Talk TT 17.3 Mon 16:00 A 151

Novel quantum dynamics with superconducting qubits — •Pedram Roushan — Google Quantum, Santa Barbara, CA, USA

In recent years superconducting qubits have become one of the leading platforms for quantum computation and simulation. We utilize these Noisy Intermediate Scale Quantum (NISQ) processors to study nonequilibrium quantum dynamics and simulate quantum phases of matter. I will present some of our recent works in studying robustness of bound states of photons [1], measurement-induced quantum information phases [2], braiding of non-Abelian anyons [3], and the universality classes of dynamics in the 1D Heisenberg chain [4]. Time permitting, I will talk about our effort on analog simulation, using the native Hamiltonian of the device. A goal of this talk is to provide a sense of what NISQ discoveries to anticipate and a time scale for them.

[1] Morvan et al., Nature 612, 240*245 (2022) [2] Hoke et al., Nature 622, 481*486 (2023) [3] Andersen et al., Nature 618, 264*269 (2023)

[4] Rosenberg et al., Arxiv.org/abs/2306.09333

TT 17.4 Mon 16:30 A 151

Programmable adiabatic demagnetization on noisy quantum devices — •Anne Matthies[1,2], Mark Rudner[3], Achim Rosch[1], and Erez Berg[2] — [1]University of Cologne, Cologne, Germany — [2]Weizmann Insitute of Science, Rehovot, Israel — [3]University of Washington, Seattle, USA

We propose a simple, robust protocol to prepare a low-energy state of an arbitrary Hamiltonian on a quantum computer. The protocol is inspired by the "adiabatic demagnetization" technique, which can cool solid-state systems to extremely low temperatures. The adiabatic cooling protocol is demonstrated via an application to the transverse field Ising model. We use fraction of the qubits to model a bath that is coupled to the system. The bath spins are prepared in the polarized ground state subject to a strong simulated Zeeman field. By an adiabatic downward sweep of the magnetic field, we transfer energy and entropy from the system to the bath qubits. A measurement and reset of the bath qubits allow the restart of the protocol cycle. We find that the algorithm's performance at a finite error rate depends on the nature of the excitations; systems with non-local (topological) excitations are more challenging to cool. Finally, we explore ways to mitigate this problem partially.

TT 17.5 Mon 16:45 A 151

Topological quantum phase transitions in exact two-dimensional isometric tensor networks — •Yu-Jie Liu[1], Kirill Shtengel[2], and Frank Pollmann[1] — [1]Technical University of Munich — [2]University of California, Riverside

Isometric tensor networks (isoTNS) form a subclass of tensor network states that have an additional isometric condition, which implies that they can be efficiently prepared with a linear-depth quantum circuit. In this work, we introduce a procedure to construct isoTNS encoding of certain 2D classical partition functions. By continuously tuning a parameter in the isoTNS, the many-body ground state undergoes quantum phase transitions, exhibiting distinct 2D topological order. We illustrate this by constructing an isoTNS path with bond dimension D = 2 interpolating between distinct symmetry-enriched topological (SET) phases. At the transition point, the isoTNS wavefunction is related to a gapless point in the classical six-vertex model and can be interpreted as a superposition of world lines of random walking particles. The critical wavefunction supports a power-law correlation along one spatial direction while remains long-range ordered in the other spatial direction. We provide an exact linear-depth parametrized local quantum circuit that realizes the path. The above features can therefore be efficiently realized on a programmable quantum device. At the end, we briefly discuss the possibility of isoTNS paths interpolating between other 2D topological phases.

TT 17.6 Mon 17:00 A 151

Quantum simulation of the 1D Fermi-Hubbard model as a Z2 lattice-gauge theory — •Uliana Khodaeva[1], Dmitry Kovrizhin[2], and Johannes Knolle[1,3,4] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]LPTM, CY Cergy Paris Universite, UMR CNRS 8089, Pontoise 95032 Cergy-Pontoise Cedex, France — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [4]Blackett Laboratory, Imperial College of London, London SW7 2AZ, United Kingdom

The Fermi-Hubbard model is one of the central paradigms in the physics of strongly-correlated quantum many-body systems. Here we propose a quantum circuit algorithm based on the Z2 lattice gauge theory (LGT) representation of the one-dimensional Fermi-Hubbard model, which is suitable for implementation on current NISQ quantum computers. Within the LGT description there is an extensive number of local conserved quantities commuting with the Hamiltonian. We show how these conservation laws can be used to implement an efficient error-mitigation scheme. The latter is based on a post-selection of states for noisy quantum simulators. While the LGT description requires a deeper quantum-circuit compared to a Jordan-Wigner (JW) based approach, remarkably, we find that our error-correction protocol leads to results being on-par with a standard JW implementation on noisy quantum simulators.

TT 17.7 Mon 17:15 A 151

Quantum control on MPS manifolds — Marko Ljubotina, •Elena Petrova, and Maksym Serbyn — IST Austria, Am Campus 1, 3400 Klosterneuburg, Austria

The progress of quantum devices necessitates the development of methods for determining the optimal steering operators, that can efficiently drive quantum systems along desired trajectories of states. In my talk, I will introduce a method for constructing such operators using matrix product states (MPS). Our technique is able to build operators with different supports. To evaluate the effectiveness of our approach, we test it on a specific trajectory. Our analysis involves a comparison of operators with various supports and different free parameter choices. We identify the optimal set of parameters and demonstrate converging behaviour as the support size is increased. The resulting Floquet systems for the closed trajectory of our choice violate the Eigenstate Thermalization Hypothesis (ETH).

TT 17.8 Mon 17:30 A 151

Non-interacting limit of the many-body mean level density as an indicator of integrable vs. chaotic single particle dynamics — •Georg Maier[1], Carolyn Echter[1], Juan-Diego Urbina[1], Caio Lewenkopf[2], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg — [2]Instituto de Física, Universidade Federal Fluminense

A celebrated result of semiclassical analysis states that two definitorial aspects of a system's classical dynamics, integrability and chaos, are universally reflected in the spectral fluctuations of its quantized version. According to this picture, therefore, the mean level density (that encodes the smooth, mean features of the spectrum) provides just a system-dependent background that is routinely removed to focus on fluctuations. I will present that, contrary to a naive application of this paradigm, the smooth part of the many-body level density is extremely sensitive to the nature of the single-particle phase space. Specifically, while the spectral fluctuations of many body systems in the mean field limit can be shown to be Poissonian for both chaotic and integrable single-particle dynamics, it is the average level density the one that reflects such distinction. Our results are based on the study of the mean level density obtained from averaging over ensembles of single-particle spectra with the characteristic fluctuations representing the integrable and chaotic dynamics of the weakly interacting (mean field) limit. We are then able to obtain closed analytical expressions for systems with N=2,3 bosons/fermions, while extensive numerical simulations support our claims for larger values.

TT 17.9 Mon 17:45 A 151

Theory of Two-Dimensional Nonlinear Spectroscopy for Correlated Magnons in Three-Dimensional Canted Antiferromagnets — •Wonjune Choi[1,2], Daniel Schultz[3], Jonas Habel[1,2], Johannes Knolle[1,2], and Yong Baek Kim[3] — [1]Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]University of Toronto, Toronto, Canada

We investigate how nonlinear response functions can capture the correlated dynamics of magnons, a phenomenon beyond the reach of linear spin wave theory. A recent experiment on the S=5/2 canted antiferromagnet YFeO3 [Zhang et al., arXiv:2301.12555] observed puzzling second-order dynamical responses that cannot be explained by the Landau-Lifshitz-Gilbert simulation. Our key finding addresses this puzzle by revealing that the experimentally observed new signals result from the quantum correction of the ground state and the mode-mode couplings between the distinct magnon modes at the reduced Brillouin zone center. These many-body quantum effects, dynamically generated by three magnon interactions, originate from the Dzyaloshinskii-Moriya interaction responsible for the noncollinear antiferromagnetic order. Our work highlights the potential application of nonlinear spectroscopy as a promising experimental route to understanding intertwined dynamics among correlated magnons.

TT 18: Superconductivity: Poster

Time: Monday 15:00–18:00 Location: Poster C

TT 18.1 Mon 15:00 Poster C

Terahertz investigations on ALD-grown superconducting NbN thin films — •Yayi Lin[1], Frederik Bolle[1], Martin Dressel[1], Detlef Born[2], Heidemarie Schmidt[2], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Leibniz Institute of Photonic Technology (IPHT), Jena, Germany

Niobium nitride (NbN) thin films are high-disorder superconductors, that have attracted significant interest in recent years. Due to its high critical temperature (T_c up to 17 K) and large energy gap, NbN is applied in single photon detectors, microwave resonators, and superconducting quantum circuits.

As the energy gap of NbN is located in the terahertz (THz) region (3 - 100 cm^{-1}, 100 GHz - 3 THz), we use THz spectroscopy to directly determine the energy gap from the complex optical conductivity ($\hat{\sigma}$). By measuring the THz transmission, $\hat{\sigma}$ can be derived, which encodes various superconducting properties of NbN.

Here, we measured NbN grown by atomic layer deposition (ALD) with the nominal thicknesses of 4.5, 5.0, 10.0, and 20.0 nm on Al_2O_3 substrates, in both THz frequency-domain spectroscopy (THz-FDS; frequencies 3 - 40 cm^{-1}) and THz time-domain spectroscopy (THz-TDS; 10 - 100 cm^{-1}), at temperatures down to 2.7 K, revealing T_c, the complex optical conductivity, energy gap, and superfluid density.

TT 18.2 Mon 15:00 Poster C

Nanoscale Characterization of Superconducting Nitrides for Qubits — •Janine Lorenz[1,2,3], Amin Karimi[1], Yorgo Haddad[4], Sven Linzen[5], Rami Barends[4], F. Stefan Tautz[1,2,3], and Felix Lüpke[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA) - Fundamentals of Future Information Technology, Germany — [3]Institut für Experimentalphysik IV A, RWTH Aachen, Germany — [4]Peter Grünberg Institut (PGI-13), Forschungszentrum Jülich, Germany — [5]Leibniz Institute of Photonic Technology, Friedrich-Schiller-Universität Jena, Germany

Superconducting nitrides like NbTiN are promising candidates for advancing the performance of transmon qubits as they offer distinct advantages compared to conventional aluminum-based quantum circuits. Notably, NbTiN thin films offer improved chemical stability, show elevated critical temperatures up to 15 K and have a higher kinetic inductance, all of which are important properties for good qubit performance.

Here, we present a comprehensive investigation of superconducting nitride thin films using scanning probe techniques. We find that our polycrystalline 5 nm and 11 nm NbTiN films show a homogeneous superconducting gap throughout the surface. Applying BCS theory we extract critical temperatures of 10 K and 11.5 K, respectively. To improve structural and superconducting properties of our films we explore different post-deposition treatment methods with a focus on thermal annealing in different gas atmospheres.

TT 18.3 Mon 15:00 Poster C

Broadband microwave measurements on superconducting granular aluminum — •Jan Pusskeiler, Aniruddha Deshpande, Martin Dressel, and Marc Scheffler — 1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

Granular aluminum is an interesting superconductor because its critical temperature T_c can be changed by tuning the grain decoupling, measured by the normal-state resistivity. The resulting phase diagram contains a dome-shaped superconducting phase originating from the increasing superconducting energy gap Δ for weaker coupling of the grains. Decoupling on the other hand also suppresses the superfluid stiffness J due to phase fluctuations of the superfluid condensate. Hence, on the high resistivity side of the dome $J < \Delta$ and the superfluid density limits T_c [1]. The height of the superconducting dome (maximum T_c) is determined by the grain size, which can be reduced by cryogenic cooling of the substrate during sample fabrication.

We perform broadband microwave measurements in Corbino reflection geometry in the frequency range from 100 kHz to 20 GHz at temperatures down to 1.15 K. We investigate granular aluminum thin films that are grown at different substrate temperatures and that cover different parts of the superconducting dome. We determine their impedance, which gives access to the complex conductivity. We can thus observe how the superfluid density decreases with increased grain decoupling. Furthermore, we observe absorption features that we interpret as signatures of plasmonic modes of the superfluid condensate.

[1] U. S. Pracht *et al.*, Phys. Rev. B **93** (2016) 100503(R)

TT 18.4 Mon 15:00 Poster C

Vortex effects in a superconducting $[(SnSe)_{1+\delta}]_3[NbSe_2]_1$ Van-der-Waals superlattice — •Wieland G. Stoffel[1], Linus Grote[1], Mahni Müller[1], Theodor Griffin[1], Olivio Chiatti[1], Danielle Hamann[2], David C. Johnson[2], and Saskia F. Fischer[1,3] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Department of Chemistry and Materials Science Institute, University of Oregon, Eugene OR 97403, USA — [3]Center for the Science of Materials Berlin, 12489 Berlin, Germany

In recent years, many materials have shown a transition between 2D and 3D superconducting behaviour [1]. Layered superconductors provide a promising framework to study those transitions. A new approach to understanding the interplay between the layers are ferecrystals, which are a Van-der-Waals bound composites of superconducting layers and spacers (here: $NbSe_2$ and SnSe) [2].

In this work we characterise the collapse of the superconducting state of a $[(SnSe)_{1+\delta}]_3[NbSe_2]_1$ ferecrystal in terms of the critical current, temperature, and magnetic field. This enables the determination of both the in-plane and out-of-plane Ginzburg-Landau coherence length, as well as the observation of effects on the IV-characteristic caused by the formation of vortices. These effects are analysed in terms of a Berezinskii-Kosterlitz-Thouless transition and the formation of phase-slip lines. The latter also explains an anomaly in the temperature dependence of the critical currents.

[1] C. Parra *et al.*, Proc. Natl. Acad. Sci. 118.16 (2021)
[2] O. Chiatti *et al.*, J. Phys. Condens. Matter **35** 215701 (2023)

TT 18.5 Mon 15:00 Poster C

Superconductivity in quasi-2D Weyl semimetal candidate trigonal $PtBi_2$ via chemical tuning — •Soumen Ash[1], Kilian Srowik[1], Reza Firouzmandi[1], Laura Teresa Corredor Bohorquez[1], Silke Hampel[1], Saicharan Aswartham[1], and Bernd Büchner[1,2] — [1]Institute for Solid State Research, Leibniz IFW Dresden, 01069 Dresden, Germany — [2]Institute of Solid State and Materials Physics, TU Dresden, 01062 Dresden, Germany

Novel quantum states like topological superconductors that host exotic excitations like Majorana fermions have stimulated intense research due to their fundamental physics and potential applications for quantum information technology. Recent discovery of sub-Kelvin superconductivity in quasi-2D Weyl semimetal candidate $PtBi_2$ has offered a new platform to explore the effect of chemical tuning on its superconducting and topological properties. We have carried out (i) Ir doping at Pt-site, (ii) Te and Se doping at Bi-sites, and (iii) Cu intercalation into the van der Waals layers of trigonal $PtBi_2$ via solid-state reactions and successfully grown plate-like single crystals using a stoichiometric melt growth technique. Detailed structural, electrical transport, magnetic, and thermodynamic characterizations have been conducted. Doping of chalcogen atoms at Bi-sites induces a structural phase transition from noncentrosymmetric structure (space group: $P31m$) to centrosymmetric structure (space group: $P\overline{3}m$). We report superconductivity in $Pt_{0.9}Ir_{0.1}Bi_2$, $PtBi_{1.8}Te_{0.2}$, $PtBi_{1.9}Se_{0.1}$, and $Cu_{0.1}PtBi_2$ with comparatively higher $T_c \approx 2.3 - 2.4$ K. This work opens up a new avenue to get further insights into the superconductivity in trigonal $PtBi_2$.

TT 18.6 Mon 15:00 Poster C

3D van Hove singularities near the Fermi level in $NiTe_2$ and $PdTe_2$ — •Emily C. McFarlane[1], Jonas A. Krieger[2], Antonio Sanna[1], Camilla Pellegrini[1], Mihir Date[1], Gabriele Domaine[1], Banabir Pal[1], Pranava K. Sivakumar[1], Anirban Chakraborty[1], Stuart S. P. Parkin[1], and Niels B. M. Schröter[1] — [1]Max Planck Institute of Microstructure Physics Weinberg 2, 06120 Halle, Germany — [2]Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

The type-II Dirac semimetal $NiTe_2$ has been used as the non-superconducting barrier in devices demonstrating the Josephson diode effect (JDE) at 20mK [1]. However from the Allen-Dynes formula,

$NiTe_2$ is estimated to have a T_c of 1.5K [2]. In isostructural $PdTe_2$, a saddle-point van Hove singularity (vHs) and its proximity to the Fermi level (E_F) is thought to be important for its type-I superconductivity with T_c=1.7K [3]. We investigated the electronic band structure of $NiTe_2$ and $PdTe_2$ to understand the lack of superconductivity in $NiTe_2$ and origin of the JDE.

We present soft X-ray ARPES measurements of the bulk band structure to confirm the location of this vHs in $NiTe_2$ and $PdTe_2$, and show that it is closer to E_F in $NiTe_2$. We also present a new approach to superconducting-DFT calculations which suggests a magnetic instability is responsible for suppressing superconductivity in $NiTe_2$.

[1] B. Pal *et al.* Nature Physics **18** 1228-1233 (2022).
[2] J. Zhang, G. Q. Huang J. Phys.: Condens. Matter **32** 205702 (2020)
[3] K. Kim *et al.* Phys. Rev. B **97** 165102 (2018).

TT 18.7 Mon 15:00 Poster C

Superconducting transition temperatures of V and V-Ti alloys in the presence of electronic correlations — •Dylan Jones[1,2], Andreas Östlin[1], Andreas Weh[1], Florian Beiuseanu[3], Ulrich Eckern[4], Levente Vitos[5], and Liviu Chioncel[1,2] — [1]Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, Germany — [2]ACIT, University of Augsburg, Germany — [3]Faculty of Science, University of Oradea, Romania — [4]Institute of Physics, University of Augsburg, Germany — [5]Department of Materials Science and Engineering, Royal Institute of Technology, Stockholm, Sweden

Ordinary superconductors are widely assumed insensitive to small concentrations of nonmagnetic impurities, whereas strong disorder suppresses superconductivity, ultimately leading to a superconductor-insulator transition. In between these limiting cases, a fascinating regime may emerge where disorder enhances superconductivity. This effect is discussed here for the β-phase of V-Ti alloys. Disorder is modeled using the CPA while local electronic interactions are treated using DMFT. The McMillan formula is employed to estimate the superconducting T_c, showing a maximum at a Ti concentration of around 0.33 for a local Coulomb interaction U in the range of 2-3 eV. Our calculations quantitatively agree with the experimentally observed concentration dependent increase of T_c, and its maximal value of about 20%. We show that including local electronic correlations are a necessary extension for an improved computation of the superconducting T_c even in such simple materials like V and V-Ti alloys.

TT 18.8 Mon 15:00 Poster C

Superconductivity in noncentrosymmetric lanthanum sesquichalcogenide La_3Se_4 — •moumita naskar[1], soumen ash[2], debendra prasad panda[3], chandan kumar vishwakarma[4], brajesh kumar mani[4], a sundaresan[3], ashok kumar ganguli[2], rajib sarkar[1], hans-henning klauss[1], and dmytro s inosov[1] — [1]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01069 Dresden, Germany — [2]Department of Chemistry, Indian Institute of Technology Delhi, New Delhi 110016, India — [3]School of Advanced Materials and Chemistry and Physics of Materials Unit, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India — [4]Department of Physics, Indian Institute of Technology Delhi, New Delhi 110016, India

We have discussed the superconducting properties of lanthanum sesquiselenide La_3Se_4 with superconducting transition temperature T_c=8.5 K. It crystallizes in the noncentrosymmetric cubic Th_3P_4-type structure with space group I-43d. Specific heat measurement classified La_3Se_4 as a strongly coupled superconductor. To determine the nature of the superconducting gap symmetry of La_3Se_4, ^{139}La-NMR measurements have been performed. From the density functional theory based first-principles simulations, we observe the number of states at the Fermi energy is dominated mainly by d and f electrons of La. Furthermore, we observe band crossings along the high-symmetry k lines in the vicinity of the Fermi energy. These bands are observed to split due to the removal of spin degeneracy associated with spin-orbit coupling, with the splitting energy E_{SOC}= 65 meV.

TT 18.9 Mon 15:00 Poster C

Revisiting spin-orbit coupling and correlations in Sr_2RuO_4 by QSGW — •Weiyi Guo[1], Christoph Friedrich[2], and Irene Aguilera[1] — [1]Institute of Physics, University of Amsterdam, 1090 GL, Amsterdam, The Netherlands — [2]Peter Grünberg Institute (PGI-1) and Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The superconductor Sr_2RuO_4 exhibits strong spin-orbit coupling (SOC). Extensive theoretical and experimental studies make Sr_2RuO_4 a good testbed for ab-initio many-body methods for the simulation of the electronic structure. We demonstrate the Fermi surface and quasiparticle band topology from QSGW+SOC, how it improves the DFT+SOC results, and the general agreement between simulation and experiments. We also discuss a possible application of GW+(E)DMFT to the system.

TT 18.10 Mon 15:00 Poster C

The three Fermi pockets of $NbSe_2$ - Investigating a Kohn-Luttinger like mechanism in TMDC monolayers. — •Julian Siegl, Anton Bleibaum, Magdalena Marganska-Lyzniak, John Schliemann, and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, Regensburg, Germany

We investigate a possible superconducting pairing generated by competing Coulomb repulsion processes in monolayer $NbSe_2$. The two spin-orbit split Fermi surfaces (FS) of ML $NbSe_2$ in the K and K′ valley can support a superconducting gap, with predominant f-wave symmetry, when the short-range intervalley scattering is stronger than the long-range intravalley one. Upon inclusion of the third FS centered at the Gamma point an additional competing pairing channel favoring s-wave symmetry opens for strong interpocket scattering. The competition between these two channels is governed by the relative strengths of the three processes involved, resulting either in one, two or three symmetry related values of the gaps at the FSs. We estimate the relevant interactions by calculating the dielectric susceptibility and the screened Coulomb potential in the RPA approximation for a DFT-based tight-binding model. The multi-orbital nature of the valence band results in preferential screening of short-range scattering processes, favoring the interpocket scattering. Far from being a spectator, the third Fermi pocket turns out to be a powerful player, even to the point of changing the symmetry of the order parameter.

TT 18.11 Mon 15:00 Poster C

Real-space mapping of Yu-Shiba-Rusinov states around magnetic defects on superconducting surfaces — •Raffaele Aliberti[1,2], David Antognini Silva[1,2], Adamantia Kosma[1], Stefan Bleugel[1], and Philipp Ruessmann[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [2]RWTH Aachen University,Aachen, Germany — [3]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany

Magnetic impurities on superconductors generally give rise to Yu-Shiba-Rusinov (YSR) bound states which, when coupled suitably in chains of magnetic atoms, can give rise to Majorana zero modes. We study the behaviour of YSR states at isolated magnetic impurities and focus on mapping out their spatial extent. In particular, we investigate the interplay of the electronic structure of the superconductor with the extent of resulting YSR states. A better understanding and control of such states can lead to reliably produce superconducting spin qubits, important for topologically protected quantum computers.

In our work we employ the Kohn-Sham Bogoliubov-de Gennes method within the full-potential relativistic Korringa-Kohn-Rostoker Green function method [1,2] interfaced with the AiiDA infrastructure for high-throughput automation [3].

[1] P. Rüßmann and S. Blügel, Phys. Rev. B **105**, 125143 (2022).
[2] P. Rüßmann *et al.*, Proc. SPIE 12656, Spintronics XVI, 126560S (2023); https://doi.org/10.1117/12.2678145
[3] P. Rüßmann *et al.*, npj Comput Mater **7**, 13 (2021).

TT 18.12 Mon 15:00 Poster C

Controlling Majorana modes in magnetic adatom chains. — •Ioannis Ioannidis — Institute for Theoretical Physics, Hamburg, Germany

Controlling impurity spins in superconductors led to the observation of promising signatures of Majorana zero modes (MZMs) but manipulating these states for quantum information processing remains an open challenge. We propose using an ancillary Yu-Shiba-Rusinov state to manipulate and fuse MZMs in topological superconductors. We demonstrate that its positioning, spin orientation, and coupling energy facilitate the efficient control of MZMs in a variety of implementations. Our approach relies on well-established techniques, such as scanning-tunneling microscopy and electron-spin resonance, opening the path towards fault-tolerant quantum computation with MZMs in adatom-superconductor systems.

TT 18.13 Mon 15:00 Poster C

Spontaneous split of surface states in d-wave superconductors — •Ambjörn Joki, Kevin Seja, Mikael Fogelström, and Tomas Löfwander — Chalmers University of Technology, Gothenburg, Sweden

Since the experimental discovery [1] of the split of surface states at pair-breaking edges in two-dimensional d-wave superconductors, different theories have been put forward in attempts to explain it. These theories can be grouped into two main categories, explaining the split either by spontaneous currents [2] or surface magnetisation [3]. To study the competition between these mechanisms, we are using a tJ-model [4-5] that includes strong correlation effects, as previously done without magnetism [6]. By combining a mean-field approach with the Gutzwiller approximation we can treat magnetism and superconductivity on the same footing.

[1] M. Covington et al., Phys. Rev. Lett. 79, 277 (1997)
[2] M. Håkansson et al., Nat. Phys. 11, 755 (2015)
[3] A. Potter and P. A. Lee, Phys. Rev. Lett 112, 117002 (2014)
[4] M. Ogata and A. Himeda, JPSJ 72, 374 (2003)
[5. R. B. Christensen et al., Phys. Rev. B 84, 184511 (2011)
[6] D. Chakraborty et al., npj Quantum Mater. 7, 44 (2022)

TT 18.14 Mon 15:00 Poster C

Nematic susceptibility in heavily hole-doped iron based superconductors — •Franz Eckelt[1], Xiaochen Hong[1], Vilmos Kocsis[2], Bernd Büchner[2], Vadim Grinenko[3], and Christain Hess[1] — [1]Bergische Universität Wuppertal, Wuppertal, Germany — [2]Leibniz-Institute for Solide State and Materials Research (IFW-Dresden), 01069 Dresden, Germany — [3]Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai, China

We investigate the elastoresistivity of the heavily hole doped iron-based superconductor $Ba_{1-x}K_xFe_2As_2$ in the range x= 0.68 - 0.98 using a piezoelectric measurement technique. We observe a divergent increase in elastoresistance along the [110] direction during cooling for all samples studied so far. We discuss our findings in terms of nematic fluctuations and Fermi surface effects in the vicinity of a Lifshitz transition.

TT 18.15 Mon 15:00 Poster C

Investigating the CDW phases and structural transitions in $BaNi_2As_2$ by means of Fluctuation Spectroscopy — •Julian Beu[1], Marvin Kopp[1], Markus König[2], Amir Haghighirad[3], Matthieu Le Tacon[2], and Jens Müller[1] — [1]Institute of Physics, Goethe-University Frankfurt, Frankfurt (Main), Germany — [2]MPI CPfS, Dresden, Germany — [3]KIT, Karlsruhe, Germany

The link between charge density waves (CDW), spin density waves (SDW) and superconductivity is of interest in the theory of unconventional superconductivity ever since these effects have been found near the superconducting transition of many unconventional superconductors, more recently in the iron-based superconductors. In this work we focus on $BaNi_2As_2$, a structurally close analogue of the 122 iron-pnictide superconductors, hosting a similar high-temperature structure and structural transitions. In contrast to the iron-pnictides however, no magnetic ordering was observed, and CDW phases replace the SDW phase. Also, there have been reports of an electronic nematic phase above the structural transitions[1], where the electronic system breaks the usual rotational symmetry. We investigate the charge carriers in $BaNi_2(As_{1-x}P_x)_2$, analyzing the resistance and noise power spectral density as a function of temperature. The samples are structured with a meander current path by a FIB process in order to increase resistance by at least two orders of magnitude, rendering noise measurements possible. Resistance noise spectroscopy often reveals hidden microscopic characteristics and can help further our understanding of the CDW phases and structural transitions. [1] Phys. Rev. B 106, 144507.

TT 18.16 Mon 15:00 Poster C

^{75}As NMR investigations of the quartic-metal phase in $Ba_{1-x}K_xFe_2As_2$ — •F. Bärtl[1,2], S. Luther[1], E. Babaev[3], J. Wosnitza[1,2], H. Kühne[1], R. Sarkar[2], K. Kihou[4], C.-H. Lee[4], H.-H Klauss[2], and V. Grinenko[2,5] — [1]HLD-HZDR, Dresden — [2]IFMP-TUD, Dresden — [3]Department of Physics, KTH Royal Institute of Technology, Stockholm — [4]AIST, Tsukuba — [5]TDLI, Shanghai Jiao Tong University

$Ba_{1-x}K_xFe_2As_2$ is a hole-doped superconductor (SC), for which samples in a doping range of $0.7 \leq x \leq 0.8$ yield a broken-time-reversal-symmetry (BTRS) SC state ($s+is$). Recently, an electron-quadrupling state (pairing of Cooper pairs) was reported to form above T_c in this doping range [1], which is not possible within the mean-field BCS theory. Instead, this is a fluctuations-stabilized phase that requires the existence of pre-formed pairs above T_c, which can manifest itself as a pseudogap. The indication for superconducting fluctuations well above T_c in BKFA with an $s + is$ state was found in measurements of the spontaneous Nernst effect [1], but spectroscopic evidence is lacking so far. Here, we present ^{75}As NMR measurements of $Ba_{0.25}K_{0.75}Fe_2As_2$, where we employ spectroscopy and relaxometry to probe the low-energy density of states at temperatures ranging across the presumed quartic-metal phase. We find a weak slope change of the temperature-dependent nuclear spin-lattice relaxation rate at temperatures above $T_c = 7$ K and 8 T, indicating the manifestation of a pseudo-gap-like state below $T^* \approx 12$ K in the bulk of the sample.

[1] Grinenko, V. *et al.* Nat. Phys. **17**, 1254 (2021)

TT 18.17 Mon 15:00 Poster C

Strain-induced structural change and diffuse scattering in $HgBa_2CuO_{4.09}$ — •Mai Ye[1], Wenshan Hong[2], Tom Lacmann[1], Mehdi Frachet[1], Igor Vinograd[1], Gaston Garbarino[3], Sofia-Michaela Souliou[1], Amir-Abbas Haghighirad[1], Yuan Li[2], and Matthieu Le Tacon[1] — [1]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [2]International Center for Quantum Materials, School of Physics, Peking University, 100871 Beijing, China — [3]European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble Cedex, France

We study the structural change and diffuse scattering induced by a-axis compressive strain in $HgBa_2CuO_{4.09}$ at $T_c = 78$ K, using synchrotron X-ray diffraction. The high-temperature superconductor exhibits negative Poisson ratio below 0.6% strain. Although the c-axis lattice parameter at 1% strain is 0.1% larger than its zero-strain value, the Cu-O bond length is 1.2% shorter than the zero-strain value. Strain-induced diffuse scattering appears at the two sides of Bragg peaks along the strain direction. Such diffuse scattering has a wavenumber of (0.5,0,0), corresponding to a modulation with a period of twice the a-axis lattice parameters. The diffuse-scattering features saturate at 0.2% strain and exhibit little change on cooling below T_c.

TT 18.18 Mon 15:00 Poster C

Microscopic Insights into London Penetration Depth: Application to $CeCoIn_5$ — •Mehdi Biderang[1] and Alireza Akbari[2] — [1]Department of Physics, University of Toronto, 60 St. George Street, Toronto, Ontario, M5S 1A7, Canada — [2]Ruhr-University Bochum, D-44801 Bochum, Germany

We present a comprehensive theoretical framework for describing the magnetic penetration depth incorporating microscopic calculations that account for various superconducting gap symmetries. Our results underscore the pivotal influence of band structure, Fermi surface topology, and the symmetry of the superconducting order parameter. Leveraging our insights into the heavy-fermion superconductor $CeCoIn_5$, we investigate both local (London) and non-local (Pippard) responses to external magnetic fields across a range of temperatures. Our analyses in the low-temperature regime provide compelling macroscopic evidence supporting the nodal character within the superconducting state, specifically with a $d_{x^2-y^2}$ symmetry. Moreover, our findings align with the characteristics of Pippard-type superconductivity, carrying significant implications for forthcoming experimental endeavors.

TT 18.19 Mon 15:00 Poster C

High-field torque and magnetotransport in UTe_2 single crystals — •Freya Husstedt[1,2], Beat Valentin Schwarze[1,2], Jean-Pascal Brison[3], Georg Knebel[3], Motoi Kimata[4], Dai Aoki[4], Toni Helm[1], and J. Wosnitza[1] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence ct.qmat, HZDR, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Centre CEA de Grenoble, France — [4]Institute for Materials Research, Tohoku University, Japan

To date, the structure of the Fermi surfaces of the heavy-fermion superconductor UTe_2 is strongly debated [1]. We performed angle-dependent magnetic-torque and magnetotransport measurements on high-quality UTe_2 single crystals with $T_c = 2$ K. We observe quantum oscillations starting at about 15 T. The de Haas-van Alphen frequencies show very good agreement with previous reports [2, 3]. We compare our results to band-structure calculations performed with the full potential-local orbital code. The hysteretic response of magnetic torque in the superconducting phase and the transition in magnetoresistance provided further details about the anisotropic H-T phase diagram of UTe_2.

[1] D. Aoki *et al.*, J. Phys.: Condens. Matter **34**, 243002 (2022).
[2] D. Aoki *et al.*, J. Phys. Soc. Jpn. **91**, 083704 (2022).
[3] A. G. Eaton *et al.*, arXiv preprint arXiv:2302.04758 (2023).

TT 18.20 Mon 15:00 Poster C

Non-linear optical effects of superconductors: light-induced vs. dc supercurrents
— •Jakob Dolgner and Dirk Manske —
Max Planck Institute for Solid State Research, Stuttgart, Germany

It is established that the presence of supercurrent enables THz-spectroscopy Second Harmonic Generation (SHG) even in otherwise inversion symmetric superconductors which do not show this response in equilibrium [1,2]. Recently, an SHG resonance at $\Omega = 2\Delta$ was observed in Nb_3Sn in the absence of a static supercurrent and accredited to dynamical symmetry breaking [3]. On the other hand, such effects have never been observed in prior experiments [4]. We analyse the possible origins for this discrepancy in observations. In particular, we illuminate the mechanism of dynamical symmetry breaking and subsequent supercurrent generation proposed in [3].
[1] Nakamura et al., PRL 122.25 (2019)
[2] Moor et al., PRL 118.4 (2017)
[3] Yang et al., Nat. Photonics 13.10 (2019)
[4] Matsunaga et al., Science 345.6201 (2014)

TT 18.21 Mon 15:00 Poster C

Prediction of high-T_c superconductivity in ternary actinium beryllium hydrides at low pressure — •kun gao — ZGH, RUB, Bochum, Germany

Hydrogen-rich superconductors are promising candidates to achieve room-temperature superconductivity. However, the extreme pressures needed to stabilize these structures significantly limit their practical applications. An effective strategy to reduce the external pressure is to add a light element M that binds with H to form MH x units, acting as a chemical precompressor. We exemplify this idea by performing ab initio calculations of the Ac-Be-H phase diagram, proving that the metallization pressure of Ac-H binaries, for which critical temperatures as high as 200 K were predicted at 200 GPa, can be significantly reduced via beryllium incorporation. We identify three thermodynamically stable ($AcBe_2H_{10}$, $AcBeH_8$, and $AcBe_2H_{14}$) and four metastable compounds (fcc $AcBeH_8$, $AcBeH_{10}$, $AcBeH_{12}$ and $AcBe_2H_{16}$). All of them are superconductors. In particular,fcc $AcBeH_8$ remains dynamically stable down to 10 GPa, where it exhibits a superconducting-transition temperature T_c of 181 K. The Be-H bonds are responsible for the exceptional properties of these ternary compounds and allow them to remain dynamically stable close to ambient pressure. Our results suggest that high-Tc superconductivity in hydrides is achievable at low pressure and may stimulate experimental synthesis of ternary hydrides.

TT 18.22 Mon 15:00 Poster C

Collective excitations in competing phases in two and three dimensions — •Joshua Althüser and Götz Uhrig — TU Dortmund, Otto-Hahn-Str. 4, 44227 Dortmund, Deutschland

We investigate the superconducting (SC), charge-density wave (CDW), and antiferromagnetic (AFM) phases in the extended Hubbard model at zero temperature and half-filling. We employ the iterated equations of motion approach [1,2] to compute the two-particle Green's functions and by extension, the corresponding spectral densities. This renders a comprehensive analysis of the behaviour of collective excitations possible as the model's parameters are changed across phase transitions. We identify the well-known amplitude (Higgs) and phase (Leggett) modes within the superconducting phase and observe a similar excitation in the CDW phase which shift towards zero energy as the system approaches the phase transition to the SC phase. In the CDW phase, close to the phase transition to the AFM phase, we find a collective mode which does not change significantly and another modes which becomes soft as the phase boundary is approached.
[1] P.Bleicker, G.S. Uhrig, Phys. Rev. A 98, 033602 (2018)
[2] M.Kalthoff, F. Keim, H. Krull, G.S. Uhrig, Eur. Phys. J. B 90, 97 (2017)

TT 18.23 Mon 15:00 Poster C

Signatures of a pair-density wave state in the third harmonic generation. — •Pascal Derendorf[1], Peayush Choubey[2], and Ilya Eremin[1] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany — [2]Indian Institute of Technology-Roorkee, Roorkee, India

We investigate the signatures of a unidirectional pair-density wave (PDW) state in the third harmonic generation (THG) using an effective microscopic model, developed in Refs. [1,2]. The system possesses a unidirectional PDW state in thermodynamic equilibrium ground state without extra need for an additional perturbation such as external Zeeman field. We extend this model under the non-equilibrium by including a periodic driving in the form of external ac-field. The signatures of the emerging massive modes on the THG are derived via a gauge-invariant effective action approach. We discuss the similarities and differences between the PDW's s-wave and d-wave pairing channels and study the difference between the phase modes of s- and d-wave and the phase modes between the finite momentum pairings Δ_q at $q = -Q$ and $q = Q$.
[1] F. Loder et al., Phys. Rev. B 81, 020511(R) (2010)
[2] J. Wårdh and M. Granath, Phys. Rev. B 96, 224503 (2017)

TT 18.24 Mon 15:00 Poster C

UHV cleaving of superconducting Nb tips for scanning tunneling microscopy — Carolina A. Marques[1], Aleš Cahlík[1], Berk Zengin[1], Tohru Kurosawa[2], and •Fabian D. Natterer[1] — [1]Department of Physics, University of Zurich, Switzerland — [2]Department of Applied Sciences, Muroran Institute of Technology, Japan

In scanning tunneling microscopy (STM), superconducting tips have been widely used because they enhance energy resolution, allow the study of Josephson tunneling, and provide an easy way to characterize and optimize the noise and energy resolution of a low-temperature experimental setup. In this work, we revisit the cleaving of superconducting wires in UHV and describe a one-step *in-situ* procedure to produce Nb tips with a well-resolved superconducting gap. We measure the superconducting gap of the Nb tip on Au(111) to prove the quality of the tips. Using a fully gapped tip, we optimize the RF filtering of our STM and determine its base temperature. We show that after coating the Nb tip with Au, suppressing the superconducting gap, the gap can be gradually recovered by sputtering with Ar^+ ions, allowing the tuning of the gap size.

TT 18.25 Mon 15:00 Poster C

Optical Scanning Tunneling Microscopy at Low Temperature — •Pegah Farahi Shandiz[1,2], Alexina Ollier[1,3], Lei Fang[1,3], Won-jun Jang[1,3], Soonhyeong Lee[1,3], Sangwon Yoon[1,3], Minsu Seo[1,3], and Andreas Heinrich[1,2] — [1]Center for Quantum Nanoscience, Institute for Basic Science, Seoul 03760, South Korea — [2]Department of Physics, Ewha Womans University, Seoul 03760, South Korea — [3]Ewha Womans University, Seoul 03760, South Korea

Advances in fabricating atomic scale structure opened up new possibilities. One of interest is the optical properties. Recent experiments on nanomaterial shows that the optical properties vary drastically from bulk to nanoscale such as absorption, reflection, and light emission. These open up new avenues for technological advancements in various fields, such as electronics, energy, medicine, and quantum communication applications. Understanding the properties of such material at atomic scale involves the development of techniques capable of atomic resolution. The STM junction reveals itself as a solution and proves advantageous. Indeed, placing the STM tip in close proximity to a specific area on the sample allows localized optical interactions .Integrating the principles of STM and optical spectroscopy gain insights into electronic, vibrational, and even photonic properties with unprecedented precision. Here, we present a home built optical STM, engineered to conduct measurements at low temperature (1K) under UHV. The optical STM is incorporated with a homebuilt Joule-Thomson refrigerator to enhance spatial resolution, stability, and reveal quantum phenomena.

TT 18.26 Mon 15:00 Poster C

Long range triplet proximity effect in a Josephson junction with a precessing magnetization — •Miad Mansouri — Dahlem Center for Complex Quantum Systems and Physics Department, FU Berlin, Arnimallee 14, 14195 Berlin, Germany

We calculate the current phase relation for a SFS junction with a precessing magnetization in the quantum limit. We use scattering theory to find the bound states in such a junction, by artificially connecting an ideal lead reservoir to the junction, with the role of temperature being taken by the strength of the barrier between junction and reservoir.

TT 18.27 Mon 15:00 Poster C

Fabrication Limits and Design Rules for Fabricating Optimized In-Situ Multi-Terminal Josephson Junctions — •Justus Teller[1,3,4], Christian Schäfer[1,3,4], Gerrit Behner[1,3,4], Abdur Rehman Jalil[2,3], Benjamin Bennemann[2,3], Peter Schüffelgen[1,3], Detlev Grützmacher[1,3,4], and Thomas Schäpers[1,3,4] — [1]Peter Grünberg Institute (PGI-9): Institute of Semiconductor Nanoelectronics, Forschungszentrum Jülich, Jülich, 52425, Germany — [2]Peter Grünberg Institute (PGI-10): Institute of Energy-efficient Information Technology, Forschungszentrum Jülich, Jülich, 52425, Germany — [3]Jülich Aachen Research Alliance, Jülich, 52425, Germany — [4]RWTH Aachen University, Aachen, 52074, Germany

In connection with topological insulator, multi-terminal Josephson junctions offer a promising platform for topological quantum computation. In-situ stencil lithography is a well-established technique for fabricating molecular-beam-epitaxy-grown high-transparency Josephson junctions. However, there is still a lack of knowledge about design limits and the corresponding reliability of the used stencil masks. This work describes the fabrication of in-situ Josephson junctions in detail and shows data of more than a thousand stencil masks from two chips examined under scanning electron microscope. The stencil masks are optimized for two-, three-, and four-terminal Josephson junctions. Design rules for fabricating reliable stencil masks are explained. Deviations between design and realized structure are discussed. The mask reliability is computer simulated by using the finite element method.

TT 18.28 Mon 15:00 Poster C

Current phase relation of HgTe nanowire Josephson junctions in an axial magnetic field — •Niklas Hüttner, Wolfgang Himmler, Ralf Fischer, Dmitriy Kozlov, Dieter Weiss, and Christoph Strunk — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

The band structure of Topological surface states hosted by 3D Topological insulators such as HgTe can be tuned to a Dirac shape. For this a magnetic field ($B_{\|}$) is applied axial to HgTe nanowire structures[1]. Using such nano wires as weak links in a Josephson junction allows to tune between trivial and topological supercurrents[2]. We directly probe the current phase relation (CPR) of a such a device with the asymmetric SQUID method. The nanowire junction is in the short junction regime[2] and features a strongly anharmonic CPR that can be described by the generalized Kulik-Omelyanchuk theory[3]. At $B_{\|} = 0$ a high transparency of $\bar{D} \approx 0.95$, an induced gap $\Delta^* \approx 0.15\,\mathrm{meV}$, and an approximate number of channels $n \approx 9\,\mathrm{to}\,10$ is evaluated[3]. Varying $B_{\|}$ controls the magnetic flux Φ enclosed by the topological surface state. Even for $|\Phi| \ll \Phi_0$ the φ_0 shift can be adjusted between $\pm\pi$. In the range $0 - 1.5\,\Phi_0$ we observe a strong modulation of both the critical current and the content of higher harmonics. — The HgTe material was kindly provided by Nikolay N. Mikhailov and Sergey A. Dvoretsky, Novosibirsk.

[1] A. Cook *et al.*, Phys. Rev. B **84**, 201105 (2011)
[2] R. Fischer *et al.*, Phys. Rev. Res. **4**, 013087 (2022)
[3] A. A. Golubov *et al.*, Rev. Mod. Phys. **76**, 411 (2004)

TT 18.29 Mon 15:00 Poster C

Superconducting Diode Effect in Josephson Junction with Altermagnet — •Osamu Kanehira[1], Yusuke Masaki[1], and Hiroaki Matsueda[1,2] — [1]Department of Applied Physics, Tohoku University, Sendai, Japan. — [2]Center for Science and Innovation in Spintronics, Tohoku University, Sendai, Japan.

Superconducting diode effects (SDEs) refer to a non-reciprocity in a critical current of superconductors (SCs). Since diodes are key building blocks for electronic devices, the SDE can be applied to superconducting electronic devices like quantum computers. However, in many experimental reports, the SDEs require a magnetic field or a magnetization of ferromagnets (FMs), although the magnetic field can have a bad effect on the superconducting devices.

To avoid this problem, we focus on an altermagnet (AM), which has no net magnetization like an antiferromagnet but has a spin-split band structure like the FM due to its crystal structure. In addition, SC/AM junctions show transport properties like those of SC/FM junctions, and thus the SC/AM junctions are expected to exhibit the field-free SDE without the magnetization and a stray field.

In this study, we theoretically investigate the SDE in an SC/AM/SC planar Josephson junction with Rashba SOC by the numerical calculation of the Josephson current. In the poster presentation, we will compare the results of the SC/AM/SC junction with those of the SC/FM/SC junction and discuss the advantages and disadvantages of the SC/AM/SC junction.

TT 18.30 Mon 15:00 Poster C

On-off switch and sign change for a nonlocal Josephson diode in spin-valve Andreev molecules — •Erik Wegner Hodt and Jacob Linder — Department of Physics, Center for Quantum Spintronics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

Andreev molecules consist of two coherently coupled Josephson junctions and permit nonlocal control over supercurrents. By making the barriers magnetic and thus creating a spin valve, we predict that a nonlocal Josephson diode effect occurs that is switchable via the magnetic configuration of the barriers. The diode effect is turned on, off, or changes its sign depending on whether the spin valve is in a parallel, normal, or antiparallel configuration. These results offer a way to exert complete control over a nonlocal Josephson diode effect via the spin degree of freedom.

TT 18.31 Mon 15:00 Poster C

YBCO Josephson junction arrays and resistors made by focused Helium ion beam irradiation — •Moritz Meichsner, Christoph Schmid, Dieter Koelle, Edward Goldobin, and Reinhold Kleiner — Physikalisches Institut, Center for Quantum Science and LISA+, Universität Tübingen, Germany

We use focused-helium-ion-beam (He-FIB) irradiation to "write" different devices in epitaxially grown $YBa_2Cu_3O_7$ thin films. The He-FIB irradiation changes the local properties of the YBCO film on the nanoscale – in particular, it can produce locally normal conducting or even insulating regions in the YBCO film. For example, by scanning with the He-FIB along a single line across a lithographically prepatterned YBCO microbridge, we can produce Josephson Junctions [1]. When irradiating a larger area, we can fabricate resistors with Ohmic behavior that can be used in resonant circuits or as load resistors. Moreover, by writing several junctions next to each other one can realize Josephson junction arrays. In this work, the interaction of Josephson junctions in such arrays is investigated. To achieve better coupling between the junctions, a He-FIB resistor was fabricated in parallel to the array. Biasing this circuit by a dc current results in an additional ac current through the array, provoking junction synchronization.

[1] B. Müller et al., Phys. Rev. Applied **11**, 044082 (2019).

TT 18.32 Mon 15:00 Poster C

$YBa_2Cu_3O_7$ constriction-type Josephson junctions with integrated shunt resistors fabricated by focused-helium-ion-beam irradiation. — •Christoph Schmid[1], Moritz Meichsner[1], Dominik Hanisch[2], Max Pröpper[2], Meinhard Schilling[2], Edward Goldobin[1], Dieter Koelle[1], and Reinhold Kleiner[1] — [1]Physikalisches Institut, Center for Quantum Science and LISA$^+$, Universität Tübingen — [2]Institut für Elektrische Messtechnik und Grundlagen der Elektrotechnik, Technische Universität Braunschweig

We report on the investigation of $YBa_2Cu_3O_7$ (YBCO) Josephson junctions (JJs) fabricated by irradiation with a focused helium ion beam (He-FIB). With this method one can locally modify YBCO thin films, to write insulating or normal conducting regions, including Josephson barriers, depending on the He-FIB irradiation dose D. We investigated the electric properties of YBCO areas with typical lateral size of $30 \times 2000\,\mathrm{nm}^2$, irradiated with $D \sim 40\,\mathrm{ions/nm}^2$. Such a dose preserves the YBCO crystal structure but supresses the critical temperature T_c completely. Thus, such areas can be used as shunt resistors with dose-dependent resistivity and ohmic $I-V$ characteristics (IVCs). Moreover, we created constriction-type JJs (cJJs) between resistive areas. By constricting the cJJ width down to 6 nm, we observe resistively-shunted-junction (RSJ) like IVCs with small excess currents and characteristic voltages of 3 – 60 mV, making such JJs interesting for high-frequency applications. Our fabrication method opens a way to fabricate nano-circuits with integrated nm-sized cJJs and resistors/resistive areas during a single He-FIB irradiation process.

TT 18.33 Mon 15:00 Poster C

Antenna Structures for YBCO Josephson Junction Arrays — •Max Pröpper[1], Dominik Hanisch[1], Christoph Schmid[2], Paul Julius Ritter[1], Marius Neumann[1], Julius Mumme[1], Edward Goldobin[2], Dieter Koelle[2], Reinhold Kleiner[2], Meinhard Schilling[1], and Benedikt Hampel[1] — [1]Institut für Elektrische Messtechnik und Grundlagen der Elektrotechnik, Technische Universität Braunschweig, 38106 Braunschweig, Germany — [2]Physikalisches Institut, Center for Quantum Science and LISA+, Universität Tübingen, Germany

High-temperature superconductors like yttrium barium copper oxide (YBCO) are promising candidates for a voltage standard working at liquid nitrogen temperatures. Their ability to function at THz frequencies is advantageous, as this significantly reduces the number of Josephson junctions (JJs) needed for an array with comparable voltage output. To achieve this, JJs with low parameter variation are necessary. A promising method for fabricating consistent JJs is the use of a helium focused ion beam (He-FIB). In this work, we present JJ arrays made from YBCO based on a direct writing He-FIB process. The arrays are positioned directly at the feed point of various antenna structures, aiming to optimize the coupling efficiency of radiation to the JJs. A DC characterization of the JJs was performed. Furthermore, the JJ arrays were irradiated with frequencies up to the THz regime using a far-infrared laser system. The I-V characteristics of the JJs are analyzed and resulting output voltages characterized. Finally, the results are compared to simulations performed with CST Studio.

TT 18.34 Mon 15:00 Poster C

YBCO heterostructures for SQUID-on-lever — Katja Wurster[1], •Simon Koch[1], Varun Harbola[2], Yu-Jung Wu[2], Reinhold Kleiner[1], Jochen Mannhart[2], and Dieter Koelle[1] — [1]Physikalisches Institut, Center for Quantum Science (CSQ) and LISA+, Universität Tübingen, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany

Scanning SQUID microscopy (SSM) is a powerful technique for imaging magnetic fields or dissipation processes. The use of the high-T_c cuprate superconductor $YBa_2Cu_3O_7$ (YBCO) combined with custom made Si AFM Cantilevers could enable SSM in the Tesla range and at temperatures up to about 80 K with a high spatial resolution. However, YBCO has a complex crystal structure and a small coherence length, which leads to a high sensitivity to defects on the atomic scale. High quality YBCO films can only be obtained by epitaxial growth on lattice-matched substrates. Therefore, the challenge with this approch is the integration of YBCO thin films on Si wafers. We intend to use $Sr_3Al_2O_6$ (SAO) or $Sr_2CaAl_2O_6$ (SCAO), which are lattice-matched to perovskite materials, such as $SrTiO_3$ (STO). SAO and SCAO can be dissolved in water, i.e. it can be used as a sacrificial layer for the realisation of free-standing single-crystalline perovskite thin films, including YBCO. We present our process for the fabrication of YBCO heterostructures based on pulsed laser deposition (PLD) and discuss the optimization of growth conditions and properties of the used materials. Finally, we present our preliminary attempts to transfer YBCO films onto Si surfaces.

TT 18.35 Mon 15:00 Poster C

Machine Learning assisted Quantum Error Correction on the Rotated Surface Code — •Theo Haas, Kai Meinerz, and Simon Trebst — Theoretical Physics, University of Cologne, Germany

In going beyond the current era of noisy intermediate-scale quantum (NISQ) processors, quantum error correction will be an indispensable tool to reach fault-tolerant quantum computing. However, the originally developed class of combinatorial decoders, such as minimum-weight perfect matching (MWPM) and union find, exhibit scaling behavior that will not allow to decode $O(10^5 - 10^6)$ qubits within one clock cycle. Here we discuss refinements to a recently suggested multi-level decoder that combines machine learning and combinatorial decoder in a hierarchical manner. Simulating this 2-stage decoding for the rotated surface code of varying instances, we show that (i) we can efficiently decode $O(10^6)$ qubits, while (ii) pushing the error threshold beyond the reach of conventional decoders. We further explore the potential of multi-level machine-learning decoders and their Implementation on FPGA platforms. their Implementation on FPGA platforms.

TT 18.36 Mon 15:00 Poster C

Topological quantum phase transitions of toric code states under weak measurement — •Finn Eckstein, Guo-Yi Zhu, and Simon Trebst — Institute for Theoretical Physics, University of Cologne, Germany

The toric code is a paradigmatic model for topological order and robust quantum memory that has been seminal in the conceptualisation of fault-tolerant quantum computation. But while toric code states are stable to Pauli noise and exhibit a finite error threshold, they are inherently unstable when the syndrome measurements are infinitesimally tuned away from a strong (projective) measurement to weak measurements. Here we expand on this long-known observation and investigate toric code states when introducing weak measurements of individual qubits. We analytically demonstrate that, for varying the measurement angle on the Bloch sphere, the quantum problem can be exactly mapped to a classical Ashkin-Teller model subject to non-Hermitian random bond couplings (which originate from the anyon statistics of the toric code). By combining state-of-the-art hybrid tensor network / Monte Carlo numerical simulations we chart out the entanglement phase diagram and its topological quantum phase transitions.

TT 18.37 Mon 15:00 Poster C

Stability of Nishimori cat states and non-equilibrium entanglement transitions — •Malte Pütz, Guo-Yi Zhu, and Simon Trebst — Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Cologne, Germany

Shallow quantum circuits that combine unitary gates with non-unitary measurements, so-called monitored quantum circuits, can create long-range entanglement (LRE) in O(1) steps - substantially faster than local unitary circuits, where entanglement creation is bounded by an information lightcone (Lieb-Robinson bounds). An open question is the stability of such engineered LRE when the circuit itself exhibits imperfections (such as incomplete gate operations or shifted measurements). Here we build on recent work from our group discuss the preparation of 'Nishimori cat' states, which exhibit a robustness to such imperfections, and explore extensions to imperfect lattice geometries (interpolating between one and two spatial dimensions) and Gaussian coherent noise. We characterize the post-measurement quantum wavefunction by various entanglement quantities and show exotic quantum criticality induced by the inclusion of such circuit imperfections. Our work employs state-of-the-art numerical simulation techniques, including hybrid Monte Carlo / tensor network calculations.

TT 18.38 Mon 15:00 Poster C

Many-body effects in microwave-driven gates for transmon qubits — •Christoph Berke and Simon Trebst — Institut für theoretische Physik, Universität zu Köln

Transmon qubits arise from the quantization of nonlinear resonators systems that are prone to the buildup of strong, possibly even chaotic, fluctuations. One may wonder to what extent fast gate operations, which involve the transient population of states outside the computational subspace, can be affected by such instabilities. We here consider the eigenphases and -states of the time evolution operators describing a universal gate set, and analyze them by methodology otherwise applied in the context of many-body physics. Specifically, we discuss their spectral statistic, the distribution of time dependent level curvatures, and state occupations in- and outside the computational subspace.

TT 18.39 Mon 15:00 Poster C

Interaction of Josephson Photonics Devices with Quantum pulses — •Hanna Zeller[1], Lukas Danner[1,2], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Josephson photonics devices have predominantly been used to create microwave radiation in a process where a Cooper pair tunneling across a dc-biased Josephson junction creates photonic excitations in a microwave cavity connected in series. In turn, there are also situations where incoming photons are required to enable the Cooper pair transfer. In fact, this scenario has been investigated as a technology for amplifiers or single (microwave-) photon detectors [1].

To study such processes we use a recently developed formalism which can describe the incidence of generic traveling pulses of quantized radiation onto a quantum device [2,3]. In- and outgoing signals are modeled by auxiliary cavities coupled in a cascaded manner to the quantum device where the pulse shape is associated with a time dependent loss rate while the full quantum state of the corresponding mode is encoded in the auxiliary cavities. Here, we present first results demonstrating that the resulting cascaded master equation is optimally suited to study the operation of Josephson photonics devices as detectors.

[1] R. Albertet al., accepted by Phys. Rev. X, arXiv:2303.03173.
[2] A. H. Kiilerich et al., Phys. Rev. Lett. **123**, 123604 (2019).
[3] A. H. Kiilerich et al., Phys. Rev. A **102**, 023717 (2020).

TT 18.40 Mon 15:00 Poster C

Investigation of multi-qubit architecture based on supercon-

ducting quarton qubits — •Hossam Tohamy[1], Alex Kreuzer[1], Alexandru Ionita[1], Thilo Krumrey[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie (KIT) — [2]Institut für Quantenmaterialien und -technologien (IQMT), Karlsruher Institut für Technologie (KIT)

In the pursuit of optimizing superconducting qubits, significant attention has been directed toward exploring the transmon-type multi-qubits architecture. A recent addition to qubit designs, the quarton, represents a flux qubit characterized by a quartic potential. This novel design offers a substantial positive anharmonicity, with a magnitude of three to five larger than that of the transmon qubit. This enhanced anharmonicity enables faster and higher fidelity gate operations. Here, we construct quarton qubits utilizing a gradiometric architecture, employing vertically stacked junctions. We present comprehensive spectroscopy and time domain measurements conducted on these qubits, and compare the experimental results with theoretical models. This work is aimed at realizing a multiqubit architecture based on quarton qubits.

TT 18.41 Mon 15:00 Poster C

Spin Transport Simulation using Quartic Flux Qubits — •Thilo Krumrey[1], Alex Kreuzer[1], Hossam Tohamy[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institu für Technologie, 76131 Karlsruhe, Germany — [2]IQMT, Karlsruher Institu für Technologie, 76131 Karlsruhe, Germany

With the advent of the modern quantum technologies, the demand for precise measurement and control remains still a challenge, especially for large and noisy systems. On the other hand, the ability to control the state of individual or few qubits also offers new possibilities to explore entanglement and interference. For instance, the quantum version of the Wheatstone resistance bridge [1] could allow for comparative measurements of coupling energy scales using the interference of spin currents.

We propose an implementation of such a quantum measurement approach, by employing superconducting quantum circuits. In particular, we use flux qubits in which the loop and junction inductance are tailored to be equal resulting in a *quartic* potential with a large positive anharmonicity [2]. This enables us to develop a specialised integrated circuit with the required topology. The multi-qubit and multi-resonator arrangement is designed to be flexible due to the flux tuneability of the qubits and avoiding frequency crowding. We will present design considerations, simulation data as well as first fabrication and measurement results.

[1] K. Poulsen *et al.*, PRL **128**, 240401 (2022)
[2] F. Yan *et al.*, arXiv:2006.04130v1

TT 18.42 Mon 15:00 Poster C

A mm-wave platform for superconducting qubits — •Urs Strobel[1], Jakob Lenschen[1], Jürgen Lisenfeld[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Institut für Quanten Materialien und Technologien (IQMT), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany

Superconducting quantum circuits which are operating at frequencies one order of magnitude larger than those demonstrated until now, e.g. at a frequency of about 100 GHz, would offer numerous new possibilities. Due to the increased qubit energy level separation, such qubits could be operated at temperatures much higher than their present counterparts, qubit logic gates can be performed faster and circuit components reduced in size thus allowing for a smaller footprint, denser packaging and better integration. These potential advantages face many challenges and pose intriguing physics questions.

We are developing a versatile experimental platform for the low temperature investigation of mm-wave resonators and qubits. This includes the mm-wave cryogenic wiring, sample holders and thin film process technology for the superconducting qubits. We explore several suitable superconducting thin film materials, which we study for a better comparison with conventional materials also at microwave frequencies.

TT 18.43 Mon 15:00 Poster C

Quantum Coherence of Josephson Vortices in High Impedance Long Junctions — •Julian Feiler[1], Micha Wildermuth[1], Jan Nicolas Voss[1], Maximilian Kristen[1,2], Mikhail V. Fistul[3], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [3]Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany

The physics of Josephson vortices in long junctions spans from nonlinear soliton dynamics with relativistic effects to the interesting applications of coherent microwave generation. In the majority of the past experiments, the vortices are modelled as classical particles and only a small subset showed signatures of a quantum behaviour. The main reason originates in the low impedance electromagnetic environment of the vortices which was set by the geometry of the electrodes. With the advent of high kinetic inductance electrode materials, such as granular aluminium, this constraint is relaxed and Josephson vortices behaving as quantum particles are now within reach.

In the presented experiment, we employ a coupled long Josephson junction-resonator system and characterise it at milli-Kelvin temperatures. We show spectroscopic data with magnetic fields applied inplane and, to tune out residual z-components, also perpendicular to the plane of the junction. We observe indications of quantum two-level systems and present associated coherence and relaxation times.

TT 18.44 Mon 15:00 Poster C

Waveguide QED with photon-photon interaction — •Adrian Paul Misselwitz[1,2,3] and Peter Rabl[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

In quantum optics and solid state systems, light-matter interactions are usually studied under the premise, that the quantized electromagnetic field is represented by a set of independent harmonic oscillator modes. In this work we go beyond this assumption and consider the coupling of real or artificial two-level atoms to photonic waveguides in the presence of strong photon-photon interactions. Specifically, we consider superconducting qubits that are coupled to 1D and 2D arrays of coupled microwave resonators, where the presence of Josephson nonlinearities gives rise to strong interactions between the propagating photons. We investigate the few-excitation spectra of this systems and show how the interplay between atom-photon and photon-photon interactions gives rise to different classes of multi-photon bound states. Finally, we discuss how the presence of photon-photon interactions changes the photon-mediated interactions between the atoms and results in unconventional dipole-dipole interactions, which are absent in linear electromagnetic environments.

TT 18.45 Mon 15:00 Poster C

Design and fabrication of Niobium-trilayer based Dimer Josephson Junction Array Amplifier — •Bhoomika R Bhat, Asen L Georgiev, Fabian Kaap, Victor Gaydamachenko, Christoph Kissling, Judith Felgner, Mark Bieler, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Quantum computation and other applications utilizing microwave signals at powers of a few fW benefit from amplification with the smallest possible noise added. Josephson parametric amplifiers are a well-established class of devices that can meet this condition. We design a Niobium-trilayer-based Dimer Josephson Junction Array Amplifier (DJJAA) [1], a standing wave parametric amplifier, which has several pairs of modes so called dimers, in the 4 to 8 GHz range. In principle, each of these dimers can be used to achieve nondegenerate amplification using the four-wave mixing mechanism. Our device, consisting of arrays with 800-1200 dc-SQUIDs is fabricated in Nb/Al-AlO$_x$/Nb trilayer technology. We present our design flow, which employs finite element simulations and the fabrication process.

[1] P. Winkel et al., Phys. Rev. Applied 13, 024015 (2020).

TT 18.46 Mon 15:00 Poster C

Recent insights into the low frequency excess flux noise in superconducting quantum devices — •Anna Ferring-Siebert[1], Fabian Kaap[2], David Mazibrada[1], Lukas Münch[1], Andreas Fleischmann[1], Christian Enss[1], and Sebastian Kempf[3,4,1] — [1]KIP, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany. — [2]currently at PTB, Bundesallee 100, 38116 Braunschweig, Germany. — [3]IMS, KIT, Hertzstraße 16, 76187 Karlsruhe, Germany. — [4]IPE, KIT, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany.

In many applications low frequency excess flux noise (EFN), with a frequency dependence of $1/f^{\alpha}$, limits the performance of superconducting quantum devices such as SQUIDs and Qubits. Although it was long believed that its magnitude expressed in units of magnetic flux $S_{\Phi}(1\,\mathrm{Hz})$ and exponent α are fairly independent of the device material and inductance, there meanwhile exist hints for the contrary. It is also known that EFN can depend on the equipment used for device fabrication, the reason for that however remained unknown up to now.

In this contribution, we discuss origins of fabrication induced EFN and means to minimize it. We show that material layers deposited with commercial deposition equipment can contain magnetic impurities causing EFN. We also present how we have modified commercial sputtering sources to reduce EFN. Finally, measurements investigating the dependence of EFN on device inductance and material choice are discussed.

TT 18.47 Mon 15:00 Poster C

Hybrid Qubits in Kitaev Chains — •Tobias Kuhn, Raffael L. Klees, and Mónica Benito — Universität Augsburg

The goal of this project is to investigate superconducting quantum dot arrays integrated with superconducting circuits as possible platforms for hybrid qubits. Under the appropriate magnetic fields, the effective mechanism of superconducting pairing along such arrays was predicted to be a spinless p-wave type, leading to the realization of a Kitaev chain with Majorana zero modes. When two such chains are embedded in a transmon circuit, hybrid qubits are formed [2] that could harness the controllability of transmon qubits and the topological protection of Majorana modes. In particular, we derive an effective low-energy Hamiltonian of the minimal Kitaev model [3], study extensions to longer chains as well as embeddings into circuit QED architectures [4]. As a future goal, the ability to perform single-qubit operations will be a first step towards quantum computing in such hybrid devices [5,6].

[1] A. Y. Kitaev, Phys.-Usp. **44**, 131 (2001)
[2] D. M. Pino, R. S. Souto, R. Aguado, arXiv:2309.12313 (2023)
[3] M. Leijnse and K. Flensberg, Phys. Rev. B **86**, 134528 (2012)
[4] A. Blais, A. L. Grimsmo, S. M. Girvin, and A. Wallraff, Rev. Mod. Phys. **93**, 025005 (2021)
[5] A. Bargerbos *et al.*, Phys. Rev. Lett. 131, 097001 (2023)
[6] M. Geier *et al.*, arXiv:2307.05678 (2023)

TT 18.48 Mon 15:00 Poster C

Dc-SQUIDs with distributed lossy lines to damp LC resonances — •Lukas Münch, Anna Ferring-Siebert, Daniel Hengstler, Sebastian Hilscher, Nicolas Kahne, Fabian Krämer, David Mazibrada, Alexander Stoll, Andreas Fleischmann, and Christian Enss — KIP, Heidelberg University

SQUIDs are sensitive superconducting magnetic flux to voltage converters, whose operation is based on the Josephson effect. In particular at mK temperatures this sensitivity can be degraded by LC-resonances in inductances and capacitances of different structures of the SQUID design. To damp the resonances and reduce their influence on the SQUID characteristics, lumped-element resistors are commonly placed into the SQUID circuitry, which need precise simulations to determine the appropriate resistance values and positions.

In this contribution we show results for a dc-SQUID with a new damping strategy, using lossy lines for the input coil and the feed lines. For the input coil we use a thin gold layer which is fabricated in a bilayer process underneath the superconducting coil. For the parallel pair feed lines, on the other hand, we damp inductively through large areas of gold on top which are galvanically decoupled by an insulating layer. We compare the different damping schemes regarding the resonance features in their SQUID characteristics and noise contributions. For future designs we also plan tests with SQUID-washers made of lossy lines.

TT 18.49 Mon 15:00 Poster C

Optimisation Of Cross-Type Josephson Tunnel Junction Based dc-SQUIDs — •A. Stoll[1], F. Bauer[2,1], L. Münch[1], D. Hengstler[1], A. Ferring-Siebert[1], N. Kahne[1], D. Mazibrada[1], A. Reifenberger[1], A. Fleischmann[1], S. Kempf[2,3,1], and C. Enss[1] — [1]KIP, Heidelberg University — [2]IMS, Karlsruhe Institute of Technology — [3]IPE, Karlsruhe Institute of Technology

Superconducting Quantum Interference Devices (SQUIDs) are among the most sensitive wideband detectors for magnetic flux today. Based on the Josephson effect, they are able to convert small magnetic flux changes into a measurable voltage signal. For this study, microfabricated Josephson tunnel junctions (JJs) make up the basic elements of the SQUIDs. Very often window-type JJs are used due to their reliable wafer-scale fabrication process. The JJ area in the window-type geometry is defined by openings in an insulating layer and is thus limited in its size by the alignment accuracy. To circumvent this, the cross-type geometry was introduced in which the JJ area is defined by the overlap area of two crossing stripes. The transition to cross-type JJs is motivated by reducing the junction area as well as parasitic capacitances. This will in turn relax parasitic effects, e.g. LC-resonances, as well as improve the energy resolution $\epsilon \propto \sqrt{LC}$ of dc-SQUIDs.

We present the characteristic properties, performance and noise spectra of different design variants of dc-SQUIDS based on cross-type JJs. These results showcase the potential of moving even closer to the quantum limit by utilising the cross-type geometry.

TT 18.50 Mon 15:00 Poster C

A dc-SQUID flux ramp modulation multiplexer in 4x32 configuration — •D. Mazibrada[1], A. Abeln[1], A. Ferring-Siebert[1], N. Kahne[1], D. Hengstler[1], L. Hoibl[1], L. Münch[1], D. Richter[1], A. Stoll[1], T. Wolber[3], T. Muscheid[3], N. Karcher[3], M. Weber[3], O. Sander[3], A. Fleischmann[1], L. Gastaldo[1], S. Kempf[2,3,1], and C. Enss[1] — [1]KIP, Heidelberg University, Germany. — [2]IMS, Karlsruhe Institute of Technology, Germany. — [3]IPE, Karlsruhe Institute of Technology, Germany.

Superconducting quantum interference devices (SQUIDs) are flux-to-voltage converters with high sensitivity which offer a large bandwidth. With the flux ramp modulation (FRM) multiplexing technique it is possible to read out several dc-SQUIDs through a single line.

In this contribution we discuss our first FRM dc-SQUID multiplexer to read out a 16x16 metallic magnetic calorimeter array. It relaxes the hardware requirements of a SQUID system and allows a linearized readout while achieving a large dynamic range. We installed 16 individual SQUID chips containing 2 arrays, each combining 4 dc-SQUIDs connected in series. The SQUIDs operate in open-loop mode, where each SQUID in an array is provided with a different flux ramp signal while we measure the voltage across an entire array. The flux ramp modulation signals are shared by all 32 arrays, so the entire setup acts as a 4x32 configuration. This reduces the number of wires by almost a factor of 8 compared to a brute force parallel SQUID readout of the detector. This approach allows a cost-effective, simultaneous readout with adequate energy resolution.

TT 18.51 Mon 15:00 Poster C

Comparative Analysis of Aluminium- and Niobium-based Josephson Parametric Amplifiers — •Felix Henrich[1], Alexander Stoll[1], Federica Mantegazzini[2], Felix Ahrens[2], Claudio Gatti[3], Andreas Fleischmann[1], Loredana Gastaldo[1], and Christian Enss[1] — [1]Kirchhoff-Institute of Physics, Heidelberg University, Germany — [2]Fondazione Bruno Kessler, Trento, Italy — [3]Laboratori Nazionali di Frascati, Frascati, Italy

Josephson Parametric Amplifiers (JPAs) are devices used to amplify ultralow-power microwave signals. Their capability to operate at or even surpass the Standard Quantum Limit (SQL) with high gain enables unprecedented possibilities in quantum information processing and detector readout.

We present the characterization of flux-driven JPA designs consisting of a Superconducting QUantum Interference Device (SQUID), based on crosstype Josephson tunnel Junctions (JJs), combined with a superconducting coplanar waveguide resonator. The JPAs were fabricated using either Nb or Al as the superconductor. The aluminium versions feature a $Al\backslash Al_2O_3\backslash Al$ tri-layer, while the niobium counterparts employ a $Nb\backslash Al\backslash Al_2O_3\backslash Nb$ tri-layer, facilitated by the planarization of the tri-layer in sputtered SiO_2 to avoid electrical shorts at the side wall of the JJs.

We compare the key parameters obtained from the Nb-based JPAs and Al-based JPAs and discuss our observations.

TT 18.52 Mon 15:00 Poster C

Identification of Noise Sources in Superconducting Microstructures — •M. Renger, D. Hengstler, M. Herbst, F. Kaiser, D. Mazibrada, L. Münch, A. Reifenberger, C. Ständer, R. Yang, A. Fleischmann, L. Gastaldo, and C. Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Improving the performance of a superconducting device often means identifying and eliminating noise. Many potential noise sources are independent of the specific experimental set-up and transferable across many device categories such as qubits, SQUIDs, and superconducting detectors. We have constructed a stand-alone device able to representably probe specific noise sources. The set-up consists of a Wheatstone-like bridge of microfabricated superconducting inductors and a pair of two-stage dc-SQUID read-out chains. Cross-correlation removes noise contributions from the read-out electronics giving us the sum total of all noise in the superconducting circuit. If, in comparison, the Wheatstone bridge is AC-driven, we can measure a sample material's magnetic noise via the material's complex AC susceptibility using the fluctuation-dissipation theorem. The experiment is performed at temperatures between $T = 10\,\mathrm{mK}$ and $1000\,\mathrm{mK}$ in the frequency range from $f = 100\,\mathrm{mHz}$ to $100\,\mathrm{kHz}$ on an experimental holder with excellent thermal coupling and shielding. We present new measurements of SiO_2 and Ag:Er thin films and an macroscopic sample of $YbRh_2Si_2$, conducted with new versions of our device with increased symmetry and coupling.

TT 18.53 Mon 15:00 Poster C

Broadband ESR spectroscopy of $Er:Y_2SiO_5$ at mK temperatures — •Jianpeng Chen[1,2], Georg Mair[1,2], Ana Strinic[1,2,3], Chiun Fu[1,2], Achim Marx[1,2], Kirill Fedorov[1,2,3], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Technical University of Munich, School of Natural Sciences, Garching,Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

Crystals doped with rare-earth ions are promising for the implementation of quantum memories, which are frequency-compatible with superconducting quantum circuits operated in the microwave regime. Erbium-167 is an ideal candidate for a microwave-addressed quantum memory since it exhibits ZEro First-Order Zeeman (ZEFOZ) transitions at low magnetic fields [1], Here, we present broadband ESR spectroscopy data [2] of $Er:Y_2SiO_5$ measured at millikelvin temperatures. With a goal to identify the optimal transitions for coherent microwave storage. Our results show that $Er:Y_2SiO_5$ is promising for encoding quantum information for longer times within ZEFOZ states at microwave frequencies.

[1] A. Ortu et al., Nat. Mater 17, 671 (2018)
[2] A. Strinic et al., DPG Spring Meeting (2023)

TT 18.54 Mon 15:00 Poster C

Fabrication of over-coupled transmission line resonators for broadband microwave spectroscopy — •Chiun Fu[1,2], Georg Mair[1,2], Niklas Bruckmoser[1,2], Jianpeng Chen[1,2], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Technical University of Munich, School of Natural Sciences, Garching, Germany — [2]Walther-Meißner-Institute, Bavarian Academy of Sciences and Humanities, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Spin ensembles are promising for the development of developing quantum memories [1]. However, coupling the spins of rare-earth ions with narrow bandwidth microwave resonators limits their operation to a narrow frequency range. We design over-coupled resonators to reduce their quality factor and thereby expand the bandwidth available for the coupled spin-photon system. Here, we introduce the over-coupled coplanar transmission line (oCPTL) resonator having an interdigital capacitor structure between the linear taper and meandered transmission line. Increasing the coupling capacitance results in an increasing bandwidth of the resonator available for coupling to the rare-earth spin ensembles. The design of the over-coupled transmission line resonators, fabrication details, and the measurement results at cryogenic temperatures will be discussed.

[1] M. Guo, S. Liu, W. Sun et al., Front. Phys. 18, 21303 (2023)
[2] M. Göppl, A. Fragner, M. Baur et al. J. Appl. Phys. 104, 113904 (2008)

TT 18.55 Mon 15:00 Poster C

Broadband electron spin resonance spectroscopy of Er ions in $CaWO_4$ with planar waveguides — •Georg Mair[1,2], Jianpeng Chen[1,2], Ana Strinic[1,2,3], Roman Kolesov[4], Tobias Hanke[4], Michael Stanger[2], Andreas Erb[1,2], Hans Huebl[1,2,3], Kirill Fedorov[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meissner-Institute, Bavarian Academy of Sciences, Garching — [2]Technical University of Munich, School of Natural Sciences, Physics Department, Garching — [3]Munich Center for Quantum Science and Technology, Munich — [4]3rd Institute of Physics and Center of Applied Quantum Technology, University of Stuttgart, Stuttgart

Hybrid systems comprising qubits and quantum memory units have been proposed to improve processor architecture in applications of quantum computing with superconducting circuits [1]. Suitable quantum memory candidates in the microwave regime are rare-earth ions in crystal host lattices, such as Er:$CaWO_4$. Broadband ESR spectroscopy at 12 mK reveals desired ZEFOZ (Zero First-Order Zeeman) transitions at low magnetic fields, where the longest coherence times of the hyperfine spin states are expected due to their minimized sensitivity to fluctuations of external fields [2]. We present advances in the fabrication of superconducting transmission lines utilizing a planar waveguide geometry to enhance coupling of propagating microwaves to spin systems.

[1] É. Gouzien, N. Sangouard, Phys. Rev. Lett. **127**, 140503 (2021)
[2] A. Ortu et al. Nat. Mater **17**, 671 (2018)

TT 18.56 Mon 15:00 Poster C

Pyroelectricity in a Lithium Niobate Phase Modulator During Thermal Transition to and from Cryogenic Temperatures — Frederik Thiele, •Thomas Hummel, Nina A. Lange, Felix Dreher, Maximilian Protte, Felix vom Bruch, Sebastian Lengeling, Harald Herrmann, Christof Eigner, Christine Silberhorn, and Tim J. Bartley — Department of Physics & Institute for Photonic Quantum Systems, Paderborn University, Warburger Straße 100, 33098 Paderborn, Germany

Lithium niobate ($LiNbO_3$) is a promising platform for quantum optics, due to the high nonlinearity, electro-optic effect, and low loss waveguiding. Integrating superconducting nanowire single-photon detectors requires operation at cryogenic temperatures. The transition to and from cryogenic temperatures creates free charge carriers due to the pyroelectric effect. These charge carriers are distributed in the material, inducing electric fields. The electric fields affect the refractive index inside, and the electrical structures on top of the $LiNbO_3$. When the electric fields are too strong, charge carriers recombine causing a local electrical discharge. We measure the electrical discharges and changes in birefringence with a phase-modulator in bulk Z-cut $LiNbO_3$ with titanium in diffused waveguides. For this we connect a current meter across the electrodes to measure the electrical discharges, and put the phase modulator in the Sénarmont configuration to measure changes in the birefringence. Monitoring these properties during thermal transition shows correlations between electrical discharges and optical discontinuities, where the rate of events depends on the temperature.

TT 18.57 Mon 15:00 Poster C

Axial Cryogenic current comparator (CCC) for FAIR — •Lorenzo Crescimbeni[1,2], David Haider[2], Thomas Sieber[2], Frank Schmidl[1], Thomas Stöhlker[1,2,4], Ronny Stolz[3], Volker Tympel[4,2], and Vvyacheslav Zakosarenko[3,5] — [1]Friedrich-Schiller-University Jena, Germany — [2]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany — [3]Leibniz Institute of Photonic Technology (Leibniz IPHT), Jena, Germany — [4]Helmholtz-Institute Jena, Germany — [5]Supracon AG, Jena, Germany

The Cryogenic Current Comparator (CCC) is a superconducting device based on an ultrasensitive SQUID magnetometer (fT range). Measuring the beam's azimuthal magnetic field, it provides a calibrated non-destructive measurement of beam current with a resolution of 10 nA or better, independent from ion species and without tedious calibrations procedure. The non-interceptive absolute intensity measurement of weak ion beams (<1 muA) is essential in heavy ion storage rings and in transfer lines at FAIR. With standard diagnostics, this measurement is challenging for bunched beams and virtually impossible for coasting beams.

To improve the performance of the detector a new type of CCC using an alternative magnetic shield geometry has been developed. The socalled "axial" geometry will allow for much higher magnetic shielding factor, an increased pick-up area, and an expected lower noise component at low frequencies. Hereby the construction process and the results of test will be discussed, together with further improvements of the detector aimed to provide the best possible CCC version to FAIR.

TT 18.58 Mon 15:00 Poster C

Noise Thermometers for mK- and μK-Temperatures — •Leo Knapp, Pascal Willer, Christian Ständer, Nathalie Probst, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

To measure mK-temperatures is a big challenge in solid state physics labs. We developed a prototype of a cross-correlated, current sensing noise thermometer for mK-temperatures. The basic concept relies on the thermal motion of charge carriers in a bulk metal resistor. Two DC-SQUIDs detect the corresponding noise signal which is then recorded via two identical but independent amplifier chains. The method of cross correlation is used to eliminate uncorrelated noise contributions from the amplifier chains. As resistor material we use the alloy $Ag_{60}Cu_{40}$. We show that this approach towards a relative primary thermometer is able to cover the complete temperature range below 4 K. We discuss the design, the considerations that lead to it and present first experimental results down to mK temperatures.

TT 18.59 Mon 15:00 Poster C

Material Studies for Magnetic Penetration Depth Thermometers — •F. Kaiser, N. Grun, L. Münch, M. Herbst, M. Renger, D. Hengstler, A. Reifenberger, A. Fleischmann, L. Gastaldo, and C. Enss — KIP, Heidelberg University, Germany

Microcalorimeters are energy-dispersive particle detectors, well known for their applications in high-resolution X-ray spectroscopy. They are operated at mK temperatures and convert the energy of incoming photons into a temperature rise, which can be read out using a temperature-sensitive material. In current magnetic microcalorimeters paramagnetically doped normal-metals are a popular choice for the temperature sensor as they allow for precision X-ray spectroscopy, with their excellent energy resolution over a large energy range combined with a very good linearity.
This contribution discusses superconductors as a potential sensor material. In the form of magnetic penetration depth thermometers, we use the Meißner-Ochsenfeld effect to measure the temperature dependent London penetration depth of the superconducting film with a highly-sensitive SQUID magnetometer. This technology promises an even better energy resolution in exchange for a reduced dynamic range.
With a dedicated, wheatstone-like impedance bridge we measured the superconducting transitions of different superconducting materials (Ti, AlMn 2500 ppm, etc.) and investigated the impact of different sensor geometries.

TT 18.60 Mon 15:00 Poster C

Metallic Magnetic Calorimeter for the Search of Alpha Decay in Os-184 — •Nathalie Probst[1], Andreas Reifenberger[1], Fedor Danevych[2], Andreas Fleischmann[1], and Christian Enss[1] — [1]KIP, Heidelberg University, Germany — [2]Institute for Nuclear Research of NASU

Excesses of the daughter nuclide W-180 found in meteorites and terrestrial rocks claim an alpha decay for Os-184 with the half-life $\tau_{1/2} = (1.1 \pm 0.2) \cdot 10^{13}$ yr which is in contradiction with the theoretical prediction $\tau_{1/2} = (2.1 - 7.5) \cdot 10^{13}$ yr. While the half-life $\tau_{1/2} = (2.0 \pm 1.1) \cdot 10^{15}$ yr of Os-186 was directly measured in laboratory experiments, for Os-184 only a lower limit $\tau_{1/2} > 2.0 \cdot 10^{13}$ yr was determined.

In this work we aim to directly measure the half-life of Os-184 for the first time and in addition reach a substantially higher precision for the value of the half-life of Os-186. Therefore, bulk superconducting osmium is used as a particle absorber for a metallic magnetic calorimeter (MMC). Compared to germanium detectors which are commonly used for particle detection, this detector stands out with a small detector volume which reduces the background of myonic and cosmic radiation to a minimum.

With the energy resolution being in the keV-range, we will answer the question whether the alpha decay in Os-184 exists. We discuss first results including the characterization with external sources.

TT 18.61 Mon 15:00 Poster C

Towards large-area 256-pixel MMC arrays for high resolution X-ray spectroscopy — •A. Abeln, S. Allgeier, D. Hengstler, D. Kreuzberger, D. Mazibrada, L. Münch, A. Orlow, A. Reifenberger, A. Stoll, A. Fleischmann, L. Gastaldo, and C. Enss — Kirchhoff-Institute for Physics, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Metallic Magnetic Calorimeters (MMCs) are energy-dispersive cryogenic particle detectors. Operated at temperatures below 50 mK, they provide very good energy resolution, high quantum efficiency as well as high linearity over a large energy range. In many precision experiments in X-ray spectroscopy the photon flux is small, thus a large active detection area is desirable. Therefore, we develop arrays with increasing number of pixels. For a cost-effective read-out of a growing number of detector channels we investigate different multiplexing techniques.
In this contribution we present a detector setup comprising a novel dense-packed 16×16 pixel MMC array. The pixels provide a total active area of 4 mm × 4 mm and are equipped with 5 μm thick absorbers made of gold. This ensures a stopping power of at least 50 % for photon energies up to 20 keV. The expected energy resolution is $\Delta E = 1.4$ eV (FWHM) at an operating temperature of 20 mK. Furthermore the detector setup features 16 in-house made SQUID chips each with 2×4 flux-ramp modulated dc-SQUIDs which enables us to read out 128 detector channels with 32 read-out channels. We present design considerations and discuss the detector performance.

TT 18.62 Mon 15:00 Poster C

Large-area MMC-based photon detector operated at mK temperatures — •Ashish Jadhav, Christian Enss, Andreas Fleischmann, Daniel Hengstler, Andreas Reifenberger, Daniel Unger, and Loredana Gastaldo — Kirchhoff Institute for Physics, Heidelberg, Germany

We present the development of a large area, high-energy resolution photon detector based on low temperature metallic magnetic calorimeters (MMCs). The detector is to be the photon detector in a combined photon-phonon (P2) detector to be coupled to molybdate scintillating crystals in the AMoRE experiment. The final P2 detector utilises a 3-inch Si wafer. A central area, weakly coupled to the rest of the wafer is defined to detect visible photons emitted by particle interactions in the scintillating crystal. The outer part of the wafer contains three double-meander MMC detectors as phonon detectors to monitor temperature changes in the crystal resting on gold spacers. The most challenging part is the photon detector based on a stripline pickup coil design. We present the R&D on a large area silicon photon detector with stripline MMC geometry. We discuss the results obtained and the implications of the photon detector for the AMoRE experiment.

TT 18.63 Mon 15:00 Poster C

Advances in microfabrication of Metallic Magnetic Calorimeters — •Daniel Kreuzberger, Andreas Reifenberger, Andreas Abeln, Alexander Orlow, Daniel Hengstler, Andreas Fleischmann, and Christian Enss — Heidelberg University

Metallic Magnetic Calorimeters (MMCs) are low temperature particle detectors which can reliably be produced with multilayer microfabrication techniques. Moreover, the consequent use of these techniques allows for the fabrication of thousands of virtually identical detectors as required for large, dense packed arrays. Using various examples of current MMC detectors which are actively used for high resolution x-ray spectroscopy, we present the status of our microfabrication processes. This includes the fabrication of overhanging x-ray absorbers made of gold with a thickness up to 100 μm. For this, a newly developed fabrication process is presented, preventing almost all athermal phonons from escaping in the substrate without thermalization in the sensor. We also discuss copper filled Through-Silicon-Vias (TSV) used to heatsink the detector pixels to the wafer backside.

TT 18.64 Mon 15:00 Poster C

A dedicated 2-dimensional array of metallic magnetic microcalorimeters to resolve the 29.18keV doublet of ^{229}Th — •A. Striebel, A. Abeln, S. Allgeier, A. Brunold, J. Geist, D. Hengstler, D. Kreuzberger, A. Orlow, L. Gastaldo, A. Fleischmann, and C. Enss — Heidelberg University

The isotope ^{229}Th has the nuclear isomer state with the lowest presently known excitation energy, which possibly allows to connect the fields of nuclear and atomic physics with the potential application as a nuclear clock. In order to excite this very narrow transition with a laser a precise knowledge of the transition energy is needed. Recently the isomer energy (8.338 ± 0.024) eV [Kraemer et al., arXiv:2209.10276, 2022] could be precisely determined. To get valuable insights, we will improve our high-resolution measurement [Sikorsky et al., PRL 125, 2020] of the γ-spectrum following the α-decay of ^{233}U. This decay partially results in excited ^{229}Th with a nuclear state at 29.18 keV. Resolving the doublet, that in turn results from de-excitation to the ground and isomer state, respectively, would allow an independent measurement of the isomer energy as well as the branching ratio of both transitions. To resolve this doublet, a 2D detector array consisting of 8×8 metallic magnetic calorimeters (MMCs) was fabricated.

MMCs are operated at mK temperatures and convert the energy of a single incident γ-ray photon into a temperature pulse which is measured by a paramagnetic temperature sensor. We discuss the detector properties, including an energy resolution of 3.1 eV (FWHM) at 5.9 keV and present first spectra of ^{229}Th taken with this detector.

TT 18.65 Mon 15:00 Poster C

Characterization of Photoresists for DeepUV Direct Writing Lithography — •Niels Fiedler[1], Andreas Reifenberger[1], Lukas Münch[1], Alexander Stoll[1], Ludwig Hoibl[2], Andreas Fleischmann[1], and Christian Enss[1] — [1]KIP, Heidelberg University — [2]Heidelberg Instruments Mikrotechnik GmbH

Photoresists play a key role in the transfer of patterns as protective and structuring layers for the production of micro- and nanofabricated devices. Optical maskless lithographic systems have proven to be powerful and versatile tools in research and development environments, but their resolution is limited to $\approx 0.6\,\mu$m due to the photon wavelengths of the optical systems in use. In the framework of the SuperLSI project, Heidelberg Instruments is developing a maskless lithographic system featuring a 266 nm DeepUV optical system aiming for a resolution down to 200 nm in the patterned photoresist. At the same time, it is necessary to find and characterize suitable resists and compatible developers. Here we present first results on several resist systems (DuPont UV5-0.6 and UVN2300, micro resist technology ma-N 2400) that we used to realize sub-500 nm superconducting lines. We discuss the structural accuracy as well as etching and developer compatibilities with materials used in the production of superconducting electronics (Nb, Al). The significantly reduced linewidth allows us to work on improvements of quantum sensors like SQUIDs that benefit from smaller Josephson Junctions (JJs). We will present first characterization measurements of cross-type JJs with a junction area well below 1 μm^2.

TT 18.66 Mon 15:00 Poster C

Novel Susceptibility Thermometer for mK-Temperatures Based on Au:Er Micro-Fabricated on a Al_2O_3 Substrate — •Wassily Holzmann, Nathalie Probst, Andreas Fleischmann, Andreas Reifenberger, Andreas Reiser, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University

Limited options exist for thermometers at mK- and sub-mK- temperatures that combine speed, high sensitivity, and reliability. Here, we present a novel concept of a susceptibility thermometer based on the paramagnetic alloy Au:Er 2000 ppm that has the potential to meet these requirements. To ensure optimal thermal contact, the 9 μm thick Au:Er sensor sputter deposited on a copper sheet is pressed onto superconducting meander-shaped readout coils with 6 μm pitch, microfabricated on a Al_2O_3 wafer, using springs. Two such coils, filled with Au:Er, and two empty coils form a wheatstone-like bridge with the filled coils opposed. The inductance of the empty coils is chosen to balance the bridge at a specific temperature, where the thermometer can be operated as extremly sensitive zero-detector, fully independent of any overall gain drift. The coils have a combined length of 129 m, which results in an voltage signal that can be readout with room temperature electronics. For certain applications, this can serve as an individual fixed point for precise temperature stabilization. The imbalance due to the paramagnetic contribution of the Au:Er at all other temperatures is used to establish a temperature scale by calibration with another thermometer, in our case a noise thermometer. We will discuss the design, fabrication, readout, and operation.

TT 18.67 Mon 15:00 Poster C

Wafer calorimeter development for the Direct Search Experiment for Light Dark Matter with Superfluid Helium (DELight) — •Friedrich Wagner[1], Lena Hauswald[1], Michael Müller[1], Fabienne Bauer[1], and Sebastian Kempf[1,2] — [1]Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology, Germany. — [2]Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Germany.

The dark matter (DM)-nucleon scattering parameter space of Light Dark Matter (LDM) has been barely probed, as it requires an energy detection threshold as low as a few eV. The "Direct search Experiment for Light dark matter" (DELight) aims investigating this challenging parameter space by using superfluid ^{4}He as target material. Superfluid ^{4}He provides not only a low nuclear mass and a high radiopurity level, but also various signal channels for event classification. For signal detection, DELight will use energy- and time-resolving cryogenic wafer calorimeters with eV-scale energy resolution, some of which will be located above the liquid, while others will be immersed in the superfluid. The detectors will be based on magnetic microcalorimeters (MMCs) that are operated in athermal mode, i.e. the energy of an incident particle is converted into an athermal phonon population that is sensed via normal or superconducting phonon collectors heating up a paramagnetic temperature sensor that is situated in a weak magnetic field. Here, we present our most recent R&D efforts related to detector layout and fabrication technology, both ultimately paving the way towards wafer calorimeters with $O(20\,\mathrm{eV})$ energy threshold.

TT 18.68 Mon 15:00 Poster C

ELECTRON - High-resolution electron spectroscopy of a novel tritium source using next-generation microcalorimeters — •Fabienne Bauer[1], Lena Hauswald[1], Neven Kovac[2], Marie-Christin Langer[1], Michael Müller[1], Rudolf Sack[2], Beate Bornschein[2], Markus Steidl[2], Magnus Schlösser[2], Kathrin Valerius[2], and Sebastian Kempf[1] — [1]Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute for Astroparticle Physics (IAP), Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

Magnetic microcalorimeters (MMCs) are cryogenic single-particle detectors which are used for various challenging applications such as X-ray spectroscopy, mass spectrometry or radionuclide metrology. Due to their outstanding performance, they are considered as potential detector technology for a next-generation KATRIN-like neutrino mass experiment, ultimately aiming for investigating the ordering of the neutrino masses by performing a differential measurement of the tritium beta spectrum. To verify the suitability of MMCs for such an experiment, systematic effects potentially degrading the expected performance have to be investigated. Within this context, we present our project ELECTRON aiming to systematically study MMC-based electron detection. We will present our cryogenic set-up which can be used to measure external electrons from multiple different sources and discuss the results of our latest measurements. Finally, we present the status of our attempt to perform the world's first measurement of the tritium spectrum using an atomic tritium source and an MMC.

TT 18.69 Mon 15:00 Poster C

Lab::Measurement – measurement control with Perl 5 — Simon Reinhardt, Mia Schambeck, Erik Fabrizzi, and •Andreas K. Hüttel — Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany

`Lab::Measurement` is a collection of object-oriented Perl 5 modules for control of test and measurement devices. It allows for quickly setting up complex tasks with diverse hardware. Instruments can be connected via GPIB (IEEE 488.2), USB, or VXI-11 / raw network sockets on Ethernet. Internally, third-party backends as, e.g., Linux-GPIB or the NI-VISA library are used, in addition to lightweight drivers for USB and TCP/IP-based protocols. This enables cross-platform portability of measurement scripts between Linux and Windows machines. Based on roles within `Moose` that provide communication standards such as SCPI, dedicated instrument driver classes take care of internal details. A high-level sweep layer allows for fast and flexible creation of nested measurement loops, where, several input variables are varied and data is logged into a customizable folder structure. Sweeps can also be retrieved directly from an instrument as, e.g., a spectrum or network analyzer. Recent enhancements include support for the Zurich Instruments HDAWG waveform generator, the Synktek MCL1-540 lock-in, the Bluefors dilution refrigerator temperature control, the American Magnetics AMI430 magnet supply, as well as many improvements for Lakeshore temperature controllers. `Lab::Measurement` is free software and available at `https://www.labmeasurement.de/` —

[1] S. Reinhardt *et al.*, Comp. Phys. Comm. **234**, 216 (2019)

TT 18.70 Mon 15:00 Poster C

Two-stage magnetic shielding for superconducting circuits in an adiabatic demagnetization refrigerator — •Lino Visser[1], Marc Neis[2], Jéferson Guimarães[2], Markus Jerger[2], Pavel Bushev[2], Vincent Mourik[1], and Rami Barends[2] — [1]JARA-Fit Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany — [2]Peter Grünberg Institut 13 Institute for Functional Quantum Systems, Forschungszentrum Jülich GmbH, Jülich, Germany

Adiabatic demagnetization refrigeration (ADR) is a promising technology for future quantum technology applications. Cooling units for ADRs are cheap and reliable while enabling base temperatures comparable to those obtained in dilution refrigerators. A challenge are the residual magnetic fields originating from the magnet used for recharging the paramagnetic salts, as these lower the operation fidelity of superconducting circuits. Here, we present the design of a 4 Kelvin two-stage mu-metal and Niobium magnetic shield with ports for 4 RF wires, and 48 DC lines. The lowest temperature stage enters the magnetic shield through a feedthrough, and contains an additional Copper infrared shield around the sample space. Using finite element simulations, we quantify the magnetic shielding factor before manufacturing. To benchmark the ADRs shielding performance, we characterize a set of Niobium resonators, measuring their quality factor. First results indicate a competitive performance of these resonators in our customized set-up.

TT 18.71 Mon 15:00 Poster C

Cooling power on different stages of a pulse tube cryocooler depending on regenerator design — •Xaver Herrmann[1], Jack-André Schmidt[1,2], Bernd Schmidt[1,2], Jens Falter[2], and André Schirmeisen[1,2] — [1]Instiute of Applied Physics, Justus-Liebig University, Giessen, Germany — [2]TransMIT-Center for Adaptive Cryotechnology and Sensors, Giessen, Germany

Closed-cycle cryocoolers have become a reliable and important tool for low temperature scientific research[1]. Here we focus on Gifford-McMahon (GM) type pulse tube cryocoolers (PTC), which offer low maintenance and long measurement periods[2]. A critical part in cryocoolers is the regenerator. It strongly affects the temperature and cooling power achievable with a cryocooler[3, 4]. This poster will look at various regenerator fillings and associated losses, as well as the resulting cooling power achieved for a high input power system(11 kW). For comparison REGEN 3.3 simulation results will be shown.

[1] R. Güsten, et al., Nature 568 (2019) 357
[2] R. Radebaugh, J. Phys.: Condens. Matter 21 (2009) 164219
[3] J.M. Pfotenhauer, Cryocoolers 13 (2005) 463
[4] D. Abraham, IOP Conf. Ser.: Mater. Sci. Eng 1250 (2022) 012132

TT 19: Quantum Coherence (joint session TT/DY)

Time: Monday 16:15–18:00 Location: H 3025

Invited Talk TT 19.1 Mon 16:15 H 3025

Quantum thermodynamics and its statistical mechanics: Facts, debatable issues and still unsolved problems — •Peter Hänggi — 1 University of Augsburg, Dept. Physics, 86159 Augsburg, Germany

The present state of the art of this topic contains several subtleties, pitfalls, inconsistencies as well as still open issues. Those are present in both, classical and quantum settings. Even at manifest thermal equilibrium, these thermodynamic notions become surprisingly tricky when strong system-bath interactions matter. A particular intriguing difficulty comprises the notorious invasive character of quantum measurements; i.e., the role of quantum back-action. Fact is: If anything can be said at all, - it preferably should be stated most clearly (Ludwig Wittgenstein, 1889-1951).

[1] D. Castelvecchi, Nature 543 (2017) 597 ; Z. Merali, Nature 551 (2017) 20
[2] P. Hänggi and P. Talkner, Nature Physics 11 (2015) 108
[3] P. Talkner and P. Hänggi, Phys. Rev. E 93 (2016) 022131
[4] P. Talkner and P. Hänggi, Rev. Mod. Phys. 92 (2020) 041002.

TT 19.2 Mon 16:45 H 3025

Efficiency of pulsed electron spin resonance protocols for quantum state storage with phosphorus donors in silicon — •Patricia Oehrl[1,2], Nadezhda Kukharchyk[1,2,3], Kirill G. Fedorov[1,2,3], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Garching, Germany — [3]Munich Center for Quantum Science and Technologies (MCQST), Munich, Germany

The storage of quantum states is considered to be a key element for the successful realization of a multimode quantum network [1]. Solid-state spin ensembles, such as phosphorus donors in silicon, offer exceptional coherence times and resonant transitions in the GHz range [2]. Therefore, they are promising candidates for the realization of quantum memories without frequency conversion techniques. Here, we present a hybrid system consisting of a superconducting lumped-element microwave resonator coupled to a phosphorus donor electron spin ensemble hosted in isotopically engineered silicon. We use continuous-wave spectroscopy complemented by pulsed excitation and time-domain detection techniques. To this end, we operate our hybrid system at millikelvin temperatures and moderate static magnetic fields. We investigate the performance of our hybrid system with regard to quantum memory applications by analyzing the storage efficiency based on various pulse shapes and sequences.

[1] M. Pompili et al., Science 372 (2021) 6539
[2] M. Steger et al., Science 336 (2012) 1280

TT 19.3 Mon 17:00 H 3025

Characterization of hyperfine transitions of rare-earth spin ensembles via broadband ESR spectroscopy at mK temperatures — •Ana Strinic[1,2,3], Patricia Oehrl[1,2,3], Owen Huisman[4], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meissner-Institute, Bavarian Academy of Sciences and Humanities, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technologies, Munich, Germany — [4]Delft University of Technology, Delft, The Netherlands

Hybrid quantum systems consisting of a superconducting quantum processor coupled to a quantum memory (QM) offer great potential for quantum computing [1]. For interfacing the two components, a microwave (mw) QM is advantageous, since losses due to frequency transduction can be avoided. A potential platform for mw QMs are rare-earth spin ensembles, due to their hyperfine transitions in the GHz regime, which exhibit long coherence times [2]. In this work, we study the hyperfine transitions in $^{167}Er{:}^{7}LiYF_4$ using broadband microwave spectroscopy employing a coplanar waveguide. The high resolution ESR spectra obtained at 10 mK allow to quantify the parameters of the spin Hamiltonian, in particular the hyperfine and quadrupole coefficients. Moreover, this technique allows to directly address various hyperfine transitions at their zero first-order Zeeman points, which is key for the implementation of mw QM schemes.

[1] E. Gouzien, N. Sangouard, Phys. Rev. Lett. 127 (2021) 140503
[2] P.Y. Li et al., Phys. Rev. Appl. 13, 024080 (2020)

TT 19.4 Mon 17:15 H 3025

Dichroic cavity mode splitting and lifetimes from interactions with ferromagnetic metal — •Henning G. Hugdal, Eirik Jaccheri Høydalsvik, and Sol H. Jacobsen — Center for Quantum Spintronics, Department of Physics, NTNU, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

We study the effect of ferromagnetic metals (FM) on the circularly polarized modes of an electromagnetic cavity and show that broken time-reversal symmetry leads to a dichroic response of the cavity modes. In the simple model of only one spin split band, the Zeeman coupling between the FM electrons and cavity modes leads to an anticrossing for mode frequencies comparable to the spin splitting. However, this is only the case for one of the circularly polarized modes, while the other is unaffected by the FM. Hence, the cavity photons display a dichroic response to the presence of the FM, allowing for the determination of the spin-splitting of the FM using polarization-dependent transmission experiments. Moreover, using a spin-split two-band model, we show that also the lifetimes of the cavity modes display a polarization dependent response. The reduced lifetime of modes of only one polarization could potentially be used to engineer and control circularly polarized cavities.

TT 19.5 Mon 17:30 H 3025

Diagrammatic approach to quantum heat transport in the quantum Rabi model — •Luca Magazzu[1], Elisabetta Paladino[2,3], and Milena Grifoni[1] — [1]University of Regensburg — [2]Università di Catania, Italy — [3]INFN, Sez. Catania, Italy

A diagrammatic approach to quantum transport in Liouville space, valid for bosonic/fermionic environments, is applied to bosonic heat transport in the quantum Rabi model. Heat transport at weak interaction with the heat baths is controlled by the qubit-oscillator coupling g. Universality of the linear conductance versus the temperature is found below a coupling-dependent Kondo-like temperature.

At low temperature, coherent 4th-order processes dominate transport yielding a T^3 behavior for the thermal conductance κ. In the high-temperature regime, incoherent emission/absorption processes constitute the main transport mechanism, giving resonant peaks, at low g, when the qubit frequency matches the one of the oscillator. In these conditions, the spectrum of the Rabi model displays quasi-degeneracies that produce non-vanishing coherences at the steady state which, in turn, impact κ.

In moving from the weak to the ultrastrong qubit-oscillator coupling regime, the low-T conductance converges to the one of an effective two-level system. At high T, κ makes a transition from a resonant peak to a broad, zero-bias peak regime, a behavior that parallels the one found for the spin-boson model at strong qubit-bath coupling.

TT 19.6 Mon 17:45 H 3025

An on-demand source of energy-entangled electrons using Levitons — Bruno Bertin-Johannet, Laurent Raymond, •Flavio Ronetti, Jérôme Rech, Thibaut Jonckheere, Benoît Grémaud, and Thierry Martin — Aix-Marseille Univ, Université de Toulon, CNRS, CPT, Marseille, France

The on-demand generation of single- and few-electron states in mesoscopic systems has opened the way to the fascinating field of electron quantum optics (EQO), where individual fermionic quantum states are manipulated with methods borrowed from photonic quantum-optical experiments. In this framework, a train of Lorentzian voltage pulses represents one of the most reliable experimental protocol to inject coherent single-electronic states, known as Levitons, into ballistic channels of meso-scale devices. In this talk, we will discuss how the propagation of Levitons is affected by the presence of correlations between electrons and how these effects can be exploited in potential applications for quantum electronics and quantum information. We propose a device where EQO is combined with a BCS superconductor – a reservoir of Cooper pairs. With spin polarized wave guides, this version of the Cooper pair beam splitter is driven by an AC drive, and observables such as period-averaged noise are computed using a Keldysh-Nambu-Floquet formalism. This allows to propose an on-demand source of non-local energy-entangled states. By measuring current fluctuations we propose a way to observe the entangled nature of this state.

TT 20: Quantum Dots and Quantum Wires (joint session TT/HL)

Time: Monday 16:45–18:15 Location: H 3007

TT 20.1 Mon 16:45 H 3007

Quantum Dot Source-Drain Transport Response at Microwave Frequencies — •Harald Havir — Lund University

Quantum dots are frequently used as charge sensitive devices in low temperature experiments to probe electric charge in mesoscopic conductors where the current running through the quantum dot is modulated by the nearby charge environment. Recent experiments have been operating these detectors using reflectometry measurements up to GHz frequencies rather than probing the low frequency current through the dot. In this talk I will present the work "Quantum Dot Source-Drain Transport Response at Microwave Frequencies" where we use an on-chip coplanar waveguide resonator to measure the source-drain transport response of two quantum dots at a frequency of 6 GHz with the aim to further increase the bandwidth limit for charge detection. Similar to the low frequency domain, the response is here predominantly dissipative. For large tunnel coupling, the response is still governed by the low frequency conductance, in line with Landauer-Büttiker theory. For smaller couplings, our devices showcase two regimes where the high frequency response deviates from the low frequency limit and Landauer-Büttiker theory: When the photon energy exceeds the quantum dot resonance linewidth, degeneracy dependent plateaus emerge. These are reproduced by sequential tunneling calculations. In the other case with large asymmetry in the tunnel couplings, the high frequency response is two orders of magnitude larger than the low frequency conductance G, favoring the high frequency readout.

TT 20.2 Mon 17:00 H 3007

Relaxation to persistent currents in a Hubbard trimer coupled to fermionic baths — •Nikodem Szpak[1], Gernot Schaller[2], Ralf Schützhold[2,3], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, 47057 Duisburg, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

We consider a ring of fermionic quantum sites, modeled by the Fermi-Hubbard Hamiltonian, in which electrons can move and interact strongly via the Coulomb repulsion. The system is coupled to fermionic cold baths which by the exchange of particles and energy induce relaxation in the system. We describe the system effectively by the Lindblad master equations in various versions valid for different coupling parameter regimes. The early relaxation phase proceeds in a universal way, irrespective of the relative couplings and approximations. The system settles down to its low-energy sector and is consecutively well approximated by the Heisenberg model. In the late relaxation, different Lindblad approaches push the system towards different final states with opposite spin orders, from ferromagenetic to antiferromagnetic. Due to spin frustration in the trimer, degenerate ground states are formed by spin waves (magnons). The system described by the global coherent version of the Lindblad operators relaxes towards the final states carrying directed persistent spin currents.

[1] N. Szpak et. al., arXiv:2311.06331

TT 20.3 Mon 17:15 H 3007

Spatially-resolved dissipation in a quantum wire with a coherent scatterer — •Nico Leumer[1,2], Denis Basko[3], Rodolfo Jalabert[1], Dietmar Weinmann[1], and Robert Whitney[3] — [1]IPCMS, France — [2]DIPC, Spain — [3]LPMMC, France

The recent advent of astonishing measurement techniques allows the near-atomic resolution of tiny local temperature changes, even three orders of magnitude lower than the sample temperature itself [1]. The new approaches confirmed earlier estimations that dissipation (accompanying electric current) is not shared equally among two 1d wires attached to a point contact. Moreover, the formation of so called heat-spots (small and confined areas of increased temperature) were observed in the quantum regime [2]. Evidently, dc charge transport possesses the key to further unravel the microscopic mechanisms behind spatial dissipation profiles.

Based on a model of two 1d wires sandwiching a scatterer, we investigated the spatial distribution of the dissipated power for generic transmission of the scatterer. We present the mechanism behind the formation of heat/ cold spots and the key role of the electric potential, which is required to maintain the electric current against the increased wire's resistivity in close vicinity to the point contact. Additionally, we report on the self-consistent calculation of the steady state current which obeys a four-point Landauer type relation w.r.t. the voltage drop inside the scatterer.

[1] D. Halbertal et al., Nature 539 (2016) 407
[2] Q. Weng et al., Nat. Commun. 12 (2021) 4752

TT 20.4 Mon 17:30 H 3007

Multi-terminal interacting-quantum-dot-based devices — •Peter Zalom — Institute of Physics, Czech Academy of Sciences, Na Slovance 2, CZ-18200 Praha 8, Czech Republic

Recent breakthroughs in experimental physics pave the way for the creation of intricate nanoscale devices featuring three or more superconducting electrodes. Such multi-terminal systems differ markedly from conventional two-lead Josephson junctions due to the supercurrent distribution into the constituent terminals. Exerting full phase-control leads then to a multitude of practical applications.

In this talk, we explore the potential for using nanowires or carbon nanotubes in the central scattering region to enhance the existing functionalities via the underlying quantum phase transitions. Our findings, as elucidated in [1], lay the foundation for purely phase-controlled superconducting transistor and diode effects in three-terminal systems even in the absence of inter-lead couplings. Proceeding with more complex architectures requires, however, development of new Numerical Renormalization Group (NRG) methods to accommodate arbitrary gapped tunneling densities of states. This critical development, recently detailed in Ref. [2], significantly expands our theoretical understanding, particularly in devices incorporating topological effects.

[1] P. Zalom, M. Žonda and T. Novotný, arXiv:2310.02933 (2023).
[2] P. Zalom, Phys. Rev. B 108 (2023) 195123.

TT 20.5 Mon 17:45 H 3007

Ground state topology of a four-terminal superconducting double quantum dot — •Wolfgang Belzig[1], Lev Teshler[1], Hannes Weisbrich[1], Jonathan Sturm[2], Raffael Klees[3], and Gianluca Rastelli[4] — [1]Universität Konstanz — [2]Universität Würzburg — [3]Universität Augsburg — [4]CNR INO BEC Group Trento

In recent years, various classes of systems were proposed to realize topological states of matter. One of them are multiterminal Josephson junctions where topological Andreev bound states are constructed in the synthetic space of superconducting phases. Crucially, the topology in these systems results in a quantized transconductance between two of its terminals comparable to the quantum Hall effect. In this work, we study a double quantum dot with four superconducting terminals and show that it has an experimentally accessible topological regime in which the non-trivial topology can be measured. We also include Coulomb repulsion between electrons which is usually present in experiments and show how the topological region can be maximized in parameter space.

[1] L. Teshler, H. Weisbrich, J. Sturm, Raffael L. Klees, G. Rastelli, W. Belzig, SciPost Phys. 15 (2023) 214

TT 20.6 Mon 18:00 H 3007

Nonmonotonic buildup of spin-singlet correlations in double quantum dot — •Kacper Wrześniewski, Tomasz Ślusarski, and Ireneusz Weymann — Faculty of Physics, Adam Mickiewicz University, Poland

Dynamical buildup of spin-singlet correlations between the two quantum dots is investigated by means of the time-dependent numerical renormalization group method. By calculating the time evolution of the spin-spin expectation value upon a quench in the hopping between the quantum dots, we predict a nonmonotonic buildup of spin-singlet state. In particular, we find that in short timescales the effective exchange interaction between the quantum dots is of ferromagnetic type, favoring spin-triplet correlations, as opposed to the long-time limit, when strong antiferromagnetic correlations develop and eventually an entangled spin-singlet state is formed between the dots. We also numerically determine the relevant timescales and show that the physics is generally governed by the interplay between the Kondo correlations on each dot and exchange interaction between the spins of both quantum dots.

This work was supported by the Polish National Science Centre from funds awarded through decisions No. 2017/27/B/ST3/00621 and No. 2022/45/B/ST3/02826. We also acknowledge the computing time at the Poznan Supercomputing and Networking Center.

[1] K. Wrześniewski, T. Ślusarski, I. Weymann, Rev. B 108 (2023) 144307.

TT 21: Focus Session: Strongly Disordered Superconductors

The very nature of the disorder-induced superconductor-insulator transition has remained enigmatic in the past two decades. Very recently, a new generation of experiments has been performed that addresses not only DC-properties, but also the fate of the superfluid stiffness very close to the superconductor-insulator transition. These experiments reveal the superfluid dynamics at the transition in unprecedented clarity and were enabled by the advent of high-resolution microwave techniques. This provides a natural link to quantum circuits, where the ultra-high kinetic inductance is exploited in these materials is exploited for new types of high-fidelity quantum bits.

Organizers: Christoph Strunk (University of Regensburg), Ferdinand Evers (University of Regensburg)

Time: Tuesday 9:30–12:45 Location: H 0104

Invited Talk TT 21.1 Tue 9:30 H 0104

The fate of the superfluid density near the superconductor-insulator transition — •Benjamin Sacepe — Neel Institute, CNRS Grenoble, France

Superconducting films of amorphous Indium Oxide (a:InO) undergo a transition to insulation with increasing disorder, which is due to the localization of pre-formed Cooper pairs. The continuous decrease in critical temperature as critical disorder is approached suggests an equally continuous suppression of superfluid density. In this talk I will discuss a systematic study of the superfluid density measured via plasmon dispersion spectroscopy of microwave resonators made of a:InO, combined with DC resistivity measurements, as a function of disorder. We observed that the superfluid stiffness defines the superconducting critical temperature over a wide range of disorder, highlighting the dominant role of phase fluctuations. Furthermore, we found that the superfluid density remains surprisingly finite at the critical disorder, indicating an unexpected first-order nature of the disorder-driven quantum phase transition to insulator.

Invited Talk TT 21.2 Tue 10:00 H 0104

Vortices in dirty superconducting films — •Elio König — Max-Planck Institute for Solid State Research, 70569 Stuttgart, Germany

In this talk about the long standing question of superconductivity in dirty two-dimensional samples I will first review exemplary experiments and summarize theories put forward within the two main paradigms dubbed "bosonic" and "fermionic" approach, respectively.

Next, I will present a theory for the finite temperature vortex-unbinding transition in homogeneously disordered superconducting films. This theory incorporates the effects of quantum, mesoscopic, and thermal fluctuations stemming from length scales ranging from the superconducting coherence length down to the Fermi wavelength and allows to determine the dependence of essential observables on microscopic characteristics.

Finally, the last part of the talk is dedicated to the voltage generation in 2D superconducting films of finite width (strips) at zero temperature and subjected to a finite current bias. We show by means of a variational Ansatz that the voltage is generated by multi-vortex configurations (instead of single or double vortex configurations considered previously). At the border of its applicability, our theory also evidences the superconductor-insulator quantum phase transition.

Invited Talk TT 21.3 Tue 10:30 H 0104

Superfluid stiffness of a strongly disordered superconductor close to the superconductor-insulator transition — •Alexander Weitzel[1], Lea Pfaffinger[1], Ilaria Maccari[2], Klaus Kronfeldner[1], Thomas Huber[1], Lorenz Fuchs[1], Simon Reinhardt[1], James Mallord[1], Sven Linzen[3], Evgeni Il'ichev[3], Nicola Paradiso[1], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, D-93040 Regensburg, Germany — [2]Department of Physics, Stockholm University, Stockholm SE-10691, Sweden — [3]Leibniz Institute of Photonic Technology, D-07745 Jena, Germany

In superconducting thin films, the superconductor-insulator transition (SIT) is a paradigmatic example of a quantum phase transition: With increasing disorder the critical temperature of the superconductor is suppressed towards zero until an insulating ground state that is expected at a critical level of disorder with normal state resistance $R_N \simeq h/4e^2$. Notably, in many materials the mechanism of the SIT is not entirely clear, with competing explanations based on suppression of the order parameter modulus or proliferation of phase fluctuations. Using a tank circuit compatible with dc transport measurements, we investigate ultra-thin atomic layer deposited NbN films and trace the evolution of the superfluid stiffness as a function of disorder close to the SIT. We observe a sharp Berezinskii-Kosterlitz-Thouless transition in dc transport and in superfluid stiffness that persists even up to $R_N \simeq h/e^2$. In the vicinity of the SIT, phase fluctuations suppress the superfluid stiffness, consistent with a bosonic mechanism of SIT.

15 min. break

Invited Talk TT 21.4 Tue 11:15 H 0104

Thermally enhanced superconductivity and photonic dissipation in Josephson junction arrays — •Andrew P. Higginbotham — James Franck Institute and Department of Physics, 929 E 57th St, Chicago, IL 60637, USA — IST Austria, Am Campus 1, 3400 Klosterneuburg, AT

I will present two studies exploring the limits of superconductivity in long Josephson junction arrays. The first study shows that apparent superconductivity persists for vastly weaker chains than expected within a zero-temperature theory. This behavior is consistent with thermal effects, which effectively melt the insulator and restore superconducting behavior [1]. The second study finds dissipation arising from photon-photon interactions. I will discuss the possible relevance of this dissipation as a source of photonic friction in equilibrium, and as a source of many-body stabilization in nonequilibrium.
[1] S. Mukhopadhyay et al., Nat. Phys. **19** (2023) 1630.

Invited Talk TT 21.5 Tue 11:45 H 0104

Spectral Gap and Order Parameter Statistics in Disordered Superconducting Films — •Matthias Stosiek — Department of Applied Physics, Aalto University, Finland

The interplay of disorder and superconductivity leads to a rich variety of phenomena like the development of superconducting islands at superconductor-insulator transitions or an enhancement of the superconducting critical temperature.

These phenomena are enabled by the local fluctuations of superconducting observables. In particular, two observables are of outstanding interest: the superconducting order parameter and the spectral gap of the local density of states. While identical in absolute value in BCS theory, these observables can differ dramatically in dirty superconductors. In many previous studies, this difference was assumed to be negligible in the weakly disordered regime.

In the here presented work, we aim to elucidate this assumption. For this, we conducted a computational study of disordered thin-film superconductors within fully self-consistent mean-field theory. To produce our results, we employed a self-written, highly optimized self-consistency solver [1] that we made publicly available [2]. Our results include: (i) demonstration of only small correlations between the two observables even in the weakly disordered regime; (ii) indications of a non-local relation between order parameter and spectral gap.
[1] M. Stosiek, B. Lang, F. Evers, Phys. Rev. B 101 (2020) 144503
[2] https://github.com/ccmt-regensburg/self_ consistency_ solver

TT 21.6 Tue 12:15 H 0104

Temperature-Dependent Vortex Dynamics and Current Limitations in a $[(SnSe)_{(1+\delta)}]_3[NbSe_2\ ]_1$ Ferecrystal — •Linus P. Grote[1], Wieland G. Stoffel[1], Mahni Müller[1], Theodor U. Griffin[1], Olivio Chiatti[1], Danielle Hamann[2], David C. Johnson[2], and Saskia F. Fischer[1,3] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Department of Chemistry and Materials Science Institute, University of Oregon, Eugene OR 97403, USA — [3]Center for the Science of Materials Berlin, 12489 Berlin, Germany

The evidence of two-dimensional superconductivity in van der Waals superlattices has recently received a lot of attention [1]. Our study investigates the temperature, magnetic field, and current-dependent superconducting properties of a ferecrystal - a layered van der Waals heterostructure with $NbSe_2$ monolayers separated by SnSe spacers [2]. Current-voltage characteristics indicate a Berezinskii-Kosterlitz-Thouless phase transition and suggest two-dimensional superconductivity, while an intermediate temperature range exhibits phase slip lines and reduced critical currents. Magnetic field measurements reveal the nature of phase slip lines and determine the in-plane and out-of-plane Ginsburg-Landau coherence lenghts. Our findings contribute insights into the complex interplay of vortex behavior and superconducting properties in superconducting heterostructures, enhancing understanding of superconductor current limitations.
[1] A. Devarakonda et al., Science **370** (2020) 231
[2] O. Chiatti et al., J. Phys.: Condens. Matter **35** (2023) 215701

TT 21.7 Tue 12:30 H 0104

Finite-size scaling in the vicinity of the BKT transition — •Lea Pfaffinger[1], Alexander Weitzel[1], Sven Linzen[2], Evgenii Il'ichev[2], Nicola Paradiso[1], and Christoph Strunk[1] — [1]Experimental and Applied Physics, University Regensburg, Germany — [2]Leibniz Institute of Photonic Technology, Jena, Germany

In 2D superconducting thin films the unbinding of thermal vortex-antivortex pairs should lead to a finite resistance above the Berezinskii-Kosterlitz-Thouless (BKT) temperature [1]. However, experimental results often showed a broadened transition by correlated disorder in the samples. Very recently, this was avoided in homogeneously disordered 3nm NbN films grown by atomic layer deposition [2]. Finite size effects were expected to affect the transition for sizes smaller than $\Lambda_p = 2\lambda^2/d$, but surprisingly, the transition in our films agrees with theory down to a width of $10\mu\text{m} \simeq \Lambda_p \ll 2\text{mm}$. When further reducing the width to $w \lesssim 1\mu$m, we observe a finite resistance even for $T < T_{BKT}$. We study the evolution of this broadened transition regime vs. width and additionally compare the power law exponent in IV characteristics with theoretical predictions.
[1] J. Kosterlitz, D. Thouless, J. Phys. C: Solid State Phys., **6** (1973) 1181
[2] A. Weitzel et al., Phys. Rev. Lett. **131** (2023) 186002
[3] A. Anderson, J. Lidmar, Phys. Rev. B, **87** (2013) 224506

TT 22: Focus Session: Frustrated Magnetism and Local Order (joint session MA/TT)

Recent experimental findings illustrate unexpected spin glass behavior in a variety of frustrated magnets. Often their description goes beyond conventional pictures of spin glasses. For instance, the interplay of antiferromagnetism and spin glass behavior was recently studied. Such systems could be used to study the gradual evolution of spin glass behavior in an itinerant magnet without a change of the crystallographic environment. In this context, the discovery of the so-called self-induced spin glass in elemental neodymium showed that glassy behavior can even exist in the absence of disorder, leading to local magnetic order in the absence of long-range order. This focus session brings together experts from different subfields of frustrated magnetism and with different experimental and theoretical expertise, in order to exchange conceptual ideas beyond "traditional" paradigms of spin glasses and frustrated magnetism. These conceptual ideas are linked to fields such as artificially built frustrated magnets (e.g. spin ice), multi-well systems with complex dynamics, or fragile magnetic systems that may exhibit complex magnetic order.

Coordinators: Daniel Wegner and Alexander A. Khajetoorians (Radboud University, Nijmegen)

Time: Tuesday 9:30–13:15 Location: H 1058

Invited Talk TT 22.1 Tue 9:30 H 1058

Neutron scattering studies of spin-freezing phenomena at quantum phase transitions — •Christian Pfleiderer — School of Natural Sciences, Department of Physics, Technical University of Munich, D-85748 Garching, Germany — Centre for QuantumEngineering (ZQE), Technical University of Munich, D-85748 Garching, Germany — Heinz Maier-Leibnitz Zentrum (MLZ), Technical University of Munich, D-85748 Garching, Germany — Munich Centre for

Quantum Science and Technology (MCQST), Technical University of Munich, D-85748 Garching, Germany

A cornerstone of the statistical and thermal physics of condensed matter systems concerns their energy landscape and the associated ergodicity. Conventional and topologically non-trivial forms of long-range magnetic order represent weak forms of non-ergodicity that allow to explore classical and quantum dynamics, as well as the origin and nature of topological protection. In contrast, strong forms of non- ergodicity related to glassy configurations and freezing transitions permit the comparison of quantum versus thermally driven relaxation as constrained, e.g., by disorder. Combining the results of neutron depolarization, neutron diffraction, and neutron spectroscopy with magnetization and ac susceptibility measurements, similarities and differences of spin freezing phenomena at selected quantum phase transitions will be presented. This includes the putative formation of reentrant spin glass behaviour in $Fe_{1-x}Cr_x$, a Kondo cluster glass in $CePd_{1-x}Rh_x$, and a spin liquid in $HgCr_2Se_2$ under pressure.

Invited Talk TT 22.2 Tue 10:00 H 1058

Frustrations, glassiness and complexity of spin systems with large spatial dimension — •Mikhail Katsnelson — Radboud University, Nijmegen, Netherlands

It was suggested some time ago [1] that spin system can behave as a glass without disorder, due to frustrations only (self-induced spin-glass state). Recent experimental discovery of glass-like magnetic state in elemental Nd at low temperatures [2] creates a very strong motivation to improve our theoretical understanding of such an opportunity. We have shown [3] that the glassiness without disorder can be derived quite rigorously for classical Heisenberg model in the limit of large spatial dimension, where an accurate and controllable mathematical treatment turns out to be possible.

For frustrated quantum spin systems, the sign structure of the ground state has a high complexity, in a sense that the machine learning of this structure is very difficult [4]. This problem however can be mapped to the classical Ising model of a very large dimension which allows to reach a progress in determining this sign structure [5].

[1]. A. Principi and M. I. Katsnelson, Phys. Rev. B 93, 054410 (2016); Phys. Rev. Lett. 117, 137201 (2016). [2] U. Kamber et al, Science 368, eaay6757 (2020); B. Verlhac et al, Nature Phys. 18, 905 (2022). [3] A. Mauri and M. I. Katsnelson, arXiv:2311.09124. [4] T. Westerhout et al, Nature Commun. 11, 1593 (2020). [5] T. Westerhout, M. I. Katsnelson, and A. A. Bagrov, Commun. Phys. 6, 275 (2023).

Invited Talk TT 22.3 Tue 10:30 H 1058

Self-Induced Spin Glass Phase and Thermally Induced Order in dhcp Nd — •Anders Bergman — Uppsala University, Uppsala, Sweden

Among the wide variety of magnetic orders found in frustrated magnets, one of the most intriguing phases is manifested by the spin glass state where the magnetization exhibit glassy dynamics, including ageing and memory effects. The peculiar dynamics of spin glass materials has historically been associated with disorder where magnetic frustration can cause an energy landscape with several local minima combined with larger energy barriers, resulting in non-ergodic behavior and glassy dynamics.

Recent theoretical and experimental findings have however indicated the existence of glassy dynamics in a material with limited chemical disorder: elemental and crystalline Nd [1]. In this talk, we will present results indicating that: I) the low temperature state of dhcp Nd can be described as a self-induced spin glass and II) dhcp Nd undergoes a phase transition from the self-induced spin glass phase to an ordered spin-spiral phase with increasing temperature [2].

Using first-principles DFT calculations of magnetic exchange interactions combined with atomistic spin dynamics simulations we can show that the complex magnetism of dhcp Nd is driven by an intrinsic frustration of the exchange interactions between Nd atoms at the cubic and the hexagonal sites in the dhcp structure.

[1] U. Kamber, et. al, Science 6757 368 (2020)
[2] B. Verlhac, et. al, Nature Physics 905 18 (2022)

TT 22.4 Tue 11:00 H 1058

Spatially resolved aging and rejuvenation in a self-induced spin glass — •Lorena Niggli[1], Julian H. Strik[1], Zhengyuan Liu[1], Anders Bergman[2], Mikhail I. Katsnelson[1], Daniel Wegner[1], and Alexander A. Khajetoorians[1] — [1]Institute for Molecules and Materials, Radboud University, Nijmegen, The Netherlands — [2]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

Spin glasses are a puzzling form of magnetic matter lacking long range order and possessing multiple relaxation time scales indicative of aging. These findings are based on ensemble thermodynamic measurements, which leave more to be known about the behaviour of the magnetization locally. Recently, we have discovered that the low temperature magnetic phase of elemental neodymium behaves like a proposed self-induced spin glass relying solely on spin frustration in the absence of disorder for glassiness [1,2]. Here, we explore the aging behaviour of Nd(0001) using spin-polarized scanning tunneling microscopy in varying magnetic fields. We observe a transition from an initial state, reached after cooling into the glass phase, towards a distinct final state, as we perturb the system. Temperature cycling allows us to rejuvenate the system back into its initial state, which hints towards a thermally written memory in this glassy system. Using a new analysis method, we quantify the favourability of the observed local order as well as investigate its link to the energy landscape.

[1] U. Kamber et al., Science 368 (2020).
[2] B. Verlhac et al., Nature Physics 18 (2022).

TT 22.5 Tue 11:15 H 1058

Multipolar order in the 5d double perovskite Ba_2MgReO_6 from DFT+DMFT — Maximilian E. Merkel and •Claude Ederer — Materials Theory, ETH Zürich, Switzerland

We establish the effect of electronic correlations and strong-spin-orbit coupling on the emergence of the insulating state and the quadrupolar order in the magnetically frustrated 5d double perovskite Ba_2MgReO_6 (BMRO). BMRO exhibits a tetragonally distorted paramagnetic phase below $T_q \sim 33\,\mathrm{K}$ and a non-collinear magnetically ordered state below $T_m \sim 18\,\mathrm{K}$. Using density functional theory in combination with dynamical mean-field theory (DFT+DMFT), we demonstrate that BMRO should be classified as a normal Mott insulator where the spin-orbit coupling is not crucial for the formation of the insulating state. Our calculations further reveal a subtle interplay between the electronic quadrupolar order and the Jahn-Teller distortion, where the primary instability is of electronic origin but the coupling to the structural distortion determines the specific character of the emerging order.

15 min. break

Invited Talk TT 22.6 Tue 11:45 H 1058

Frustrated Quantum Devices: Pathways to leverage exotic order in novel spintronic technologies — •James Analytis — University of California at Berkeley, 366 Physics North, Berkeley, CA 94705, USA

Materials at the boundary of critical phase transitions are of significant fundamental interest, not least due because of their connection to unconventional superconductivity and quantum magnetism. One characteristic shared by many such systems is the presence of coupled order parameters that underlie these phase transitions. Here, we explore how this coupling manifests in the response of these materials when driven out of equilibrium by applied currents. We demonstrate how magnetic and charge textures can be electrically manipulated, suggesting possible applications for exotic materials in spintronics technologies.

TT 22.7 Tue 12:15 H 1058

Noncoplanar and chiral spin states on the way towards Néel ordering in fullerenes — •Attila Szabó[1], Sylvain Capponi[2], and Fabien Alet[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]Laboratoire de Physique Théorique, Toulouse, France

Magnetic ordering can be detected in finite lattices through the emergence of Bragg peaks in ground-state structure factor or through the spectrum of low-energy excited states, which form an Anderson tower of states generated by Goldstone modes of the incipient symmetry breaking. In this talk, I will generalise these methods to large fullerenes, where incipient Néel ordering on the network of hexagonal faces is frustrated by a low density of pentagons. Using high-accuracy variational Monte Carlo based on group-convolutional neural networks, we obtain the symmetry-resolved low-energy spectrum of the spin-1/2 Heisenberg model on several highly symmetric fullerene geometries, including the famous C_{60} buckminsterfullerene. We show that their correlation functions contain high-intensity Bragg peaks consistent with Néel-like ordering, while the low-energy spectrum is organised into a tower of states. Competition with frustration, however, turns the simple Néel order into a noncoplanar one. Remarkably, we find and predict chiral incipient ordering in a large number of fullerene structures. Our findings may have interesting ramifications for the nature of superconductivity in metal fullerides.

TT 22.8 Tue 12:30 H 1058

Frustrated magnetism in novel layered Mott insulators. — •Sergii Grytsiuk[1], Mikhail I. Katsnelson[1], Erik G.C.P. van Loon[2], and Malte Rösner[1] — [1]Institute for Molecules and Materials, Radboud University, Heijendaalseweg 135, 6525AJ Nijmegen, The Netherlands — [2]NanoLund and Division of Mathematical Physics, Physics Department, Lund University, Sweden

Via ab initio down folding, we show that the layered van der Waals distorted kagome compounds Nb_3X_8 (X=Cl, Br, and I) are Mott insulators. We demonstrate that the monolayer of these compounds has a frustrated triangular AFM order, while in bulk, an intriguing interplay between intra- and interlayer AFM coupling promotes magnetic frustration further. We show that this leads to chiral in-plane spiralisation of frustrated triangular AFM order at high temperatures and strong collinear interlayer AFM coupling at low temperatures. Furthermore, we explain the "mystic" magnetic phase transition and the nature of the putative "non-magnetic" phase at low temperatures observed in Nb3Cl8, which has not been explained theoretically until now. Finally, our finding offers new opportunities for controlling such non-trivial frustrated magnetism in these layered Mott insulators via doping or substrate screening.

Invited Talk TT 22.9 Tue 12:45 H 1058

New Frontiers in Artificial Spin Ice: Phase Transitions in Two and Three Dimensions — •Gavin M. Macauley[1,2], Luca Berchialla[1,2], Aleksandra Pac[1,2], Tianyue Wang[1,2], Armin Kleibert[3], Valerio Scagnoli[1,2], Peter M. Derlet[4], and Laura J. Heyrderman[1,2] — [1]Laboratory for Mesoscopic Systems, Department of Materials, ETH Zurich, 8093 Zurich, Switzerland — [2]Laboratory for Multiscale Materials Experiments, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland — [3]Swiss Light Source, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland — [4]Condensed Matter Theory Group, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

Artificial spin ices are arrays of strongly correlated nanomagnets, which are coupled through the dipolar interaction. While originally envisaged as a two-dimensional analogue to frustrated rare-earth pyrochlores, they are now studied since they exhibit behaviour such as glassiness and charge fragmentation, and topologically induced textures such as magnetic 'monopoles' [1]. In this talk, I will introduce artificial spin ice and discuss some recent work performed in the Laboratory for Mesoscopic Systems. By way of example, I will discuss how they can be used as a platform to study phase transitions by focusing on the example of a rotated kagome-like lattice in two-dimensions and an artificial spin ice based on the buckyball in three-dimensions. These systems have complex phase diagrams, with crossovers, phase transitions, and phase coexistence. [1] Skjaervo, S.H., Marrows, C.H., Stamps, R.L. and Heyderman, L.J. Nat. Rev. Phys. 2, 13-28 (2020).

TT 23: Topological Insulators and Weyl Semimetals (joint session MA/TT)

Time: Tuesday 9:30–13:00 Location: H 2013

TT 23.1 Tue 9:30 H 2013

behavior of Dirac fermion in non-symmorphic CeTX2 systems — •Sawani Datta[1,4], Khadiza Ali[2], Rahul Verma[1], Denis Vyalikh[3], Bahadur Singh[1], A Thamizhavel[1], Saroj P Dash[2], and Kalobaran Maiti[1] — [1]Tata Institute of Fundamental Research, Mumbai, India — [2]Chalmers University of Technology, Gotheborg, Sweden. — [3]DIPC, Donostia, San Sebastian, Spain — [4]Max Plank Institute for Solid State Research, Stuttgart, Germany

We have studied the behavior of Dirac fermions in the presence of strong electron correlation in nonsymmorphic Kondo lattice systems, CeTX2 (T=Cu/Ag, X-As/Sb) employing high-resolution angle-resolved photoemission spectroscopy [1]. Experiments reveal crossings of highly dispersive linear bands at the Brillouin zone boundary protected by non-symmorphic symmetry [2]. In addition, anisotropic Dirac cones are observed constituted by the square net Sb(As) 5p(4p) states forming a diamond-shaped nodal line. The Dirac bands are linear in a wide energy range with an unusually high slope and exhibit distinct Dirac points in these highly spin-orbit coupled systems. Along with these bulk crossings, CeCuAs2 also exhibits a surface Dirac crossing at the Γ-point. These results seed the emergence of an area of robust topological fermions even in the presence of strong correlation. [1] S. Datta et al. arXiv:2311.05278 [2] L. M. Schoop et al., Nat. Commun. 7, 11696 (2016).

TT 23.2 Tue 9:45 H 2013

Isotropic 3D topological phases with broken time reversal symmetry — Helene Spring[1], Anton R. Akhmerov[1], and •Daniel Varjas[2,3,4] — [1]Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 4056, 2600 GA Delft, The Netherlands — [2]Department of Physics, Stockholm University, AlbaNova University Center, 106 91 Stockholm, Sweden — [3]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, Germany — [4]IFW Dresden and Würzburg-Dresden Cluster of Excellence ct.qmat, Helmholtzstr. 20, 01069 Dresden, Germany

Axial vectors, such as current or magnetization, are commonly used order parameters in time-reversal symmetry breaking systems. These vectors also break isotropy in three dimensional systems, lowering the spatial symmetry. We demonstrate that it is possible to construct a fully isotropic and inversion-symmetric three-dimensional medium where time-reversal symmetry is systematically broken. We propose an amorphous system with scalar time-reversal symmetry breaking, implemented by hopping through chiral magnetic clusters along the bonds. The average spatial symmetries alone protect a statistical topological insulator phase in this system. We demonstrate the topological nature of our model by constructing a bulk integer topological invariant, which guarantees gapless surface spectrum on any surface with several overlapping Dirac nodes, analogous to crystalline mirror Chern insulators. We also show the expected transport properties of a three-dimensional statistical topological insulator, which remains critical on the surface for odd values of the invariant.

TT 23.3 Tue 10:00 H 2013

Behavior of Dirac Fermions in Kondo lattice systems — •Kalobaran Maiti — Department of Condensed Matter Physics and Materials Science, Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400005, India

We studied the behavior of Dirac fermions in novel Kondo lattice system employing ARPES. We show that a binary system, SmBi show signature of multiple gapped and un-gapped Dirac cones in the band structure. Employing ultra-high-resolution ARPES, we discover destruction of a surface Fermi surface across the Neel temperature while the behavior of Dirac cones survive across the magnetic transition. ARPES data of a non-symmorphic Kondo lattice system, CeAgSb2 exhibit distinct Dirac cones as well as diamond-shaped nodal lines; the slope of these linear bands is unusually high, larger than that in graphene and maintains its high value in a wide energy range indicating robust high velocity of these relativistic particles. The slope becomes smaller in the vicinity of strongly correlated Ce 4f bands forming a kink; a unique case due to correlation induced effects.

References: 1. Sawani Datta et al., arXiv:2311.05278 2. A.P. Sakhya et al. Phys. Rev. Mater. 2021, 5, 054201. 3. A.P. Sakhya et al. Phys. Rev. B 2022, 106, 085132.

TT 23.4 Tue 10:15 H 2013

Strain control on band topology and surface states in antiferromagnetic EuCd2As2 — •Nayra Alvarez[1], Rodrigo Jaeschke[1], Venkata Krishna[1], Adrian Valadkhani[2], Roser Valenti[2], Libor Smejkal[1], and Jairo Sinova[1,3] — [1]Institut für Physik, Johannes Gutenberg Universität — [2]Institut für Theoretische Physik, Goethe-Universität Frankfurt — [3]Inst. of Physics Academy of Sciences of the Czech Republic

Topological semimetal antiferromagnets provide a rich source of exotic topological states which can be controlled by manipulating the orientation of the Neel vector, or by modulating the lattice parameters through strain. We investigate via ab initio density functional theory calculations, the effects of shear strain on the bulk and surface states in two antiferromagnetic EuCd2As2 phases with out-of-plane and in-plane spin configurations. We demonstrate the control of the band topology and how they can lead to hinge modes as well, which may prove useful to realize the long-sought after axion states and to stimulate further research in the field of strain effects on Dirac semimetals[1].

[1] Pari, Nayra A. Álvarez, et al. "Strain control of band topology and surface states in antiferromagnetic EuCd2As2." arXiv preprint arXiv:2310.19186 (2023)

TT 23.5 Tue 10:30 H 2013

Nonlocal Spin Dynamics Arising From Induced Interactions at the Interface of a Topological Insulator and a Ferromagnet — •Christian S. Johnsen and Asle Sudbø — Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

In recent years, topologically stable magnetic textures called skyrmions have received much attention for their potential uses in information technology. One such use is making skyrmions the information carriers in low-dissipation information storage devices because skyrmions can be moved using exceedingly small currents. One proposed setup is to move them using a low-dissipation current on the surface of a topological insulator. In this work, an effective field theory for the spins in such a heterostructure is derived. The theory shows time-dependent induced spin-spin interactions such as DMI and the presence of non-negligible retardation effects which alter the system's spin dynamics. In particular, we derive an inertial term and various dissipative terms in the Landau-Lifshitz-Gilbert equation.

TT 23.6 Tue 10:45 H 2013

Surface reconstruction effects in thin films of Antiferromagnetic Topological Insulator $MnBi_2Te_4$ — •Shahid Sattar and Carlo Maria Canali — Department of Physics and Electrical Engineering, Linnaeus University, Kalmar SE-39231, Sweden

Intrinsic magnetic topological insulator $MnBi_2Te_4$ (MBT) characterized by a non-zero topological Z_2 index has recently gained significant interest and attention. Experiments on thin films of MBT have confirmed the presence of the anomalous quantum Hall and axion insulating phases in odd and even septuple-layer films respectively. In this work, we investigate surface reconstruction effects on topological characteristics in thin films of MBT using first-principles calculations and an effective $\mathbf{k}\cdot\mathbf{p}$ model Hamiltonian. We discuss the implications of surface reconstruction on both the Chern and axion insulating phases and discuss the presence of Rashba surface states for the latter. Our results provide a theoretical framework needed to elucidate the nature of surface reconstruction in magnetic TI thin films, which can be useful for their experimental realization.

TT 23.7 Tue 11:00 H 2013

The MT Protected Topological States and Local Symmetry in 2D Antiferromagnetic SrMn2Bi2 — •Hao Wang[1], Chengwang Niu[2], Libor Smejkal[3,4], and Yuriy Mokrousov[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]School of Physics, State Key Laboratory of Crystal Materials, Shandong University, Jinan 250100, China — [3]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [4]Institute of Physics Academy of Sciences of the Czech Republic, Cukrovarnicka 10, Praha 6, Czech Republic

Antiferromagnetic topological insulators (AFMTIs) represent a novel class of topological states for spintronics. Understanding symmetry protection and exploring AFMTIs with desirable properties are crucial. In this study, through first-principles calculations and symmetry analysis, we investigate the topological properties of monolayer SrMn2Bi2, demonstrating sensitivity to magnetic configurations. In the out-of-plane AFM ground state, we observe a gapless helical edge state protected by the mirror plane combined with time-reversal symmetry. In the FM state, this system resides in a quantum anomalous Hall phase, and topology trivial for in-plane magnetization. We show that the topological properties can be efficiently manipulated by strain. Additionally, constructing proper Wannier functions obeying symmetry constraints is crucial to avoid spurious states in surface spectra. Our work provides an ideal candidate for AFMTIs and guides the symmetry analysis of magnetic topological materials using Wannier functions.

15 min. break

TT 23.8 Tue 11:30 H 2013

Electrical Activity of Topological Chiral Edge Magnons — •Robin R. Neumann[1], Alexander Mook[2], Jürgen Henk[1], and Ingrid Mertig[1] — [1]Martin Luther University Halle-Wittenberg, Halle (Saale), Germany — [2]Johannes Gutenberg University, Mainz, Germany

Magnons, the bosonic quasiparticles of spin waves, have been predicted to feature similar topological phases as electrons. In particular, the topological band structure of the quantum Hall systems has its magnonic analogue in the topological magnon insulator (TMI), which hosts topologically protected chiral edge excitations. Beyond theoretical studies, however, there exist no direct experimental evidence of their existence as the lack of charge renders them invisible to most surface-sensitive probes.

In this talk I demonstrate how magnetoelectric coupling imparts an electric dipole moment to the chiral magnons that manifests in equilibrium and nonequilibrium. Considering a two-dimensional ferromagnetic TMI, an electric edge polarization perpendicular to the sample's edges is driven by thermal fluctuations of the collinear magnetic ground state in equilibrium. On the other hand, the TMI features a unique in-gap resonance in its electrical absorption spectrum that stems from the chiral magnons showcasing their electrical activity. These results suggest THz spectroscopy as promising probe for topological magnons.

TT 23.9 Tue 11:45 H 2013

Interplay of magnetism and band topology in $Eu_{1-x}Ca_xMg_2Bi_2$ (x=0, 0.5, 0.67) from first principles study — •Amarjyoti Choudhury, Narayan Mohanta, and Tulika Maitra — IIT Roorkee,India

The recent discovery of time-reversal symmetry-breaking magnetic Weyl semimetals (WSMs) has sparked extensive research in quantum topological materials. We systematically studied magnetic orders, electronic structure, and the interplay between magnetic order and band topology in $EuMg_2Bi_2$ (EMB) and its Ca-doped variant using density functional theory (DFT). Our investigation reveals various magnetic order-driven topological phases, such as a topological insulator in the A-type antiferromagnetic (A-AFM) phase with Eu moments along the *b*, a Dirac semimetal in the A-AFM phase with Eu moments along the *c* direction, and a Weyl semimetal in the ferromagnetic (FM) phase with Eu moments along the *c* direction. These phases are energetically close and tunable by external factors like magnetic field or chemical substitution. In the FM state of $EuMg_2Bi_2$, we identify an ideal Weyl semimetal with a single pair of Weyl points (WPs) close to the Fermi level along Γ-A direction. Doping with 50% and 67% Ca at Eu sites moves the WPs even closer to the Fermi level, making it highly desirable for applications. Additionally, the separation between WPs decreases in doped compounds, impacting anomalous Hall conductivity (AHC). Our first-principles calculation of AHC shows high peak values at these WPs, decreasing with Ca doping, indicating Ca as a potential external handle to tune AHC in this system.

TT 23.10 Tue 12:00 H 2013

Chiral spin textures in the B20 material family — •Iñigo Robredo[1], Jonas Krieger[2], Niels Schröter[2], Maia Vergniory[1], and Claudia Felser[1] — [1]MPI CPfS — [2]MPI Microstructure Physics

The spin texture of electronic bands has been studied for decades in magnetic materials due to its promising applications in the field of spintronics, which aims to exploit the spin degree of freedom. Recently, it has been shown that non-magnetic materials can present exotic spin textures, which makes them promising for microelectronics applications due to the lack of stray fields. In order to present non-trivial spin degeneracies, these systems break crystalline rotoinversion symmetries, and are thus structurally chiral. In this work we revisit the chiral toy model in space group 198 introduced in Ref [1] as a proxy for materials in the B20 family and study the spin textures as a function of spin-orbit coupling strength. We study the spin texture of the surface Fermi arcs, which has also attracted attention recently [2], and show that the spin-momentum locking varies along the surface BZ.

[1] Mao Lin, Iñigo Robredo, Niels B. M. Schröter, Claudia Felser, Maia G. Vergniory, and Barry Bradlyn Phys. Rev. B 106, 245101 [2] Jonas A. Krieger, Samuel Stolz, Inigo Robredo, et al, arXiv:2210.08221

TT 23.11 Tue 12:15 H 2013

Nonlinear optical diode effect in a magnetic Weyl semimetal — •Christian Tzschaschel[1,2], Jian-Xiang Qiu[2], Xue-Jian Gao[3], Hou-Chen Li[2], Chunyu Guo[4], Hung-Yu Yang[5], Cheng-Ping Zhang[3], Ying-Ming Xie[3], Yu-Fei Liu[2], Anyuan Gao[2], Damien

Bérubé[2], Thao Dinh[2], Sheng-Chin Ho[2], Yuqiang Fang[6,7], Fuqiang Huang[6,7], Johanna Nordlander[2], Qiong Ma[5], Fazel Tafti[5], Philip J.W. Moll[4], Kam Tuen Law[3], and Suyang Xu[2] — [1]Max Born Institute, Berlin, Germany — [2]Harvard University, Cambridge, USA — [3]Hong Kong University of Science and Technology, Hong Kong, China — [4]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [5]Boston College, Chestnut Hill, USA — [6]Shanghai Institute of Ceramics, Chinese Academy of Science, Shanghai, China — [7]College of Chemistry and Molecular Engineering Peking University, Beijing, China

We report the observation of a nonlinear optical diode effect (NODE) in the magnetic Weyl semimetal CeAlSi, where the magnetic state of CeAlSi introduces a pronounced directionality in the nonlinear optical second-harmonic generation (SHG). By physically reversing the beam path, we observe a strong directional contrast over a wide bandwidth exceeding 250 meV. Supported by first-principles calculations, we establish the linearly dispersive bands emerging from Weyl nodes as the origin of the extreme bandwidth. We further demonstrate current-induced magnetization switching and thus electrical control of the NODE in a spintronic device structure. Our results advance ongoing research to identify novel phenomena in magnetic quantum materials.

TT 23.12 Tue 12:30 H 2013

Origin of incommensurate magnetic order in rare-earth magnetic Weyl semimetals — •Juba Bouaziz[1], Gustav Bihlmayer[1], Christopher E. Patrick[2], Julie B. Staunton[3], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich JARA, D-52425 Jülich, Germany — [2]Department of Materials, University of Oxford, Parks Road, Oxford OX1 3PH, United Kingdom — [3]Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

We investigate rare-earth magnetic Weyl semimetals through first-principles simulations, analyzing the connection between incommensurate magnetic order and the presence of Weyl nodes in the electronic band structure. Focusing on PrAlSi, NdAlSi, and SmAlSi, we demonstrate that the reported helical ordering does not originate from the nesting of topological features at the Fermi Surface or the Dzyaloshinskii-Moriya interaction. Instead, the helical order arises from frustrated isotropic short-range superexchange between the 4f moments facilitated by pd-hybridization with the main group elements. Employing a spin Hamiltonian with isotropic exchange and single-ion anisotropy we replicate the experimentally observed helical modulation. Funding: European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (Grant No. 856538, project "3D MAGiC")

TT 23.13 Tue 12:45 H 2013

Surface magnon spectra of nodal loop semimetals — •Assem Alassaf[1], László Oroszlány[2], and János Koltai[3] — [1]Department of Physics of Complex Systems, ELTE Eötvös Loránd University, Pázmány Péter sétány 1/A, 1117 Budapest, Hungary — [2]Department of Physics of Complex Systems, ELTE Eötvös Loránd University, Pázmány Péter sétány 1/A, 1117 Budapest, Hungary; MTA-BME Lendület Topology and Correlation Research Group, Budafoki út 8., H-1111 Budapest, Hungary — [3]Department of Biological Physics, ELTE Eötvös Loránd University, Pázmány Péter sétány 1/A, 1117 Budapest, Hungary

in this paper, we establish a connection between the bulk topological structure and the magnetic properties of drumhead surface states of nodal loop semimetals. We identify the magnetic characteristics of the surface states and compute the system*s magnon spectrum by treating electron-electron interactions on a mean-field level. We draw attention to a subtle connection between a Lifshitz-like transition of the surface states driven by mechanical distortions and the magnetic characteristics of the system. Our findings may be experimentally verified, e.g. by spin-polarized electron energy loss spectroscopy of nodal semimetal surfaces.

TT 24: Quantum-Critical Phenomena

Time: Tuesday 9:30–13:15 Location: H 2053

TT 24.1 Tue 9:30 H 2053

Quantum criticality on a compressible lattice — Saheli Sarkar[1], •Lars Franke[2], Nikolas Grivas[2], and Markus Garst[1,2] — [1]Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, D-76131 Karlsruhe, Germany — [2]Institute of Theoretical Solid State Physics, Karlsruhe Institute of Technology, D-76131 Germany

The stability of a quantum critical point in the $O(N)$ universality class with respect to an elastic coupling, that preserves $O(N)$ symmetry, is investigated for isotropic elasticity in the framework of the renormalization group (RG) close to the upper critical dimension $d = 3 - \epsilon$. With respect to the Wilson-Fisher fixed point, we find that the elastic coupling is relevant in the RG sense for $1 \leq N \leq 4$, and the crystal becomes microscopically unstable, i.e., a sound velocity vanishes at a finite value of the correlation length ξ. For $N > 4$, an additional fixed point emerges that is located at a finite value of the dimensionless elastic coupling. This fixed point is repulsive and separates the flow to weak and strong elastic coupling. As the fixed point is approached the sound velocity is found to vanish only asymptotically as $\xi \to \infty$ such that the crystal remains microscopically stable for any finite value of ξ. The fixed point structure we find for the quantum problem is distinct from the classical counterpart in $d = 4 - \epsilon$, where the crystal always remains microscopically stable for finite ξ.

TT 24.2 Tue 9:45 H 2053

Quantum critical Dirac semimetals and finite-temperature effects — •Mireia Tolosa-Simeón[1], Laura Classen[2,3], and Michael M. Scherer[1] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]Department of Physics, Technical University of Munich, Garching, Germany

The chiral Ising-, XY-, and Heisenberg models serve as effective descriptions of Dirac semimetals undergoing a quantum phase transition into a symmetry-broken ordered state. Interestingly, their quantum critical points govern the physical behavior of the system in the vicinity of the transition even at finite temperatures. In this contribution, we explore the chiral models at zero and finite temperature, both in the Dirac phase as well as in the symmetry-broken phases. To that end, we set up a functional renormalization group approach, which allows us to systematically track (1) the phenomenon of pre-condensation, (2) the manifestation of the Mermin-Wagner-Hohenberg theorem due to pseudo-Goldstone fluctuations at finite temperatures, and (3) the quantitative behavior of the system in the quantum critical fan, e.g., by calculating the quasiparticle weight. Our work aims at a more holistic understanding of chiral models near their quantum critical point, including, e.g., the description of non-Dirac-liquid behavior, in analogy to the non-Fermi-liquid behavior in metallic quantum critical points.

TT 24.3 Tue 10:00 H 2053

Exotic quantum criticality in pyrochlore iridates — •David Jonas Moser and Lukas Janssen — Technische Universität Dresden, Dresden, Deutschland

Luttinger semimetals are three-dimensional strongly-spin-orbit-coupled systems, in which valence and conduction bands touch quadratically at the Fermi level. They provide a rich playground for highly unconventional physics and serve as a parent state to a number of exotic states of matter, such as Weyl semimetals, topological insulators, or spin ice. Here, we discuss various quantum critical phenomena beyond standard quantum criticality, including quasiuniversality and fixed point annihilation scenarios. Our results are relevant for the low-temperature behavior of rare-earth pyrochlore iridates, such as $Pr_2Ir_2O_7$ or $Nd_2Ir_2O_7$.

TT 24.4 Tue 10:15 H 2053

Quantum criticality of the antiferromagnetic XXZ square lattice bilayer with long-range interactions — •Patrick Adelhardt and Kai Phillip Schmidt — Department of Physics, Staudtstraße 7, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany

The majority of numerical approaches investigating quantum systems with algebraically decaying long-range interactions is restricted to one dimensions or to two-dimensional systems with quickly-decaying long-range interactions.While models with discrete symmetries like the long-range transverse-field Ising model have been studied thoroughly, much less is known about long-range models with continuous symmetries. We study the breakdown of the rung-singlet phase in the two-dimensional XXZ bilayer model with unfrustrated staggered long-range interactions. To this end we use the method of perturbative continuous unitary transformations (pCUT) with classical Monte Carlo simulations yielding high-order series in the thermodynamic limit about the limit of isolated dimers. This allows us to determine the critical point, the dispersion in the rung-singlet phase close to it, as well as critical exponents as a function of the decay exponent. While for quickly-decaying interactions we identify three critical regimes with 3D XY, Heisenberg, and Ising criticality depending on the anisotropy in the XXZ Hamiltonian, for strong interactions we observe a single long-range mean-field regime and continuously varying critical exponents between these regimes.

TT 24.5 Tue 10:30 H 2053

(Almost) Everything is a Dicke model — •Andreas Schellenberger and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Erlangen, Deutschland

We investigate classes of interacting quantum spin systems in a single-mode cavity with a Dicke coupling, as a paradigmatic example of correlated light-matter systems. Coming from the limit of weak light-matter couplings and large system sizes, we map the relevant low-energy sector of these models onto the exactly solvable Dicke model.

We apply the outcomes to the Dicke-Ising model as a paradigmatic example [1,2], in agreement with results obtained by mean-field theory [2]. We further accompany and verify our findings with finite-size calculations, using exact diagonalization and the series expansion method pcst++ [3].

[1] J. Rohn et al., Phys. Rev. Research 2 (2020) 023131
[2] Y. Zhang et al., Sci Rep 4 (2014) 4083
[3] L. Lenke et al., Phys. Rev. A 108 (2023)

TT 24.6 Tue 10:45 H 2053

Quantum Monte Carlo simulation of the Dicke-Ising model on hypercubic lattices — •Anja Langheld, Max Hörmann, and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We study the Ising model in a light-induced quantized transverse field [1, 2] using quantum Monte Carlo to investigate the influence of light-matter interactions on correlated quantum matter. To avoid a direct sampling of the photons, we develop a quantum Monte Carlo algorithm based on the recently introduced wormhole algorithm for spin-boson systems [3], in which the bosonic degrees of freedom are integrated out analytically.

We provide quantitative phase diagrams and critical properties for ferromagnetic as well as antiferromagnetic interactions on hypercubic lattices. For antiferromagnetic interactions, we confirm the existence of a non-trivial intermediate phase, displaying magnetic order and finite photon density at the same time, predicted by a semi-classical mean-field study [1]. However, this intermediate phase turns out to be much smaller and certain phase transitions turn out to be of first order rather than of second order. In the case of ferromagnetic interactions, a change in the order of the quantum phase transition for finite Ising coupling and longitudinal field is observed.

[1] J. Rohn et al., Phys. Rev. Research 2 (2020) 023131
[2] Y. Zhang et al., Sci Rep 4 (2014) 4083
[3] M. Weber et al., Phys. Rev. Lett. 119 (2017) 097401

TT 24.7 Tue 11:00 H 2053

From Nordic Walking in Wess-Zumino-Witten Theory to Deconfined Pseudocriticality — •Bilal Hawashin[1], Astrid Eichhorn[2], Lukas Janssen[3], Michael Scherer[1], and Shouryya Ray[2] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany — [2]CP3-Origins, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark — [3]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

An exciting class of non-Landau transitions are deconfined quantum critical points (DQCP) which exhibit emergent fractional excitations and gauge fields at criticality. The primary example in the study of DQCPs has been a system of half-integer spins on a square lattice with competing interactions. Whether or not this system shows true criticality is a major open question in the field. In fact, numerical simulations for this model provide evidence for weak-first order behavior. The effective field theory describing the behaviour between those orders is a 3D Wess-Zumino-Witten theory with target manifold S^4. I will discuss a first study of this model using the non-perturbative functional renormalization group. We show that the Wess-Zumino-Witten term gives rise to two possible mechanisms explaining pseudocriticality and drifting exponents: (1) the well-known Walking mechanism and (2) a new mechanism, dubbed Nordic Walking. We provide an estimate for effective thermodynamic critical exponents and their drifts as a function of system size.

15 min. break

TT 24.8 Tue 11:30 H 2053

Manipulating topology of quantum phase transitions by flavor enhancement — •Gabriel Rein[1,2], Marcin Raczkowski[1], Toshihiro Sato[2,3], Zhenjiu Wang[4], and Fakher F. Assaad[1,2] — [1]Institut für Theoretische Physik und Astrophysik Universität Würzburg, 97074 Würzburg, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany — [3]Theoretical Solid State Physics, IFW Dresden, 01069 Dresden, Germany — [4]Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 München, Germany

We consider a dynamically generated quantum spin Hall (QSH) state, characterized by skyrmion excitations of the SO(3) order parameter carrying charge $2e$. A model described in [1] uses parameter λ to drive a continuous transition, akin to deconfined quantum criticality, from a QSH insulator to an s-wave superconductor (SSC) via the condensation of charge $2e$ skyrmions. Here we enhance the symmetry of the model by introducing an additional flavor index $N_f = 2$. Remarkably, we observe a new Kékulé (VBS) phase and transitions between QSH/SSC as well as VBS/SSC. All phase transitions turn out to be of Ginzburg-Landau type. For the VBS/SSC transition we argue that this is due to a θ-term at $\theta = N_f \pi$. For the QSH/SSC transition, we conjecture that in 2+1 d the non-linear sigma model with level N_f Wess-Zumino-Witten term has relevant operators that induce ordered phases, thus requiring fine-tuning for observing a continuous transition. Similarities to the 1+1 d case [2] are highlighted.

[1] Y. Liu *et al.*, Nat. Comm. **10** (2019) 2658
[2] I. Affleck *et al.*, Phys. Rev. B **36** (1987) 5291

TT 24.9 Tue 11:45 H 2053

Deconfined Quantum Criticality in the long-range, anisotropic Heisenberg Chain — •Anton Romen[1,2], Stefan Birnkammer[1,2], and Michael Knap[1,2] — [1]Technical University Munich (TUM), TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany

Deconfined quantum criticality describes continuous phase transitions that are not captured by the Landau-Ginzburg paradigm. In our work, we investigate deconfined quantum critical points in the long-range, anisotropic Heisenberg chain. With matrix product state simulations, we show that the model undergoes a continuous phase transition from a valence bond solid to an antiferromagnet. We extract the critical exponents of the transition and connect them to an effective field theory obtained from bosonization techniques. We show that beyond stabilizing the valance bond order, the long-range interactions are irrelevant and the transition is well described by a double frequency sine-Gordon model. We propose how to realize and probe deconfined quantum criticality in our model with trapped-ion quantum simulators.

TT 24.10 Tue 12:00 H 2053

Magnetic Structure of the spin-1/2 antiferromagnetic XXZ chain $PbCo_2V_2O_8$ — •Cintli Aguilar Maldonado[1], Konrad Puzniak[1,2], Ralf Feyerherm[1], Karel Prokes[1], Nazmul Islam[1], Lukas Keller[3], Yurii Skourski[4], and Bella Lake[1,2] — [1]Helmholtz-Zentrum Berlin, Germany — [2]Technische Universität Berlin, Germany — [3]Paul Scherrer Institut, Switzerland — [4]Helmholtz-Zentrum Dresden-Rossendorf, Germany

The quasi-1D antiferromagnetic materials $AM_2V_2O_8$, have been found to harbour a wealth of exotic phases including Quantum phase transitions as a function of applied magnetic field. Here the M-sites are filled by a magnetic transition metal ion such as Cu^{2+}, Ni^{2+}, Co^{2+}

or Mn^{2+}, while the divalent A-site ion and V^{5+} are non-magnetic. Depending on the nature of the magnetic ion, different spin moments and anisotropies can be explored. Of particular interest are the members $ACo_2V_2O_8$ where A = Sr, Ba, which give rise to effective 1D spin-1/2 antiferromagnets with Heisenberg-Ising (or XXZ) exchange anisotropy due to the Co^{2+} ions which form 4-fold screw chains along the tetragonal **c**-axis. The intrachain coupling is strong and antiferromagnetic, while the interchain coupling is weak and eventually gives rise to long-range antiferromagnetic Néel order at sufficiently low temperatures. In this work $PbCo_2V_2O_8$, a new and unexplored member of the $ACo_2V_2O_8$ family, is studied by means of neutron powder and single crystal diffraction to determine the magnetic structure in zero magnetic field. The development of the magnetic structure under applied magnetic fields is also explored.

TT 24.11 Tue 12:15 H 2053

Quantum phase transition in the quasi-1D Ising antiferromagnet $SrCo_2V_2O_8$ in a transverse magnetic field
— •Konrad Puzniak[1,2], Cintli Aguilar-Maldonado[1], Anup Bera[3], Ralf Feyerherm[1], Nazmul Islam[1], Manfred Reehuis[1], Wolfgang Schmidt[4], Martin Boehm[4], Paul Steffens[4], Astrid Schneidewind[5], Igor Radelytskyi[5], Christian Balz[6], Ross Stewart[6], and Bella Lake[1,2] — [1]Helmholtz-Zentrum Berlin, Berlin, Germany — [2]TU Berlin, Berlin, Germany — [3]Solid State Physics Division, Bhabha Atomic Research Centre, Mumbai, India — [4]Institut Laue Langevin, Grenoble, France — [5]Jülich Centre at MLZ, Garching, Germany — [6]Neutron and Muon Source, Didcot, UK

The one-dimensional spin-1/2 antiferromagnet with Heisenberg-Ising (XXZ) anisotropy is an ideal model system to explore fundamental physics concepts. We focus on the properties of its member, which is $SrCo_2V_2O_8$. This compound crystallizes in the tetragonal space group $I4_1cd$. The Co^{2+} ions have effective $S = 1/2$ moments that are arranged in screw chains along the **c** axis. Weak interchain coupling gives rise to long-range magnetic order below $T_N = 5$ K. We report on inelastic neutron scattering, low-temperature heat capacity, and neutron diffraction conducted on single crystal $SrCo_2V_2O_8$ under transverse fields along the tetragonal **a**/**b** direction. In a transverse magnetic field applied along the **a** axis, $SrCo_2V_2O_8$ undergoes a transition at the field of $\mu_0 H^a_{c2} \approx 6.84$ T and the Néel-type magnetic ordering moment is completely suppressed in a magnetic field along the **a** axis, marking the emergence of a 3D quantum critical point.

TT 24.12 Tue 12:30 H 2053

Search for ferromagnetic quantum phase transitions in CePt
— •Florian Kübelbäck[1], Marc Seifert[1], Pau Jorba[1], Michael Schulz[2], Georg Benka[1], Andreas Bauer[1,3], and Christian Pfleiderer[1,2,3,4] — [1]Physik-Department, Technical University of Munich, D-85748 Garching, Germany — [2]MLZ, Technical University of Munich, D-85748 Garching, Germany — [3]Zentrum für Quantum Engineering (ZQE), Technical University of Munich, D-85748 Garching, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Technical University of Munich, D-85748 Garching, Germany

We report the growth of single crystal of CePt by means of the optical floating-zone method and the investigation of the low-temperature properties of this ferromagnetic compound. We combine x-ray diffraction, magnetization, and ac susceptibility measurements at ambient pressure with neutron depolarization studies on polycrystalline samples in diamond anvil cells at high pressure [1] to study the evolution of the magnetic properties. For lab-based measurements of the magnetization under high pressure, a bespoke coil set was converted for use in a Quantum Design Physical Property Measurement System.

[1] P. Jorba et al., Phys. Status Solidi B 2100623 (2022).

TT 24.13 Tue 12:45 H 2053

Failure of the Baym-Kadanoff construction to match consistently quantum dynamics with thermodynamic critical behavior
— Václav Janiš[1], Vladislav Pokorný[1], and •Šimon Kos[2] — [1]Institute of Physics, The Czech Academy of Sciences, Na Slovance 2, CZ-18200 Praha 8, Czech Republic — [2]University of West Bohemia, Univerzitní 8, CZ-301 00 Plzeň, Czech Republic

We disclose a serious deficiency of the Baym-Kadanoff construction of thermodynamically consistent conserving approximations. There are two vertices in this scheme: dynamical and conserving. The divergence of each indicates a phase instability. We show that each leads to incomplete and qualitatively different behavior at different critical points. The diagrammatically controlled dynamical vertex from the Schwinger-Dyson equation does not obey the Ward identity and cannot be continued beyond its singularity. The divergence in the conserving vertex, obeying the conservation laws, does not invoke critical behavior of the spectral function and the specific heat. Any description of critical behavior, hence, remains unreliable unless the fluctuations of the order parameter in the conserving vertex lead to a divergence coinciding with that of the dynamical vertex.

TT 24.14 Tue 13:00 H 2053

Quantum Monte Carlo simulations with nonlocal relativistic fermions
— •Thomas C. Lang[1] and Andreas M. Läuchli[2,3] — [1]University of Innsbruck, Innsbruck, Austria — [2]Paus Scherer Institut, Villigen, Switzerland — [3]École polytechnique fédérale de Lausanne, Lausanne, Switzerland

We compare large scale quantum Monte Carlo simulations of the Hubbard model at half filling with a single Dirac cone and on the honeycomb lattice close to the critical point, which separates a Dirac semimetal from an antiferromagnetically ordered phase where SU(2) spin rotational symmetry is spontaneously broken. The nonlocal nature of the finite size Dirac operator in real space results in a discontinuity at the boundary of the Brillouin zone. By comparing local and nonlocal Hamiltonians we discuss the efficiency of low energy effective Hamiltonians with respect to finite size corrections, momentum resolution and their applicability depending on the dimensionality of the problem. We address artefacts of the dynamically induced long range interaction in the ordered phase, the recovery of isotropy and linearity of the fermions and bosons close to criticality and extract the critical exponents, which are believed to belong to the chiral Heisenberg Gross-Neveu-Yukawa universality class.

TT 25: Nonequilibrium Quantum Systems I (joint session TT/DY)

Time: Tuesday 9:30–13:00 Location: H 3005

TT 25.1 Tue 9:30 H 3005

Periodically Driven Heavy-Fermion Systems — •Michael Turaev[1] and Johann Kroha[1,2] — [1]Physikalisches Institut, Universität Bonn, Germany — [2]School of Physics & Astronomy, University of St. Andrews, UK

In this work we study the effects of terahertz (THz) light irradiation on heavy-fermion systems. A typical model for such systems is the periodic Anderson model where strongly repulsive, localized electrons in the 4f shell of rare-earth ions hybridize with a sea of conduction electrons. The Kondo effect induces a new flat band of heavy-fermions, near the Fermi energy. Applying a stationary THz light field induces a time-periodic hybridization between the conduction and the 4f electrons, rather than a modulation of the on-site 4f energy, due to the dipole selection rules. On one hand, the Floquet theorem predicts that the periodic driving produces replicas of the Kondo resonance, centered around multiples of the driving frequency. However, the THz light field could also break up the Kondo singlets, thereby destroying the heavy-fermion state altogether.

To analyze such a scenario we use the non-equilibrium dynamical mean field theory (DMFT), combined with the Floquet-Keldysh Green function method. We obtain that for weak driving compared to the bare hybridization, the Kondo effect is preserved and Floquet replicas of the heavy-fermion bands are observed. However, a strong driving can lead to an efficient suppression of the Kondo effect where the spectral weight of the flat band is reduced.

TT 25.2 Tue 9:45 H 3005

Stabilization of a paramatrically driven BEC: an open quantum system approach — •Larissa Schwarz, Simon B. Jäger, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

We theoretically analyze the effects of periodically modulated repulsive interactions in a Bose-Einstein condensate (BEC) that features intrinsic damping mechanisms. We derive a master equation describing the dynamics of the momentum modes of the BEC in the parameter regime of weak driving strengths. Above a threshold for the modulation strength we find that the BEC becomes unstable. Below this threshold the combination of damping and periodic driving guides the system into a stationary state that shows an enhancement of fluctuations for specific momentum modes that can be controlled by the driving frequency. We analyze the stationary state of these fluctuations, quantify the condensate depletion and analyze the squeezed and anti-squeezed quadratures generated by the parametric driving, emphasizing the possibility to generate non-classical states of matter.

TT 25.3 Tue 10:00 H 3005

Charge density wave melting in higher dimensional Holstein models — •Eva Paprotzki[1], Alexander Osterkorn[2], Vibhu Mishra[3], and Stefan Kehrein[3] — [1]I. Institut für Theoretische Physik, Universität Hamburg — [2]Institut "Jožef Stefan", Ljubljana, Slovenien — [3]Institut für Theoretische Physik, Georg-August-Universität Göttingen

We study the Holstein model after a quench from the insulating charge density wave (CDW) state. Employing a semiclassical treatment of the phonons ('Truncated Wigner Approximation'), we are able to track the CDW order parameter in two- and three-dimensional systems. The number of dynamical variables increases only quadratically with system size. We pose the question whether the order parameter dynamics in higher-dimensional lattices can be connected to the dynamics of the one-dimensional case via factorization. Next to an analytical estimation for the time scale of such a relation, we provide numerical evidence for the weak and strong coupling regime based on our semiclassical methods. An additional semiclassical description of the electrons ('fermionic Truncated Wigner Approximation') yields better agreement with exact reference data in one spatial dimension for the order parameter and, in particular, for the phonon number than the approach with purely phononic semiclassical dynamics.

TT 25.4 Tue 10:15 H 3005

Quantum geoemtry and dynamics in in-homogeneous fields — •Chen Xu[1,2], Andreas Haller[1], Suraj Hegde[2], Tobias Meng[2], and Thomas L. Schmidt[1] — [1]Department of Physics and Materials Science, University of Luxembourg, Luxembourg — [2]Faculty of Physics, TU Dresden, Germany

We revisit the problem of nonequilibrium semiclassical electron transport in the presence of inhomogeneous external perturbations. For this purpose, we study the quantum geometry of Bloch band structure beyond the Berry connection contribution. We provide a systematic way of obtaining semiclassical equations of motion in an N-band system and for higher order variations in inhomogeneities, we compute geometric corrections containing for example Berry phase and quantum geometric tensor. We also demonstrate how to derive the dynamics from a generic coupling between Bloch momentum and an inhomogeneous external field, thus generalizing previous studies.

TT 25.5 Tue 10:30 H 3005

Non-equilibrium Eliashberg theory for photon-mediated superconductivity — •Michele Pini[1], Christian H. Johansen[1,2], and Francesco Piazza[3,1] — [1]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [2]Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń, Grudziądzka 5, 87-100 Toruń, Poland — [3]Institute of Physics, Universität Augsburg, 86159 Augsburg, Germany

In the recent years, new mechanisms have been proposed to induce photon-mediated superconductivity in a non-thermal steady-state. Within these settings, the photon-electron interaction which generates the pairing can assume a form analogous to an electron-phonon interaction. This suggests a description of the superconducting phase transition within Eliashberg theory, similarly to phonon-mediated superconductivity. However, as soon as photons and electrons are pulled away from mutual equilibrium, a standard Matsubara formulation of Eliashberg theory becomes impossible. To tackle this issue, we derive a more general non-equilibrium version of Eliashberg theory. We then apply this theory to describe the superconducting phase transition in a generic non-thermal steady-state setting. We present a numerical solution of the non-equilibrium Eliashberg equations and show that bringing the system out of equilibrium can have dramatic effects on the superconducting phase transition.

Note: The authors M. Pini and C. H. Johansen contributed to this work equally.

TT 25.6 Tue 10:45 H 3005

Few-body purity as an arrow of time in the Lanczos picture — •Merlin Füllgraf and Jochen Gemmer — Department of Mathematics/Computer Science/Physics, University of Osnabrück, D-49076 Osnabrück, Germany

The Lanczos method to compute autocorrelation functions in quantum mechanics gives rise to so-called Lanczos coefficients associated with operator growth in the respective systems. These coefficients can be interpreted as hopping amplitudes of a semi-infinite tight-binding model whose first site corresponds to the correlation function itself. In this picture we introduce a few-body purity and study it against the background of an arrow of time. Moreover, we investigate the influence of structures in the Lanczos coefficients on this quantity and propose a qualitative model solely based on these coefficients describing their influence on the systems' dynamics.

[1] D.E. Parker, X. Cao, A. Avdoshkin, T. Scaffidi, E. Altman, Phys. Rev. X 9 (2019) 041017
[2] V.S. Viswanath, G. Müller, The Recursion Method: Applications to Many-Body Dynamics, Springer, New York (2008).

TT 25.7 Tue 11:00 H 3005

Hilbert space fragmentation and slow dynamics in particle-conserving quantum East models — •Pietro Brighi[1], Marko Ljubotina[2], and Maksym Serbyn[2] — [1]University of Vienna, Boltzmanngasse 5, 1090 Vienna Austria — [2]ISTA, am Campus 1, 3400 Klosterneuburg Austria

Quantum kinetically constrained models have recently attracted significant attention due to their anomalous dynamics and thermalization. In this work, we introduce a hitherto unexplored family of kinetically constrained models featuring conserved particle number and strong inversion-symmetry breaking due to facilitated hopping. We demonstrate that these models provide a generic example of so-called quantum Hilbert space fragmentation, that is manifested in disconnected sectors in the Hilbert space that are not apparent in the computational basis. Quantum Hilbert space fragmentation leads to an exponential in system size number of eigenstates with exactly zero entanglement entropy across several bipartite cuts. These eigenstates can be probed dynamically using quenches from simple initial product states. In addition, we study the particle spreading under unitary dynamics, and find faster than diffusive dynamics at high particle densities, crossing over into logarithmically slow relaxation at smaller densities. Our work suggests that particle conserving constrained models with inversion symmetry breaking realize so far unexplored dynamical behavior and invite their further theoretical and experimental studies.

15 min. break

TT 25.8 Tue 11:30 H 3005

Influence of low- and high-energy magnetic excitations on electron dynamics in the vicinity of the Mott transition: a non-equilibrium D-TRILEX study — •Nagamalleswara Rao Dasari[1], Hugo U. R. Strand[2], Martin Eckstein[1], Alexander I. Lichtenstein[1], and Evgeny A. Stepanov[3] — [1]Institut für Theoretische Physik, Universität Hamburg, Notkestraße 9 , 22607 Hamburg, Germany — [2]School of Science and Technology, Orebro University, SE-70182 Obrebo, Sweden — [3]CPHT, CNRS, École polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France

We present a simplified real-time diagrammatic method based on the dual triply irreducible local expansion (D-TRILEX) formalism and apply it to the single-band extended Hubbard model. In the vicinity of Mott-transition, we observed signatures of "water-fall" structures at low-binding energies and sharp dispersive high-energy bands in the momentum-resolved electronic spectrum. In the photo-excitation dynamics, these spectral features melt very slowly on the electronic time scale, allowing us to measure these slow dynamics in the time-resolved photo-emission spectrum. In addition, the electron-magnon interaction in metals manifests through the fast relaxation of electronic kinetic energy due to the rapid thermalization of magnons much earlier than the electron's thermalization time scale. However, in the Mott-insulators, the photo-excited charge carriers transfer their excess kinetic energy to low-energy magnons instead of low-energy electrons (expected for impact ionization), leading to a non-thermal magnon distribution on a typical electronic time scale.

TT 25.9 Tue 11:45 H 3005

Effective time-dependent temperature method for fermionic master-equations — •Lukas Litzba, Eric Kleinherbers, Nikodem Szpak, and Jürgen König — Faculty of Physics and CENIDE, University of Duisburg-Essen, 47057 Duisburg, Germany

We consider a quantum system coupled to a fermionic environment at a fixed temperature. Using the Redfield equation with time-dependent coefficients, we analyze the reduced evolution of the system. We find that the time-dependence of these coefficients can be described by an effective time-dependent contact temperature. In this way, we obtain a method which includes non-Markovian effects and can be applied to various types of Gorini-Kossakowski-Sudarshan-Lindblad equations. With this, we discuss its application to a simple setup consisting of quantum dots which may be realized experimentally. At short times, the effective temperature appears to be much higher than the true temperature of the environment but asymptotically it settles down towards the true environment value. This behavior follows from the formation of coherences between the system and the environment for short times, which is related to a transfer of energy from the coupling term of the Hamiltonian into the system.

TT 25.10 Tue 12:00 H 3005

Mean-field Decoupling of Single Impurity Anderson Model through Auxiliary Majorana Fermions — •Irakli Titvinidze[1], Julian Stobbe[1], Alexey N. Rubtsov[2], and Georg Rohringer[1] — [1]I. Institute of Theoretical Physics, University of Hamburg, 20355 Hamburg, Germany — [2]Moscow

We present a new method to study the time evolution of the single impurity Anderson model. We perform a mean-field decoupling of the impurity and the chain. This is achieved by introducing a pair of auxiliary Majorana fermions between the impurity and the chain. We obtain a self-consistent set of equations for the impurity and the chain. By solving them in equilibrium we obtain a phase transition between phases in which the mean field parameters are zero and we have a well-defined spin on the impurity, and the regime in which the mean field parameters take finite values and there is no well-defined spin. Once we know the equilibrium properties of the system, we quench one or more model parameters and study the time evolution of the impurity and the chain. Within our mean-field treatment, we obtain a coupled set of differential equations for the impurity and chain and find that the results converge to their equilibrium values for most quenches. For very strong interactions, the excitations are trapped and the oscillations never persist.

TT 25.11 Tue 12:15 H 3005

Emergence of unitary symmetry of microcanonically truncated operators in chaotic quantum systems — •jiaozi wang[1], jonas richter[2,3], mats lamann[1], robin steinigeweg[1], jochen gemmer[1], and anatoly dymarsky[4] — [1]U Osnabrück, Germany — [2]U Stanford, USA — [3]LU Hannover, Germany — [4]U Kentucky, USA

We study statistical properties of matrix elements entering the eigenstate thermalization hypothesis by studying the observables written in the energy eigenbasis and truncated to small micro- canonical windows. We put forward a picture, that below certain energy scale collective statistical properties of matrix elements exhibit emergent unitary symmetry. In particular, below this scale the spectrum of the microcanonically truncated operator exhibits universal behavior for which we introduce readily testable criteria. We support this picture by numerical simulations and demonstrate existence of emergent unitary symmetry scale for all considered operators in chaotic many-body quantum systems. We discuss operator and system-size dependence of this energy scale and put our findings into context of previous works exploring emergence of random-matrix behavior in narrow energy windows.

[1] J. Wang, M. Lamann, J. Richter, R. Steinigeweg, A. Dymarsky, J. Gemmer, Phys. Rev. Lett. 128 (2022) 180601
[2] J. Wang, J. Richter, M. H. Lamann, R. Steinigeweg, J. Gemmer, A. Dymarsky, arXiv: 2310.20264 (2023)

TT 25.12 Tue 12:30 H 3005

Periodically Driven Spin-1/2 XXZ Antiferromagnetic Chains — •Dominic Windecker[1], Aslam Parvej[2], and Sebastian Eggert[1] — [1]University of Kaiserslautern-Landau, Landesforschungszentrum OPTIMAS — [2]Universität Hamburg

Time-periodically driven quantum systems are of great interest due the possibility of unconventional states of matter and Floquet engineering. The interplay of many-body interactions and time-periodic manipulations facilitate new phenomena in the steady state. We analyze the Floquet steady states of finite spin-1/2 XXZ antiferromagnetic chains with periodically driven anisotropy parameter at frequencies below the band width, so that resonances are in principle possible. We use three different numerical real-time approaches (TS1, TS2 and RK4) with an adiabatic time-evolution protocol by ramping up the driving amplitude of the external periodic drive to prepare a non-equilibrium Floquet steady state. Stability, accessibility, preparation and characteristics of parametric resonance states in finite systems are discussed.

TT 25.13 Tue 12:45 H 3005

Tuning the switching behavior of oligophenyls in metal-molecule-metal junctions by fluorine substituents — •Shengming Zhang[1], Zhiqiang Li[2], Joachim Reichert[1], Hai Bi[2], and Johannes Barth[1] — [1]Physics Department E20, Technical University of Munich, Germany — [2]Jihua Laboratory, Foshan, China

Single-molecule junctions represent a promising avenue in the realm of nanometer-scale electronic device development. Numerous investigations have concentrated on the I-V relationship, which often falls short in fully characterizing a single-molecule junction. In our study, we use Raman spectroscopy as a complementary tool to explore the vibrational states of individual, covalently bound molecules while sweeping the bias. Our focus is on a series of three terphenyl species. The first molecule incorporates four methyl side groups which aim to hinder the planarization of the neutral molecules. The molecules get transiently charged above a certain threshold voltage and coplanarize their phenyl rings. This conformational change goes along with an extension of the π-electron system, increases the polarizability and thus the Raman activity of the molecules significantly. In the second and third molecule, one resp. two methyl groups where fluorine substituted in order to tune the alignment of the HOMO to the Fermi level of the electrodes upon junction formation. This way, we can steer the threshold voltage where transient charging is planarizing the molecule. This approach underscores the tunability of characteristic transport properties in a molecular model system by intricate changes in its molecular structure.

TT 26: Nanotubes and Nanoribbons

Time: Tuesday 9:30–11:30 Location: H 3007

TT 26.1 Tue 9:30 H 3007

Electronic transport in bent carbon nanotubes — Eric Kleinherbers[1,2], Thomas Stegmann[3], and •Nikodem Szpak[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, 47057 Duisburg, Germany — [2]Department of Physics and Astronomy, University of California, Los Angeles, California 90095, USA — [3]Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, 62210 Cuernavaca, Mexico

We study the electronic transport through uniformly bent carbon nanotubes. For this purpose, we describe the nanotube with the tight-binding model and calculate the local current flow by employing nonequilibrium Green's functions (NEGF) in the Keldysh formalism. In addition, we describe the low-energy excitations using an effective Dirac equation in curved space with a strain-induced pseudomagnetic field, which can be solved analytically for the torus geometry in terms of the Mathieu functions. We obtain a perfect quantitative agreement with the NEGF results. For nanotubes with an armchair edge, already a weak bending of 1

[1] E. Kleinherbers, T. Stegmann, N. Szpak, Phys. Rev. B 107 (2023) 195424

TT 26.2 Tue 9:45 H 3007

Microwave generation and vortex jets in superconductor nanotubes — •Vladimir M. Fomin[1,2], Oleksandr V. Dobrovolskiy[3], and Igor Bogush[1,2] — [1]Leibniz IFW Dresden, IET, 01069 Dresden, Germany — [2]Moldova State University, 2009 Chişinău, Republic of Moldova — [3]University of Vienna, Nanomagnetism and Magnonics, Superconductivity and Spintronics Laboratory, 1090 Vienna, Austria

The dynamics of superconducting (Abrikosov) vortices determine the resistive response of superconductors. In pinning-free planar thin films, the penetration and motion of vortices are controlled by edge defects, leading to such arrangements as vortex chains, vortex jets, and phase-slip regimes. Relying upon the time-dependent Ginzburg-Landau equation, we predict that these vortex patterns should appear in superconductor open nanotubes even without edge defects, due to the inhomogeneity of the normal magnetic induction component. Distinct from planar thin films, the vortex jets are constrained within the half-tubes and correlate strongly between them. Due to a stronger confinement of single vortex chains in tubes of small radii, we reveal jumps in the average voltage and frequency of microwave generation, which occur when the number of fluxons moving in the half-tubes increases by one. We also realize non-symmetric vortex jets and chains by tilting the magnetic field in the plane perpendicular to the nanotube axis, with a jet-to-chain transition unseen for planar constrictions. In all, our findings are essential for novel 3D superconductor devices, which can operate in few- and multi-fluxon regimes.

TT 26.3 Tue 10:00 H 3007

Superconducting vortex diode effect in open nanotubes — Rodrigo H. de Bragança[1,2], Igor Bogush[2,3], and •Vladimir M. Fomin[2,3] — [1]Universidade Federal de Pernambuco, Departamento de Física, Centro de Ciências Exatas e da Natureza, 50740-560 Recife, Brasil — [2]Leibniz IFW Dresden, IET, 01069 Dresden, Germany — [3]Moldova State University, 2009 Chişinău, Republic of Moldova

Due to advances in high-tech roll-up technology and direct-write nanoprinting using focused electron and ion beams, novel complex-geometry 3D nanoarchitectures have been fabricated that provide new tools for controlling vortex motion. We focus on the vortex ratchet effect due to periodic asymmetric pinning potentials, which bias or rectify the vortex motion, in a rolled-up open Nb nanotube of a small thickness with a paraxial slit. It is demonstrated that the nontrivial topology of the screening currents in the open nanotube together with asymmetric pinning centers give rise to a superconducting vortex diode effect. Numerical simulations have provided the current–voltage characteristics and the efficiency of the superconducting diode effect. Vortices move over paths along two narrow channels, where the normal component of the magnetic field is close to maximal. We attribute the high efficiency of the diode effect in the system to the asymmetric pinning centers placed in the narrow channels, where the vortices move. In the system under analysis, we obtain a twice higher resistance for the transport current in one direction than in another one. These results shed light on the perspectives of application of 3D superconducting nanoarchitectures by virtue of the superconducting diode effect.

TT 26.4 Tue 10:15 H 3007

Superfluidity without superfluid: frictionless He-transport through a carbon nanotube — •Alberto Ambrosetti, Pier Luigi Silvestrelli, and Luca Salasnich — Università degli Studi di Padova (Italy)

In a conventional superfluid, such as ^{4}He or dilute atomic-gases at very low temperatures, a mesoscopic particle can freely move, experiencing no friction. According to Landau's superfluidity criterion, the quasi-linear collective excitation spectrum of the superfluid forbids quantum scattering between the superfluid and the moving mesoscopic particle, below a critical velocity. Here we predict frictionless-motion also in the absence of conventional superfluids, namely when a He atom flows inside a narrow carbon nanotube (CNT). Due to the quasi-linear spectrum of its collective plasmon and phonon modes, the CNT represents a solid analog of the superfluid medium, and admits extension of Landau's criterion of superfluidity. The superfluidity mechanism accordingly acquires broader generality, and is shown to persist up to much higher temperatures.

TT 26.5 Tue 10:30 H 3007

Magnetotransport in iron-filled nanotubes: learning about the properties of iron nanoparticle chains — Subhadeep Datta[1], •Magdalena Marganska[2], Luca Magazzu[2], and Milena Grifoni[2] — [1]School of Physical Sciences, Indian Association for the Cultivation of Science, Kolkata, India — [2]Institute for Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany

Carbon nanotubes, with their hollow cores, are often used to encapsulate smaller molecules and nanoparticles. The properties of the smaller system can then be studied through their influence on the carbon nanotube behaviour. We present the results of an experiment measuring magnetotransport in quantum dots created from carbon nanotubes filled with iron/iron oxide nanoparticles. We observe the signatures of the magneto-Coulomb effect and hybridization between the electronic states of iron and of the nanotube dependent on the gate voltage. From the hysteretic behaviour of the conductance we extract the possible magnetization curves of the iron nanoparticles, identifying the ferromagnetic nature of their interactions.

TT 26.6 Tue 10:45 H 3007

Ultrafast Dynamics of Laser-Excited Topological Edge States in Graphene Nanoribbon Heterostructures — •Jan-Philip Joost and Michael Bonitz — Kiel University, Institute for Theoretical Physics and Astrophysics, 24098 Kiel, Germany

The electromagnetic properties of finite graphene nanoribbon (GNR) heterostructures are strongly affected by localized topological edge states [1].Recently, we showed for 7-9-armchair-GNRs that the increased electronic correlations of these states results in increased magnetic moments at the ribbon edges accompanied by a significant energy renormalization of the topological end states, even in the presence of a metallic substrate [2]. Here, we improve the description of the system by including long-range Coulomb interactions within the Pariser–Parr–Pople Model. We study the ultrafast electron response in a freestanding unit cell of the 7-9-armchair-GNR following a laser excitation by employing our newly developed dynamically screened ladder (DSL) approximation within the G1–G2 scheme [3], which goes well beyond the *GW* description by including strong coupling effects. We find that the localized edge states play a major role in the ultrafast electron dynamics within the first 30fs after the laser interaction.

[1] J.-P. Joost et al., Nano Lett. **19** (2019) 9045
[2] D. J. Rizzo et al., Nature **560** (2018) 204
[3] J.-P. Joost et al., Phys. Rev. B **105** (2022) 165155

TT 26.7 Tue 11:00 H 3007

Ionic liquid gating of MoS_2 nanotubes and ribbons — •Konstantin D. Schneider[1], Robin T. K. Schock[1], Stefan Obloh[1], Matthias Kronseder[1], Matjaž Malok[2], Maja Remškar[2], and Andreas K. Hüttel[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Solid State Physics Department, Institute Jožef Stefan, 1000 Ljubljana, Slovenia

Due to its intrinsic layered, quasi-two dimensional nature the semiconductor MoS_2 is at the center of many research efforts. While its optical parameters and semiconducting characteristics are the main focus of research, previous work has also shown that MoS_2 exhibits superconductivity when increasing its charge density by heavily doping the MoS_2 surface using an ionic liquid gate [1]. Here we present our efforts to reach superconductivity in MoS_2 nanotubes and -ribbons, the intrinsically one-dimensional variants of this material. Our nanotubes are grown via a chemical transport reaction, yielding diameters down to 7 nm and lengths up to several millimeters. For device definition, we utilize fabrication methods previously developed to create MoS_2 quantum dots [2]. To maximise the contact area of MoS_2 and the ionic dopant, the nanotubes are suspended by transferring them onto predefined contacts. DEME-TFSI is then applied to the chip prior to cooldown.

[1] T. Ye *et al.*, Science **338** (2012) 1193
[2] R. T. K. Schock *et al.*, Adv. Mater. **35** (2023) 2209333

TT 26.8 Tue 11:15 H 3007

Ab-initio study of electromigration forces on atoms on graphene nanoribbons — •Susanne Leitherer[1], Mads Brandbyge[2], and Gemma C. Solomon[1,3] — [1]Nano-Science Center and Department of Chemistry, Copenhagen University,Denmark — [2]Department of Physics, Technical University of Denmark,Denmark — [3]NNF Quantum Computing Programme, Niels Bohr Institute, University of Copenhagen, Denmark

In this contribution, we study the electromigration of atoms on 2D armchair graphene nanoribbons, as investigated in recent scanning probe experiments [1], employing first principles electronic structure and transport calculations [2]. Our findings show that the electromigration forces on the adatoms are related to the induced charges in the adsorbate-surface bonds rather than only to the induced atomic charges [3]. A left/right effective bond order can be used to predict the force direction. Focusing in particular on 3d transition metal atoms, we show how a simple model of a metal atom on benzene can explain the forces in an inorganic chemistry picture. Our study demonstrates that models including the ligand field of the atoms might provide a better understanding of adsorbate migration on 2D surfaces under non-equilibrium conditions.

[1] T. Preis et al., Nano Lett. 21 (2021) 8794
[2] N. Papior et al., Comput. Phys. Commun. 212 (2017) 8
[3] S.Leitherer et al., JACS-Au (2023, accepted)

TT 27: Correlated Electrons: Other Materials

Time: Tuesday 9:30–13:00 Location: H 3010

TT 27.1 Tue 9:30 H 3010

Orbital imaging in VO_2 across the insulator to metal transition — •Paulius Dolmantas[1], Chun-Fu Chang[1], Martin Sundermann[1,2], Hlynur Gretarsson[1,2], Marcus Schmidt[1], Maurits W. Haverkort[3], and Arata Tanaka[4] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]DESY/PETRA-III, Hamburg, Germany — [3]Institute for Theoretical Physics, Heidelberg University, Heidelberg, Germany — [4]Department of Quantum Matter, Hiroshima University, Japan

Transition metal oxide VO_2 undergoes an metal to insulator transition (MIT) at 340 K from insulating monoclinic phase to a metallic rutile phase. For many decades this MIT in VO_2 has been extensively studied and still is a subject of debate whether it is driven by Mott-Hubbard mechanism or Peierls mechanism. X-ray absorption measurements together with multiplet theory calculations indicated orbital redistribution from almost isotropic in the metallic phase at 373 K to strongly σ orbital polarized at 300 K, suggesting a collaborative Mott-Peierls transition mechanism. Using recently developed X-ray-based orbital-imaging method, we experimentally and directly observe an orbital redistribution across the transition, no theoretical calculations involved. We find that at 20K VO_2 has indeed mainly σ orbital character in the insulating phase. The σ orbital polarization vanishes above the transition. This direct observation of the orbital redistribution across a MIT shall have significant implications for abinitio modeling of metal-insulator transitions.

TT 27.2 Tue 9:45 H 3010

Manipulating the metal-insulator transition in ultrathin oxide films by strain engineering — •Sizhao Huang, Martin Kamp, Fabian Hartmann, Philipp Scheiderer, Judith Gabel, Michael Sing, and Ralph Claessen — Physikalisches Institut and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany

Correlation-induced metal-insulator transitions (MIT) in transition-metal oxides (TMO) have been intensively studied in the past, especially on bulk samples [1]. In TMO films, numerous phenomena can be induced by strain or by reducing the film thickness towards the 2D limit, as, e.g., in $SrVO_3$ (SVO) [2]. In our previous studies on $SrTiO_3$ (STO) capped SVO films, a transition from the Mott insulating state at 6 u.c. to metallic behaviour at 10 u.c. film thickness has been found. In order to further control the MIT transition, we have grown coherently strained SVO thin films on various substrates with different lattice constants by pulsed laser deposition (PLD). Using x-ray photoelectron spectroscopy, reciprocal space mapping and transport measurements, we demonstrate that the MIT in SVO thin films can be fine-tuned by both film thickness and strain, which clears the way for Mottronics applications.

TT 27.3 Tue 10:00 H 3010

The Lorenz ratio as a guide to scattering contributions to Planckian transport — •Fei Sun[1], Simli Mishra[1], Ulrike Stockert[1], Ramzy Daou[2], Naoki Kikugawa[3], Robin S. Perry[4,5], Elena Hassinger[1], Sean A. Hartnoll[6], Andrew P. Mackenzie[1,7], and Veronika Sunko[1,8] — [1]MPI, CPfS, Dresden, Germany — [2]CRISMAT, Caen, France — [3]National Institute for Materials Science, Ibaraki, Japan — [4]University College London, London, UK — [5]ISIS Neutron and Muon Source, UK — [6]University of Cambridge, Cambridge, UK — [7]University of St. Andrews, St. Andrews, UK — [8]University of California Berkeley, USA

A characteristic quantum-mechanical time scale of approximately $\hbar/k_{BT}$ has been identified recently in both theory and experiment, leading to speculation that it may be the shortest meaningful time in many-body physics. It can be probed in depth by studying the scattering of electrons in solids, however, in metallic oxides, which are among the most studied materials, analysis of electrical transport does not satisfactorily identify the relevant scattering mechanism at high T near room temperature. We employ a contactless optical method to measure thermal diffusivity in two Ru-based layered perovskites, $Sr_3Ru_2O_7$ and Sr_2RuO_4, and use the measurements to extract the dimensionless Lorenz ratio. We show how the analysis of high-T thermal transport can both give important insight into dominant scattering mechanisms, and be offered as a stringent test of theories attempting to explain anomalous scattering.

TT 27.4 Tue 10:15 H 3010

Ferromagnetism in epitaxial $Ca_{1-x}Sr_xIrO_3$ thin films grown by metal-organic aerosol deposition — •Robert Gruhl, Ludwig Scheuchenpflug, Robin Heumann, and Philipp Gegenwart — Experimentalphysik VI, Universität Augsburg, Germany

$SrIrO_3$ is a paramagnetic semimetal with strong spin-orbit coupling which can give rise to various interesting physical states [1]. The isostructural and isoelectric perovskite phase of $CaIrO_3$ has very similar properties but a significantly smaller unit cell [2]. This enables a tuning of the lattice parameter over a wide range by chemical doping in the form of $Ca_{1-x}Sr_xIrO_3$.

Suprisingly small amounts of Calcium lead to a ferromagnetic phase in the investigated fully strained thin films as indicated by an emergent anomalous Hall effect. This behaviour is accopanied by an unusual increase in the out-off-plane lattice parameter.

Epitaxial thin films of $Sr_{1-x}Ca_xIrO_3$ are deposited on STO(001) substrates by metal-organic aerosol deposition, which conveniently allows to grow thin films with varying chemical compositions, since in contrast to PLD no target is required. The structural properties of the samples are investigated by x-ray diffraction and TEM imaging. The electronic and magnetic properties are studied by Hall- and mag-

netoresistance as well as magnetization mesasurements.
[1] K. Kleindienst *et al.*, Phys. Rev. B 98, 115113 (2018).
[2] A. Biswas *et al.*, J. Appl. Phys. 21, 195305 (2015).

TT 27.5 Tue 10:30 H 3010

Dynamics of exciton-polaritons in optically driven ZnO nano-particles — Andreas Lubatsch[1] and •Regine Frank[2,3] — [1]Physikalisches Institut, Rheinische Friedrich Wilhelms Universität Bonn — [2]College of Biomedical Sciences, Larkin University, Miami, Florida, USA — [3]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain

We implement externally excited ZnO Mie resonators in a framework of a generalized Hubbard Hamiltonian to investigate the lifetimes of excitons and exciton-polaritons outthermodynamical equilibrium. Our results are derived by a Floquet-Keldysh-Green's formalism with Dynamical Mean Field Theory (DMFT) and a second order iterative perturbation theory solver (IPT). We find polaritons that result from the Fano resonance in the sense of coupling of the continuum of the LDOS to the ZnO resonator with lifetimes between 0.6 ps and 1.45 ps. Our results are compared to rescent experiments of ZnO polariton lasers and to ZnO random lasers.
[1] A. Lubatsch, R. Frank, Appl. Sci. 10 (2020) 1836
[2] A. Lubatsch, R. Frank, Symmetry 11 (2019) 1246
[3] T.-C. Lu, et. al., Opt. Express 20 (2010) 5530

TT 27.6 Tue 10:45 H 3010

Superconductivity and Mottness in Organic Charge Transfer Materials — Henri Menke[1,2], Marcel Klett[1], Kazushi Kanoda[1,3], Antoine Georges[4], Michel Ferrero[5], and •Thomas Schäfer[1] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart — [2]University of Erlangen-Nürnberg — [3]University of Stuttgart — [4]Center for Computational Quantum Physics, Flatiron Institute — [5]CPHT, CNRS, École Polytechnique, Palaiseau

The phase diagrams of organic superconductors assemble a plethora of fundamental phenomena of strongly correlated systems in two dimensions. We analyze a minimal model for these compounds, the Hubbard model on an anisotropic triangular lattice, by means of cutting-edge quantum embedding methods, respecting the lattice symmetry. We determine the crossover from a Fermi liquid to a Mott insulator by momentum-selective destruction of the Fermi surface reminiscent of a pseudogap. In the immediate vicinity of the metal-insulator crossover we demonstrate the existence of unconventional superconductivity by directly entering the symmetry-broken phase. Our results are in remarkable agreement with experimental phase diagrams of κ-organics for which we motivate future spectroscopic studies of hot and cold spots.

TT 27.7 Tue 11:00 H 3010

Increase of resistance noise across the Mott transition — •Tim Thyzel[1], Jens Müller[1], Harald Schubert[1], Michael Lang[1], Takahiko Sasaki[2], and Hiroshi Yamamoto[3] — [1]Institute of Physics, Goethe-Universität Frankfurt, Frankfurt (Main), Germany — [2]Institute of Materials Research, Tohoku University, Sendai, Japan — [3]Institute for Molecular Science, Graduate University for Advanced Studies, Okazaki, Japan

The Mott metal-insulator transition, being driven by the Coulomb interaction between crystal electrons, is of fundamental interest in the field of strongly correlated electron systems. Using the quasi-two-dimensional organic metal κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Cl as a model compound for the Mott transition, we examined the slow dynamics in the charge transport by means of fluctuation spectroscopy.

This method reveals a marked, smooth increase in the low-frequency resistance noise as the system is tuned from its insulating to the metallic phase by changing the bandwidth using hydrostatic pressure. Our finding contributes to the discussion about the nature of finite-temperature Mott criticality [1,2], and raises questions about the role of disorder in the charge dynamics near a Mott instability.

In addition to bandwidth control, we make use of the field effect for carrier doping of a system close to the Mott transition [3]. This will allow us to explore the changes in charge dynamics without modifying the band structure.
[1] Gati, Science Adv. 2, e1601646
[2] Hartmann, Phys. Rev. Lett. 114, 216403
[3] Yamamoto, Nat. Commun. 4, 2379

15 min. break

TT 27.8 Tue 11:30 H 3010

Influence of chemical/structural modifications in layered organic salts κ-(BEDT-TTF)$_2$X near the Mott transition probed by magnetic quantum oscillations. — •Shamil Erkenov[1,2], Florian Kollmannsberger[1,2], Werner Biberacher[1], Ilya Sheikin[3], Toni Helm[4], Natalia Kushch[1], Rudolf Gross[1,2], and Mark Kartsovnik[1] — [1]Walther-Meißner-Institut, Garching, Germany — [2]Technische Universität München, Garching, Germany — [3]Laboratoire National des Champs Magnétiques Intenses, Grenoble, France — [4]Hochfeld-Magnetlabor Dresden, HZDR, Dresden, Germany

One of the prominent systems for studying Mott metal-insulating transition (MIT) are organic salts κ-(BEDT-TTF)$_2$X. These salts have different electronic ground states, determined by electronic corelations U/t and spin frustration ratio t'/t, which can be tuned by a pressure or via chemical/structural modifications, such as anion substitution or ordering of the BEDT-TTF ethylene endgroups. It was believed that chemical/structural modifications act similarly to physical pressure and change electronic state of the system via changing U/t. However, first-principles band-structure calculations [1] suggest that anion substitution in κ salts influences the ground state primarily through the change of the ratio t'/t rather than U/t. Here we report on comparative studies of magnetic quantum oscillations in the κ salts, with X = Cu(NCS)$_2$, Cu[N(CN)$_2$]Y (Y=Cl, Br) and Cu$_2$(CN)$_3$ to trace the correlations between the anion substitution and the mentioned ratios.
[1] T. Koretsune and C. Hotta, Phys. Rev. B **89**, 045102 (2014).

TT 27.9 Tue 11:45 H 3010

Field-driven tuning of magnetic excitations in the van der Waals compound CuCrP$_2$S$_6$ (CCPS) — •Joyal John Abraham[1,2], Sebastian Selter[1], Yuliia Shemerliuk[1], Saicharan Aswartham[1], Bernd Büchner[1,3], Vladislav Kataev[1], and Alexey Alfonsov[1] — [1]Leibniz IFW Dresden, D-01069 — [2]Institute for Solid State and Materials Physics, TU Dresden, D-01069 — [3]Institute for Solid State and Materials Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, D-01062

High-frequency ESR was performed on a single crystal of CCPS. The magnetic Cr^{3+} ions forming ferromagnetic layers are diluted with non-magnetic Cu^{1+} ions which makes it interesting compared to other members in the metal-P$_2$S$_6$ family. The adjacent layers are coupled antiferomagnetically. We have found that at 300 K, CCPS behaves as a paramagnet with almost spin-only g-factors showing a small anisotropy. Below $T \approx$ 200-250 K, the ESR line shifts from the paramagnetic position indicating the presence of a broad range of short-range spin-spin correlations. In the ordered state below $T_N = 30$ K, we observed two excitation gaps and a spin flop at 0.43 T. Remarkably, at stronger magnetic fields a crossover from the antiferromagnetic (AFM) resonance modes to the FM modes, unexpected for a canonical antiferromagnet takes place. Application of the linear spin wave theory enabled us to quantify the exchange (A) and anisotropic constants. The value of A is found to be comparable to the value of the easy-plane uniaxial anisotropy, which explains such an unusual AFM-FM crossover.

TT 27.10 Tue 12:00 H 3010

^{31}P NMR studies of quasi-two-dimensional magnetic correlations in ACrP$_2$S$_6$ (A= Cu, Ag) — •Saramgi Chencheriparambil Sivan[1,2], Ranjith Kumar Kizhake Malayil[1], Lukas Prager[1], Saicharan Aswartham[1], Bernd Büchner[1,2], and Hans-Joachim Grafe[1] — [1]Leibniz IFW Dresden, D-01069 — [2]Institute for Solid State and Materials Physics, TU Dresden, D-01069

The AA'P$_2$S$_6$ (A, A' = transition metal ions) family of quasi-two-dimensional van der Waals materials has proven to be a model system for low-dimensional magnetism. These materials provide an ideal platform to study the Hamiltonians of fundamental magnetism models, including the Ising, XY, and Heisenberg models. Here we present detailed ^{31}P NMR measurements on single-crystal samples of ACrP$_2$S$_6$. The high-temperature single narrow NMR line shows a splitting at about 160 K for CuCrP$_2$S$_6$, which is due to the antiferroelectric transition, while a *pake−doublet* NMR spectrum is observed for AgCrP$_2$S$_6$ at room temperature. In CuCrP$_2$S$_6$, we observed further line splitting below 30 K, reflecting the antiferromagnetic (AFM) order. At $T_N = 30$ K, the NMR spin-lattice relaxation rate T_1^{-1}(T) in CuCrP$_2$S$_6$ shows a sharp peak due to the critical fluctuations. The temperature dependence of $(T_1T)^{-1}$ shows a broad maximum at about 60 K and a critical enhancement at T_N. T_N are anisotropic near the critical regime.

$AgCrP_2S_6$ exhibits AFM order at 20 K, as evidenced by the clear splitting of the NMR spectra and the divergence of T_1^{-1}(T) at T_N. In contrast to $CuCrP_2S_6$, the temperature dependence of $(T_1T)^{-1}$ shows only a critical enhancement around T_N without a broad anomaly.

TT 27.11 Tue 12:15 H 3010

Elastoresistance of the itinerant antiferromagnet $Ca_{1-x}Sr_xCo_{2-y}As_2$: Analysis of different symmetry channels — •Teslin Rose Thomas, N. S. Sangeetha, Sven Graus, Max Brückner, Andreas Kreyssig, and Anna E. Böhmer — Lehrstuhl für Experimentalphysik IV, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum

It is becoming common to study correlated electron systems using elastoresistance, the change in electrical resistance under strain. An interesting aspect of this technique is the possibility of applying symmetry-selective strain to the system under investigation. In this study, we present the method of uniaxial/biaxial elastoresistance and how it can be applied to study various symmetry channels. The method is applied to the itinerant antiferromagnet $Ca_{1-x}Sr_xCo_{2-y}As_2$ that shows a collapsed-to-uncollapsed tetragonal structural crossover and interesting magnetic orderings upon Sr substitution [1, 2]. We observe prominent and diverse signals in the different symmetry channels, especially a large A_{1g} (non-symmetry breaking) elastoresistance.

We acknowledge support from the Deutsche Forschungsgemeinschaft (DFG) under CRC/TRR 288 (Project A02).

[1] N. S. Sangeetha et al., Phys. Rev. Lett. 119 (2017) 257203
[2] Bing Li et al., Phys. Rev. B 100 (2019) 024415

TT 27.12 Tue 12:30 H 3010

Phases and Exotic Phase Transitions of a Two-Dimensional Su-Schrieffer-Heeger Model — •Anika Götz[1], Martin Hohenadler[1], and Fakher Assaad[1,2] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, 97074 Würzburg, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Am Hubland, 97074 Würzburg, Germany

We study a Su-Schrieffer-Heeger electron-phonon model on a square lattice with auxiliary-field quantum Monte Carlo simulations. Adding a symmetry-allowed interaction permits analytical integration over the phonons at the expense of discrete Hubbard-Stratonovich fields with imaginary-time correlations. We investigate the phase diagram at the O(4)-symmetric point as a function of hopping t and phonon frequency ω_0. For $t = 0$, where electron hopping is boson-assisted, the model maps onto an unconstrained $\mathbb{Z}_2$ gauge theory. A key quantity is the emergent effective flux per plaquette, which equals π in the assisted-hopping regime and vanishes for large t. Phases in the former regime can be understood in terms of instabilities of emergent Dirac fermions. Our results support a direct and continuous transition between a $(\pi, 0)$ valence bond solid (VBS) and an antiferromagnetic (AFM) phase with increasing ω_0. By increasing the electronic interaction the critical phonon frequency can be lowered, driving the transition to a first order one. In addition the role of doping away from half-filling is studied. For large t and small ω_0, we find finite-temperature signatures of a previously reported (π, π) VBS ground state related to a nesting instability. With increasing ω_0, AFM order again emerges.

TT 27.13 Tue 12:45 H 3010

Study of M_3O_{12} trimers in transition metal cluster Mott insulators — •Vaishnavi Jayakumar[1] and Ciarán Hickey[1,2,3] — [1]Institute for Theoretical Physics, University of Cologne, Germany — [2]School of Physics, University College Dublin, Belfield, Dublin 4, Ireland — [3]Centre for Quantum Engineering, Science and Technology, University College Dublin, Dublin 4, Ireland

Recent progress in the synthesis of transition metal compounds which are potential cluster Mott insulators provides an opportunity to study these materials more closely. In this work, we use exact diagonalization techniques to study the series of 12L hexagonal perovskites $Ba_4NbM_3O_{12}$ and consider different fillings of $3d$ to $5d$ transition-metal M ions. These perovskites consist of linear face-sharing M_3O_{12} trimer clusters, and can be best described as lying between the localized-electron picture and molecular orbital picture. We find that the local effective degrees of freedom and other ground-state properties can be shown to be due to an interplay between strong correlations and hopping within the clusters. In addition, we also perform an exhaustive study of all possible fillings on these trimer clusters. Our results show, for example, that there can exist ground state degeneracies that are due to cluster or orbital point group symmetries, in parameter regimes where we might conventionally expect to see a unique ground state. We use our study to hence propose ground state properties and phase diagrams for materials that are likely to be synthesized in the future.

TT 28: Topology: Other Topics

Time: Tuesday 9:30–12:15 Location: H 3025

TT 28.1 Tue 9:30 H 3025

Theory of local $\mathbb{Z}_2$ topological markers for finite and periodic systems — •Nicolas Baù and Antimo Marrazzo — Dipartimento di Fisica, Università degli Studi di Trieste, Strada Costiera 11, Trieste, I-34151, Italy

Topological invariants are global properties of the ground-state wave function, typically defined as winding numbers in reciprocal space. Over the years, a number of topological markers have been introduced, allowing to probe the topological order locally in real space even for disordered and inhomogeneous systems [1]. In this talk, I will address time-reversal symmetric systems in two dimensions and introduce two local $\mathbb{Z}_2$ topological markers [2]. The first formulation is based on a generalization of the spin-Chern number [3] while the second one is based solely on time-reversal symmetry [4]. Then, I will introduce a formulation of the local Chern marker for extended systems with periodic boundary conditions [5], and I extend it to the aforementioned $\mathbb{Z}_2$ markers [2]. Finally, I will show numerical simulations to validate the approach, including pristine disordered and inhomogeneous systems, such as topological/trivial heterojunctions.

[1] R. Bianco, R. Resta, Phys. Rev. B **84** (2011) 241106(R)
[2] N. Baù, A. Marrazzo, in preparation
[3] E. Prodan, Phys. Rev. B **80** (2009) 125327
[4] A. A. Soluyanov, D. Vanderbilt, Phys. Rev. B **85** (2012) 115415
[5] N. Baù, A. Marrazzo, arXiv:2310.15783 (2023)

TT 28.2 Tue 9:45 H 3025

A minimal quantum dot-based Kitaev chain with only local superconducting proximity effect — •William Samuelson, Viktor Svensson, and Martin Leijnse — Division of Solid State Physics and NanoLund, Lund University, Lund, Sweden

The possibility to engineer a Kitaev chain in quantum dots coupled via superconductors has recently emerged as a promising path toward topological superconductivity and possibly nonabelian physics. In this talk, I will discuss how some of the main experimental hurdles on this path can be avoided by using only local proximity effect on each quantum dot in a geometry resembling a two-dot version of the proposal in New J. Phys. **15** 045020 (2013), see `arXiv:2310.03536`. There is no need for narrow superconducting couplers, additional Andreev bound states, or spatially varying magnetic fields; it suffices with spin-orbit interaction and a constant magnetic field, in combination with control of the superconducting phase to tune the relative strengths of elastic cotunneling and an effective crossed-Andreev-reflection-like process generated by higher-order tunneling. We use a realistic spinful, interacting model and show that high-quality Majorana bound states can be generated already in a double quantum dot.

TT 28.3 Tue 10:00 H 3025

Signatures of topologically non-trivial band structures based on real-space simulations — •Bendegúz Nyári[1,2], Lászlóffy András[3], Levente Rózsa[3], László Szunyogh[1,2], and Balázs Újfalussy[3] — [1]Department of Theoretical Physics, Budapest University of Technology and Economics, Budapest, Hungary — [2]HUN-REN-BME Condensed Matter Research Group, Budapest University of Technology and Economics, Budapest, Hungary — [3]HUN-REN Wigner Research Centre for Physics, Budapest Hungary

The topological properties of magnetic chains placed on superconductors can be derived from momentum-space quantities related to an infinite chain. The topologically non-trivial band structure gives rise to Majorana end states at zero energy in finite chains.

However, without a translational symmetric system in hand, it is also possible to identify the signatures of the band topology in real-space calculations of finite chains based on the superconducting order parameter and the quasiparticle density of states. Also the spectrum of the chain can be approximated based on the quasiparticle spectrum obtained from the Fourier transformed density of states.

In this talk, I apply this theory to Fe chains on Au/Nb(110) [1] and Mn chains on Nb(110) and study the topology of the band structure.

[1] B.Nyari *et al.*, Phys. Rev. B **108** (2023) 134512

TT 28.4 Tue 10:15 H 3025

Topological charge pumping in quantum many-body systems at finite temperature — •Suman Mondal[1], Eric Bertok[1], Armando Aligia[2], Robin Steinigeweg[3], and Fabian Heidrich-Meisner[1] — [1]Georg-August-Universität Göttingen — [2]Centro Atómico Bariloche and Instituto Balseiro — [3]University of Osnabrück

Adiabatic and periodic variations of the lattice parameters can make it possible to transport charge through a system even without net external electric or magnetic fields, known as Thouless charge pumping. The amount of charge pumped in a cycle is quantized and determined by the system's topology, which is robust against perturbations such as disorder and interactions. Recently, there has been a lot of interest in studying the Thouless pump at finite temperature to characterize the topology in finite temperature. We explore the finite temperature properties of a two-component fermionic Thouless pump in the presence of on-site interactions. It is theoretically studied and experimentally observed that, in the groundstate, on one hand, the system exhibits a breakdown of quantized pumping with increasing interaction. On the other hand, it is possible to define a pumping path that shows interaction-induced pumping. We will discuss these phenomena at finite temparatures. We will show a correlation between the excitation gaps in the system and the meltdown of the pump.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) via FOR 2414.

TT 28.5 Tue 10:30 H 3025

Topological properties of a non-Hermitian quasi-1D chain with a flat band — •Carolina Martínez-Strasser[1,2,3], Miguel Ángel J. Herrera[1,2], Aitzol García-Etxarri[2,4], Giandomenico Palumbo[5], Flore K. Kunst[3], and Dario Bercioux[2,4] — [1]Department of Physics, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), 20018 Donostia–San Sebastián, Spain — [3]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [4]IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5 48009 Bilbao, Spain — [5]School of Theoretical Physics, Dublin Institute for Advanced Studies, 10 Burlington Road, Dublin 4, Ireland

We explore the spectral characteristics of a non-Hermitian quasi-1D lattice in two different dimerization configurations. The lattice exhibits a zero-energy flat band, and an accumulation of bulk eigenstates at the boundaries. Despite this behavior, we identify non-trivial edge states at zero energy for the first configuration through a real-space topological invariant called the biorthogonal polarization. For the second configuration, we analyze the finite quantum metric associated with the flat band. Interestingly, this configuration exhibits the skin effect, even though the system has a spectrum that is purely real or imaginary. Both non-Hermitian diamond chains can be mapped to models of Su-Schrieffer-Heeger chains, either non-Hermitian or Hermitian, both featuring a flat band. This mapping provides valuable insights into the system's properties.

15 min. break

TT 28.6 Tue 11:00 H 3025

Time-frequency representation of Andreev-reflected charge pulses — •Benjamin Roussel[1], Pablo Burset[2], and Christian Flindt[1] — [1]Aalto University, Aalto, Finland — [2]Universidad Autonoma de Madrid, Madrid, Spain

The most fundamental AC electric current consists of a single electron and a single hole at each period of the drive. While this has been a long-held theoretician dream, the experimental progress of the past 15 years have made it come true. It is now possible to generate, manipulate and probe electric current down to a single charge in a ballistic conductor. This is the focus of electron quantum optics, in which electrons are manipulated at the most elementary level, similarly to photons in quantum optics.

The field has now reached maturity, demonstrating the experimental techniques, and is now envisioned for technological applications, in particular in metrology. However, some aspects of electronic correlations have yet to be explored. At the interface between a normal metal and a superconductor, Andreev reflections can happen, producing a quantum superposition of an electron and a hole. This generates superconducting correlations, that can be exploited for electron quantum optics.

In this talk, I will present how Andreev reflections can be understood using the language of electron quantum optics. Introducing Wigner-like time-frequency representation for this process, I will analyze how an incoming electron is scattered by the interface.

TT 28.7 Tue 11:15 H 3025

Non-Hermitian Physics in multi-terminal devices: topological ohmmeter — Viktor Könye[1,2], •Kyrylo Ochkan[1,2], Anastasiia Chyzhykova[1,3], Jan Carl Budich[2,4], Jeroen van den Brink[1,2,4], Ion Cosma Fulga[1,2], and Joseph Dufouleur[1,2] — [1]IFW Dresden, Deutschland — [2]Würzburg-Dresden Cluster of Excellence ct.qmat — [3]Taras Shevchenko National University of Kyiv — [4]TU Dresden

We exploit the topological properties of non-Hermitian matrices to build a very sensitive ohmmeter. The ohmmeter is realized in a multi-terminal, linear electric circuit with a non-Hermitian conductance matrix, where the target resistance plays the role of the perturbation. We show that its relative accuracy increases exponentially with the number of terminals, and for large resistances outperforms a standard measurement by over an order of magnitude. This paves the way towards leveraging non-Hermitian conductance matrices in high-precision electronic sensing

TT 28.8 Tue 11:30 H 3025

Extended Hatano-Nelson model, exceptional points and spectral symmetry — •Julius T. Gohsrich[1,2], Jacob Fauman[1,2], and Flore K. Kunst[1] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany

Non-Hermitian systems attract a lot of attention in recent years as effective description of open quantum systems. A prominent example in this context is the Hatano-Nelson model. While historically the model has short-range non-reciprocal hoppings, long-range hopping has not been systematically studied. In this talk, I will present our results on the extended Hatano-Nelson model. Using analytical techniques, we demonstrate how the underlying physics of the original Hatano-Nelson model is enriched when longer-range hoppings are also included. I will discuss how the crucial elements of the Hatano-Nelson model, namely, the non-Hermitian skin effect and the exceptional points, are modified for the generalized model.

TT 28.9 Tue 11:45 H 3025

Analytic approches to non-hermitan systems: Hatano-Nelson model with onsite impurity — •Nico Leumer and Dario Bercioux — DIPC, San Sebastian, Spain

The topology of non-hermitian (nh) systems is undoubtedly a new and interesting field of research. The change from hermitian to non-hermitian Hamiltonian's demanded the adaptation of former well-established concepts [1]. A striking feature is that nh single band models as the Hatano-Nelson (HN) inherit non-trivial topology.

Since spectra and eigenvectors of nh systems may show numerical instabilities close to so called exceptional points, analytic validation is important. In this perspective, we show that our exact approach using Fibonacci polynomials is also capable of treating generic boundary conditions and arbitrary systems length in the nh case [2, 3]. For the sake of a showcase, we present results for Hatano-Nelson model with periodic and open boundary conditions. For the latter, we include also an impurity at (of) arbitrary position (strength) in order to better illustrate the potential of our technique.

Importantly, the impurity strength influences wavefunction profiles and leads to the formation of linearly decaying modes already for the hermitian case. Interestingly, these specific modes mark a crossover in the energy spectrum where a single mode leaves the band and becomes energetically separated from all remaining ones.

[1] E. J. Bergholtz et al., Rev. Mod. Phys. 93 (2021) 015005
[2] N. Leumer et al., J. Phys.: Condens. Matter 32 (2020) 445502
[3] N. G Leumer, J. Phys. A: Math. Theor. 56 (2023) 435202

TT 28.10 Tue 12:00 H 3025

Symmetry-induced higher-order exceptional points in two dimensions — •Anton Montag[1,2] and Flore Kunst[1] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Departement of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Exceptional points (EPs) appear in non-Hermitian systems as points where the eigenvalues and eigenvectors coalesce. Even without any symmetries they are an abundant feature of non-Hermitian systems. In general, an EP of order n (EPn), where n eigenvectors coalesce, emerges if $2(n-1)$ real constraints are imposed. Symmetries that are local have been shown to reduce this number of constraints. In this work, we analyze higher-order EPs in two-dimensional parameter space induced by symmetries. We show that EP3s appear pairwise in the presence of any symmetry local in parameter space, and we illuminate the spectral structure around the EP3 pair. For each symmetry we show different general features that accompany the EP3s. Further we find EP4s and closely related EP5s induced by multiple symmetries. These EPs occur pairwise and have a complex spectral structure, which can be analyzed by analytically calculating the eigenvalues around those EP pairs.

TT 29: Many-Body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)

Time: Tuesday 9:30–13:00 Location: A 151

TT 29.1 Tue 9:30 A 151

Non-equilibration, synchronization, and time crystals in isotropic Heisenberg models — •Jürgen Schnack, Patrick Vorndamme, and Peter Reimann — Bielefeld University

Isotropic, but otherwise largely arbitrary Heisenberg models in the presence of a homogeneous magnetic field are considered, including various integrable, non-integrable, as well as disordered examples, and not necessarily restricted to one dimension or short-range interactions. Taking for granted that the non-equilibrium initial condition and the spectrum of the field-free model satisfy some very weak requirements, expectation values of generic observables are analytically shown to exhibit permanent long-time oscillations, thus ruling out equilibration [1]. If the model (but not necessarily the initial condition) is translationally invariant, the long-time oscillations are moreover shown to exhibit synchronization in the long run, meaning that they are invariant under arbitrary translations of the observable [2]. Analogous long-time oscillations are also recovered for temporal correlation functions when the system is already at thermal equilibrium from the outset, thus realizing a so-called time crystal.

[1] P. Reimann, P. Vorndamme, J. Schnack, Phys. Rev. Research 5, 043040 (2023)

[2] P. Vorndamme, H.-J. Schmidt, Chr. Schröder, J. Schnack, New J. Phys. 23, 083038 (2021)

TT 29.2 Tue 9:45 A 151

Many-body localization in random exchange coupling Heisenberg chain — •Yilun Gao and Rudolf A. Römer — Department of Physics, University of Warwick, Coventry, CV4 7AL

Disordered quantum systems have become an important research topic in modern condensed matter physics ever since the discovery of Anderson localization. The investigation of many-body localization in quantum interacting systems has received much recent attention following the increase of computational power and improvement in numerical methods. We focus on a Heisenberg spin chain with full SU(2) symmetry where the exchange couplings between neighboring spins are taken to be disordered. Sparse matrix diagonalization method is applied when calculating eigenvalues and eigenvectors of the Hamiltonian matrix. By understanding the structure of eigenvalues and eigenvectors in terms of spin symmetry, we investigate the participation ratio and entanglement entropy as a function of disorder strength. We average over many disorder realizations and compare the results for different system sizes. We find, for small system sizes, a clear distinction between the SU(2)-invariant random exchange model and the more often studied random field model.

TT 29.3 Tue 10:00 A 151

Long-range spectral statistics of the Rosenzweig-Porter model — •Wouter Buijsman — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The Rosenzweig-Porter model is a single-parameter random matrix ensemble that supports an ergodic, fractal, and localized phase. Introduced over sixty years ago, this model recently gained renewed interest as a toy model for the many-body localization transition. We construct a unitary (Floquet) equivalent of this model, for which we numerically study the long-range spectral statistics [1,2]. The construction is based on interpreting the Rosenzweig-Porter model as a Brownian quantum system [3]. Our main result is the observation that the transition between the ergodic and fractal phases can be probed through the spectral form factor. Complementing previous results on the level spacing distribution, this establishes that spectral statistics are sufficient to fully map out the phase diagram of the model. We quantitatively discuss the scaling of the Thouless time, and point out the possible universality of the spectral form factor at the transition between the fractal and the localized phases.

[1] W. Buijsman and Y. Bar Lev, *Circular Rosenzweig-Porter random matrix ensemble*, SciPost Phys. **12**, 082 (2022).

[2] W. Buijsman, *Long-range spectral statistics of the Rosenzweig-Porter model*, arXiv:2309.14043 (2023).

[3] W. Buijsman, *Efficient circular Dyson Brownian motion algorithm,* arXiv: 2309.07457 (2023).

TT 29.4 Tue 10:15 A 151

Interplay of many-body interactions and quasiperiodic disorder in the all-bands-flat diamond chain — •Aamna Ahmed[1], Nilanjan Roy[2], and Auditya Sharma[3] — [1]University of Augsburg, Germany — [2]Nanyang Technological University (NTU), Singapore — [3]Indian Institute of Science Education and Research (IISER) Bhopal, India

While the physics of flat band systems, quasiperiodic disorder and many-body interactions have been important fields of activity, the interplay of these features has only scantily been explored. This talk will discuss the effect of many-body interactions and quasiperiodic Aubry André (AA) disorder on the one-dimensional all-band-flat (ABF) diamond lattice[**1,2**].

We show that coupling the ABF diamond lattice with nearest-neighbour interactions yields a non-ergodic phase independent of the strength of interaction. Interestingly, the resulting phases in the interacting diamond lattice depend on the symmetry and the strength of the applied quasiperiodic disorder. An exciting finding is the emergence of non-equilibrium quantum caging behaviour for specially engineered many-body initial states. Our work provides an insight into the phase diagram of an interacting flat band system subjected to quasiperiodic disorder via a non-equilibrium dynamical study.

1. Interplay of many-body interactions and quasiperiodic disorder in the all-band-flat diamond chain, **PRB 107, 245110 (2023)**

2.Flat-band-based multifractality in the all-band-flat diamond chain, **PRB 106, 205119 (2022)**

TT 29.5 Tue 10:30 A 151

Prethermalization in an Interacting Flat Band System — •Mirko Daumann and Thomas Dahm — Universität Bielefeld, Fakultät für Physik, Postfach 100131, D-33501 Bielefeld

Studying the influence of a weakly perturbed flat band on transport of interacting particles reveals anomalous diffusion and prethermalization. For very weak perturbations transport is getting slower than regular diffusion because of repulsive particle-particle interaction. The effect can be understood by a canonical transformation of dispersive and flat band eigenstates into a basis of light and heavy quasiparticles which are trapping each other. They are subjected to orbital conservation laws what enables a treatment of the phenomenon in terms of the Born-Oppenheimer approximation and allows an illustration in a familiar physical picture analogous to electrons and nuclei. This approach furthermore sheds light on the thermalization process in such a system in general.

Methodology: Transport properties are calculated by simulating the broadening of initially localized wave packets of spinless fermions in a quasi one-dimensional Hubbard model with three-orbital diamond structure. Initial states are constructed in the framework of dynamical quantum typicality. Time evolution is performed by either the Lanczos algorithm or full diagonalization if possible.

TT 29.6 Tue 10:45 A 151

Hilbert space fragmentation in anyonic chains — •Ludwig Zweng, Nico Kirchner, and Frank Pollmann — Technical University of Munich (TUM)

Hilbert spaces of chains of non-Abelian anyons are constrained by their fusion rules. These constraints may restrict the dynamics and lead to nontrivial thermalization behavior for such systems. As an examplary anyonic model with restricted thermalization, we suggest a one dimensional Fibonacci anyonic chain where the topological charges can perform braid moves around each other. We identify subspaces in the fusion space of this model which are left invariant by certain braid moves and by fine-tuning an additional magnetic field, we find various dynamically disconnected sectors. These sectors stem from the destructive interference of different braid processes and we expect that this model displays weak Hilbert space fragmentation. Moreover, we show that in global quenches certain initial states do not evolve to thermal states but display fidelity revivals up to late times.

TT 29.7 Tue 11:00 A 151

Quantum dynamical phase transition in Erdos-Renyi graph — •Tomohiro Hashizume[1], Felix Herbort[1], Joseph Tindall[2], and Dieter Jaksch[1] — [1]CUI, institute of quantum physics, University of Hamburg, Hamburg, Germany — [2]Centre for Computational Quantum Physics, Flatiron Institute, New York, USA

With the lack of the well-defined free energy, the dynamics of a closed quantum system reaching its equilibrium state is not constrained by the conventional statistical mechanical pricniples. In the light of expanding the temperature into the complex domain, the dynamical quantum phase transition manifests itself as non-analyticities in the logarithm of the survival probability of the initial state before the quench. Based on the duality between the equilibrium quantum phase of the transverse field Ising model and the same model on the probablistic random graph (Erdos-Rényi graph), we expand this duality to the non-equilibrium regime and study the dynamical phase transition in these models. We show that despite the consistency of the dynamical critical point for all probability of edge generalation, p, the anomality of the transition ceases to exist upon averaging the echo over all possible graphs for $p < 1$.

15 min. break

TT 29.8 Tue 11:30 A 151

Semiclassical eigenstate entanglement of bipartite Floquet systems — •Maximilian F.I. Kieler and Arnd Bäcker — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

Strongly coupled quantum systems are expected to show the same amount of entanglement as random states. However, many body systems typically have an inherent multi-partite structure, and it is not clear, how this influences the entanglement. We show for the case of chaotic, bipartite quantum maps, that the eigenstate entanglement coincides up to leading order with the random matrix result. For this the eigenstate entanglement is transferred into a dynamical quantity and evaluated using semiclassical methods. The result is given in terms of periodic orbits of the subsystems. Interestingly, the coupling acts as synchronization between these orbits, only.

TT 29.9 Tue 11:45 A 151

Floquet-Anderson localization in the Thouless pump and how to avoid it — András Grabarits[1,2], Attila Takács[1,3], Ion Cosma Fulga[4,5], and •János K. Asbóth[1,6] — [1]Dept of Theor. Physics, Budapest University of Technology and Economics — [2]Dept of Physics and Materials Science, University of Luxembourg — [3]Universite de Lorraine, CNRS, Nancy, France — [4]Leibniz Institute for Solid State and Materials Research, IFW Dresden, — [5]Wurzburg-Dresden Cluster of Excellence ct.qmat, 01062 Dresden — [6]Wigner Research Centre for Physics, Budapest

We investigate numerically how onsite disorder affects conduction in the periodically driven Rice-Mele model, a prototypical realization of the Thouless pump, when run at finite period time T. We find that at any fixed period time and nonzero disorder, increasing the system size L to infinity always leads to a breakdown of the pump by Anderson localization of the Floquet states. In a properly defined thermodynamic limit, where L/T^θ is kept constant, Anderson localization can be avoided, and the charge pumped per cycle has a well-defined value (as long as the disorder is not too strong). The exponent θ is not universal, rather, depends on the disorder strength. Our findings are relevant for practical, experimental realizations of the Thouless pump, for studies investigating the nature of its current-carrying Floquet eigenstates, as well as the mechanism of the full breakdown of the pump, expected if the disorder exceeds a critical value.

TT 29.10 Tue 12:00 A 151

Deviations from random matrix entanglement statistics for kicked quantum chaotic spin-1/2 chains — •Tabea Herrmann, Roland Brandau, and Arnd Bäcker — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

It is commonly expected that for quantum chaotic systems the statistical properties approach those of random matrices with increasing system size. We demonstrate for various kicked spin-1/2 chain models that the average eigenstate entanglement indeed approaches the random matrix result. However, the distribution of the eigenstate entanglement differs significantly. While for autonomous systems such deviations are expected, they are surprising for the more scrambling kicked systems. We attribute the origin of the deviations to the local 2×2 substructure. This is supported by similar deviations occurring in a local random matrix model with global diagonal coupling.

TT 29.11 Tue 12:15 A 151

The entanglement membrane in exactly solvable lattice models — •Michael A. Rampp, Suhail A. Rather, and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

Entanglement membrane theory is an effective coarse-grained description of entanglement and operator growth in non-integrable quantum many body systems. The central quantity containing information about the dynamics is the entanglement line tension. However, determining the entanglement line tension for microscopic models is difficult. We compute the entanglement line tension in a recently introduced class of exactly solvable unitary circuits, and show that it has a non-trivial form giving rise to a hierarchy of velocity scales, $v_E < v_B$. We find that these circuits saturate certain bounds on entanglement growth that are also saturated in holographic models. Furthermore, we relate the entanglement line tension to temporal entanglement and correlation functions. Our results shed light on entanglement membrane theory in microscopic Floquet lattice models and enable us to perform non-trivial checks on the validity of its predictions by comparison to exact calculations.

TT 29.12 Tue 12:30 A 151

Weak eigenstate thermalization hypothesis — Patrycja Łydzba[1], •Rafał Świetek[2,3], Marcin Mierzejewski[1], Marcos Rigol[4], and Lev Vidmar[2,3] — [1]Institute of Theoretical Physics, Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, 50-370 Wrocław, Poland — [2]Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, SI-1000 Ljubljana, Slovenia — [3]Department of Theoretical Physics, J. Stefan Institute, SI-1000 Ljubljana, Slovenia — [4]Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA

While the eigenstate thermalization hypothesis (ETH) is well established for quantum-chaotic interacting systems, its validity for other classes of systems remains a matter of intense debate. Focusing on quadratic fermionic Hamiltonians, we here argue that the weak ETH is satisfied for few-body observables in many-body eigenstates of quantum-chaotic quadratic (QCQ) Hamiltonians. In contrast, the weak ETH is violated for few-body observables in localized quadratic Hamiltonians. We argue that these properties can be traced back to the validity of single-particle eigenstate thermalization, and we highlight the subtle role of normalization of operators. Our results suggest that the difference between weak and no ETH in many-body eigenstates allows for a distinction between single-particle quantum chaos and localization. We test to which degree this phenomenology holds true for integrable systems such as the XYZ and XXZ models.

TT 29.13 Tue 12:45 A 151

Critical quantum dynamics of observables at eigenstate transitions — Simon Jiricek[1], •Miroslav Hopjan[2], Patrycja Łydzba[3], Fabian Heidrich-Meisner[1], and Lev Vidmar[2,4] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany — [2]Department of Theoret-

ical Physics, J. Stefan Institute, SI-1000 Ljubljana, Slovenia — [3]Department of Theoretical Physics, Wroclaw University of Science and Technology, 50-370 Wroclaw, Poland — [4]Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, SI-1000 Ljubljana, Slovenia

It is an outstanding goal to unveil the fingerprints of universal quantum dynamics at eigenstate transitions. Focusing on quadratic fermionic Hamiltonians, we identify physical observables that exhibit critical behavior at the transition. Our result is based on two ingredients: (a) A relationship between the observable time evolution in a many-body state and the transition probabilities in single-particle states, and (b) a scale invariance of transition probabilities, which generalizes the recent result for survival probabilities [1]. We then show that these properties give rise to a critical behavior in the quantum quench dynamics of observables, which share the common eigenbasis with the Hamiltonian before the quench. We numerically demonstrate this phenomenon at the localization transition in the three-dimensional Anderson model, for which the critical bahavior can be detected in experimentally relevant observables such as site occupations and particle imbalance. [1] M. Hopjan and L.Vidmar, Phys. Rev. Lett. 131, 060404 (2023)

TT 30: Focus Session: Exploring Quantum Entanglement with Superconducting Qubits and Resonators (joint session QI/TT)

Harnessing quantum entanglement is crucial for advancing quantum technologies, and superconducting qubits and resonators have shown great promise in this regard. Impressive progress is contemporarily made in generating access to intermediate-scale quantum circuits, for the exploration of applications. These advancements highlight the progress and potential of superconducting qubits in harnessing quantum entanglement, paving the way for further progress in quantum communication, computation, and sensing. Organized by Oded Zilberberg.

Time: Tuesday 9:30–13:30 Location: HFT-FT 131

Invited Talk TT 30.1 Tue 9:30 HFT-FT 131

Loophole-free Bell Inequality Violation with Superconducting Circuits — •Andreas Wallraff — Department of Physics, ETH Zurich, Switzerland

Superposition, entanglement, and non-locality constitute fundamental features of quantum physics. Remarkably, the fact that quantum physics does not follow the principle of locality can be experimentally demonstrated in Bell tests performed on pairs of spatially separated, entangled quantum systems. While Bell tests were explored over the past 50 years, only relatively recently experiments free of so-called loopholes succeeded. Here, we demonstrate a loophole-free violation of Bell's inequality with superconducting circuits [1]. To evaluate a CHSH-type Bell inequality, we deterministically entangle a pair of qubits and perform fast, and high-fidelity measurements along randomly chosen bases on the qubits connected through a cryogenic link spanning 30 meters. Evaluating more than one million experimental trials, we find an average S-value of 2.0747 * 0.0033, violating Bell's inequality by more than 22 standard deviations. Our work demonstrates that non-locality is a viable new resource in quantum information technology realized with superconducting circuits with applications in quantum communication, quantum computing and fundamental physics.

[1] S. Storz, J. Schär, A. Kulikov, P. Magnard, P. Kurpiers, J. Lütolf, T. Walter, A. Copetudo, K. Reuer, A. Akin, J-C. Besse, M. Gabureac, G. J. Norris, A. Rosario, F. Martin, J. Martinez, W. Amaya, M. W. Mitchell, C. Abellán, J-D. Bancal, N. Sangouard, B. Royer, A. Blais, and A. Wallraff, Nature 617, 265-270 (2023).

Work done in collaboration with Simon Storz, Josua Schaer, Anatoly Kulikov, Paul Magnard, Philipp Kurpiers, Janis Luetolf, Theo Walter, Adrian Copetudo, Kevin Reuer, Abdulkadir Akin, Jean-Claude Besse, Mihai Gabureac, Graham J. Norris, Andres Rosario, Ferran Martin, Jose Martinez, Waldimar Amaya, Morgan W. Mitchell, Carlos Abellan, Jean-Daniel Bancal, Nicolas Sangouard, Baptiste Royer, Alexandre Blais, and Andreas Wallraff

Invited Talk TT 30.2 Tue 10:00 HFT-FT 131

Microwave quantum networks — •Kirill G. Fedorov — Walther-Meißner-Institut, 85748 Garching, Germany — School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany

Distributing quantum entanglement between distant nodes of a large-scale network is a fundamentally important milestone for many applications in the field of quantum information processing. Here, entanglement in the form of two-mode squeezed light can be employed as a resource for various nonclassical communication protocols, such as quantum teleportation or remote qubit entanglement. Motivated by the recent breakthroughs in quantum computation & simulation with superconducting circuits operated at microwave frequencies, we demonstrate distribution of two-mode squeezed states at carrier frequencies around 5.5 GHz across a local area cryogenic quantum network. We present the experimental evidence for robustness of the microwave entanglement distribution against noise and losses in superconducting channels. Furthermore, we utilize this entanglement resource to perform a coherent state teleportation between distant cryostats with fidelities exceeding the no-cloning limit. Finally, by relying on the same technology and frequency range, we discuss remote entanglement of superconducting qubits with two-mode squeezed microwave light. Our results highlight feasibility of microwave quantum communication and pave the road towards distributed quantum computing with superconducting circuits.

TT 30.3 Tue 10:30 HFT-FT 131

Investigation of hybrid CV-DV entanglement in the microwave regime — •Simon Gandorfer[1,2], Yuki Nojiri[1,2], Fabian Kronowetter[1,2], Kedar E. Honasoge[1,2], Maria-Teresa Handschuh[1,2], Joan Agustí[1,2], Peter Rabl[1,2,3], Rudolf Gross[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Distributing entanglement between spatially separated nodes of a large-scale quantum network is a fundamentally important milestone for many applications. It also provides the quantum resource for various quantum protocols, such as quantum teleportation or remote qubit gate operations. In our experiment, we employ a superconducting transmon qubit in a superconducting 3D aluminium cavity illuminated by one mode of a microwave two-mode squeezed (TMS) state. Here, the TMS state acts as a quantum-correlated reservoir. By choosing an appropriate set of observables, we identify a joint measurement between the qubit and the second mode of the TMS state that allows us to observe a hybrid, discrete-continuous variable, entanglement. We experimentally investigate the entanglement conversion process in this novel hybrid regime and discuss its possible extensions and applications for distributed quantum computing.

TT 30.4 Tue 10:45 HFT-FT 131

Parametric coupler architecture for on-demand reset, readout and leakage recovery of superconducting qubits — •Gerhard Huber[1,2], Federico Roy[2,3], Joao Romeiro[1,2], Leon Koch[1,2], Niklas Bruckmoser[1,2], Niklas Glaser[1,2], Ivan Tsitsilin[1,2], Max Werninghaus[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, 85748 Garching, Germany — [3]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany

When using superconducting qubits thermal excitations of the initial state, leakage into non-computational states during gate operations and unwanted decoherence due to coupling to a readout mode are, however, major sources of errors. Here, we present a superconducting qubit architecture with tunable qubit-resonator coupling. This architecture allows for the efficient preparation of the qubit ground state, the recovery of leakage from higher states and for on-demand qubit readout activated by a single parametric coupler. We experimentally demonstrate a reset operation that unconditionally prepares the qubit ground state with a fidelity of 99.8 ± 0.02 % and a leakage recovery operation with a 98.5 ± 0.3 % success probability. Furthermore, we implement a coupler-driven readout with a single-shot assignment fidelity of 88 ± 0.4 %. Completing this set of elementary operations with qubit-qubit gates using the same coupling element, reduces the system complexity and facilitates the implementation of scalable quantum processors.

TT 30.5 Tue 11:00 HFT-FT 131

Novel 3D circuit QED architecture for quantum information processing — •Desislava Atanasova[1,2], Ian Yang[1,2], Teresa Hönigl-Decrinis[1,2], Daria Gusenkova[3], Ioan Pop[3], and Gerhard Kirchmair[1,2] — [1]Institute for Quantum Optics and Quantum Information, A-6020 Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [3]Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Superconducting circuits based on 3D architectures offer a way for hardware-efficient quantum information processing. Combined with nonlinearity, a single bosonic mode can replace a multi-qubit register, thus significantly reducing the required control electronics. Compared to their purely planar counterpart, 3D circuits possess longer lifetimes and a straightforward design that eases engineering the interactions in composite systems.

In this work, a superconducting coaxial cavity is coupled to a fluxonium qubit via a readout resonator. The tunability of the qubit, provided by a magnetic flux hose, is used to adjust the cavity-qubit interaction in situ. Combined with an element for two-photon dissipation, this setup could be utilized as an improved building block for a fully protected logical qubit.

15 min. break

Invited Talk TT 30.6 Tue 11:30 HFT-FT 131

Quantum sensing of axionic dark matter with a phase resolved haloscope — •Audrey Cottet — LPEM, ESPCI Paris — LPENS, Ecole Normale Supérieure de Paris

There is a general consensus that a large part of the matter and energy in the Universe is unknown. Well established candidates for dark matter are axions or axion-like particles. Their interaction with particles of the standard model is expected to be very weak. Hence, their detection requires ultimate amplification and measurement techniques. Quantum sensing is appealing in that context. We propose a new type of detector based on a non-linear quantum cavity coupled to a tunable magnetic mode. In order to circumvent the standard quantum limit of detection, we propose to exploit the phase-number variables of the electromagnetic field. The sensitivity of the detector can be pushed further by exploiting interference fringes in a cavity Schrödinger cat state. We expect a figure of merit exceeding by several orders of magnitude that of current detectors. This opens the way to real-time detection of possible axion signals. I will present how these ideas are being implemented experimentally using a hybrid cavity/magnon/superconducting circuit platform.

Invited Talk TT 30.7 Tue 12:00 HFT-FT 131

Demonstration of Quantum Advantage in Microwave Quantum Radar — Réouven Assouly, Rémy Dassonneville, Théau Péronnin, •Audrey Bienfait, and Benjamin Huard — Laboratoire de Physique à l'ENS Lyon, Lyon, France

The quantum radar promises to improve the speed of detection of a target placed in a noisy background by a factor of up to 4 in the low power regime compared to best possible classical radar. Observing this quantum advantage requires exploiting the quantum correlations through a joint measurement of the initially entangled probe and the idler which has never been performed in the previous microwave quantum radar attempts. Following a proposal by Guha and Erkmen [1], we demonstrate a quantum advantage of up to 1.2+/-0.1 in a proof-of-principle quantum radar operating at microwave frequencies.

Using a dual-purpose quantum emitter/receiver based on a Josephson ring modulator, we are able to generate two-mode squeezed states as well as perform the required joint measurement between the idler and the noisy reflected signal. After generation, the idler is stored in a memory mode while the signal half is emitted into a transmission line, goes through a tunable target after which it comes back to the quantum transceiver where it can be jointly measured with the idler using a two-mode squeezing operation followed by a photon-counting measurement via an auxiliary transmon qubit.

[1] Guha, S., Erkmen, B.I., Phys. Rev. A 80, 052310 (2009)

TT 30.8 Tue 12:30 HFT-FT 131

Hot Schrodinger Cat States in a High Coherence Niobium Cavity Coupled to a Superconducting Qubit — •Ian Yang[1,2], Thomas Agrenius[2,3], Vasilisa Usova[1,2], Oriol Romero-Isart[2,3], and Gerhard Kirchmair[1,2] — [1]Institute for Experimental Physics, University of Innsbruck, 6020 Innsbruck, Austria — [2]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, 6020 Innsbruck, Austria — [3]Institute for Theoretical Physics, University of Innsbruck, Innsbruck 6020, Austria

The observation of quantum phenomena often necessitates sufficiently pure states. The standard paradigm for creating pure states has been to cool the system of interest to the ground state or decouple it sufficiently from any hot thermal bath. This requirement can be challenging to achieve.

In this study, we prepare a non-classical state originating from a mixed state, utilising dynamics that preserve the initial purity of the state. We generate a Schrodinger cat state within a high-coherence microwave cavity, operating at a mode temperature of up to two Kelvin, which is one hundred times hotter than its environment.

Our experimental findings have implications in generating nonclassical states for other bosonic degrees of freedom such as in the motion of a massive particle. Furthermore, they reduce the purity requirements of the initial state.

TT 30.9 Tue 12:45 HFT-FT 131

Material losses characterization in superconducting resonators based on α and β Tantalum — •Ritika Dhundhwal[1], Haoran Duan[2], Lucas Brauch[1], Soroush Arabi[1], Qili Li[3], Sudip Pal[6], Jose Palomo[5], Dirk Fuchs[1], Alexander Welle[4], Mark Scheffler[6], Zaki Leghtas[5], Jasmin Aghassi-Hagmann[2], Christian Kübel[2], Wulf Wulfhekel[1], Ioan M. Pop[1,3,6], and Thomas Reisinger[1] — [1]IQMT, KIT — [2]INT, KIT — [3]PHI, KIT — [4]IFG, KIT — [5]ENS, Paris — [6]Uni Stuttgart

Implementation of tantalum as a new material platform in transmon qubit has shown promising results with coherence time exceeding 0.3 ms[1]. To understand the underlying cause for record breaking coherence times, the main focus has been on use of alpha phase tantalum to achieve high quality qubits and resonators whereas the beta phase remains largely unexplored. In this work, we compare internal quality factor in lumped element resonators as a function of photon number and temperature. We use various material characterization tools to investigate surface and bulk properties of tantalum. Further, we vary the energy participation ratio in tantalum metal-substrate and metal-air interfaces to estimate the loss tangent and get insight into dominant loss mechanism. [1] Place, A.P.M., Rodgers, L.V.H., Mundada, P. et al. Nat Commun 12, 1779 (2021).

TT 30.10 Tue 13:00 HFT-FT 131

Quantum phases in frustrated arrays of Josephson junctions: Effective XY spin models — •Benedikt Pernack, Mikhail V. Fistul, and Ilya M. Eremin — Theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany

Motivated by experiments on superconducting qubit networks [1,2], we present here a detailed analysis of collective quantum phases occurring in *frustrated* quasi-$1D$ saw-tooth arrays of small (quantum) Josephson junctions (f-JJAs). Frustration is introduced through the periodic arrangement of 0- and π-Josephson junctions with the Josephson coupling energies of different signs. In the frustrated regime the classical ground state is highly degenerate and formed by various patterns of vortex/antivortex penetrating each basic cell of an f-JJA.

In the quantum frustrated regime using the variational approach we derive an effective XY spin Hamiltonian. Depending on the length L of an f-JJA we obtain two very different regimes: a) $L \ll L_{cr} = \sqrt{C/C_0}$, where C and C_0 are a 0-Josephson junction and superconducting island capacitances, accordingly, the quantum superposition of vortex and antivortex in a single cell dominates; b) $L \gg L_{cr} = \sqrt{C/C_0}$, the quantum superposition of vortex and antivortex is strongly suppressed, and a long (short) exchange interaction is established. In latter case using mean-field analysis and numerical diagonalization of the effective

XY spin model, we characterize quantum phases in various f-JJAs.

TT 30.11 Tue 13:15 HFT-FT 131

Frustrated $2D$-Josephson junction arrays with topological constraints — •Oliver Neyenhuys, Mikhail V. Fistul, and Ilya M. Eremin — Theoretische Physik III, Ruhr-Universität Bochum, Bochum 44801, Germany

Geometrical frustration in correlated systems can give rise to a plethora of ordered states and intriguing phases. We theoretically analyze a subset of vertex-sharing frustrated lattices, built up by corner sharing superconducting triangles interrupted by 0-Josephson junctions on two edges and a π-Josephson junction on the third edge. Such lattices have multiple degenerate free energy minima composed of different patterns of vortices/antivortices (V/AV) penetrating each triangle. Exemplary for the Kagome lattices with periodically arranged 0- and π-Josephson junctions, we identify various classical and quantum phases. We derive an effective Ising-type spin Hamiltonian, describing the interaction between V/AVs. Strongly anisotropic long-range interactions between well separated V/AVs emerge from the constraints due to flux quantization in any hexagon loop. In the classically frustrated regime, we calculate the temperature-dependent spatially averaged spin polarization $m(T)$ characterizing the crossover between the ordered and disordered V/AV states. In the coherent quantum regime, we analyze the lifting of the degeneracy of the ground state and the appearance of the highly entangled states[1].

[1] O. Neyenhuys, M. Fistul and I. Eremin, Long-range Ising spins models emerging from frustrated Josephson junctions arrays with topological constraints, PhysRevB.108.165413 (2023)

TT 31: 2D Materials II: Electronic Structure (joint session O/TT)

Time: Tuesday 10:30–12:15 Location: MA 005

TT 31.1 Tue 10:30 MA 005

On the origin of circular dichroism from graphene, WSe_2, and other quantum materials — •Lukasz Plucinski — PGI-6 Forschungszentrum Jülich

On the example of graphene, within the dipole approximation, we discuss various contributions to the circular-dichroic angle-resolved photoemission (CD-ARPES) [1] which include phase shifts of the participating partial waves in the atomic photoionization [2], the finite inelastic mean free path induced CD [3], the interatomic phase shifts [4], and the CD due to multiple scattering of the excited electron [5]. Using tabulated phase shifts and radial integrals [6], we predict photon energies at which CD signal might exhibit sign changes, and compare the prediction to experimental results. Subsequently, we perform similar analysis for WSe_2, a material where orbital characters are relatively well-defined, however, varying over Brillouin zone, with different contributions at K, K', and Γ points. This can be translated into understanding CD-ARPES from topological materials. Within this context, we briefly discuss how various components needed to derive the Berry curvature, the spin characters [4], and the phases of the wave functions, can be accessed through CD-ARPES and its spin-polarized variant.

[1] Plucinski, arXiv:2309.02187 (2023), [2] Dubs et al., Phys. Rev. B 32, 8389 (1985) [3] Moser, JESRP 214, 29 (2017) [4] Heider, et al., PRL 130, 146401 (2023) [5] Daimon et al., JJAP 32, L1480 (1993) [6] Goldberg et al., JESRP 21, 285 (1981)

Topical Talk TT 31.2 Tue 10:45 MA 005

Bias free extraction of orbital angular momentum from two-dimensional materials by dichroic photoemission — Jonas Erhardt[1,2], Cedric Schmitt[1,2], Philipp Eck[2,3], Philipp Kessler[1,2], Kyungchan Lee[1,2], Giorgio Sangiovanni[2,3], Ralph Claessen[1,2], and •Simon Moser[1,2] — [1]Physikalisches Institut, Universität Würzburg, D-97074 Würzburg, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, D-97074 Würzburg, Germany — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, D-97074 Würzburg, Germany

Topological band inversion is at the heart of the quantum spin Hall insulator (QSHI) but is difficult to demonstrate experimentally. In the bulk, this band inversion is characterized by the Berry curvature, a gauge-invariant fingerprint of the wave function's geometric properties. Intimately tied to orbital angular momentum (OAM), the Berry curvature can be in principle extracted from circular dichroism in angle-resolved photoemission spectroscopy (CD-ARPES), were it not for interfering photoelectron emission channels that obscure the OAM signature. Here, we outline a full-experimental strategy to avoid such interference artifacts and isolate the clean OAM from the CD-ARPES response. Bench-marking this strategy for the recently discovered atomic monolayer QSHI indenene, we establish CD ARPES as scale-able bulk probe to experimentally classify the topology of two dimensional quantum materials with time reversal symmetry.

TT 31.3 Tue 11:15 MA 005

Orbital angular momentum of $Cr_2Ge_2Te_6$ bands using circular dichroism — •Honey Boban[1], Mohammed Qahosh[1], Xiao Hou[1], Tom G Saunderson[2,3], Yuriy Mokrousov[2,3], Claus Michael Schneider[1], and Lukasz Plucinski[1] — [1]Peter Gruenburg Institute-6, Forschungszentrum Juelich, Germany — [2]Peter Gruenburg Institute-1, Forschungszentrum Juelich, Germany — [3]University of Mainz, Germany

We present high-resolution circular-dichroic angle-resolved photoemission (CD-ARPES) spectra from graphene, WSe_2, and $Cr_2Ge_2Te_6$ (CGT), materials that exhibit different levels of band structure complexity. In graphene, where bands near the Fermi level are of single C $2p_z$ orbital nature, we investigated various contributions to dichroism, such as phase shifts and final state scattering, by varying the photon energy. In WSe_2, near the valence band maximum Γ and K points we found strong contribution of dichroism derived from the experimental geometry, in the light incidence angle dependent CD-ARPES. We use these findings to study the OAM texture of a 2D ferromagnetic material CGT [1], in which the time reversal symmetry is broken and mirror planes are absent. CGT is interesting as it offers a platform to study the interplay of ferromagnetism and spin orbit coupling, and is a potential candidate for future spintronic devices where both spin degree of freedom and orbital degree of freedom can be utilized. Therefore, understanding the initial band OAM in CGT is crucial, as it is closely linked to its quantum transport properties [2]. Ref: [1] J. Phys. Condens. Matter **7**, 69(1995), [2] Rev. Mod. Phys. **82**, 1539(2010)

TT 31.4 Tue 11:30 MA 005

Evolution of band structure in 2D Transition Metal Dichalcogenide alloy $Mo_x W_{1-x} Se_2$ — •Sarath Sasi[1], Laurent Nicolaï[1], Aki Pulkkinen[1], Christine Richter[2,3], Karol Hricovini[2,3], and Ján Minár[1] — [1]New Technologies Research Centre, University of West Bohemia, Pilsen, Czech Republic — [2]LPMS, CY Cergy Paris Université, Neuvillesur- Oise, France — [3]Université Paris-Saclay, CEA, CNRS, LIDYL, Gif-sur-Yvette, France

In the realm of two-dimensional (2D) materials research, transition metal dichalcogenides (TMDCs) have emerged as significant subjects, especially WSe_2 and $MoSe_2$, which are notable for their similar band structures. Our research aims to explore the band structure evolution in $Mo_x W_{1-x} Se_2$ alloys (x= 0 to 1) utilizing a blend of Angle-Resolved Photoemission Spectroscopy (ARPES) experimentally and its complementary theoretical one-step model photoemission calculations employing the *SPR-KKR* package [1]. Furthermore, circular dichroism [2] ARPES measurements provide an insight into the orbital characteristics, revealing Mo concentration-dependent effects that are substantiated through photoemission calculations using the coherent potential approximation(*CPA*). For homogeneous random alloys, *CPA* effectively models average scattering properties and, within the KKR formalism, ensures no extra scattering when embedding an alloy component. Studying these systems with inherent disorders uncovers fundamental insights, enhancing their potential applications.

[1]Braun, J., Minar, J., Ebert, H. (2018). Physics Reports, 740.
[2]Beaulieu, S. *et al* . (2020). Physical Review Letters, 125(21).

TT 31.5 Tue 11:45 MA 005

Photon energy dependence of circular dichroism in the topologically nontrivial surface states of WTe_2 — •Aki Pulkkinen[1], Ján Minár[1], Shoresh Soltani[2], Khadiza Ali[2], Craig Polley[2], Balasubramanian Thiagarajan[2], and Saroj Dash[2] — [1]New Technologies-Research Centre, University of West Bohemia, Pilsen, Czech Republic — [2]MAX IV Laboratory, Lund University, Lund, Swe-

den

We present a theoretical and experimental study of the distorted octahedral transition metal dichalcogenide T_d-WTe_2, a type-II Weyl semimetal renowned for its intriguing physical properties, such as strong spin-orbit coupling, giant magnetoresistance, and superconductivity. Utilizing the full potential formulation of the one-step model of photoemission, our investigation focuses on elucidating the electronic and topological properties of WTe_2. By employing the theoretical model of angle-resolved photoemission spectroscopy (ARPES) and circular dichroism (CD), our results provide detailed insights into the spin texture of electronic states near the Fermi level. These findings contribute to the ongoing exploration of WTe_2, emphasizing its potential applications in quantum computing and advanced electronic devices while bridging the gap between theoretical predictions and experimental observations, including the characteristics of surface states.

TT 31.6 Tue 12:00 MA 005

Ultrafast Hidden Spin Polarization Dynamics of Bright and Dark Excitons in 2H-WSe2 — •Mauro Fanciulli[1,2], David Bresteau[2], Jérome Gaudin[3], Shuo Dong[4], Romain Géneaux[2], Thierry Ruchon[2], Olivier Tcherbakoff[2], Jan Minar[5], Olivier Heckmann[1,2], Maria Christine Richter[1,2], Karol Hricovini[1,2], and Samuel Beaulieu[3] — [1]LPMS, CY Cergy Paris Université, 95031 France — [2]Université Paris-Saclay, CEA, CNRS, LIDYL, 91191 France — [3]Université de Bordeaux - CNRS - CEA, CELIA, 33405 France — [4]Beijing National Laboratory for Condensed Matter Physics, 100190 China — [5]University of West Bohemia, 30100 Czech Republic

We performed spin-, time- and angle-resolved extreme ultraviolet photoemission spectroscopy of excitons prepared by photoexcitation of inversion-symmetric 2H-WSe2 with circularly polarized light.

The very short probing depth of XUV photoemission permits selective measurement of photoelectrons originating from the top-most WSe2 layer, allowing for direct measurement of hidden spin polarization of bright and momentum-forbidden dark excitons.

Our results reveal efficient chiroptical control of bright excitons' hidden spin polarization. Following optical photoexcitation, intervalley scattering between nonequivalent K-K' valleys leads to a decay of bright excitons' hidden spin polarization. Conversely, the ultrafast formation of momentum-forbidden dark excitons acts as a local spin polarization reservoir, which could be used for spin injection in van der Waals heterostructures involving multilayer transition metal dichalcogenides.

TT 32: Focus Session: Spin Phenomena in Chiral Molecular Systems I (joint session O/TT)

Spin phenomena in monolayers and thin films of enantiopure chiral molecules have recently attracted great attention. These phenomena are attributed to the chiral induced spin selectivity (CISS) effect, which leads to, for instance, different transmissions for the longitudinal orientation of the electron spin through helical molecules arranged with their molecular axes perpendicular to the surface. A microscopic theoretical understanding of the CISS effect has not been achieved so far. Therefore, new tools are being developed to uncover the different influences of electronic structure, spin-orbit coupling, and (chiral) phonons on the CISS effect. Applications have already been demonstrated in spin-directed chemistry, spintronics, and quantum technologies. The purpose of this Focus Session is to review the state-of-the-art and also to report new results.

Organizers: Katharina Franke (FU Berlin), Benjamin Stadtmüller (TU Kaiserslautern), Helmut Zacharias (U Münster)

Time: Tuesday 10:30–13:15 Location: MA 141

Topical Talk TT 32.1 Tue 10:30 MA 141

The Electron's Spin and Chirality - a Miraculous Match — •Ron Naaman — Dep. of Chemical and Biological Physics, Weizmann Institute, Rehovot, Israel

Spin based properties, applications, and devices are commonly related to magnetic effects and to magnetic materials. However, we established that chiral material could act as spin filters for photoelectrons transmission, in electron transfer, and in electron transport. The effect, termed Chiral Induced Spin Selectivity (CISS), has interesting implications in wide range of fields like spintronics, spin controlled chemistry, long range electron transfer, enantio-recognition, and enantio-separation. The basic effect, and its applications and implications, will be presented.

Topical Talk TT 32.2 Tue 11:00 MA 141

Electrons, Vibrations and Chirality — •Martin B. Plenio — Institut of Theoretical Physics and Center for Quantum Biosciences, Ulm University, Germany

Chirality - the handedness of molecules and larger structures - plays an important role in a plethora of biological, chemical, and physical processes. Peptides, DNA-helices, and small chiral molecules are identical in their constitution apart from their handedness and can have completely different interactions with biological receptors. For example, their taste can vary between chocolate or mint (menthol) or their effect can be either tranquilising or cause birth defects (thalidomide) depending on their chirality.

In 2011, it was observed that photo-electrons passing through a self-assembled monolayer of double-stranded DNA with a fixed helicity on a gold surface acquire significant spin polarisation. This chirality-induced spin selectivity (CISS) has been confirmed in various molecules.

However, there is no consensus regarding the microscopic mechanism that can explain the experimental data quantitatively. Here I would like to discuss theoretical models that combine vibrational molecular dynamics and momentum conservation to provide a possible mechanism to explain CISS and discuss potential experimental signatures that one may explore to confirm or refute this hypothesis.

Topical Talk TT 32.3 Tue 11:30 MA 141

Electrical Dipole Moment Governs Spin Polarization in Charge Transport in Single α-helical Peptides Junctions — •Ismael Diez-Perez — Department of Chemistry, Faculty of Natural and Mathematical Science, Kings College London, Britannia House, 21 Swan St

The recent discovery of the CISS (Chirality-induced Spin Selectivity) has many implications for our understanding of biological ET (electron transfer/transport). In this contribution, we are presenting our latest experimental results on spin-dependence ET through single-molecule electrical contacts made of chiral alpha-helical peptide backbones. We synthesize two alpha-helical peptides with homologous sequences of different lengths, 17 and 22 amino acids, and with their two corresponding D- and L- optical isomer. The latter includes the retro-versions of the same sequence, i.e., the same peptide sequence but in an inverted order. To measure spin-dependent single-molecule ET in such structures, we use a magnetic STM break-junction approach we have previously exploited to measure magnetoresistance in single-molecule contacts. The results are explained by an intuitive picture that includes both CISS and interfacial effects. The simple picture has enough flexibility to accommodate the description of the observed differences in magnetoresistance as a function of the magnetization direction of the Ni electrode, the chirality of the peptide, and the peptide dipole orientation on the electrode surface.

TT 32.4 Tue 12:00 MA 141

Spin-Resolved Photoemission Studies of Heptahelicene and Tetrapyrrole (Sub-)Monolayers — •Paul V. Möllers[1], Bianca C. Baciu[2], Rafael Rodriguez[3], Johannes Seibel[4], Adrian J.

Urban[5], Albert Guijarro[2], Jeanne Crassous[3], Karl-Heinz Ernst[4], Hiroshi M. Yamamoto[5], and Helmut Zacharias[1] — [1]Center for Soft Nanoscience (SoN), Univ. Münster, Germany — [2]Inst. Universitario de Síntesis Orgánica, Univ. de Alicante, Spain — [3]Univ. of Rennes, CNRS, Inst. des Sciences Chimiques de Rennes (ISCR), France — [4]Eidgenössische Materialprüfungs- und Forschungsanstalt (EMPA), Swiss Federal Laboratories for Materials Science and Technology, Switzerland — [5]Inst. for Molecular Science, Research Center of Integrative Molecular Systems, Japan

We present recent results of spin-resolved photoemission studies [1] performed with layers of dithia-heptahelicene molecules [2]. A photoelectron spin polarization (SP) of more than |P| = 30% was measured at full monolayer (ML) coverage. The SP was furthermore measured at varying submonolayer coverages to probe the role of cooperative effects in its emergence. Indeed, a sharp, nonlinear increase of the SP was found at high surface coverages above 80% of a ML. We interpret this behavior not as a direct effect of intermolecular interactions on CISS, but argue that it is mediated through a phase transition in the molecular ordering within the ML. Similar measurements were performed with layers of helical tetrapyrrole complexes. [1] Möllers et al., *Isr. J. Chem.* **2022**, 62, e202200062 [2] Baciu et al., *Nanoscale Adv.* **2020**, 2, 1921 [3] Urban et al., *Chem. Eur. J.* **2023**, 29, e202300940

TT 32.5 Tue 12:15 MA 141

Spin-dependent transmission and CISS effect in PdGa — •Mayra Peralta[1], Iñigo Robredo[1,2], Xia Wang[1], Maia Vergniory[1,2], and Claudia Felser[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain

Chiral crystalline materials are an excellent framework to study Chiral Induced Spin Selectivity-related effects, since they can be grown and designed in a more controllable way and they are ordered systems where impurities and localization effects are minimised with respect to molecules. Besides, chiral crystals present topologically protected surface states and momentum locked spin states that open the way for using chiral couplings to control quantum information. In this talk I will present an analytical-computational model using a two-terminal setup and the Landauer formalism to compute spin-dependent transmission in chiral crystals, specifically in those of the group B20 as PdGa. Based on the results obtained with this model, I will evaluate the importance of chirality and spin orbit coupling in this material, to give rise to the spin-dependent transmission observed.

TT 32.6 Tue 12:30 MA 141

Chiral-induced spin selective transmission (CISS) on naturally chiral surfaces — •Chetana Badala Viswanatha[1], Johannes Stöckl[1], Benito Arnoldi[1], Sebastian Becker[1], Ka Man Yu[1], Martin Mitkov[1], Iulia Cojocariu[2], Vitaliy Feyer[2], Martin Aeschlimann[1], and Benjamin Stadtmüller[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Peter Grünberg Institute (PGI-6), Forschungszentrum Jülich GmbH, 52428 Jülich, Germany

The chiral-induced spin selectivity (CISS) effect refers to the spin-selective electron transmission via chiral molecules. So far, CISS has been studied for helical molecules on noble metal surfaces. Here, we focus on CISS in molecules grown on a chiral Cu surface. Using spin- and momentum-resolved photoelectron spectroscopy, we show that the spin-dependent electron transmission through a point-chiral molecule on the chiral Cu(643) surface depends on all three components of the electron's spin [1]. Swapping the enantiomers alters the electrons' spin component parallel to the terraces of the chiral surface. This emphasizes the role of enantiomer-specific adsorption configurations on chiral surfaces. To understand the role of substrate chirality in CISS, we focus on the effect of a surface's chirality on the electronic properties of the adsorbed molecules. We use the highly symmetric pentacene on the Cu(643) surface as an example. Our momentum-resolved photoemission data show adsorption-induced changes in the orbital emission pattern that can be attributed to the chiral nature of the Cu surface. [1] J. Phys. Chem. Lett. 2022, 13, 26, 6244-6249.

Topical Talk TT 32.7 Tue 12:45 MA 141

First-principles approaches to chiral induced spin selectivity — •Carmen Herrmann[1,2], Sumit Naskar[1], Ulrich Pototschnig[1], Aida Saghatchi[1], and Vladimiro Mujica[3] — [1]University of Hamburg, Department of Chemistry, HARBOR Bldg. 610, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre of Ultrafast Imaging, Hamburg, Germany — [3]School of Molecular Sciences, Arizona State University, Tempe, Arizona 85287-1604, USA

Exploring the spin degree of freedom offers fascinating options for nanoscale functionality, and also provides new experimental data for improving our insight into fundamental aspects of nonequilibrium physics at that scale. Chiral induced spin selectivity (CISS) is a particularly intriguing example of this, as it leads to spin preferences in electrons transported through chiral molecules, even though the molecules themselves are diamagnetic. Its underlying mechanism is still not understood [1]. We discuss recent progress in the first-principles description of CISS [2-6], such as the importance of exchange and the buildup of nonequilibrium spin in the junction. [1] F. Evers et al., Adv. Mater. 34, 2106629 (2022). [2] V. V. Maslyuk, R. Gutierrez, A. Dianat, V. Mujica, G. Cuniberti, J. Phys. Chem. Lett. 9, 5453 (2018). [3] Y. Liu, J. Xiao, J. Koo et al, Nat. Mater. 20, 638 (2021). [4] M. Zöllner, S. Varela, E. Medina, V. Mujica, C. Herrmann, J. Chem. Theory Comput., 16, 2914 (2020) [5] M. Zöllner, A. Saghatchi, V. Mujica, C. Herrmann, J. Chem. Theory Comput., 16, 7357 (2020) [6] S. Naskar, V. Mujica, C. Herrmann, J. Phys. Chem. Lett. 14, 694 (2023).

TT 33: Focus Session: Nanomechanical Systems for Classical and Quantum Sensing I (joint session TT/DY/HL/QI)

Nanomechanical and cavity-optomechanical systems have been recently established as a controllable and configurable platform that can be engineered to tackle outstanding sensing challenges both in the classical and in the quantum regime. With this focus session, experts from different but synergetically overlapping fields of nanomechanical sensing pursuing classical, non-linear and quantum approaches are brought together. The session shall provide an overview over the recent exciting developments of the techniques explored in micro- and nanomechanical systems and sensing concepts exploring quantum measurement schemes.

This joint session will be continued Wednesday afternoon (TT53) and Thursday morning (TT70). Organized by Eva Weig, Hubert Krenner, and Hans Hübl.

Time: Tuesday 11:45–13:00 Location: H 3007

TT 33.1 Tue 11:45 H 3007

Josephson Optomechanics — •Surangana Sengupta[1], Bjoern Kubala[1,2], Joachim Ankerhold[1], and Ciprian Padurariu[1] — [1]ICQ and IQST, Ulm University, Germany — [2]DLR-QT, German Aerospace Center, Ulm, Germany

In recent years, optomechanical cooling using microwave radiation has been realized in various superconducting circuits with a microwave cavity comprising a mechanical element. Circuits provide an opportunity to engineer nonlinear cavities, by using Josephson junctions, thereby generating quantum states of light for optomechanics experiments.
Here, we will theoretically describe an optomechanical setup where the cavity is realized by an LC circuit driven by a dc-biased Josephson junction. By engineering the nonlinearity, such a cavity becomes an effective N-level system, with $N = 2, 3, ...$, where the access to Fock states N and above is blocked. Consequently, the cavity emission spectrum shows Mollow-type side peaks, analogous to an optical

cavity interacting with an atom. We show that at these Mollow side peaks, the system exhibits a new, nonlinear type of optomechanical cooling. We calculate the cooling rate using the spectral density of noise due to the radiation pressure [1] and highlight how its unusual features compared to conventional optomechanics, can be explained in a dressed state picture.

[1] F. Marquardt *et.al.*, Phys. Rev. Lett. **99** (2007) 093902

TT 33.2 Tue 12:00 H 3007

Logarithmic susceptibility of a quantum parametrically modulated oscillator — •Daniel Boness[1], Wolfgang Belzig[1], and Mark Dykman[2] — [1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [2]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA

A weakly damped nonlinear oscillator modulated close to twice its eigenfrequency has two stable states, which have the same vibration amplitudes but opposite phases. The states are equally populated due to classical or quantum fluctuations.

An extra force at half the modulation frequency lifts the symmetry of the states. Even a weak force can result in a significant change of the populations, as it beats against the intensity of quantum and classical fluctuations. We develop an approach that allows us to find this population change.

We also study the effect of the extra force with frequency slightly detuned away from half the modulation frequency. For a detuning that is small compared to the switching rate the force leads to the imbalance of populations that is modulated at the frequency of the detuning. For larger detuning, the adiabatic picture breaks down and the wells are again equally populated. However, the rates of switching between the wells is exponentially increased. We calculate the change of the logarithm of the switching rate, termed logarithmic susceptibility, using the real-time instanton method. The results are relevant for controlling parametric oscillators and their application in quantum information systems.

TT 33.3 Tue 12:15 H 3007

Cavity optomechanics with carbon nanotube quantum dots — •Akong N. Loh, Furkan Özyigit, Fabian Stadler, Niklas Hüttner, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

Carbon nanotubes (CNTs) are the smallest and lightest nanomechanical beam resonators. When suspended transversally between two electrodes (Ti/Au for example) and then gated, they can act as mechanical beam resonators with large quality factors and also as quantum dots. The motion of a CNT is coupled to other degrees of freedom, such as photons, spins, and electrons. The optomechanical coupling of a single wall carbon nanotube nanomechanical resonator to a microwave cavity has been realized and quantified through optomechanically induced transparency measurements [1]. The quantum dot properties of the CNT were exploited (specifically the nonlinearity of the coulomb blockade) to significantly enhance the coupling strength [1,2]. Current work is directed towards achieving even stronger coupling and possibly groundstate cooling of the nanomechanical resonator through anti-Stokes processes. This requires significant improvement of the microwave cavity, CNT growth and transfer. All measurements are done at ∼10 mK in a dilution refrigerator.

[1] S. Blien *et al.*, Nat. Comm. **11** (2020) 1636
[2] N. Hüttner et al., Phys. Rev. Applied, in press (2023), arXiv:2304.02748

TT 33.4 Tue 12:30 H 3007

Signatures of Josephson force in a vibrating carbon nanotube junction — •Andreas K. Hüttel[1,2], Jukka-Pekka Kaikkonen[2], Keijo Korhonen[2], and Pertti Hakonen[2] — [1]Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany — [2]Low Temperature Laboratory, Dept. of Applied Physics, Aalto University, Espoo, Finland

A carbon nanotube suspended between superconducting electrodes acts simultaneously as nanomechanical resonator and as a Josephson junction. Its energy-dependent density of states and with that displacement-dependent critical current further adds to the complexity of the system, as does both mechanical and electronic nonlinearity. Measurements on such a system display complex behaviour of the vibrational resonance with respect to junction biasing. Strikingly, the resonance frequency appears to decrease in a distinct parameter region where the biasing is similar in size to the junction switching current.

Using highly parallelized Julia code, we numerically solve the coupled differential equation system of the driven (via an ac gate voltage and ac current or voltage bias) system for realistic device parameters and characterize the evolving steady state. Specific attention is given to the impact of the Josephson junction behaviour on the mechanical resonance frequency and the vibration amplitude, and on the ac signal simultaneously acting on gate and bias.

TT 33.5 Tue 12:45 H 3007

Optimization of Flux-Tunable Microwave Resonators for Strong Single-Photon Optomechanics in Nano-Electromechanical Systems — •Korbinian Rubenbauer[1,2], Thomas Luschmann[1,2], Kedar Honasoge[1,2], Achim Marx[1,2], Kirill G. Fedorov[1,2,3], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technologies, Munich, Germany

Quantum sensing leverages quantum properties to enhance the precision of sensing applications. One promising implementation for the detection of forces or accelerations are optomechanical systems which encode the displacement of a low-frequency mechanical element onto the properties of a high-frequency optical or electromagnetic resonator. We present a flux-tunable superconducting quantum circuit with an integrated superconducting quantum interference device (SQUID), where the mechanical element is embedded in the SQUID structure. This implements a magnetic field and flux tunable optomechanical interaction with the prospect of reaching the strong single-photon coupling regime. We discuss the design concept of the device and detail its optimization. We corroborate the conceptual improvements with experimental data demonstrating the performance improvements of the microwave resonator, the optomechanical coupling and the mechanical element.

TT 34: Focus Session: Dynamical Probes for Topological Magnetism

Non-equilibrium phenomena are attracting a great deal of interest. One of the main reasons for this intense research effort is to establish the coherent control of quantum states. Magnetic systems constitute promising platforms in this respect because they display quantum properties already in the groundstate. Moreover, several manifestation of coherent spin dynamics in a wide variety of materials and in different regimes (linear, nonlinear, transport, THz frequencies) have been reported. Topological protection of their quantum states adds to the advantageous properties. In view of these aspects, the proposed focus session is intended to present experimental and theoretical advances ranging from ab initio calculations over model simulations to experiments demonstrating the generation, control and detection of spin dynamics.

Organizers: Davide Bossini (University of Konstanz), Götz Uhrig (TU Dortmund University)

Time: Wednesday 9:30–12:15 Location: H 0104

Invited Talk TT 34.1 Wed 9:30 H 0104

A phononic route to ultrafast control of magnetic order — •Andrei Kirilyuk — FELIX Laboratory, Radboud University, 6525 ED Nijmegen, The Netherlands

Strong light-matter interaction constitutes the basis of all photonic applications, empowering material elements to create and mediate interactions of light with light. Among others, phonon-amplified interactions were shown to bring a specific twist into this. In this case, light couples to the spins indirectly by exciting coherent vibrations of the crystal lattice (phonons) that transfer angular momentum to the magnetic ions. The optically driven chiral phonons were shown to possibly produce giant effective magnetic fields. The mechanism allows for bidirectional control of the induced magnetisation through phonon chirality that in turn can be controlled by the polarisation of the laser pulse.

Here we show that through the resonant excitation of circularly-polarized optical phonons in paramagnetic substrates, one can permanently reverse the magnetic state of the substrate-mounted heterostructure. With the handedness of the phonons steering the direction of magnetic switching, such effect offers a selective and potentially universal method for ultrafast non-local control over magnetic order.

Moreover, a different behavior, characterized by displacive modification of magnetic potentials, can be observed when exciting materials at phonon frequencies with linearly-polarized light. The magnetic switching was shown to create very peculiar patterns, confirming the mechanism.

Invited Talk TT 34.2 Wed 10:00 H 0104

Spectroscopic signatures of spin dynamics in spin-orbit-coupled magnets: resolving quantum spin liquids versus magnetically ordered phases — •Roser Valenti — Institute of Theoretical Physics, Goethe University Frankfurt, Frankfurt a.M., Germany

In the search for material realizations of quantum spin liquid phases, spin-orbit coupled magnets – such as the so-called Kitaev materials – have been intensively studied for the last decade. Quantum spin liquid states are characterized by the absence of long-range order even at zero temperature and the presence of exotic fractionalized excitations, in contrast to spin-wave excitations found in conventional magnets. Experimentally probing and theoretically modelling the signatures and topology of these excitations is a challenging task.

In this talk we will first review and discuss the microscopic modelling of spectroscopic signatures (Raman, INS, THz) of spin dynamics in spin-orbit coupled magnets, and we will then move to nonlinear spectroscopy. Nonlinear spectroscopy has been recently suggested as a potentially powerful tool to distinguish coherent fractionalized excitations from effects of disorder or finite lifetime, which are difficult to distinguish in linear response excitation continua. In this spirit, we will introduce methods to efficiently calculate nonlinear response functions numerically, and will present results for extended Kitaev models that are relevant for the description of real materials.

Work done in collaboration with David Kaib, Marius Möller and Wolfram Brenig and funded by the DFG /TRR288.

Invited Talk TT 34.3 Wed 10:30 H 0104

Probing spin dynamics by Hall effect and emergent inductance — •Max Hirschberger[1,2], Jan Masell[2,3], and Rinsuke Yamada[1] — [1]Dept. of Applied Physics, Univ. Tokyo, Tokyo, Japan — [2]RIKEN Center for Emergent Matter Science, Wako, Japan — [3]Karlsruhe Institute of Technology, Karlsruhe, Germany

For helimagnetic textures, an ongoing interest is the investigation of spin dynamics driven by current, or generated by thermal fluctuations. We study thermally induced spin chirality using the Hall / Nernst effects [1,2], and aim to develop inductance measurements, that is the detection of a phase-shifted voltage in response to a current excitation, as a tool to probe the low-lying excitations of spirals and cycloids, supporting thermodynamic and neutron scattering techniques.

Nagaosa (2019) first proposed that current-induced spin tilting of a proper screw or cycloid texture in metallic helimagnets generates an emergent electric field $\mathbf{e}_{em}$ that is time delayed with respect to the excitation current; namely, an inductive response. This $\mathbf{e}_{em}$ can be understood as spin winding in a two-dimensional plane spanned by time and space axes [3]. We have studied $\mathbf{e}_{em}$ in spiral magnets, such as $Gd_3Ru_4Al_{12}$, and found a sizable response that is linear in frequency, but nonlinear in the excitation current [4,5].

[1] K. Kolincio, M. Hirschberger *et al.*, PNAS **118** (2021) e2023588118
[2] K. Kolincio, M. Hirschberger *et al.*, PRL **130** (2023) 136701
[3] N. Nagaosa, Jpn. J. Appl. Phys. **58** (2019) 120909
[4] T. Yokouchi, F. Kagawa, M. Hirschberger *et al.*, Nature **586** (2020) 232
[5] R. Yamada, M. Hirschberger, *et al.*, in preparation (2024)

15 min. break

Invited Talk TT 34.4 Wed 11:15 H 0104

Dissipative Spin-wave Diode and Nonreciprocal Magnonic Amplifier — •Jelena Klinovaja, Ji Zou, Stefano Bosco, Even Thingstad, and Daniel Loss — Department of Physics University of Basel Klingelbergstrasse 82 4056 Basel, Switzerland

We propose an experimentally feasible dissipative spin-wave diode comprising two magnetic layers coupled via a non-magnetic spacer. We theoretically demonstrate that the spacer mediates not only coherent interactions but also dissipative coupling. Interestingly, an appropriately engineered dissipation engenders a nonreciprocal device response, facilitating the realization of a spin-wave diode. This diode permits wave propagation in one direction alone, given that the coherent Dzyaloshinskii- Moriya (DM) interaction is balanced with the dissipative coupling. The polarity of the diode is determined by the sign of the DM interaction. Furthermore, we show that when the magnetic layers undergo incoherent pumping, the device operates as a unidirectional spin-wave amplifier. The amplifier gain is augmented by cascading multiple magnetic bilayers. By extending our model to a one-dimensional ring structure, we establish a connection between the physics of spin-wave amplification and non-Hermitian topology. Our proposal opens up a new avenue for harnessing inherent dissipation in spintronic applications.

[1] Ji Zou, S. Bosco, E. Thingstad, J. Klinovaja, D. Loss, arXiv:2306.15916

Invited Talk TT 34.5 Wed 11:45 H 0104

Floquet magnons in a periodically-driven magnetic soliton — •Helmut Schultheiss — Helmholtz-Zentrum Dresden-Rossendorf, Institut für Ionenstrahlphysik und Materialforschung, Dresden, Germany — Fakultät Physik, Technische Universität Dresden, Dresden, Germany

Magnetic vortices are prominent examples for topology in magnetism with a rich set of dynamic properties. They exhibit an intricate magnon spectrum and show a special eigen-resonance of the vortex texture itself, the gyroscopic motion of the vortex core. While there has been studies about magnon assisted reversal of the vortex core polarity, the impact of the vortex core motion on the magnon spectrum wasn't addressed so far. Both excitation types are clearly separated by one order of magnitude in their resonance frequencies, where magnons are in the lower GHz range and the vortex typically gyrates at a few hundred MHz. This clear separation allows for experiments studying the temporal evolution of the magnon spectrum when the motion of the vortex core is driven by an external stimulus. We present experimental and numerical studies on how the magnon eigenstates are transformed into Floquet bands, when the vortex ground state is periodically modulated in time by the gyroscopic motion of the vortex core. The existence of the Floquet bands is evidenced by the appearance of magnon frequency combs, where the comb spacing is determined by the frequency of the gyroscopic motion.

TT 35: Superconducting Electronics: SQUIDs, Circuit QED

Time: Wednesday 9:30–13:15 Location: H 2053

TT 35.1 Wed 9:30 H 2053

Spin Hamiltonian of 3d/4f single molecule magnets revealed by micro-SQUID-EPR — •Sagar Paul[1], Mario Ruben[2], Shouvik Chattopadhyay[3], Eufemio Moreno-Pineda[4], and Wolfgang Wernsdorfer[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Germany. — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany. — [3]Jadavpur University, Kolkata - 700032, India. — [4]Universidad de Panamá, 0824, Panamá.

The single molecule magnets (SMM) exhibit magnetic anisotropy at molecular level, slow relaxation and resonant quantum tunneling of magnetization (QTM) leading to numerous applications in molecular spintronics and quantum information processing. The hyperfine levels observed in micro-SQUID M(H) measurements open possibilities of utilizing nuclear spin in quantum computation. Further, recent observations of large decoherence times of electronic spin states in diluted single crystals of Gd SMMs [1], has re-encouraged the research on such SMMs. A combined micro-SQUID-EPR [2] stands as a unique experimental technique to precisely study the magnetism, in situ while exciting a single crystal with microwave pulse. With this technique, the M(H) loops of 3d/4f monomer/dimer SMMs studied in 30 mK - 5 K range, and for different frequencies of microwave excitation, exhibit absorption peaks associated to specific spin transitions. The peak positions plotted with RF frequency (1-40 GHz) and field angles reveal the entire spin Hamiltonian of the system [2].

[1] G. Handzlik et al., J. Phys. Chem. Lett. 11 (2020) 1508
[2] G. Taran et al., Nat. Commun. 14 (2023) 3361

TT 35.2 Wed 9:45 H 2053

Nb constriction-Josephson-junction nanoSQUIDs on cantilevers patterned by He and Ne focused ion beams — •Jan Ullmann[1], Timur Griener[1], Simon Koch[1], Simon Pfander[1], Chloé Bureau-Oxton[2], Daniel Jetter[3], Andriani Vervelaki[3], Kousik Bagani[3], Ute Drechsler[2], Oliver Kieler[4], Reinhold Kleiner[1], Martino Poggio[3], Armin Knoll[2], and Dieter Koelle[1] — [1]Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, Universität Tübingen, Germany — [2]IBM Research Europe, Zürich, Rüschlikon, Switzerland — [3]Department of Physics and Swiss Nanoscience Institute, University of Basel, Switzerland — [4]Department Quantum Electronics, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Nanopatterning of superconducting thin film structures with focused He or Ne ion beams (He/Ne-FIB) offers a flexible tool for creating constriction-type Josephson junctions (cJJs) which can be integrated into strongly miniaturized Superconducting Quantum Interference Devices (nanoSQUIDs). We present our attempts to use He/Ne-FIB for fabricating Nb nanoSQUIDs which shall provide ultra-low noise and high spatial resolution for their application in scanning SQUID microscopy (SSM). The nanoSQUIDs are designed as sensors for magnetic flux and dissipation. We address the possibility to implement multi-terminal, multi-cJJ SQUIDs on custom-made Si cantilevers, which will provide the possibility of simultaneous conventional topographic imaging by atomic force microscopy (AFM). We will discuss the status and challenges of this project to combine SSM and AFM on the nanoscale.

TT 35.3 Wed 10:00 H 2053

Development of ultrasensitive dc SQUIDs with sub-micrometer circuit elements — •Mauro Esattore[1], Michael Paulsen[2], Jörn Beyer[2], Mark Bieler[1], Oliver Kieler[1], Patryk Krzysteczko[2], and Rainer Körber[2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Abbestraße 2-10, 10587 Berlin, Germany

Since its first iteration in the early 1960s, the direct current Superconducting QUantum Interference Device (dc SQUID) has been one of the most sought-after applications of superconductor technology. Its sensitivity to even the smallest magnetic fields allows for numerous applications, be it as a magnetometer in the fields of biomagnetism, magnetic flux sensor of cryogenic detectors, or for electrical metrology. In this presentation, we discuss the use of superconductive, sub-micrometer fine-pitch coils to be used in Nb/AlOx/Nb SQUID designs. The aim is to minimize the inductive losses of the signal-to-SQUID coupling, without compromising the overall device layout. It is also possible to achieve outstanding coupled energy resolution - while using the dc SQUID as a current sensor- by adapting the input coil inductances to the impedance of the signal source. Finally, the sub-micrometer input coils allow for a much lower noise energy per bandwidth ϵ ($\epsilon \approx 16 k_B T \sqrt{LC}$ under optimum conditions) as well as a wider range on input inductances for existing sensor types. We provide an overview of the fabrication process of the sub-micrometer fine-pitch coils, and some preliminary characterization results.

TT 35.4 Wed 10:15 H 2053

Tunable Superconductor Insulator Transition in a Quantum Phase Slip Interference Device — •Jan Nicolas Voss[1], Micha Wildermuth[1], Max Kristen[1,2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Institut für Quantenmaterialien und Technologien (IQMT), Karlrsruher Institut für Technologie, Karlsruhe, German

The duality between quantum phase slip nanowires and Josephson junctions has triggered a variety of theoretical and experimental works. However, many aspects of these fluctuations are still not fully understood, especially when interference effects are considered.

We present a realization of a quantum phase slip interferometer based on two strongly coupled granular aluminum nanowires connected in series. In the experiment, the interference is controlled by a gate voltage and manifests as a periodic modulation of the critical Coulomb blockade voltage. Our data show that the modulation amplitude depends on the homogeneity of the wires. To improve the wire homogeneity, we employ the intrinsic electromigration technique ([1]) which allows to adjust the resistances and thus the Coulomb blockade of the individual wires. We observe a strong destructive interference of quantum phase slips, displaying a transition from the insulating to a superconducting state. The circuit is analyzed in detail and future applications are proposed.

[1] J. N. Voss, Y. Schön, M. Wildermuth, D. Dorer, J. H. Cole, H. Rotzinger and A. V. Ustinov, ACS Nano (2021) Mar 23;15(3):4108

TT 35.5 Wed 10:30 H 2053

Design considerations for the optimization of λ-SQUIDs — •Constantin Schuster[1] and Sebastian Kempf[1,2] — [1]Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Germany — [2]Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Germany

Cryogenic microcalorimeters such as metallic magnetic calorimeters (MMC) or superconducting transition-edge sensors (TES) have become a mature technology and are presently used in various applications requiring an excellent energy resolution. While development on these established technologies continues to progress, we have recently introduced an alternative microcalorimeter concept, called λ-SQUID. It is based on the strong temperature dependence of the magnetic penetration depth of a superconducting material, affecting the current distribution within a superconducting wire and hence its kinetic and geometric inductance. We use this effect to build a detector in which the mutual inductance between a SQUID and an input coil carrying a constant current becomes temperature sensitive. In this contribution, we present theoretical considerations regarding the design of the sensing element in a λ-SQUID to yield an optimal sensitivity and energy resolution. We show that the noise contribution form the λ-SQUID can be minimised if the specific heat of the sensing element exactly equals the particle absorber. Additionally, we consider the influence of sensing- and input coil stripline width, thickness, and separation on the detector sensitivity using a modified geometric mean distance method adapted to superconductors.

TT 35.6 Wed 10:45 H 2053

Microwave measurements of a Josephson junction based on a 2D HgTe quantum well — •Wei Liu[1,2], Stanislau Piatrusha[1,2], Lena Fürst[1,2], Lukas Lunzer[1,2], Martin P. Stehno[1,2], and Laurens W. Molenkamp[1,2] — [1]Experimentelle Physik III, Physikalisches Institut, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany. — [2]Institute for Topological Insulators, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

We measured the microwave response of a rf SQUID based on a 2D HgTe Josephson junction, by inductively coupling it to a superconducting resonator. We extract both the current-phase relation and the phase dependent dynamic dissipation between the Andreev bound states. We focus on non-topological ABSs and study their response to temperature, magnetic field and strong microwave drive. The dynamic dissipation shows a temperature-driven crossover from 2π-periodic oscillations to a π-quasiperiodic pattern with different peak heights at even and odd values of phase π. We show how the magnetic field modulates the current phase relation and the dynamic dissipation peak, leading to effects such as the half flux periodicity, the Josephson diode effect and the splitting and combining of the dissipative peaks. Under a strong microwave irradiation, both the supercurrent and the dynamic dissipation deviate from the adiabatic Josephson effect. We attribute this to the nonequilibrium occupation of Andreev bound states due to photon induced transitions across the energy gap, which enables us to map out the phase dependent effective Andreev gap.

TT 35.7 Wed 11:00 H 2053

Anisotropic magnetic field dependence in hybrid superconductor/semiconductor microwave resonator as a signature of unconventional induced superconductivity — •Simon Feyrer[1], Ignacio Lobato[1], Michael Prager[1], Dominique Bougeard[1], Carlos Balseiro[2], Marco Aprili[3], Christoph Strunk[1], and Leandro Tosi[1,2] — [1]Institute of Experimental and Applied Physics, University of Regensburg, Germany — [2]Centro Atomico Bariloche, Comision Nacional de Energia Atomica, Argentina — [3]Laboratoire de Physique des Solides, Université Paris-Saclay, France

We present measurements of the frequency response of a lumped element microwave resonator made out of hybrid Al/InAs superconductor/semiconductor 2D heterostructures. In our device, the inductor is a narrow wire taylored in the material, dominating the kinetic inductance contribution. The resonance frequency depends on temperature, on power and strongly on in-plane magnetic field. We have observed an anisotropic magnetic field dependence, stronger when the in-plane field is orientated perpendicular to the wire. This anisotropy can be explained by considering the contribution of the kinetic inductance of the InAs 2DEG, where the induced superconductivity is affected by the spin-orbit coupling [1].

[1] D. Phan et al., Phys. Rev. Lett. 128 (2022) 107701

15 min. break

TT 35.8 Wed 11:30 H 2053

Phase locking squeezed states of microwave light — Lukas Danner[1,2], Florian Höhe[2], Ciprian Padurariu[2], Joachim Ankerhold[2], and •Björn Kubala[1,2] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]ICQ and IQST, Ulm University, Ulm, Germany

Squeezed states of light constitute an important resource for various quantum technological applications, such as using the reduced fluctuations for metrology or the entanglement of a two-mode squeezed state for teleportation or quantum illumination. For all these applications stabilization of the phase is crucial. Josephson photonics devices, where microwave radiation is created by inelastic Cooper pair tunneling across a *dc-biased* Josephson junction in-series with a microwave resonator, are particularly vulnerable as they lack the reference phase provided by an ac-drive. This hampers, for instance, the direct measurement of entanglement [1]. We recently developed a full quantum mechanical theory [2] describing, first, how the intrinsic shot noise of the Josephson-photonics device inevitably diffuses the oscillators phase and how, second, the phase and frequency of the emission can be locked to a weak ac-input. Based on this theory, we show here, how locking mechanism and features change, if Josephson-photonics devices are operated at a resonance, where pairs of photons and thus squeezed radiation are created.

[1] A.Peugeot et al., Phys. Rev. X **11** (2021) 031008
[2] F. Höhe et al., arXiv:2306.15292.

TT 35.9 Wed 11:45 H 2053

Magnetic bound-states embedded in tantalum superconducting thin films — •Soroush Arabi[1], Qili Li[2], Ritika Dhundhwal[1], Lucas Brauch[1], Pal Sudip[3], Dirk Fuchs[1], Jose Palomo[4], Marc Scheffler[3], Zaki Leghtas[4], Christian Kübel[5,6,7], Thomas Reisinger[1], Ioan Pop[1,2,3], and Wulf Wulfhekel[1,2] — [1]IQMT, Karlsruhe Inst. of Technology, Karlsruhe, Germany — [2]PHI, Karlsruhe Inst. of Technology, Karlsruhe, Germany — [3]PHI, Universität Stuttgart, Stuttgart, Germany — [4]ENS, Paris, France — [5]INT, Karlsruhe Inst. of Technology, Karlsruhe, Germany — [6]Joint Research Laboratory Nanomaterials, Technical University of Darmstadt, Darmstadt, Germany — [7]KNMF, Karlsruhe Inst. of Technology, Karlsruhe, Germany

Tantalum has been established as a new material platform for superconducting quantum devices with record coherence times. This has sparked intensive efforts to quantify the sources for the high performance and to find ways to further improve it. In this work, we study different phases of tantalum thin films, grown on sapphire (Al_2O_3) and magnesium oxide (MgO) substrates using different deposition methods such as direct current magnetron sputtering and also electron beam evaporation techniques. By employing a millikelvin MBE-STM system, we characterize these thin films at nanoscale. In sputtered films that have been exposed to air we observe magnetic bound-states poisoning the superconducting gap. Moreover, we show that epitaxial films grown under ultra-high vacuum condition do not suffer from the presence of those magnetic bound states.

TT 35.10 Wed 12:00 H 2053

Engineering the speedup of quantum tunneling in Josephson systems via dissipation — Johannes Hauff[1], Joachim Ankerhold[1], Gianluca Rastelli[2], Wolfgang Belzig[3], Sabine Andergassen[4], and •Dominik Maile[1] — [1]Institute for Complex Quantum Systems, Ulm University — [2]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento — [3]Fachbereich Physik, Universität Konstanz — [4]Informatics, TU Wien

We theoretically investigate the escape rate occurring via quantum tunneling in a system affected by tailored dissipation. Specifically, we study the environmental assisted quantum tunneling of the superconducting phase in a current-biased Josephson junction. We consider Ohmic resistors inducing dissipation both in the phase and in the charge of the quantum circuit. We find that the charge dissipation leads to an enhancement of the quantum escape rate. This effect appears already in the low Ohmic regime and also occurs in the presence of phase dissipation that favors localization [1]. We further discuss the influence of temperature on the observed effect and possible technological applications.

[1] D. Maile, J.Ankerhold, S. Andergassen, W. Belzig, G. Rastelli Phys. Rev. B 106 (2022) 045408

TT 35.11 Wed 12:15 H 2053

Hybird high-T$_c$ two dimensional superconductor into quntum circuit — •Haolin Jin[1], Giuseppe Serpico[1], Christian N. Saggau[2], Tommaso Confalone[2], Yejin Lee[2], Poya Yang[1], Edourad Lense[1], Nicola Poccia[2], and Uri Vool[1] — [1]Max Planck institute for chemical physics of solids, Dresden, Germany — [2]Leibniz Institute for Solide state and Materials Research, Dresden, Germany

In the realm of superconducting quantum devices, van der Waals (vdW) materials are promising due to their high flexibility, relatively small volume, and tunable electronic properties. However, integrating the vdW material into the quantum circuit with high coherence is still an outstanding problem. In this study, we incorporate thin vdW flake of $Bi_2Sr_2CaCu_2O_8$ (BSCCO) into a Nb resonator circuit. The integration of BSCCO at the current antinode transforms the resonant mode, while maintaining a high quality factor (Q 10^4). Through temperature and power sweeping measurements, we demonstrate that the dissipation attributed to BSCCO in the circuit is predominantly due to interface dielectric losses and its behavior can be modeled by a bath of Two-Level Systems (TLS). By understanding the loss mechanisms in vdW based quantum circuits, we can optimize circuit coherence and pave the way to future hybrid circuits for quantum technology applications.

TT 35.12 Wed 12:30 H 2053

Circuit-QED hardware for simulating features of quantum gravity — •Mohammad Atif Javed, Daniel Kruti, Ahmed Kenawy, Tobias Herrig, Christina Koliofoti, Oleksiy Kashuba, and Roman-Pascal Riwar — Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich, D-52425 Jülich, Germany

The symbiosis of ideas between high-energy and condensed-matter physics has a long and fruitful tradition, be it the elusive Majorana fermion, the relativistic effects in graphene and Weyl semimetals, or the BCS theory serving as a blueprint for the Higgs mechanism. Here, we show that superconducting circuits can simulate fundamental and even highly speculative aspects of quantum gravity. We focus on two effects: Hawking radiation and quantum metrics. First, we demonstrate that the cosine behaviour of Josephson junctions allows for creating analogue wormholes with a single transient flux quench, subsequently permitting the system to evolve autonomously (unlike ultracold gases in which the drive is continuous). We propose two ways to detect the presence of these wormholes, first by observing the behavior of a wavepacket as it traverses the system and second by measuring how the correlations evolve in time in their presence. Second, using multistable Josephson junctions, we study how to create superpositions of different spacetime metrics. We can demonstrate the presence of this superposition with a wavepacket moving across the system that will split as it entangles with different metrics.

TT 35.13 Wed 12:45 H 2053

Circuit QED with two $\mathcal{PT}$-symmetric non-Hermitian qubits — •Mikhail Fistul[1], Grigory A. Starkov[2], and Ilya M. Eremin[1] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany — [2]Theoretische Physik IV, Universität Würzburg, Würzburg, Germany

Motivated by recent experiments on single non-Hermitian superconducting [1] or spin-qubits [2] we present here a detailed analysis of an exmplary $\mathcal{PT}$-symmetric circuit QED composed of two biased non-Hermitian qubits embedded in a lossless resonator [3]. We consider a resonant quantum circuit as $|\omega_r - \Omega| \ll \omega_r$, where Ω and ω_r are qubits and resonator frequencies, respectively, providing well-defined groups of quasidegenerate resonant states. Non-Hermiticity is introduced via a staggered gain/loss parameter, γ of individual qubits. Using the direct numerical diagonalization and the generalized Schrieffer-Wolff transformation we obtain the dependence of low-lying eigenspectrum on the interaction strength between a single qubit and the resonator, g, identify the $\mathcal{PT}$-symmetry broken and unbroken phases, and exeptional points of second and third order. We also show that in $\mathcal{PT}$-symmetric circuit QED non-Hermiticity mixes the "dark" and the "bright" states.

[1] W. Chen, M. Abbasi, Y. N. Joglekar, K. W. Murch, Phys. Rev. Lett. **127** (2021) 140504
[2] Y. Wu, et. al., Science **364** (2019) 878
[3] G. A. Starkov, M. V. Fistul, I. M. Eremin, arXiv:2309.09829

TT 35.14 Wed 13:00 H 2053

Nonlinear Conductivity in Superconductor MgB_2 Films — •Clemens Schmid[1], Markus Gruber[1], Corentin Pfaff[2], Karine Dumesnil[2], Thomas Hauet[2], Stephane Mangin[2], and Oleksandr Dobrovolskiy[1] — [1]Faculty of Physics and Vienna Doctoral School in Physics, University of Vienna, Vienna, Austria — [2]Université de Lorraine, CNRS, IJL, Nancy, France

Knowing the maximal vortex velocities is essential for assessing the energy relaxation mechanisms in superconductors and their applications in superconducting single-photon detectors (SSPDs) [1]. The dynamics of vortices at a few km/s velocities is furthermore interesting itself, because of the question regarding the ultimate speed limits for magnetic flux transport in superconductors and generation of sound and spin waves in heterostructures [2]. Here, we investigate the current-voltage curves of single crystal MgB_2 20 nm-thick films which have comparably high critical temperatures of 30 K [3] and are interesting as potential materials for SSPDs. In the regime of nonlinear conductivity, we investigate the escape of non-equilibrium electrons from the vortex cores and compare the associated relaxation time of quasiparticles for MgB_2 films of different structural quality and capped with a good-conductor (Au) layer. The deduced parameters are discussed in the context of crossover from global to local instability models and the application of MgB_2 films in SSPDs [4].

[1] D. Vodolazov et al., Phys. Rev. Appl. 7 (2017) 034014
[2] O. Dobrovolskiy et al., Nat. Commun. 11 (2020) 3291
[3] M. Muralidhar et al., J. Phys. D: Appl. Phys. 57 (2023) 053001
[4] I. Charaev et al., arXiv 2308.15228 (2023)

TT 36: Superconductivity: Theory I

Time: Wednesday 9:30–13:00 Location: H 3005

TT 36.1 Wed 9:30 H 3005

Interorbital Cooper pairing at finite energies in Rashba surface states — •Philipp Rüssmann[1,2], Masoud Bahari[1], Stefan Blügel[2], and Björn Trauzettel[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany

Multiband effects in hybrid structures provide a rich playground for unconventional superconductivity. We combine two complementary approaches based on density-functional theory (DFT) [1] and effective low-energy model theory in order to investigate the proximity effect in a Rashba surface state in contact with an s-wave superconductor [2]. We discuss these synergistic approaches and combine the effective model and DFT analysis at the example of a Au/Al heterostructure. This allows us to predict finite-energy superconducting pairing due to the interplay of the Rashba surface state of Au, and hybridization with the electronic structure of superconducting Al. We investigate the nature of the induced superconducting pairing, and we quantify its mixed singlet-triplet character. Our findings demonstrate general recipes to explore real material systems that exhibit interorbital pairing away from the Fermi energy.

This work was supported by the Bavarian Ministry of Economic Affairs, Regional Development and Energy and the ML4Q Cluster of Excellence (EXC 2004/1 - 390534769).

[1] P. Rüßmann and S. Blügel, Phys. Rev. B **105** (2022) 125143.
[2] P. Rüßmann *et al.*, Phys. Rev. Research **5** (2023) 043181.

TT 36.2 Wed 9:45 H 3005

Beyond the Fermi surface: full-bandwidth Migdal-Eliashberg superconductivity in superhydrides — •Roman Lucrezi[1], P. P. Ferreira[1,2], S. Hajinazar[3], H. Mori[3], H. Paudyal[3], E. R. Margine[3], and C. Heil[1] — [1]Graz Univ. of Techn. Austria — [2]Univ. de São Paulo, Brazil — [3]Binghamton Univ., USA

We present an ab-initio implementation of the full-bandwidth anisotropic Migdal-Eliashberg theory to overcome the shortcomings of the constant-DOS approach in describing superconducting properties in materials with narrow bands or critical points near the Fermi level. In contrary to the constant-DOS approach, the full-bandwidth theory takes into account electron scattering processes beyond the Fermi surface within a self-consistent determination of the mass renormalization function, energy shift, and order parameter at various temperatures while maintaining charge neutrality. We demonstrate the effectiveness of our implementation by applying it to two classes of near room-temperature superhydrides: the sodalite-like clathrates YH_6 and CaH_6, as well as the covalently-bonded H_3S and D_3S. In addition, we investigate the effects of maximizing the density of states at the Fermi level for topical electron- and hole-doped superhydrides. We compare the new full-bandwidth treatment to the previous constant-DOS approximation and reveal significant improvements in describing the superconducting state with our advanced implementation. This not only enhances precision but also offers computational efficiency, and thus provides new perspectives on high-accuracy predictions in superconductivity research.

TT 36.3 Wed 10:00 H 3005

Stability of Bogoliubov Fermi Surfaces within BCS Theory

— Ankita Bhattacharya[1,2] and •Carsten Timm[2] — [1]Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden — [2]Institute of Theoretical Physics, TU Dresden, 01062 Dresden, Germany

It has recently been realized that the gap nodes of multiband superconductors that break time-reversal symmetry generically take the form of Fermi surfaces of Bogoliubov quasiparticles. These Fermi surfaces lead to a nonzero density of states (DOS) at the Fermi energy, which typically disfavors such superconducting states. It has thus not been clear whether these states can be stable for reasonable pairing interactions or are preempted by time-reversal-symmetric states with vanishing DOS. Applying BCS theory to a paradigmatic model, we show that the time-reversal-symmetry-breaking states are indeed stabilized over broad parameter ranges at weak coupling [1]. Moreover, we introduce a fast method that involves solving the inverse BCS gap equation, does not require iteration, does not suffer from convergence problems, and can handle metastable solutions.

[1] A. Bhattacharya, C. Timm, Phys. Rev. B **107** (2023) L220501

TT 36.4 Wed 10:15 H 3005

Bogoliubov-Fermi Surfaces in 2D heterostructures — •Julia Link and Carsten Timm — TU Dresden, Germany

A characteristic feature of the superconducting state in BCS theory is the appearance of a full gap in the quasiparticle spectrum. Under various conditions, one can instead obtain an exotic form of superconductivity for which the superconducting gap contains Bogoliubov Fermi surfaces (BFSs). A BFS is a $d-1$-dimensional surface of zero-energy states in the d-dimensional momentum space. BFSs were recently observed in the two-dimensional heterostructure Al-InAs in an applied in-plane magnetic field [1]. In this talk, we present the theoretical prediction for the density of states of such a system and predict the temperature dependence of observables such as the heat capacity and the superfluid density in the presence of BFSs.

[1] Phan et al., Phys. Rev. Lett. **128** (2022) 10770

TT 36.5 Wed 10:30 H 3005

Thermoelectric Switch From Bogoliubov Fermi Surface in superconducting 3D Topological Insulator Heterostructures — •Phillip Mercebach[1], Bo Lu[2], Keiji Yada[3], Yukio Tanaka[3], and Pablo Burset[1] — [1]Department of Theoretical Condensed Matter Physics, Condensed Matter Physics Center (IFIMAC) and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain — [2]Department of Physics, Tianjin University, Tianjin 300072, China — [3]Department of Applied Physics, Nagoya University, Nagoya 464-8603, Japan

A weak magnetic field applied to a superconductor (SC) can selectively close the superconducting gap, giving rise to a segmented Fermi surface. So-called Bogoliubov Fermi surfaces (BFSs) have been observed in recent experiments in a three-dimensional topological insulator (3DTI) in proximity to a SC. Here, we employ a scattering matrix formalism to reveal signatures of the BFS in the thermoelectric transport properties of a superconducting hybrid junction on the surface of a 3DTI. We consider a setup with two normal probes (N) connected to a SC (N-SC-N configuration) to study local and nonlocal transport under an applied in-plane magnetic field. With a temperature gradient, the magnetic field creates equal local and nonlocal electric Seebeck currents which follow the orientation of the BFS. Furthermore, we predict a switch in the required voltage bias enabling local and nonlocal Peltier cooling, which again depends on the orientation of the BFS. As a result, our work opens new perspectives for applications in spintronics and exploring unconventional superconducting phases.

TT 36.6 Wed 10:45 H 3005

Complete zero-energy flat bands of surface states in fully gapped chiral noncentrosymmetric superconductors — •Clara Johanna Lapp[1,2], Julia M. Link[1,2], and Carsten Timm[1,2] — [1]Institute of Theoretical Physics, TU Dresden, 01062 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

Noncentrosymmetric superconductors can support flat bands of zero-energy surface states in part of their surface Brillouin zone. This requires that they obey time-reversal symmetry and have a sufficiently strong triplet-to-singlet-pairing ratio to exhibit nodal lines in the bulk. These bands are protected by a winding number that relies on chiral symmetry, which is realized as the product of time-reversal and particle-hole symmetry. We reveal a way to stabilize a flat band in the entire surface Brillouin zone, while the bulk dispersion is fully gapped. The necessary ingredient is an additional spin-rotation symmetry that forces the direction of the spin-orbit-coupling vector not to depend on the momentum component normal to the surface. We define a winding number which leads to flat zero-energy surface bands. In addition, we consider how a weak breaking of the additional symmetry affects the surface band, employing first-order perturbation theory and a quasiclassical approximation.

TT 36.7 Wed 11:00 H 3005

Exceeding the Chandrasekhar-Clogston limit in flat-band superconductors: A multiband strong-coupling approach — •Kristian Maeland and Asle Sudbø — Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

Hybrid systems of superconductors and magnets display promising applications in superconducting spintronics. This motivates a search for systems where superconductivity can survive larger in-plane critical magnetic fields than the conventional limit. The Chandrasekhar-Clogston (CC) limit applies to thin-film conventional superconductors with in-plane magnetic fields. For a magnetic field strength comparable to the superconducting gap, a spin-split normal state attains lower free energy than the superconducting state. A multiband superconductor with a flat band placed just below the Fermi surface has been shown to surpass the CC limit using weak-coupling theory. It is natural to anticipate corrections from strong-coupling theory in flat-band systems, owing to the large density of states of the flat bands. We derive Eliashberg equations and the free energy for a multiband superconductor in a magnetic field. First, we show that the CC limit can be exceeded by a small amount in one-band strong-coupling superconductors due to self-energy renormalization of the magnetic field. Next, we consider a two-band system with one flat band and find that the CC limit can be exceeded by a large amount also in strong-coupling theory, even when including hybridization between bands that intersect. [1] arXiv:2310.03082

15 min. break

TT 36.8 Wed 11:30 H 3005

Theory of superconductivity in thin films under an external electric field — •Alessio Zaccone[1] and Vladimir Fomin[2,3] — [1]University of Milan, Department of Physics, Milan, Italy — [2]Leibniz IFW Dresden, Germany — [3]Department of Theoretical Physics Moldova State University, Republic of Moldova

The supercurrent field effect is experimentally realized in various nanoscale devices, based on the superconductivity suppression by external electric fields being effective for confined systems. In spite of intense research, a microscopic theory and explanation of this effect is missing. Here, a microscopic theory of superconductivity in thin films is presented, which accounts for the effect of quantum confinement on the electronic density of states, on the Fermi energy, and on the topology of allowed states in momentum space. By further accounting for the interplay between quantum confinement, the external static electric field, the Thomas-Fermi screening in the electron-phonon matrix element, and the effect of confinement on the Coulomb repulsion parameter, the theory predicts the critical value of the external electric field as a function of the film thickness, above which superconductivity is suppressed. In particular, this critical value of the electric field is the lower the thinner the film, in agreement with recent experimental observations. Crucially, this effect is predicted by the theory when both Thomas-Fermi screening and the Coulomb pseudopotential are taken into account, along with the respective depencence on thin film thickness. This microscopic theory of the supercurrent field-effect opens up new possibilities for electric-field gated quantum materials.

TT 36.9 Wed 11:45 H 3005

Superconductivity due to fluctuating loop currents — Grgur Palle[1], •Risto Ojajärvi[1], Rafael M. Fernandez[2], and Jörg Schmalian[1,3] — [1]Institute for Theoretical Condensed Matter Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455, USA — [3]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Orbital magnetism and the loop currents (LC) that accompany it have been proposed to emerge in many systems, including cuprates, iridates, and kagome superconductors. In the case of cuprates, LCs have been put forward as the driving force behind the pseudogap, strange-metal behavior, and $d_{x^2-y^2}$-wave superconductivity. Here, we investigate whether fluctuating intra-unit-cell loop currents can cause unconventional superconductivity. For odd-parity LCs, we find that they are strongly repulsive in all pairing channels near the underlying quantum-critical point (QCP). For even-parity LCs, their fluctuations do give rise to unconventional pairing. However, this pairing is not amplified in the vicinity of the QCP, in sharp contrast to other known cases of pairing mediated by intra-unit-cell order parameters, such as spin-magnetic, nematic, or ferroelectric ones. Applying our formalism to the cuprates, we conclude that pairing mediated by fluctuating intra-unit-cell LCs is unlikely to yield $d_{x^2-y^2}$-wave superconductivity. We also show that loop currents, if relevant for the cuprates, must vary between unit cells and break translation symmetry.

TT 36.10 Wed 12:00 H 3005

Electronic theory for FFLO state in iron-based superconductors: role of spin-orbit coupling and pairing symmetry — •Luka Jibuti and Ilya Eremin — Rurh universität Bochum, Bochum, Germany

We develop an electronic theory of the existence and the mannerisms of the Fulde-Ferrel-Larkin-Ovchinnikov(FFLO) phase in the multiorbital iron-based superconductors. The starting point is the low energy Hamiltonian including realistic description of the spin-orbit coupling, correctly describing the Fermi surfaces of various types of iron-based superconductors. We first address the formation of FFLO state in the in-plane magnetic field in strongly hole- and electron-doped systems such as KFe2As2 and electron intercalated FeSe compounds, respectively. We also show that the formation of the FFLO state is unlikely for the s+- superconducting state in the situation when both electron and hole pockets are present at the Fermi level due to effect of the spin-orbit coupling.

TT 36.11 Wed 12:15 H 3005

Zero-field finite-momentum and field-induced superconductivity in altermagnets — •Debmalya Chakraborty and Annica M. Black-Schaffer — Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden

We explore the possibilities for spin-singlet superconductivity in newly discovered altermagnets. Investigating *d*-wave altermagnets, we show that finite-momentum superconductivity can easily emerge in altermagnets even though they have no net magnetization, when the superconducting order parameter also has *d*-wave symmetry with nodes coinciding with the altermagnet nodes. Additionally, we find a rich phase diagram when both altermagnetism and an external magnetic field are considered, including superconductivity appearing at high magnetic fields from a parent zero-field normal state.

TT 36.12 Wed 12:30 H 3005

Proximity-induced gapless superconductivity in two-dimensional Rashba semiconductor in magnetic field — •Serafim Babkin[1], Andrew Higginbotham[1,2], and Maksym Serbyn[1] — [1]Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria — [2]The James Franck Institute and Department of Physics, University of Chicago, Chicago, Illinois 60637, USA

Two-dimensional semiconductor-superconductor heterostructures form the foundation of numerous nanoscale physical systems. However, measuring the properties of such heterostructures, and characterizing the semiconductor in-situ is challenging. Motivated by experiments, we introduce a theoretical model describing a disordered semiconductor with strong spin-orbit coupling that is proximitized by a superconductor. Our model provides specific predictions for the density of states and superfluid density. Presence of disorder leads to the emergence of a gapless superconducting phase, that may be viewed as a manifestation of Bogoliubov Fermi surface. When applied to real experimental data, our model showcases excellent quantitative agreement, enabling the extraction of material parameters such as mean free path and mobility, and estimating g-tensor after taking into account the orbital contribution of magnetic field. Our model can be used to probe in-situ parameters of other superconductor-semiconductor heterostructures and can be further extended to give access to transport properties.

TT 36.13 Wed 12:45 H 3005

Singlet-Triplet Mixing, Topological Superconductivity and Topological Phase Transitions in the Triangular-Lattice Rashba Hubbard model — •Matthew Bunney[1,2], Jacob Beyer[1,2,3,4], Carsten Honerkamp[2,3], and Stephan Rachel[1] — [1]School of Physics, University of Melbourne, Parkville, VIC 3010, Australia — [2]Institute for Theoretical Solid State Physics, RWTH Aachen University, 52062 Aachen, Germany — [3]JARA Fundamentals of Future Information Technology, 52062 Aachen, Germany — [4]Institute for Theoretical Physics, University of Würzburg, Am Hubland, 97074 Würzburg, Germany

The superconducting phase diagram of the triangular-lattice Rashba Hubbard model in the absence of spin-orbit coupling features at very low fillings triplet superconductivity but otherwise singlet *d*-wave superconductivity, ubiquitous on two-dimensional hexagonal lattices. In the presence of spin-orbit coupling, the mixing of singlet and triplet pairings can be analysed within truncated-unity functional renormalization group (TU-FRG). By combining group theoretical arguments with extensive TU-FRG simulations, we show that a phase with two-dimensional E_2 irrep prevails. However, by analysing the TU-FRG results further, we find that this phase splits into various topological superconducting phases, separated by topological phase boundaries. Our work positions TU-FRG as a method which can resolve structure within the otherwise uniform many-electron phases.

TT 37: Graphene and 2D Materials (joint session TT/HL)

Time: Wednesday 9:30–11:15 Location: H 3007

TT 37.1 Wed 9:30 H 3007

Static and Dynamic Properties of a 2D Superconductor Investigated by NV Center SPM — •Sreehari Jayaram, Malik Lenger, Ruoming Peng, Rainer Stöhr, and Jörg Wrachtrup — 3rd Physics Institute, University of Stuttgart, Germany

Visualization of nanoscale dynamics in superconducting materials provides a pathway to unravel the pairing mechanisms of interacting electrons. Here, we have employed the state-of-the-art scanning NV probe technique to explore the local magnetic response of the 2D superconductor, 2H-NbSe$_2$, in which we demonstrate full dynamic sensing of vortices with high sensitivity and spatial resolution.

Utilizing this quantum probe, we present the first spatio-temporal dynamics of vortices in a 10 nm thin exfoliated 2H-NbSe$_2$, where the arrangement of the vortices show a strong correlation with the geometric confinement. Notably, we have observed the melting of vortex solids near critical temperature allowing the re-arrangement of the vortices that is governed by the cooling rate.

Additionally, our study delves into the dynamics of vortex cores, superconducting-insulator edge dynamics, and phase transitions, all unveiled through spatial-temporal noise spectroscopy with the NV probe.

TT 37.2 Wed 9:45 H 3007

Berry Phase Effects in the Transverse Conductivity of Fermi Surfaces and its Detection With Spin Qubits and NMR — •Mark Morgenthaler and Inti Sodemann — Universität Leipzig, Germany

The transverse conductivity of clean Fermi liquids at low frequencies displays a remarkably universal behaviour at long wavelengths: It is determined only by the geometrical radius of curvature of the Fermi surface, and does not depend on details such as the quasi-particle mass or their interactions. Here, we demonstrate that the Berry phase at the Fermi surface does not alter such long-wavelength universality by directly computing the transverse conductivity of two- and three-dimensional electronic systems with Dirac dispersions, such as those appearing in 2D graphene or in 3D Dirac semi-metals and in the bulk of 3D topological insulators. Interestingly however, such universality ceases to hold at wave-vectors comparable to the Fermi radius, and Dirac fermions display a distinct transverse conductivity from a featureless parabolic Fermion. We demonstrate that this difference originates entirely from the orbital magnetic moment of the quasi-particles induced by their Berry phases. We discuss how these effects can be probed by measuring the T1 relaxation time of spin qubits (such as NV centers) near 2D samples and for the nuclear spins measured in NMR for 3D samples.

TT 37.3 Wed 10:00 H 3007

Fermi Velocity renormalization in graphene from large scale Quantum Monte Carlo simulations — •Maksim Ulybyshev[1], Savvas Zafeiropoulos[2], Christopher Winterowd[3], and Fakher Assaad[1,4] — [1]Julius-Maximilians-Universität Würzburg, Germany — [2]Aix Marseille Univ, Universite de Toulon, CNRS, CPT, Marseille, France — [3]Johann Wolfgang Goethe-Universität Frankfurt am Main, Germany — [4]Würzburg-Dresden Cluster of Excellence ct.qmat, Würzburg, Germany

Through recent advancements in algorithms, we extended the capabilities of unbiased Quantum Monte Carlo (QMC) simulations up to the lattices with spatial volume of 20808 sites. These simulations were applied to both suspended graphene and graphene on substrates, enabling direct comparison with experimental data without the need for additional extrapolations. This technique allowed us to successfully confront the numerical and experimental estimates of the Fermi velocity renormalization near the Dirac point.

Our findings validate the logarithmic divergence of the Fermi velocity, but also show the limitations of the low-energy continuum theory in quantitative description of this divergence. Additionally, our research demonstrates the significance of lattice-scale physics and higher-order perturbative corrections beyond the Random Phase Approximation (RPA) for a more accurate description of the experimental data for the Fermi velocity renormalization in suspended graphene. We also propose experimental approaches to demonstrate the role of higher-order perturbative corrections.

TT 37.4 Wed 10:15 H 3007

Solitons induced by an in-plane magnetic field in rhombohedral multilayer graphene — •Max Tymczyszyn, Peter Cross, and Edward McCann — Department of Physics, Lancaster University, Lancaster LA1 4YB, United Kingdom

The low-energy band structure of rhombohedral graphene multilayers includes a pair of flat bands near zero energy, which are localized on the surface layers of a finite thin film. Introducing an in-plane magnetic field we find that the zero-energy bands persist, and that level bifurcations occur at energies determined by the component of the in-plane wave vector that is parallel to the external field. The occurrence of level bifurcations is explained by invoking semiclassical quantization of the zero-field Fermi surface of rhombohedral graphite. We find parameter regions with a single isoenergetic contour of Berry phase zero corresponding to a conventional Landau level spectrum and regions with two isoenergetic contours, each of Berry phase π, corresponding to a Dirac-like spectrum of levels. We write down an analogous one-dimensional tight-binding model and relate the persistence of the zero-energy bands in large magnetic fields to a soliton texture supporting zero-energy states in the Su-Schrieffer-Heeger model. We show that different states contributing to the zero-energy flat bands in rhombohedral graphene multilayers in a large field are localized on different bulk layers of the system, not just the surfaces.

[1] M. Tymczyszyn, P.H. Cross, E. McCann, Phys. Rev. B 108 (2023) 115425

TT 37.5 Wed 10:30 H 3007

Competing nematic semi-metallic and insulating states in bilayer graphene — •Sebastian Mantilla and Inti Sodemann — Institut für Theoretische Physik, Universität Leipzig, 04107 Leipzig, Germany

The finite density of states arising from the parabolic band touching in ideal Bernal bilayer graphene leads to spontaneous symmetry-breaking instabilities driven by weak repulsive interactions. To this date, different experiments have reported conflicting states, with some reporting a gapped state and others a metallic state that spontaneously breaks lattice rotations. Using a combination of bosonization and self-consistent Hartree-Fock theory, we propose a resolution to these conflicting reports by demonstrating the existence of two closely competing states: a semi-metallic nematic state in which the parabolic band touchings spontaneously split into a pair of linearly dispersing Dirac fermions and a fully gapped state. We find that the gapped state has slightly lower energy, but the energy difference between them is highly sensitive to the interaction strength in a BCS-like fashion. Therefore, in samples with more screening, these states are even closer in energy, and their energetic balance can be tilted by other corrections, such as the trigonal warping, which tends to favour the nematic metallic states.

TT 37.6 Wed 10:45 H 3007

Atomistic approach to correlations in multilayer graphene — •Ammon Fischer[1], Lennart Klebl[2], Tim Wehling[2], and Dante M. Kennes[1,3] — [1]Institute for Theory of Statistical Physics, RWTH Aachen University — [2]I. Institute for Theoretical Physics, Universität Hamburg, Notkestraße 9-11, 22607 Hamburg, Germany — [3]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, 22761 Hamburg, Germany

Multilayer graphene has recently attracted considerable attention due to the discovery of cascades of correlated states and superconductivity driven by displacement field tunable van-Hove singularities at low densities. While experimental efforts aim to stabilize correlated phases by proximity-induced spin-orbit coupling or by increasing the number of graphene layers in the stack, first-principle guided theoretical investigations are thwarted by the strong momentum-localization of the low-energy degrees of freedom around the valleys K,K'. Here, we discuss how correlated phenomena in few-layer graphene can be resolved by atomistic weak-coupling methods including the random-phase approximation and the functional renormalization group using ab-initio derived interaction profiles. We demonstrate that the gap between phenomenological continuum model studies and atomistic investigations can be bridged by a novel Wannierization procedure that permits to relax the strong momentum-localization of the low-energy Bloch states. This enables a well-defined downloading procedure of long-ranged Coulomb interactions to the valley-local flat bands of multilayer graphene systems subject to external displacement fields.

TT 37.7 Wed 11:00 H 3007

Pseudomagnetotransport in strained and scaled graphene — Jia-Tong Shi, Aitor Garcia-Ruiz, and •Ming-Hao Liu — Department of Physics, National Cheng Kung University, Tainan 70101, Taiwan

Graphene is highly susceptible to externally applied mechanical deformation due to its atomic thinness. As such, strained graphene has long been studied both theoretically and experimentally. Among all interesting predictions, the pseudo-magnetic field in graphene under properly designed strain fields, giving rise to effects equivalent to graphene under a strong external magnetic field on the order of 10 Tesla [1], is perhaps one of the most intensively discussed topics. Despite the experimentally observed pseudo-Landau levels due to strong pseudo-magnetic fields in graphene bubbles [2] and ripples [3], transport experiments showing strong pseudo-magnetic fields in strained graphene have so far been missing. To provide reliable guides to possible future pseudo-magnetotransport experiments on strained graphene, here we perform quantum transport simulations considering triaxially strained graphene using the scalable tight-binding model [4]. Numerical examples of transverse pseudo-magnetic focusing and pseudo-quantum Hall effect will be shown.

[1] F. Guinea, M. I. Katsnelson, A. K. Geim, Nat. Phys. **6** (2010) 30
[2] N. Levy *et al.*, Science **329** (2010) 544
[3] S. Y. Li *et al.*, Phys. Rev. Lett. **124** (2020) 106802
[4] M.-H. Liu, *et al.*, Phys. Rev. Lett. **114** (2015) 036601

TT 38: Topological Semimetals I

Time: Wednesday 9:30–11:15 Location: H 3010

TT 38.1 Wed 9:30 H 3010

Anomalous Nernst effect in the topological and magnetic material $MnBi_4Te_7$ — •Michele Ceccardi[1,2], Alexander Zeugner[3], Laura Folkers[3,4], Christian Hess[3,4,5], Bernard Buechner[3,4], Daniele Marré[1,2], Anna Isaeva[4,6], and Federico Caglieris[1,2,4] — [1]University of Genoa, Italy — [2]CNR Spin; Genoa, Italy — [3]TU Dresden, Germany — [4]IFW Dresden, Germany — [5]University of Wuppertal, Germany — [6]University of Amsterdam, Nederland

The recently discovered magnetic topological insulators $(MnBi_2Te_4)(Bi_2Te_3)n$, n = 0-4, are an ideal playground to study the influence of magnetic properties on band topology, giving access to diverse quantum states in a single compound. In the low temperature-antiferromagnetic state and vanishing magnetic field, the n = 1 system is a topological insulator protected by a combination of time reversal and a translation symmetries. It has been argued that, when the antiferromagnetic phase is forced to a the fully spin polarized state by the application of an external magnetic field, this system develops Weyl cones in the conduction band, which become accessible in presence of an intrinsic electronic doping. In this work, we experimentally prove the raising of field-induced Weyl state through the detection of an intrinsic anomalous Nernst effect in a bulk single crystal of $MnBi_4Te_7$.

TT 38.2 Wed 9:45 H 3010

Negative magnetoresistance in the Weyl semimetal $TaRhTe_4$ — •Mahdi Behnami[1], Helena Reichlova[1,2,3], Saicharan Aswartham[1], Grigory Shipunov[1], Dmitriy Efremov[1], Vilmos Kocsis[1], Marina Putti[4,5], Federico Caglieris[1,4], and Bernd Büchner[1,2] — [1]IFW Dresden, P.O. Box 270116, 01171 Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01062 Dresden, Germany — [3]Institute of Physics ASCR, v.v.i., Cukrovarnick a 10, 162 53, Praha 6, Czech Republic — [4]CNR-SPIN, 16152 Genova, Italy — [5]Department of Physics, University of Genoa, 16146 Genova, Italy

$TaRhTe_4$ is a type-II Weyl semimetal, hosting minimal Weyl points in close proximity to the Fermi level [1]. One of the most intriguing transport phenomena associated with Weyl physics is the chiral anomaly-induced negative magneto-resistance observed when magnetic and electric fields are parallel [2]. In this study, we employ a systematic measurement approach, measuring magnetoresistance along various crystallographic directions. We observe a negative sign, considered a signature of the chiral anomaly, but notably, this effect is present only along certain directions. Furthermore, this negative magneto-resistance persists up to room temperature, suggesting that $TaRhTe_4$ possesses unique properties within the emerging family of Weyl semimetals.

[1] G. Shipunov et al., J. Phys. Chem. Lett. 12, 28 (2021) 6730
[2] A. Niemann et al., Sci Rep 7 (2017) 43394

TT 38.3 Wed 10:00 H 3010

Electronic structure in the Dirac nodal-line semimetals $TaNiTe_5$ and $TaPtTe_5$ — •Maximilian Daschner[1], Friedrich Malte Grosche[1], and Ivan Kokanović[1,2] — [1]Cavendish Laboratory, University of Cambridge, Cambridge CB3 OHE, United Kingdom — [2]Department of Physics, Faculty of Science, University of Zagreb, Zagreb, Croatia

Among the nodal-line semimetals (NLSMs), Dirac nodal lines (DNLs) that are robust against spin-orbit coupling (SOC) rarely occur in (quasi) one-dimensional materials. A family of exfoliable, strong in-plane anisotropic, nonmagnetic, ternary transition semimetal tellurides, Ta-based $TaMTe_5$ (M=Ni, Pt) [1,2], has recently been shown to host nodal lines with fourfold degeneracy.

Here [3] we investigated the Fermi surface and carrier mass in $TaNiTe_5$ and $TaPtTe_5$ using magnetization and magnetic torque measurements in high-quality single crystals at fields of up to 15T. Quantum oscillations have been tracked for fields along the three crystallographic axes, supplemented by rotation studies in the b-a and b-c planes, and were interpreted with reference to band structure calculations within density functional theory.

[1] Z. Hao et al., Phys. Rev. B 104 (2021) 115158
[2] S. Xiao et al., Phys. Rev. B 105 (2022) 195145
[3] M. Daschner et al., submitted (2023)

TT 38.4 Wed 10:15 H 3010

Quantum Oscillations in AlPt: Experimental Validation and Insights into the Electronic Structures — Nico Huber[1], •Simon Röder[1], Andre Deyerling[1], Ivan Volkau[1], Andreas Bauer[1,2], Fabian Jochum[1], Christian Pfleiderer[1,2,3], and Marc A. Wilde[1] — [1]Technical University of Munich (TUM) — [2]TUM Zentrum für Quantum Engineering (ZQE) — [3]Munich Center for Quantum Science and Technology (MCQST)

B20 compounds, including AlPt, CoSi and PdGa, show a variety of interesting physical phenomena attributed to their complex electronic structure [1,2]. They host topologically non-trivial multifold crossing points and nodal planes [3] that influence the physical responses. AlPt exhibits a strong spin-orbit coupling predicted to have a distinct impact on its properties. A precise knowledge of the Fermi surface is key for their understanding and to date only limited information is available in the literature [4]. In this work, we report on previously undetected quantum oscillation frequencies in AlPt. We probed the de Haas-van Alphen effect using cantilever-based torque magnetometry in magnetic fields up to 18T and at temperatures down to 1.5K. We compare our findings with first-principle calculations and confirm the predicted band structure by matching the experimentally detected frequencies, their angular dependence and effective masses to extremal orbits on the Fermi surface.

[1] Huber et al., Nature **621** (2023) 276 (2023)
[2] Schroeter et al., Nat. Phys. **15** (2019) 759
[3] Wilde et al., Nature **594** (2021) 374
[4] Saini et.al., Phys. Rev. B **106** (2022) 125126

TT 38.5 Wed 10:30 H 3010

Quantum oscillations of the quasiparticle lifetime due to interorbit coupling — •Louw Feenstra[1,2], Nico Huber[1], Michael Schmidlechner[1], Andreas Bauer[1,4], Christian Pfleiderer[1,3,4], and Marc A. Wilde[1,4] — [1]Technical University of Munich — [2]Ludwig-Maximilians-Universität München — [3]Munich Center for Quantum Science and Technology (MCQST) — [4]TUM Zentrum für QuantumEngineering (ZQE)

A recent study on CoSi [1] revealed quantum oscillations with a frequency corresponding to the semi-classically forbidden difference between two quasiparticle orbit frequencies. These difference frequency oscillations persist up to temperatures at which their constituent frequencies are completely suppressed by thermal damping. The existence and temperature stability of these oscillations are explained by oscillations of the quasiparticle lifetime mediated by a non-linear interband coupling [2]. Here, we report on a detailed investigation of a related compound exhibiting the same phenomenology. Through angular and temperature dependent measurements of the Shubnikov-de Haas effect, a difference frequency is clearly identified and its remarkable temperature stability confirmed. In contrast to CoSi, the constituent frequencies originate from two extremal orbits on an anisotropic Fermi surface pocket arising from a single band. We demonstrate tuning of the difference frequency by rotation of the applied magnetic field.

[1] N. Huber *et al.*, Nature **621** (2023) 276
[2] V. Leeb, J. Knolle, Phys. Rev. B **108** (2023) 054202

TT 38.6 Wed 10:45 H 3010

Determination of the Fermi surface of the topological semimetal PdGa using quantum oscillations — Nico Huber[1], •Ivan Volkau[1], Alexander Engelhardt[1], Andreas Bauer[1,3], Christian Pfleiderer[1,2,3], and Marc A. Wilde[1,3] — [1]Technical University of Munich (TUM) — [2]MCQST, Munich — [3]TUM Zentrum für Quantum Engineering (ZQE), Munich

Weyl semimetals have generated great interest in recent years due to their non-trivial topological characteristics like anomalous magnetotransport and unusual photogalvanic responses [1]. However, topological band degeneracies are not limited to points but can also be enforced on entire planes in reciprocal space [2], the so-called nodal planes (NPs). The experimental identification of NPs in the ferromagnetic state of MnSi [3] and its paramagnetic sibling CoSi [4] raises the question whether they can also be observed in other B20 compounds as theory predicts. In this work, we study the Fermi surface of PdGa using quantum oscillations. Shubnikov-de Haas and de Haas-van Alphen spectra were recorded at different orientations of the magnetic field up to 18 T and at temperatures down to 1.5K. The oscillation frequencies, angular dispersion, and effective masses taken together with the calculated magnetic breakdown orbits are in good agreement with first principle calculations, confirming the predicted electronic structure of this compound.

[1] Ma *et al.*, Nat. Mater. **15** (2016) 1140
[2] Furusaki *et al.*, Sci. Bull. **62** (2017) 788
[3] Wilde *et al.*, Nature **594** (2021) 374
[4] Huber *et al.*, Phys. Rev. Lett. **129** (2022) 026401

TT 38.7 Wed 11:00 H 3010

Electronic structure of the noncentrosymmetric B20-type compound HfSn — •Dijana Milosavljevic[1], Helge Rosner[2], and Annika Johansson[1] — [1]Max Planck Institute of Microstructure Physics, Halle, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

We present a density functional study of HfSn, which belongs to the family of cubic B20 intermetallics. These materials are characterized by the absence of mirror and inversion symmetries of their crystal structures, leading to a chiral character that can accommodate a novel type of topological fermionic excitations and a wide range of exotic physical properties [1][2][3]. HfSn is the first known member of the B20 family with a transition metal from the fourth group and can only be synthesized at high temperatures [4]. Here, we present a detailed study of the electronic band structure and Fermi surface topology, employed then to construct an effective tight-binding model. Additionally, we investigate the influence of the structural details on the position of the multiply degenerate band crossings pinned at high symmetry points in the vicinity of the Fermi level. This study contributes not only to a better understanding of B20 compounds but also represents a guide to further experimental investigations, in particular those related to sample preparation.

[1] Fecher et al., Materials 17 (2022) 5812
[2] Chang et al., Nat. Mater. 17 (2018) 978
[3] Schröter et al., Science 369 (2020) 6500
[4] Schob et al., Acta Cryst. 17, 452

TT 39: Correlated Electrons: Charge Order

Time: Wednesday 9:30–12:15 Location: H 3025

TT 39.1 Wed 9:30 H 3025

Kinetic theory and collective modes in the charge-density-wave phase of $K_{0.3}MoO_3$ — Viktor Hahn, •Max O. Hansen, and Peter Kopietz — Goethe University, Frankfurt am Main, Germany

Initiated by recent measurements of collective modes in the charge-density-wave (CDW) state of the electronically quasi-one-dimensional material $K_{0.3}MoO_3$ [1], we present a theoretical study of amplitude and phase modes in the incommensurate CDW state. For this purpose we formulate a kinetic theory using an expansion in powers of connected equal-time correlations. Our linearized kinetic equations for the CDW order parameter have the same form as the phenomenological equation of motion obtained within a time-dependent Ginzburg-Landau approach. Frequencies and damping coefficients for the amplitude and phase modes in the CDW state can be extracted numerically or directly from the linearized kinetic equations. We find that the damping is strongly enhanced when the temperature approaches the critical temperature from below, in agreement with recent experiments [1].

[1] K. Warawa, N. Christophel, S. Sobolev, J. Demsar, H. G. Roskos, M. D. Thomson, Phys. Rev. B **108** (2023) 045147.

TT 39.2 Wed 9:45 H 3025

Kohn-Luttinger-like mechanism for charge density waves — •Hannes Braun — Max Planck Institute for Solid State Research, Stuttgart, Germany

We propose a Kohn-Luttinger-like mechanism for charge density waves with higher angular momentum in correlated electron systems. The mechanism describes an instability in the particle-hole direct channel, which emerges due to the feedback from the particle-hole crossed channel. Like in the original Kohn-Luttinger mechanism for superconductivity, the separation of vertex corrections in different lattice harmonics is the key for getting attractive components out of an initially repulsive interaction. We provide numerical as well as analytical arguments for the realisation of this mechanism in the triangular lattice Hubbard model with higher SU(N) symmetry, which can be implemented, e.g., in cold atomic gases or moiré bilayers of transition metal dichalcogenides.

TT 39.3 Wed 10:00 H 3025

Elastoresistance of the charge-density-wave material $NbSe_2$ — •Maik Golombiewski, Tianyi Xu, Simon Knudsen, Teslin R. Thomas, Sven Graus, Andreas Kreyssig, and Anna E. Böhmer — Lehrstuhl für Experimentalphysik IV, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum

Mono- and diselenides such as FeSe, $FeSe_2$ and $NbSe_2$ display many interesting and diverse properties. For example, FeSe is a well-known nematic superconductor, whereas $NbSe_2$ exhibits superconductivity below $T_c = 7.2$ K and a charge-density-wave (CDW) phase below $T_{CDW} = 32$ K. Optimizing growth parameters, we have grown large and homogeneous single crystals of FeSe, $FeSe_2$ and $NbSe_2$ via chemical vapor transport. Samples were characterized via x-ray diffraction, energy-dispersive x-ray spectroscopy and electrical resistance. In particular, we have determined the change of electrical resistance of $NbSe_2$ under strain, i.e., its elastoresistance, around T_{CDW}, using piezostacks and a cryogenic strain cell. A subtle anomaly in the linear elastoresistance at T_{CDW} is observed. The effect of large elastic strains on the resistance will also be discussed.

We acknowledge support by the Mercator Research Center Ruhr (MERCUR), under project number Ko-2021-0027.

TT 39.4 Wed 10:15 H 3025

Giant circular dichroism induced by electronic chirality in $TiSe_2$ — Qian Xiao[1], •Oleg Janson[2], Sonia Francoual[3], Qingzheng Qiu[1], Qizhi Li[1], Shilong Zhang[1], Wu Xie[3,4], Pablo Bereciartua[3], Jeroen van den Brink[2,5,6], Jasper van Wezel[6], and Yingying Peng[1,7] — [1]Peking University, Beijing, China — [2]Institute for Theoretical Solid State Physics, Leibniz IFW Dresden, Germany — [3]DESY, Hamburg, Germany — [4]Zhejiang University, Hangzhou, China — [5]Würzburg-Dresden Cluster of Excellence ct.qmat, Germany — [6]Institute for Theoretical Physics, University of Amsterdam, The Netherlands — [7]Collaborative Innovation Center of Quantum Matter, Beijing, China

The quasi-2D van-der-Waals material $1T$-$TiSe_2$ is known for its well-studied transition into a commensurate 2×2×2 charge density wave (CDW) state. Several experimental and theoretical studies suggested that the charge order may be chiral, yet no bulk measurement so far provided direct evidence for intrinsic broken inversion symmetry and chirality. In a resonant elastic x-ray scattering (REXS) experiment, we observe giant circular dichroism up to ∼40% at a Bragg peak forbidden in the centrosymmetric CDW structure. By performing first-principles calculations for the earlier proposed chiral structural model, we find excellent quantitative agreement with the experimental azimuthal angle dependence for different polarizations. In this way, we accurately estimate the magnitude of the inversion-breaking distortion and confirm that bulk $1T$-$TiSe_2$ has chiral electronic order.

TT 39.5 Wed 10:30 H 3025

Quenched exciton condensate in $TiSe_2$ probed by surface-sensitive electron diffraction — •Felix Kurtz[1], Tim Niklas Dauwe[1], Sergey V. Yalunin[1], Gero Storeck[1], Jan Gerrit Horstmann[2], Hannes Böckmann[1], and Claus Ropers[1,3] — [1]Max Planck Institute for Multidisciplinary Sciences, D-37077 Göttingen — [2]Department of Materials, ETH Zurich, CH-8093 Zürich — [3]4th Physical Institute, University of Göttingen, D-37077 Göttingen

Charge-density waves (CDWs) are intriguing correlated phenomena, arising from strong couplings among electrons or between electronic and lattice degrees of freedom. In particular, $TiSe_2$ showcases signs of both excitonic condensation and a Peierls mechanism driving the phase transition to the CDW state below 200 K. Jointly occurring in equilibrium, time-resolved studies are capable of disentangling these contributions [1]. Here, we employ ultrafast low-energy electron diffraction

(ULEED) [2] to trace the structural order parameter in the surface layer of $TiSe_2$ after photoexcitation. We identify a low fluence threshold similar to other time-resolved works, which allows us to directly quantify the excitonic contribution to the total lattice distortion [3]. It is completely quenched at the threshold, and from the persisting distortion we estimate a 30:70 split of the structural order parameter into excitonic and Peierls contributions. Our findings highlight the strengths of ultrafast structural probing with monolayer sensitivity offered by ULEED.

[1] M. Porer et al., Nat. Mater. 13 (2014) 857.
[2] G. Storeck et al., Struct. Dyn. 7 (2020) 034304
[3] F. Kurtz et al., under review (2023)

15 min. break

TT 39.6 Wed 11:00 H 3025

Comparative optical study of the CDW states in various TaS_2 polymorphs — •Renjith Mathew Roy[1], Maxim Wenzel[1], Sudip Pal[1], Vicky Hasse[2], Claudia Felser[2], Artem V. Pronin[1], and Martin Dressel[1] — [1]1. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany — [2]Max-Planck-Institut für Chemische Physik fester Stoffe, 01187 Dresden, Germany

We report the temperature-dependent optical conductivity of the bulk transition-metal dichalcogenides $4H_b$-TaS_2, 2H- TaS_2, and 6R-TaS_2, studied in a broad energy range from 10 meV to 2.5 eV. These kagome-structured compounds possess a charge density wave (CDW) state below T_{CDW} 22, 75, and 305 K, respectively. The presence of coexisting superconductivity and possible chiral CDW order, as well as the occurrence of topological flat bands in various polymorphs of TaS_2, fueled the recent interest in their studies [1-4]. In all three compounds, we observe a common interband response above 100 meV and distinguishable signatures of band reconstruction below TCDW. Our compassion provides a broader picture of the CDW-formation mechanism via detecting the energy gaps and possible charge localization, emerging in these quasi-2D systems.

[1] A. Ribak et al., Sci. Adv. 6, eaax9480 (2020)
[2] S. Pal et al., Phys. B: Cond. Mat. 669 (2023) 415266.
[3] I. Guillamón et al., New J. Phys. 13 (2011) 103020.
[4] J. M. Lee et al., Phys. Rev. Lett. 124 (2020) 137002.

TT 39.7 Wed 11:15 H 3025

Ultrafast dynamics in $(TaSe_4)_2I$ triggered by valence and core-level excitation — •Wibke Bronsch[1], Manuel Tuniz[2], Giuseppe Crupi[2], Michela De Col[2], Denny Puntel[2], Davide Soranzio[2], Alessandro Giammarino[2], Michele Perlangeli[2], Helmuth Berger[3], Dario De Angelis[1], Danny Fainozzi[1], Ettore Paltanin[2], Stefano Pelli Cresi[1], Gabor Kurdi[1], Riccardo Mincigrucci[1], Laura Foglia[1], Fulvio Parmigiani[1], Filippo Bencivenga[1], and Federico Cilento[1] — [1]Elettra - Sincrotrone Trieste S.C.p.A., Strada Statale 14, km 163.5, Trieste, Italy — [2]Dipartimento di Fisica, Università degli Studi di Trieste, 34127 Trieste, Italy — [3]Institute of Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

Dimensionality plays a key role for the emergence of ordered phases like charge-density-waves, that in turn can couple to and modulate the topological properties of matter. In this work, we study the outofequilibrium dynamics of the paradigmatic quasi-one-dimensional material $(TaSe_4)_2I$, that exhibits a transition into an incommensurate charge-density-wave (CDW) phase when cooled down just below room temperature, at $T_{CDW} = 263$ K. We make use of both optical laser and free-electron laser (FEL) based time-resolved spectroscopies in order to study the effect of a selective excitation of the material on the charge-density-wave phase, by probing the near-infrared/visible optical properties both along and perpendicularly to the direction of the charge-density-wave [1].

[1] W. Bronsch et al., Faraday Discuss. 237 (2022) 40.

TT 39.8 Wed 11:30 H 3025

Substrate tuning of transition temperature in thin flakes of the excitonic insulator candidate Ta_2NiSe_5 — •Yuanshan Zhang[1], Zichen Yang[1], Dennis Huang[1], Matteo Minola[1], Chuanlian Xiao[1], Masahiko Isobe[1], Bernhard Keimer[1], and Hidenori Takagi[1,2,3] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Department of Physics, University of Tokyo, Japan — [3]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Germany

The nature of the transition in Ta_2NiSe_5 to an insulator around 326 K remains an active debate. The discussion focuses on whether the transition is predominantly structural, as evidenced by an orthorhombic-to-monoclinic lattice transition, or electronic/excitonic, as understood through the interplay between the energy gap and excitonic binding energy. We have separated electron and phonon effects by employing thin Ta_2NiSe_5 flakes on both conducting Au and insulating Al_2O_3 substrates. Polarized Raman spectroscopy indicates that the lattice transition is largely unchanged in flakes as thin as 3 nm on Al_2O_3, whereas it is reduced by nearly 100 K on Au. Model analysis reveals that the underlying electronic excitation in the latter does not exhibit an excitonic instability. We discuss how the conducting substrate influences an excitonic insulator. Our findings demonstrate that the transition in Ta_2NiSe_5 is charge-sensitive and cannot be attributed solely to a lattice instability. The electronic/excitonic instability appears to have an energy scale of approximately 100 K.

TT 39.9 Wed 11:45 H 3025

Interlayer coupling between two charge density waves in $4H_b$-TaS_2 — •Carolina A. Marques[1], Berk Zengin[1], Aleš Cahlík[1], Danyang Liu[1], Helmuth Berger[2], Ana Akrap[3], and Fabian D. Natterer[1] — [1]Department of Physics, University of Zurich, Switzerland — [2]Institute of Condensed Matter Physics, École Polytechnique Fédérale de Lausanne, Switzerland — [3]Department of Physics, University of Fribourg, Switzerland

The van der Waals material $4H_b$-TaS_2 is a superlattice of alternating layers with 1H and 1T coordination structures. The charge density waves (CDW) of each individual layer persist within the bulk of the material, and the superconducting temperature is enhanced compared to the pristine 2H-TaS_2. Here, we use scanning tunneling microscopy and quasiparticle interference (QPI) to investigate the interaction between adjacent CDWs, and with the superconducting state. We identify a weakly dispersing band from QPI on the 1T surface and find domains with different orientations of the CDW, which change the observed Moiré patterns at the surface and the energy onset of the weakly dispersing band.

TT 39.10 Wed 12:00 H 3025

The pressure-induced charge-density-wave transition in $CeTe_3$ probed by time-resolved collective mode spectroscopy — •Priyanka Yogi[1], C. Vardhan Kotyada[1], J. Tauch[2], H. Schäfer[2], M. Obergfell[1,2], D. Dominko[1], A. Pashkin[3], and Jure Demsar[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany — [2]Department of Physics, University of Konstanz, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

We use time-resolved optical spectroscopy to study pressure-induced charge-density-wave (CDW) phase transition in a prototype CDW system $CeTe_3$ (T_3 540 K at ambient pressure [1]). Photoinduced reflectivity traces at 300 K and ambient pressure reveal the presence of numerous oscillatory modes with frequencies between 1.2 and 4 THz. The modes display either softening or hardening as a function of pressure, yet all disappear above 5 GPa. Moreover, these modes are quenched above critical photoexcitation density. We compare the pressure and excitation density dependent mode parameters with the available temperature, chemical- and hydrostatic-pressure dependent Raman data on RTe_3 series [1,2]. We show that all modes are CDW amplitude modes, a result of linear coupling between the electronic order and normal-state phonons at the CDW wavevector [3]. Thus, the studies reveal a pressure-induced transition into the metallic state taking place in $CeTe_3$ at the critical pressure of 5 GPa at 300 K.

[1] K. Yumigeta et al., APL Mater. 10 (2022) 111112.
[1] M. Lavagnini et al., Phys. Rev. B 78 (2008) 201101.
[2] K. Warawa et al., Phys. Rev.B 108 (2023) 045147.

TT 40: Focus Session: Recent Progresses in Criticality in the Presence of Boundaries and Defects I (joint session DY/TT)

In recent years there has been a renewed interest in critical systems in the presence of boundaries or, more generally, defects. This attention is driven by different perspectives. Numerical studies of quantum spin models have reported in some cases unexpected boundary critical behavior. This, in turns, has led to a reconsideration of the classical surface critical behavior problem, with the discovery of so-far overlooked boundary phases. In this context, numerous recent studies have considered the so-called symmetry-protected topological gapless systems, and in particular their boundary states. At the same time, advances in conformal field theory, specifically the conformal bootstrap program, have addressed the problem of boundaries and defects in conformally-invariant theories. This Focus Session brings together some of the main actors in the aforementioned advancements in boundary critical phenomena.

Organized by Francesco Parisen Toldin (Aachen) and Stefan Wessel (Aachen)

Time: Wednesday 9:30–12:30 Location: A 151

Invited Talk TT 40.1 Wed 9:30 A 151
Boundary behavior at classical and quantum phase transitions — •Max Metlitski — Physics Department, MIT, Cambridge, MA, USA

There has been a lot of recent interest in the boundary behaviour of materials. This interest is driven in part by the field of topological states of quantum matter, where exotic protected boundary states are ubiquitous. In this talk, I'll ask: what happens at a boundary of a system, when the bulk goes through a phase transition. While this question was studied in the context of classical statistical mechanics in the 70s and 80s, basic aspects of the boundary phase diagram for the simplest classical phase transitions have been missed until recently. I'll describe progress in this field, as well as some extensions to quantum phase transitions.

TT 40.2 Wed 10:00 A 151
Universal results for near-critical systems in presence of defects — •Gesualdo Delfino — SISSA, Trieste, Italy

We show how low-energy singularities in field theory lead to exact universal predictions for near-critical systems in presence of defects and present the results for the order parameter profiles in three different cases: the three-dimensional XY model with boundary conditions producing a vortex line [1], the three-dimensional Ising model with boundary conditions leading to the formation of an interface [2], and the time evolution from domain wall initial conditions in quantum one-dimensional ferromagnets [3]. In the three cases, the theoretical predictions are successfully compared with numerical results.

References:

[1] Gesualdo Delfino, Walter Selke and Alessio Squarcini, Vortex mass in the three-dimensional O(2) scalar theory, Phys. Rev. Lett. 122 (2019) 050602

[2] Gesualdo Delfino, Walter Selke and Alessio Squarcini, Particles, string and interface in the three-dimensional Ising model, Nucl. Phys. B 958 (2020) 115139

[3] Gesualdo Delfino and Marianna Sorba, Space of initial conditions and universality in nonequilibrium quantum dynamics, Nucl. Phys. B 983 (2022) 115910

TT 40.3 Wed 10:15 A 151
Emergent geometry at the critical point — •Giacomo Gori — Heidelberg University

Critical correlations in a bounded system with ordered boundary are argued to be function of a suitably chosen metric g. This isotropic metric rules the order parameter profile according to general scaling arguments. These statements are verified via extensive Monte Carlo simulations. A natural candidate for g is the solution of a differential geometry problem known as Yamabe problem i.e. find a local rescaling of a metric making curvature constant. The correct Yamabe problem to be considered entails a fractional (anomalous in physics) generalization of the Ricci scalar curvature.

TT 40.4 Wed 10:30 A 151
Many-body correlations at wetting. Exact results — •Alessio Squarcini — Institute for Theoretical Physics, Innsbruck

The exact characterization of correlations in the presence of strongly fluctuating interfaces has always been considered a difficult problem in classical statistical mechanics. In this talk we present exact results for density correlations for an interface forming a droplet in two dimensions whose endpoints are pinned on a wall. Our framework, which hinges on recently developed field-theoretical techniques, applies to interfaces entropically repelled by a hard wall as well as to the regime of wetting transitions that we characterize also via the notion of interface structure factor in capillary wave theory. We will show that for entropically repelled interfaces the finite extent of the droplet yields finite-size corrections to correlation functions. These corrections are interpreted as adsorption of bubbles and self-interaction of the interface; their exact form is identified, interpreted in terms of Brownian excursions, and finally tested against high-precision Monte Carlo simulations in the absence of adjustable parameters. This analysis allows us to resolve a 40-years old discrepancy observed in early Monte Carlo studies. For the regime of wetting we present a recent conjectured expression for n-point correlation functions whose proof is a current work in progress.

A. Squarcini and A. Tinti, SciPost Phys. 15, 164 (2023). A. Squarcini and A. Tinti, Journal of High Energy Physics, 123 (2023). A. Squarcini and A. Tinti, J. Stat. Mech. (2023) 013206

TT 40.5 Wed 10:45 A 151
Emergent conformal boundaries from finite-entanglement scaling in matrix product states — •Rui-Zhen Huang — Department of Physics and Astronomy, University of Ghent, Belgium

The use of finite entanglement scaling with matrix product states (MPS) has become a crucial tool for studying 1+1d critical lattice theories, especially those with emergent conformal symmetry. We argue that finite entanglement introduces a relevant deformation in the critical theory. As a result, the bipartite entanglement Hamiltonian defined from the MPS can be understood as a boundary conformal field theory with a physical and an entanglement boundary. We are able to exploit the symmetry properties of the MPS to engineer the physical conformal boundary condition. The entanglement boundary, on the other hand, is related to the concrete lattice model and remains invariant under this relevant perturbation. Using critical lattice models described by the Ising, Potts, and free compact boson CFTs, we illustrate the influence of the symmetry and the relevant deformation on the conformal boundaries in the entanglement spectrum.

15 min. break

Invited Talk TT 40.6 Wed 11:15 A 151
Criticality senses topology — Oleg Vasilyev[2], •Anna Maciolek[1], and Siegfried Dietrich[2] — [1]Institute of Physical Chemistry Polish Academy of Sciences, Warsaw — [2]Max-Planck-Institute for Intelligent Systems, Stuttgart

It is well known that near the critical point, the behavior of a condensed matter system is characterized by the universality class. According to the concept of universality, the critical exponents governing the power law behavior of physical quantities, as well as the corresponding scaling functions, are the same within one universality class. In this lecture I will ask the question to what extent critical behavior "recognizes" the topology of the manifold supporting the critical system. This question is important because topological surfaces can either form spontaneously, such as vesicle membranes in biological systems, or they can be fabricated, such as Möbius rings, from microsized single crystals or from self-assembled chiral block copolymers. I will talk about our recent research that tried to answer this question for Ising-like systems, using Monte Carlo simulations of the Ising model on finite two-dimensional manifolds with different topologies.

TT 40.7 Wed 11:45 A 151

Critical Casimir forces for quenched surface disorder in the 2d Ising model — Luca Cervellera and •Fred Hucht — Fakultät für Physik, Universität Duisburg-Essen

For the anisotropic square-lattice Ising model, the critical Casimir amplitude and force can be calculated exactly for many geometries and boundary conditions. From a recent exact solution for the cylinder with length L, circumference M, and with arbitrary quenched random boundary conditions at one boundary, we determine the full density of thermodynamic states $\omega(f^{(\mathrm{ex})}, m_{\mathrm{B}})$, with excess free energy per boundary spin $f^{(\mathrm{ex})}$ and boundary magnetization m_{B}, at criticality. From an analysis of this quantity we can derive the disorder averaged Casimir potential and Casimir force for different aspect ratios and disorder ensembles.

TT 40.8 Wed 12:00 A 151

Quantifying nonuniversal corner free energy contributions in weakly-anisotropic two-dimensional critical systems — •Florian Kischel and Stefan Wessel — RWTH Aachen University, Aachen, Germany

Confined two-dimensional critical systems with corners along the boundary of the spatial domain exhibit a logarithmic contribution to the free energy density. For conformal invariant bulk systems, this corner term has been derived by Cardy and Peschel in terms of the underlying central charge. However, for weakly anisotropic systems, the corner term deviates from this conformal field theory prediction, and the question arises, whether this anisotropy effect can be further quantified in a general way in terms of the asymptotic critical fluctuations. Here, we derive an exact formula for the corner free energy contribution of weakly-anisotropic two-dimensional critical systems in the Ising universality class on rectangular domains, expressed in terms of quantities that specify the anisotropic fluctuations. The resulting expression compares well to numerical exact calculations that we perform for the anisotropic triangular Ising model and quantifies the nonuniversality of the corner term for anisotropic critical two-dimensional systems. Our generic formula is exected to apply also to other weakly-anisotropic critical two-dimensional systems that allow for a conformal field theory description in the isotropic limit.

TT 40.9 Wed 12:15 A 151

Confinement of magnetic solitons and edge states in van-der Waals FeOCl — •Angela Möller[1], Martin Panthöfer[1], Stefanie Berinskat[1], Fabian Predelli[2], and Peter Lemmens[2] — [1]Dept. Chemistry, JGU Mainz, Mainz, Germany — [2]IPKM, TU Braunschweig, Braunschweig, Germany

In a comparative and systematic study of the isostructural van-der Waals materials ScOCl, ScOBr, FeOCl, the origin of unconventional magnetic properties of FeOCl has been investigated. Evidence for a size dependent order parameter and fluctuations are found in Mössbauer and Raman spectroscopy in conjunction with thermodynamic data and X-ray diffraction. We discuss our data in relation to soliton condensation into topological edge states.

Funding by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) under the projects 443703006 (CRC 1487) and 442589410 is gratefully acknowledged. PL and FP acknowledge support by DFG GrK 1952/2, Metrology for Complex Nanosystems-NanoMet and DFG EXC-2123 QuantumFrontiers - Light and Matter 390837967.

TT 41: Superconducting Qubits (joint session QI/TT)

Time: Wednesday 9:30–13:15 Location: HFT-FT 131

TT 41.1 Wed 9:30 HFT-FT 131

Improving Fabrication Methods for High Coherence Superconducting Qubits — •Niklas Bruckmoser[1,2], Leon Koch[1,2], David Bunch[1,2], Ivan Tsitsilin[1,2], Kedar E. Honasoge[1,2], Thomas Luschmann[1,2], Lasse Södergren[1,2], Christian Schneider[1,2], Max Werninghaus[1,2], and Stefan Filipp[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany

The development of superconducting qubits and resonators with long coherence times and high quality factors is an essential milestone on the way towards useful quantum applications. While significant improvements in coherence time have been achieved over the last years, reaching qubit lifetimes well beyond 0.1 ms involves careful investigation of all fabrication processes. In this talk, we show that achieving such high-quality devices becomes possible through a combination of substrate cleaning, etching optimization, and post-process sample cleaning. By using resonator measurements as a figure of merit to minimize TLS loss, we achieve internal quality factors of more than $Q_{\mathrm{int}} = 1 \times 10^7$ for thin-film niobium coplanar waveguide resonators in the single-photon regime and observe transmon qubits with single-shot lifetimes as high as $T_1 = 0.7$ ms. Additionally, we exploit the high quality of the niobium resonators as sensors to investigate losses arising from different types of silicon substrates.

TT 41.2 Wed 9:45 HFT-FT 131

Enhanced parameter targeting in flip-chip geometry for large-scale superconducting quantum computing — •Léa Richard[1,2], Agata Skoczylas[1,2], Franziska Wilfinger[1], Niklas Bruckmoser[1,2], Leon Koch[1,2], David Bunch[1,2], Lasse Södergren[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

In order to use quantum computing to tackle classically intractable problems, quantum processors must grow to larger scales. However, routing multiple control lines to an increasing number of qubits is not feasible in current superconducting planar architectures.

Using 3D-integration techniques, such as flip-chip bonding, plays a crucial role in mitigating this problem. A challenge arising from this new technology is the precise control of the vertical placement of the chips. In quantum circuits, capacitances and inductances are determined by the geometry of the electrodes. Hence, in a flip-chip assembly, it depends on the gap separating the two bonded chips. During the bonding process, variations may occur, preventing an accurate parameter targeting.

In this talk, we discuss the fabrication of thermally evaporated indium bumps and review the development of an optimized flip-chip bonding process. Moreover, we present a method for improved interchip spacing control and parameter targeting through the use of polymer spacers.

TT 41.3 Wed 10:00 HFT-FT 131

Frequency tuning of superconducting qubits by junction annealing — •Julius Feigl[1,2], Leon Koch[1,2], Florian Wallner[1,2], Niklas Bruckmoser[1,2], David Bunch[1,2], Lasse Södergren[1,2], Christian Schneider[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany

When scaling superconducting quantum processors beyond a couple of qubits, frequency collisions can become a limiting factor for gate fidelities. These collisions arise from parameter variations in the fabrication process, resulting in imprecise frequency targeting. A solution to enhance frequency targeting of individual superconducting qubits is the controlled annealing of the Josephson junction. In fact, Josephson junction resistance can be increased by local heating via a tightly focused laser beam. This leads to a modified Josephson inductance. In our work, we investigate wafer-scale laser annealing of fixed-frequency transmons with Al/AlOx/Al junctions. We explore the influence of annealing parameters on the resistance change for various junction sizes. The observed variations of the junction resistance after the annealing step reveal different temperature regimes for annealing. Temperatures exceeding 200 °C induce a reduction of up to 35 % in resistance, while temperatures below lead to an increase of up to 5 % in resistance. Consequently, we present a prospective approach to bi-directional an-

nealing.

TT 41.4 Wed 10:15 HFT-FT 131

All-nitride superconducting devices for quantum computing
— •Thomas Smart, Roudy Hanna, Michael Schleenvoigt, Albert Hertel, Abdur Rehman Jalil, Detlev Grützmacher, and Peter Schüffelgen — Forschungszentrum Jülich GmbH, Wilhelm-Johnen-Strasse, Jülich, 52425, Germany

The ongoing search for better superconducting devices for quantum computing has led to many proposals on how these devices can be improved to yield longer coherence times. Nitride based superconducting devices have been proposed as a potential platform for the next generation of quantum computing due to their stability and desirable superconducting properties. Here, we present the fabrication of all-nitride superconducting devices via molecular beam epitaxy on c-plane sapphire. These devices exhibit high crystalline quality and desirable superconducting properties. We explore the advantages of these devices compared to commonly used alternatives and how the use of reconstructed sapphire yields ideal growth qualities.

TT 41.5 Wed 10:30 HFT-FT 131

Magnetic field dependence of a Josephson travelling wave parametric amplifier
— •Lucas Janssen[1], Christian Dickel[1], Guilliam Butseraen[2], Jonas Krause[1], Alexis Coissard[3], Luca Planat[3], Gianluigi Catelani[4], Nicolas Roch[2], and Yoichi Ando[1] — [1]University of Cologne, Cologne, Germany — [2]Institut Néel, Grenoble, France — [3]Silent Waves, Grenoble, France — [4]Technology Innovation Institute, Abu Dhabi, United Arab Emirates

We investigate the magnetic field dependence of a Josephson travelling-wave parametric amplifier (TWPA) that is designed as a version of photonic crystal. We show that the change in photonic bandgap and plasma frequency of the TWPA can be modelled by considering the suppression of the critical current in the Josephson junctions (JJs) of the TWPA due to the Fraunhofer effect and closing of the superconducting gap in magnetic fields. These dependencies allow us to tune the operation of the TWPA by magnetic fields in a wide range of frequencies without using SQUIDs. The JJ geometry is found to be crucial for the magnetic-field dependences: for example, the TWPA bandgap can be widely shifted without losing gain or bandwidth by an in-plane magnetic field in one direction, while in the other in-plane direction the TWPA performance is severely compromised already at 2mT. With out-of-plane field, the TWPA's response is hysteretic, and it is severely compromised at 5mT. We also show that we can use magnetic shielding to use the TWPA in experiments where high fields are required.

TT 41.6 Wed 10:45 HFT-FT 131

Embedded Amplifier for Efficient Superconducting Qubit Readout
— •Lindsay Orr[1,2], Benton Miller[3,4], Florent Lecocq[3,5], and Anja Metelmann[1] — [1]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [3]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA — [4]Department of Physics, University of Colorado, Boulder, Colorado 80309, USA — [5]Department of Electrical, Computer, and Energy Engineering, University of Colorado, Boulder, Colorado 80309, USA

High fidelity qubit readout is a cornerstone of quantum computing. In superconducting architecture, this is typically achieved by routing signals from a readout cavity to a parametric amplifier via microwave circulators. The use of these off-chip components enables the independent design and optimization of the readout cavity and parametric amplifier. However, the intrinsic losses and large magnetic fields of these circulators reduces measurement efficiency and inhibits scalability. Our strategy to circumvent this is to perform the amplification and signal routing directly on-chip, by coupling a transmon qubit to a nonreciprocal multimode parametric system. As a consequence of this, the qubit and amplifier become a single open quantum system with a large Hilbert space. In this talk, we will discuss the theoretical challenges in understanding the quantum dynamics, focusing on extracting qubit measurement and dephasing rates.

TT 41.7 Wed 11:00 HFT-FT 131

Three wave mixing with a dimer Josephson junction array amplifier
— •Mitchell Field[1], Nicolas Zapata[1], and Ioan M. Pop[1,2,3] — [1]Institute of Quantum Materials and Technology, Karlsruhe Institute of Technology — [2]Physikalisches Institut, Karlsruhe Institute of Technology — [3]1. Physikalisches Institut, University of Stuttgart

Superconducting Josephson junction parametric amplifiers are robust, low noise amplifiers used to improve the signal to noise ratio of microwave quantum measurements. A common way to generate amplification is with the intrinsic non-linearity of superconducting quantum interference devices (SQUIDs), which sustain four wave mixing processes. In this work we re-engineer an established optical lithography design for dimer Josephson junction array amplifiers [1] by replacing SQUIDs with superconducting non-linear asymmetric inductive elements (SNAILs) [2] which we use to introduce a three wave mixing process. The asymmetric Josephson potential of SNAILs induces a so-called Kerr-free point [3], which we use to improve the dynamic range [4] and increase the signal-pump detuning to several gigahertz.

1. Winkel, P. et al. Phys. Rev. Applied 13, 024015 (2020).
2. Frattini, N. E. et al. Applied Physics Letters 110, 222603 (2017).
3. Sivak, V. V., Shankar, S., Liu, G., Aumentado, J. & Devoret, Phys. Rev. Appl. 13, 024014 (2020).
4. Eichler, C. & Wallraff, A. EPJ Quantum Technol. 1, 119 (2014).

15 min. break

TT 41.8 Wed 11:30 HFT-FT 131

Single-qubit gates on Fluxonium qubits with a sub-harmonic drive
— •Johannes Schirk[1,2], Florian Wallner[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Ivan Tsitsilin[1,2], Niklas Glaser[1,2], Vincent Koch[1,2], Longxiang Huang[1,2], Klaus Liegener[1,2], Max Werninghaus[1,2], Etienne Denois[3], Dominique Sugny[3], Christian Schneider[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Laboratoire Interdisciplinaire Carnot de Bourgogne, CNRS-Université de Bourgogne, Dijon, France

Current implementations of superconducting quantum processors rely on microwave drive lines and flux bias lines to control qubits. To ensure fast and high-fidelity operations, the coupling between the qubit and the control lines must be sufficiently large, which in turn increases energy relaxation of the qubits. In this talk, we present a new approach to control Fluxonium qubits. We experimentally realize high-fidelity single-qubit gates by applying a parametric drive to the qubit's flux line, eliminating the need for an additional charge line. Moreover, we demonstrate the ability to drive the qubit with a sub-harmonic drive frequency at a fraction of its resonance frequency, using a multi-photon process to excite the qubit. This allows us to place a low-pass filter on the flux line below the qubit's resonance frequency, thereby suppressing energy relaxation into this single remaining control line.

TT 41.9 Wed 11:45 HFT-FT 131

High-Fidelity Readout of Fluxonium Qubits
— •Florian Wallner[1,2], Johannes Schirk[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Ivan Tsitsilin[1,2], Niklas Glaser[1,2], Vincent Koch[1,2], Longxiang Huang[1,2], Klaus Liegener[1,2], Max Werninghaus[1,2], Christian Schneider[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany

Fast and high-fidelity qubit readout is one of the fundamental operations for quantum computation. A higher readout fidelity significantly reduces the number of experiments needed to reach the specified accuracy. Recently, the use of measurements in a mid-circuit fashion with classical feedback became an important resource for efficient quantum circuits. Here the performance of the readout is even more critical for the resulting circuit fidelity. In this talk we report on our recent advances to improve the readout of superconducting Fluxonium qubits. We demonstrate dispersive readout within $1.2\,\mu$s with assiment fidelities higher than 98.3 % and a QNDness of up to 98.0 %. These high numbers enable us to use an active feedback based reset that outperforms passive methods to initialize the qubit. Due to our high readout photon number of $\bar{n} > 50$ we can mitigate the use of a parametric amplifier. Moreover, through dedicated flux pulses we can utilize the dispersive shift landscape of the qubits. With this, we can protect the qubit during idling times and significantly enhance the resonator shift during readout improving the readout fidelity even further.

TT 41.10 Wed 12:00 HFT-FT 131

Improving Transmon Qudit Measurement on IBM Quantum Hardware — •Tobias Kehrer, Tobias Nadolny, and Christoph Bruder — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

The Hilbert space of a physical qubit typically features more than two energy levels. Using states outside the qubit subspace can provide advantages in quantum computation. To benefit from these advantages, individual states of the d-dimensional qudit Hilbert space have to be discriminated properly during readout. In this contribution (arXiv:2307.13504), we propose and analyze two measurement strategies that improve the distinguishability of transmon qudit states. Both strategies aim to minimize drive-frequency dependent assignment errors of qudit states. Based on a model describing the readout of IBM Quantum devices, these strategies are compared to the default measurement. In addition, we employ higher-order X-gates that make use of two-photon transitions for qudit state preparation.

TT 41.11 Wed 12:15 HFT-FT 131

Automated Characterization of Superconducting Quantum Processors — •Konstantin Lehmann, Adam Lawrence, Timo van Abswoude, Thorsten Last, and Adriaan Rol — Orange Quantum Systems B.V., Elektronicaweg 10, 2628 XG Delft, NL

The qubit count of transmon-based quantum processors is steadily increasing. Some processors are already beyond the 100-qubit scale [1]. In order to keep the development cadence of those quantum processors high, the test time per qubit need to be strongly reduced from days to hours. Therefore, we developed the library SCQT and its accompanied automation framework GRACE.

SCQT is based on the open-source measurement framework Quantify [2]. It supports adaptive measurements to reduce the size and duration of large experiments. SCQT is designed with processor-scaling in mind and is equipped for features like tuneable couplers, leakage correction and cross-talk correction.

GRACE extracts the quantities of interest from the calibration protocols and transitions smoothly to the next protocol. This level of automation allows to take longer measurements without supervision, thereby reducing significantly the effort to characterize transmon-based quantum processors.

[1] https://www.ibm.com/quantum/roadmap
[2] https://quantify-os.org/

TT 41.12 Wed 12:30 HFT-FT 131

Suppression of coherent errors in Cross-Resonance gates via recursive DRAG — •Boxi Li[1,2], Tommaso Calarco[1,2,3], and Felix Motzoi[1] — [1]Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), D-52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

The high-precision control of quantum logical operations is a prerequisite to increasing circuit depths in quantum processors, implementing useful quantum algorithms, and reaching fault-tolerant scalable architectures. A ubiquitous approach used for entangling gates has been all-microwave control of superconducting qubits, primarily using the Cross-Resonance two-qubit gate; however, fidelities are still limited by control imperfections. Here, we derive a universal analytical pulse shape that significantly improves fidelities in Cross-Resonance gates, suppressing both the three off-resonant transitions on the control qubit and unwanted two-qubit rotation operators. Experimentally tested on the IBM Quantum Platform, our proposed drive pulse demonstrates successful suppression of coherent errors, allowing for much faster gates than the current state-of-the-art. Despite limited remote access, across multiple qubit pairs, we achieve a notable two to threefold reduction in error for the CNOT gate, resulting in coherence-limited gates with fidelities in the 99.7% range, higher than any publicly accessible CNOT gate on the IBM Quantum Platform.

TT 41.13 Wed 12:45 HFT-FT 131

Superconducting Qubit reset using Demolition Measurement — •Ashutosh Mishra[1], Frank Wilhelm-Mauch[1], and Shai Machnes[1,2] — [1]Peter Grünberg Institute - Quantum computing Analytics (PGI-12) Forschungszentrum Jülich, Jülich, Germany — [2]Qruise GmbH, Saarbrücken, Germany

Superconducting qubits have been a popular choice for quantum computing, but still are noisy and have been plagued with errors. The error budget of surface code as presented by Google Quantum AI [1] had almost half the errors due to measurement, leakage and qubit idle during measurement and reset. Measurement and reset of the qubits also constitute a large fraction of the time between two experiments. Since algorithms like VQE, QEC rely on multiple measurements to either estimate better parameters for the anstaz or to detect errors, reducing the time taken to measure and reset the qubit can significantly increase the data taking rate and at the same time reduce qubit idling errors. In this project we look for a scheme for combining the measurement and reset processes of the qubit and the readout resonator using optimal control tools. We demonstrate that one can perform a qubit readout, clear leakage population of the qubit and then empty the resonator and reset the qubit to the ground state within $1\mu s$.

[1] "Suppressing quantum errors by scaling a surface code logical qubit." Nature 614, no. 7949 (2023): 676-681.

TT 41.14 Wed 13:00 HFT-FT 131

Renormalization effects in driven quantum phase slip junctions — •Christina Koliofoti and Roman-Pascal Riwar — Forschungszentrum Jülich, Peter Grünberg Institut (PGI-2), 52425 Jülich, Deutschland

Quantum circuit theory is a powerful tool to describe superconducting circuits. In its language, quantum phase slips (QPSs) are considered to be the exact dual to the Josephson effect. This duality renders the integration of QPS junctions into a unified theoretical framework challenging. As we argue, different existing formalisms may be inconsistent, and the correct inclusion of time-dependent flux driving requires introducing a large number of auxiliary, nonphysical degrees of freedom. We resolve these issues by describing QPS junctions as inductive rather than capacitive elements, and reducing the Hilbert space to account for a compact superconducting phase. Our treatment provides an approach to circuit quantization exclusively in terms of node-flux-node variables, and eliminates spurious degrees of freedom. In this talk we present in particular the possibility of a voltage-dependent renormalization of the QPS amplitude, by accounting for spatial variations of the electric field built up across the junction.

TT 42: 2D Materials III: Electronic Structure (joint session O/TT)

Time: Wednesday 10:30–13:00 Location: MA 005

TT 42.1 Wed 10:30 MA 005

Semiclassical theory for plasmons in inhomogeneous two-dimensional systems — •Tjacco Koskamp, Koen Reijnders, and Mikhail Katsnelson — Radboud University, Nijmegen, The Netherlands

We construct a general theory for plasmons in inhomogeneous two-dimensional systems. Plasmons, quantized collective oscillations of conduction electrons in solids, can be used to manipulate and control light. This requires heterostructures of nanometer size, which are by definition spatially inhomogeneous, and difficult to describe analytically. Here, we present a novel semi-analytical method to describe plasmons in two-dimensional inhomogeneous media within the framework of the Random Phase Approximation (RPA). Our approach [1] is based on the semiclassical approximation, which is formally applicable when the length scale of the inhomogeneity is much larger than the plasmon wavelength. Within this framework, we obtain a classical Hamiltonian that describes the dynamics of quantum plasmons, given by the Lindhard function with spatially varying parameters. The classical trajectories generated by this Hamiltonian can be viewed as the analog of rays in geometrical optics. By subsequently adding the wave-like character of the plasmons to these classical trajectories, we can describe, for instance, plasmon scattering and plasmonic bound states. As an example, we compute the differential cross section for plasmon scattering by a radially symmetric impurity.

[1] T. M. Koskamp, M. I. Katsnelson, K. J. A. Reijnders, Phys. Rev. B 108, 085414 (2023)

TT 42.2 Wed 10:45 MA 005

Imaging dielectric near-field modes of hexagonal boron nitride by photoemission electron microscopy — •Yaolong Li[1,2], Martin Aeschlimann[2], Quan Sun[1], Yunan Gao[1], Xiaoyong Hu[1], and Qihuang Gong[1] — [1]Department of Physics, Peking University, Beijing, China — [2]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

Low-loss dielectric modes are important features and functional bases of fundamental optical components in on-chip optical devices. However, dielectric near-field modes are challenging to reveal with high spatiotemporal resolution and fast direct imaging. Here, we present a method to address this issue by applying time-resolved photoemission electron microscopy to a low-dimensional wide-bandgap semiconductor, hexagonal boron nitride (hBN). Using a low-loss dielectric planar waveguide as the fundamental structure, static vector near-field vortices with different topological charges and the spatiotemporal evolution of waveguide modes are directly revealed. With the lowest order vortex structure, strong nanofocusing in real space is realized. Near-vertical photoemission in momentum space and narrow spread in energy space are simultaneously observed due to the atomically flat surface of hBN and the small photoemission horizon set by the limited photon energies. Our approach provides a strategy for the realization of flat photoemission emitters. Revealing low-loss dielectric near-field modes of hexagonal boron nitride by photoemission electron microscopy. Nat. Commun. 14, 4837 (2023).

TT 42.3 Wed 11:00 MA 005

Noble metal dichalcogenides: Optoelectronic and non-linear response — George de Coster[1], Stefan Heiserer[1], Simon Schlosser[1], Zdenek Sofer[2], Tanja Stimpel-Lindner[1], Georg Duesberg[1], and •Paul Seifert[1] — [1]Institute of Physics, University of the Bundeswehr Munich, Faculty of Electrical Engineering and Information Technology, Werner-Heisenberg-Weg. 39, 85577 Neubiberg, Germany — [2]Department of Inorganic Chemistry, University of Chemistry and Technology Prague, Technická 5, 166 28 Prague 6, Czech Republic

Noble metal dichalcogenides belong to the material class of layered 2D materials. In particular, these materials transition from direct band gap semiconductor to semi-metal with increasing layer thickness and were shown to host type-II Dirac semi-metallic behavior, as well as topological surface states and superconductivity [1,2]. We analyze the low-frequency optoelectronic response of PdTe2 using THz time domain spectroscopy. Frequency resolved measurements reveal signatures of second order non-linear response whose symmetry constrains are consistent with the occurrence of anisotropy in its optoelectronic response to THz radiation [3]. The latter is verified in polarization resolved THz spectroscopy. The optical response at higher energies likewise exhibits this anisotropy. Our results elucidate the spectral optoelectronic response in PdTe2 at low energies and discuss its anisotropy in light of its underlying symmetry constraints. References: [1] W. Zheng et al., PRB 97, 235154 (2018) [2] O.J. Clark et al., PRL 120, 156401 (2018) [3] C. Guo et al. Sci. Adv. 6, 36 (2020)

TT 42.4 Wed 11:15 MA 005

On the the nature of transient and metastable nonequilibrium phases in 1T-TaS2 — •Tanusree Saha[1,2], Arindam Pramanik[3], Barbara Ressel[1], Alessandra Ciavardini[1], Primož Rebernik Ribič[4], and Giovanni De Ninno[1,4] — [1]University of Nova Gorica, 5270 Ajdovščina, Slovenia — [2]Universität Duisburg-Essen, 47057 Duisburg, Germany — [3]Tata Institute of Fundamental Research, Mumbai 400005, India — [4]Elettra Sincrotrone Trieste, 34149 Trieste, Italy

Photoexcitation of materials with complex ground states can drive them into new out-of-equilibrium phases. In this talk, I will present the characteristics of these phases and the recovery dynamics in a complex system, the charge density wave (CDW)-Mott insulator 1T-TaS2, studied using time- and angle-resolved photoemission spectroscopy. We observe strong similarities between the band structures of the transient phase and the structurally undistorted equilibrium phase, with evidence for the coexistence of insulating and metallic phases. Following the transient phase, we find that the restorations of Mott and CDW orders begin around the same time, highlighting that the Mott transition is tied to the CDW distortion. During recovery, a metastable phase, driven by the CDW lattice order, emerges but only in the strong photoexcitation regime and is a commensurate CDW-Mott insulating phase but with a smaller CDW amplitude. Finally, I will briefly discuss our future work, where we aim to study how the nature of the metastable phase and electron correlations in photoexcited 1T-TaS2 can be tuned by an external parameter, e.g. pump fluence.

TT 42.5 Wed 11:30 MA 005

Self-hybridized exciton-polaritons in thin films of Ruddlesden-Popper-Perovskites — •Maximilian Black[1], Parsa Darman[2], Sara Darbari[2], and Nahid Talebi[1] — [1]Institute for Experimental and Applied Physics, Kiel University, 24118 Kiel, Germany — [2]Faculty of Electrical and Computer Engineering, Tarbiat Modares University, 14115-111 Tehran, Iran

Lead halide perovskites have emerged as platforms for exciton-polaritonic studies at room temperature thanks to their excellent photoluminescence efficiency and great synthetic versatility. In this work we find proof of strong exciton-photon coupling in cavities formed by the layered crystals themselves, a phenomenon known as self-hybridization effect. We use multi-layers of high quality Ruddlesden-Popper perovskites in their 2D crystalline form, benefiting from their quantum-well excitonic resonances and the strong Fabry-Perot resonances resulting from the total-internal-reflection at their smooth surfaces. Optical spectroscopy reveals bending of the cavity modes typical for exciton-polariton formation, and photoluminescence spectroscopy shows thickness dependent splitting of the excitonic resonance. Additionally, local optical excitation of the flakes in photoluminescence measurements unveils long in-plane propagation of the excited modes. In previous works the influence of the incident angle is often overlooked, motivating this work to focus on tuning the in-plane momentum of the incident light to the polaritonic resonances. We therefore pave the way towards an effective way to study the rich physics of exciton-polaritons in Ruddlesden-Popper 2D perovskites.

TT 42.6 Wed 11:45 MA 005

Inelastic tunneling into polaronic bound states in single-layer MoS_2 — Camiel van Efferen[1], Arne Schobert[2], Tfyeche Tounsi[1], Michael Winter[2], Mark Georger[1], Affan Safeer[1], Christian Krämer[1], Jeison Fischer[1], Jan Berges[3], Thomas Michely[1], •Roberto Mozara[2], Tim Wehling[2,4], and Wouter Jolie[1] — [1]II. Physikalisches Institut, U zu Köln — [2]I. Institut für Theoretische Physik, U Hamburg — [3]U Bremen Excellence Chair, Bremen Center for Computational Materials Science, and MAPEX Center for Materials and Processes — [4]The Hamburg Centre for Ultrafast Imaging

The presentation delves into the nuanced conductivity of two-dimensional MoS_2, a prominent transition metal dichalgogenide, by examining its response to doping-induced variations. In particular, we explore the intriguing phenomena of polarons, quasiparticles that emerge from the interplay of electrons with lattice vibrations. Employing advanced techniques such as scanning tunneling microscopy and spectroscopy, we unveil the manifestation of polaronic bound states in metallic 2D MoS_2, shedding light on their stability and formation dynamics. The investigation is enriched by density-functional theory calculations with a recently developed electron-lattice downfolding technique, emphasizing the role of renormalized M-phonons in shaping the electronic landscape of metallic MoS_2. This synthesis of experimental insights and theoretical perspectives offers a comprehensive understanding of the interplay between electrons and phonons in 2D MoS_2.

TT 42.7 Wed 12:00 MA 005

Strain-dependent electromechanical and optoelectronic properties of free-standing PtSe2 films — •Natalie Galfe, Stefan Heiserer, Maximilian Wagner, Michael Loibl, Silke Boche, Simon Schlosser, Oliver Hartwig, Tanja Stimpel-Lindner, Cormac Ó Coileáin, Kangho Lee, George de Coster, Paul Seifert, and Georg S. Duesberg — University of the Bundeswehr Munich

We report on the piezoresistive and optoelectronic properties of free-standing noble metal dichalcogenide $PtSe_2$ films under controlled strain. Bridges of polycrystalline $PtSe_2$ films with different geometries were fabricated directly on target substrates. The pre-structered platinum channels were selenized through thermally assisted conversion and the resulting $PtSe_2$ electrically contacted and underetched. The controlled strain of the bridges was induced by application of back-gate voltages. This makes them an excellent platform to study the impact of strain on transport and optoelectronic properties.

Increasing tensile strain shows a decrease in the electrical resistance, which is attributable to an enhancement of the density of states at the Fermi level. Raman analysis of the channel under increasing static strain displays a blue-shift of the Raman modes, which can be attributed to a decrease in effective film thickness which is supported by finite element simulations of the polycrystalline films. By applying AC gate voltages, the geometry-dependent eigenfrequencies of the bridges can be determined proving their expected mechanical oscillations. The results lead to a deeper understanding of this novel material class and serve as a platform for further applications.

TT 42.8 Wed 12:15 MA 005

Direct visualization of conduction band electrons in gated single layer TMDC via micro ARPES — •Chakradhar Sahoo[1], Yann in 't Veld[2], Alfred J. H. Jones[1], Zhihao Jiang[1], Paulina E. Majchrzak[1], Kimberly Hsieh[1], Kenji Watanabe[3], Takashi Taniguchi[4], Yong P. Chen[1], Jill A. Miwa[1], Malte Rösner[2], and Søren Ulstrup[1] — [1]Department of Physics and Astronomy, Interdisciplinary Nanoscience Center, Aarhus University, 8000 Aarhus C, Denmark — [2]Institute for Molecules and Materials, Radboud University, 6525 AJ Nijmegen, the Netherlands — [3]Research Center for Functional Materials, National Institute for Materials Science, Tsukuba 305-0044, Japan — [4]International Center for Materials Nanoarchitectonics, National Institute for Materials Science, Tsukuba 305-0044, Japan

Electric field induced doping effects in the electronic structure of single-layer (SL) semiconductors is crucial for electronic and optoelectronic applications. However, direct visualization of doped electronic structure remains challenging for in situ gated devices. Here, we apply in operando micrometer scale angle-resolved photoemission spectroscopy at the ASTRID2 light source to characterize the electronic structure of a SL WS2 gated device. Using micromechanical cleaving and transfer methods, the SL WS2 is partially contacted to a graphene top electrode and placed on a boron nitrite dielectric on a graphite back-gate. We directly visualize distinct conduction band populations, band gap renormalization and charge transfer processes across the bare WS2 and graphene/WS2 interface. Our observations provide a better understanding of band renormalization and carrier doping in 2D devices.

TT 42.9 Wed 12:30 MA 005

Deexcitation of highly charged ions at surfaces — •Anna Niggas, Matthias Werl, Daniel Thima, Filip Vukovic, Matthias Bernhart, Friedrich Aumayr, and Richard A. Wilhelm — TU Wien, Institute of Applied Physics, Vienna, Austria

Strong electronic excitations at the nanoscale can trigger nanopore formation on 2D materials and their heterostructures. One possible way to achieve these excitations are impacts of slow highly charged ions (HCIs), e.g., Xe^{40+} ions: Upon approaching the surface, resonant electron transfer leads to a population of high-n shells of the ion, with subsequent radiative and non-radiative decay, resulting in energy deposition in the very first surface layers of the material.

To unravel these deexcitation dynamics, we employ a complex coincidence spectrometer to detect correlated pairs of HCIs transmitted through 2D materials and electrons emitted from the material due to the ion impact. Filtering options for ion charge state, scattering angle, and energy loss, as well as electron number and energy, can be used for a detailed analysis of deexcitation channels. For instance, a charge-state-separated analysis of the HCI-induced electron yield from graphene shows that the number of emitted electrons increases continuously with the number of electrons captured by the projectile, reaching up to $100\,e^-$ per incident ion. Furthermore, we observe a sudden increase in the electron yield for ions filling up their valence shell.

In this contribution, we will discuss how these coincidence measurements help us understand the deexcitation of HCIs and how we can use our method to access material properties.

TT 42.10 Wed 12:45 MA 005

Ultrafast Electron Diffuse Scattering as a Tool for Studying Phonon Transport: Phonon Hydrodynamics and Second Sound Oscillations — •Laurenz Kremeyer[1], Tristan Britt[1], Bradley Siwick[1,2], and Samuel Huberman[3] — [1]Department for Physics, McGill University, Montreal, Canada — [2]Department for Chemistry, McGill University, Montreal, Canada — [3]Department of Chemical Engineering, McGill University, Montreal, Canada

Hydrodynamic phonon transport phenomena, like second sound, have been observed in liquid Helium more than 50 years ago. More recently second sound has been observed in graphite at over 200 K using transient thermal grating techniques[1]. In this work we explore the signatures of second sound in ultrafast electron diffuse scattering (UEDS) patterns. We use density functional theory and solve the Boltzmann transport equation to determine time-resolved non-equilibrium phonon populations and subsequently calculate one-phonon structure factors and diffuse scattering patterns to simulate experimental data covering the regimes of ballistic, diffusive, and hydrodynamic phonon transport. For systems like graphite, UEDS is capable of extracting time-dependent phonon occupancies across the entire Brillouin zone [2] and ultimately lead to a more fundamental understanding of the hydrodynamic phonon transport regime.

[1] Ding et al. *Nat. Comm.* **13** 285 (2022)
[2] René de Cotret et al. *Phys. Rev. B.* **100** 214115 (2019)

TT 43: Focus Session: Spin Phenomena in Chiral Molecular Systems II (joint session O/TT)

Time: Wednesday 10:30–12:30 Location: MA 141

Topical Talk TT 43.1 Wed 10:30 MA 141

Chiral-induced Spin Selectivity in Hybrid Chiral Molecule/ Metal Systems — Ashish Moharana[1], Yael Kapon[2], Fabian Kammerbauer[1], David Anthofer[1], Shira Yochelis[2], Yossi Paltiel[2], and •Angela Wittmann[1] — [1]Johannes Gutenberg Universität Mainz, Germany — [2]Hebrew University Jerusalem, Israel

The chiral-induced spin selectivity (CISS) effect has recently gained significant attention in the field of spintronics. The remarkably high polarization efficiency of chiral molecules via the CISS effect paves the path toward novel, sustainable hybrid chiral molecule magnetic applications. While research has predominantly focused on transport properties so far, in our work, we explore spintronic phenomena at hybrid chiral molecule magnetic interfaces to elucidate the underlying mechanisms of the chiral-induced spin selectivity effect. For this, we investigate the interfacial spin-orbit coupling in chiral molecule/metal thin film heterostructures by probing the chirality and spin-dependent spin-to-charge conversion. Our findings validate the central role of spin angular momentum for the CISS effect, paving the path toward the functionalization of hybrid molecule-metal interfaces via chirality.

Topical Talk TT 43.2 Wed 11:00 MA 141

Chirality-induced spin selectivity at the single-molecule scale — •Daniel Emil Bürgler[1], Mohammad Reza Safari[1], Frank Matthes[1], Nicolae Atodiresei[1], Claus Michael Schneider[1], and Karl-Heinz Ernst[2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, Germany — [2]Molecular Surface Science Group, Empa, Dübendorf, Switzerland

Chirality-induced spin selectivity (CISS) leads to spin-selective electron transport in chiral molecules and enantiospecific adsorption on magnetic surfaces. To advance the development of theoretical models, well-defined single-molecule experiments are needed. Here, we report CISS effects for single chiral heptahelicene molecules that are sublimed under ultra-high vacuum onto uncoated single-crystalline and perpendicularly magnetized Co nanoislands. We use spin-polarized scanning tunneling microscopy (SP-STM) to (i) determine the handedness of individual heptahelicenes and the magnetization direction of the underlying Co nanoisland and (ii) measure spin-polarized transport through single molecules. Analysis of more than 740 molecules provides unequivocal evidence for enantioselective adsorption and reveals that enantioselection must occur in a physisorbed transient precursor state. $I-V$ curves of two enantiomers under otherwise identical conditions show at 5 K magnetochiral conductance asymmetries of up to 50% when either the molecular handedness is exchanged or the magnetization of the STM tip or Co substrate is reversed. The results demonstrate that CISS is a single-molecule effect and rule out electron-phonon coupling and ensemble effects as its primary mechanisms.

TT 43.3 Wed 11:30 MA 141

Spin polarization through a helical molecule- functinalized tip dependence on the tip-sample distance observed by ambient STM — •Thi Ngoc Ha Nguyen[1], Lech Tomasz Baczewski[2], Olav Hellwig[3], and Christoph Tegenkamp[1] — [1]Analysis of Solid Surfaces, Nanostructures and Quantum Materials, Chemnitz University of Technology, Germany — [2]Institute of Physics, Polish Academy of Sciences, Warszawa, Poland — [3]Functional Magnetic Materials, Chemnitz University of Technology, Chemnitz, Germany

Polyalanine (PA) with an alpha-helix conformation has gathered recently a lot of interest as the propagation of electrons along the helical backbone structure comes along with spin polarization of the transmitted electron. However, studies on a molecular scale are still rare, although this length scale provides direct insight into the role of molecular properties. We studied now in detail with a PA molecule-functionalized Au tip on magnetic Au/Co/Au/Pt/Al2O3 substrates and probed the transmission by local spectroscopy (STS). Because of the high spatial resolution, our setup allows to study this CISS effect on the nanoscale and probe the importance of cooperative effects. Using this functionalized tip, we found that the spin polarization (SP) significantly varies with tip-sample distance. Interestingly, the SP through the self-assembled film of PA on the same substrate at different non-functionalized Au tip-sample distance doesn't show significant change. Our observation provides that the overlaping tip and sample orbitals, the coupling as well as the electric field strength in the close proximity of tip - sample surface take the main roles on this SP variation.

TT 43.4 Wed 11:45 MA 141

Chirality-induced spin selective quantum capacitance — •Theiler Pius Markus — ETH Zürich, Zürich, Switzerland

The absence of symmetries has a significant impact on physics, particularly in chiral molecules or crystals lacking mirror symmetry. When an electric charge interacts with such chiral materials, the spin of the charge aligns even at room temperature. This spin polarization is known as chirality-induced spin selectivity (CISS). Although the exact mechanism behind the effect remains unclear, it may have played a role in the origin of life and significantly impacted biological processes. The effect has potential applications in chemical catalysis, renewable energy, and quantum technologies. This work aims to elucidate the key mechanism behind CISS surface potential changes upon toggling the enantiomer or magnetic polarization of the substrate. For the first time, chiral α-helical polypeptide films are investigated with time-resolved Kelvin-probe atomic force microscopy to probe the dynamics of the surface potential and a CISS quantum capacitance. This discovery of the CISS quantum capacitance leads to the conclusion that CISS is a persistent effect and paths the way to a fundamental reinterpretation of the CISS effect.

TT 43.5 Wed 12:00 MA 141

Magnetization generation in helical molecular junctions — •Richard Korytár[1], Jan van Ruitenbeek[2], and Ferdinand Evers[3] — [1]Univerzita Karlova, Prague, Czech Republic — [2]Leiden University — [3]University of Regensburg

Despite extensive experimental and theoretical literature on the spin-selective transport in helical molecules [1], a satisfactory theoretical explanation of the effect is lacking [2]. We present analytical calculations of charge and spin conductances in a minimal model of a helical molecule with spin orbit coupling attached to non-magnetic leads. The calculations extend previous studies, which focused on spin-polarization [5,3]. The band-structure of the model exhibits spin-momentum locked bands analogous the the edge modes of a quantum spin Hall system. The spin currents in the left and right lead carry opposite signs and consequently both leads pick up parallel magnetizations (in linear response). We discuss the feedback of resulting spin accumulations in the leads to the charge current [4].

[1] Ron Naaman, Yossi Paltiel & David H. Waldeck, Nature Reviews Chemistry, volume 3, pages 250*260 (2019)

[2] Evers et al., Adv. Mater. 2022, 34, 2106629

[3] J. M. van Ruitenbeek, R. Korytár, F. Evers, J. Chem. Phys. 159, 024710 (2023)

[4] R. Korytár, J. M. Ruitenbeek, F. Evers, in preparation

[5] K. Michaeli and R. Naaman, J. Phys. Chem. C 123, 17043 (2019)

TT 43.6 Wed 12:15 MA 141

Study of magneto-optical properties of cobalt-layers by adsorption of α-helical polyalanine self-assembled monolayers — •Lokesh Rasabathina[1], Apoorva Sharma[1], Julia Krone[1], Annika Morgenstern[1], Thi Ngoc Ha Nguyen[1], Markus Gössler[2], Karin Leistner[2], Christoph Tegenkamp[1], Georgeta Salvan[1], and Olav Hellwig[1] — [1]Institute of Physics, Chemnitz University of Technology, 09126 Chemnitz, Germany — [2]Institute of Chemistry, Chemnitz University of Technology, Chemnitz, 09111, Germany

High spin polarization in helical polyalanine molecules enables selective electron transport with a defined spin direction, a phenomenon known as Chirality Induced Spin Selectivity (CISS). This discovery holds promising implications for organic spintronic devices. Furthermore, the adsorption of pure enantiomers of α-helical polyalanine on a gold-covered ferromagnetic thin film, termed Magnetism Induced by the Proximity of Adsorbed Chiral molecules (MIPAC), can influence the magnetization of the ferromagnetic thin film. In our ongoing research, we are delving into the magnetic properties of thin films and attempt to increase the size of atomically smooth terraces at the Au(111) surface. By varying parameters such as deposition pressure and annealing temperature, we aim to understand how alterations in the Au surface affect the arrangement of molecules and how the molecule adsorption at the Au surface depends on the magnetic properties and state of the underlying magnetic thin film.

TT 44: Twisted Materials / Systems

Time: Wednesday 11:30–13:00 Location: H 3007

TT 44.1 Wed 11:30 H 3007

Large tunable kinetic inductance in a graphene based superconductor — Rounak Jha[1,2], Martin Endres[1], Kenji Watanabe[3], Takashi Taniguchi[4], Mitali Banerjee[2], Christian Schönenberger[1,5], and •Paritosh Karnatak[1] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Laboratory of Quantum Physics (LQP), École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland — [3]Research Center for Functional Materials, National Institute for Material Science, 1-1 Namiki, Tsukuba 305-0044, Japan — [4]International Center for Materials Nanoarchitectonics, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan — [5]Swiss Nanoscience Institute, University of Basel, CH-4056 Basel, Switzerland

Graphene based twisted moiré heterostructures host a flat band at the magic angle where the kinetic energy of charge carriers is quenched and interaction effects dominate. This results in emergent phases such as correlated insulators and superconductors that are electrostatically tunable. In this work, we investigate superconductivity in magic angle twisted trilayer graphene (MATTG) by integrating it as a weak link in a SQUID (superconducting quantum interference device) loop of superconducting Molybdenum Rhenium. We study the current phase relation of MATTG in various configurations and show that superconducting MATTG has a large kinetic inductance up to 75 nH per square which is electrostatically tunable. This opens avenues for using MATTG as a tunable element in superconducting circuits.

TT 44.2 Wed 11:45 H 3007

Dynamical correlations and order in magic-angle twisted bilayer graphene — •Gautam Rai[1], Lorenzo Crippa[2], Dumitru Călugăru[3], Haoyu Hu[4], Luca de' Medici[5], Antoine Georges[6,7,8,9], B. Andrei Bernevig[3,4,10], Roser Valentí[11], Giorgio Sangiovanni[2], and Tim Wehling[1,12] — [1]U Hamburg — [2]U Würzburg — [3]Princeton U — [4]DIPC, Donostia-San Sebastian — [5]ESPCI, Paris — [6]Collège de France, Paris — [7]Flatiron Institute, New York — [8]École Polytechnique, Palaiseau Cedex — [9]Université de Genève — [10]IKERBASQUE, Bilbao — [11]Goethe U Frankfurt — [12]Hamburg CUI

In magic-angle twisted bilayer graphene, transport, thermodynamic and spectroscopic experiments pinpoint at a competition between distinct low-energy states with and without electronic order. We use Dynamical Mean Field Theory (DMFT) to study the emergence of electronic correlations and long-range order without strain. We explain the nature of emergent insulating and correlated metallic states by three central phenomena: (i) the formation of local spin and valley isospin moments around 100K, (ii) the ordering of these moments around 10K, and (iii) a cascadic redistribution of charge between localized and delocalized electronic states upon doping. Depending on the presence (absence) of order, we find insulating gaps (spectral weight depletion) at integer fillings, and a good (bad) metal at fractional fillings. Our findings provide a unified understanding of the most puzzling aspects of STS and transport experiments, including the isospin Pomeranchuk effect and doping-induced compressibility cascades.

TT 44.3 Wed 12:00 H 3007

Chiral Pseudo Spin Liquids in Tunable Moire Heterostructures — Clemens Kuhlenkamp[1,2,3], Wilhelm Kadow[1,2], Atac Imamoglu[3], and •Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany — [3]Institute for Quantum Electronics, ETH Zürich, CH-8093 Zürich, Switzerland

We propose multi-layer moiré structures in strong external magnetic fields as a novel platform for realizing highly-tunable, frustrated Hubbard physics with topological order. Identifying a layer degree of freedom as a pseudo spin, allows us to retain SU(2) symmetry while controlling ring-exchange processes and concurrently quenching the kinetic energy by large external magnetic fields. This way, a broad class of interacting Hubbard-Hofstadter states and their transitions can be studied. Remarkably, in the limit of strong interactions the system becomes Mott insulating and we find exceptionally stable chiral pseudo spin liquid phases which are induced by the magnetic field. We discuss how layer pseudo-spin can be probed in near-term experiments. As the magnetic flux can be easily tuned in moiré systems, our approach provides a promising route towards the experimental realization and control of topologically ordered phases of matter.

TT 44.4 Wed 12:15 H 3007

Exploring unconventional transport in flat-band systems by quantum geometry — •Johannes Mitscherling[1], Dan S. Borgnia[1], and Joel E. Moore[1,2] — [1]Department of Physics, University of California, Berkeley, California 94720, USA — [2]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

Characterization of the ground state and its excitations is fundamental to understanding the transport properties of any quantum material. Until recently, this mostly meant studying the dispersive features of the band structure and the topological features of the quantum state manifold. The featureless dispersion of flat-band materials challenges this approach since all transport quantities proportional to the quasiparticle velocity vanish. We show how quantum geometry, an emerging field of study with remarkable power to capture the parameter-local properties of the quantum states, can be used to analyze unconventional transport phenomena in flat-band systems. This talk will discuss the role of quantum geometric quantities other than the Berry curvature, such as the quantum metric. Given its broad applicability, quantum geometry is a promising tool for characterizing and understanding multiband systems with non-trivial quantum geometry even beyond flat-band systems.

TT 44.5 Wed 12:30 H 3007

Double resonance of twisted photon states and related transfer of orbital angular momentum to chiral model systems — Silvia Müllner[1], •Peter Lemmens[1], and Angela Möller[2] — [1]IPKM, TU-BS, Braunschweig, Germany — [2]Dept. Chemistry, JGU Mainz, Germany

Twisted photon states that contain spin (helicity) and orbital angular momentum (chirality) are used to probe topological properties of chiral model systems. As the latter we recently identified chiral liquid crystals [1]. Their optical properties are dominated by a twistedness with a pitch length tailored both by temperature and composition. Using these two parameters as well as curved interfaces introduced by dispersed nanoparticles we establish resonances of pitch length with the geometry as well as with the OAM transfer.

Work supported by DFG GrK 1952/2, Metrology for Complex Nanosystems, NanoMet and DFG EXC-2123 QuantumFrontiers - Light and Matter 390837967.

[1] S. Müllner, et al., Phys. Rev. Lett. 129 (2022) 207801.

TT 44.6 Wed 12:45 H 3007

Particle dynamics and ergodicity breaking in twisted-bilayer optical lattices — •Ganesh C. Paul — Technische Universität Braunschweig, Institut für Mathematische Physik, Mendelssohnstraße 3 , 38106 Braunschweig, Germany

Recent experiments have realized a twisted-bilayer-like optical potential for ultracold atoms, which in contrast to solid-state setups may allow for an arbitrary ratio between the inter- and intralayer couplings. For commen- surate moiré twistings, a large-enough interlayer coupling results in particle transport dominated by channel formation. For incommensurate twistings, the interlayer coupling acts as an effective disorder strength. Whereas for weak couplings the whole spectrum remains ergodic, at a critical value part of the eigenspectrum transitions into multifractal states. A similar transition may be observed as well as a function of an energy bias between the two layers. Our theoretical study reveals atoms in a twisted-bilayer system of square optical lattices as an interesting platform for the study of ergodicity breaking and multifractality.

TT 45: $PtBi_2$ and Weyl Superconductors

Time: Wednesday 11:30–13:15 Location: H 3010

TT 45.1 Wed 11:30 H 3010

Unconventional Nernst effect in Weyl semimetal $PtBi_2$ — •Federico Caglieris[1,2,6], Michele Ceccardi[1,6], Dmitriy Efremov[2], Grigory Shipunov[2], Saicharan Aswartham[2], Arthur Veyrat[2], Joseph Dufouleur[2], Christian Hess[2,4,5], Bernd Büchner[2,3,4], and Daniele Marré[1,6] — [1]CNR-SPIN, 16152 Genoa, Italy — [2]IFW Dresden, 01069 Dresden, Germany — [3]Institut für Festkörperphysik, TU Dresden, 01069 Dresden, Germany — [4]Center for Transport and Devices, TU Dresden, 01069 Dresden, Germany — [5]Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, 42097 Wuppertal, Germany — [6]University of Genoa, 16146 Genova, Italy

Trigonal $PtBi_2$ represents an exceptional playground for the exploration of topological materials. In fact, it is a Weyl semimetal with broken inversion symmetry and strong spin-orbit coupling, showing also superconductivity at low temperatures. The Nernst effect has been proven to be a powerful technique to investigate the fermiology of unconventional materials and in systems characterized by non-trivial topology, it often assumes distinctive anomalous features, as observed in various Weyl semimetals. In this work, we deeply investigate the evolution of the Nernst coeffcient in a sigle crystal of trigonal-$PtBi_2$ as a function of different parameters: temperature (T), magnetic field (B) and angle between the magnetic field direction and the c-axis of the sample. In particular, we found an unconvetional Nernst phenomenology, resulting from a combination of the peculiar Fermi surface of $PtBi_2$, its non-trivial topology and the incipient superconductivity.

TT 45.2 Wed 11:45 H 3010

Topology and superconductivity in trigonal-$PtBi_2$ — •Jiang Qu, Ankit Kumar, Arthur Veyrat, Louis Veyrat, Romain Giraud, Bernd Büchner, and Joseph Dufouleur — Leibniz-Institute for Solid State and Materials Research (IFW Dresden), Helmholtzstraße 20, 01069 Dresden, Germany and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

The layered type-I Weyl semimetal trigonal-$PtBi_2$ (t-$PtBi_2$) is a promising candidate for topological superconductors with broken inversion symmetry and strong spin-orbit coupling. In this talk, we first present methods developed to exfoliate t-$PtBi_2$ into thin layers with a modified mechanical exfoliation technique. We then focus on the result of the investigations of the low dimensional superconductivity in t-$PtBi_2$ exfoliated flakes by transport measurements [1]. Finally, we present a complete study of magnetoresistance above the superconducting transition for a magnetic field oriented in any direction, highlighting the highly untrivial properties of this material.

[1] A. Veyrat et al., Nano Lett. 23 (2023) 1229 and arxive:2101.01620

TT 45.3 Wed 12:00 H 3010

A puzzling superconducting weyl semimental: band structure and effective model of $PtBi_2$ — •Riccardo Vocaturo[1], Klaus Koepernic[1], Jorge Facio[2], Cosma Fulga[1], Oleg Janson[1], and Jeroen van den Brink[1] — [1]Leibniz Institute for Solid State and Materials Research (IFW) Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Centro Atomico Bariloche, Instituto de Nanociencia y Nanotecnologia (CNEA-CONICET) and Instituto Balseiro, Av. Bustillo, 9500, Argentina

Weyl semi-metals are interesting phases of matter where topological crossings in the bulk band-structure dictates the presence of protected surface states, i.e. Fermi arcs. Recently, theoretical and experimental works have been suggesting a possible interplay between this features and the presence of superconductivity, both in the bulk and at the surface. In this study we focuses on Trigonal-$PtBi_2$, an inversion-breaking type-I Weyl semimetal, known for its intriguing superconducting properties and distinctive metallic phase. For instance, despite reports of high-Tc superconductivity on the surface and robust BKT transition in think flakes, bulk-$PtBi_2$ is found to be a sub-Kelvin superconductor, posing several theoretical question. In this work, we perform DFT calculations to analyze its electronic structure and surface states. Additionally, we propose a minimal tight-binding model able to reprocisde the number and distribution of Weyl points, preserving the all the crystal symmetries, which we believe to be very helpful in reducing the complexity of this system.

TT 45.4 Wed 12:15 H 3010

Surface superconductivity on time-reversal symmetric Weyl systems: a self-consistent approach — •Mattia Trama[1,2,3], Viktor Könye[3], Ion Cosma Fulga[3], and Jeroen van den Brink[3,4] — [1]Physics Department "E.R. Caianiello", Universitá degli Studi di Salerno, Fisciano, Italy — [2]INFN-Sezione di Napoli, Naples, Italy — [3]Institute for Theoretical Solid State Physics, IFW Dresden and Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany — [4]Institute for Theoretical Physics, TU Dresden, Dresden, Germany

The recent discovery of the superconducting surface on the time-reversal symmetric Weyl semimetal PtBi2 has raised the question of the origin of such a phenomenon. Indeed, such a compound exhibits a critical temperature difference between the surface and the bulk of about an order of magnitude. Here we propose an explanation for this phenomenon using a time-reversal symmetric Weyl model for a finite system, invoking standard local s-wave singlet pairing as the superconducting coupling. Our self-consistent calculation predicts a different critical temperature for the surface and the bulk, leading to the possibility of superconductivity in only few layers of the material. We also predict a temperature dependence on the penetration of surface superconductivity, suggesting a competition between two order parameters.

TT 45.5 Wed 12:30 H 3010

Topological Fermi arcs in superconducting Weyl semimetal candidate t-$PtBi_2$ revealed by quasiparticle interference — •Sebastian Schimmel[1,2], Sven Hoffmann[1,2], Riccardo Vocaturo[2], Joaquin Puig[3], Grigoriy Shipunov[2], Oleg Janson[2], Saicharan Aswartham[2], Danny Baumann[2], Julia Besproswanny[1,2], Bernd Büchner[2], Jeroen van den Brink[2], Yanina Fasano[2,3], Jorge I. Facio[3], and Christian Hess[1,2] — [1]Bergische Univertsität Wuppertal, 42119 Wuppertal, Germany — [2]Leibniz Institute for Solid State and Materials Research, 01069 Dresden, Germany — [3]Centro Atómico Bariloche and Instituto Balseiro, CNEA,CONICET and Instituto de Nanociencia y Nanotecnología , 8400 San Carlos de Bariloche, Argentina

Trigonal $PtBi_2$ (t-$PtBi_2$) is promising candidate material for topological superconductivity. Ab-initio calculations predicted Weyl-nodes near the Fermi-level [1], and ARPES [2] as well as STM/STS [3] reveal signatures of surface superconductivity at $T > 5$ K – one order of magnitude higher T than the bulk Tc. Here we report on the Weyl nature of t-$PtBi_2$ experimentally addressed via quasiparticle interference investigations. The revealed scattering channels can be attributed to the predicted Fermi arcs – the hall mark surface features of a Weyl semimetal. Our findings thus experimentally corroborate the non-trivial topology of the surface electrons in t-$PtBi_2$.

[1] A. Veyrat et al., ACS Nano Lett. (2023)
[2] A. Kuibarov et al., arXiv:2305.02900 (2023)
[3] S. Schimmel et al., arXiv:2302.08968 (2023)

TT 45.6 Wed 12:45 H 3010

Axion electrodynamics of Weyl superconductors with broken time-reversal symmetry — •Flavio Nogueira[1], Vira Shyta[1], and Jeroen van den Brink[1,2] — [1]Institute for Theoretical Solid State Physics, IFW Dresden — [2]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat

Weyl superconductors with broken time-reversal symmetry are effectively described by a Higgs axion electrodynamics, where the axion term is given by a magnetoelectric coupling yielding a planar Hall effect in the normal phase. This leads to significant changes in the electrodynamics of superconductors. Here we investigate how the application of an external magnetic field changes the nature of superconductivity both in absence and in the presence of vortices. In fact, due to the axion term, an electric field is generated, which in turn induces electric charge densities on the material surfaces, thus leading to interesting vortex dynamics on the surface. An interesting result following from our analysis is an axion-induced ac Josephson effect provided the sample is thin enough.

TT 45.7 Wed 13:00 H 3010

Chiral Meissner state in time-reversal invariant Weyl superconductors — •Vira Shyta[1], Jeroen van den Brink[1,2], and Flavio S. Nogueira[1] — [1]Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01069 Dresden, Germany

Weyl semimetals have nodes in their electronic structure at which electrons attain a definite chirality. Due to the chiral anomaly, the non-conservation of charges with given chirality, the axion term appears in their effective electromagnetic action. We determine how this affects the properties of time-reversal invariant Weyl superconductors (SCs) in the London regime. For type II SCs the axion coupling generates magnetic B-fields transverse to vortices, which become unstable at a critical coupling so that a transition into type I SC ensues. In this regime an applied B-field not only decays inside the SC within the London penetration depth, but the axion coupling generates an additional perpendicular field. Consequently, when penetrating into the bulk the B-field starts to steadily rotate away from the applied field. At a critical coupling the screening of the magnetic field breaks down. The novel chiral SC state that emerges has a periodically divergent susceptibility that separates onsets of chiral Meissner regimes. Thus the axion leaves very crisp experimentally accessible signatures in Weyl SCs.

TT 46: Focus Session: Evolution of Topological Materials into Superconducting Nanodevices (joint session HL/TT)

The focus session intends to span the arc between topological materials and superconducting nanodevices, both experimentally and theoretically. Such structures are interesting for applications in future topological quantum circuits. In recent years, the number of topological materials and the knowledge about them has rapidly increased. As part of the focus session, material properties of layered systems made of topological materials, especially in combination with superconductors, are discussed. On the other hand, the special challenges in the nanofabrication of these materials for use in future topological quantum processors are addressed. Another focus is the quantum transport in nanoscale hybrid structures.

Organized by Thomas Schäpers, Philipp Rüßmann, and Peter Schüffelgen

Time: Wednesday 11:45–13:00 Location: EW 202

TT 46.1 Wed 11:45 EW 202

Induced superconducting correlations in the quantum anomalous Hall insulator — •Anjana Uday[1], Gertjan Lippertz[1,2], Kristof Moors[3], Henry F. Legg[4], Rikkie Joris[2], Andrea Bliesener[1], Lino M. C. Pereira[2], Alexey Taskin[1], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne, Köln, Germany — [2]KU Leuven, Quantum Solid State Physics, Leuven, Belgium — [3]Peter Grünberg Institute 9, Forschungszentrum Jülich & JARA Jülich-Aachen Research Alliance, Jülich, Germany — [4]Department of Physics, University of Basel, Basel, Switzerland

Crossed Andreev reflection (CAR) has been reported in a hybrid quantum Hall (QH)/Superconductor (SC) system [1]. Similar experiments would be of great interest for quantum anomalous Hall (QAH) systems. It has been predicted that if Cooper pairing is induced in a QAH insulator, the system turns into a stereotypical spinless chiral p-wave superconductor associated with chiral Majorana edge states. In the QAH/SC system superconductivity can be suppressed by applying a magnetic field while keeping the 1D chiral edge state intact. Here we report the observation of crossed Andreev reflection (CAR) across a narrow superconducting Nb electrode contacting the chiral edge state of a QAHI, evinced by a negative nonlocal voltage measured downstream from the grounded Nb electrode. By changing the Nb width, the characteristic length of the CAR process is identified to be about 100 nm, which is three times longer than the superconducting correlation length in Nb.

[1] Lee et al., Nat. Phys., 13 (2017) 693-698

TT 46.2 Wed 12:00 EW 202

Work function engineering in superconducting Ir/Nb(110) films — •Adamantia Kosma[1], Stefan Blügel[1], and Philipp Rüssmann[1,2] — [1]Forschungszentrum Jülich — [2]University of Würzburg

The topological superconducting hybrid structures have been attracting considerable research interest in recent years, as they are promising candidates for topologically protected qubits. Because of this, a substantial demand for appropriate superconducting substrates has been created. In our study we explore the superconducting properties of Ir/Nb(110) films. Our focus is on the investigation of the change in the work function and the size of the proximity-induced superconducting gap of Ir overlayers deposited on Nb(110). The work function plays a crucial role in determining the behavior of electrons at the superconducting surface, thereby influencing the charge transport. In the specific context of superconductor hybrid structures for Majoranas, the target is to effectively manage the work function mismatch while maintaining a robust proximity effect through the overlayer. This approach will also provide valuable information for studying the proximity effect in a topological insulator/superconductor(TI/SC) system. Our findings are based on first-principles calculations using the full-potential Korringa-Kohn-Rostoker Green function method and its Kohn-Sham Bogoliubov-de Gennes (KS-BdG) extension to describe superconducting heterostructures [1].

We thank the ML4Q (EXC 2004/1 - 390534769) for funding.

[1] P. Rüßmann, and S. Blügel, Phys. Rev. B **105**, 125143 (2022).

TT 46.3 Wed 12:15 EW 202

Superconducting transition metal dichalcogenites for TI-based topological superconducting devices — •Philipp Rüssmann — Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany

Proximitized topological insulators (TIs) are promising materials to build topological superconductors with the promise to realise Majorana-zero modes and topologically protected quantum devices. Here, we present an overview over our recent computational studies of heterostructures between superconducting transition-metal dichalcogenites (TMDCs) and TIs [1,2]. We compare different TMDC/TI interfaces and analyze the influence of the TMDCs on charge doping, band alignment and the superconducting proximity effect in the TI.

In our work we employ Kohn-Sham Bogoliubov-de Gennes simulations for the superconducting electronic structure based on density functional theory which is implemented in the full-potential relativistic Korringa-Kohn-Rostoker Green function method [3,4].

[1] Xian-Kui Wei *et al.*, arXiv 2311.16590 (2023)
[2] Abdur Rehman Jalil *et al.*, in preparation (2023)
[3] P Rüßmann and S Blügel, PRB **105**, 125143 (2022).
[4] JuDFTteam/JuKKR (2022). doi: 10.5281/zenodo.7284738

TT 46.4 Wed 12:30 EW 202

Superconducting diode effect in topological insulator nanowire Josephson junctions — •Ella N. Nikodem, Jakob Schluck, Mahasweta Bagchi, Zhiwei Wang, and Yoichi Ando — Physics Institute II, University of Cologne, Zülpicher Straße 77, 50937 Köln, Germany

Topological insulator nanowires coupled to conventional superconductors were predicted to host Majorana zero modes more than a decade ago [1]. An indication of the presence of such Majorana bound states in Josephson junction devices based on these nanowires is an enhanced superconducting diode effect in the topological regime, attributed to their 4π-periodic contribution to the current phase relation [2]. In this talk, we report our investigations of the superconducting diode effect in side-contacted etched nanowires made from exfoliated flakes of the bulk-insulating topological insulator BiSbTeSe2. We observed a strong dependence of the critical current on gate voltage and the magnetic field along the nanowire, as well as a significant superconducting diode effect. Its direction and magnitude can be switched by tuning the aforementioned parameters. Possible relevance of the Majorana bound states in the observed diode effect will be discussed.

[1] A. Cook and M. Franz, Phys. Rev. B 84, 201105(R) (2011).
[2] H. F. Legg et al., arXiv:2301.13740 (2023).

TT 46.5 Wed 12:45 EW 202

Nanoscale patterning of topological insulator thin film using a helium ion microscope — •Holger Mirkes[1,2], Filippo Romano[1,2], and Christoph Kastl[1,2] — [1]Walter Schottky Institute and Physik-Department, Technical University of Munich, Germany. — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany.

The helium ion microscope has evolved as a versatile tool for not only nanoscale imaging, but also nanoscale fabrication with a resolution well below 10 nm, limited only by substrate proximity effects for atomically thin films [1]. Here, we discuss the application of He-ion beam milling for nanofabrication of lateral superlattice structures in topological insulator thin films. We present results both on supported films grown by molecular beam epitaxy as well as on suspended films prepared by scotch tape exfoliation. The superior resolution of the He-ion microscope may be used to create lateral superlattice structures with topologically protected satellite Dirac cones [2]. The research is supported through the European Union*s Horizon Europe Research and Innovation Programme under Grant Agreement No 101076915 (2DTopS).

[1] E. Mitterreiter et al., Nano Lett. 2020, 20, 4437*4444.
[2] J. Cano et al., Phys. Rev. B 2021, 103, 155157.

TT 47: Superconducting Electronics: Qubits I (joint session TT/QI)

Time: Wednesday 15:00–18:15 Location: H 0104

TT 47.1 Wed 15:00 H 0104

Simultaneous flux-locking of gradiometric fluxonium qubits — •Denis Bénâtre[1], Mathieu Féchant[1], Nicolas Zapata[1], Patrick Paluch[1], Nicolas Gosling[1], and Ioan Pop[1,2] — [1]IQMT, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany — [2]PHI, Karlsruhe Institute of Technology, Karlsruhe, Germany

Gradiometric fluxoniums are a novel type of fluxonium qubits introduced by Gusenkova et al. (Appl. Phys. Lett. 120, 2022). Benefiting from their double-loop geometry, gradiometric fluxoniums are substantially less sensitive to global magnetic fields, while retaining all regular fluxonium properties. Going further, we propose to show the simultaneous locking of a handful of gradiometric fluxoniums at a flux point corresponding to the so-called sweet spot of operation, allowing them to be used without the need for external flux biasing after locking. This is done by trapping a fluxon in the most external loop of each device with an external magnetic field while crossing the metal-to-superconductor transition.

TT 47.2 Wed 15:15 H 0104

Superconducting flux qubits with stacked Josephson junctions — •Alex Kreuzer[1], Hossam Tohamy[1], Thilo Krumrey[1], Alexandru Ionita[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie (KIT) — [2]Institut für Quantenmaterialien und -technologien (IQMT), Karlsruher Institut für Technologie (KIT)

Josephson junctions are commonly employed as nonlinear inductive components in superconducting qubits, allowing to tailor specific circuit properties. The promising flux qubit types like fluxonium or quarton qubits require compact inductances, often implemented as arrays of Josephson junctions. Challenges arise due to stray capacitance, originating from the capacitive coupling of an array island to the ground, leading to parasitic resonances at GHz frequencies that can degrade or compromise qubit performance. To address this limitation, we investigate an alternative approach: implementing qubit inductances by stacking Josephson junctions vertically. Junction stacks help to minimize the parasitic capacitance of their electrodes to the ground. We present transport characteristics of the stacks as well as microwave loss measurement data using a quarton-type flux qubit with stacked Josephson junctions. The experimental data are compared to results of numerical simulations.

TT 47.3 Wed 15:30 H 0104

Pure kinetic inductance coupling between generalized flux qubits and their readout — •Soeren Ihssen[1], Simon Geisert[1], Patrick Winkel[1,2], Martin Spiecker[1], Mathieu Fechant[1], Patrick Paluch[1,2], Nicolas Gosling[1], Nicolas Zapata[1], Thomas Reisinger[1], Wolfgang Wernsdorfer[1], and Ioan M. Pop[1,2,3] — [1]IQMT, Karlsruhe Institute of Technology, Germany — [2]PHI, Karlsruhe Institute of Technology, Germany — [3]Physics Institute 1, Stuttgart University, Germany

We develop a qubit-readout circuit coupled through the kinetic inductance of superconducting granular aluminum (grAl). Utilizing the material properties of grAl to implement the dispersive shift removes the need for electromagnetic coupling. This enables a localized tuning knob to engineer the readout independent of the capacitance matrix. If the capacitance matrix is designed to be symmetric, the qubit-readout coupling is entirely mediated by the grAl kinetic inductance. We validate the pure kinetic coupling concept and demonstrate various generalized flux qubit regimes from plasmon to fluxon, with dispersive shifts ranging from 30 kHz to 7 MHz at the half-flux quantum sweet spot. Using purely kinetic coupling, we achieve readout performance comparable to standard electromagnetic coupling, with quantum state preparation fidelity of 99.7 % and 92.7 % for the ground and excited states, respectively, and below 0.1 % leakage to non-computational states. The excited state fidelity is limited by qubit relaxation to the ground state with quantum demolishing effects below 1%.

TT 47.4 Wed 15:45 H 0104

Fully tunable Flux Qubits for TLS Research — •Benedikt Berlitz, Alexey V. Ustinov, and Jürgen Lisenfeld — Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Material defects forming two-level-systems (TLS) present a source of decoherence and unwanted degrees of freedom in superconducting quantum systems. The qubits in turn can be used as a tool to study the properties of TLS. We fabricated superconducting flux qubits specifically to be used as TLS detectors, aiming for good coherence in a large frequency range. The goal is to gather comparable data of many defects located within the same device. We will describe design, fabrication and measurements of the fabricated samples. Studying TLS with these tools will enhance our understanding of the underlying physics of TLS in amorphous materials and hopefully reveal a path to achieving higher coherence with superconducting qubits.

TT 47.5 Wed 16:00 H 0104

Mapping the lateral positions of individual material defects in superconducting transmon qubits — •Alexander K. Händel, Alexey V. Ustinov, and Jürgen Lisenfeld — Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Material defects are limiting the coherence of superconducting circuits and mitigating their effects is vital in the realization of functional quantum devices. With transmon qubits, the spatial distribution of most coherence breaking defects is likely to be inhomogeneous, due to the qubit's electric field strength varying greatly with position, affecting a defects participation ratio. By tuning the resonance frequency of individual defects with static electric fields induced by on-chip electrodes we are able to resolve their positions on the qubit chip. We present first results of mapping the positions of defects in a transmon qubit, distinguishing defects on the qubit capacitor from those residing on the leads of Josephson junctions. Our results identify critical circuit components which contain major defects detrimental for the qubit performance and provide valuable information to improve qubit design and fabrication methods.

TT 47.6 Wed 16:15 H 0104

Experiments on the Influence of Infrared Photons on Super-

conducting Qubits — •Markus Griedel[1,2], Sebastian Koch[2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Institut für Quanten Materialien und Technologien (IQMT) — [2]Physikalisches Institut (PHI) - KIT, 76131 Karlsruhe, Germany

The energy gap of superconductors allows for a large variety of ultra-low noise applications, as for instance, for using them to construct qubits. At sufficiently low temperatures, the number of excitations above the gap is generally low but not zero. Such excitations can be created by numerous external influences, including absorption of high energy particles from radioactive decay or extraterrestrial space. Also stray infrared photons play a role, since their energy is larger than the energy gap of conventional superconductors used for making qubit. One external leakage pathway is the dielectric of a coaxial cable used to manipulate and read out the qubit which connects to room temperature electronics. Here, the combination of the dielectric's transparency to infrared photons and the high infrared photon flux from elevated cryogenic temperature stages make the insertion of a low-pass filter with a sharp cutoff well below the superconducting gap frequency an important requirement.

In this contribution, we present experimental investigation of the influence of infrared photons on superconducting qubits. We have measured the dephasing and decay times as well as the qubit temperature in response to incident photon flux. We explore usage of various materials for making infrared filters.

TT 47.7 Wed 16:30 H 0104

Measuring and understanding quasiparticle effects in magnetic-field-resilient 3D transmons (Experiment) — •Jonas Krause[1], Christian Dickel[1], Giampiero Marchegiani[2], Lucas Janssen[1], Gianluigi Catelani[2,3], and Yoichi Ando[1] — [1]University of Cologne — [2]Technology Innovation Institute Abu Dhabi — [3]Forschungszentrum Juelich

Recent research shows quasiparticle-induced decoherence of superconducting qubits depends on the superconducting gap asymmetry due to the different thickness of the top and bottom films in Al-AlOx-Al junctions [1]. With magnetic-field-resilient transmons [2] we investigate this from a new angle. We present spectroscopy and parity-switching-time (τ_p) measurements of a 3D transmon up to 400 mT in-plane field. The magnetic field tunes the transmon frequency f_{01} without a strong reduction in T_2^*. The gap asymmetry, initially close to hf_{01}, causes a non-monotonic evolution of τ_p. After an increase with in-plane field up to 150 mT, τ_p decreases at higher fields. Higher Josephson harmonics are needed to accurately model the spectrum [3]. At low fields, small parity splitting requires qutrit pulse sequences for parity measurements. Magnetic fields are an interesting tuning knob to study quasiparticle loss and gap engineering because they allow changing both the gap and gap difference. Charge-parity measurements are also a readout mechanism for topological qubits which often require high fields.

[1] G. Marchegiani et al., RX Quantum 3 (2022) 040338
[2] J. Krause et al., Phys. Rev. Applied 17 (2022) 034032
[3] D. Willsch et al., arXiv:2302.0919

TT 47.8 Wed 16:45 H 0104

Measuring and understanding quasiparticle effects in magnetic-field-resilient 3D transmons (Theory) — Jonas Krause[1], Christian Dickel[1], Giampiero Marchegiani[2], Luc Janssen[1], •Gianluigi Catelani[2,3], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne, Germany — [2]Quantum Research Center, Technology Innovation Institute, UAE — [3]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Juelich, Germany

In this talk, we present the modeling of the charge-parity lifetime (τ_p) of a magnetic-field resilient 3D transmon [1]. Experimentally, the lifetime τ_p depends non-monotonically on the in-plane magnetic field. We explain this unexpected behavior within a generalized approach to quasiparticle decoherence. The model accounts for the transmon being a SQUID measured mainly at the bottom sweet spot and for the magnetic field tuning (Fraunhofer effect). It also incorporates effects of temperatures on the order of the transmon frequency. At zero field, the qubit frequency f_{01} is nearly resonant with the superconducting gap difference [2], so quasiparticle tunneling gives a sizable contribution to the parity-switching rate $1/\tau_p$. Increasing the in-plane field, f_{01} decreases and becomes detuned from the gap difference, causing the initial growth in τ_p, while photon-assisted qubit transitions increase producing the subsequent decay at higher fields. We show that τ_p and the qubit lifetime T_1 can be consistently described by the model.

[1] J. Krause et al., Phys. Rev. Appl. 17 (2022) 034032
[2] G. Marchegiani et al., PRX Quantum 3 (2022) 040338

TT 47.9 Wed 17:00 H 0104

Near quantum-limited amplification up to 1 T using granular aluminum — •Nicolas Zapata[1], Ivan Takmakov[1,2], Dennis Rieger[1,2], Simon Günzler[1,2], Ameya Nambisan[1], Thomas Reisinger[1], Wolfgang Wernsdorfer[1,2], and Ioan Pop[1,2] — [1]IQMT, Karlsruhe Institute of Technology, 76131 Karslruhe, Germany — [2]PHI, Karlsruhe Institute of Technology, 76131 Karslruhe, Germany

Josephson Junction based amplifiers have become essential components for the readout of microwave quantum circuits. Despite the advances made over the last decade, they still have limited applicability in systems that require high magnetic fields. The use of high kinetic inductance materials like granular Aluminum (grAl), opens the path for low noise amplification in Tesla fields thanks to their in-plane resilience [1] and negligible high order non-linearities [2], which is particularly attractive for the readout of semiconducting spin-qubits [3] and single molecular magnet qubits [4]. Here we present a non-degenerate parametric amplifier made of two coupled grAl resonators forming a Bose-Hubbard dimer [5, 6]. We report near quantum-limited 20 dB amplification, with an instantaneous bandwidth of few MHz and signal-to-pump detuning above 100 MHz, which was stable up to 1 T.

[1] K. Borisov et al., Appl. Phys. Lett. 117 (2020) 120502
[2] N. Maleeva et al., Nat. Commun. 9 (2018) 3889
[3] J. Stehlik et al., Phys. Rev. Appl. 4 (2015) 014018
[4] C. Godfrin et al., Phys. Rev. Lett. 119 (2017) 187702
[5] C. Eichler et al., Phys. Rev. Lett. 113 (2014) 110502
[6] P. Winkel, I. Takmakov et al., Phys. Rev. Appl. 13 (2020) 024015

TT 47.10 Wed 17:15 H 0104

Phase-flux symmetries in three-wave mixing Josephson travelling wave parametric amplifiers — •Daniil E. Bazulin[1,2], Kedar E. Honasoge[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Thomas Luschmann[1,2], Achim Marx[2], Stefan Filipp[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Enabling the three-wave mixing process in Josephson Travelling Wave Parametric Amplifiers (JTWPAs) requires inversion symmetry breaking of an effective potential. This task can be achieved in various ways by exploiting either flux- or phase-bias regimes. Moreover, common JTWPA coupling schemes additionally introduces two distinct possibilities of flux or phase pumping. As the result, we identify four interrelated bias and pump schemes, which we theoretically and experimentally analyze in our samples based on Superconducting Nonlinear Asymmetric Inductive Elements (SNAILs). We show that the nonlinear behavior of such a JTWPA strongly depends on the chosen bias-pumping scheme, unraveling novel experimental control schemes for optimal JTWPA performance.

TT 47.11 Wed 17:30 H 0104

rf-SQUID-based three-wave-mixing traveling-wave parametric amplifier — •Victor Gaydamachenko, Christoph Kissling, Marat Khabipov, Fabian Kaap, Sergey Lotkhov, Ralf Dolata, Alexander B. Zorin, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Traveling-wave parametric amplifiers (TWPAs) are one of the most promising devices for the improvement of the readout efficiency of fW-range microwave signals at a bandwidth of several GHz. By adding only a minimal amount of noise close to the absolute limit allowed by quantum mechanics, quantum technologies and other applications benefit from their usage. We realize a TWPA based on an array of 2000 rf-SQUIDs with phase-matching achieved by periodic capacitance loading, which we optimized by time-domain circuit simulations. Our TWPA is fabricated using Nb/Al-AlO$_x$/Nb trilayer technology. In the three-wave mixing regime the device provides an average gain of 18 dB between 3 and 7 GHz and exhibits a saturation power of approximately -90 dBm. Here, we present the design and experimental results including noise characterization of the device.

TT 47.12 Wed 17:45 H 0104

Frequency targeting and geometric effects in fabrication of superconducting tunable resonators — •Maria-Teresa Handschuh[1,2], Kedar E. Honasoge[1,2], Wun Yam[1,2], Florian Fesquet[1,2], Achim Marx[1], Rudolf Gross[1,2,3], and Kirill G.

Fedorov[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Achieving a high-volume and high-quality fabrication process of uniform nonlinear resonators based on Josephson junctions is one of the central challenges in applied quantum information processing with superconductors. Here, we report on the realization of a reliable fabrication process for Nb resonators with Al/AlOx/Al Josephson junctions and circuits on 4-inch high-resistivity silicon wafers, ensuring precise control over relevant parameters. We address the challenges associated with the large-scale fabrication by investigating the impact of geometric irregularities on device performance, including finite-size geometry effects and center-to-edge effects. Undesired frequency shifts can arise from variations in device dimensions and inhomogeneous oxidation techniques. We overcome these challenges by a systematic analysis, allowing us to improve the controllability and accuracy of resonator frequency tuning. This enables the reproducible fabrication of low-loss tunable resonators for quantum information processing applications.

TT 47.13 Wed 18:00 H 0104

Characterizing the origin of non-Markovian noise in superconducting qubits and its effect on quantum algorithms — •Ivan Rungger, Abhishek Agarwal, Lachlan Lindoy, Deep Lall, and Francois Jamet — National Physical Laboratory, Teddington TW11 0LW, United Kingdom

Non-Markovian noise can be a significant source of errors in superconducting qubits. It is caused by ubiquitous effects such as quasiparticle induced charge parity fluctuations, as well as frequency fluctuations induced by two level systems or other defects. We develop a method based on mirrored pseudo-identity gates to characterise the non-Markovian noise in qubits [1]. We show that Markovian noise models fail to capture the experimental behaviour, and that only by including the non-Markovian components one can describe the experiments. We further present fast time-resolved characterization techniques that allow us to identify the physical origin of the non-Markovian noise. We find large changes of the dominating noise contributions, such as qubit frequency fluctuations, over both long time-scales of hours and days, and also over very short micro-seconds time-scales. We show that the developed noise model allows us to predict and then mitigate the effects of noise in quantum computing applications.

[1] A. Agarwal, L. P. Lindoy, D. Lall, F. Jamet, I. Rungger, arXiv:2306.13021 (2023)

TT 48: Focus Session: Unconventional Thermoelectric Phenomena and Materials (joint session MA/TT)

Thermoelectric effects have been discussed for several decades and have found widespread applications. This Focus Session, a joint venture of the divisions MA (Magnetism) and TT (Low Temperature), will thematise recent developments, namely "unconventional" thermoelectric phenomena and materials [see, e.g., K. Uchida and J. P. Heremans, Joule 6, 2240 (2022)]: these include transverse thermoelectric effects, such as the ordinary and anomalous Nernst effects, where the generated charge current is perpendicular to the temperature gradient. The latter – similar to the anomalous Hall effect – relies on the spin-orbit interaction or on canted spin textures, and ensuing topological electronic structures. Transverse thermoelectricity can be found even without a magnetic field, namely in goniopolar materials (e.g., $NaSnAs_2$). Finally, nano-structured coherent quantum hybrid systems, containing dots as well as normal-conducting and superconducting elements, show remarkable – generally nonlocal – thermoelectric properties.

Coordinators: Ulrich Eckern (University of Augsburg, ulrich.eckern@uni-a.de) Max Hirschberger (The University of Tokyo, hirschberger@ap.t.u-tokyo.ac.jp)

Time: Wednesday 15:00–17:45 Location: H 1058

Invited Talk TT 48.1 Wed 15:00 H 1058

Enhanced Nernst effect in van der Waals tellurides — M. Behnami[1], M. Gillig[1], S. Aswartham[1], G. Shipunov[1], D. Efremov[1], B. R. Piening[1], I. V. Morozov[1], K. Ochkan[1], J. Dufouleur[1], V. Kocsis[1], C. Hess[1,5], M. Putti[4,6], F. Caglieris[1,4], B. Büchner[1,2], and •H. Reichlova[1,2,3] — [1]IFW Dresden, Germany — [2]IFMP, Technische Universität Dresden, Dresden, Germany — [3]Institute of Physics ASCR, Praha, Czech Republic — [4]CNR-SPIN, Genova, Italy — [5]Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, Germany — [6]Department of Physics, University of Genova, Italy

The increase in the Nernst effect and its anomalous component in magnetically ordered materials is actively researched, and I will start the talk with a brief overview of these efforts. Subsequently, I focus on layered van der Waals materials, which have garnered significant attention in current research due to their distinct properties not inherent in bulk compounds. Particularly intriguing are the topologically non-trivial telluride van der Waals type-II Weyl semimetals with substantial spin-orbit coupling. I will present a systematic exploration of the Nernst effect in this family of materials. We identified a large linear segment of the Nernst coefficient that scales with mobility; however, it does not conform to the previously reported Fermi liquid framework.

Invited Talk TT 48.2 Wed 15:30 H 1058

Hybrid transverse magneto-thermoelectric cooling in artificially tilted multilayers — •Ken-ichi Uchida — National Institute for Materials Science, Tsukuba, Japan

In artificially tilted multilayers comprising two different conductors that are alternately and obliquely stacked, transverse thermoelectric conversion occurs, in which charge and heat currents are interconverted in the orthogonal direction. Although transverse thermoelectric conversion also occurs in homogeneous materials as intrinsic transport phenomena owing to the effects of magnetic fields, magnetization, and spins on conduction carriers, such magneto-thermoelectric effects have been investigated independently of thermoelectrics for artificially tilted multilayers. Here, we show that the synergy of these different principles improves the performance of transverse thermoelectric conversion. Using lock-in thermography techniques, we visualize transverse thermoelectric conversion processes in artificially tilted multilayers and experimentally clarify how nonuniform charge currents are converted into orthogonal heat currents. Through the measurements of temperature change under magnetic fields, we quantify the contributions of the magneto-thermoelectric effects in the artificially tilted multilayers and demonstrate magnetically enhanced hybrid transverse thermoelectric cooling. By replacing one of the conductors in the multilayer with permanent magnets, the same functionality is obtained even in the absence of magnetic fields, paving the way for the creation of thermoelectric permanent magnets. This study provides a new material design guideline for transverse thermoelectrics.

Invited Talk TT 48.3 Wed 16:00 H 1058

Nonlocal heat engines with hybrid quantum dot systems — •Rafael Sánchez[1], Mojtaba S. Tabatabaei[2], David Sánchez[3], and Alfredo Levy Yeyati[1] — [1]Dep. Física teórica de la materia condensada and Ifimac, Universidad Autónoma de Madrid, Madrid, Spain — [2]Department of Physics, Kharazmi University, Tehran, Iran — [3]Institute for Cross-Disciplinary Physics and Complex Systems IFISC (UIB-CSIC), Palma de Mallorca, Spain

The energy absorbed by a conductor from a non-equilibrium environment can be rectified to generate finite electrical power. Typically, this depends on tiny energy-dependent asymmetries of the device, formed by e.g. a quantum dot [1]. We show that larger currents are expected in hybrid systems, where a superconductor hybridizes the even-parity states in the quantum dot [2]. We consider the environment to consist on a quantum dot Coulomb-coupled to the conductor and tunnel-coupled to a hot reservoir. Two main mechanisms contribute to the generation of power. On one hand, the non-equilibrium charge fluctuations in the second dot correlate with the Andreev processes, hence injecting Cooper pairs in the superconductor. This provides the necessary symmetry breaking energy transfer. On the other hand, this mechanism competes with quasiparticle contributions, which benefit from the sharp features of the superconducting density of states, and is able to increase the engine performance [3].

[1] H. Thierschmann et al., Nature Nanotech. 10, 854 (2015)
[2] S. M. Tabatabaei et al., Phys. Rev. Lett. 125, 247701 (2020)
[3] S. M. Tabatabaei et al., Phys. Rev. B 106, 115419 (2022)

15 min. break

Invited Talk TT 48.4 Wed 16:45 H 1058

Large anomalous Nernst thermoelectric performance in $YbMnBi_2$ — •Yu Pan[1,2], Congcong Le[2], Bin He[2], Sarah Watzman[3,4], Mengyu Yao[2], Johannes Gooth[2], Joseph Heremans[3], Yan Sun[2], and Claudia Felser[2] — [1]Chongqing University, Chongqing, China — [2]Max Planck Insitute for Chemical Physics of Solids, Dresden, Germany — [3]The Ohio University, Columbus, USA — [4]University of Cincinnati, Cincinnati, USA

The anomalous Nernst effect (ANE) have attracted increasing attention since the surge of topological semimetals, because the associated unique transverse geometry of ANE facilitates thermoelectric device fabrication. Topological ferromagnets with large Berry curvatures show large ANEs; however, they face drawbacks such as strong magnetic disturbances and low mobility due to high magnetization. Searching for materials with large ANE thermopower, low resistivity (high mobility), and low thermal conductivity are of great interest. It is found that $YbMnBi_2$, as a canted antiferromagnet, present a large ANE competitive to those of ferromagnets while with much lower resistivity and thermal conductivity. The canted spin structure of Mn guarantees a non-zero Berry curvature, but generates only a weak magnetization three orders of magnitude lower than that of general ferromagnets. The heavy Bi with a large spin-orbit coupling enables a large ANE and low thermal conductivity, whereas its highly dispersive $p_{x/y}$ orbitals ensure low resistivity. These results suggest $YbMnBi_2$ as an excellent candidate for transverse thermoelectrics.

Invited Talk TT 48.5 Wed 17:15 H 1058

A path to suistainable and scalable production of high-performance thermoelectric materials — •Maria Ibáñez — Institute of Science and Technology Austria, Am Campus 1, Klosterneuburg, Austria

Over the past few years, there has been a significant surge in interest surrounding solution-based techniques due to their cost-effectiveness and scalability in the production of high-performance thermoelectric materials. Herein, our primary focus will be on Ag_2Se, an important thermoelectric material for harnessing thermoelectricity at or near room temperature, an area where the selection of high-performing materials is currently limited. While Ag_2Se shows great promise, the main problems are the large discrepancy in the reported properties. These discrepancies often stem from the intricate control of defects within the material, such as vacancies, interstitial atoms, dislocations, grain boundaries, and precipitates. We will show that our solution-based synthesis method enables precise defect control, especially avoiding fluctuations in stoichiometry. Additionally, we will illustrate how we can fine-tune microstructural defects, including strain, dislocations, and grain boundary density, leveraging the characteristic phase transition of Ag_2Se during the sintering process. Our results will highlight that besides stoichiometry, the microstructure is crucial for tuning Ag_2Se transport properties. Furthermore, we will highlight the sustainability and scalability of our approach, where solvents can be reused and energy consumption minimized, contributing to a more environmentally friendly production process.

TT 49: Frustrated Magnets: Strong Spin-Orbit Coupling I

Time: Wednesday 15:00–18:15 Location: H 2053

TT 49.1 Wed 15:00 H 2053

Two-dimensional optical spectroscopy of a Kitaev magnet — •Wolfram Brenig[1] and Olesia Krupnitska[1,2] — [1]Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany — [2]Institute for Condensed Matter Physics, NASU, Svientsitskii Str. 1, 79011 Lviv, Ukraine

We study electric field induced second order two-dimensional spectroscopy (2DS) in a Kitaev magnet. This frustrated magnet hosts a quantum spin-liquid, featuring fractionalization in terms of mobile Majorana fermion and static $\mathbb{Z}_2$ flux-vison elementary excitations. We show that finite temperature 2DS does not only probe characteristic features of both fractional excitations, but also and depending on the directions analyzed within the two-dimensional frequency plane, allows to extract single quasiparticle lifetimes from the multi-particle continua of the 2DS response functions. These properties will be discussed both, in the homogeneous flux state at low temperatures, as well as in the random flux state at elevated and up to high temperatures. At the flux proliferation crossover, we suggest an interpolation between these two temperature regimes.

Work profited from interaction with Roser Valentí, Marius Möller and David Kaib.

TT 49.2 Wed 15:15 H 2053

Bond disorder in extended Kitaev-Heisenberg models — •Georgia Fragkopoulou and Matthias Vojta — Technische Universität Dresden

We study the effect of bond disorder in extended Kitaev-Heisenberg models on the honeycomb lattice, relevant for materials such as α-$RuCl_3$, in the semiclassical limit using a combination of T-matrix and real-space spin-wave approaches. Focussing on the regime of large applied magnetic field, we discuss two distinct but related disorder-induced phenomena, namely spin textures and in-gap states. Depending on whether the impurity and the field direction break the discrete lattice symmetries, impurity-induced textures either arise at arbitrary field and impurity strength and without spontaneous symmetry breaking, or they only occur beyond a certain impurity strength and are accompanied by spontaneous symmetry breaking. The latter can be understood precursors of a low-field ordered phase and induce magnetic states below the bulk gap. A finite impurity concentration turns these isolated states into impurity bands. As a result, there is a large field regime above the bulk transition to the high-field state where impurity-induced states fill the bulk spin gap. We illustrate the field dependence of these in-gap states for parameters relevant for α-$RuCl_3$, and we connect our results to heat-transport and NMR data which indicated their presence.

TT 49.3 Wed 15:30 H 2053

Finite-size effects in Heisenberg-Kitaev models — •Wilhelm Krüger and Lukas Janssen — Institute for Theoretical Physics, TU Dresden, 01062 Dresden

The Heisenberg-Kitaev model is a paradigmatic model to describe the magnetism in honeycomb-lattice Mott insulators with strong spin-orbit coupling, such as A_2IrO_3 (A = Na, Li), α-$RuCl_3$, and $Na_2Co_2TeO_6$. Due to the sign problem in quantum Monte Carlo simulations, the model can be studied numerically exactly only on small lattices. Here, we investigate in detail the finite-size effects, by carefully comparing numerical exact diagonalization calculations with semi-analytical nonlinear spin-wave theory. This allows us to establish a protocol to obtain improved estimates for various observables from finite-size extrapolations to the thermodynamic limit, including the spectral gap, the local magnetization, and phase transition points.

TT 49.4 Wed 15:45 H 2053

Spin-Peierls Kitaev-Heisenberg models: auxiliary field quantum Monte Carlo studies — Toshihiro Sato[1], •João Carvalho-Inacio[2], Jeroen van den Brink[1], and Fakher F. Assaad[2] — [1]IFW Dresden — [2]University of Würzburg

Recently we have formulated auxiliary field quantum Monte Carlo simulations Heisenberg-Kitaev model [1]. This approach offers the possibility of reaching temperature scales roughly a factor two smaller that the magnetic scale before running into severe negative sign problems. Here we show that we can generalize this approach to include Einstein phonons. Importantly we show that the inclusion of phonons does not render the sign problem more severe such that the approach offers the possibility of investigating signatures of fractionalization on phonon spectral functions.

[1] T. Sato, F. F. Assaad, Phys. Rev. B 104 (2021) L081106.

TT 49.5 Wed 16:00 H 2053

Spin vestigial orders in extended Heisenberg-Kitaev models near hidden SU(2) points: Application to $Na_2Co_2TeO_6$ — •Niccolò Francini and Lukas Janssen — Technische Universität Dresden, Dresden, Germany

The honeycomb magnet $Na_2Co_2TeO_6$ has recently been argued to realize an approximate hidden SU(2) symmetry that can be understood by means of a duality transformation. Using classical Monte Carlo simulations, we study the finite-temperature phase diagram of the Heisenberg-Kitaev-Γ-Γ′ model near the hidden-SU(2)-symmetric point, in the presence of a six-spin ring exchange perturbation. At low temperatures, the model features collinear single-**q** zigzag and noncollinear triple-**q** ground states, depending on the sign of the ring exchange coupling. In the vicinity of the hidden-SU(2)-symmetric point, the magnetic long-range orders melt in two stages. The two phases at intermediate temperatures spontaneously break spin rotational and lattice translational symmetries, respectively, leaving time reversal symmetry intact, and are understood as vestigial orders of the underlying magnetic states. We identify these vestigial orders as $\mathbb{Z}_3$ spin nematic and $\mathbb{Z}_4$ spin current density wave phases. The latter is a candidate for the paramagnetic 2D long-range-ordered state observed in $Na_2Co_2TeO_6$.

TT 49.6 Wed 16:15 H 2053

Magnetic ground state of the Kitaev material $Na_2Co_2TeO_6$ — Wilhelm G. F. Krüger, Niccolò Francini, and •Lukas Janssen — TU Dresden, Dresden, Germany

Among the candidate Kitaev materials, the honeycomb Mott insulator $Na_2Co_2TeO_6$ has received significant recent attention. The nature of its magnetic ground state, however, has been a matter of considerable debate. We reveal an unusually high symmetry in the single-crystal neutron scattering spectrum that is inconsistent with a zigzag ground state and instead indicates a noncoplanar triple-**q** magnetic ordering. Implications concerning the proximity of $Na_2Co_2TeO_6$ to the Kitaev quantum spin liquid will be pointed out as well.

[1] W. G. F. Krüger, W. Chen, X. Jin, Y. Li, L. Janssen, Phys. Rev. Lett. **131** (2023) 146702
[2] N. Francini, L. Janssen, arXiv:2311.08475

15 min. break

TT 49.7 Wed 16:45 H 2053

Field and polarization dependent quantum spin dynamics in the honeycomb magnet $Na_2Co_2TeO_6$: Magnetic excitations and continuum — •Patrick Pilch[1], Laur Peedu[2], Anup Kumar Bera[3], Seikh Mohammad Yusuf[3,4], Urmas Nagel[2], Toomas Rõõm[2], and Zhe Wang[1] — [1]Department of Physics, TU Dortmund University, Dortmund, Germany — [2]National Institute of Chemical Physics and Biophysics, Tallinn, Estonia — [3]Solid State Physics Division, Bhabha Atomic Research Centre, Mumbai, India — [4]Homi Bhabha National Institute, Anushaktinagar, Mumbai, India

We report terahertz spectroscopic measurements of quantum spin dynamics in the spin-1/2 honeycomb magnet $Na_2Co_2TeO_6$ as a function of applied magnetic field with different terahertz polarizations [1]. Distinct field dependencies of the resolved spin dynamics are identified in three regimes, which are separated by two critical fields at $B_{c1} \approx 7$ and $B_{c2} \approx 10$ T. A polarization selective continuum is observed in the intermediate phase, featuring spin fluctuations of a proximate quantum spin liquid.

[1] Pilch et al., Phys. Rev. B 108, L140406 (2023)

TT 49.8 Wed 17:00 H 2053

Rotational disorder in the triangular spin-liquid candidate $Na_2BaCo(PO_4)_2$ — Vera P. Bader[1], Ivo Heinmaa[2], Raivo Stern[2], Felix Schilberth[3], Joachim Deisenhofer[3], Istvan Kézsmárki[3], Philipp Gegenwart[1], and •Alexander A. Tsirlin[1,4] — [1]EP VI, EKM, University of Augsburg, Germany — [2]NICPB, Tallinn, Estonia — [3]EP V, EKM, University of Augsburg, Germany — [4]Felix Bloch Institute, Leipzig University, Germany

Using high-resolution x-ray diffraction, nuclear magnetic resonance, and infrared spectroscopy, we resolve the previously overlooked ferro-rotational distortion in the spin-$\frac{1}{2}$ triangular antiferromagnet $Na_2BaCo(PO_4)_2$. Cooperative rotations of the CoO_6 octahedra reduce the symmetry to $P\bar{3}$ while leading to only minor changes in the spin Hamiltonian. The rotations are accompanied by Na displacements that indicate an inherent structural randomness, which is present even at low temperatures and increases on heating. Our *ab initio* molecular dynamics simulations suggest that Na disorder is intimately linked to the cooperative rotations. We propose two mechanisms that may lead to the suppression of magnetic order in $Na_2BaCo(PO_4)_2$ due to structural randomness and elucidate the unusually low Néel temperature ($T_N/J \simeq 0.1$) of this material. Our results suggest the importance of lattice degrees of freedom and hidden randomness for the physics of spin-liquid candidates.

TT 49.9 Wed 17:15 H 2053

Understanding the Magnetic Behavior of $CoNb_2O_6$: Insights from Ab Initio Modeling — •Amanda Konieczna[1], Stephen M. Winter[2], and Roser Valentí[1] — [1]Goethe University Frankfurt — [2]Wake Forest University

The quasi-one-dimensional Ising-like system $CoNb_2O_6$ has been a subject of intense investigation, particularly regarding its microscopic model and the potential role of Kitaev interactions. Despite various experiments, the system's magnetic behavior remains a topic of debate with different suggestions arising [1,2]. We employ an ab initio-based model to investigate $CoNb_2O_6$'s magnetism. The approach involves the modeling of an ab-initio derived Hubbard Hamiltonian and utilizing projective diagonalization techniques to construct a Spin Hamiltonian. This presentation discusses the results of our theoretical modeling approach in the context of experimental observations to give further insights into $CoNb_2O_6$'s magnetic behavior.

[1] Coldea *et al.*, Phys. Rev. B **108** (2023) 184417
[2] Armitage *et al.*, Nat. Phys. **17** (2021) 832

TT 49.10 Wed 17:30 H 2053

Understanding the Hamiltonian of α-$RuCl_3$ through Non-Linear Spin-Wave Analysis — Jonas Habel[1,2], Roderich Moessner[3], and •Johannes Knolle[1,2,4] — [1]Technical University of Munich, Germany — [2]Munich Center for Quantum Science and Technology, Germany — [3]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [4]Blackett Laboratory London, UK

α-$RuCl_3$ has attracted much attention recently due to its potential to host a Kitaev spin liquid at intermediate magnetic fields, whose stability crucially depends on the model Hamiltonian and its parameters. These parameters are commonly probed by performing inelastic neutron scattering (INS) in the high-field limit, where the magnetic moments are fully polarized and spin-wave excitations are well-defined, and subsequently fitting the observed INS intensity to a theoretical linear spin-wave prediction. However, experimental estimates vary widely, in particular for the Kitaev interaction, which is vital for a spin liquid phase. Our work aims to improve these estimates by incorporating non-linear spin-wave effects in the theoretical computations. Concretely, we investigate neutron scattering data for a three-dimensional multi-layer of α-$RuCl_3$ using an augmented Kitaev-Heisenberg model. Preliminary results show that non-linear quantum interactions have a significant impact on the spin-wave spectrum and should not be neglected when fitting model parameters to INS data.

TT 49.11 Wed 17:45 H 2053

The role of phonons in the thermal Hall effect of α-$RuCl_3$ — •Ralf Claus, Jan Bruin, Yosuke Matsumoto, and Hidenori Takagi — Max-Planck-Institut für Festkörperforschung, Stuttgart 70569, Deutschland

The observation of a half-integer quantized plateau in the thermal Hall conductivity κ_{xy} of the Kitaev quantum spin liquid candidate α-$RuCl_3$ was interpreted as evidence for a topological Majorana edge mode [1]. Recently, additional studies of κ_{xy} were performed [2], including those offering different explanations for the possible heat carrying particles such as topological magnons [3] and phonons [4]. To narrow down the nature of these itinerant quasiparticles, we performed a comprehensive study of the thermal Hall angle $\tan(\theta) = \kappa_{xy}/\kappa_{xx}$ on samples grown using CVT and Bridgman techniques. Surprisingly, we find that $\tan(\theta)$ is fairly similar among different samples despite large differences in the longitudinal thermal conductivity κ_{xx}. This scaling suggests a substantial role of phonons and puts constraints on the Majorana or topological magnon scenarios. Furthermore, we propose a mechanism involving phonon drag, which would explain the dependence of the Hall amplitude on the longitudinal phonon conductivity.

[1] Kasahara et al., Nature 559 (2018) 227
[2] Bruin, Claus et al., Nat. Phys. 18 (2022) 401
[3] Czajka et al., Nat. Mater. 22 (2023) 36
[4] Lefrançois et al., Phys. Rev. X 12 (2022) 021025

TT 49.12 Wed 18:00 H 2053

β-RuCl$_3$ / graphene heterostructures: a new playground for exotic physics — •Aleksandar Razpopov, Sananda Biswas, and Roser Valentí — Institut für Theoretische Physik, Goethe Universität, Frankfurt, Germany

In recent years emerging novel phases in α-RuCl$_3$-graphene heterostructures have been intensively discussed [1-4] in the context of Kitaev physics and its charge transfer properties. In contrast, β-RuCl$_3$, a polymorph of α-RuCl$_3$, has received much less attention. This system has a chain-like structure of Ru ions instead of the honeycomb lattice pattern in α-RuCl$_3$. Recently, 1D-heterostructures of β-RuCl$_3$ on graphene have been fabricated in the form of high quality uniform and long-single crystalline atomic scale wires [5]. In this talk, we will present a first principles study of the electronic structure of β-RuCl$_3$/graphene heterostructures and will discuss the importance of strain effects to control charge transfer between these two compounds and its relevance for the resulting electronic properties.

[1] Rossi et al., Nano Lett. 23, 17, 8000
[2] Balgley et al., 22, 10, 4124
[3] Biswas et al., Phys. Rev. Lett. 123, 237201
[4] V. Leeb et al., Phys. Rev. Lett. 126, 097201
[5] Tomoya et al., Adv. 9, eabq5561

TT 50: Superconductivity: Theory II

Time: Wednesday 15:00–18:00 Location: H 3005

TT 50.1 Wed 15:00 H 3005

Floquet engineering Higgs dynamics in superconductors — •Tobias Kuhn[1], Björn Sothmann[2], and Jorge Cayao[3] — [1]Institute of Physics, University of Augsburg, D-86135 Augsburg, Germany — [2]Department of Physics, University of Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [3]Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden

The order parameter Δ of periodically driven superconductors with frequency Ω shows spontaneous symmetry breaking analogue to Higgs mechanism [1]. The resulting Higgs mode can be resonantly excited in subgap regime at $\Omega = \Delta$ through non-linear coupling to light [2]. We develop a Floquet approach to study Higgs dynamics captured by anomalous Floquet Green's functions. This description exploits the drives periodicity to considerably reduce the complexity of the time-dependent problem [3]. Interestingly, the Floquet approach naturally offers a physical explanation for the renormalized steady state order parameter as a result of photon processes between Floquet subbands. As an example, we demonstrate Floquet engineering Higgs modes in time-periodic s-wave superconductors. Notably, the theory can easily be extended to spin-triplet superconductors and complex interactions as well.

[1] R. Shimano, N. Tsuji, Annu. Rev. Condens. Matter Phys. **11** (2020) 103
[2] N. Tsuji, H. Aoki, Phys. Rev. B **92** (2015) 064508
[3] J. Cayao, C. Triola, A. M. Black-Schaffer, Phys. Rev. B **103**, 104505 (2021).

TT 50.2 Wed 15:15 H 3005

Theory of Superconductors in non-equilibrium: response of the Higgs mode — •Sida Tian[1], Rafael Haenel[1,2], and Dirk Manske[1] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]Quantum Matter Institute, University of British Columbia, Vancouver V6T 1Z4, Canada

Collective modes in superconductors encode rich information about the superconducting state. Experimentally probing them requires THz lasers that push the system away from equilibrium. Here we present a response theory based on Keldysh formalism that allows one to capture the dynamics of a superconductor in the non-equilibrium regime. The method is based on a generalisation of the Kubo formula, and compute the response of a non-equilibrium state subject to a small external perturbation. Because of this, we can also isolate contributions from different channels to the electromagnetic response kernel. This theory allows one to capture phenomena in pump-probe experiment beyond Matsubara formalism, and gives insight into the dynamics of superconductors away from equilibrium.

TT 50.3 Wed 15:30 H 3005

Non-equilibrium THz response of time-reversal symmetry breaking superconductors — •Silvia Neri and Dirk Manske — Max Planck Institute for Solid State Research D-70569, Stuttgart, Germany

Time-reversal symmetry breaking (TRSB) superconductors are unconventional superconductors that show a rich collective mode spectra. These collective excitations in superconductors provide crucial information of the symmetry broken phase, in particular, serving as a fingerprint for determining the ground state gap symmetry. In this work we consider multiple TRSB superconductors characterized by an order parameter of the form $\Delta = \Delta_1 + i\Delta_2$. We provide a classification scheme of the collective excitations in the above systems as a function of the ratio between the components Δ_1/Δ_2. In order to excite the many modes in the systems we have adopted two different probes: a quench symmetry of the condensate and a finite momentum transfer induced by an external electric field. Both methods allow us to excite and identify the different modes in the spectra. Furthermore, we have numerically simulated the response resulting from an excitation scheme mimicking a pump-prob experimental scenario. We have calculated the transient optical response identifying and classifying the resulting spectra also in terms of the component ratio. Our classification could provide a way to distinguish between different order parameters symmetries of a TRSB superconducting condensate and estimate the magnitude of the different components constituting the sample.

TT 50.4 Wed 15:45 H 3005

Nonthermal superconductivity in photodoped multiorbital Hubbard systems — •Sujay Ray — University of Fribourg, 1700 Fribourg, Switzerland

Superconductivity in laser-excited correlated electron systems has attracted considerable interest due to reports of light-induced superconductinglike states. Here we explore the possibility of nonthermal superconducting order in strongly interacting multiorbital Hubbard systems, using nonequilibrium dynamical mean field theory. We find that a staggered η-type superconducting phase can be realized on a bipartite lattice in the high photodoping regime, if the effective temperature of the photocarriers is sufficiently low. The η superconducting state is stabilized by Hund coupling - a positive Hund coupling favors orbital-singlet spin-triplet η pairing, whereas a negative Hund coupling stabilizes spin-singlet orbital-triplet η pairing.

TT 50.5 Wed 16:00 H 3005

Nonequilibrium quasiparticle distribution in superconducting resonators: effect of pair-breaking photons — •Paul Benedikt Fischer[1,2] and Gianluigi Catelani[1,3] — [1]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [3]Quantum Research Center, Technology Innovation Institute, Abu Dhabi 9639, UAE

In the superconducting state, the presence of the finite gap in the excitation spectrum implies that the number of excitations (quasiparticles) is exponentially small at temperatures well below the critical one. Nevertheless, experiments at low temperature usually find a finite, non-negligible density of quasiparticles whose origin has been attributed to various non-equilibrium phenomena. Here, we investigate the role of photons with energy exceeding the pair-breaking threshold 2Δ as a possible source for these quasiparticles in superconducting resonators. Modeling the interacting system of quasiparticles, phonons, sub-gap and pair-breaking photons using a kinetic equation approach, we find analytical expressions for the quasiparticles' density and their energy distribution. Applying our theory to measurements of quality factor as function of temperature and for various powers, we find they could be explained by assuming a small number of photons above the pair-breaking threshold.

TT 50.6 Wed 16:15 H 3005

High-T$_c$ phononic superconductivity at room pressure: Insights from ab initio simulations — •Antonio Sanna[1], Camilla Pellegrini[1], Miguel A. L. Marques[2], and Tiago Cerqueira[3] — [1]Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany — [2]CFisUC, Department of Physics, University of Coimbra, Portugal — [3]Ruhr University Bochum, Germany

The recent discovery of near room temperature conventional superconductivity at high pressure has triggered an intense search for new phonon-mediated superconductors, which is driven and led by modern computational techniques.

While room temperature and even hot-superconductivity appears to be likely possible under pressure, it is not yet clear if these extreme superconducting states can be achieved at room pressure.

We present the ab initio SCDFT and Eliashberg[1,2] characterization of several superconductors which have been predicted by means of an extensive high throughput scan involving over 200 000 stable or nealy-stable metallic compounds[3]. Although none of the predicted materials have critical temperatures above 100K, several are comparable or even superior to MgB_2. The analysis of these materials and the extensive high throughput data is used to estimate the likelihood of finding new technologically useful phononic superconductors via high-throughput search.

[1] Sanna et al., Phys. Rev. B 108 (2023) 064511
[2] Pellegrini et al., J. Phys. Mater. 5 (2022) 024007
[3] Cerqueira et al., adma.202307085 (2023)

15 min. break

TT 50.7 Wed 16:45 H 3005

Ab initio calculations of superconducting transition temperatures beyond GW-RPA — •Camilla Pellegrini[1], Carl Kukkonen[2], and Antonio Sanna[1] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany — [2]33841 Mercator Isle, Dana Point, California 92629, USA

In ab initio calculations of superconducting properties, the Coulomb repulsion is accounted for at the GW level [1,2] and is usually computed in the random phase approximation (RPA), which neglects vertex corrections both at the polarizability level and in the self-energy. Although this approach is unjustified, the brute force inclusion of higher-order self-energy corrections is computationally prohibitive.

We propose a generalized GW self-energy, where vertex corrections are incorporated into W by employing the Kukkonen and Overhauser (KO) ansatz for the effective interaction between two electrons in the electron gas [3]. By computing the KO interaction in the adiabatic local density approximation, and using it in the Eliashberg equations, we find that vertex corrections lead to a systematic decrease of the critical temperature (T$_c$), ranging from a few percent in bulk lead to more than 40

[1] C. Pellegrini, R. Heid, A. Sanna, J. Phys. Mater. 5 (2022) 024007
[2] A. Sanna, C. Pellegrini, E.K.U. Gross, Phys. Rev. Lett. 125 (2020) 057001
[3] C. Pellegrini, C. Kukkonen, A. Sanna, Phys. Rev. B 108 (2023) 064511

TT 50.8 Wed 17:00 H 3005

Bypassing the BCS-to-BEC crossover in strongly correlated superconductors: resilient coherence from multiorbital physics — •Niklas Witt[1,2], Yusuke Nomura[3], Sergey Brener[1], Ryotaro Arita[4,5], Alexander I. Lichtenstein[1,2], and Tim Wehling[1,2] — [1]University of Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Germany — [3]Keio University, Japan — [4]University of Tokyo, Japan — [5]RIKEN CEMS, Japan

Superconductivity emerges from the spatial coherence of a macroscopic condensate of Cooper pairs. Increasingly strong binding and localization of electrons into these pairs compromises the condensate's phase stiffness, thereby limiting critical temperatures – a phenomenon commonly known as the BCS-to-BEC crossover. In this study [1], we report on the circumvention of the BCS-BEC crossover present in a multi-orbital model of alkali-doped fullerides (A_3C_{60}). Our findings reveal a localized superconducting regime characterized by a robustly short coherence length and a domeless rise in critical temperature with increasing pairing interaction. We identify strong correlations and multi-orbital effects as the underlying cause of this behavior. These insights are derived from the development of a theoretical framework to calculate the fundamental intrinsic length scales of superconductors, namely the coherence length (ξ_0) and the London penetration depth (λ_L). Importantly, our approach allows for the determination of these scales in microscopic theories and from first principles, even in the presence of strong electron correlations.

[1] N. Witt et al., arXiv:2310.09063 (2023)

TT 50.9 Wed 17:15 H 3005

Splitting of d-wave surface states: Edge ferromagnetism or spontaneous supercurrents? — •Kevin Marc Seja, Niclas Wall-Wennerdal, Tomas Löfwander, and Mikael Fogelström — MC2 - Microtechnology & Nanoscience, Chalmers University of Technology, Gothenburg, Sweden

At pair-breaking surfaces of a d-wave superconducting grain, Andreev bound states appear in the middle of the superconducting energy gap. The resulting large density of states at zero energy is energetically highly unfavorable. Experimentally, the associated tunneling-conductance peak was found to split spontaneously into two finite-energy peaks at low temperatures[1]. Two suggested mechanisms for this are either ferromagnetic interaction at the surfaces[2], or the establishment of phase gradients in the order parameter[3]. It is an open question which of the two cases minimizes the free energy at finite temperatures. Here we present a theoretical study of this problem using the quasiclassical theory of superconductivity. We include a magnetic Fermi liquid interaction, allow for a complex order parameter, and solve the underlying transport and self-energy equations selfconsistently in 2D by finite element method[4]. Depending on interaction strength and temperature, we find either a first-order transition to a purely magnetic or a second-order transition to a current-carrying state. We discuss key differences between the two phases.

[1] Covington et al., Phys. Rev. Lett. 79 (1997) 277
[2] Potter & Lee - Phys. Rev. Lett. 112 (2014) 117002
[3] Håkansson et al., Nat. Phys. 11 (2015) 755
[4] Seja & Löfwander - Phys. Rev. B 106 (2022) 144511

TT 50.10 Wed 17:30 H 3005

Shedding light on collective modes in 2D superconductors — •Benjamin Levitan[1,2], Erez Berg[1], Yuval Oreg[1], Mark Rudner[3], and Ivan Iorsh[1,4] — [1]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, Israel — [2]Institute for Theoretical Physics, University of Köln, Köln, Germany — [3]Department of Physics, University of Washington, Seattle, WA, USA — [4]Department of Physics, Engineering Physics and Astronomy, Queen's University, Kingston, Ontario, Canada

The order parameter of a conventional single-band superconductor, being a complex number, lives in a two-dimensional configuration space. Accordingly, there are always at least two collective excitation modes associated with superconducting order: the condensate may fluctuate in amplitude or overall phase. In unconventional superconductors, finer order-parameter structure and/or subdominant pairing channels can provide additional directions in which fluctuations may occur, yielding a richer spectrum of collective modes.

I will discuss our theoretical study of the collective modes in two-dimensional unconventional superconductors, using rhombohedral trilayer graphene (RTG) as an illustrative case study. RTG hosts an annular Fermi sea prior to the onset of superconductivity; I will show how the two Fermi surface components can give rise to an in-gap Leggett mode in the superconducting state. I will then show how the linear absorption spectrum for AC out-of-plane displacement fields can yield insight into the superconducting gap structure, and even into the nature of the underlying microscopic interactions responsible for pairing.

TT 50.11 Wed 17:45 H 3005

Fractal superconductivity — •Robert Canyellas — Institute for Molecules and Materials, Radboud University, Heyendaalseweg 135, 6525AJ Nijmegen, The Netherlands

Fractal structures such as the Sierpinski gasket have been theoretically predicted to enhance the critical temperature of superconductivity, as compared with regular crystals, while maintaining the macroscopic phase coherence of the Cooper pairs. Before, the analysis has been performed for the *s*-wave attractive Hubbard model. In our work, we extend it to the different types of pairing symmetries, such as p and d-wave, for the extended attractive Hubbard model on the Sierpinski gasket and carpet geometries. We use the Bogoliubov-de Gennes mean field theory and the kernel polynomial method implementation to compute the spatial profile of the order parameter and the superfluid density, and derive the phase diagram of the system.

TT 51: Topological Semimetals II

Time: Wednesday 15:00–17:00 Location: H 3007

TT 51.1 Wed 15:00 H 3007

Singularity theory of Weyl-point creation and annihilation — •György Frank[1], Gergö Pintér[1], and András Pályi[1,2] — [1]Department of Theoretical Physics, Budapest University of Technology and Economics, M. egyetem rkp. 3., H-1111 Budapest, Hungary — [2]MTA-BME Quantum Dynamics and Correlations Research Group, M. egyetem rkp. 3., H-1111 Budapest, Hungary

Weyl points (WP) are robust spectral degeneracies, which can not be split by small perturbations, as they are protected by their non-zero topological charge. For larger perturbations, WPs can disappear via pairwise annihilation, where two oppositely charged WPs merge, and the resulting neutral degeneracy disappears. In this work [1], we reveal and analyze a fundamental connection of the WP mergers and singularity theory: phase boundary points of Weyl phase diagrams, i.e., control parameter values where Weyl point mergers happen, can be classified according to singularity classes of maps between manifolds of equal dimension. We demonstrate this connection on a Weyl–Josephson circuit where the merger of 4 WPs draw a swallowtail singularity, and in a random BdG Hamiltonian which reveal a rich pattern of fold lines and cusp points. Our results predict universal geometrical features of Weyl phase diagrams, and generalize naturally to creation and annihilation of Weyl points in electronic (phononic, magnonic, photonic, etc) band-structure models, where Weyl phase transitions can be triggered by control parameters such as mechanical strain.

[1] Gy. Frank, G. Pintér, A. Pályi, arXiv:2309.05506 (2023)

TT 51.2 Wed 15:15 H 3007

Quantum oscillations from interface Fermi arcs — Adam Yanis Chaou, •Vatsal Dwivedi, and Maxim Breitkreiz — Freie Universität Berlin

Fermi arcs — the characteristic boundary signatures of Weyl semimetals — generically also appear at a weakly coupled interface between two Weyl semimetals. We study the magnetotransport across such an interface in presence of a magnetic field normal to the interface, and describe signatures of these interface modes in the quantum oscillations. These oscillations stem from a momentum-space analog of Aharonov-Bohm interference of electrons moving along various branches of the interface Fermi arcs. The localization of the interface modes along the transport direction manifests in a strong field-angle anisotropy of the oscillations, which distinguishes them from conventional Shubnikov-de Haas oscillations and makes them identifiable even in complex quantum oscillation spectra.

TT 51.3 Wed 15:30 H 3007

Fermi-Arc Metals — •Maxim Breitkreiz, Tommy Li, and Piet Brouwer — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany

Weyl-semimetal superstructures with spatially varying positions of Weyl nodes host a chiral-symmetry preserving Fermi-arc metal state, where the chirality is carried by three-dimensional flat bands instead of Weyl nodes, which can be understood as being built from Fermi arc-like states. In this talk I introduce this novel topological state and discuss some of its characteristic transport and interaction effects. In particular, I will show that a helical node-position variation supports an excitonic instability leading to a dynamical axion insulator.

TT 51.4 Wed 15:45 H 3007

Multiplicative topological semimetals — •Adipta Pal[1,2], Joe H. Winter[1,2,3], and Ashley M. Cook[1,2] — [1]Max Planck Intitute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany — [3]SUPA, School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews KY169SS, UK

Exhaustive study of topological semimetal phases of matter in equilibriated electonic systems and myriad extensions has built upon the foundations laid by earlier introduction and study of the Weyl semimetal, with broad applications in topologically-protected quantum computing, spintronics, and optical devices. We extend recent introduction of multiplicative topological phases to find previously-overlooked topological semimetal phases of electronic systems in equilibrium, with minimal symmetry-protection. We look into the multiplicative counterpart of the Weyl semimetal and find rich and distinctive bulk-boundary correspondence and response signatures that greatly expand understanding of consequences of topology in condensed matter settings, such as limits on Fermi arc connectivity and structure and transport signatures such as the chiral anomaly.

TT 51.5 Wed 16:00 H 3007

Stability of Weyl node merging processes under symmetry constraints — •Viktor Könye[1], Gabriele Naselli[1], György Frank[2], Gergö Pintér[2], Dániel Varjas[1], János Asbóth[2], András Pályi[2], and Cosma Fulga[1] — [1]IFW Dresden, Dresden, Germany — [2]Budapest University of Technology and Economics, Budapest, Hungary

Weyl semimetals are topological materials with topologically protected band crossing points called Weyl nodes, characterized by a linear low energy dispersion relation and chirality given by an integer Chern number. By continuously changing the system parameters the number of nodes can only change through charge conserving mergings or creations. When no symmetries are present in the system the most likely process is pairwise annihilation and creation. Pairwise annihilation can be forbidden by adding symmetry constraints and multi-node merging processes can be observed.

Motivated by the prediction of a three-node process in $MoTe_2$ we study merging processes in the presence of C_2T symmetry. We find that, when this symmetry is present, the most common merging process involves a three-node process. Additionally we propose a way to realize these merging processes in $SrSi_2$ and in bilayer graphene.

TT 51.6 Wed 16:15 H 3007

Weak $\mathbb{Z}_2$ Supertopology — •Kirill Parshukov[1], Moritz M. Hirschmann[1,2], and Andreas P. Schnyder[1] — [1]Max Planck Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany — [2]RIKEN Center for Emergent Matter Science, Wako, Saitama 351-0198, Japan

We study symmetry-enforced $\mathbb{Z}_2$ topology in non-magnetic centrosymmetric materials. We provide a classification of space groups whose symmetries enforce a nontrivial $\mathbb{Z}_2$ indicator for all bands, independent of material details. For the found space groups we list all 2D subplanes in the Brillouin zone (BZ) that host the non-trivial 2D indicator. In the presence of strong spin-orbit coupling, the enforced indicator leads to quantum spin Hall states in the 2D subplanes of the BZ. If the spin-orbit coupling is negligible, the indicator enforces quantized π Berry phases along special contours. The enforced π Berry phases correspond to an odd number of Dirac nodal lines piercing the topological planes. We discuss experimental consequences and list a number of example materials.

TT 51.7 Wed 16:30 H 3007

Fundamental laws of chiral band crossings — •Kirill Alpin[1], Moritz M. Hirschmann[1,2], Niclas Heinsdorf[1,3], Andreas Leonhardt[1], Wan Yee Yau[1,4], Xianxin Wu[1,5], and Andreas P. Schnyder[1] — [1]Max Planck Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany — [2]RIKEN Center for Emergent Matter Science, Wako, Saitama 351-0198, Japan — [3]Stewart Blusson Quantum Matter Institute, University of British Columbia, Vancouver BC V6T 1Z4, Canada — [4]Institute for Theoretical Physics III, University of Stuttgart, D-70550 Stuttgart, Germany — [5]Institute for Theoretical Physics, Chinese Academy of Sciences, Beijing, China

We derive two fundamental laws of chiral band crossings: (i) a local constraint relating the Chern number to phase jumps of rotation eigenvalues and (ii) a global constraint determining the number of chi-

ral crossings on rotation axes. Together with the fermion doubling theorem, these laws describe all conditions that a network of chiral band crossing must satisfy. We apply the fundamental laws to prove the existence of enforced double Weyl points, nodal planes, and generic Weyl points, among others. Combining the local constraint with explicit low-energy models, we determine the generic topological phase diagrams of all multifold crossings. Remarkably, we find a fourfold crossing with Chern number 5, which exceeds the previously conceived maximum Chern number of 4. We identify materials crystallizing in space group 198, such as B20 materials and BaAsPt, as suitable compounds with this Chern number 5 crossing.

TT 51.8 Wed 16:45 H 3007

Representation-enforced topology and signatures of quantum geometry in hexagonal nodal-plane materials — •Raymond Wiedmann[1], Moritz M. Hirschmann[1,2], Kirill Alpin[1], Niclas Heinsdorf[1,3], Wan Yee Yau[1,4], Andreas Leonhardt[1], Johannes Mitscherling[1,5], and Andreas P. Schnyder[1] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]RIKEN Center for Emergent Matter Science, Wako, Saitama, Japan — [3]Department of Physics and Astronomy & Stewart Blusson Quantum Matter Institute, University of British Columbia, Vancouver BC, Canada — [4]Max Planck Institute of Molecular Cell Biology and Genetics, Dresden, Germany — [5]Department of Physics, University of California, Berkeley, California, USA

Nodal planes can carry a topological charge, which has to be compensated by Weyl points of opposite charge in the Brillouin zone, due to the fermion doubling theorem. Depending on the symmetries and constraints of the system, this can allow for a very high Chern number of the nodal plane. We study under which circumstances the interplay of Wyckoff positions and orbital content leads to representation-enforced topological nodal planes in hexagonal systems, finding Chern numbers of up to $\nu = 16$. Since the anomalous Hall effect scales with the Chern number, one expects a strong response in conductivity measurements of such materials. Another effect that influences the conductivity is the quantum metric. We investigate the signatures of topological and trivial nodal planes in the electrical and optical conductivity caused by the non-trivial quantum geometry of the bands.

TT 52: Nickelates II

Time: Wednesday 15:00–16:15 Location: H 3010

Invited Talk TT 52.1 Wed 15:00 H 3010

A tale of two kinds of superconducting nickelates — •Frank Lechermann — Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Layered nickelates have been of interest since the early days of high-T_c superconducting (SC) cuprates as possible additional representants of unconventional superconductors. But only in 2019, a stable SC phase has been identified in thin-films of Sr-doped $NdNiO_2$ with a $T_c \sim 20\,K$ [1]. Further SC members from this class of low-valence nickelates have been spotted afterwards. And just when the debate about the similarity between SC cuprates and nickelates, both with akin $3d^{9-x}$ formal transition-metal valence, was at its zenith, a SC bilayer nickelate of formal $3d^{8-x}$ valence was detected at high pressure with $T_c \sim 80\,K$ in spring 2023 [2]. Interestingly, according to our theoretical investigations [3,4] all these SC nickelates have a multiorbital Ni-e_g flat-band scenario in common.

In this talk, it will be shown that an advanced combination of density functional theory (DFT) and dynamical mean-field theory (DMFT) provides unique access to this novel playground of high-T_c nickelate superconductivity. Albeit the whole field is still at its infancy, the multiorbital regime together with the SC properties at distinctly different $3d$ electron count renders obvious that many further surprises may be uncovered in the future.

[1] D. Li et al., Nature 572 (2019) 624
[2] H. Sun et al., Nature 621 (2023) 493
[3] F. Lechermann, Phys. Rev. X 10 (2020) 041002
[4] F. Lechermann et al., arXiv:2306.05121 (2023)

TT 52.2 Wed 15:30 H 3010

Tuning of the carrier localization, magnetic and thermoelectric properties in ultrathin $(LaNiO_{3-\delta})_1/(LaAlO_3)_1(001)$ superlattices by oxygen vacancies — •Manish Verma and Rossitza Pentcheva — Department of Physics, Universität Duisburg-Essen

Understanding the role of defects on the complex behavior of transition metal oxides in bulk and the ultrathin limit is at the forefront of condensed matter physics. Using a combination of density functional theory calculations with an on-site Coulomb repulsion term (DFT+U) and Boltzmann transport theory within the constant relaxation time approximation, we explore the effect of oxygen vacancies on the electronic, magnetic, and thermoelectric properties in ultrathin $(LaNiO_{3-\delta})_1/(LaAlO_3)_1(001)$ superlattices (SLs). For the pristine SL, an antiferromagnetic charge-disproportionated (AFM-CD) $(d^8\underline{L}^2)_{S=0}(d^8)_{S=1}$ phase is stabilized, irrespective of strain. At $\delta =$ 0.125 and 0.25, the localization of electrons released from the oxygen defects in the NiO_2 plane triggers a charge-disproportionation, leading to a ferrimagnetic insulator both at a_{STO} (tensile strain) and a_{LSAO} (compressive strain). At $\delta = 0.5$, an insulating phase emerges with alternating stripes of Ni^{2+} (high-spin) and Ni^{2+} (low-spin) and oxygen vacancies ordered along the [110] direction (S-AFM), irrespective of strain. This results in a robust n-type in-plane power factor of 24 $\mu W/K^2$ cm at a_{STO} and 14 $\mu W/K^2$ cm at a_{LSAO} at 300 K (assuming relaxation time $\tau = 4$ fs). Additionally, the pristine and $\delta = 0.5$ SLs are shown to be dynamically stable.

TT 52.3 Wed 15:45 H 3010

influence of $SrTiO_3$ capping layer on infinite-layer nickelate thin films — •martando rath[1], yu chen[1], guillaume krieger[2], daniele preziosi[2], and marco salluzzo[1] — [1]CNR-SPIN, Napoli, Italy — [2]Université, de Strasbourg, CNRS, IPCMS UMR, France

By using core-level x-ray photoemission spectroscopy (XPS), we studied the electronic properties of epitaxial $NdNiO_2$ thin films. In particular, we compare the surface-interface electronic structure of $SrTiO_3$ (STO)-capped and uncapped $NdNiO_2$ samples by core-level Nd $3d$ and Ni $2p$ XPS spectra. Our preliminary results show the enhancement of $3d^94f^4\underline{L}$ ($\underline{L}$ stands for a hole on the oxygen ligands) compared to $3d^94f^3$ peak in Nd $3d_{5/2}$ of the nickelates sample capped with STO layer, which suggests the formation of a $Nd(Ti,Ni)O_3$ layer at the upper interface. The origin of this layer, recently found also at the bottom interface with the STO-single crystal, has been attributed to the polar discontinuity between neutral STO planes and charged $NdNiO_2$. A single $Nd(Ti,Ni)O_3$ layer indeed is able to solve the polar-catastrophe which would otherwise occur due to the alternating charged $(NiO_2)^{3-}$ and Nd^{3+} layers. Furthermore, we find substantial differences of the Ni $2p$ spectra, which indicates the sample with capping layer preserves the Ni^{1+} charge state with a fraction of Ni^{2+} in the final photo-excited state.

TT 52.4 Wed 16:00 H 3010

Gap Structure Evolution of Infinite-Layer Lanthanum Nickelates from Enhanced Correlations — •Fabian Jakubczyk[1,2], Armando Consiglio[2,3], Domenico Di Sante[4], Ronny Thomale[2,3], and Carsten Timm[1,2] — [1]Institute of Theoretical Physics, Technische Universität Dresden, 01069 Dresden — [2]Würzburg-Dresden Cluster of Excellence ct.qmat — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, 97074 Würzburg, Germany — [4]Department of Physics and Astronomy, University of Bologna, I-40127 Bologna, Italy

The newly discovered superconducting infinite-layer nickelates and in particular their gap symmetry pose challenges for the research community. For instance, controversial magnetotransport measurements point at either isotropic or anisotropic superconductivity, with possibly crucial impact of the rare-earth element. On the other hand, the existence of orbital-selective correlations, which are particularly strong for the Ni $3d_{x^2-y^2}$ orbital, seems to be generally accepted. In our work, we investigate potential spin-triplet superconductivity in lanthanum-based nickelates from the perspective of spin-fluctuation pairing and orbital selectivity. For this purpose, we construct a minimal model including Ni $3d$, as well as La $5d$ degrees of freedom. A gap structure with odd parity indeed becomes favored for a reasonable choice of interaction strength and quasiparticle renormalization. We therefore identify $LaNiO_2$ as a member of the nickelate family that is substantially different from isostructural *d*-wave cuprate superconductors.

TT 53: Focus Session: Nanomechanical Systems for Classical and Quantum Sensing II (joint session HL/DY/TT/QI)

Nanomechanical and cavity-optomechanical systems have been recently established as a controllable and configurable platform that can be engineered to tackle outstanding sensing challenges both in the classical and in the quantum regime. With this focus session, experts from different but synergetically overlapping fields of nanomechanical sensing pursuing classical, non-linear and quantum approaches are brought together. The session shall provide an overview over the recent exciting developments of the techniques explored in micro- and nanomechanical systems and sensing concepts exploring quantum measurement schemes.

Organized by Eva Weig, Hubert Krenner, and Hans Hübl.

Time: Wednesday 15:00–17:45 Location: EW 202

TT 53.1 Wed 15:00 EW 202

Quantum backaction evasion in cavity magnomechanics — •Victor Augusto Sant Anna V Bittencourt[1], Clinton A. Potts[2], John P. Davis[3], and Anja Metelmann[1,4,5] — [1]ISIS (UMR 7006), Universite de Strasbourg, 67000 Strasbourg, France — [2]Kavli Institute of NanoScience, Delft University of Technology, PO Box 5046, 2600 GA Delft, Netherlands — [3]Department of Physics, University of Alberta, Edmonton, Alberta T6G 2E9, Canada — [4]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, 76131, Karlsruhe, Germany — [5]Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, 76344, Eggenstein-Leopoldshafen, Germany

Magnetic excitations (magnons) hosted in a solid can couple to mechanical vibrations of the material (phonons) via a radiation-pressure like interaction due to magneto-elastic effects. When the magnet is loaded on a microwave cavity, phonons can be driven and measured via the microwave while having the tunability of the magnetic excitations. Nevertheless, the noise added to mechanics can hinders both potential applications of the system at the quantum level and measurements of the phonon mode. Here, we propose a scheme to evade quantum backaction on a phonon mode of a cavity magnomechanical system by using a two-tone microwave drive. We study the robustness of the different possible backaction evading schemes, and show that measurements of the phonon mode can be performed with added noise below the standard quantum limit.

TT 53.2 Wed 15:15 EW 202

Optical detection of guided GHz acoustic phonons in a semiconductor hybrid microcavity — •Mingyun Yuan[1], Antonio Crespo-Poveda[1], Alexander S. Kuznetsov[1], Klaus Biermann[1], Alexander Poshakinskiy[2], and Paulo V. Santos[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5, 10117 Berlin, Germany — [2]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels, Spain

The interaction between acoustic phonons and optical quasiparticles has profound implication in both understanding of light-matter interaction and acousto-optical applications. We report on the optical detection of phonon echos resulting from the interaction between acoustic phonons and exciton polaritons in a hybrid (Al,Ga)As microcavity grown by molecular beam epitaxy. The microcavity spacer embedding multiple quantum wells is surrounded by Bragg mirrors designed to enable polariton formation. Simultaneously, the spacer-quantum wells and the Bragg reflectors act as the core and cladding regions, respectively, of an acoustic waveguide sustaining GHz acoustic phonons propagating along [110], excited by side bulk-acoustic-wave transducers. The acoustic modulation gives rise to an optical comb in the polariton photoluminescence, in which both the guided phonon modes and the substrate phonon modes are identified via Fourier transform. Our results demonstrate the robust generation of guided acoustic phonons above 6 GHz as well as their effective coupling to the polaritons, and showcase the sensitive optical detection of acoustic modes.

TT 53.3 Wed 15:30 EW 202

Topological phononic waveguides with ultralow loss — •Ilia Chernobrovkin[1], Xiang Xi[1], Jan Kosâta[2], Oded Zilberberg[3], Anders Sørensen[1], and Albert Schliesser[1] — [1]Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen, Denmark — [2]Institute for Theoretical Physics, ETH Zürich, 8093 Zürich, Switzerland — [3]Department of Physics, University of Konstanz, 78464 Konstanz, Germany

Topological insulators have long intrigued researchers in terms of fundamental physical properties as well as potential applications. The advantages of topological insulators have been extended to the realm of bosonic defects or waveguiding systems and overturned some of conventional views of photonic or phononic wave manipulation. However, the existing topological phononic waveguides still have large transportation loss, which limits its applications.

In our work, we combine the so-called soft-clamping technique - which can dramatically suppress mechanical losses - with non-trivial topology, designed to enable valley-locked propagation along a topological edge. Our systems are based on sub-100 nm thin, highly stressed membrane made of silicon nitride membranes. Our preliminary experimental results show a measured Q-factor above 1 million for whispering-galley megahertz-frequency elastic modes along a closed triangular path of length of ~10 mm, which corresponds to a classical coherent length of tens of meters. Our system can be considered promising for use in phononic circuits for coherent microwave signal processing or interconnection.

TT 53.4 Wed 15:45 EW 202

Dry processing of high Q 3C-silicon carbide nanostring resonators — •Felix David, Philipp Bredol, and Eva Weig — Technical University of Munich - Chair of Nano and Quantum Sensors, Garching, Germany

We fabricate string resonators from strongly stressed 3C-silicon carbide (SiC) grown on a silicon substrate. The conventional fabrication process involves electron-beam lithography with PMMA to define a metallic hard mask for the subsequent dry-etching step via a liftoff process. This requires some wet-chemical process steps, which can destroy our samples. Here we describe an alternative process, which avoids all wet-chemical process steps to enable superior quality. It involves the use of a negative electron-beam resist as an etch mask, as well as the completely reactive-ion etching-based release of the nanostrings. The dry-processed nanostrings can be fabricated with a high yield and exhibit high mechanical quality factors at room temperature. Due to the high reliability combined with the high process speed, it also allows us to investigate material-intensive questions, such as the influence of etching depth and undercut on the mechanical quality factor.

TT 53.5 Wed 16:00 EW 202

Spatial Mode Mapping of 2D Mechanical Resonators — •Lukas Schleicher, Leonard Geilen, Alexander Holleitner, and Eva Weig — TU München, Garching, Deutschland

We present studies on the spatial mapping of mechanical modes of 2D resonators based on monolayer transition-metal dichalcogenides. A spatially resolved mode mapping allows us to investigate non-isotropic pre-strain and other transfer-related artefacts, such as cracks and surface contaminations, which may result from the fabrication process. We compare the mechanical properties of drums with various sizes and fabrication methods of the 2D resonators.

15 min. break

TT 53.6 Wed 16:30 EW 202

Electrochemical etching strategy for shaping monolithic 3D structures from 4H SiC wafers — •André Hochreiter, Fabian Gross, Morris Niklas Möller, Michael Krieger, and Heiko Weber — Lehrstuhl für Angewandte Physik Universität Erlangen-Nürnberg, Germany

Silicon Carbide's (SiC) as wide bandgap semiconductor has outstanding material properties, which enable applications like already available commercial power-electric devices, and applications in quantum sensing. For mechanical applications of SiC, extremely high quality factors are predicted, but on-chip 3D shaping of SiC is difficult due to its chemical robustness. We report on an electrochemical etching (ECE) strategy, which solely relies on a doping contrast introduced by targeted ion-implantation of p-dopants on n-type material. With such a dopant-selective etching, n-doped regions remain inert and p-type regions are removed. We present devices as diverse as monolithic cantilevers, membranes and disk-shaped optical resonators etched out a single crystal wafer. The electrochemically etching process leaves the etched surface with low roughness, which can even be improved by annealing.

TT 53.7 Wed 16:45 EW 202

Probing the Mechanical Loss of Individual Surfaces of a Nanomechanical String Resonator — •Philipp Bredol, Felix David, and Eva Weig — Technical University of Munich, Chair of Nano and Quantum Sensors, 85748 Munich, Germany

Stressed nanostring resonators are a promising platform for sensing applications and quantum technologies because of their small footprint and high mechanical quality factors. In this contribution we show that the dissipation caused by sidewall surfaces and the dissipation caused by bottom and top surfaces can be individually determined from the mechanical response spectrum. This information helps to evaluate and adjust fabrication parameters such as etchant chemistry, etch mask materials and possible annealing steps. Being able to characterize the mechanical loss mechanisms that limit a given device is important for integration with other structures and to further push the performance of nanostring resonators.

TT 53.8 Wed 17:00 EW 202

Parametric normal mode splitting for coupling strength estimation — •Ahmed A. Barakat, Avishek Chowdhury, Anh Tuan Le, and Eva M. Weig — Technical University of Munich, Munich, Germany

The experimental estimation of the linear coupling strength between two nanomechanical modes is a challenging task. For dielectrically actuated nano-string resonators, the coupling strength between in-plane and out-of-plane modes is usually estimated by tuning the modal eigenfrequencies using a bias voltage up to the occurrence of the avoided crossing. In this contribution, we introduce a novel approach using parametric excitation to estimate the linear coupling strength at any bias voltage.

In addition to a broadband noise excitation, the proposed approach involves parametrically driving in the direction of at least one of the eigenmodes with a frequency that resonates with the difference between both eigenfrequencies causing a parametric normal mode splitting. Using the dependence of the splitting width on the coupling strength, a mathematical model is introduced and perturbed around the parametric excitation frequency using the multiple scales method. The locus of the splitting is derived analytically and agrees well with the experimental results, leading to an accurate estimation of the coupling strength.

TT 53.9 Wed 17:15 EW 202

Tunable near-infrared exciton-polariton optomechanical GHz rulers of light — •Alexander Kuznetsov, Klaus Biermann, and Paulo V. Santos — Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5-7, 10117 Berlin, Germany

Frequency combs, which consist of many equidistant optical lines, are photonic analogues of spatial rulers. Such rulers of light can be used for high-resolution spectroscopy, ranging, optical and atomic clocks, and for large-scale quantum systems. On-chip miniaturized and low-power comb-sources are, therefore, of great importance. Here, we demonstrate generation of tunable combs using spatially confined light-matter quasiparticles – exciton-polaritons – coherently modulated by GHz phonons inside a hybrid photon-phonon (Al,Ga)As patterned microcavity. Using non-resonant optical excitation, we create polariton Bose-Einstein-like condensates (BEC) with long temporal coherence reaching $\tau_{BEC} \approx 2$ ns. The BEC is modulated by piezoelectrically generated strain of bulk acoustic wave (BAW) phonons with frequency $f_{BAW} = 7$ GHz and RF-tunable amplitude. Since $\tau_{BEC} \gg 1/f_{BAW}$, the modulation is coherent and leads to the emergence of well-resolved phonon sidebands, separated by f_{BAW}, in the polariton emission spectrum. For large BAW amplitudes, the comb contains up to 50 well-resolved lines with nearly-flat profile. The demonstrated RF-induced comb functionality may be useful for the realization of on-chip arrays of tunable GHz optical combs as well as coherent optical-to-microwave bi-directional conversion.

TT 53.10 Wed 17:30 EW 202

Imaging acoustic fields on metasurfaces — •Alessandro Pitanti[1,2,3], Mingyun Yuan[1], Simone Zanotto[3], and Paulo Ventura Santos[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., 5-7 Hausvogteiplatz, Berlin 10117, Germany — [2]Dipartimento di Fisica E. Fermi, Università di Pisa, Largo B. Pontecorvo 3, Pisa 56127, Italy — [3]NEST, CNR Istituto Nanoscienze and Scuola Normale Superiore, piazza San Silvestro 12, Pisa 56127, Italy

The last decades have witnessed a rich activity towards the integration of acoustic technologies within electro-optical circuits in high-frequency hybrid devices. The main role in this trend has been played by surface acoustic waves (SAW), easily integrable in several material platforms via piezoelectricity. Given their high frequency and quality factors, simple SAW delay-line resonators have found application as sensors, filters, and oscillators for telecommunication applications. More complex manipulation of acoustic waves would boost SAW-based technologies, becoming a key for the transition to 6G; complete wave manipulation and control in the GHz range would offer the most promise for integration with modern communication technologies.

In this context, we illustrate the use of light-interferometry and atomic force microscopy based scanning probe techniques for a fine investigation of GHz acoustic fields in mechanical metasurfaces. Focusing on the role of symmetries in wave scattering, we show complex wave manipulation, leading to asymmetric negative refraction and anisotropic transmission of mechanical waves.

TT 54: 2D Materials IV: Graphene (joint session O/TT)

Time: Wednesday 15:00–18:00 Location: MA 005

TT 54.1 Wed 15:00 MA 005

Ultra-large polymer-free suspended graphene films — •Lukas Kalkhoff, Sebastian Matschy, Ann-Sophie Meyer, Leon Lasnig, Nele Junker, Lars Breuer, and Marika Schleberger — Universität Duisburg-Essen, Fakultät für Physik, Germany

The quest to preserve graphene's unique characteristics has intensified the demand for advanced preparation methods. The production of large area graphene films has been constrained by the necessity of a polymer film, like PMMA, during the transfer process, leading to unavoidable contaminations. In this talk, we show our approach to fabricate triple-layer graphene films, without the use of polymers, freely suspended across circular holes with diameters of 100-300 micrometers. This technique achieves a high yield and also ensures remarkable uniformity of the electronic properties of graphene, both across and within individual holes [1].

Using confocal Raman and THz spectroscopy we can confirm that the structural and electronic properties of these triple-layer films are akin to monolayer graphene. This discovery has significant implications, particularly in their application as ion-electron converters in time-of-flight mass spectrometry and similar fields. Remarkably, these graphene films are two orders of magnitude thinner than conventional carbon foils used in such experiments, yet they maintain robustness and a high electron yield, as proven under picosecond ion bombardment. This marks a critical step toward replacing existing carbon films or polymer-based graphene with cleaner, more precisely defined graphene films. [1] L. Kalkhoff *et al.*, 2023, arXiv:2311.08137

TT 54.2 Wed 15:15 MA 005

Design of electronic structure and transport in S-doped few-layer graphene — •Armin Sahinovic[1], Paolo Fortugno[2], Nicholas Wilson[3], Hartmut Wiggers[2], and Rossitza Pentcheva[1] — [1]Department of Physics, Universität Duisburg-Essen — [2]Institute for Energy and Materials Processes - Reactive Fluids, Universität Duisburg-Essen — [3]Department of Chemical Engineering, University of Waterloo

While the properties of N- and S-doped graphene have been addressed previously [1], the interplay between defects, doping and the layered structure of FLG are largely unknown. Based on density functional theory calculations we explore the formation energies and electronic structure of different defect types as a function of concentration and distribution. We find a layer dependence of the doping allowing for a design of the electronic structure. The surface layers are favored for doping, giving rise to buckling and a modified band structure such as a band gap opening not found for doping the center layers. Experiments on the synthesis of S-doped FLG in a microwave plasma reactor show S incorporation and a conductivity increase of up to 50%. This is consistent with the transport properties, obtained via BoltZtrap2 [2], revealing that S doping enhances the conductivity in FLG. We hereby show that tailoring the S incorporation into FLG enables one to design the electronic structure in view of energy conversion and storage applications.

[1] J.H Lee et al., Nanomaterials, 9, 268 (2019)
[2] G.K.H. Madsen et al., Comput. Phys. Commun., 231, 140 (2018)

Topical Talk TT 54.3 Wed 15:30 MA 005

Tuning quantum electronic transport in nanoporous graphene — •Aran Garcia-Lekue — Donostia International Physics Center (DIPC), San Sebastian, Spain — Ikerbasque, Basque Foundation for Science, Bilbao, Spain

Recent experimental advances have demonstrated that graphene nanoribbons (GNRs) can be laterally coupled with atomic precision to obtain a nanoporous graphene (NPG) structure with highly anisotropic electronic properties.[1] Moreover, simulations have shown that the lateral coupling of GNRs leads to sizable interribbon transmission giving rise to intriguing interference patterns,[2] and that such interribbon transmission can be switched on/off by the chemical modification of the coupling bridges.[3]

Using density functional theory (DFT) and a multiscale transport method based on DFT combined with nonequilibrium Green's functions (NEGF), we have carried out electronic structure and current simulations for different NPG systems. First, in collaboration with our experimental colleagues, we have explored a new NPG that, provided by specifically designed coupling bridges, shows additional degrees of freedom to control the in-plane current.[4] Besides, we have investigated a bilayer composed of NPG and graphene, concluding that the interlayer current can be tuned by changing their relative twist angle.

[1] Moreno et al., Science 360, 199 (2018) [2] Calogero et al., ; Nano Lett. 19, 576 (2019) [3] Calogero et al., JACS 141, 13081 (2019) [4] Moreno et al., JACS 145, 8988 (2023)

TT 54.4 Wed 16:00 MA 005

Visualizing band hybridization and moiré effects in gate-tunable twisted graphene layers using nanoARPES — •Zhihao Jiang[1], Kimberly Hsieh[1], Paulina Majchrzak[1], Alfred Jones[1], Chakradhar Sahoo[1], Youngju Park[2], Dongkyu Lee[2], Kenji Watanabe[3], Takashi Taniguchi[3], Jill Miwa[1], Jeil Jung[2], Yong P. Chen[1], and Søren Ulstrup[1] — [1]Aarhus University, Denmark — [2]University of Seoul, Korea — [3]National Institute for Materials Science, Japan

Twisted graphene layers have emerged as an intriguing class of quantum materials that display surprising correlation effects, including superconductivity, Mott insulators as well as strange metal phases. The possibility to tune these states using twist angle and electrostatic doping provides a promising route to interrogate the underpinning interactions between the electronic states. Here, we use angle-resolved photoemission spectroscopy with spatial resolution at the new micro- and nanoARPES branch at the ASTRID2 synchrotron light source at Aarhus University in Denmark to visualize the electronic states of twisted graphene layers integrated in device architectures. Specifically, we reveal the flat bands in twisted bilayer and double-bilayer graphene around the magic angles and systematically track the evolution of hybridization effects and moiré bands with small twist angles up to 6°. The interactions in the systems are further tuned by in situ electrostatic doping using a back-gate electrode. Our study paves the way for directly engineering band structure and correlation effects in twisted two-dimensional materials.

TT 54.5 Wed 16:15 MA 005

Direct Mn implantation into graphene on Cu(111) substrate: understanding defect production in 2D materials from first-principles calculations — •Silvan Kretschmer[1], Renan Villarreal[2], Lino M. C. Pereira[2], and Arkady V. Krasheninnikov[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden 01328, Germany — [2]Quantum Solid State Physics, KU Leuven, 3001 Leuven, Belgium

Defects influence the properties of 2D materials tremendously, as they essentially consist of surface-only. Contrary to what their name implies, defects not only have detrimental effects, but also are introduced to tune the magnetic, electronic and optical response of 2D materials. The defect induced changes in the material and the concentration of defects produced, e.g by ion irradiation can be rationalized using first-principles calculations [1,2]. Here, we report on our recent simulation results obtained in collaboration with an experimental group on the probability to dope graphene with Mn atoms. Specifically, using ab-initio molecular dynamics we calculated the formation probability of Mn substitutional impurities in graphene on Cu(111) substrate under low-energy ion irradiation.

[1] S. Kretschmer, et.al, ACS Appl. Mater. Interfaces 10 (36), 30827–30836 (2018)
[2] S. Kretschmer, et. al, J. Phys. Chem. Lett. 13, 514–519 (2022)

TT 54.6 Wed 16:30 MA 005

Investigating swift heavy ion induced defects in graphene and MoS_2 on SiO_2/Si via Raman spectroscopy — •Kevin Vomschee[1], Yossarian Liebsch[1], Leon Lasnig[1], Osamah Kharsah[1], Lars Breuer[1], Henning Lebius[2], Abdenacer Benyagoub[2], Clara Grygiel[2], and Marika Schleberger[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Duisburg, Germany — [2]CIMAP/GANIL, Caen, France

In the past years, ions have been used as a tool for the so-called defect engineering of 2D materials such as graphene and single-layer molybdenum disulfide (MoS_2). The potential impact of swift heavy ion irradiations on strain or doping in 2D materials and, in the case of graphene, also on defect formation can be effectively characterized using Raman spectroscopy. The irradiation of graphene on SiO_2/Si substrates with 91 MeV $^{129}Xe^{23+}$ and 967 MeV $^{129}Xe^{43+}$ at GANIL creates a so called D-peak indicating the presence of defects. The area ratio of the D-peak to the G-peak, another Raman peak that is not defect dependent, is recorded for accumulated ion fluences of up to $2.5{\cdot}10^{13}cm^{-2}$. Our Raman spectroscopy measurements show that swift heavy ion-induced defects in graphene are smaller in size than those investigated in earlier experiments by highly charged, slow Xe ions and keV Ar^{+} irradiation. We also observed that the 91 MeV $^{129}Xe^{23+}$ ion beam does not significantly change strain or doping of CVD-grown MoS_2 monolayers on a similar substrate for fluences of up to $4{\cdot}10^{12}cm^{-2}$, but sputters away the monolayer at a fluence of $2.5{\cdot}10^{13}cm^{-2}$. The fluence dependent sputtering can be observed in a decaying intensity of the spectra.

TT 54.7 Wed 16:45 MA 005

Hyperlens enabled defect imaging in hBN-covered few-layer graphene — •Lina Jäckering, Konstantin G. Wirth, and Thomas Taubner — I. Institute of Physics (IA), RWTH Aachen University

Most of the unique phenomena of few-layer graphene (FLG) can only be observed when the FLG flake is encapsulated in hexagonal Boron Nitride (hBN) [1]. The fabrication process of encapsulated graphene devices can alter the stacking order and induce defects within the FLG flake [2]. The present stacking order and possible defects significantly influence the graphene sample's electronic properties. Therefore, the visualization of stacking domains and defects in graphene flakes before, during, and after the fabrication of a transport device is of great interest. Here, we show that scanning near-field optical microscopy (s-SNOM) can visualize submicrometer-sized defects in FLG below 33 nm hBN. We attribute the achieved super-resolution imaging of buried defects to the hyberbolic nature of hBN [3]. hBN hosts hyperbolic phonon polaritons that enable super-resolution focusing through a cover layer of hBN, the so called hyperlensing effect [3]. Here, we present the first practical application of the hyperlensing effect in a hBN-FLG heterostructure. Our work paves the way for characterization of FLG devices during fabrication. [1] Dean et al. Nat. Nanotechnol. **5**, 722 (2010). [2] Geisenhof et al. ACS Appl. Nano Mater. **2**, 6067 (2019). [3] Li et al. Nat. Commun. **6**, 7507 (2015).

TT 54.8 Wed 17:00 MA 005

Alkali metal (AM) adsorption on pristine and defective graphite surfaces — •Jafar Azizi, Holger Euchner, and Axel Gross — Institute of Theoretical Chemistry, Ulm University, 89069 Ulm, Germany

While carbon derivatives are still the anodes of choice for Li- and post-Li ion batteries, the quest for improving their properties is ongoing. In particular, when considering soft and hard carbon materials the impact of heteroatoms on Alkali metal adsorption and storage is hardly investigated on the atomistic scale. To gain more insight into the underlying mechanisms, a density functional theory-based study of Li, Na, and K adsorption on pristine and defective graphite surfaces, considering different heteroatom impurities (such as N, S, Si, and O), has been performed. Our results show that on the surface of pure graphite,the adsorption of Li and K ions is energetically more favorable as compared to Na ions. However, in the presence of defects and impurities, Na adsorption also becomes feasible. In general, AM adsorption in the vicinity of defects and impurities is largely favored, putting constrain on the number of AM atoms that participate in charge/discharge processes.

TT 54.9 Wed 17:15 MA 005

Enhancement of graphene phonon excitation by a chemically engineered molecular resonance — Xiaocui Wu[1], •Nicolas Néel[1], Mads Brandbyge[2], and Jörg Kröger[1] — [1]Institut für Physik, Technische Universität Ilmenau, D-98693 Ilmenau, Germany — [2]Center of Nanostructured Graphene, Department of Physics, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark

The abstraction of pyrrolic hydrogen from a single phthalocyanine on graphene turns the molecule into a sensitive probe for graphene phonons. The inelastic electron transport measured with a scanning tunneling microscope across the molecular adsorbate and graphene becomes strongly enhanced for a graphene out-of-plane acoustic phonon mode. Supporting density functional and transport calculations elucidate the underlying physical mechanism. A molecular orbital resonance close to the Fermi energy controls the inelastic current while specific phonon modes of graphene are magnified due to their coupling to symmetry-equivalent vibrational quanta of the molecule. Funding by the Deutsche Forschungsgemeinschaft through Grant No. KR 2912/17-1 is acknowledged.

TT 54.10 Wed 17:30 MA 005

Accelerated First-Principles Exploration of Structure and reactivity in Graphene Oxide — •Zakariya El-Machachi, Damyan Frantzov, Nijamudheen Abdulrahiman, and Volker L. Deringer — Department of Chemistry, University of Oxford, Oxford OX1 3QR, UK

Graphene oxide (GO) materials are widely studied, and yet their atomic-scale structures remain to be fully understood. Here we show that the chemical and configurational space of GO can be rapidly explored by advanced machine-learning methods, combining on-the-fly acceleration for first-principles molecular dynamics with message-passing neural-network potentials. The first step allows for the rapid sampling of chemical structures with very little prior knowledge required; the second step affords state-of-the-art accuracy and predictive power. We showcase the performance of the method by applying it to a model of a partially disordered GO nanoflake and its thermal evolution. Our work provides a platform for routine, quantum-mechanically accurate, and realistic-scale simulations of diverse carbonaceous materials.

TT 54.11 Wed 17:45 MA 005

Let's Go on Graphs: X-ray Absorption Spectroscopy of Graphene Oxide using Graph Neural Networks — •Samuel J. Hall[1], Kanishka Singh[1,2], Qinyuan Zhou[1,2], and Annika Bande[1,3] — [1]Helmholtz-Zentrum Berlin, Germany — [2]Institute of Chemistry and Biochemistry, Freie Universität Berlin, Germany — [3]Leibniz Universität Hannover, Germany

Graphene oxide (GO) materials, while promising for various applications, can be difficult to fully understand and predict its properties due to the highly irregular molecular structure arising from several oxygen functionalizations across the surface. X-ray absorption spectroscopy (XAS) experiments and simulations can help provide valuable insight by characterizing the electronic structure of materials. However, there are problems with complex spectra being hard to interpret and the prohibitive computational simulation cost for large extended systems. We have developed a machine learning model utilizing graph neural networks (GNN) based on a database of 319 GO-derivative molecules, consisting of 7984 individual atomic XAS spectra calculated with time-dependent density functional theory (TDDFT), that can accurately simulate XAS spectra at a significant lower cost. We show how the model can learn through either the combined spectra of the GO-derivative molecules or the individual atomic spectra to make predictions based on either the larger global environment or the local atomic environment and can further be applied to larger extended systems.

TT 55: Topology and Symmetry Protected Materials (joint session O/TT)

Time: Wednesday 15:00–17:45 Location: HL 001

TT 55.1 Wed 15:00 HL 001

Interaction Effects in a 1D Flat Band at a Topological Crystalline Step Edge — •Souvik Das[1], Glenn Wagner[2], Johannes Jung[3], Artem Odobesko[3], Felix Kuester[1], Florian Keller[3], Jedrzej Korczak[4], Andrzej Szczerbakow[5], Tomasz Story[4], Ronny Thomale[6], Titus Neupert[2], Matthias Bode[3], Paolo Sessi[1], and Stuart S. P. Parkin[1] — [1]Max Planck Institute of Microstructure Physics, Halle 06120,Germany — [2]Department of Physics, University of Zürich, 8057 Zürich, Switzerland — [3]Physikalisches Institut, Experimentelle Physik II, Universität Würzburg, 97074 Würzburg, Germany — [4]Institute of Physics and International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, 02-668 Warsaw, Poland — [5]Institute of Physics, Polish Academy of Sciences, 02-668 Warsaw, Poland — [6]Institut für Theoretische Physik und Astrophysik Universität Würzburg, 97074 Würzburg, Germany

We utilize scanning tunneling microscopy and spectroscopy to explore the behavior of the 1D step-edge channels in PbSnSe, a topological crystalline insulator, under the influence of doping. By doping distinct 3d adatoms in PbSnSe we observed that once the energy position of the step edge is brought close to the Fermi level, a new correlation gap starts to open. Our experimental findings are rationalized in terms of enhanced interaction effects since the electron density of states condenses into a 1D channel. This enables us to realize a unique system to study how topology and many-body electronic effects intertwine.

TT 55.2 Wed 15:15 HL 001

Quantifying the Electronic Structure of at the Boundary of Topological Insulators by Means of Combined STM and AFM — •Christoph S. Setescak[1], Adrian Weindl[1], Andrea Donarini[2], and Franz J. Giessibl[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, Universitätstraße 31, 93080 Regensburg, Germany — [2]Institute of Theoretical Physics, University of Regensburg, Universitätstraße 31, 93080 Regensburg, Germany

We show that combined STM and AFM can characterize the surface electronic structure of topological insulators in the Bi2Se3-family. The electronic structure is described by an effective tight-binding Hamiltonian, which is derived from a GW-DFT calculation. A circumspect application of Bardeens model of tunneling current enables us to rigorously interpret tunneling spectroscopy experiments and thus identify characteristic points in the halfspace bandstructure. Furthermore, our experiments demonstrate, that spatially resolved maps of the local density of states can resolve individual electronic degrees of freedom energetically as well as spatially. We observed quasiparticle interference in the topological boundary mode of Bi2Te3 at one-dimensional defects, which enables us to quantify subtle hexagonal warping terms in the dispersion relation of the boundary mode. Our recent measurements, in combination with the ability to structurally characterize defects and the crystal structure at the picometer scale, underscore the potential of combined AFM and STM in exploring the evolution of topological phases amidst varying degrees of disorder.

TT 55.3 Wed 15:30 HL 001

Discovery of Segmented Fermi Surface — •Hao Zheng — Shanghai Jiao Tong University, Shanghai, China

Since the early days of Bardeen-Cooper-Schrieffer theory, it has been predicted that a sufficiently large supercurrent can close the energy gap in a superconductor and create gapless Bogoliubov quasiparticles through the Doppler shift of quasiparticle energy due to the Cooper pair momentum[1]. In this gapless superconducting state, zero-energy quasiparticles reside on a segment of the normal state Fermi surface, while its remaining part is still gapped. However, the segmented Fermi surface of a finite-momentum state carrying a supercurrent has never been detected directly. We use quasiparticle interference (QPI) technique to image field-controlled Fermi surface of Bi2Te3 thin films proximitized by the superconductor NbSe2. By applying a small in-plane magnetic field, a screening supercurrent is induced which leads to finite-momentum pairing on topological surface states of Bi2Te3[2]. Our measurements and analysis reveal the strong impact of finite Cooper pair momentum on the quasiparticle spectrum, and thus pave the way for STM study of pair density wave and FFLO states in unconventional superconductors. [1] Phys. Rev. 137, A783-A787 (1965) [2] Science 374, 1381-1385(2021)

TT 55.4 Wed 15:45 HL 001

Carrier Injection Observed by Interface-Enhanced Raman Scattering from Topological Insulators on Gold Substrates. — Sarah Scheitz, Tomke Eva Glier, Christian Nweze, •Malte Felix van Heek, Isa Moch, Robert Zierold, Robert Blick, Nils Huse, and Michael Rübhausen — Institute of Nanostructure and Solid-State Physics, University of Hamburg, Hamburg, 22761, Germany

The electron-phonon interaction at the interface between topological insulator (TI) of bismuth/tellurium and gold substrate as a function of TI nanoflakes thickness is studied with a sub-micron Raman spectroscopy. We show the presence of interface-enhanced Raman Scattering and strong phonon renormalization induced by carriers injected from the gold substrate into the topological surface in contact with the gold substrate. The associated electron-phonon coupling shows an approximate linear behavior as function of nanoflake thickness. The strongly nonlinear change of the Raman scattering cross-section as a function of flake thickness can be associated with band bending effects at the metal-TI interface. This provides spectroscopic evidence for strongly modified band structure in the first few quintuple layers of bismuth selenide and tellurium selenide TI.

TT 55.5 Wed 16:00 HL 001

Plasmonic Hot carrier Injection from Single Gold Nanoparticles into Topological Insulator (Bi_2Se_3) Nanoribbons — Christian Nweze[1], Tomke Eva Glier[1], •Mika Rerrer[1], Sarah Scheitz[1], Yalan Huang[2], Robert Zierold[2], Robert Blick[2], Wolfgang Parak[2], Nils Huse[2], and Michael Rübhausen[1] — [1]Institut für Nanostruktur- und Festkörperphysik, Centre for Free Electron Laser Science (CFEL), Universität Hamburg, Luruper Chaussee 149, 22761, Hamburg, Germany — [2]Institut für Nanostruktur- und Festkörperphysik, Centre for Hybrid Nanostructures (CHyN), Universität Hamburg, Luruper Chaussee 149, 22761, Hamburg, Germany

Plasmonic gold nanoparticles (AuNP) injecting hot carriers (HC) into the topological insulator (TI) are studied with sub-micron spatially resolved Raman spectroscopy. We study the impact of single AuNP with sizes between 40 nm–140 nm on the topological surface states of single nanoribbons. In resonance at 633 nm excitation wavelength, we find phonon renormalization in the E_g^2- and A_{1g}^2- modes that we attribute to plasmonic hot carrier injection filling the Dirac cone of the Bi_2Se_3 TI. The phonon modes are enhanced by a factor of 350 when tuning the excitation wavelengths into interband transition of the Bi_2Se_3 TI and in resonance with the localized surface plasmon of AuNP. AuNP size-dependent Raman studies show strongest HC injection for particles with a size of 108 nm in agreement with the resonance energy of the localized surface plasmons in AuNP. HC injection opens the opportunity to locally manipulate the electronic properties of the TI.

TT 55.6 Wed 16:15 HL 001

Phase-resolved near-field mapping of tight-binding lattices — •Hans-Joachim Schill, Anna Sidorenko, and Stefan Linden — Physikalisches Institut, Universität Bonn, D-53115-Bonn, Germany

The propagation of light in coupled arrays of dielectric loaded surface plasmon polariton waveguides (DLSPPWs) closely resembles the dynamics of a lattice Schrödinger equation, making it an excellent platform for simulating condensed matter lattice systems. The real and momentum space intensity distributions can be simply recorded by leakage radiation microscopy. In order to also capture the local near-field amplitude and phase with sub-wavelength resolution, we employ scattering-type scanning near-field optical microscopy in transmission mode. As an example, to discuss the capabilities of this dual-technique approach, we investigate the topological edge state in a plasmonic variant of the Su-Schrieffer-Heeger model. The topological nature of this state has been shown previously by spectral imaging of the edge mode residing in the band gap [1], but the characteristic electric field oscillation remained elusive, until now.

[1] F. Bleckmann, Z. Cherpakova (Fedorova), S. Linden and A. Alberti, "Spectral imaging of topological edge states in plasmonic waveg-

uide arrays", Phys. Rev. B 96, 045417 (2017)

TT 55.7 Wed 16:30 HL 001

The Trimer Chain: Robust Chiral Edge Mode in Artificial Electronic Lattices — •Rian Ligthart[1], Amber Visser[1], Dario Bercioux[2], and Ingmar Swart[1] — [1]Debye Institute for Nanomaterials Science, Utrecht University, the Netherlands — [2]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain

Artificial electronic lattices are a promising tool to study topology on an atomic scale. The Scanning Tunnelling Microscope (STM) allows to build the topological lattices by manipulating single atoms with nanoscale precision and to probe their electronic properties. Here, the semiconductor InAs(111)A surface with adsorbed Cs atoms is studied. Vertical and lateral manipulation allow to place multiple Cs-adatoms in vicinity of each other. Lines of positively charged Cs atoms create a potential well that confines the surface state electrons of InAs due to local band bending. The confined state acts as an artificial atom and can be used to construct a variety of structures. [1]

Artificial atoms can therefore be used as a platform to study the topological properties of model systems such as the SSH [2] and trimer chain. The trimer chain is similar to the SSH chain but has an extra atom in its unit cell. The extra hopping term introduces an extra degree of freedom in the system allowing to separate the the edge modes on the left and right side of the chain in energy. The trimer chain can therefore host a robust chiral edge mode on one side of the chain.

[1] E. Sierda, et al. Science 380, 1048-1052(2023)

[2] Van Dong Pham, et al. Phys. Rev. B, 105, 125418

TT 55.8 Wed 16:45 HL 001

Manipulating Sunken Adatoms on Topological Insulator Bi_2Se_3 — Emma Grasser, •Adrian Weindl, Alfred J. Weymouth, and Franz J. Giessibl — Faculty of Physics, University of Regensburg, D-93053 Regensburg, Germany

Topological insulators (TIs) are a class of materials whose bulk is insulating, while their surface houses gapless topological boundary modes. These surface states possess a linear, spin-polarized dispersion relation and are thus protected from back-scattering by time-reversal symmetry. An open question remains whether surface doping of magnetic elements can suppress this topological protection. Nanostructures made from magnetic adatoms are proposed to enhance the magnetic scattering and may enable the observation of backscattering and the emergence of exotic quantum well states on the surfaces of topological insulators.

To this end, we study the manipulation characteristics of Fe adatoms on the surface of topological insulator Bi_2Se_3 with atomic force microscopy (AFM). The Fe adatoms adsorb in a sunken position in both hollow sites, rendering manipulation difficult. Nonetheless, we find a manipulation mechanism where the Fe atom is pulled from its sunken adsorption site towards the tip. We propose that the Fe atom develops a chemical bond to the probe tip while still bound to the surface as well. This state is stable for tip-sample distances of up to several hundreds of pm and can be used for controlled lateral manipulation. We demonstrate the controllability of manipulation by the construction of a small nanostructure.

TT 55.9 Wed 17:00 HL 001

Giant tunable out-of-plane spin polarization in topological antimonene — •Polina Sheverdyaeva[1], Conor Hogan[2,3], Gustav Bihlmayer[4], Jun Fujii[5], Ivana Vobornik[5], Matteo Jugovac[1,6], Asish K. Kundu[1,7], Sandra Gardonio[8], Zipporah Rini Benher[8], Giovanni Di Santo[9], Sara Gonzalez[9], Luca Petaccia[9], Carlo Carbone[1], and Paolo Moras[1] — [1]ISM-CNR, Trieste, Italy — [2]ISM-CNR, Roma, Italy — [3]Dipartimento di Fisica, Università di Roma "Tor Vergata", Roma, Italy — [4]PGI and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [5]IOM-CNR, Trieste, Italy — [6]PGI, Forschungszentrum Jülich, Jülich, Germany — [7]ICTP, Trieste, Italy — [8]University of Nova Gorica, Ajdovščina, Slovenia — [9]Elettra - Sincrotrone Trieste S.C.p.A.,Trieste, Italy

We show first-principles calculations and angle- and spin- resolved photoemission studies of a heterointerface built of a single bilayer of β-antimonene and a bulk bismuth selenide. The trivial insulator β-antimonene inherits the topological surface state of the substrate as a result of a topological proximity effect. The new topological state exhibits an unusually high, almost complete out-of-plane spin polarization within the substrate gap, that we explain by a symmetry-protected band crossing of spin-polarized surface states. The spin polarization can be finely and reversibly tuned from nearly full out-of-plane to nearly full in-plane by electron doping. Our findings pave the way towards advanced spintronics applications exploiting the giant out-of-plane spin polarization of topological surface states.

TT 55.10 Wed 17:15 HL 001

Orbital-momentum locking in chiral topological semimetal CoSi — •Stefanie Suzanne Brinkman[1], Xin Liang Tan[1,2], Øyvind Finnseth[1], Anders Christian Mathisen[1], Ying-Jiun Chen[2], Christian Tusche[2], and Hendrik Bentmann[1] — [1]Center for Quantum Spintronics, Department of Physics, NTNU, Norway — [2]Forschungszentrum Jülich, Peter Grünberg Institut, Jülich, Germany

The chiral topological semimetal CoSi has a rich electronic structure in which unconventional chiral fermions and long surface Fermi arcs are observed near the Fermi level [1]. We studied the bulk electronic structure in CoSi using soft X-ray angle-resolved photoemission (ARPES) experiments via the ASPHERE endstation at PETRA III (DESY, Hamburg). We investigated the orbital character of the electronic states using circular dichroism in ARPES. Our results reveal the effect of the chiral crystal symmetry on the orbital structure in momentum space, and provide evidence of orbital-momentum locking as recently theoretically predicted [2]. This chirality-driven orbital texture with an accompanying large orbital Hall effect [2] paves the way towards applications of topological semimetals in spin- and orbitronics.

[1] Rao, Z. et al. Observation of unconventional chiral fermions with long Fermi arcs in CoSi. Nature 567, 496-499 (2019).

[2] Yang, Qun et al. Monopole-like orbital-momentum locking and the induced orbital transport in topological chiral semimetals. PNAS 120, 48 (2023).

TT 55.11 Wed 17:30 HL 001

Boundary-induced delocalization of vortices in the topological superconductor — •Qiao-Yan Yu — Shanghai Jiao Tong University, Shanghai, China

Planar defects are predicted to induce a delocalization of Abrikosov vortices in superconductors. These delocalized vortices are perturbated by the supercurrent and thus might carry a fraction of a flux quantum. In this work, we constructed a topological superconductor heterostructure by growing Bi2Te3 thin films with molecular beam epitaxy on the superconductor NbSe2. We reveal that the domain boundary induced partial spatial distribution of vortex and screened in-gap bound states within the vortex which crossing the boundary. Our results show the signature of impact of domain boundary on the Majorana zero mode.

TT 56: Focus Session: Recent Progresses in Criticality in the Presence of Boundaries and Defects II (joint session DY/TT)

In recent years there has been a renewed interest in critical systems in the presence of boundaries or, more generally, defects. This attention is driven by different perspectives. Numerical studies of quantum spin models have reported in some cases unexpected boundary critical behavior. This, in turns, has led to a reconsideration of the classical surface critical behavior problem, with the discovery of so-far overlooked boundary phases. In this context, numerous recent studies have considered the so-called symmetry-protected topological gapless systems, and in particular their boundary states. At the same time, advances in conformal field theory, specifically the conformal bootstrap program, have addressed the problem of boundaries and defects in conformally-invariant theories. This Focus Session brings together some of the main actors in the aforementioned advancements in boundary critical phenomena.

Organized by Francesco Parisen Toldin (Aachen) and Stefan Wessel (Aachen)

Time: Wednesday 15:00–16:15 Location: A 151

Invited Talk TT 56.1 Wed 15:00 A 151

Conformal boundary conditions of symmetric quantum critical states — •Long Zhang — University of Chinese Academy of Sciences, Beijing 100190, China

Some quantum critical states cannot be smoothly deformed into each other without either crossing some multicritical points or explicitly breaking certain symmetries even if they belong to the same universality class. This brings up the notion of "symmetry-enriched" quantum criticality. While recent works in the literature focused on critical states with robust degenerate edge modes, we propose that the conformal boundary condition (b.c.) is a more generic characteristic of such quantum critical states. In the first part of this talk, we show that in two families of quantum spin chains, which generalize the Ising and the three-state Potts models, the quantum critical point between a symmetry-protected topological phase and a symmetry-breaking order realizes a conformal b.c. distinct from the simple Ising and Potts chains at both the physical and the entangling boundaries. Furthermore, we argue that the conformal b.c. can be derived from the bulk effective field theory, which realizes a novel bulk-boundary correspondence in symmetry-enriched quantum critical states. In the second part, we will show the effect of finite-entanglement scaling of matrix-product states on their conformal b.c. at both the physical and the entangling boundaries.

TT 56.2 Wed 15:30 A 151

Universal fragility of spin-glass ground-states under single bond changes — Mutian Shen[1], Gerardo Ortiz[2], Yang-Yu Liu[3], •Martin Weigel[4], and Zohar Nussinov[1] — [1]Department of Physics, Washington University, St. Louis, MO 63160, USA — [2]Department of Physics, Indiana University, Bloomington, IN 47405, USA — [3]Harvard Medical School, Boston, MA, 02115, USA — [4]Institut für Physik, Technische Universität Chemnitz, 09107 Chemnitz, Germany

We examine the effect of changing a single local bond on ground states of the Edwards-Anderson Ising spin-glass in two and three dimensions and with a Gaussian distribution of couplings. We find such ground states to be exceedingly fragile: altering the strength of only a single bond beyond a critical threshold value leads to a new ground state that differs from the original one by a cluster ("critical zero energy droplet") of flipped spins whose boundary and volume diverge with system size — an effect that is reminiscent of the more familiar phenomenon of disorder chaos. At the same time, these elementary clusters provide the lowest-energy macroscopic excitations in short-range spin-glasses above the lower critical dimension. The presence of such excitations with fractal boundaries provides a strong characterization of the spin-glass phase in these systems. Within numerical accuracy, the size of these clusters is governed by a nearly universal power-law distribution with exponents depending on the spatial dimension of the system. The critical coupling strengths follow a stretched Gaussian distribution that is largely set by the local coordination number of the lattice.

TT 56.3 Wed 15:45 A 151

Random Matrices and the Free Energy of Ising-Like Models with Disorder — •Nils Gluth, Thomas Guhr, and Fred Hucht — Fakultät für Physik, University of Duisburg-Essen, Duisburg, Germany

We consider an Ising model with quenched surface disorder, the disorder average of the free energy is the main object of interest. Explicit expressions for the free energy distribution are difficult to obtain if the quenched surface spins take values of ± 1. Thus, we choose a different approach and model the surface disorder by Gaussian random matrices. The distribution of the free energy is calculated. We chose skew-circulant random matrices and compute the characteristic function of the free energy distribution. We show numerically the distribution becomes log-normal for sufficiently large dimensions of the disorder matrices, and in the limit of infinitely large matrices the distributions are Gaussian. Furthermore, we establish a connection to the central limit theorem.

TT 56.4 Wed 16:00 A 151

The Griffiths phase and beyond: a large deviations study — •Lambert Münster[1], Alexander K. Hartmann[2], and Martin Weigel[1] — [1]Institut für Physik, TU Chemnitz, 09107 Chemnitz, Germany — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26129 Oldenburg, Germany

The Griffiths phase is a temperature range in systems with quenched disorder that reaches from the critical temperature of the pure system to the corresponding critical temperature in the presence of disorder. In this phase, the possibility of large fluctuations in the disorder degrees of freedom leads to broad distributions in response functions. For example, inside the Griffiths phase of the two-dimensional bond-diluted Ising model the distribution of the magnetic susceptibility is expected to have an exponential tail [1]. A large-deviation Monte Carlo algorithm is used to sample this distribution [2,3], and the exponential tail is extracted over a wide range of the support down to probabilities of the order of 10^{-300}. A connection between the local fraction of ferromagnetic bonds and the size of the magnetic susceptibility is demonstrated numerically. Furthermore the distribution of the magnetic susceptibility is also investigated at the ferromagnetic phase transition, inside the ferromagnetic phase and at zero temperature, revealing interesting differences and similarities between the cases.

[1] A. J. Bray, Phys. Rev. Lett. **59**, 586 (1987).
[2] A. K. Hartmann, Phys. Rev. E **65**, 056102 (2002).
[3] K. Hukushima, Y. Iba, J. Phys. Conf. Ser. **95**, 012005 (2008).

TT 57: Topology: Poster

Time: Wednesday 15:00–18:00 Location: Poster E

TT 57.1 Wed 15:00 Poster E

Orbital magnetization of Dirac electrons on surfaces with constant curvature — •Maximilian Fürst[1], Denis Kochan[2], and Klaus Richter[1] — [1]University of Regensburg, Germany — [2]Slovak Academy of Sciences, Slovakia

Topological insulator (TI) nanowires exhibit strong spin-orbit coupling with surface states that are well-protected against backscattering [1]. Shaping such nanowires, i.e. varying their cross-section smoothly along the nanowire axis, opens up the possibility to study curvature effects of the TI surface states. This yields significant modifications of the magneto transport features [2] and allows for studying quantum Hall physics in curved 2D space showing peculiar spectra of Landau levels [3]. Complementary to this, here we study the orbital magnetic response of nanowires with curved surfaces. In particular, we consider the magnetic susceptibility for conducting surfaces with constant Gaussian curvature in presence of a coaxial, homogeneous magnetic field.

[1] X.-L. Qi and S.-C. Zhang, Rev. Mod. Phys. 83, 1057 (2011)
[2] R. Kozlovsky, A. Graf, D. Kochan, K. Richter, C. Gorini, Phys. Rev. Lett. 124, 126804 (2020)
[3] M. Fuerst, D. Kochan, C. Gorini, K. Richter, arXive2307.09221 (2023)

TT 57.2 Wed 15:00 Poster E

Quantum coherent transport and Electron-electron interaction in $BiSbTe_3$ single crystals — •Indu Rajput, Sonali Baral, Mukesh Kumar Dasoundhi, Devendra Kumar, and Archana Lakhani — UGC-DAE Consortium for Scientific Research, University Campus, Khandwa Road, Indore-452001, India

The ternary alloy $(Bi_{1-x}Sb_x)_2Te_3$ serves as a promising Topological insulators (TIs), switching between p and n-type semiconductors by fine tuning of E_F by varying the concentration x[1]. While the precise Bi:Sb ratio crucially positions the E_F within the band, the role of defects that occurs during growth process of single crystals remains largely unexplored despite their observations in other TIs [2]. Here we present the effect of defects on the magnetotransport properties of $BiSbTe_3$ single crystals. Two distinct crystals, S1 and S2 sourced from the same boule, exhibit contrasting behaviors: S1 displays metallic traits, while S2 represents a complex multi-transport mechanism involving thermal activation, hopping conduction of localized charge carriers, quantum coherent transport, and electron-electron interaction across varying temperatures. Comprehensive analysis of resistivity and magnetoresistance patterns unveils weak antilocalization behavior, elucidated by the Hikami-Larkin-Nagaoka formula. These observations suggest the presence of multichannel quantum coherent transport, which depends on the thickness of sample.

[1] J. Zhang, et al. Nat. Commun. **2**, 574 (2011)
[2] A. Lakhani et al. Appl. Phys. Lett. **114**, 182101 (2019)

TT 57.3 Wed 15:00 Poster E

Nearly perfectly compensated Topological Insulator $Bi_{1.08}Sn_{0.02}Sb_{0.9}Te_2S$ without charge puddles? — •Rajendra Loke, Rohit Sharma, Mahasweta Bagchi, Yongjian Wang, Yoichi Ando, Thomas Lorenz, and Joachim Hemberger — Physics Institute II, University of Cologne, Zülpicher Straße 77, D-50937 Cologne, Germany.

In topological insulators the bulk conductivity can successfully be suppressed by compensation doping. However, fluctuations of the Coulomb potential usually lead to the formation of mesoscopic charge puddles, which strongly influence the transport properties as magnetic fields may generate a percolating path for conductivity. But even in the non-percolating case, the high DC-resistivity can be overcome at high enough frequencies. The cut-off frequency ν_c, for which AC-conductivity sets in, is related the puddle size and may be located in the microwave regime. The value of ν_c is magnetic field dependent, giving rise to a large positive magnetoconductivity in the gigahertz range [1]. Here we present impedance spectroscopy measurements on various TI systems. While e.g. $BiSbTeSe_2$ (BSTS) shows large positive magneto-conductivity in the GHz range due to the increase of the puddle size in magnetic field, the system $Bi_{1.08}Sn_{0.02}Sb_{0.9}Te_2S$ (Sn-BSTS) only exhibits the Weak Anti-localization effect, a signature of the surface states of Dirac materials, associated with negative magneto-conductivity. Therefore, in Sn-BSTS does not show any signature of puddle formation (in the frequency range measured so far).

TT 57.4 Wed 15:00 Poster E

Band structure and topology of the chiral semimetal CoSi — •B.V. Schwarze[1,2], J. Hornung[1], K. Manna[3], S. Shekhar[3], S. Chattopadhyay[1], C. Felser[3], and J. Wosnitza[1,2] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany

CoSi is a chiral semimetal hosting an exceptional topology critically depending on the spin-orbit coupling (SOC). Without SOC, the topology features two band-touching nodes with a Chern number of two and nodal planes. With SOC, the two band-touching nodes have a Chern number of four and there is an additional singular Weyl point. To date, the experimental significance of the SOC in CoSi is controversial.

Here, we present our detailed investigation of the bulk band-structure of CoSi with band-structure calculations and angular-dependent de Haas-van Alphen measurements up to 18 T and down to 40 mK. Our results reveal six clearly spin-split bands crossing the Fermi energy, substantiating the significance of the SOC and verifying the topology. Furthermore, we report on three additional quantum-oscillation frequencies which are predicted by calculations but have never been observed before.

TT 57.5 Wed 15:00 Poster E

Anomalous Hall Effect in $EuSn_2As_2$ Thin Flakes — •Evgenii Maltsev, Louis Veyrat, Joseph Dufouleur, Romain Giraud, Nicolas Perez Rodriguez, and Bernd Büchner — IFW Dresden, Dresden, Germany

$EuSn_2As_2$ is an intrinsic antiferromagnetic topological insulator (TI) with a Néel temperature $T_N = 24$ K and an easy-plane anisotropy. Despite the interest in magnetic TIs, no transport measurements of $EuSn_2As_2$ nanostructures were reported up until now. Here, we present the first magnetotransport study on exfoliated nanostructures of $EuSn_2As_2$ with thicknesses between 60nm to 140nm. In particular, we study the magnetoresistance with respect to magnetic field orientation tilted between out-of-plane and in-plane directions. A small easy-plane magnetic anisotropy is found as previously reported for macrocrystals. Moreover, an anomalous Hall effect (AHE) is observed below T_N. The complex AHE shape does not appear directly compatible with a simple easy-plane anisotropy pointing to a potentially more complex magnetism in $EuSn_2As_2$ nanostructures.

We thank Kirill Pervakov for the help with crystal growth and Dr. Vladimir Pudalov for mentoring.

TT 57.6 Wed 15:00 Poster E

Nonlinear transport in the topological semimetal $ZrTe_5$ — •Yongjian Wang[1], Henry F. Legg[2,3], Thomas Bömerich[2], Jinhong Park[2], Sebastian Biesenkamp[1], Alexey Taskin[1], Markus Braden[1], Achim Rosch[2], and Yoichi Ando[1] — [1]Institute of Physics II, University of Cologne, D-50937 Köln, Germany — [2]Institute for Theoretical Physics, University of Cologne, D-50937 Köln, Germany — [3]Department of Physics, University of Basel, CH-4056 Basel, Switzerland

The topological semimetal $ZrTe_5$ has been a focus of significant interest in recent years. Here we report our discovery that $ZrTe_5$ crystals in proximity to a topological quantum phase transition present gigantic magnetochiral anisotropy (MCA) [1] and non-ohmic behavior [2]. The MCA in $ZrTe_5$ is the largest ever observed to date as a bulk property, which is explained by the combination of very low carrier density, inhomogeneities, and a torus-shaped Fermi surface induced by breaking of inversion symmetry [1]. Besides, in $ZrTe_5$ samples with extremely low carrier density, pronounced nonlinear current-voltage characteristics were observed when the current and magnetic field are both along the crystallographic a-axis. The non-ohmic behavior in the $ZrTe_5$ having torus Fermi surface is likely due to the combined effect of ultra-flat bands and charge puddles, the former shows up as a result of Landau quantization when the magnetic field is applied in the torus plane [2].

[1] Y. Wang et al., PRL 128, 176602 (2022)
[2] Y. Wang et al., PRL 131, 146602 (2023)

TT 57.7 Wed 15:00 Poster E

Evolution of Floquet topological quantum states in driven semiconductors — Andreas Lubatsch[1] and •Regine Frank[2,3] — [1]Physikalisches Institut, Rheinische Friedrich Wilhelms Universität Bonn — [2]College of Biomedical Sciences, Larkin University, Miami, Florida, USA — [3]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain

Spatially uniform excitations can induce Floquet topological bandstructures within insulators which have equal characteristics to those of topological insulators. We demonstrate the evolution of Floquet topological quantum states for electromagnetically driven semiconductor bulk matter. We show the direct physical impact of the mathematical precision of the Floquet-Keldysh theory when we solve the driven system of a generalized Hubbard model with our framework of dynamical mean field theory (DMFT) in the non-equilibrium with physical consequences for optoelectronic applications.

[1] A. Lubatsch, R. Frank, Eur. Phys. J. B 92 (2019) 215
[2] A. Lubatsch, R. Frank, Symmetry 11 (2019) 1246
[3] P.-C. Chang, J.G. Lu, Appl. Phys. Lett. 92 (2008) 212113

TT 57.8 Wed 15:00 Poster E

Exploring the Effects of a 1D Periodic Potential on a 3D Topological Insulator — •Albert Koop, Alexander Altmann, Dimitriy Kozlov, and Dieter Weiss — Institute of Experimental and Applied Physics, University of Regensburg, Germany

In this work, we have investigated the effect of a weak 1-dimensional periodic potential on the conductivity of 3D high-mobility topological insulator (TI) based on 80nm HgTe film. A stripe gate formed the modulation potential, while a uniform gate additionally covered the whole structure. This makes it possible to change both the position of the Fermi level and the strength of the 1D potential. The classical magnetoresistance ρ_{xx} manifests a pronounced oscillation with minima described by the commensurability condition $2R_c/a = (\lambda - 1/4)$ with $\lambda = 1, 2, 3...$ where R_c is the cyclotron radius and a is the period of the 1D potential. We observed the commensurability features coming from both electrons and holes. On the electron side, the contribution of top-surface electrons (i.e., topological electrons located closer to the gate) dominated in the observed pattern, while all other carriers acted as a background. However, in the valence band, where bulk holes and Dirac electrons coexist, we observed the previously unexplored situation that both electrons and holes can contribute to the commensurability oscillations.

HgTe provided by N. Mikhailov and S. A. Dvoretskii, Novosibirsk.

TT 57.9 Wed 15:00 Poster E

Minimal Model of the Magnetic Weyl Semimetal $EuCd_2As_2$ — •Hannah Price and Carsten Timm — Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany

Weyl semimetals provide an interesting new landscape to study frustrated magnetism due to the mixed charge and spin response. We investigate the interaction and magnetic order of rare-earth magnetic moments mediated by RKKY interactions. In particular, we will examine the proposed Weyl semimetal $EuCd_2As_2$. Using symmetry arguments we determine a minimal tight-binding model of the electronic and magnetic properties of the material. Additionally, we study the magnetic ordering of the rare-earth magnetic moments using classical Monte Carlo simulations.

TT 57.10 Wed 15:00 Poster E

Instabilities driven by electron-electron interactions in Weyl semimetals — •Eva Lopez Rojo, Julia M. Link, and Carsten Timm — TU Dresden, Germany

The consequences of electron-electron interactions in the presence of two Weyl points has been previously studied [1-3]. Inter-valley interactions, meaning interactions between electrons in each of the Weyl cones with opposite chirality, have been found to give rise to an excitonic instability. The resulting exciton condensate spontaneously breaks chiral symmetry, transforming the Weyl semimetal into an axionic insulator. The resulting charge density wave phase and its topological properties have also been examined. In this poster, we introduce a formalism that enables the exploration of how the aforementioned axionic physics extends to a more realistic scenario featuring multiple Weyl points.

[1] Z. Wang and S.-C. Zhang, Phys. Rev. B **87**, 161107(R) (2013).
[2] D. Sehayek, M. Thakurathi, and A. A. Burkov, Phys. Rev. B **102**, 115159 (2020).
[3] E. Bobrow, C. Sun, and Y. Li, Phys. Rev. Res. **2**, 012078(R) (2020).

TT 57.11 Wed 15:00 Poster E

Topological flat bands in d-wave superconductors — •Gabriele Domaine[1,2], Yiran Liu[2], Tohru Kurosawa[3], Julia Diana Küspert[4], Pietro Maria Bonetti[2], Shigemi Terakawa[1], Ding Pei[5], Mihir Date[1], Matteo Minola[2], Izabela Biało[4], Timur Kim[6], Matthew D. Watson[6], Jiabao Yang[1], Naoki Momono[3], Migaku Oda[7], Neven Barišić[8], Cephise Cacho[6], Stuart Stephen Papworth Parkin[1], Johan Chang[4], Bernhard Keimer[2], Andreas P Schnyder[2], and Niels B. M. Schröter[1] — [1]Max Planck Institute of Microstructure Physics, Halle (Saale), Germany — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany — [3]Department of Applied Sciences, Muroran Institute of Technology, Muroran, Japan — [4]Physik-Institut, Universität Zürich, Zürich, Switzerland — [5]Synchrotron-SOLEIL, Université Paris-Saclay, Saint-Aubin, BP48, Gif sur Yvette, Paris F91192, France — [6]Diamond Light Source, Harwell Campus, Didcot, OX11 0DE, United Kingdom — [7]Department of Physics, Hokkaido University, Sapporo, Japan — [8]Department of Physics, Faculty of Science, University of Zagreb, Bijenička cesta 32, 10000 Zagreb

In superconductors with a d(x2-y2)-gap symmetry, the existence of a non-zero winding number leads to the appearance of zero-energy flat-bands on certain edges. These bands are protected by the chiral symmetry and occupy a two-dimensional region of the Brillouin zone bounded by the projections of the superconducting nodes. A recently established approach to cleave crystals by means of micronotches paves the way for the study of these surface states by ARPES.

TT 57.12 Wed 15:00 Poster E

STM studies on the Weyl-semimetal and superconductor trigonal $PtBi_2$ — •Julia Besproswanny[1], Sebastian Schimmel[1], Sven Hoffmann[1], Gregory Shipunov[2], Saicharan Aswartham[2], Joaquin Puig[3], Yanina Fasano[3], Danny Baumann[2], Jeroen van den Brink[2], Ricardo Vocaturo[2], Jorge I. Facio[3], Bernd Büchner[2], and Christian Hess[1] — [1]University of Wuppertal, 42119 Wuppertal, Germany — [2]IFW Dresden, 01069 Dresden, Germany — [3]Centro Atómico Bariloche, Instituto Balseiro, 8400 Bariloche, Argentina

We report a comprehensive study of the type-I Weyl-semimetal $PtBi_2$, exploring its topological and superconducting properties through low-temperature scanning tunneling microscopy and spectroscopy.

Quasi-particle-interference measurements confirm the topological nature through the presence of Fermi-arcs. Spectroscopic investigations reveal sample dependent electronic structure near the Fermi-level, ranging from metallic characteristics to the presence of particle-hole symmetric energy gaps implying superconductivity. Most notably, the largest observed energy gap suggests a critical temperature T_c in the range of 120 K, two orders of magnitude above the previously reported T_c measured via bulk-sensitive methods. The data provide indications that the superconductivity possibly arises out of topological surface states. This would make trigonal $PtBi_2$ a potential candidate for an intrinsic topological superconductor with a T_c above liquid nitrogen temperatures, highlighting it as a promising material for technological applications in quantum computing.

TT 57.13 Wed 15:00 Poster E

Majorana Chains using 2π Domain Walls — •Daniel Hauck[1], Stefan Rex[2,3], and Markus Garst[1] — [1]Karlsruhe Institute of Technology, Institute for Theoretical Solid State Physics, Wolfgang-Gaede-Str. 1, 76131 Karlsruhe — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [3]Institute for Theoretical Condensed Matter Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe

Superconductor-magnet hybrid structures provide a platform for investigating topological phases with localized Majorana states. Such states have previously been predicted in the presence of elongated Skyrmions in the magnetic layer. Here, we consider 2π domain walls that can be easily controlled experimentally. We show that Majorana states can occur in these systems and discuss the possibility of building Majorana chains using a sequence of 2π domain walls.

TT 57.14 Wed 15:00 Poster E

Majorana bound state signatures on the magnetic flux-dependent zero bias conductance — •Cajetan Heinz[1], Patrik Recher[1,2], and Fernando Dominguez[1] — [1]Institute of Mathematical Physics, Technical University of Braunschweig, D-38106

Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology Braunschweig, D-38106 Braunschweig, Germany

We propose a theoretical framework designed to unravel the p-wave character of the Majorana bound state (MBS) through an analysis of the periodicity in the flux-dependent zero-bias conductance. Our goal is to obtain an experimentally detectable signal that cannot be mimicked by zero energy Andreev bound states. We use a tight-binding model that describes a quantum spin Hall insulator (QSHI) - topological superconductor junction, where a MBS is expected to form at the NS boundary. By applying a magnetic flux, we explore the scattering processes of the QSHI edge states with the MBS. This configuration manifests distinct indicators of a topological non-trivial phase even in the presence of non-zero temperatures and weak coupling between the superconductor and the normal part. Additionally, we employ a scattering network to gain insight into the underlying physics governing the junction.

TT 57.15 Wed 15:00 Poster E

Chiral Majorana network in the BHZ model — Lena Bittermann[1], Patrik Recher[1,2], and •Fernando Dominguez[1] — [1]Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology Braunschweig, D-38106 Braunschweig, Germany

We investigate the energy spectrum and conductance properties of a 2 dimensional topological superconductor, which varies its Chern number spatially with a chessboard pattern. This can be achieved, for example, in topological superconductors described by the BHZ model, where the presence of a spatial dependent electric field can modulate the relative strength of the Rashba and the Dresselhaus spin-orbit coupling [1]. In this scenario, a pair of copropagating chiral Majorana modes appears at the interfaces with a Chern number difference of 2, resulting into a chiral Majorana network that extends over the whole system. To this aim, we develop a Chalker-Coddington scattering model [2], that captures the basic scattering processes that occur at the vortices between four different boundaries. We investigate further, the impact of defects and disorder in the conductance properties.

[1] L. Weithofer and P. Recher, New J. Phys. 15, 085008 (2013)
[2] J. T. Chalker and P. D. Coddington, J. Phys. C: Solid State Phys. 21, 2665 (1988)

TT 57.16 Wed 15:00 Poster E

Photonic noise spectroscopy of Majorana bound states — •Lena Bittermann[1], Fernando Dominguez[1], and Patrik Recher[1,2] — [1]Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology Braunschweig, D-38106 Braunschweig, Germany

We propose a route to detect Majorana bound states (MBSs) by coupling a topological superconductor to quantum dots (QDs) in a pnp junction. Here, two MBSs are coherently coupled to the electron levels of the two QDs, and via electron-hole recombination, photons are emitted. We focus on the cross-correlated shot noise and the polarization of the emitted photons, and discuss the processes of crossed Andreev reflection, elastic cotunneling and local tunneling processes [1]. Our detection scheme allows us to probe the existence of non-local triplet superconducting correlations and that two MBSs comprise a single fermion [2]. We compare our results to the ones obtained from quasi-Majorana bound states [3], giving rise to signatures that deviate from the MBSs scenario.

[1] L. Bittermann, C. De Beule, D. Frombach, P. Recher, PRB 106, 075305 (2022).
[2] A. Y. Kitaev, Phys.-Usp. 44, 131 (2001).
[3] G. Kells, D. Meidan, P. W. Brouwer, PRB 86, 100503(R) (2012).

TT 57.17 Wed 15:00 Poster E

Long Range Interactions in Synthetic Dimensions — •Patrick Geraghty[1] and Matteo Rizzi[2] — [1]University of Cologne, Cologne, Germany — [2]University of Cologne, Cologne, Germany

In recent cold atom experiments, the utilization of internal degrees of freedom as synthetic dimensions has enabled the simulation of higher-dimensional systems. Specifically, magnetic quantum numbers have been employed to transform a 1D chain of atoms into a synthetic 2D lattice, resulting in the realization of an integer quantum Hall state. However, this configuration introduces highly anisotropic and long-range particle interactions. To facilitate theoretical analysis, we develop a 1D effective model in the limit of infinite interaction anisotropy. This model serves as a simplified representation, allowing us to explore the impact of long-range interactions on the phases realized in the system. Our investigation delves into the emergence of new phases, the study of phase transitions, and the stability of configurations under the influence of extreme long-range interactions. This research contributes to a deeper understanding of the intricate interplay between synthetic dimensions and particle interactions in cold atom systems.

TT 57.18 Wed 15:00 Poster E

Topology of open spin chains — •Alexander Sattler and Maria Daghofer — Institut für Funktionelle Materie und Quantentechnologien, Universität Stuttgart, 70550 Stuttgart, Germany

Some spin chains, for example the Haldane chain or a topological dimerized chain, feature topologically protected edge states that are robust against some kind of noise. Despite their great appeal such spin states have not yet been created in a controlled manner in solid states environments, as spin chains on surfaces, where such a robustness can be quantified. We are here interested in the robustness of edge states against the coupling with surface.

Beyond that, since no physical system is perfectly isolated, it is of general interest to study whether the topological robustness is still given if there is a coupling with an environment.

The theoretical investigation is based on an alternating Heisenberg spin chain with spin-1/2, which is investigated by means of exact diagonalization. The coupling with the environment is modeled with the Lindblad-Master equation, whereby the jump operators are chosen in such a way that decoherence and spin flips occur.

We find, that the analyzed topological spin chain is susceptible to coupling with an environment just like topologically trivial spin chains. This can be seen in the time evolution of e.g. the topological energy gap, entropy, fidelity and edge state magnetization.

TT 57.19 Wed 15:00 Poster E

Non-Hermitian topological ohmmeter — Viktor Könye[1,2], Kyrylo Ochkan[1,2], •Anastasiia Chyzhykova[1,3], Jan Carl Budich[4,2], Jeroen van den Brink[1,2,4], Ion Cosma Fulga[1,2], and Joseph Dufouleur[1,2] — [1]Leibniz Institute for Solid State and Materials Research, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, 01062 Dresden, Germany — [3]Taras Shevchenko National University of Kyiv, Volodymyrska Street 60, 01033 Kyiv, Ukraine — [4]Department of Physics, TU Dresden, 01062 Dresden, Germany

We introduce and experimentally implement a groundbreaking electronic ohmmeter that capitalizes on the unique properties of non-Hermitian matrices, specifically their spectral sensitivity. Notably, the precision of our multi-terminal device, characterized by a non-Hermitian conductance matrix, increases exponentially with the number of terminals. We demonstrate its superiority over a standard measurement, achieving precision levels exceeding an order of magnitude. Our findings not only represent a significant advancement in addressing the critical challenge of accurately measuring large resistances but also establish a broader framework for leveraging the timely and interdisciplinary field of non-Hermitian topology in the domain of high-precision sensing.

TT 57.20 Wed 15:00 Poster E

Phonon topology and winding of spectral weight in graphite — •Stanislav E. Nikitin[1], N. D. Andriushin[2], A. S. Sukhanov[2], A. N. Korshunov[3], M. S. Pavlovskii[4], and M. C. Rahn[2] — [1]Paul Scherrer Institut, Switzerland — [2]TU Dresden, Germany — [3]ESRF, France — [4]Krasnoyarsk

The topology of electronic and phonon band structures of graphene is well studied and known to exhibit a Dirac cone at the K point of the Brillouin zone. In the talk I will discuss our recent results on phonon topology in graphite, the 3D analogue of graphene. We found a pair of modes that exhibit a weak anticrossing at the K point and can be viewed as a Dirac cone approximant. The spectral weight exhibit harmonic modulation above and below the Dirac energy in agreement with predictions for the Dirac point. We illustrate how such intensity modulation can be understood in terms of atomic displacements. Our results demonstrate how inelastic x-ray scattering can be used to experimentally investigate topological properties of the phonon band structure.

TT 57.21 Wed 15:00 Poster E

Symmetry-enforced topological band degeneracies in non-Hermitian periodic systems — •Reuel Dsouza[1,2] and Andreas

Schnyder[1] — [1]Max-Planck-Institute for Solid State Physics, D-70569 Stuttgart, Germany — [2]Department of Physics, University of Stuttgart, Germany

Non-Hermitian Hamiltonians are effective descriptions of non-equilibrium systems, in which quantities such as energy or particle number are not conserved. Similar to Hermitian systems, periodic non-Hermitian Hamiltonians can exhibit non-trivial band topologies, depending on the on-site and lattice symmetries. An important class of symmetries that gives rise to topological band degeneracies are the non-symmorphic symmetries, such as screw rotation or glide mirror. Here, we apply these symmetries to non-Hermitian Bloch Hamiltonians. We show that these symmetries give rise to interesting complex energy eigenvalue spectra with symmetry-enforced exceptional points as well as regular band degeneracies. We characterize these degeneracies with discriminant and vorticity numbers and develop a general classification of symmetry-enforced band degeneracies.

TT 57.22 Wed 15:00 Poster E

Topological phase diagram of the s-d–Hubbard model on finite clusters — •Christian Jöns — Max-Planck-Institut für Struktur und Dynamik der Materie, Hamburg, Germany

Topological concepts in solid-state physics are widely used and applied, e.g., to classify topological insulators. Furthermore, these concepts allow to better understand the famous quantum-Hall effect. The state of quantum-Hall systems with broken time-reversal symmetry is described by the quantized Chern number, a topological invariant. A nonzero Chern number also implies the existence of protected edge states which are observable experimentally.

Here, we consider topological classification starting from an intrinsic parameter manifold different from the reciprocal space. We study interacting electron systems with local spin exchange coupled to the S^2 and products of S^2. These manifolds represent the configuration spaces of a single or several impurity spins assumed as classical vectors. Topological classification of the s-d–Hubbard model on finite clusters in different geometries is achieved by means of the Nth spin-Chern number. Phase diagrams in the Hubbard-U – exchange-coupling-J plane are computed and discussed. With an analytical relation between the linear response and the spin-Chern number we can look for new insights of $\langle \hat{s} \rangle (\vec{S})$, with $\vec{S} \in S^2$.

TT 57.23 Wed 15:00 Poster E

Fractonic excitations in the U(1)-enriched toric code? — •Maximilian Vieweg and Kai Phillip Schmidt — Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We study the properties of different symmetry sectors in the U(1)-enriched toric code[1]. Only distinct symmetry sectors posses states which exhibit maximal connectivity in the Hilbert space. We argue that these symmetry sectors have a ground state energy that lies bellow other symmetry sectors without such states. This claim is consistent with our ED calculation and previous QMC calculations done by Kai-Hsin Wu et al.[1]. This leads to energy barriers which restrict the mobility of plaquette excitations under small magnetic perturbations in complete analogy to fracton excitations. Furthermore we use perturbation theory on a finite system to study the kinetic hopping processes of these excitations.

[1] K.-H. Wu, A. Khudorozhkov, G. Delfino, D. Green, C. Chamon, Phys. Rev. B 108 (2023) 115159

TT 58: $SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor: Poster (joint session TT/KFM/MA/O)

Strontium titanate ($SrTiO_3$) is a paradigmatic material that plays an important role in various fields of solid-state physics, surface science and catalysis: The pure bulk phase is a wide-band-gap semiconductor that upon cooling becomes a textbook quantum paraelectric. When slightly doped, $SrTiO_3$ turns into a Fermi-liquid-type metal that becomes superconducting at extremely low charge carrier density. $SrTiO_3$-based surfaces and interfaces host un-conventional electronic states such as quasi-two-dimensional electron liquid, magnetism and superconductivity. Despite intensive studies over the past decades, $SrTiO_3$ continues to reveal surprising new phenomena that challenge the established views on this material. To this end achieving light-induced nonequilibrium states and the recent preparation of a 2D oxide based on $SrTiO_3$ opens new playgrounds for research. This Focus Session will present exciting developments in the study of electronic states that are based on the peculiar properties of $SrTiO_3$.

Please note that this Focus Session comprises four parts: Posters are presented within the TT poster session TT58, Wed 15:00-18:00, poster area E. Invited talks are compiled in the session TT62 (Thursday, 9:30 to 12:45, H0104), Contributed talks will be presented in sessions TT72 (Thursday 15:00-18:00, H0104) and TT83 (Fri 9:30-12:30, H0104).

Organizers: Rossitza Pentcheva, University of Duisburg-Essen, Marc Scheffler, University of Stuttgart

Time: Wednesday 15:00–18:00 Location: Poster E

TT 58.1 Wed 15:00 Poster E

Optical conductivity of superconducting Nb:$SrTiO_3$ in magnetic fields at GHz frequencies — •Cenk Beydeda[1], Markus Thiemann[1], Martin Dressel[1], Hans Boschker[2], Jochen Mannhart[2], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart

Doped $SrTiO_3$ was among the first unconventional superconductors, the application of the BCS theory is questionable due to the small Fermi energy. Here we present the optical conductivity ($1-30\,\mathrm{GHz}$) of superconducting Nb:$SrTiO_3$ in magnetic field. We observe features typical of an s-wave single-gap dirty type II superconductor. We attribute a kink in the magnetic field dependence to 2 distinct superconducting bands. We observe values of the real part of the optical conductivity exceeding the normal state value multiple times for rising magnetic field. Excessive losses at low frequency $hf \ll 2\Delta$ in dependence of temperature are a known feature of superconductivity and a result of coherence effects of the Cooper pairs in the superconducting state (coherence peak). The excessive losses we observe with rising magnetic field are substantially different from the coherence peak, especially in magnetic field dependence and absolute values. As far as we know, excessive losses of this type were not observed in any other superconductor. It is not clear whether Nb:$SrTiO_3$ is the only material that can show excessive losses of this type. We present an interpretation of our data in terms of Caroli-de Gennes-Matricon modes in the vortex state, reproducing the effect of excessive losses qualitatively.

TT 58.2 Wed 15:00 Poster E

Ultrafast second harmonic generation spectroscopy of $SrTiO_3$ surfaces and interfaces — Mahendra Kabbinahithlu, Newsha Vesalimahmoud, Tobias Lojewski, Ping Zhou, Katharina Ollefs, and •Andrea Eschenlohr — Faculty of Physics and CENIDE, University Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany

Perovskite oxide heterostructures can exhibit properties at their interfaces that are very different from the bulk, for example a two-dimensional electron gas [1]. These properties emerge from charge carrier localization or charge transfer, which motivates an interface-sensitive analysis of the charge configuration and charge carrier dynamics. Second harmonic generation (SHG) spectroscopy is an interface-sensitive probe in centrosymmetric materials, suitable for the investigation of $SrTiO_3$-based heterostructures [2]. We perform pump-probe SHG spectroscopy with < 30 fs time resolution in the visible wavelength range (1.9-2.5 eV) at $SrTiO_3$(001) surfaces as well as $LaTiO_3/SrTiO_3$ heterostructures, and discuss the polarization-, wavelength- and time-dependence of the observed SHG response.

[1] H. Y. Hwang, Y. Iwasa, M. Kawasaki, B. Keimer, N. Nagaosa, Y. Tokura, Nat. Mater. **11**, 103 (2012).
[2] A. Rubano, D. Paparo, Materials **16**, 4337 (2023).

TT 58.3 Wed 15:00 Poster E

Low-temperature GHz response of quantum paraelectrics $SrTiO_3$ and $KTaO_3$ — Vincent T. Engl, Nikolaj G. Ebensperger, Cenk Beydeda, Lars Wendel, Marius Tochtermann, Ilenia Neureuther, Ishan Sarvaiya, Martin Dressel, and •Marc Scheffler — 1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

The low-temperature dielectric properties of $SrTiO_3$ and $KTaO_3$ are characteristic of their quantum paraelectric nature: upon cooling, the real part ϵ_1 of the dielectric function strongly increases, but eventually levels off at high values of ≈ 20000 for $SrTiO_3$ and ≈ 4000 for $KTaO_3$. In particular for $SrTiO_3$ it is very demanding to combine such dielectric bulk material with conventional GHz circuitry. We present superconducting coplanar Nb resonators on $SrTiO_3$ and $KTaO_3$ substrates, where in the case of $SrTiO_3$ we employ a distant flip chip geometry. Taking advantage of several resonator modes, we determine the dielectric properties of the two materials at frequencies around 1 GHz and at temperatures down to 25 mK. We thus access regimes of frequency and temperatures, where the dielectric properties of $SrTiO_3$ and $KTaO_3$ have barely been studied.

For the case of $SrTiO_3$, we find an unexpected temperature dependence of the real part ϵ_1 of the dielectric constant: at temperatures below 5 K, where ϵ_1 is expected to vary little upon further cooling, we find a clear maximum around 3 K and a weak minimum around 200 mK. We also observe a strong suppression of microwave losses in both $SrTiO_3$ and $KTaO_3$ for temperatures down to the mK range.

TT 58.4 Wed 15:00 Poster E

ferromagnetic two-dimensional electron gas in oxide interfaces — •Yu Chen[1], Maria D'Antuono[1,2], Martando Rath[1], Cinthia Piamonteze[3], Daniele Preziosi[4], Benoit Jouault[5], Daniela Stornaiuolo[1,2], and Marco Salluzzo[1] — [1]CNR-SPIN, Napoli, Italy — [2]Università di Napoli "Federico II", Italy — [3]Photon Science Division, Paul Scherrer Institut, Switzerland — [4]Université de Strasbourg, CNRS, IPCMS UMR, France — [5]Laboratoire Charles Coulomb, UMR 5221, CNRS, Université de Montpellier, France

Interfacial inversion symmetry breaking triggers novel phenomena not observed in bulk materials, such as unconventional superconductivity and magnetism. Here, we report on the realization of ferromagnetic two-dimensional electron gas (2DEG) at (001) and (111) interfaces between $LaAlO_3$, $EuTiO_3$, and $SrTiO_3$. At variance with the octahedral and quasi-octahedral symmetry in bulk $SrTiO_3$ and (001) interface, trigonal crystal field is reconstructed at (111) interface. The experiments of transport, magnetic and x-ray spectroscopy indicate that the filling of Ti $3d$ bands in the $EuTiO_3$ layer and at the interface with $SrTiO_3$ induces an exchange interaction between Eu-$4f^7$ magnetic moments. We observe carrier density-dependent ferromagnetic correlations and anomalous Hall effect, sizable in-plane orbital moment possibly related to Ti-$3d$ electrons occupying bands with the main $3d_{xz,zy}$ and a_{1g} orbital characters at (001) and (111) interfaces, respectively. Our findings show intriguing interplay between ferromagnetism, spin-orbit coupling, and symmetry breaking at oxide 2DEG, serving as a guide for the materials design of advanced spintronics.

TT 58.5 Wed 15:00 Poster E

Role of excitonic effects in optical and x-ray absorption spectroscopy of $SrTiO_3$: insights from a combined first principles and many-body theory approach — •V. Begum-Hudde[1], M. E. Gruner[2], and R. Pentcheva[2] — [1]University of Illinois Urbana-Champaign, USA. — [2]University of Duisburg-Essen, Duisburg, Germany.

We present a comprehensive study of the optical[1] and x-ray absorption spectrum[2] (XAS) in the paradigmatic oxide, $SrTiO_3$. Our results demonstrate that inclusion of the quasiparticle effects with single-shot G_0W_0 as well as the electron-hole (e-h), and electron-(core)hole interactions by solving the Bethe-Salpeter Equation (BSE) is integral to accurately describe both the valence and core electron excitations. For the optical spectra, the effect of the exchange-correlation functional is observed to progressively reduce from 1.5 eV variance in the onset of the spectrum in the independent particle picture to 0.3 eV upon inclusion of excitonic corrections. The Ti-$L_{2,3}$ XAS edge is concurrent with experiment w.r.t. the energetic positions of the four-peak structure which is characteristic of Ti octahedral coordination in $SrTiO_3$. We also analyze the origin of prominent peaks in the spectra and identify the orbital character of the relevant contributions by projecting the e-h coupling coefficients from the BSE eigenvectors on the band structure. The spatial distribution of the first bound exciton wave function of the O K edge exhibits an intriguing two-dimensional spread in the x-y plane despite the three-dimensional nature of the material.

[1] Phys. Rev. Mater. **3**, 065004 (2019)
[2] Phys. Rev. Res. **5**, 013199 (2023)

TT 58.6 Wed 15:00 Poster E

Boosting the Edelstein effect of two-dimensional electron gases by ferromagnetic exchange — •Gabriel Lazrak[1], Annika Johansson[2], Börge Göbel[2,3], Ingrid Mertig[2,3], Agnès Barthélémy[1], and Manuel Bibès[1] — [1]Laboratoire Albert Fert, Université Paris-Saclay, CNRS, Thales, Palaiseau, FRANCE — [2]Max Planck Institute of Microstructure Physics, Halle, GERMANY — [3]Martin Luther University Halle-Wittenberg, Halle, GERMANY

In this work, we show that making STO 2DEGs ferromagnetic significantly boosts the conversion efficiency of charge and spin currents through direct and inverse Edelstein effects (EE/IEE). Starting from the experimental band structure of non-magnetic SrTiO3 2DEGs, we mimic magnetic exchange coupling by introducing an out-of-plane Zeeman term in a tight-binding model. We then calculate the band structure and spin textures for increasing internal magnetic fields and compute the Edelstein effect using a semiclassical Boltzmann approach. The conversion efficiency initially rises with magnetic field strength, reaching a maximum before declining. This behavior results from the interplay between exchange coupling and the effective Rashba interaction. Our experimental focus is on the 2DEG at the SrTiO3/EuO interface to introduce ferromagnetism into the system.

TT 58.7 Wed 15:00 Poster E

Impact of a Si(001) substrate on the electronic reconstruction and two-dimensional electron gas formation at $LaTiO_3/SrTiO_3$(001) — •Andri Darmawan and Rossitza Pentcheva — Department of Physics, University of Duisburg-Essen

The two-dimensional electron gas (2DEG) formed at oxide interfaces e.g. between the band insulator $SrTiO_3$ and the Mott insulator $LaTiO_3$ has attracted a lot of attention [1]. However, despite the high carrier density at the interface, the carrier mobility is lower compared to semiconductor materials. A strategy to overcome this shortcoming is the integration of the oxide system on a semiconductor substrate [2]. Based on density functional theory calculations with a Hubbard U term we modeled $LaTiO_3/SrTiO_3$(001) with and without a Si(001) substrate. We explore systematically the sample geometry and the effect of the termination to Si(001) on the electronic reconstruction at the $LaTiO_3/SrTiO_3$(001) interface. The comparison between the two systems indicates lower effective masses and consequently higher mobility of the 2DEG at $LaTiO_3/SrTiO_3$/Si(001).

Funding by DFG within CRC1242 and computational time at the Leibniz Supercomputer Center (project pr87ro) are gratefully acknowledged.

[1] A. Ohtomo et al., Nature 419, 378 (2002)
[2] E. N. Jin et al., APL Mater. 2, 116109 (2014)

TT 59: Transport: Poster

Time: Wednesday 15:00–18:00 Location: Poster E

TT 59.1 Wed 15:00 Poster E

Thermal noise and electrical characterization of mode coupled GaAs/AlGaAs quantum point contacts — •Daniel Nickel[1], Birkan Düzel[1], Olivio Chiatti[1], Sven S. Buchholz[1], and Saskia F. Fischer[1,2] — [1]Novel Materials Group,Humboldt-Universität zu Berlin,10099 Berlin, Germany — [2]Center for the Science of Materials Berlin, 12489 Berlin, Germany

Noise measurements are a useful tool to investigate intrinsic system properties in thermodynamic equilibrium. This work investigates the thermal noise and electrical properties of etched single and double quantum point contacts (QPCs) in GaAs/AlGaAs heterostructures at T = 4.2 K. Both QPCs exhibit conductance plateaus indicative of ballistic transport in one dimension. The transconductance as a function of the top and back gate voltages yields information regarding the degeneracies of the 1D subband energies of the double QPC. Crossings are observed when two energy levels are degenerate and anti-crossings are observed when a hybridization of the 1D wave functions occurs. The single QPC subband structure is well-detected in voltage noise measurements in accordance with the expected thermal noise using the Johnson-Nyquist theorem. For the double QPC, additional noise beyond the expected thermal noise is observed. This additional noise occurs in mode coupled states with hybridized wave functions and simultaneous phase-coherent transport, as well as in degenerate states. The increase in voltage fluctuations is discussed in relation to shot noise through the tunnel barrier and correlations between noise sources.

TT 59.2 Wed 15:00 Poster E

Quantum dots in suspended or graphite-gated MoS_2 nanotubes — •Stefan B. Obloh[1], Robin T. K. Schock[1], Jonathan Neuwald[1], Matthias Kronseder[1], Matjaž Malok[2], Maja Remškar[2], and Andreas K. Hüttel[1] — [1]Institute for Experimental and Applied Physics, University ofRegensburg, 93040 Regensburg, Germany — [2]Solid State Physics Department, Institute Jožef Stefan,1000 Ljubljana, Slovenia

MoS_2 as a semiconductor has attracted a lot of attention due to its 2D nature, strong spin-orbin coupling, broken inversion symmetry, and spin-split bands. By tuning the carrier density in MoS_2 with ionic liquid gating, intrinsic superconuctivity has been achieved [1]. Recent works were able to demonstrate single level transport in planar [2,3] and nanotube-based [4] devices. A remaining challenge lies in reducing the effects of substrate inhomogenity and surface charges, resulting in disordered quantum dots. To mitigate this, one can suspend the tubes above the substrate or shield them from the amorphous SiO_2. We show first measurements of nanotubes suspended between contacts as well as placed onto a hBN substrate back-gated with graphite.

[1] J. T. Ye *et al.*, Science **338**, 1193 (2012)
[2] R. Krishnan *et al.*, Nano Lett. **23**, 6171 (2023)
[3] P. Kumar *et al.*, Nanoscale **15**, 18023 (2023)
[4] R. T. K. Schock *et al.*, Adv. Mat. **35**, 13 (2023)

TT 59.3 Wed 15:00 Poster E

Nanomechanics with nanoassembled carbon nanotubes circuits — •Sophie Klingel[1], Tim Althuon[1], Tino Cubaynes[1,2], Aljoscha Auer[1], Christoph Sürgers[1], and Wolfgang Wernsdorfer[1,2] — [1]Physikalisches Institut (PHI), Karlsruhe Institute of Technology — [2]Institute for Quantum Materials and Technologies (IQMT), Karlsruhe Institute of Technology

Carbon nanotubes (CNT) are a one dimensional allotrope of elemental carbon which feature a unique combination of properties like low mass and high mechanical tensile strength, resulting in resonance frequencies suited for experiments. In combination with a high electronic tunability, these properties make CNT excellent components for nanoelectromechanical systems (NEMS). One possibility to create a NEMS is with a double quantum dot in a suspended CNT.

In our experiments, we connected a CNT grown on a separate chip to the contact electrodes via a mechanical nanoassembly technique. While this technique allows to select and place a single CNT on a precise location, the resistance between the CNT and the electrode was until now high, blocking access to the open quantum dot regime. We managed to drastically lower the resistance between the CNT and the electrode by developing a novel two-step annealing technique based on current-induced and radiative thermal annealing steps. Along with a more detailed presentation of this technique, some of our nanomechanical and quantum transport measurement results will be showcased.

TT 59.4 Wed 15:00 Poster E

Towards single-photon optomechanics using superconducting quantum interference — •Mohamad El Kazouini, Benedikt Wilde, Timo Kern, Christoph Füger, Kevin Uhl, Dieter Koelle, Reinhold Kleiner, and Daniel Bothner — Physikalisches Institut, Center for Quantum Science (CQ) and LISA^{+}, Universität Tübingen, Germany

Cavity optomechanics explores the coupling between mechanical oscillators and electromagnetic modes through radiation-pressure. Various milestone experiments have been reported, such as groundstate cooling or non-classical mechanical states preparation. All experiments so far, however, utilize only the first-order interaction in the linearized regime, mainly due to small single-quantum coupling rates. Increasing the single-photon coupling rates would not only unlock the optomechanical single-photon regime, but also grant access to higher-order terms of the interaction, enabling for instance mechanical cat-state preparation. Flux-mediated optomechanics (FMOM) is a strong candidate for achieving this groundbreaking regime. In FMOM, the mechanical oscillator is a microbeam integrated into a superconducting quantum interference device (SQUID), which is part of a microwave LC circuit. The single-quantum coupling rates in FMOM are proportional to an external magnetic field, but all FMOM implementations so far are based on Al, that has low magnetic-field-tolerance. Implementing it with high-field-compatible superconducting circuits is therefore the main challenge for maximized coupling rates. On our poster, we will present our progress in developing niobium-based FMOM devices.

TT 59.5 Wed 15:00 Poster E

Analysis of magnetism in monolayer graphene beyond half filling — •Maxime Lucas, Andreas Honecker, and Guy Trambly de Laissardière — Laboratoire de Physique Théorique et Modélisation, CY Cergy Paris Université / CNRS, France

Recent studies of twisted bilayer graphene (or other 2D materials) have been stimulated by the discovery of correlations between electronic flatband states due to a moiré pattern [1]. It is shown experimentally and theoretically that the filling of the flat bands affects their magnetic properties significantly. On the other hand, the effect of doping on a simple graphene layer is still unclear. Indeed, its half-filled case is well known and has been studied by various theoretical approaches (real-space mean-field theories (MFT), Monte Carlo) [2], but unlike other lattices [3] its magnetic properties beyond half filling are mostly unexplored [4]. Here, we present our analysis of graphene magnetism using a combination of the Hubbard model and MFT.

[1] Y. Cao et al., Nature **556**, 43 (2018); Nature **556**, 80 (2018)
[2] M. Raczkowski, R. Peters, T.T. Phùng, N. Takemori, F.F. Assaad, A. Honecker, J. Vahedi, Phys. Rev. B **101**, 125103 (2020), and Refs. therein.
[3] R. Scholle, P. M. Bonetti, D. Vilardi, W. Metzner, Phys. Rev. B **108**, 035139 (2023)
[4] S. Jiang, A. Mesaros, Y. Ran, Phys. Rev. X **4**, 031040 (2014)

TT 59.6 Wed 15:00 Poster E

Suspended carbon nanotube – superconducting coplanar resonator hybrid systems — •Akong N. Loh, Furkan Özyigit, Fabian Stadler, Nicole Kellner, Niklas Hüttner, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

The combination of carbon nanotubes (providing quantum dots and beam-like nano-electromechanical systems) and superconducting coplanar electronics (providing GHz cavities, fast read-out, and potentially even qubits) enables a multitude of interesting low-temperature experiments. We have recently shown optomechanically induced transparency in such a combined system [1,2], where the nonlinearity of Coulomb blockade leads to an enhancement of the single photon coupling up to $g_0 \simeq 95\,\mathrm{Hz}$. The carbon nanotubes are grown separately and deposited into the prefabricated resonator geometries [3], leading to flexibility and increased fabrication yield. Our current work is directed towards achieving strong optomechanical coupling, and towards time-domain control of the combined hybrid system, with ongoing im-

provements of the microwave cavity [4], CNT growth and transfer.
[1] S. Blien *et al.*, Nat. Comm. **11**, 1636 (2020)
[2] N. Hüttner *et al.*, PR Applied, in press (2023), arXiv:2304.02748
[3] S. Blien *et al.*, PSS(B) **255**, 1800118 (2018)
[4] N. Kellner *et al.*, PSS(B) 2300187 (2023)

TT 59.7 Wed 15:00 Poster E

Coplanar on-chip resonators for kinetic inductance measurements on 2D-crystals — •Lorenz Bauriedl, Sami Campopiano, Alexander Kirchner, Nicola Paradiso, and Christoph Strunk — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

Experimental access to the small kinetic inductance of low-resistive metallic superconductors is traditionally achieved by increasing the ratio of sample length to cross section. This limits one to materials available at sufficient size and renders measurements on exfoliated 2D superconductors hardly possible. We devised a method to access the inductance signature of materials such as $NbSe_2$. Incorporating a $NbSe_2$ nanowire into a high Q-factor on-chip niobium resonator enables us to measure the inductive response, while DC ports allow simultaneous investigation of transport properties. Spiral inductors fabricated in tandem with the resonator serve as low-pass filters for the DC ports and create the high impedance enviroment necessary to detect even minute changes in the inductance.

TT 59.8 Wed 15:00 Poster E

Utilizing Scanning Nitrogen Vacancy Center for 2D Correlated Electron Systems — •Malik Lenger, Sreehari Jayaram, Ruoming Peng, Rainer Stöhr, and Jörg Wrachtrup — 3rd Physics Institute, University of Stuttgart, Germany

Visualization of nanoscale dynamics in superconducting materials provides a pathway to unravel the pairing mechanisms of interacting electrons. Here, we have employed the state-of-the-art scanning NV probe technique to explore the local magnetic response of the 2D superconductor, 2H-$NbSe_2$, in which we demonstrate full dynamic sensing of vortices with high sensitivity and spatial resolution. Utilizing this quantum probe, we present the first spatio-temporal dynamics of vortices in a 10 nm thin exfoliated 2H-$NbSe_2$, where the arrangement of the vortices show a strong correlation with the geometric confinement. Notably, we have observed the melting of vortex solids near critical temperature allowing the re-arrangement of the vortices that is governed by the cooling rate. Additionally, our study delves into the dynamics of vortex cores, superconducting-insulator edge dynamics, and phase transitions, all unveiled through spatial-temporal noise spectroscopy with the NV probe.

TT 59.9 Wed 15:00 Poster E

Adsorped or intercalated nickel atoms in graphene based materials: stability and electronic properties — •Daniel Dick[1,2,3], Florian Fuchs[1,2,3], and Jörg Schuster[1,2,3] — [1]Center for Microtechnologies, Chemnitz University of Technology, Chemnitz, Germany — [2]Fraunhofer Insitute for Electronic Nano Systems (ENAS), Chemnitz, Germany — [3]Center for Materials, Architectures and Integration of Nanomembranes (MAIN), Chemnitz University of Technology, Chemnitz, Germany

Graphene based materials such as graphene fibers or thin films offer promising electrical properties, which can be further improved by adsorption or by intercalation of dopants. A variety of electron donating species can be considered to fabricate intercalation compounds, many of which have not been studied yet.

We investigate atomic structure, stability and electronic structure of nickel doped graphene, bilayer graphene and graphite using density functional theory. Different positions of the nickel atom are compared. We demonstrate that the energetically optimal position of the nickel atom depends on the nickel concentration. While the nickel atom is in the middle of a hexagon in graphene, it is located at an off-center position in graphite. Furthermore, the stability of the nickel intercalant decreases with increasing nickel concentration. The nickel atom introduces additional bands in the band structure. These bands are located near the Fermi level, leading to improved conductance.

TT 59.10 Wed 15:00 Poster E

Quantum Monte Carlo simulations of electronic transport in finite-sized graphene sheets and its dependence on the boundary conditions. — •Adrien Reingruber, Maksim Ulybyshev, and Fakher Assaad — Institut für Theoretische Physik und Astrophysik, Universität Würzburg

The realization of ultra-clean graphene samples with predominant electron-electron scattering, opened the possibilities to study electron transport in hydrodynamic regime, where the electronic transport properties are characterized by viscous Poiseuille flow[1] or the breakdown of Wiedemann-Franz law[2]. Only recently these effects were measured experimentally. Furthermore, newly optimized quantum Monte Carlo (QMC) techniques[3] enable us to simulate experimentally relevant lattice sizes starting from microscopic models in order to reproduce and understand better the aforementioned effects. A major challenge is the implementation of correct boundary conditions that yield a vanishing current flow at the edge of finite-sized graphene samples. In this work we study the influence of disorder and various types of electronic interactions on the conductivity profiles inside thin graphene wires using unbiased QMC simulations and discuss the feasibility to achieve hydrodynamic transport from a microscopic perspective.
[1] M.J.H. Ku et al., Nature 583, 537 (2020)
[2] J. Crossno et al., Science 351, 1058 (2016)
[3] M. Ulybyshev, S. Zafeiropoulos, C. Winterowd, F. Assaad, arXiv:2104.09655 (2021)

TT 59.11 Wed 15:00 Poster E

Integer and fractional moiré Chern insulators in van der Waals bilayers — •Mirko Bacani, Rajarshi Bhattacharyya, and Florian Otto — attocube systems AG, Haar, Germany

Moiré van der Waals (vdW) materials have become established playground for exploring band topology and strong-correlations phenomena. Cryogenic nanopositioning and nanorotating setups of attocube systems are widely used in such nanoscale studies because they provide supreme stability and ultra-low-vibrations environment. These cryogenic scanning setups include confocal microscopes and various scanning probe microscopes.

We present here a selection of remarkable results achieved with attocube systems technology in labs of our customers with emphasis on integer and fractional moiré Chern insulators (MCIs) in vdW bilayers: Scanning magnetometry of an integer MCI $MoTe_2/WSe_2$ shows that its magnetization can be flipped with a very low current [1], which is appealing for utilization in energy-efficient magnetic memories. Magneto-optical study of the same heterostructure discovered a valley-nonpolarized quantum anomalous Hall state [2]. Magic angle twisted bilayer graphene (MATBG), identified as an integer MCI [3], reveals orbital magnetism induced by local Berry curvature as the function of the integer filling factor [4]. Moreover, MATBG can also exhibit fractional Chern insulating states (FCIS) even in low magnetic fields $B<12T$ [5]. FCIS that survive in $B=0$ have been identified magneto-optically in twisted bilayer $MoTe_2$ using trions as the local probe for real-space imaging of spin polarization [6].

TT 59.12 Wed 15:00 Poster E

Quantum diffusion in magic-angle twisted bilayer graphene — •Taher Rhouma, Ahmed Missaoui, and Guy Trambly de Laissardière — Laboratoire de Physique théorique et Modélisation, CY Cergy Paris Université / CNRS, Cergy-Pontoise, France.

The discovery of correlated insulators and superconductivity due to flat bands in twisted bilayer graphene (TBG) [1] at so-called “magic angles” has stimulated the study of their electronic properties. Here we present a theoretical study of the electronic structure and quantum transport properties of these flat-band states, considering as well as possible the structural effect of local defects, such as resonant and non-resonant scatterers. Our real space method [2,3] takes into account all the effects of defects on the electronic structure itself and the effects of multiple scattering on conductivity. It shows, among other things, that due to the incredibly low velocity of flat-band states, the usual Bloch-Boltzmann theories are no longer valid.
[1] Y. Cao et al., Nature **556**, 43 (2018); Nature **556**, 80 (2018)
[2] F. Triozon et al., Phys. Rev. B **65**, 220202 (2002)
[3] O. Faizy Namarvar et al., Phys. Rev. B **101**, 245407 (2020)

TT 59.13 Wed 15:00 Poster E

Z_n-periodic quasiparticle pump in quantum spin helices — •Anshuman Tripathi[1], Felix Gerken[1,2], Peter Schmitteckert[3], Mircea Trif[4], Michael Thorwart[1,2], and Thore Posske[1,2] — [1]1. Institut für Theoretische Physik, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [3]HQS Quantum Simulations GmbH, Karlsruhe, Germany — [4]International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

Various topologically degenerate spaces return to an initial state only after more than one cycle of external adiabatic manipulation, e.g., Majorana zero mode exhibits the 4π Josephson effect and more exotic anyons a higher order of cyclic periodicity. Here, we study the winding-up of easy-plane quantum spin helices in spin-1/2 chains by twisting the boundary fields. At Heisenberg anisotropy $\Delta = -|J|/2$, the system returns to the ground state after n cycles of the adiabatic time evolution, where n increases linearly in dependence on the chain length. This unifies arbitrary periodicities in a single system and connects the winding-up to adiabatically pumped helical quantum spin quasiparticles. Extrapolation to long spin chains reveals a universal linear scaling curve. Our work also connects phantom helices to adiabatically pumped spin-current maximizing helices.

TT 59.14 Wed 15:00 Poster E

Electrically and Acoustically Biased Resonators for Investigations of Dielectric Low Temperature Properties of Amorphous Solids — •Christian Ständer, Jan Blickberndt, Valentin Hell, Andreas Reifenberger, Andreas Fleischmann, Andreas Reiser, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University, D-69120 Heidelberg

The low temperature properties of amorphous solids are governed by atomic tunnelling systems, which can be described as two-level systems (TLS) with a distribution of their energy splitting E, as assumed by the phenomenological standard tunnelling model. Recent interest in these systems due to their deteriorative effects on the performance of superconducting quantum devices lead to novel experimental investigations of atomic tunnelling systems driven by novel measurement techniques.

We use newly designed microfabricated superconducting LC-resonators to study the dielectric rf-response of the amorphous sample in the presence of an electric bias field. A novel method of applying this electrical bias field was introduced to the resonators. Compared to previous experiments, the bias field is applied via an electrode placed above the resonator chip. We present first results of this new way of introducing a bias, which modifies the energy splitting E of a TLS.

In addition we achieved a similar effect as with the electrical bias field with a mechanical strain field. To induce such a strain field, the amorphous substrate of the resonator chip was flexed by a piezo-actuator.

TT 59.15 Wed 15:00 Poster E

Dynamic Control of Dielectric Loss in a Bulk Glass by Manipulation of Atomic Tunneling Systems via Electric Bias Fields — •Jan Blickberndt, Christian Ständer, Lukas Münch, Marcel Haas, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg, Germany

Atomic tunneling systems (TSs) are inherent to disordered structures and strongly determine the low temperature dielectric properties of amorphous solids. However, they also manifest as parasitic surface defects in superconducting quantum devices, contributing significantly to noise and decoherence. Here we investigate the non-equilibrium dielectric loss of atomic tunneling systems in a bulk glass sample by measuring the quality factor of a superconducting microstructured LC-resonator. Our approach involves the application of an electric bias field via a cover electrode, which allows us to modulate the TSs energy splitting, inducing Landau-Zener transitions experimentally observed as an alteration of the resonator loss. We are able to control the loss by varying the bias rate via the amplitude or frequency of the bias signal. Our results indicate a constant loss for slow bias rates due to TS saturation. Increasing the bias rate disrupts the TS saturation and leads to an increased loss. In the limit of fast continuous bias sweeps, the bias frequency exceeds the TS relaxation rate, and interference of multiple coherent Landau-Zener transitions is possible, resulting in a decreasing dielectric loss and ultimately a return to the saturation limit. We are able to confirm our experimental findings with a Monte-Carlo based numerical simulation of the tunneling dynamics.

TT 59.16 Wed 15:00 Poster E

Non-linear Dynamics of Two-level Tunneling Systems in Non-equilibrium — •Anton Jarecka, Jan Blickberndt, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg, Germany

The performance of state-of-the-art superconducting quantum devices is predominantly limited by the dielectric loss as well as the related noise and decoherence effects, which are known to originate from atomic tunneling systems (TSs). In an effort to further understand the coupling of such TSs to superconducting quantum devices, we investigate their dielectric properties and non-equilibrium behavior under the influence of high frequency electric bias fields utilizing a novel resonator setup. The superconducting resonator consists of four identical interdigital capacitors (IDCs) microstructured on to a dielectric bulk glass sample, arranged in a Wheatstone bridge and two inductors, resulting in two decoupled resonance frequencies. A cover electrode is used to create the electrical bias field that modulates the TSs' energy splitting which allows to probe the non-linear behavior of the same ensemble of TS at two different resonator frequencies independently. This can be used to measure the dielectric loss of an excited TS by moving it from one resonance frequency to the other. Experiments of this type will give further insight into the non-linearities of an ensemble of TSs.

TT 59.17 Wed 15:00 Poster E

Relaxation dynamics of quantum many-body systems with phonon degrees of freedom using the multi-trajectory Ehrenfest method — •Heiko Georg Menzler, Suman Mondal, and Fabian Heidrich-Meisner — Georg-August-Universität Göttingen

As the primary goal of our research we want to study the delocalization of interacting electrons in the presence of disorder and phonons, that is the stability of many-body localization in a solid-state environment. However, large mixed bosonic-fermionic Hilbert spaces make full quantum solutions numerically costly. Therefore, we want to analyze the model in the multi-trajectory Ehrenfest (MTE) formalism in the limit of adiabatic (slow) phonons by treating the phonons classically. We apply this formalism to study the decay of spatially inhomogeneous particle distributions as a function of electron-phonon coupling. As a main result, we observe a delocalization at sufficiently long times and strong electron-phonon coupling. The core idea of the MTE method—which is a well established method in quantum chemistry—is to separate fast and slow degrees of freedom while the slow phononic environment is treated in the classical limit. In this project we extend the established methodology to deal with many-body electron subsystems by implementing time-dependent Lanczos and TEBD time evolution in conjunction with MTE and use this new take on the MTE method to analyze disordered system in the presence of phonons.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) via FOR 5522 and SFB 1073.

TT 59.18 Wed 15:00 Poster E

Delocalization in a partially disordered interacting many-body system — •Suman Mondal and Fabian Heidrich-Meisner — Institut für Theoretische Physik, Georg-August-Universität Göttingen, Göttingen, Germany

We study a partially disordered one-dimensional system with interacting particles. Concretely, we only impose a disorder potential to every other site, followed by a clean site. The numerical analysis of finite systems reveals that the ergodic regime with a large entanglement extends to higher disorder strengths compared to a fully disordered system. More importantly, at large disorder, there exist eigenstates with large entanglement entropies and significant correlations between the clean sites. These states have almost volume-law scaling, embedded into a sea of area-law states, reminiscent of inverted scar states. These eigenstate features leave fingerprints in the nonequilibrium dynamics even at large disorder regime, with a significant initial state dependence. We demonstrate that certain types of initial charge density wave states decay significantly, while others preserve their initial inhomogeneity as is typical for many-body localized systems. This initial condition-dependent dynamics may give us extra control over the system to study delocalization dynamics at large disorder strength and should be experimentally feasible with ultracold atoms in optical lattices.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) via FOR 5522.

TT 59.19 Wed 15:00 Poster E

Nonlinear Cavity Optomechanics for Enhanced Cooling — •Nicolas Diaz-Naufal[1], David Zoepfl[2,3], Lukas Deeg[2,3], Christian M. F. Schneider[2,3], Mathieu L. Juan[4], Gerhard Kirchmair[2,3], and Anja Metelmann[1,5,6] — [1]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universitaet Berlin, 14195 Berlin, Germany — [2]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, 6020 Innsbruck, Austria — [3]Institute for Experimental Physics, University of Innsbruck, 6020 Innsbruck, Austria — [4]Institut Quantique and Departement de Physique, Universite de Sherbrooke, Sherbrooke, Quebec, J1K 2R1, Canada — [5]Institute for Quantum Materials and Technology and Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [6]Institut de Science et de Ingenierie Supramoleculaires (ISIS, UMR7006), University of Strasbourg and CNRS

Cavity optomechanics is fundamental for numerous quantum science and technology applications and recently the use of cavity nonlinearities has attracted a lot of interest. In this study, we show that in a nonlinear optomechanical system, the nonlinearity can be used to enhance the efficiency of backaction cooling of the mechanical mode in the unresolved sideband regime. In addition, we explore the enhancements in the cooling limits achieved when employing a nonlinear optomechanical system, as opposed to an identical linear system, driven by squeezed input light. Furthermore, we demonstrate the validity of this theory above bifurcation, aligning with experimental results.

TT 60: Cryogenic Detectors and Sensors, Refrigeration and Thermometry

Time: Wednesday 16:00–17:45 Location: H 3025

TT 60.1 Wed 16:00 H 3025

MOCCA: a 4k-pixel molecule camera for the position and energy resolved detection of neutral molecule fragments — •Abdullah Özkara[1], Christian Enss[1], Andreas Fleischmann[1], Lisa Gamer[2], Loredana Gastaldo[1], Daniel Hengstler[1], Christopher Jakob[2], Daniel Kreuzberger[1], Ansgar Lowack[1], Oldřich Novotny[2], Andreas Reifenberger[1], Dennis Schulz[1], and Andreas Wolf[2] — [1]Heidelberg University — [2]Max Planck Institute for Nuclear Physics, Heidelberg

The MOCCA detector is a 4k-pixel high-resolution molecule camera based on metallic magnetic calorimeters and read out with SQUIDs that is able to detect neutral molecule fragments with keV kinetic energies. It will be deployed at the Cryogenic Storage Ring CSR at the Max Planck Institute for Nuclear Physics in Heidelberg, a storage ring built to prepare and store molecular ions in their rotational and vibrational ground states, enabling studies on electron-ion interactions. To reconstruct the reaction kinematics, MOCCA measures the energy and position of the molecule fragments incidenting on the detector, even with multiple particles hitting the detector simultaneously.

We present an improved read-out scheme which uses a logarithmic decay time spacing. This makes it possible to use only 32 SQUID channels for the read-out of 4094 pixels of the detector. In addition, we compare the simulations of this read-out scheme to previous measurements.

TT 60.2 Wed 16:15 H 3025

MMC Array to Study X-ray Transitions in Muonic Atoms — •Daniel Hengstler, Andreas Abeln, Eric Biedert, Thomas Elias Cocolios, Ofir Eizenberg, Christian Enss, Andreas Fleischmann, Loredana Gastaldo, Cesar Godinho, Michael Heines, Paul Indelicato, Daniel Kreuzberger, Klaus Kirch, Andreas Knecht, Jorge Machado, Ben Ohayon, Nancy Paul, Randolf Pohl, Katharina von Schoeler, Daniel Unger, Stergiani Marina Vogiatzi, and Frederik Wauters — for the QUARTET Collaboration

The QUARTET collaboration aims to improve the accuracy of absolute nuclear charge radii of light nuclei from Li to Ne. A proof-of-principle measurement with lithium, beryllium and boron has recently been performed at the Paul Scherrer Institute. Conventional solid-state detectors do not provide sufficient accuracy in the relevant energy range. We use a low temperature Metallic Magnetic Calorimeter (MMC) array for high-precision X-ray spectroscopy of low-lying states in muonic atoms. MMCs are characterized by a high resolving power of several thousand and a high quantum efficiency in the energy range of interest. We present the experimental setup and the performance of the detector used. We discuss the first preliminary spectra and systematic effects in this first measurement. The obtained data in combination with the achieved energy resolution and calibration should allow a more precise characterization of the muonic X-ray lines. With the knowledge gained, a significant improvement in the determination of nuclear charge radii is expected.

TT 60.3 Wed 16:30 H 3025

Optimizing microwave SQUID multiplexers for magnetic microcalorimeter readout — •Martin Neidig[1], Constantin Schuster[1], Lena Hauswald[1], Mathias Wegner[2,1], Stefan Wünsch[1], and Sebastian Kempf[1,2] — [1]Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Germany — [2]Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Germany

Magnetic microcalorimeters (MMCs) are cryogenic particle detectors which have achieved a high level of maturity. Thanks to reliable microfabrication processes, large-scale MMC arrays consisting of hundreds or even thousands of detectors are meanwhile feasible, presenting the challenge of developing a suitable multiplexing technique. In this respect, microwave SQUID multiplexing is the current state of the art. Here, the individual detector signals can be frequency-encoded by inductively coupling each detector to a non-hysteretic rf-SQUID which in turn is inductively coupled to microwave resonator with unique resonance frequency. This enables the simultaneous readout of hundreds of detectors using a single transmission line, typically utilizing a bandwidth of 4 to 8 GHz. In this contribution. we discuss the advantages of operating microwave SQUID multiplexers at frequencies above 8 GHz, showcasing increased multiplexing factor, improved readout sensitivity and reduced device dimensions. Additionally, we present first measurements aiming to prove the feasibility of such devices. Finally, we address challenges associated with connecting a microwave SQUID multiplexer to an actual detector chip.

TT 60.4 Wed 16:45 H 3025

PrimA-LTD: Advanced magnetic microcalorimeters for radionuclide metrology — •Michael Müller[1], Alexander Göggelmann[2], and Sebastian Kempf[1,3] — [1]Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology — [2]Physikalisch-Technische Bundesanstalt (PTB) Braunschweig — [3]Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology

High uncertainties of available radioactive decay data are more and more a limitation for many applications in science, medicine and industry. Therefore, the EMPIR project “PrimA-LTD” aims to demonstrate advanced decay energy spectroscopy using magnetic microcalorimeters (MMCs), that, in contrast to conventional techniques, provide very low energy threshold and nearly 100 % detection efficiency. In MMCs, the temperature-dependent magnetization of paramagnetic temperature sensor is used to sense the temperature rise resulting from particle absorption in a thermally coupled absorber with utmost precision. We developed two detector types, one being a high energy resolution spectrometer for improving fundamental decay data of ^{55}Fe that is ion-implanted into microfabricated particle absorbers. The other type demonstrates high flexibility in metrological activity measurements by introducing a reusable MMC setup that allows using wire-bonded external absorber/source composites. To estimate their performance, we introduced a simulation framework based on a state space model, applicable to arbitrary detector configurations and benchmarked this model with measured data acquired within the project.

TT 60.5 Wed 17:00 H 3025

Tilting of a small scale 4 K pulse tube cryocooler driven by a low input power oil-free Helium compressor — •Jack-Andre Schmidt[1,2], Bernd Schmidt[1,2], Jens Falter[2], Jens Höhne[3], Sebastian Schaile[4], and André Schirmeisen[1,2] — [1]Justus-Liebig-Universität Giessen, Giessen, Germany — [2]TransMIT GmbH, Giessen, Germany — [3]Pressure Wave Systems GmbH — [4]attocube systems AG

Among the family of regenerative cryocoolers, GM-type pulse tubes (PTC) in particular stand out because they have no moving mechanical parts at cryogenic temperatures. The working principle of PTCs relies on the cyclic pressure waves of Helium gas at relatively high pressure differences around 1 MPa. These pressure levels are commonly provided by dedicated Helium gas compressors, which represent the main unit of energy consumption in the cryo system with input powers ranging from 1 kW to above 10 kW. Here we present a combination of the smallest so far reported 4 K PTC Susy driven by an oil-free low power compressor technology IGLU achieving cooling powers necessary for typical optical quantum components below 4.2 K. The IGLU compressor is based on a mechanism with hydraulically driven metal bellows, providing minimum maintenance and maximum mobility. This combination reaches the physical minimum temperature of 2.2 K at no load, and a cooling capacity of 240 mW at 4.2K, with the compressor operating at maximum speed at 1.3 kW input power. Additionally we present the results of tilted operation of the whole setup.

TT 60.6 Wed 17:15 H 3025

Experimental investigations and numerical simulations of the pressure drop in different regenerator fillings of a single stage GM-type pulse tube cooler — •Elias Eisenschmidt[1,3], Jack-Andre Schmidt[2,3], Bernd Schmidt[2,3], Jens Falter[3], and Andre Schirmeisen[2,3] — [1]Technische Hochschule Mittelhessen, Giessen, Germany — [2]Justus-Liebig-University, Giessen, Germany — [3]TransMIT-Center for Adaptive Cryotechnology and Sensors, Giessen, Germany

In this talk, numerical flow simulations and measurements of a single stage pulse tube cryocooler (PTS 8030, TransMIT GmbH) will be discussed. The goal of the investigation is to get a closer look at the pressure drop of different regenerator fillings. The numerical simulations in particular allow a deeper understanding of the flow pattern inside the different regenerator-fillings. [1, 2]

The results of the experiments can for example be used to build a holistic numerical simulation. Similar simulations were already performed, but in most papers, pressure and mass flow were assumed to be sinusoidal. With the conducted pressure measurements, it is possible to perform simulations using the experimental pressure wave as the inlet condition.

[1] L.M.Qiu, Y.L.He, Z.H.Gan, X.B.Zhang, G.B.Chen, Cryogenics 47 (2007) 49
[2] P. P. Steijaert, Thermodynamical aspects of pulse-tube refrigerators, Technische Universiteit Eindhoven, 1999

TT 60.7 Wed 17:30 H 3025

Development of a miniaturized, modular, nuclear demagnetization stage — •Leo Maximov[1], Nico Huber[1], Andreas Bauer[1], Yusuke Nago[2], Keiya Shirahama[2], and Christian Pfleiderer[1] — [1]Physik-Department, Technical University of Munich, D-85748 Garching, Germany — [2]Keiyo University, Hiyoshi 3-14-1, Kohoku-ku, Yokohama, Japan

Experimental studies of condensed matter systems at sub-milli Kelvin temperatures are effectively only possible by virtue of nuclear adiabatic demagnetization refrigeration (NADR). While copper is the most commonly used refrigerant for NADR, both the development and operation of copper based NADR-stages are technically demanding and limited due to the very low starting temperatures needed for demagnetization. To overcome these limitations, hyperfine-enhanced refrigerants may be used. Here, we present the design and implementation of a compact, miniaturized, modular nuclear demagnetization stage for optional use with a conventional dilution refrigerator. Comprising a superconducting aluminum heat switch, a demagnetization stage using $PrNi_5$ with a bespoke superconducting coil, and a CMN thermometer, the setup is conceived for exploratory studies in the milli-Kelvin regime and below. Moreover, we report the successful crystal growth of polycrystalline $PrNi_5$ as well as a comprehensive study of its low-temperature properties, particularly with regard to the potential use as a cooling medium.

TT 61: Correlated Electrons: 1D Theory

Time: Wednesday 16:30–18:00 Location: H 3010

TT 61.1 Wed 16:30 H 3010

Phase diagram of the extended anyon Hubbard model in one dimension — •Sebastian Eggert[1], Martin Bonkhoff[2], Kevin Jägering[1], Shijie Hu[3], Axel Pelster[1], and Imke Schneider[1] — [1]University of Kaiserslautern-Landau, Landesforschungszentrum OPTIMAS — [2]Universität Hamburg — [3]Beijing Computational Science Research Center

We study one-dimensional lattice anyons with extended Hubbard interactions. At unit filling a repulsive next-nearest neighbor interaction generally leads to gapped phases, but it is far from trivial which correlations are the dominant ones as a function of topological exchange angle and on-site interaction U. We find that a careful derivation of all terms in the Luttinger liquid theory predicts an intermediate phase between a Mott insulator for large repulsive U and a charge density wave at negative U. As a function of exchange angle the intermediate phase changes from Haldane insulator for pseudo bosons to a dimerized phase for pseudo fermions at an interesting multicritical point. Our results are confirmed by extensive numerical simulations.

TT 61.2 Wed 16:45 H 3010

Finite one-dimensional anyons with fixed boundary condition: The Anyonic Luttinger Liquid — •Pascal Jung[1], Martin Bonkhoff[2], Imke Schneider[1], and Sebastian Eggert[1] — [1]University of Kaiserslautern-Landau, Landesforschungszentrum OPTIMAS — [2]Universität Hamburg

Recently lattice anyons in one-dimension have been the center of theoretical and experimental research as a prototypical system with statistically generated interactions. Due to the fundamentally broken parity and the different velocities in the left and right direction, it is non-trivial to find the many-body solution for standing waves in a finite 1D system with box-like boundary conditions. We now describe how the corresponding Luttinger liquid theory with a current-density coupling can be solved by a novel mode expansion which incorporates the correct reflection conditions for fixed boundary condition. It is therefore possible to fully calculate the asymptotic space-time correlation function and determine the corresponding low-energy structure factor, which provides a characteristic hallmark for the Anyonic Luttinger Liquid.

TT 61.3 Wed 17:00 H 3010

Influence of oxygen orbitals on the pairing behavior in the Emery model for doped ladders — •Gökmen Polat and Eric Jeckelmann — Institut für Theoretische Physik, Leibniz Universität Hannover

We investigate the Emery model on ladder-like lattices including two legs of copper d-orbitals and various numbers of oxygen p-orbitals. Various periodic ladder structures are considered with unit cells Cu_nO_m with ratio n/m from 2/5 to 2/3. We calculate gaps, pair binding energy, density distribution, and pairing correlation functions on ladders with open boundary conditions using the density matrix renormalization group (DMRG). We show that the presence or absence of chain-end p-orbitals can lead to the formation of localized boundary states and strongly influences the pairing properties at low doping. More generally, the pairing behavior of finite-size ladders upon hole or electron doping depends sensitively on which p-orbitals are included and on the strength of their hybridization with the copper d-orbitals. We show that these finite-size effects play a role in the apparent failure of the Emery model for cuprate ladders that has been reported recently [1].

[1] Song et al., Phys. Rev. B 107 (2023) L241108

TT 61.4 Wed 17:15 H 3010

Valence-bond order in quantum spin chains with a dissipative spin-Peierls coupling — •Manuel Weber — Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

Quantum spin chains exhibit critical phases of matter that might become unstable when coupled to environmental degrees of freedom. Here, we study the effect of bond dissipation on the one-dimensional antiferromagnetic spin-1/2 Heisenberg model. In analogy to the spin-Peierls problem, the dissipative bath is described by local harmonic oscillators that modulate the spin exchange coupling, but instead of a single boson frequency we consider a continuous bath spectrum $\propto \omega^s$. Using an exact quantum Monte Carlo method for retarded interactions, we show that for $s < 1$ any finite coupling to the bath induces valence-bond-solid order, whereas for $s > 1$ the critical phase of the isolated chain remains stable up to a finite critical coupling. We find that, even in the presence of the gapless bosonic spectrum, the spin-triplet gap remains well defined for any system size, from which we extract a dynamical critical exponent of $z = 1$. We provide evidence for a Berezinskii-Kosterlitz-Thouless quantum phase transition that is governed by the $SU(2)_1$ Wess-Zumino-Witten model. Our results suggest that the critical properties of the dissipative system are the same as for the spin-Peierls model, irrespective of the different interaction range, i.e., power-law vs. exponential decay, of the retarded dimer-dimer interaction, indicating that the spin-Peierls criticality is robust with respect to the bosonic density of states.

TT 61.5 Wed 17:30 H 3010

Quantum simulation of the tricritical Ising model in tunable Josephson junction ladders — •Niklas Tausendpfund[1,2], Lorenzo Maffi[3], Matteo Rizzi[1,2], and Michele Burrello[3] — [1]Peter Grünberg Institut 8, Forschungszentrum Jülich, Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Köln, Germany — [3]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

Modern hybrid superconductor-semiconductor Josephson junction arrays are a promising platform for analog quantum simulations. Their controllable and non-sinusoidal energy/phase relationship opens the way to implement non-trivial interactions and to study the emergence of exotic quantum phase transitions. Here we present the analysis of a 2-leg ladder geometry composed of Josephson junctions. Our results support the existence of tricritical Ising phase transitions based on bosonization and matrix product state techniques. This proposal provides a useful one-dimensional building block for designing exotic topological orders in two-dimensional scalable Josephson junction arrays.

TT 61.6 Wed 17:45 H 3010

Stability of Floquet-Bloch states in 1D strongly correlated fermions subject to perturbations — •Karun Gadge and Salvatore R. Manmana — Institute for Theoretical Physics, Georg-August-University Goettingen

Recent experiments have shown many exciting applications of Floquet engineering, where the interaction of the light field with electrons in materials is used to tailor the band structure. However, for strongly correlated systems, many questions concerning the formation and stability of these Floquet-Bloch states (FBs) are still open. Here, we investigate for the influence of electron-electron interactions, a perturbing noise in the coherent driving, and the presence of electron-phonon interactions on the FBs visible in time-resolved single-particle spectral functions. In particular, using exact diagonalizations and matrix product states (MPS) we treat a chain of interacting spinless fermions in 1D, which for strong interactions forms a correlated charge density wave insulator. Even in the presence of strong electron-electron interactions, we find replicas of the full holon continuum in the spectral function, as well as an aditional in-gap mode related to the Villain mode of quantum antiferromagnets at low temperatures [1]. We discuss results for different intensity and frequency of the light field, as well as for the stability of the FBs in the presence of classical phonons and incoherent noise in the driving.

[1] A. Osterkorn, C. Meyer, S.R. Manmana, Commun. Phys. 6 (2023) 245

TT 62: Focus Session: $SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor I (joint session TT/KFM/MA/O)

Strontium titanate ($SrTiO_3$) is a paradigmatic material that plays an important role in various fields of solid-state physics, surface science and catalysis: The pure bulk phase is a wide-band-gap semiconductor that upon cooling becomes a textbook quantum paraelectric. When slightly doped, $SrTiO_3$ turns into a Fermi-liquid-type metal that becomes superconducting at extremely low charge carrier density. $SrTiO_3$-based surfaces and interfaces host un-conventional electronic states such as quasi-two-dimensional electron liquid, magnetism and superconductivity. Despite intensive studies over the past decades, $SrTiO_3$ continues to reveal surprising new phenomena that challenge the established views on this material. To this end achieving light-induced nonequilibrium states and the recent preparation of a 2D oxide based on $SrTiO_3$ opens new playgrounds for research. This Focus Session will present exciting developments in the study of electronic states that are based on the peculiar properties of $SrTiO_3$.

Please note that this Focus Session comprises four parts: Posters are presented within the TT poster session TT58 (Wed 15:00-18:00, poster area E). Invited talks are compiled in the session TT62 (Thursday, 9:30 to 12:45, H0104), Contributed talks will be presented in sessions TT72 (Thursday 15:00-18:00, H0104) and TT83 (Fri 9:30-12:30, H0104).

Organizers: Rossitza Pentcheva, University of Duisburg-Essen, Marc Scheffler, University of Stuttgart

Time: Thursday 9:30–12:45 Location: H 0104

Invited Talk TT 62.1 Thu 9:30 H 0104

Ferroelectricity and Superconductivity in $SrTiO_3$ — •Susanne Stemmer — University of California, Santa Barbara, USA

Polar superconductors have attracted significant interest for their potential to host unconventional superconductivity. One candidate is doped strontium titanate ($SrTiO_3$), which can undergo successive ferroelectric and superconducting transitions. Recent experimental observations of a factor of two enhancement of the superconducting transition temperature in ferroelectric samples and the fact that both ferroelectricity and superconductivity vanish around the same carrier density, hint at common physical interactions relevant for both phenomena. We will discuss our understanding of ferroelectricity in strained $SrTiO_3$ films, and experiments aimed at elucidating the connection between superconductivity and ferroelectricity.

Although the ferroelectric transition of strained, undoped $SrTiO_3$ is usually described as a classic displacive transition, we show that it has pronounced order-disorder characteristics. Increasing the carrier concentration causes polar nanodomains to break up into smaller clusters. (Local) polar order appears to be essential to the superconducting state. For example, in strained $SrTiO_3$ films, suppression of superconductivity is correlated to the destruction of the (global) ferroelectric state, either by overdoping, by decreasing the film thickness or by alloying large amounts of a rare earth ion. We discuss how the length scale of polar order emerges as an important parameter in controlling the superconductivity of $SrTiO_3$.

Invited Talk TT 62.2 Thu 10:00 H 0104

Dilute superconductivity in doped strontium titanate — •Kamran Behnia — LPEM-ESPCI, Paris, France

Dilute superconductivity survives in bulk strontium titanate when the Fermi temperature falls well below the Debye temperature. The onset of the superconducting dome is dopant dependent. The threshold density fpr superconductivity is much lower for mobile electrons introduced by removing oxygen atoms compared to those brought by substituting Ti with Nb. Our study of quantum oscillations reveals a difference in the band dispersion between the dilute metals made by these doping routes and our band calculations demonstrate that the rigid band approximation does not hold when mobile electrons are introduced by oxygen vacancies. We identify the band sculpted by these vacancies as the exclusive locus of superconducting instability in the ultradilute limit.

Invited Talk TT 62.3 Thu 10:30 H 0104
Polarons and Excitons in quantum-paraelectric $SrTiO_3$ — •Cesare Franchini — University of Vienna & Bologna

$SrTiO_3$ stands as one of the most extensively investigated materials, captivating attention due to its distinctive electronic properties emerging from its quantum paraelectric nature. Positioned on the cusp of various collective phases, this material holds significant potential for exploitation in electronic and optical applications. In this presentation, we delve into the biphonon collective behaviors and quasiparticle properties of $SrTiO_3$ in both bulk and reduced dimensions, leveraging a combination of single-particle and many-body methods supported by machine learning techniques. Our exploration commences with an examination of temperature-dependent quantum and anharmonic effects employing a synergy of machine-learned potentials and the stochastic self-consistent harmonic approximation [1,2]. Shifting focus, we investigate the electron-phonon-driven formation of polarons, scrutinizing the interplay between spatially localized small polarons and dispersive large polarons in both bulk $SrTiO_3$ [3,4] and on the bulk-terminated $SrTiO_3$(001) surface [5,6]. In conclusion, our study delves into the optical and excitonic properties, with particular emphasis on the emergence of strongly bound excitonic peaks in the monolayer limit [7,8].

[1] Adv. Quantum Technol. 6 (2023) 2200131
[2] Phys. Rev. Mater. 7 (2023) L030801
[3] Phys. Rev. B 91 (2015) 085204
[4] npj Computational Materials 125 (2022)
[5] Phys. Rev. Mater. 3, 034407 (2019); Phys. Rev. B 103 (2021) L241406
[6] Phys. Rev. Mater. 7 (2023) 064602
[7] Phys. Rev. Mater. 5 (2021) 074601
[8] arXiv:2303.14830

15 min. break

Invited Talk TT 62.4 Thu 11:15 H 0104
Controlling ferroelectrics with light — •Andrea Cavalleri — Max Planck Institute for the Structure and Dynamics of Matter, Hamburg — Department of Physics, University of Oxford

I will discuss how irradiation of ferroelectrics with intense, far and mid-infrared pulses, which are made resonant with certain phonon modes, can be used to manipulate the ferroelectric polarization. Two cases have been identified so far. On the one side, irradiation of a low temperature ferroelectric phase (e.g. in $LiNbO_3$) can achieve switching of the polarization. In incipient ferroelectric phases (e.g. in $SrTiO_3$), can lead to the formation of a long range ordered phase with stronger ferroelectricity than the paraelectric ground state. The microscopic physics of these phenomena are only in part clear, and I will discuss progress in this area.

Invited Talk TT 62.5 Thu 11:45 H 0104
Terahertz electric field driven dynamical multiferroicity in $SrTiO_3$ — •Stefano Bonetti — Ca' Foscari University of Venice, Venice, Italy

In recent years, the ultrafast dynamical control and creation of novel ordered states of matter not accessible in thermodynamic equilibrium is receiving much attention. Among those, the theoretical concept of dynamical multiferroicity has been introduced to describe the emergence of magnetization by means of a time-dependent electric polarization in non-ferromagnetic materials. However, the experimental verification of this effect is still lacking. Here, we provide evidence of room temperature magnetization in the archetypal paraelectric perovskite $SrTiO_3$ due to this mechanism. To achieve it, we resonantly drive the infrared-active soft phonon mode with intense circularly polarized terahertz electric field, and detect a large magneto-optical Kerr effect. A simple model, which includes two coupled nonlinear oscillators whose forces and couplings are derived with ab-initio calculations using self-consistent phonon theory at a finite temperature, reproduces qualitatively our experimental observations on the temporal and frequency domains. A quantitatively correct magnitude of the effect is obtained when one also considers the phonon analogue of the reciprocal of the Einstein - de Haas effect, also called the Barnett effect, where the total angular momentum from the phonon order is transferred to the electronic one. Our findings show a new path for designing ultrafast magnetic switches by means of coherent control of lattice vibrations with light.

TT 62.6 Thu 12:15 H 0104
Emergence of a quantum coherent state at the border of ferroelectricity in $SrTiO_3$ — •Matthew Coak[1,2], Charles Haines[2], Cheng Liu[2], Stephen Rowley[2,3], Gilbert Lonzarich[2], and Siddharth Saxena[2] — [1]School of Physics and Astronomy, University of Birmingham, Birmingham, UK — [2]Cavendish Laboratory, University of Cambridge, Cambridge, UK — [3]Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

$SrTiO_3$ exists on the border of ferroelectricity in the vicinity of a quantum critical point (QCP). It is this proximity to a quantum critical point and the fluctuations associated with it which are responsible for $SrTiO_3$'s strikingly non-classical dielectric susceptibility.

I will discuss our results utilising ultra-high precision measurements of the the dielectric susceptibility to demonstrate an unconventional quantum paraelectric state exhibiting 'order by disorder' - a fluctuation-induced enhancement of electric polarization up to a coherence temperature T^*. We show that in the vicinity of T^* this phenomenon can be understood quantitatively in terms of the hybridization of the critical electric polarization field and the volume strain field of the lattice.

We argue that this coherent optical-acoustic phonon state emerges from the QCP and is critical to our understanding of the mechanisms behind the quantum criticality and the phenomena resulting from it. At still lower temperatures, well below T^*, we observe a breakdown of this unconventional form of quantum paraelectricity and the emergence of a new instanton liquid phase.

TT 62.7 Thu 12:30 H 0104
Dynamics of the critical phonon modes in quantum paraelectric $SrTiO_3$ — •Shiyu Deng[1,2], Charles S. Haines[1,3], Matthew J. Coak[1,4], Alexandre Ivanov[2], Andrea Piovano[2], Andrew R. Wildes[2], and Siddharth S. Saxena[1] — [1]Cavendish Laboratory, University of Cambridge — [2]Institut Laue-Langevin — [3]University of East Anglia — [4]University of Birmingham

The proximity of $SrTiO_3$ to a ferroelectric quantum critical point (FE QCP) has become a promising new branch of the study of quantum critical phenomena. New forms of quantum order have been reported in SrTiO3 different from the quantum paraelectric state via dielectric measurements.

We report our recently performed triple-axis inelastic neutron scattering experiments on single-crystal $SrTiO_3$ at the temperature and pressure region of interest. These were the first direct measurements deep into the enigmatic 'quantum polar-acoustic state' in the vicinity of the FE QCP. Measurements are taken at and around $q = 0$ in multiple directions in reciprocal space to explore the transverse acoustic and soft optical phonon modes and their hybridization. In addition, we explore how pressure affects the underlying phonon modes in $SrTiO_3$. Our observations address directly the coupling of the soft optical mode with the acoustic phonons, and its response to external pressure. We believe this could help us understand the importance of anharmonic lattice dynamics and quantum fluctuations in $SrTiO_3$.

TT 63: Focus Session: Emerging Magnetic Phenomena from Chiral Phonons I (joint session MA/TT)

Contemporary efforts in spintronics focus on utilizing and controlling electronic angular momentum for possible applications in data storage and processing. Only recently, an alternative has arisen in the form of angular momentum generated by circularly polarized (chiral) phonons. Chiral phonons have been shown to lead to a variety of novel magnetic phenomena, including a phonon Hall, phonon Einstein-de Haas, phonon Barnett, and phonon Zeeman effect. Phonon angular momentum can be utilized to control the magnetic state of solids and even to induce magnetization in nonmagnetic materials. These discoveries make the angular momentum of chiral phonons a promising tool for the control of magnetic materials and an emerging quantity of interest for spintronic applications. The goal of this focus session is to highlight topical research on novel magnetic phenomena arising from chiral phonons and to connect this rapidly developing field to the broader audience working in magnetism and spintronics.

Coordinators: Sebastian T. B. Goennenwein, Universität Konstanz, sebastian.goennenwein@uni-konstanz.de Ulrich Nowak, Universität Konstanz, ulrich.nowak@uni-konstanz.de

Time: Thursday 9:30–12:15 Location: H 1058

Invited Talk TT 63.1 Thu 9:30 H 1058
Giant effective magnetic fields from chiral phonons — •Dominik M. Juraschek — Tel Aviv University, Tel Aviv 6997801, Israel

Chiral phonons conventionally describe circularly polarized lattice vibrations that carry angular momentum. In dielectric materials, the circular motions of the ions create a macroscopic magnetic field when driven with an ultrashort laser pulse, which has previously been shown to reach the order of millitesla. Here, we predict that this magnetic field can effectively reach up to the tesla scale, when enhanced by orbit-lattice coupling [1,2]. Our predictions have been experimentally confirmed in a recent study [3]. We demonstrate theoretically that these giant phono-magnetic fields can be utilized to generate nonequilibrium spin configurations in antiferromagnets, leading to a light-induced weak ferromagnetic state [4]. Finally, whereas the above phenomena are based on circularly polarized chiral phonons, we further demonstrate that the crystal structure can be transiently made chiral with linearly polarized phonons that are quasistatically displaced by nonlinear phonon coupling [5]. These "linearly polarized chiral phonons" make it possible to create chiral crystal structures on demand with implications for chiral magnetic and electronic properties. [1] Juraschek et al., PRResearch, 4, 013129 (2022) [2] S. Chaudhary, D. M. Juraschek, et al., arXiv:2306.11630 (2023) [3] J. Luo et al., Science 382, 698 (2023) [4] T. Kahana, D. A. Bustamante Lopez, and D. M. Juraschek, arXiv:2305.18656 (2023) [5] C. Romao and D. M. Juraschek, arXiv:2311.00824 (2023)

Invited Talk TT 63.2 Thu 10:00 H 1058
Chiral phonons in quantum materials revealed by the thermal Hall effect — •Gael Grissonnanche — Ecole Polytechnique, Palaiseau, France

It is becoming surprisingly clear that phonons can produce a large thermal Hall effect across a wide range of quantum materials, from cuprate superconductors [1,2] to titanates [3], iridates [4], and frustrated magnets [5]. The thermal Hall effect represents the deflection of a heat current by a perpendicular magnetic field. It is usually interpreted as coming from mobile hot electrons deflected by the Lorentz force. While trivial in metals, this effect is now found in insulators, and phonons that carry no charge are responsible for it. Phonons are the most common low-energy excitations in solids. Yet the handedness they acquire in a magnetic field * which triggers the thermal Hall effect * remains an enigma. In this talk, I will present the results that have led to the emergence of a new field of research aimed at discovering the origin of the thermal Hall effect of phonons and how this might relate to the question of chiral phonons measured by other probes.

[1] Grissonnanche et al. Nature 571, 376 (2019) [2] Grissonnancheet al. Nat. Phys. 16, 1108 (2020) [3] Li et al. Phys. Rev. Lett. 124, 105901 (2020) [4] Ataei et al. Nat. Phys. (2023) [5] Lefrançois et al. Phys. Rev. X 12, 021025 (2022)

Invited Talk TT 63.3 Thu 10:30 H 1058
Phonon chirality and thermal Hall transport — •Benedetta Flebus[1] and Allan H. MacDonald[2] — [1]Department of Physics, Boston College, 140 Commonwealth Avenue, Chestnut Hill, Massachusetts 02467, USA — [2]Department of Physics, the University of Texas at Austin, Austin, Texas 78712, USA

In recent years, a rapidly increasing amount of studies has reported novel physical phenomena arising from lattice vibrations that carry angular momentum, i.e., chiral phonons. In this talk, I will discuss both intrinsic and extrinsic sources of chiral phonon transport. First, I will show that in ionic crystals a phonon Hall viscosity contribution can emerge as a result of the Lorentz forces on moving ions [1]. I will then explain how phonon scattering from defects that break time-reversal symmetry, such as charged impurities, can yield giant thermal Hall effects that are consistent with recent experimental observations [2].

[1] B. Flebus and A. H. MacDonald, The phonon Hall viscosity of ionic crystals, Phys. Rev. Lett. (in press). [2] B. Flebus and A. H. MacDonald, Charged defects and phonon Hall effects in ionic crystals, Phys. Rev. B 105 (22), L220301 (2022).

15 min. break

Invited Talk TT 63.4 Thu 11:15 H 1058
Orbital magnetic moment of phonons in diamagnetic and paraelectric perovskites — Filip Kadlek[1], Christelle Kadlek[1], •Martina Basini[2,3], Sergey Kovalev[4], Jan-Christoph Deinert[4], Stefano Bonetti[1,5], and Stanislav Kamba[1] — [1]Institute of Physics of the Czech Academy of Sciences, Praha, Czech Republic — [2]Department of Physics, Stockholm University, Stockholm, Sweden — [3]Deparment of Materials and Nanophysics, KTH Royal Institute of Technology, Stockholm Sweden — [4]Helmholz Zentrum Dresden-Rossendorf, Germany — [5]Department of Molecular Sciences and Nanosystems, Ca' Foscari University of Venice, Venice, Italy

In the present work, we demonstrate transient magnetism in $KTaO_3$ induced by chiral phonons. In particular, the infrared-active soft phonon was circularly excited by means of intense quasi-monochromatic THz pulses produced by the TELBE facility and the magnetic moment was probed by magneto-optical Faraday effect. The evidence will be compared with our previous results on $SrTiO_3$. We anticipate that, contrary to $SrTiO_3$, $KTaO_3$ does not undergo any structural phase transition at low temperature so that we could efficiently excite the soft phonon below 100K, where the phonon effective charge is larger and a higher value of the induced orbital magnetic moments per unit cell is expected.

Invited Talk TT 63.5 Thu 11:45 H 1058
Spin-lattice coupling in multiscale modeling — •Markus Weissenhofer[1,2], Sergiy Mankovsky[3], Svitlana Polesya[3], Hannah Lange[3], Akashdeep Kamra[4], Hubert Ebert[3], and Ulrich Nowak[5] — [1]Uppsala University, Uppsala, Sweden — [2]Freie Universität Berlin, Berlin, Germany — [3]LMU Munich, Munich, Germany — [4]Universidad Autónoma de Madrid, Madrid, Spain — [5]University of Konstanz, Konstanz, Germany

In recent years, it has been shown that it is not only possible to transfer angular momentum from the spin system to the lattice on ultrashort time scales, but also that this process can be reversed by using circularly polarized terahertz light pulses [1].

To contribute to the understanding of angular momentum transfer between spin and lattice degrees of freedom, we have developed a theoretical multiscale framework for spin-lattice coupling [2], which is linked to ab-initio calculations on the one hand and magnetoelastic continuum theory on the other. Here I will discuss how this framework can be used to calculate magnon-phonon coupling parameters, emphasizing the importance of a Dzyaloshiskii-Moriya type interaction for angular momentum transfer in iron, and to perform simulations to study the combined magnetic and mechanical motion of ferromagnetic nanoparticles.

[1] Dornes et al., Nature (London) 565, 209 (2019); Tauchert al., Nature (London) 602, 73 (2022); Luo et al., Science 382, 698 (2023). [2] Mankovsky et al., PRL 129, 067202 (2022); Weißenhofer et al., PRB 108, L060404 (2023).

TT 64: Spin Transport and Orbitronics, Spin-Hall Effects I (joint session MA/TT)

Time: Thursday 9:30–12:45 Location: H 2013

TT 64.1 Thu 9:30 H 2013

Fluctuation mediated spin-orbit torque enhancement in the noncollinear antiferromagnet Mn3Ni0.35Cu0.65N — Arnab Bose[1], Aga Shahee[1], Tom G. Saunderson[1], •Adithya Rajan[1], Dongwook Go[2], Aurélien Manchon[3], Yuriy Mokrousov[1,2], and Mathias Kläui[1] — [1]Institut für Physik, Johannes-Gutenberg-Universität Mainz, 55099 Mainz, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich, 52424 Jülich, Germany — [3]CINaM, Aix-Marseille Université, CNRS, Marseille, France

Spin fluctuations near magnetic phase transitions play a pivotal role in generating exotic phenomena. This study focuses on experimental investigation of temperature-dependent spin torques in the noncollinear antiferromagnet Mn3Ni0.35Cu0.65N (MNCN). Our findings reveal a significant and nontrivial temperature dependence of spin-orbit torques (SOT), peaking near MNCN's Néel temperature. This behavior cannot be explained by conventional scattering mechanisms of the SHE. Notably, a maximum SOT efficiency of 30 % is measured, surpassing that of commonly studied nonmagnetic materials like Pt. Theoretical calculations support a negligible SHE and a pronounced orbital Hall effect, explaining the observed spin torques. We propose a novel mechanism where fluctuating antiferromagnetic moments induce substantial orbital currents near the Néel temperature. These results provide a promising avenue for enhancing spin torques, with potential applications in magnetic memory.

TT 64.2 Thu 9:45 H 2013

First-principles calculation of the orbital current and orbital accumulation in metallic layers — •Daegeun Jo[1], Dongwook Go[2,3], Peter Oppeneer[1], and Hyun-Woo Lee[4] — [1]Department of Physics and Astronomy, Uppsala University, P.O. Box 516, SE-75120 Uppsala, Sweden — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [3]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [4]Department of Physics, Pohang University of Science and Technology, Pohang, South Korea

Recently, the orbital degree of freedom has emerged as a new element for the electrical control of magnetization in magnetic devices. Notably, magneto-optical measurements have demonstrated that the orbital angular momentum is accumulated by the orbital Hall effect in metallic films consisting of light elements such as Ti [Y.-G. Choi *et al.*, Nature **619**, 52-56 (2023)] and Cr [I. Lyalin *et al.*, Phys. Rev. Lett. **131**, 156702 (2023)]. However, the relationship between the orbital Hall current and the boundary orbital accumulation remains unclear. In this work, we present the theoretical calculations of the orbital Hall current and the current-induced orbital accumulation in various metallic films based on the first-principles calculations. We show that the orbital accumulation is properly described by considering the torque contribution from the crystal field in addition to the conventional orbital current.

TT 64.3 Thu 10:00 H 2013

Using first principles methods to describe spin-orbitronic and superconducting phenomena — •Tom G. Saunderson[1,2], Dongwook Go[1,2], Maria Teresa Mercaldo[3], Mario Cuoco[4], Martin Gradhand[1,5], and Yuriy Mokrousov[1,2] — [1]Institute of Physics, JGU, 55099 Mainz, Germany — [2]PGI and IAS, Forschungszentrum Jülich, Germany — [3]Universitá di Salerno, IT-84084 Fisciano, Italy — [4]CNR-SPIN, IT-84084 Fisciano (SA), Italy — [5]University of Bristol, Bristol BS8 1TL, UK

Recent advancements in orbitronics demonstrate remarkable efficiency gains using cost-effective materials [1], while spin-Hall mediated responses notably intensify near the superconducting transition [2]. Breaking inversion or time-reversal symmetry efficiently extracts these unconventional currents, however for material-specific predictions first principles techniques are essential. Although theoretical methods for orbital currents are well-established, first principles techniques for supercurrents are still in their infancy. This talk aims to explore two approaches. Firstly, we employ maximally localized Wannier functions to investigate the influence of p-d hybridizations on enhancing the orbital Rashba Edelstein effect on particular surfaces of known metallic systems. Secondly, we utilize a Green's function-based superconducting first principles code to induce unconventional triplet densities in superconductors featuring complex orbital degrees of freedom and inversion symmetry breaking. Such methods will pave the way for first principles-based modeling of superconducting spintronics. [1] Nature 619, 52 (2023) [2] ACS Nano 14, 15874 (2020)

TT 64.4 Thu 10:15 H 2013

Investigation of the topological transport properties for the MAB phase — •Fu Li, Ruiwen Xie, and Hongbin Zhang — Institute of Materials Science, Technology University of Darmstadt, 64287, Darmstadt, Germany

Compounds of MAB phases, i.e, Ternary transition metal borides with nano-laminated structures, have attracted significant attention due to their intriguing physical properties. In this work, we evaluate the topological transport properties(anomalous and spin Hall conductivities) of MAB compounds, aiming to uncover potential applications in the field of spintronics. After constructing the maximally localized Wannier functional automatically, the anomalous and spin Hall conductivities are obtained based on the Wannier interpolation. It is observed several compounds exhibit significant anomalous and spin Hall conductivities, which can be understood based on the underlying electronic structure. Furthermore, the influence of magnetization direction on spin Hall conductivity is studied for those compounds where the inversion symmetry is broken due to the antiferromagnetic ordering. We find that the magnitude of spin Hall conductivity can be tailored by the magnetization direction, offering possible applications in spintronics.

TT 64.5 Thu 10:30 H 2013

Unconventional Spin-Orbit Torques in CrPt3 — •Robin Klause[1], Yuxuan Xiao[2,3], Jonathan Gibbons[1,4], Axel Hoffmann[1], and Eric Fullerton[2] — [1]University of Illinois Urbana-Champaign — [2]University of California San Diego — [3]TDK Corporation — [4]Western Digital Corporation

Spin-orbit torques can efficiently control magnetization states using charge currents. However, with conventional spin-orbit torques, where charge current, spin current, and spin polarization are mutually perpendicular only in-plane magnetization parallel to the spin polarization can be switched field-free and deterministically. The topological semimetal CrPt3 has potential for generating unconventional spin-torques due to its ferrimagnetic ordering, topological band structure and high anomalous Hall conductivity. As CrPt3 exhibits ferrimagnetic behavior only in its chemically ordered phase while it is paramagnetic in its chemically disordered phase we can compare spin-torque generation in the two phases and investigate whether unconventional torques originate from the magnetic or crystal structure. We studied spin-torque generation in epitaxial CrPt3(110) films using angle dependent spin-torque ferromagnetic-resonance measurements with currents applied along specific crystal directions. We reveal unconventional spin-torques in both chemically ordered and disordered CrPt3 when current flows along the [1-11] and [-111] crystal directions. We conclude that the unconventional torque originates from the crystal order since these directions lack a mirror plane, allowing unconventional torques to be generated.

TT 64.6 Thu 10:45 H 2013

Spin and orbital Edelstein effect in a bilayer $SrTiO_3$ system — •Sergio Leiva[1], Börge Göbel[1], Jürgen Henk[1], Ingrid Mertig[1], and Annika Johansson[2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle (Saale), Germany. — [2]Max Planck Institute of Microstructure Physics, Halle, Germany

The spin and orbital Edelstein effect have proved promising phenomenons to generate spin and orbital polarization from a charge current in systems without inversion symmetry [1-5]. The present work studies the current-induced spin and orbital magnetization in a $SrTiO_3/LaAlO_3$ interface with a tight-binding model and the semiclassical Boltzmann theory. We studied a monolayer, a pseudo-monolayer, and a bilayer system for the STO to replicate experimental data from ARPES. For the bilayer model [6], we compare the orbital effect from the atomic-centered approximation (ACA) and the modern theory of orbital magnetization (MTOM)[7]. We found that the orbital Edelstein effect from ACA is larger than the spin Edelstein effect [5] and the orbital effect from MTOM. This difference between ACA and MTOM shows the relevance of the modern theory for heterostructure systems.

[1] D. Go *et al.*, Sci. Rep. **7**, 46742 (2017)
[2] T. Yoda *et al.*, Nano Lett., **18**, 916 (2018).
[3] L. Salemi *et al.*, Nat. Commun. **10**, 5381 (2019)
[4] D. Hara *et al.*, Phys. Rev. B, **102**, 184404 (2020).
[5] A. Johansson *et al.*, Phys. Rev. Research, **3**, 013275 (2021).
[6] S. Leiva M. *et al.* arXiv:2307.02872 (2023).
[7] T. Thonhauser *et al.* Phys. Rev Lett. **95**, 137205 (2005).

TT 64.7 Thu 11:00 H 2013

Electrically induced angular momentum flow between separated ferromagnets — •Matthias Grammer[1,2], Richard Schlitz[3], Tobias Wimmer[1,2], Janine Gückelhorn[1,2], Luis Flacke[1,2], Sebastian T.B. Goennenwein[4], Rudolf Gross[1,2,5], Hans Huebl[1,2,5], Akashdeep Kamra[6], and Matthias Althammer[1,2] — [1]Walther-Meißner-Institut, BAdW, Garching, Germany — [2]School of Natural Sciences, TUM, Garching, Germany — [3]Department of Materials, ETH Zürich, Zürich, Switzerland — [4]Department of Physics, University of Konstanz, Konstanz, Germany — [5]Munich Center for Quantum Science and Technology, München, Germany — [6]IFIMAC and Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Madrid, Spain

The transfer of angular momentum between electrons, magnons and phonons is pivotal for spintronic devices making use of angular momentum currents. Here, we demonstrate angular momentum transfer between two isolated ferromagnetic metal strips on diamagnetic substrates [1]. Experimentally we apply a DC charge current at one of the magnetic electrodes which is converted into an electronic spin current and consequently transfered to the magnonic system. Using the inverse process at the second electrode, we can detect the induced angular momentum flow between the electrodes up to micron distances. We attribute this transfer mechanism to dipolar and potentially phononic interactions.

[1] R. Schlitz et al., arXiv:2311.05290(2023)

15 min. break

TT 64.8 Thu 11:30 H 2013

Orbital Hall effect and orbital edge states caused by *s* electrons — •Oliver Busch, Ingrid Mertig, and Börge Göbel — Institut für Physik, Martin-Luther-Universität, D-06099 Halle

An orbital current can be generated whenever an object has a translational degree of freedom and a rotational degree of freedom. In condensed matter physics, intra-atomic contributions to the transverse orbital transport, labeled the orbital Hall effect, rely on propagating wave packets that must consist of hybridized atomic orbitals [1]. However, interatomic contributions have to be considered as well because they give rise to an alternative mechanism for generating orbital currents [2].

As we show, even wave packets consisting purely of *s* electrons can transport orbital angular momentum if they move on a cycloid trajectory [3]. We introduce the kagome lattice with a single *s* orbital per atom as the minimal model for the orbital Hall effect and observe the cycloid motion of the electrons in the surface states.

[1] D. Go *et al.*, Physical Review Letters **121**, 086602 (2018)
[2] A. Pezo *et al.*, Physical Review B **106**, 104414 (2022)
[3] O. Busch *et al.*, Physical Review Research 5, 043052 (2023)

TT 64.9 Thu 11:45 H 2013

Spin-to-charge conversion in ferromagnetic heterostructures — •Misbah Yaqoob[1], Fabian Kammerbauer[2], Tom G. Saunderson[2], Vitaliy I. Vasyuchka[1], Dongwook Go[3], Hassan Al-Hamdo[1], Gerhard Jakob[2], Yuriy Mokrousov[2,3], Mathias Kläui[2], and Mathias Weiler[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany — [3]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Spin-orbit torques (SOTs) can be used for efficient control of magnetization and the electrical detection of spin dynamics through the inverse spin Hall effect (iSHE) [1]. We investigate spin-to-charge conversion in ferromagnetic heterostructures based on perpendicular magnetic anisotropy (PMA) multilayers of [Co/Ni] and [Co/Pt] that generate SOTs in adjacent CoFeB thin films with in-plane magnetic anisotropy (IPA). We extract the spin dynamics and SOTs [2] using vector network analyzer ferromagnetic resonance spectroscopy (VNA-FMR). In our experiments, we found that our multilayers generate SOTs comparable in magnitude to Pt, in agreement with first-principles calculations. Additionally, we observed a pronounced dependence of the SOT on the IPA CoFeB layer thickness.

[1] T. Jungwirth *et al.*, Nat. Mater. **11**, 382 (2012).
[2] A. J. Berger *et al.*, Phys. Rev. B **97**, 94407 (2018).

TT 64.10 Thu 12:00 H 2013

Modelling layer resolved spin-orbit torque assisted magnetization dynamics in Pt/Co bilayers — •Harshita Devda[1], Andras Deak[2], Leandro Salemi[3], Levente Rozsa[4], Laszlo Szunyogh[2], Peter M. Oppeneer[3], and Ulrich Nowak[1] — [1]University of Konstanz, Konstanz, Germany — [2]Budapest University of Technology and Economics, Budapest, Hungary — [3]Uppsala University, Uppsala, Sweden — [4]Wigner Research Centre for the Physics, Budapest, Hungary

Spin-orbit-torque(SOT) devices have acquired extensive attention for their unique features, encompassing low power consumption and efficient data storage capabilities. Recent discoveries of the Orbital Hall Effect and the Orbital Rashba-Edelstein Effect have added more intricacy to the understanding of magnetization switching mechanisms in these devices, especially in Nonmagnetic/Ferromagnet systems. To address this, we present a model for a Pt/Co bilayer system where we utilized Atomistic Spin Dynamics simulations, incorporating abinitio calculated interaction parameters mapped to the Hamiltonian and electrically induced moments from first-principles calculations. Our descriptive model reveals the Spin and Orbital Hall Effect as the dominant mechanism behind magnetization switching in Pt/Co at low electric field strengths. Conversely, there is a significant magnetization dependence of the interface-generated moments at high field, leading to counterintuitive anti-switching behaviour with enhanced layer-resolved behavior in the presence of orbital moments.

TT 64.11 Thu 12:15 H 2013

Investigating Orbital Hall Effect Materials for Efficient Magnetization Control with In-plane and Perpendicular Magnetic Anisotropic Ferromagnets — Rahul Gupta[1], •J. Omar Ledesma Martin[1,2], Chloe Bouard[2], Fabian Kammerbauer[1], Sylvain Martin[2], Gerhard Jakob[1], Marc Drouard[2], and Mathias Kläui[1,3] — [1]Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Antaios, 35 Chemin du Vieux Chêne, 38240 Meylan, France — [3]Center for Quantum Spintronics, Department of Physics, Norwegian, University of Science and Technology, NO-7491 Trondheim, Norway

There is considerable potential in the Orbital Hall Effect (OHE) and the Spin Hall Effect (SHE) as electrical means for controlling the magnetization of spintronic devices. Here Ru stands out exhibiting an orbital Hall conductivity four times greater than that of Pt.

This work, assesses the efficiency of four distinct stacks in devices with perpendicular Magnetic Tunnel Junctions (MTJ). Following the formula Ta/OHE/Pt/[Co/Ni]3/Co/MgO/CoFeB/Ta/Ru, where the OHE materials are Ru, Nb, and Cr. Additionally, a sample wit Pt instead of OHE serves as a reference.

The results demonstrate an improvement in the Ru samples, exhibiting higher damping-like torque and lower switching current density compared to both the other samples and the Pt reference. These findings, including first-principle calculations, underscore the potential of Ru as an OHE material for enhancing the performance and power consumption of spintronic devices.

TT 64.12 Thu 12:30 H 2013

Unlocking the Potential of Rare-Earth Dichalcogenides for Topological Spintronics and Orbitronics — Mahmoud Zeer[1,2], Dongwook Go[1,3], •Peter Schmitz[1,2], Tom G. Saunderson[3], Wulf Wulfhekel[4], Stefan Blügel[1,2], and Yuriy Mokrousov[1,3] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [2]Department of Physics, RWTH University, Aachen, Germany — [3]Institute of Physics, Johannes Gutenberg-University, Mainz, Germany — [4]Institute of Quantum Materials and Technologies, Karlsruhe Institute of Technology, Karlsruhe, Germany

We investigate the electronic, magnetic and transport properties of rare-earth dichalcogenides, specifically monolayers of H-phase EuX2 and GdX2 (X = S, Se, Te), using first-principle methods. We show that this family of materials exhibits high magnetic moments, wide bandgaps, and significant anomalous, spin, and orbital Hall conductivities. While the hybridization of p- and f- states in EuX2 occurs just below the Fermi energy, GdX2 displays a non-trivial p-like spin-polarized electronic structure at the Fermi level, which results in manifestly p-based magnetotransport properties. We unravel the role of correlations and strain in influencing the position and hybridization character between the p-, d-, and f-states, which has a direct impact on the quantized Hall response. Our findings suggest that rare-earth dichalcogenides hold promise as a platform for topological spintronics and orbitronics. [1,2] [1] Physical Review Materials 6 (7), 074004 [2] arXiv preprint arXiv:2308.08207.

TT 65: Frustrated Magnets: General I

Time: Thursday 9:30–13:00 Location: H 2053

TT 65.1 Thu 9:30 H 2053

Elastocaloric Effect of the Shastry-Sutherland Compound $SrCu_2(BO_3)_2$ under Uniaxial Pressure — •Francisco Lieberich[1], Pascal Puphal[2], Ekaterina Pomjakushina[3], Andrew P. Mackenzie[1], and Elena Gati[1] — [1]MPI for Chemical Physics of Solids, Dresden, Germany — [2]MPI for Solid State Research, Stuttgart, Germany — [3]PSI, Villigen, Switzerland

$SrCu_2(BO_3)_2$ stands out as the prototypical system embodying the frustrated Shastry-Sutherland model, in which interacting dimers are arranged orthogonally on a square lattice. The intra- and inter-dimer interactions J and J' can be tuned by hydrostatic pressure, leading to a sequence of quantum phase transitions with increasing coupling ratio J'/J [1]. The application of uniaxial pressure holds the potential to break the lattice symmetry and thereby to extend the study of the Shastry-Sutherland model to the case of two inequivalent dimers. This generalized model is predicted to give rise to novel ground states [2]. To determine the entropic landscape of $SrCu_2(BO_3)_2$ under compressive uniaxial pressure up to $\sim$ 1GPa, we utilize measurements of the AC elastocaloric effect, a thermodynamic probe for investigating strain-tuned quantum materials [3]. We compare and contrast our results with the phase diagram under hydrostatic pressure [1] to disentangle the effects of symmetry-breaking and symmetry-conserving strains on the Shasty-Sutherland lattice.

Work supported by the DFG through SFB 1143.

[1] Guo et al., Phys. Rev. Lett. 124 (2020) 206602
[2] Boos et al., Phys. Rev. B 100 (2019) 140413(R)
[3] Ikeda et al., Rev. Sci. Instrum. 90 (2019) 083902

TT 65.2 Thu 9:45 H 2053

Strain-tuned change of the Young's modulus of the triangular antiferromagnet $PdCrO_2$ — •Nina Stilkerich[1,2], Tobias Ritschel[1], Seunghyun Khim[2], Andrew P. Mackenzie[2,3], Jochen Geck[1], and Clifford W. Hicks[2,4] — [1]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01062 Dresden, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany — [3]Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St. Andrews, St. Andrews KY16 9SS, United Kingdom — [4]School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

The delafossite $PdCrO_2$ is a frustrated antiferromagnet below its Neel temperature of 37.5K. Its triangular lattice can be compressed towards a square-like configuration with stress applied along the [-1 1 0] direction. Under high compression, a transition to Néel-type order is expected [1,2,3]. Here, we present a candidate for this transition discovered by stress-strain measurements. Related lattice changes were investigated in an in-house XRD+strain measurement. Combining both techniques, we report a substantial change in the Young's modulus across both the double-to-single-q and possible spiral-to-Neel transition, showing that magnetic interactions have a strong influence on the elastic moduli.

[1] D. Sun et al., New J. Phys. 23 (2021) 123050
[2] A.Yoshimori, J. Phys. Soc. Japan 14 (1959) 807
[3] J.Villain, J. Phys. Chem. Solids 11 (1959) 202

TT 65.3 Thu 10:00 H 2053

Investigation of magnetoelastic couplings on pyrochlore lattices up to B=162T saturation magnetic fields — •Nan Tang[1], Masaki Gen[2], Huiyuan Man[3], Kazuyuki Matsuhira[4], Akira Matsuo[5], Koichi Kindo[5], Akihiko Ikeda[6], Yasuhiro H. Matsuda[5], Philipp Gegenwart[1], Yoshimitsu Kohama[5], and Satoru Nakatsuji[3,5] — [1]Universität Augsburg, Augsburg, Germany — [2]RIKEN Center for Emergent Matter Science, Saitama,Japan — [3]The Johns Hopkins University, Maryland, USA — [4]Kyushu Institute of Technology, Fukuoka, Japan — [5]University of Tokyo, Chiba, Japan — [6]University of Electro-Communications, Tokyo, Japan

Magnetoelastic couplings are interesting due to their ability to generate nontrivial phenomena both of fundamental interest and technological significance. Hence, a comprehensive study based on both experiments and simulations acts as a valuable guide in disentangling the mechanism underlying material deformation. We will discuss magnetization and magnetostriction of two spin ices $Ho_2Ti_2O_7$ and $Pr_2Zr_2O_7$ up to B =162 T. For $Ho_2Ti_2O_7$, ΔL(B) passes a maximum around 40 T, in contrast to the monotonic behaviour of $Pr_2Zr_2O_7$. Our model based on point-charges and Born von Karman springs calculates the crystal-field striction and exchange striction, respectively, and the sum could explain the experiments well. These results showcase that magnetoelasticity in complicated frustrated magnets can be unraveled by very simple models.

TT 65.4 Thu 10:15 H 2053

Impact of magnetic frustration and site randomness on millikelvin adiabatic demagnetization refrigeration performance of rare-earth oxides — •Tim Treu[1], Prachi Telang[1], Marvin Klinger[1], Unnikrishnan Arjun[2], Anton Jesche[1], and Philipp Gegenwart[1] — [1]Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg — [2]Solid State and Structural Chemistry Unit, Indian Institute of Science, Bangalore

Recently Ytterbium- and Gadolinium-oxide based frustrated magnets have been characterized as excellent millikelvin adiabatic demagnetization refrigerants. Compared to traditional paramagnetic hydrated salts, they offer several advantages: higher entropy density for similar minimal temperatures, chemical stability and UHV compatibility. We report a comparative study of various different Yb- and Gd-based oxides (including [1-4] and further unpublished results) and analyze the impact of geometrical frustration and site-randomness on their ADR performance.

Work supported by the German Research Foundation through project 514162746 (GE 1640/11-1).

[1] Y. Tokiwa et al., Commun. Mater. 2 (2021) 42
[2] A. Jesche et al., Phys. Rev. B 107 (2023) 104402
[3] U. Arjun et al., Phys. Rev. Applied 20 (2023) 014013
[4] U. Arjun et al., arXiv:2310.00961.

TT 65.5 Thu 10:30 H 2053

Spin-lattice coupling in Mn_3Ge and Mn_3Sn — •Aleksandr Sukhanov[1], Artem Korshunov[2], Nikita Andriushin[1], Alexei Bosak[2], and Marein Rahn[1] — [1]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, D-01069 Dresden — [2]European Synchrotron Radiation Facility (ESRF), BP 220, F-38043

Grenoble Cedex, France

Strong spin-lattice coupling in a material can be evidenced in spectroscopy by hybridization of magnons and phonons, which are quanta of spin excitations and crystal-lattice vibrations in ordered materials, respectively. In this case, an avoided crossing can be formed when the bare magnon and phonon dispersions intersect in reciprocal space at some momentum and energy.

The isostructural hexagonal compounds Mn_3Ge and Mn_3Sn are both characterized by a noncollinear spin order due to the geometric frustration of the kagome lattice formed by Mn ions. In this talk, we will discuss the results of our recent single-crystal inelastic x-ray scattering experiments on these two compounds. We were able to clearly resolve momenta and energy of the spin-lattice hybrid excitations in Mn_3Ge, whereas Mn_3Sn seem to show no signs of spin-lattice coupling in its spectra.

TT 65.6 Thu 10:45 H 2053

Anomalous critical exponents and other peculiarities of Li_2CuO4_2 — •Stefan-Ludwig Drechsler[1], Wolfram Lorenz[1], Ulrich K. Rössler[1], Roman Kuzian[2], Waldemar Hergett[3], and Rüdiger Klingeler[3] — [1]IFW-Dresden, Germany — [2]Intern. Phys. Center, San Sebastian, Spain — [3]Heidelberg University, Germany

We report anomalously small critical exponents for the sublattice magnetization of the critical exponent β for various single crystals of Li_2CuO_2 including recent data from the literature [1-3]. The obtained reduced values $\beta < 0.37$ as compared to the 3d-isotropic Heisenberg model are ascribed to a relevant magneto-elastic coupling especially along the *c*-axis and to the vicinity of a multicritical point to a noncollinear chiral phase resulting in the presence of Lifshits invariants (LI) in the free energy not yet considered so far for the highly symmetric lattice structure of Li_2CuO_2. The experimental Néel-temperature T_N is analyzed in terms of frustrating interchain couplings derived from a spin-wave analysis of inelastic neutron scattering data [1] leading to a sizable lowering by about 30%. Slightly different values for the coupling constants as compared with [2] are interpreted in terms of a *two-phased* single crystal there leading to a sharp peak near 9.5 K and a broader shoulder near 9.1 K within a Fisher-plot for $d(T\chi(T))/dT$. Noteworthy is also a negative cusp near 2.5 K in the context of LI and weak ferromagnetism below 2.3 K.

[1] W.E.A. Lorenz *et al.*, EPL **88** (2009) 37002
[2] E. Zoghlin *et al.*, Phys. Rev. B **108** (2023) 064408
[3] E.M.L. Chung *et al.*, Phys. Rev. B **68** (2003) 144410

TT 65.7 Thu 11:00 H 2053

Specific heat of azurite up into the 1/3 magnetization plateau phase — •Carolin Kastner[1], Ralf Feyerherm[2], and Stefan Süllow[1] — [1]IPKM, TU Braunschweig, Germany — [2]HZB, Berlin, Germany

One dimensional frustrated quantum spin systems are a focus of extensive research efforts due to their exotic magnetic properties at low temperatures. The natural mineral azurite $Cu_3(CO_3)_2(OH)_2$ is one such material, reported as a model compound of the distorted diamond chain. In this system, the Cu^{2+} ions carry spin-1/2 moments that form monomers and dimers arranged as chains along the crystallographic *b* axis. An extended 1/3 magnetization plateau was observed to arise at around 11 T when the monomers are fully polarized.

We have investigated the specific heat of azurite up to 14 T to gain insight into the thermodynamic properties in the plateau phase. Below the magnetization plateau, the material exhibits long-range magnetic order, with the specific heat exhibiting a magnon gap behaviour $C_{\mathrm{mag}} \propto \exp\frac{-\Delta_m}{T}$. In the plateau phase, also a gap-like behaviour $C_{\mathrm{mag}} \propto \exp\frac{-\Delta_p}{T}$ is present. The parameters Δ_m, Δ_p seemingly disappear at the suppression of antiferromagnetic order of the monomer spins, possibly reflecting quantum critical behaviour.

15 min. break

TT 65.8 Thu 11:30 H 2053

Magnetic properties and phase diagram of triangular-lattice antiferromagnet $TlErSe_2$ — •Bastian Rubrecht[1], Mirtha Pillaca[2], Pritam Bhattacharyya[1], Liviu Hozoi[1], Dmitriy Efremov[1], Ellen Häussler[2], Thomas Doert[2], and Anja Wolter-Giraud[1] — [1]Leibniz-Institut für Festkörper- und Werkstoffforschung (IFW), Dresden, Germany — [2]Fakultät für Chemie und Lebensmittelchemie TU Dresden, Dresden, Germany,

The triangular-lattice (TL) antiferromagnet is a well-known case of strongly frustrated magnetism. Here, the delafossites, with the general chemical formula $A^{+I}RE^{+III}X_2$ (*A*: alkaline/monovalent cation, *RE*: rare-earth cation and *X*: chalcogen anion), offer a rich platform for exploring exotic magnetic phases arising from the degenerate ground state manifold.

By introducing different elements at the *A* site and choosing the magnetic rare-earth ion, one can tune the anisotropy of the magnetic interactions as well as the single-ion anisotropy, two defining parameters for the system's ground state.

In this study, we investigate $TlErSe_2$, a novel material realizing an antiferromagnetically coupled effective spin-1/2 model on a TL. Our zero-field ^{3}He specific heat studies revealed a phase transition at 0.42 K, which is successively suppressed with an increasing applied magnetic field. From magnetization and ^{3}He specific heat measurements on a polycrystalline $TlErSe_2$ sample, we construct the magnetic phase diagram and discuss the possible nature of the observed phases.

TT 65.9 Thu 11:45 H 2053

Magnon-phonon hybridization in the canted antiferromagnet $MnSc_2Se_4$ — •Jeremy Sourd[1], L Prodan[2], V Tsurkan[2], J Grumbach[3], M Dörr[3], A Miyata[4], T Gottschall[1], J Wosnitza[1,3], and S Zherlitsyn[1] — [1]Dresden High Magnetic Field Laboratory (HLD-EMFL), HZDR, Germany — [2]Institute for Experimental Physics, University of Augsburg, Germany — [3]Institute of Solid State and Materials Physics, TU Dresden, Germany — [4]Institute of Solid State Physics, University of Tokyo, Japan

The antiferromagnetic spinel compounds $MnSc_2X_4$ (X = S, Se) show extraordinary properties with various field induced phases due to their relatively small ordering temperature $T_N < 2.5$ K and saturation field μ_0 $H_c < 15$ T. Thanks to the exchange-striction coupling between the localized $S = 5/2$ Mn^{2+} ions and the crystal lattice, ultrasound experiments permit to explore the $H-T$ phase diagram of this system in detail. Whereas $MnSc_2S_4$ shows a very rich phase diagram with a skyrmion phase induced by magnetic field, no transition is observed in $MnSc_2Se_4$ between the zero-field antiferromagnetic phase and the fully polarized state. Furthermore, our ultrasound data on $MnSc_2Se_4$ are qualitatively reproduced by a magnon-phonon hybridization term arising from exchange-striction coupling between the crystal lattice and canted spin-wave fluctuations.

TT 65.10 Thu 12:00 H 2053

Spin-1/2 Heisenberg diamond-like decorated honeycomb lattice in a magnetic field from the perspective of localized magnons and exact diagonalization — •Katarína Karľová[1], Jozef Strečka[2], Malo Rouxel[1], and Andreas Honecker[1] — [1]Laboratoire de Physique Théorique et Modélisation, CNRS UMR 8089, CY Cergy Paris Université, France — [2]Department of Theoretical Physics and Astrophysics, P.J. Šafárik University, Košice, Slovakia

The spin-1/2 quantum Heisenberg model on a two-dimensional diamond-like decorated honeycomb lattice is investigated by combining the analytical and numerical methods. The ground-state phase diagram of the investigated model includes besides fully polarized state, monomer-dimer phase, ferrimagnetic phase of Lieb-Mattis type, spin canted phase with a continuously rise of the magnetization with increasing of the magnetic field and macroscopically degenerate dimer-tetramer phase. It is shown that the localized-magnon approach based on a simple classical lattice-gas model of hard-core monomers provides a proper description of low-temperature magnetism and magnetothermodynamics of the investigated frustrated quantum spin system in a highly frustrated parameter region. The results obtained from the localized-magnon approach are corroborated by the exact numerical diagonalization of small-size systems as well as the density-matrix renormalization group calculations.

TT 65.11 Thu 12:15 H 2053

Continuous similarity transformation for critical phenomena: bilayer antiferromagnetic Heisenberg-model and J_1-J_2-model — •Matthias R. Walther[1], Dag-Björn Hering[2], Götz S. Uhrig[2], and Kai P. Schmidt[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Institut für Theoretische Physik I, Staudtstraße 7, 91058 Erlangen — [2]Technische Universität Dortmund, Department of Physics, Condensed Matter Theory, Otto-Hahn-Str. 4, 44227 Dortmund

We apply continuous similarity transformations (CSTs) to the bilayer antiferromagnetic Heisenberg model and the antiferromagnetic J_1-J_2 model on the square lattice. The bilayer Heisenberg model features a well studied, continuous phase transition in the O(3) universality class between a gapless Néel phase and a gapped paramagnetic dimer phase (valence bond solid). The $J_1 - J_2$ features a gapless Néel phase for $J_1 \gg J_2$, a gapless columnar phase for $J_2 \gg J_1$ and an intermediate phase whose nature is still under debate. We start in both models from the magnetically ordered, collinear phases and approach the quantum phase transitions by the melting of the long-range magnetic order. The CST flow equations are truncated in momentum space by the scaling dimension d so that all contributions with $d \leq 2$ are taken into account. This amounts up to tracking all linear and quadrilinear terms while neglecting hexatic and higher terms. We locate critical points and estimate critical exponents from the flow of the couplings, the ground-state magnetization and the ground-state energy.

TT 65.12 Thu 12:30 H 2053

Quantum phases of the XXZ model with repulsive dipolar Ising interactions on two-dimensional lattices — •Jan Alexander Koziol[1], Giovanna Morigi[2], and Kai Phillip Schmidt[1] — [1]Department of Physics, Staudtstraße 7, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany — [2]Theoretical Physics, Saarland University, Campus E2.6, D-66123 Saarbrücken, Germany

We analyse the ground-state quantum phase diagram of the XXZ model with repulsive dipolar Ising interactions on two-dimensional lattices. The ground state results from the interplay between the lattice geometry and the long-range interactions, which we account for by means of a classical spin mean-field approach. This extended classical spin mean-field theory accounts for the long-range Ising interaction without truncation. The mean-field analysis is limited by the size of the considered unit cells. We consider three different lattice geometries: square, honeycomb, and triangular. In the limit of zero XY-interactions the ground state is always a devil's staircase of solid (gapped) phases. Such crystalline phases with broken translational symmetry are robust with respect to finite hopping amplitudes. At intermediate XY-interactions, these gapped phases melt, giving rise to various lattice supersolid phases, which can have exotic features with multiple sublattice densities. Our results are of immediate relevance for experimental realisations of self-organised crystalline ordering patterns, e.g., with ultracold dipolar atoms in an optical lattice.

TT 65.13 Thu 12:45 H 2053

Extracting quantum-critical properties from directly evaluated enhanced perturbative continuous unitary transformations — •Lukas Schamriss[1], Matthias R. Walther[1], Dag-Björn Hering[2], and Kai P. Schmidt[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstr. 7, 91058 Erlangen, Germany — [2]Condensed Matter Theory, TU Dortmund University, Otto-Hahn Str. 4, 44221 Dortmund, Germany

Ising models in a transverse field are paradigmatic models for quantum phase transitions of various universality classes depending on the lattice geometry and the choice of antiferromagnetic or ferromagnetic coupling. We investigate the quantum phase diagram of the bilayer antiferromagnetic transverse-field Ising model on the triangular lattice with an Ising-type interlayer coupling. Without a field, the model hosts a classically disordered ground state, and in the limit of decoupled layers it exhibits a 3dXY 'order by disorder' transition. Our starting point for the unknown parts of the phase diagram is a high-order perturbative calculation from the limit of isolated dimers. Directly evaluated enhanced perturbative continuous unitary transformations (deepCUTs) are used to calculate non-perturbatively extrapolated numerical data for the ground-state energy and the energy gap which coincide with the perturbative series up to the order with respect to which the deepCUT is truncated. We develop a general scheme to extract quantum critical properties from the deepCUT data based on critical scaling and a strict correspondence between the truncation used for deepCUT and the length scale of correlations at the critical point.

TT 66: Superconductivity: Yu-Shiba-Rusinov and Andreev Physics

Time: Thursday 9:30–12:30 Location: H 3005

TT 66.1 Thu 9:30 H 3005

Proximity-superconductivity of noble metal surface states — •Christian von Bredow, Lucas Schneider, Howon Kim, Torben Hänke, Khai That Ton, Kirsten von Bergmann, Jens Wiebe, and Roland Wiesendanger — Department of Physics, University of Hamburg, Hamburg, Germany

Adding superconductivity to gapless materials via the proximity effect can lead to a variety of interesting physical phenomena including topologically non-trivial states [1,2,3]. Rashba-split surface states, proximitized by a superconducting substrate, have recently been of particular interest as they combine large spin-orbit coupling with a large superconducting gap, making them a popular system in the search for topological superconductivity [4].

We study the mechanism of proximity-induced superconductivity in the Shockley-type surface states of thin films of Cu and Ag, grown on Nb(110), the elemental superconductor with the highest critical temperature, via STM. The tunneling spectra exhibit a multitude of sharp peaks at low energies, which can be assigned to two types of Andreev-bound states in the thin film and in the surface state.

[1] L. Schneider et al., Nature 621 (2023) 60
[2] J. Ortuzar et al., Phys. Rev. B 108 (2023) 024511
[3] T. Tomanic et al., Phys. Rev. B 94 (2016) 220503(R)
[4] A. C. Potter et al., Phys. Rev. B 85 (2012) 094516

TT 66.2 Thu 9:45 H 3005

Observation of zero-energy modes in Gd atomic chains on superconducting Nb(110) — •Yu Wang — Physikalisches Institut, Experimentelle Physik II, Universitaet Wuerzburg, Am Hubland, D-97074 Würzburg, Germany

The proposal to generate topologically protected edge states by linking Yu-Shiba-Rusinov states within a 1D chain of magnetic adsorbates has sparked considerable interest to the study of YSR states. Numerous research studies have been conducted on 3d transition metals placed on various superconducting substrates. In contrast, experimental results for 4f -shell rare-earth metals are scarce. However, rare-earth metals such as Gd, Tb, Dy, on superconductors are highly intriguing owing to highly localized strong magnetic moment of the 4f orbital which is primarily screened by outer electronic shells. In this experimental study, we investigate Yu-Shiba-Rusinov states induced by Gd adatoms on a superconducting Nb(110) surface. We are able to engineer Gd atom chains along the substrate's [110] and [001] directions, revealing distinct behaviors in differently oriented chains. [110]-oriented Gd chains exhibit spectroscopic features at their ends, identifying them as trivial edge states, while [001]-oriented Gd chains display zero-energy edge states, suggesting non-trivial nature.

TT 66.3 Thu 10:00 H 3005

First principles analysis of Gd nanostructures on superconducting Nb(110) — •David Antognini Silva[1], Philipp Rüssmann[1,2], and Stefan Blügel[1] — [1]Peter Günberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Germany — [2]Würzburg University, Germany

Materials that combine magnetism, spin-orbit interaction and conventional s-wave superconductivity are a suitable platform to study Yu-Shiba-Rusinov (YSR) states [1-3] and Majorana zero modes (MZM) [4], that can be used as building blocks of fault-tolerant topological qubits.

Recently, STM experiments for Gd chains on Nb(110) surface showed indication of MZMs at the ends of the chains [5]. To better understand the nature of those modes, we implemented the Bogoliubov-de Gennes (BdG) formalism in the juKKR impurity code [6] that allows the material-specific description of defects in superconductors from first principles, and applied it to Gd adatom nanostructures placed on the superconducting Nb(110) surface. We analyze the YSR states arising from the coupling of the magnetic Gd atoms and investigate their dependence on the geometry of the nanocluster and its magnetic ordering.

This work was funded by the DFG through Germany's Excellence Cluster ML4Q (EXC 2004/1 - 390534769).

[1] L. Yu, Acta Physica Sinica **21** (1965) 75
[2] H. Shiba, Prog. Theor. Phys. **40** (1968) 435
[3] A. I. Rusinov, Sov. J. Exp. Theor. Phys. **29** (1969) 1101
[4] Nadj-Perge *et al.*, Science **346** (2014) 6209

[5] Y. Wang *et al.*, arXiv.2311.09742
[6] https://iffgit.fz-juelich.de/kkr/jukkr

TT 66.4 Thu 10:15 H 3005

Andreev reflection in single-molecule junctions — •Lorenz Meyer, Nicolas Néel, and Jörg Kröger — Institut für Physik, Technische Universität Ilmenau, D-98693 Ilmenau, Germany

Electron transport across a single phthalocyanine (2H-Pc) molecule on Pb(111) is explored with a scanning tunneling microscope. The two variants of the molecule, 2H-Pc and pyrrolic-H abstracted Pc, behave differently when a normal-metal tip is vertically approached. While 2H-Pc shows a gradually increasing zero-bias resonance in spectra of the differential conductance with decreasing tip-molecule separation, spectroscopy of Pc reveals an invariant Bardeen-Cooper-Schrieffer energy gap. These results are discussed in terms of Andreev reflection and the occurrence of Yu-Shiba-Rusinov bound states.

Funding by the Deutsche Forschungsgemeinschaft through Grant No. KR2912/18-1 is acknowledged

TT 66.5 Thu 10:30 H 3005

Ab-initio investigation of Yu-Shiba-Rusinov states of 3*d* adatoms interacting with Rashba-split surface states — •Ilias Klepetsanis[1,2], Philipp Rüssmann[1,3], Jens Wiebe[4], and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany — [3]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany — [4]Universität Hamburg, 20355 Hamburg, Germany

The interplay between magnetism and superconductivity has long been under the scope of condensed matter physics research, as two seemingly competing phenomena of order. Here, we employ the Bogoliubov-de-Gennes full-potential relativistic Korringa-Kohn-Rostoker Green function method [1] to study Yu-Shiba-Rusinov states emerging when 3*d* magnetic adatoms are interfaced with different spacers deposited on Nb surfaces. These spacers are heavily investigated to introduce Rashba surface states and engineer the strength of spin-orbit coupling at the vicinity of a superconductor, which leads to unconventional superconducting pairing [2]. In particular, we explored the cases of (111) films of Cu, Ag, Au as well as $BiAg_2$/Ag and $BiCu_2$/Cu.

We acknowledge funding by the DFG (SPP 2244; LO 1659/7-1; ML4Q Cluster of Excellence EXC 2004/1 – 390534769).

[1] P. Rüßmann, S. Blügel, Phys. Rev. B **105** (2022) 125143
[2] P. Rüßmann *et al.*, Phys. Rev. Research **5** (2023) 043181

TT 66.6 Thu 10:45 H 3005

Full counting statistics of Yu-Shiba-Rusinov bound states — •David Christian Ohnmacht[1], Wolfgang Belzig[1], and Juan Carlos Cuevas[2] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain

We adapt the concept of full counting statistics (FCS) to provide the deepest insight thus far into the spin-dependent transport in systems containing Yu-Shiba-Rusinov (YSR) states [1]. Such systems include single-impurity junctions with a normal and a superconducting (SC) STM tip, as well as double-impurity systems [2]. The FCS concept allows us to identify every tunneling process that plays a role in these situations and to classify them according to the charge transferred in them. In particular, our approach is able to reproduce the experimental results recently reported on the shot noise of a single-impurity junction with a normal STM tip [3]. We also predict the signatures of resonant multiple Andreev reflections in the shot noise of single-impurity junctions with two SC electrodes and show that the FCS approach allows us to understand conductance features that have been incorrectly interpreted in the literature. In the case of double-impurity junctions we show that the direct tunneling between YSR states is characterized by a strong reduction of the Fano factor that reaches a minimum value of 7/32.

[1] D. C. Ohnmacht et. al., Phys. Rev. Res. 5 (2023) 033176
[2] H. Huang et. al., Nat. Phys. 16 (2020) 1227
[3] U. Thupakula et. al., Phys. Rev. Lett. 128 (2022) 247001

15 min. break

TT 66.7 Thu 11:15 H 3005

DC Josephson effect between two Yu-Shiba-Rusinov bound states — •Wolfgang Belzig[1], Subrata Chakraborty[1], Danilo Nikolic[2], Ruben Suano Souto[3], and Juan Carlos Cuevas[3] — [1]Universität Konstanz — [2]Universität Greifswald — [3]UA MAdrid

Motivated by recent experiments [1], we present here a theoretical study of the DC Josephson effect in a system comprising two magnetic impurities coupled to their respective superconducting electrodes and which exhibit Yu-Shiba-Rusinov (YSR) states. Using a mean-field Anderson model with broken spin symmetry to compute the supercurrent in this system for an arbitrary range of parameters (coupling between the impurities, orientation of the impurity spins, etc.). We predict a variety of physical phenomena such as (i) the occurrence of multiple 0-π transitions in the regime of weak coupling that can be induced by changing the energy of the YSR states or the temperature; (ii) the critical current strongly depends on the relative orientation of the impurity spins and it is maximized when the spins are either parallel or antiparallel, depending on the ground state of the impurities; and (iii) upon increasing the coupling between impurities, triplet superconductivity is generated in the system and it is manifested in a highly nonsinusoidal current-phase relation. Our predictions can be tested experimentally with the existing realization of this system and the main lessons of this work are of great relevance for the field of superconducting spintronics.

[1] Nat. Phys. 16 (2020) 1227
[2] S. Chakraborty, D. Nikolić, R. S. Souto, W. Belzig, J. C. Cuevas, Phys. Rev. B 108 (2023) 094518

TT 66.8 Thu 11:30 H 3005

Identifying Ising superconductors - The role of unconventional Andreev reflection in the formation of bound states — •Michael Hein[1], Juan Carlos Cuevas[2], and Wolfgang Belzig[1] — [1]Universität Konstanz — [2]Universidad Autónoma de Madrid

Magnetic impurities on superconducting surfaces induce so called *Yu-Shiba-Rusinov* (YSR) bound states. They have been widely studied using scanning tunnelling microscopy (STM) with substrates made of conventional superconductors [1]. In this work we investigate theoretically whether and how these states occur in unconventional Ising superconductors [2]. One of our main findings is the existence of subgap states even in the case of non-magnetic impurities. To shed light on the origin of these states, we also study the unconventional Andreev reflection at the interface between an Ising superconductor and a normal metal. This work paves the way for the understanding of the proximity effect in Ising superconductors and predicts different transport signatures that would allow to experimentally identify Ising superconductors.

[1] B. W. Heinrich et al., Prog. Surf. Sci. 93 (2018) 1
[2] G. Tang et al., Phys. Rev. Lett. 126 (2021) 237001

TT 66.9 Thu 11:45 H 3005

Thermocurrent spectroscopy of Yu-Shiba-Rusinov states in single-molecule junctions — •Pascal Gehring — IMCN/NAPS, Université Catholique de Louvain, Louvain-la-Neuve, Belgium

The interaction between magnetic impurities and superconductors leads to fascinating phenomena resulting from the competition between Kondo screening and Cooper pair formation. For example, individual magnetic impurities can form states within the superconducting gap, called Yu-Shiba-Rusinov (YSR) bound states, that create sharp features in the density of states. Here, We employ our recently developed thermocurrent spectroscopy set-up to experimentally study the thermoelectric properties of a neutral and stable all-organic radical molecule coupled to proximity induced superconducting break-junction electrodes at millikelvin temperatures. We find that the sharp YSR features also result in a strong enhancement of their thermoelectric response. By varying the external magnetic field a quantum phase transition from the Kondo into the YSR regime is induced with a twofold increase of the thermoelectric current.

TT 66.10 Thu 12:00 H 3005

Impact of evanescent scattering modes in short junctions — •Daniel Kruti and Roman-Pascal Riwar — Jülich Research Centre and Cologne University

Superconducting junctions are essential building blocks for quantum hardware, and their fundamental behaviour is still a highly active research field. For generic junctions, the emergence of subgap Andreev bound states is conveniently described by Beenakker's formula, representing an important starting point for both analytic and numeric studies. In this work, we critically reassess two common assumptions: that in the short junction limit scattering is approximately energy independent and dominated by planar channels. We argue that cross-channel scattering can lead to a strong energy-dependence which is particularly pronounced when the system is tuned close to a change of the channel number – even if energy is small compared to the Thouless energy. We provide a general recipe to include evanescent modes, and apply it to the example of a ballistic junction with nontrivial geometry. We show that the interplay between evanescent modes and energy-dependant scattering has a significant influence on the Andreev spectrum, especially close to the superconducting gap. In particular, the energy-dependence of the scattering matrix breaks the symmetry which allows for the Andreev spectrum to touch the gap. Evanescent modes effectively restore this symmetry. We expect our work to be relevant for contemporary experimental and theoretical studies of ultra-small junctions and their (dissipative) transport properties.

TT 66.11 Thu 12:15 H 3005

On-demand population of Andreev levels by their ionization in the presence of Coulomb blockade — •Aleksandr Svetogorov[1], Wolfgang Belzig[1], Pavel Kurilovich[2], Vladislav Kurilovich[2], Michel Devoret[2], and Leonid Glazman[2] — [1]Universität Konstanz, Konstanz, Germany — [2]Yale University, New Haven, USA

A mechanism to deterministically prepare a nanowire Josephson junction in an odd parity state is proposed. The mechanism involves population of two Andreev levels by a resonant microwave drive breaking a Cooper pair, and a subsequent ionization of one of the levels by the same drive. Robust preparation of the odd state is allowed by a residual Coulomb repulsion in the junction. A similar resonant process can also be used to prepare the junction in the even state. Our theory explains a recent experiment [1].

[1] J. J. Wesdorp et al., Phys. Rev. Lett. 131 (2023) 117001

TT 67: Unconventional Superconductors

Time: Thursday 9:30–13:15 Location: H 3007

Invited Talk TT 67.1 Thu 9:30 H 3007

Giant lattice softening at a uniaxial-pressure-tuned Lifshitz transition in the unconventional superconductor Sr_2RuO_4 — •Hilary M. L. Noad — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

In the unconventional superconductor Sr_2RuO_4, properties such as the transition temperature, the upper critical field, and the in-plane normal-state resistivity depend strongly on uniaxial pressure along the [100] direction. Underlying this behaviour is a pressure-tuned Lifshitz transition, at which there is a change in topology of one of the three quasi-two-dimensional Fermi surfaces. We investigated the influence of this electronic transition on the lattice by using a piezo-based uniaxial pressure cell to measure the stress-strain relation of Sr_2RuO_4 across the Lifshitz transition, revealing a large and strongly temperature dependent softening of the [100] Young's modulus at the Lifshitz transition [1]. Through thermodynamic considerations and comparison to a tight-binding model, we show that the softening is indeed driven by conduction electrons. Moreover, the model describing this effect exhibits quantum critical elasticity, raising intriguing questions about the relationship between the superconductivity of Sr_2RuO_4 and the electronically driven softening of the lattice.

[1] H.M.L. Noad, K. Ishida, Y.-S. Li, E. Gati, V. Stangier, N. Kikugawa, D.A. Sokolov, M. Nicklas, B. Kim, I.I. Mazin, M. Garst, J. Schmalian, A.P. Mackenzie, C.W. Hicks, *Science* **382** (2023) 447.

TT 67.2 Thu 10:00 H 3007

Measurements of the elastocaloric effect on strained Sr_2RuO_4 in magnetic fields. — •Aleksei Frolov[1], You-Sheng Li[1], Naoki Kikugawa[2], Andreas W. Rost[3], Andrew P. Mackenzie[1,3], and Michael Nicklas[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany. — [2]National Institute for Materials Science, Japan. — [3]Scottish Universities Physics Alliance, School of Physics and Astronomy, University of St Andrews, St Andrews, UK

Recently, elastocaloric measurements under uniaxial stress have been shown to be a powerful tool for exploring the intriguing properties of the unconventional superconductor Sr_2RuO_4[1]. The results revealed an entropy peak in the normal state coinciding with the optimal superconducting T_c at the Van Hove strain, and traced an adjacent magnetic phase transition at higher strains. To study their interplay, thermodynamic measurements under magnetic field are highly desirable.

The aim of the present study was twofold: i) to investigate the phase diagram of the unconventional superconductor Sr_2RuO_4 in magnetic fields by thermodynamic means; ii) to extend the scope of the method for measuring the elastocaloric effect under uniaxial stress to high magnetic fields and to lower temperatures.

We have obtained high-resolution data on the elastocaloric effect in magnetic fields up to 16 T in a wide temperature range down to less than 1 K, providing new insights into the intriguing phase diagram of Sr_2RuO_4. We discuss the effect of the magnetic field on the superconducting and on the magnetic phase as well as their relationship.

[1] Y. S. Li *et al.*, Nature 607 (2022) 276

TT 67.3 Thu 10:15 H 3007

Evidence for vertical line nodes in Sr_2RuO_4 from non-local electrodynamics — •Javier Landaeta[1,2], Konstantin Semeniuk[2], Joost Aretz[2], Ismardo Bonalde[3], Jörg Schmalian[4], Andrew Mackenzie[2], and Elena Hassinger[1] — [1]Institute of Solid State and Materials Physics, TU Dresden, 01069, Dresden, Germany — [2]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [3]Centro de Física, Instituto Venezolano de Investigaciones Científicas, Caracas 1020-A, Venezuela — [4]Institute for Theoretical Condensed Matter Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

By determining the superconducting lower and upper critical fields $H_{c1}(T)$ and $H_{c2}(T)$, respectively, in a high-purity spherical Sr_2RuO_4 sample via ac-susceptibility measurements, we obtain the temperature dependence of the coherence length ξ and the penetration depth λ down to $0.04\,T_c$. Given the high sample quality, the observed T^2 dependence of λ at low temperatures cannot be explained in terms of impurity effects. Instead, we argue that the weak type-II superconductor Sr_2RuO_4 has to be treated in the non-local limit. In that limit, the penetration depth data agree with a gap structure having vertical line nodes of the superconducting gap, while horizontal line nodes cannot account for the observation.

TT 67.4 Thu 10:30 H 3007

Identification of the magnetic phase of Sr_2RuO_4 under uniaxial pressure through a.c. Young's modulus measurements — •C.I. O'Neil[1,2], Z. Hu[1,2], N. Kikugawa[3], D.A. Sokolov[1], A.S. Gibbs[2,4,5], A.P. Mackenzie[1,2], H.M.L. Noad[1], and E. Gati[1] — [1]MPI - CPfS, Dresden, Germany — [2]University of St Andrews, UK — [3]National Institute for Materials Science, Japan — [4]ISIS Pulsed Neutron and Muon Source, UK — [5]MPI - FKF, Stuttgart, Germany

Pressure tuning allows one to explore the link between electronic and lattice degrees of freedom in quantum materials. In this respect, Sr_2RuO_4 has recently been established as an important model system [1]. Here, under [1 0 0] strain, an electronic Lifshitz transition drives a giant lattice softening, giving rise to a strongly changing Young's modulus, $E(\epsilon)$. To further explore non-linear elasticity in quantum materials, we developed an a.c. technique to measure $E(\epsilon)$. Owing to its improved resolution, we can clearly identify a response of the lattice to a magnetic transition, which has been reported to occur on the high-stress side of the Lifshitz transition [2]. Through the combination of the a.c. $E(\epsilon)$ and a.c. elastocaloric measurements, we can revisit the phase diagram under [1 0 0] compression and discuss the interplay of magnetism with other electronic phases in Sr_2RuO_4. Furthermore, we can resolve a change in lattice relaxation upon entering this magnetic phase, extracted from the imaginary part of the a.c. response.

Work is supported by the DFG through TRR288 (Elasto-Q-Mat).

[1] Noad *et al.*, Science **382** (2023) 6669
[2] Grinenko *et al.*, Nat. Phys. **17** (2021) 748

TT 67.5 Thu 10:45 H 3007

Non-local electronic correlations and spin excitations in Sr_2RuO_4 — •Maria Chatzieleftheriou[1], Silke Biermann[1,2,3], Yvan Sidis[4], and Evgeny Stepanov[1,2] — [1]Ecole Polytechnique, Palaiseau, France — [2]Collège de France, Paris, France — [3]ETSF, Palaiseau, France — [4]CEA/CNRS, Gif-sur-Yvette, France

In this work we study the effect of non-local correlations on the electronic properties of Sr_2RuO_4. We go beyond the state-of-the-art single-site description of Dynamical Mean-Field Theory (DMFT) [1] by deploying the D-TRILEX [2-4] self-consistent diagrammatic expansion method. We calculate the magnetic susceptibility and find that accounting for spatial fluctuations indeed leads to a very good agreement with the experimental evidence. In particular, we find an accurate description of the static spin susceptibility and observe a dome-like structure centred around the Γ point, in agreement with the experimental evidence and in contrast to previous theoretical studies. Moreover, we observe the quasi-ferromagnetic fluctuations reported in the experimental work [5] upon increasing the Hund's exchange coupling.

[1] A. Georges et al., Rev. Mod. Phys. 68 (1996) 13
[2] E. A. Stepanov et al., Phys. Rev. B 100 (2019) 205115
[3] V. Harkov et al., Phys. Rev. B 103 (2021) 245123
[4] M. Vandelli et al., SciPost Phys. 13, 0366
[5] P. Steffens et al. Phys. Rev. Lett. 122 (2022) 047004 (2019)

TT 67.6 Thu 11:00 H 3007

Field-induced compensation of magnetic exchange as the possible origin of reentrant superconductivity in UTe_2 — •Toni Helm[1], Motoi Kimata[2], Kenta Sudo[2], Atsuhiko Miyata[1], Markus Koenig[3], Ilya Sheikin[4], Alexandre Pourret[5], Georg Knebel[5], Dai Aoki[2], Jochen Wosnitza[1], and Jean-Pascal Brison[5] — [1]Dresden High Magnetic Field Laboratory, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]IMR, Tohoku University, Japan — [3]Max Planck Institute CPfS Dresden, Germany — [4]LNCMI Grenoble, France — [5]CEA, University des Alpes, Grenoble, France

The potential spin-triplet heavy-fermion superconductor UTe_2 exhibits signatures of multiple distinct superconducting phases. For field aligned along the b axis, a metamagnetic transition occurs at $\mu_0 H_m = 35$ T. It is associated with magnetic fluctuations that may be beneficial for the field-reinforced superconductivity surviving up to H_m. Once the field is tilted away from the b towards the c axis, a reentrant superconducting phase emerges just above H_m. We conducted magnetic-torque and magnetotransport measurements in pulsed magnetic fields. We determine the record-breaking upper critical field of $\mu_0 H_{c2} \approx 73$ T and its evolution with angle. Furthermore, the normal-state Hall effect experiences a drastic suppression indicative of a reduced band polarization above H_m in the angular range around 30° caused by a partial compensation between the applied field and an exchange field. This promotes the Jaccarino-Peter effect as a likely mechanism for the reentrant superconductivity above H_m.

TT 67.7 Thu 11:15 H 3007

The rich superconducting phase diagram of UTe_2 — •Alexander Eaton[1], Zheyu Wu[1], Theodore Weinberger[1], Friedrich Malte Grosche[1], Andrej Cabla[2], and Michal Valiska[2] — [1]Cavendish Laboratory, University of Cambridge, UK — [2]Department of Condensed Matter Physics, Charles University, Prague, Czech Republic

Few materials manifest two or more distinct superconducting phases. Under various conditions of applied pressure and magnetic field tilt angle, the heavy fermion paramagnet UTe_2 has been observed to host up to five separate superconducting states. Several of these show numerous characteristics indicative of spin-triplet pairing, which may have important technological applications in the field of quantum computing. This talk will review recent developments in our knowledge of the UTe_2 phase diagram, attained from measurements on a new generation of pristine quality crystals grown in a molten salt flux. Our recent high field and high pressure experiments have uncovered new anomalous regions of the multi-dimensional phase space not previously observed in lower quality samples. A discussion will be given as to how these new observations may help point towards possible microscopic theories to reconcile the diverse array of exotic physical phenomena at play in UTe_2.

15 min. break

TT 67.8 Thu 11:45 H 3007

Thermodynamic transitions and topology of spin-triplet superconductivity: Application to UTe_2 — Henrik S. Røising, Max Geier, •Andreas Kreisel, and Brian M. Andersen — Niels Bohr Institute, University of Copenhagen, DK-2200 Copenhagen, Denmark

The discovery of unconventional superconductivity in the heavy-fermion material UTe_2 has reinvigorated research of spin-triplet superconductivity. We perform a theoretical study of coupled two-component spin-triplet superconducting order parameters and their thermodynamic transitions into the superconducting state. With focus on the behavior of the temperature dependence of the specific heat capacity, we find that two-component time-reversal symmetry breaking superconducting order may feature vanishing or even negative secondary specific heat anomalies. The origin of this unusual specific heat behavior is tied to the non-unitarity of the composite order parameter. Additionally, we supply an analysis of the topological surface states associated with the different possible spin-triplet orders: single-component orders host Dirac Majorana surface states in addition to possible bulk nodes. A second component breaking time-reversal symmetry gaps these surfaces states producing chiral Majorana hinge modes. DFT+U band-structure calculations support that these topological phases are realized in UTe_2 when introducing weak superconducting pairing. Our topological analysis suggests measurable signatures for surface-probe experiments to acquire further evidence of the superconducting pairing symmetry.

TT 67.9 Thu 12:00 H 3007

Quantum interference between quasi-2D Fermi surface sheets in UTe_2 — •Theodore Weinberger[1], Zheyu Wu[1], David Graf[2], Yurii Skourski[3], Andrej Cabala[4], Michal Vališka[4], F. Malte Grosche[1], and Alexander Eaton[1] — [1]Cavendish Laboratory, University of Cambridge, Cambridge, UK — [2]NHMFL, Tallahassee, Florida, USA — [3]HLD-EMFL, Dresden, DE — [4]Department of Condensed Matter Physics, Charles University, Prague, CZ

Superconductivity in UTe_2 exhibits extreme resilience to applied magnetic field, with critical fields exceeding 60 T. This, alongside the observation of distinct superconducting states in different regions of the phase diagram suggest unconventional, likely triplet pairing states. If a chiral pairing state were realised, this would mean that UTe_2 could host topologically protected Majorana surface states. Quantum oscillation studies resolving the precise nature of the Fermi surface in UTe_2, enabled by a new generation of high-quality crystals, provide valuable input for a full theoretical understanding of the topology of the pairing state. Here, we present and discuss high field contactless resistivity data, in which oscillations are observed with frequencies and effective masses that differ markedly from prior de Haas-van Alphen effect studies. These magnetoconductance oscillations can be understood as a quantum interference effect from quasiparticles tunnelling across quasi-2D Fermi surface sheets at high magnetic fields. A large variation in the apparent effective masses for the various interference paths yields valuable insight into the electronic bandstructure underpinning unconventional superconductivity in UTe_2.

TT 67.10 Thu 12:15 H 3007

Exposing quantum criticality and odd-parity superconductivity in $CeRh_2As_2$ with hydrostatic pressure — •Konstantin Semeniuk[1], Meike Pfeiffer[2,1], Javier Landaeta[2,1], Seunghyun Khim[1], and Elena Hassinger[2,1] — [1]MPI CPfS, Dresden, Germany — [2]TU Dresden, Germany

The locally non-centrosymmetric Kondo-lattice system $CeRh_2As_2$ hosts a multi-phase superconductivity ($T_c = 0.4$ K), a state "Phase I" of currently unknown origin ($T_0 = 0.5$ K), and displays antiferromagnetic ordering below T_c. At the magnetic-field-induced transition between the superconducting (SC) states SC1 and SC2, the parity of the SC order parameter has been proposed to change from even to odd. This idea is supported by the field-temperature phase diagram, but is yet to be verified directly. Alternatively, Phase I or magnetic order could play a role in the phenomenon. Other pertinent questions include the origin of the non-Fermi-liquid behavior, and the impact of the staggered Rashba interaction on the ordered states.

By tuning $CeRh_2As_2$ with hydrostatic pressure, we investigated the interplay of Phase I and the SC states. Measurements of resistivity and heat capacity show that Phase I is fully suppressed at $P_0 = 0.5$ GPa, terminating in a quantum critical point (QCP), which is responsible for the non-Fermi-liquid physics and the colossal quasiparticle masses. The SC phase forms an unusually broad dome around the QCP, remaining robust at 2.7 GPa with $T_c = 0.2$ K. Crucially, the two SC states still exist for $P > P_0$, definitively excluding the involvement of Phase I in the SC1-SC2 switching.

TT 67.11 Thu 12:30 H 3007

Evidence of finite-momentum pairing in a centrosymmetric bilayer — •Dong Zhao, Lukas Debbeler, Matthias Kühne, Sven Fecher, Nils Gross, and Jurgen Smet — Max Planck Institute for Solid State Research, Stuttgart

A phase characterized by a spatially modulated order parameter is counter-intuitive because of the entropy penalty that the modulations incur. Its possible existence in superconductors was first proposed under the condition that the formation of Cooper pairs is limited to some segments of the Fermi surface and that the Cooper pairs carry momentum above the Pauli limit. This prediction motivated experimental efforts to identify such non-uniform superconducting states in organic superconductors, heavy fermion compounds and cuprates. Here we report evidence of another type of finite-momentum pairing that manifests below the Pauli limit. It is driven by the orbital effect and does not rely on Fermi surface segmentation. We have evidence of this spatially modulated superconducting state in a hexagonal MoS2 bilayer through remote intercalation that offers both balanced doping and firm out-of-plane coherence across both layers.

TT 67.12 Thu 12:45 H 3007

Local probe of the effective charge of a nodal superconductor — •Maialen Ortego Larrazabal[1], Jiasen Niu[2], Jian-Feng Ge[2], Genda Gu[3], Ingmar Swart[1], and Milan P. Allan[2] — [1]Debye Institute for Nanomaterials Science, Utrecht University, 3508 TA Utrecht, The Netherlands — [2]Leiden Institute of Physics, Leiden University, 2333 CA Leiden, The Netherlands — [3]Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory, NY 11973 Upton, USA

Shot-noise is a powerful tool for determining the effective charge of the carriers of mesoscopic systems. This method provides unique information about a broad range of materials such as superconductors and fractional quantum Hall systems [1,2]. We combine scanning tunnelling microscopy with shot-noise spectroscopy in order to get local information with atomic resolution [3]. In a s-wave BCS superconductor, we observe shot-noise doubling inside of the superconducting gap due to Andreev reflection processes [4]. For superconductors with d-wave pairing symmetry, however, things get more complicated, as the nodal quasiparticles change the situation. Here, I will discuss first results of local shot-noise measurements on the unconventional superconductor $Bi_2Sr_2Ca_2Cu_1O_{8+p}$.

[1] Y. Ronen et al., Proc. Natl. Acad. Sci. U. S. A. 113 (2016) 1743
[2] R. de-Picciotto et al., Nature 389 (1997) 162
[3] K. M. Bastiaans et al., Rev. Sci. Instrum. 89 (2018) 093709
[4] K. M. Bastiaans et al., Phys. Rev. B 100 (2019) 104506

TT 67.13 Thu 13:00 H 3007

Superconductivity with high upper critical field in Ta-Hf Alloys — •Pavan Kumar Meena, Sonika Jangid, Roshan Kumar Kushwaha, and Ravi Prakash Singh — Indian Institute of Science Education and Research Bhopal

Recently, there has been considerable interest in exploring superconducting alloys for potential applications in superconducting devices [1-4]. In this study, I will present our findings on superconductivity in TaxHf1-x alloys, utilizing magnetization, electrical resistivity, and specific heat measurements on polycrystalline samples [5]. The crystal structures of these alloys are composition dependent. Notably, when we substituted Hf (a Type-I superconductor with a critical temperature, T_c, of 0.12 K) with Ta (also a Type-I superconductor with a T_c of 4.4 K), a remarkable enhancement in TC was observed, along with a transition to Type-II superconductivity featuring high upper-critical fields. This transition is of particular interest from the perspective of materials science. Our specific heat measurements provided evidence of strong coupling superconductivity, aligning with conventional principles of superconductivity. These metallic alloys exhibit both metallic properties and a high upper-critical field, making them highly promising for practical superconducting devices like SQUID and qubits.

[1] T. G. Berlincourt et al., Phys. Rev. 131 (1963) 140
[2] J. K. Hulm et al., Phys. Rev. 123 (1961) 1569
[3] K. M. Wong et al., Phys. Rev. B 30 (1984) 1253
[4] A. P. Place et al., Nat. Commun. 12 (2021) 1779
[5] P. K. Meena et al., arXiv: 2305.19253 (2023)

TT 68: Superconductivity: Properties and Electronic Structure

Time: Thursday 9:30–13:15 Location: H 3010

TT 68.1 Thu 9:30 H 3010

Annealing $Tl_2Ba_2CuO_{6+\delta}$ - a step towards the origin of cuprate superconductivity — •Ayanesh Maiti[1,2,3], Seunghyun Khim[1], Carsten Putzke[2], Philip Moll[2], and Andrew Mackenzie[1,3] — [1]MPI for Chemical Physics of Solids, Dresden, Germany — [2]MPI for Structure and Dynamics of Matter, Hamburg, Germany — [3]University of St Andrews, St Andrews, Scotland

Cuprate superconductors have attracted a lot of attention due to their high T_c's that can reach up to 130 K in ambient pressure. However, the physics underlying their properties has remained obscured by (i) multitudes of complex orders that appear near the superconducting phase, and (ii) the inseparable effects of the disorder that is introduced as they are doped.

Decades of past research have identified one promising candidate, $Tl_2Ba_2CuO_{6+\delta}$, that can be used to explore the superconductivity in the (seemingly) less complicated overdoped region of the cuprate phase diagram, using samples with minimal disorder.

We have grown high-quality single crystals of $Tl_2Ba_2CuO_{6+\delta}$ with negligible orthorhombicity (<0.1%), and can be annealed reversibly across a very wide doping range (p = 0.05-0.29). This indicates that our samples are close to having perfect cation stoichiometry and no substitutional defects - solving a major issue which was faced by the previous efforts. This puts us in a position to map out the full phase diagram of clean cuprates, and thus take the crucial first step towards resolving the origin of their high T_c superconducting order.

TT 68.2 Thu 9:45 H 3010

Tracing the Higgs-CDW interplay in coherently-driven superconductors — •Liwen Feng[1,3], Tim Priessnitz[1], Jan-Christoph Deinert[4], Sergey Kovalev[4], Stefan Kaiser[1,3], and Hao Chu[1,2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Shanghai Jiaotong University, China — [3]Technical University Dresden, Germany — [4]Helmholtz-Zentrum Dresden-Rossendorf, Germany

Superconductivity (SC) and charge-density-wave (CDW) often coexist in the low temperature phase diagrams of various materials, particularly high-Tc superconductors. Exploring the interplay between SC and CDW has become crucial in understanding the physics of these complex systems. We have established Higgs Spectroscopy using phase-resolved THz-Third Harmonic Generation to study the order parameter dynamics in superconductors [1]. Our investigations of the dynamics between THz-driven CDW and Higgs amplitude modes throughout several families of superconductors ranging from 2H-$NbSe_2$, hole- and electron-doped cuprates $La_{2-x}Sr_xCuO_4$ (x ∼0.12) and $La_{2-x}Ce_xCuO_4$ (x ∼0.1), to bismuthate superconductors BaRbBiO. We describe the interplay of Higgs and the CDW mode in the framework of a generalized Fano model. Going beyond the amplitude and phase response [2], the time-domain reveals a dynamical interplay of a Higgs-CDW hybrid in the THz driven state [3].

[1] H. Chu et al., Nat. Commun. 11 (2020) 1793.
[2] H. Chu, et al., Nat Commun. 14 (2023) 1343.
[3] L. Feng et al., Phys. Rev. B, 108 (2023) L100504.

TT 68.3 Thu 10:00 H 3010

Tracing the dynamics of superconducting order via transient terahertz third harmonic generation — •Min-Jae Kim[1,2,3], Sergey Kovalev[4], Mattia Udina[5], Gideok Kim[2], Matteo Puviani[2], Thales de Olivera[4], Jan-Christoph Deinert[4], Dirk Manske[2], Lara Benfatto[5], and Stefan Kaiser[1,2,3] — [1]Institute of Solid State and Materials Physics, Technical University Dresden, Dresden, 01062, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, 70569, Germany — [3]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Stuttgart, 70569, Germany — [4]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, 01328, Germany — [5]Department of Physics and ISC-CNR, Sapienza University of Rome, Rome, 00185, Italy

Nonlinear THz third harmonic generation (THG) was shown to directly probe internal degrees of freedoms of the superconducting condensate and its exposure to external collective modes in the framework of driven Higgs modes. Here we extend this idea to light-driven nonequilibrium states in superconducting $La_{2-x}Sr_xCuO_4$ establishing a transient Higgs spectroscopy [1]. We perform an optical pump-THz-THG drive experiment and using 2D-spectroscopy we disentangle the driven TH response into the excited quasiparticles and condensates response. As such the light induced changes of the THG signals probe the ultrafast pair breaking dynamics and transient pairing amplitude of the condensate.

[1] Kim et. al., arXiv:2303.03288

TT 68.4 Thu 10:15 H 3010

Unusual Low-Energy Collective Charge Excitations in High-Tc Cuprate Superconductors — Vyacheslav Silkin[1], Stefan-Ludwig Drechsler[2], and •Dmitri Efremov[2] — [1]Donostia International Physics Center (DIPC), 20018 San Sebastiian/Donostia, Basque Country, Spain Departamento de Polimeros y Materiales Avanzados: Fisica, Quimica y Tecnologia, Facultad de Ciencias Quimicas, Universidad del Pais Vasco UPV/EHU, 20080 San Sebastiian/Donostia, Basque Country, Spain and IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Basque Country, Spain — [2]Leibniz Institute for Solid State and Materials Research IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany

Here, we present our study investigating the low-energy charge excitations in the normal state of HTSC cuprates. Our findings demonstrate that the unique characteristics of the electronic band structure at low energies significantly influence the nature of the intraband collective modes. This effect leads to the emergence of a novel type of mode with exceptionally high intensity. The study presents a non-Lorentzian spectral function, incorporated with popular collective excitations such as conventional plasmons and spin fluctuation. The nodal and antinodal directions reveal the presence of two distinct modes exhibiting maximal spectral weight. Moreover, an antinodal direction presents the intensity of a quasi-one-dimensional plasmon, which gradually transforms into a prolonged, soft mode over an extensive momentum range.

TT 68.5 Thu 10:30 H 3010

Possible unconventional vortex lattice in LiFeAs single crystals by μSR — •G. Lamura[1], T. Shiroka[2,3], T. Winyard[4], M. Speight[5], J. Quintanilla[6], P. Gentile[7], F. Anger[8], and S. Wurmehl[8] — [1]Cnr-Spin, Genova, IT — [2]ETH, Zurich, CH — [3]Paul Scherrer Institut, CH — [4]University of Edinburgh, UK — [5]University of Leeds, UK — [6]University of Kent, Canterbury, UK — [7]Cnr-Spin, Salerno, IT — [8]IFW, Dresden, DE

Muon spectroscopy (μSR) is able to study the vortex lattice (VL) of type II superconductors: positive muons implanted in interstitial sites probe different magnetic local fields B_{loc} depending on the relative position of Abrikosov vortices: the Fourier Transform of the measured time-dependent asymmetry $FT\{A(t)\} \propto n(B_{loc})$, the local field distribution. A skyrmion-vortex chains model was recently proposed to distinguish nematic superconductors [1]. It consists of stripes of skyrmions (spatially separated half-quantum vortices) parameterized by the separation between the chains and the inter-skyrmion separation along the same chain: the resulting $n(B_{loc})$ presents a double-peak instead of the one-peak structure of the usual Abrikosov VL. Here we show our experimental results by μSR on a high-purity LiFeAs single crystal (T_c=17K) [2]. We likely found the evidence of such an unconventional mixed state: $FT\{A(t)\}$ data at 2 K shows a small splitting of the main superconducting peak up to 7 K. This could confirm the nematicity of superconductivity in LiFeAs, in agreement with previous ARPES results [3].

[1] Phys. Rev. Lett. 130 (2023) 226002.
[2] J. Cryst. Growth 627 (2024) 127473.
[3] Phys. Rev. B 102 (2020) 184502.

TT 68.6 Thu 10:45 H 3010

What scanning tunneling spectra on superconductors can tell us about the spectral density of the pairing boson — •Thomas Gozlinski[1,2], Mirjam Henn[1], Thomas Wolf[1], Matthieu LeTacon[1], Jörg Schmalian[1], and Wulf Wulfhekel[1] — [1]Karlsruhe Institute of Technology (KIT) — [2]Ludwig-Maximilians-Universität München (LMU)

A detailed interpretation of scanning tunneling spectra obtained on superconductors enables one to gain information on the pairing boson. Decisive for this approach are inelastic tunneling events. Due to the lack of momentum conservation in tunneling from or to the sharp tip, those are enhanced in the geometry of a scanning tunneling microscope compared to planar tunnel junctions. We will introduce the theoretical framework [1] and discuss the reliability and limitations of our method by taking the examples of real scanning tunneling spectra obtained on conventional [2] and unconventional [3,4] superconductors. Especially for the d-wave cuprate superconductors [4] we propose how the boson excitation spectrum can be compared to and complement glue functions determined from optical spectroscopy or ARPES.

[1] P. Hlobil et al., Phys. Rev. Lett. **118** (2017) 167001.
[2] M. Schackert et al., Phys. Rev. Lett. **114** (2015) 047002.
[3] J. Jandke et al., Phys. Rev. B **100** (2019) 020503(R).
[4] T. Gozlinski et al., arXiv:2306.03890 (2023)

TT 68.7 Thu 11:00 H 3010

Tunneling spectroscopy on hybrid superconductor-ferromagnet bilayers made of non-centrosymmetric NbRe and Co — •Marcel Strohmeier[1], Carla Cirillo[2], Carmine Attanasio[3], Angelo Di Bernardo[1,3], and Elke Scheer[1] — [1]Universität Konstanz, Fachbereich Physik, 78464 Konstanz, Germany — [2]CNR-SPIN, c/o Università degli Studi di Salerno, 84084 Fisciano (Sa), Italy — [3]Dipartimento di Fisica 'E.R. Caianiello', Università degli Studi di Salerno, 84084 Fisciano (Sa), Italy

In recent years non-centrosymmetric superconductors have attracted increasing attention as they reveal various properties of unconventional superconductivity. With the absence of inversion symmetry and an asymmetric Rashba-like spin-orbit coupling a mixed spin-singlet and spin-triplet pairing state is predicted for these materials. In our talk we focus on polycrystalline non-centrosymmetric $Nb_{0.18}Re_{0.82}$. Studies on the upper critical field of thin-film micrometric strips have shown that the Pauli-contribution might play a minor role in terms of the underlying pair breaking mechanism. In addition, FMR measurements on NbRe/Co/NbRe trilayers suggest that the observed Gilbert damping can be explained by assuming a spin-pumping scenario across a spin-triplet S-F-S interface. However, the SC order parameter of NbRe is still under debate. We present first low-temperature scanning tunneling spectroscopy measurements on pure NbRe as well as NbRe/Co bilayers fabricated by magnetron sputtering. With a high spatial and energy resolution we probe the LDOS for different film thicknesses to get insights into the intrinsic pairing symmetry of the superconductor.

15 min. break

TT 68.8 Thu 11:30 H 3010

Control of the superconducting pairing in the van der Waals superconductor $NbSe_2$ via magnetic intercalation — •Mohammad Hemmati[1,2], Stefan Blügel[1,2], and Philipp Rüssmann[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [2]RWTH Aachen University, Aachen, Germany — [3]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany

We investigate the superconducting properties of $NbSe_2$ using first-principles calculations within the Korringa-Kohn-Rostoker Green function method, accompanied by a description of superconductivity via the Bogoliubov-de Gennes formalism [1]. The Coherent Potential Approximation (CPA) is employed to address the effects of magnetic transition-metal impurities on the electronic structure [2]. Adding low concentrations of randomly placed magnetic atoms inside the van der Waals gap of superconducting $NbSe_2$ influences the superconducting order parameter before suppressing the superconductivity at larger impurity concentrations. This allows us to control the superconducting pairing and engineer the triplet order parameter in $NbSe_2$ with varying concentration and chemical composition of magnetic the impurities.

— This work was supported by the ML4Q Cluster of Excellence (EXC 2004/1 * 390534769).

[1] P. Rüßmann and S. Blügel, Phys. Rev. B **105** (2022) 125143.
[2] P. Rüßmann, D. Silva, M. Hemmati *et al.*, Spintronics XVI (2023) 12656.

TT 68.9 Thu 11:45 H 3010

Engineering interband coupling of a two-band superconductor by topological defects — •Qili Li[1], Thomas Gozlinski[1], Ryohei Nemoto[2], Toyo Kazu Yamada[2], Jörg Schmalian[1], and Wulf Wulfhekel[1] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Chiba University, Chiba, Japan

Two-band or multiband superconductors like MgB2, Fe-based superconductors, NbSe2 and Pb [1,2] are in great interest. Fantastic properties are predicted owing to interband coupling in multiband superconductors, such as solitons, vortices with fractional flux, non-Abrikosov vortices, topological knot and odd-frequency pairing. Here, we investigate interband coupling in the two-band superconductor Pb by scanning tunnelling microscopy at 45 mK. We find that the interband coupling is significantly changed by topological defects, i.e., stacking fault tetrahedrons widely existing in face centered cubic crystals. Intra- and interband coupling are directly spatially resolved by fitting our experimental results self-consistently with Schopohl-Scharnberg-McMillan (SSM) model [3,4]. Our findings pave the way to explore the predicted properties in multiband superconductors.

[1] Phys. Rev. Lett. 114 (2015) 157001.
[2] Sci. Adv. 9, eadh9163 (2023).
[3] Phys. Rev. 175 (1968) 537.
[4] Solid State Commun. 22 (1977) 37 1-374.

TT 68.10 Thu 12:00 H 3010

Visualizing delocalized quasiparticles in the vortex state of NbSe$_2$ — •Jian-Feng Ge[1,2], Koen Bastiaans[3], Jiasen Niu[2], Tjerk Benschop[2], Maialen Larrazabal[4], and Milan Allan[2] — [1]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany — [2]Leiden Institute of Physics, Leiden University, 2333 CA Leiden, The Netherlands — [3]Department of Quantum Nanoscience, Kavli Institute of Nanoscience, Delft University of Technology, 2628 CJ Delft, The Netherlands — [4]Debye Institute for Nanomaterials Science, Utrecht University, 3508 TA Utrecht, The Netherlands

Bogoliubov quasiparticles play a crucial role in understanding the behavior of a superconductor at the nanoscale, particularly in a vortex lattice where they are thought to be confined to the vortex cores. Here, we use scanning tunneling noise microscopy, which can locally quantify quasiparticles by measuring the effective charge, to observe and image delocalized quasiparticles around vortices in NbSe$_2$ for the first time. Our data reveals a strong spatial variation of the quasiparticle concentration when tunneling into the vortex state. We find that quasiparticle poisoning dominates when vortices are less than four times the coherence length apart. Our results set a new length scale for quasiparticle poisoning in vortex-based Majorana qubits and yield information on the effect of vortices in quantum circuits. Finally, we can describe our findings within the Ginzburg-Landau framework, but the microscopic origin of the far-extending quasiparticles is yet to be understood.

TT 68.11 Thu 12:15 H 3010

Multi-Knob tuning of electron-phonon interactions in TMDCs — •Michael Winter, Dominik Benner, and Tim Wehling — I. Institute of Theoretical Physics, University Hamburg, Hamburg

Transition metal dichalcogenides (TMDs or TMDCs) are gaining significant interest due to their layered nature and the observation of exotic quantum phases, e.g., superconductivity and Mott physics, as well as the prediction of multi-knob tunability of these phases.

In this project, we work towards the general understanding of TMD-[hetero]bilayers from quantum-lattice models. We carry out large scale and wide parameter range ab initio calculations including plane wave density functional theory, density functional perturbation theory, and subsequent electron-phonon interaction calculations. The resulting model can incorporate effects of external electric field, pressure and there-like. With a special focus, we report on results obtained for a heterobilayer of molybdenum disulfide and tungsten diselenide.

TT 68.12 Thu 12:30 H 3010

Gate controlled switching in non-centrosymmetric superconducting devices - Comparison of fabrication methods — •Jennifer Koch[1], Leon Ruf[1], Elke Scheer[1], and Angelo Di Bernardo[1,2] — [1]Universität Konstanz, Konstanz, Germany — [2]Università degli Studi di Salerno, Fisciano (SA), Italy

Gate-controlled supercurrent (GCS) devices have become of great interest as the superconducting equivalent to complementary metal-oxide-semiconductor (CMOS) logic. The idea behind this technology stems from the recent discovery that superconducting devices can be controlled electrically with the application of a gate voltage [1-3]. We investigate gate-controlled switching devices made of the non-centrosymmetric superconductor $Nb_{0.18}Re_{0.82}$ and compare how the fabrication process influences the physical properties. We examine the differences between devices fabricated with the top-down (dry-etching) and bottom-up (lift-off) approaches, as well as how the usage of different gases in the dry-etching step affects the GCS.

[1] G. De Simoni et al., Nat. Nanotechnol. 13 (2018) 802.
[2] F. Paolucci et al., Nano Lett. 18 (2018) 4195.
[3] F. Paolucci et al., Phys. Rev. Applied 11 (2019) 024061.

TT 68.13 Thu 12:45 H 3010

Curvilinear superconducting vortices in three-dimensional nano architecture — •Elina Zhakina[1], Luke Turnbull[1], Weijie Xu[1], Markus König[1], Paul Simon[1], Wilder Carrillo-Cabrera[1], Amalio Fernandez-Pacheco[2], Dieter Suess[3], Claas Abert[3], Vladimir M. Fomin[4,5], and Claire Donnelly[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany — [2]Institute of Applied Physics, TU Wien, Vienna, Austria — [3]University of Vienna, Vienna, Austria — [4]Leibniz IFW Dresden, Dresden, Germany — [5]Moldova State University, Republic of Moldova

When one patterns superconductors into three dimensional, curvilinear nanoarchitectures, intriguing phenomena in the superconductivity, and behaviour of superconducting vortices, arise due to both geometric- and topology-induced effects. In this context, we present an innovative approach to creating superconducting 3D nanoarchitectures through focused electron-beam-induced deposition of tungsten. This method empowers the realization of 3D superconducting nanostructures featuring a critical temperature near 5 K. Our experimental work proves the existence and propagation of superconducting vortices within these 3D superconducting nanostructures. We also uncover the profound geometrical effects inherent to 3D nanoarchitectures, such as the angular dependence of the upper-critical magnetic field, which one can harness to design the local superconducting state of the system. The introduction of this technique opens up new horizons for experimental investigations into the dynamics of vortices within the superconducting order parameter in curved 3D nanoarchitectures.

TT 68.14 Thu 13:00 H 3010

Cousin of Fe-based Superconductors SrNi$_2$P$_2$: electronic structure, superelasticity and elastocaloric cooling — •Adrian Valadkhani[1], Seok-Woo Lee[2], Paul C. Canfield[3], and Roser Valentí[1] — [1]Goethe University, Frankfurt am Main, Germany — [2]University of Connecticut, Connecticut, USA — [3]Iowa State University, Ames, USA

$SrNi_2P_2$ is a $ThCr_2Si_2$-structured intermetallic compound that undergoes various volume collapse transitions under strain. Recently a high recoverable compressive strain rate of 14% [1] was measured for this system. Typical values for such strain rates are less than one percent, which are limited by premature plastic deformation or fracture. This recoverable strain rate also takes place for tensile strain with a maximum of about 5%. For $SrNi_2P_2$, a double lattice collapse was proposed as the underlying mechanism. This double lattice collapse comes along with a unique elastocaloric double cooling and heating effect, which contrasts strongly to the one of conventional materials with alternating cooling and heating [2]. In this talk we present ab initio density functional theory (DFT) calculations of the electronic structure of this material under various strain conditions and discuss the microscopic origin of the various collapsed phases observed experimentally, superelasticity and the possibility of employing this class of materials as prototypes for elastocaloric cooling at low temperatures.

[1] S. Xiao et al., Nano Lett. 2021, 21, 19, 7913
[2] S. Xiao, A. Valadkhani, S. Rommel, P. C. Canfield, M. Aindow, R. Valentí, S.-W. Lee, just submitted

TT 69: Nonequilibrium Quantum Systems II (joint session TT/DY)

Time: Thursday 9:30–13:00 Location: H 3025

TT 69.1 Thu 9:30 H 3025

Nontrivial damping of quantum many-body dynamics in the spin-1/2 XXZ chain — •Mariel Kempa and Robin Steinigeweg — U Osnabrück, Germany

Understanding how the dynamics of a given quantum system with many degrees of freedom is altered by the presence of a generic perturbation is a notoriously difficult question. Recent works predict that, in the overwhelming majority of cases, the unperturbed dynamics is just damped by a simple function, e.g., exponentially as expected from Fermi's golden rule. While these predictions rely on random-matrix arguments and typicality, they can only be verified for a specific physical situation. It also remains unclear how frequent and under which conditions counterexamples to the typical behavior occur. We address this question from the perspective of projection-operator techniques, where exponential damping of a density matrix occurs in the interaction picture but not necessarily in the Schrödinger picture. We show that a nontrivial damping in the Schrödinger picture can emerge if the dynamics in the unperturbed system possesses rich features, for instance due to the presence of strong interactions. We substantiate our theoretical arguments by large-scale numerical simulations of spin transport in a perturbed spin-1/2 XXZ chain.
[1] T. Heitmann et al., Phys. Rev. E 104 (2021) 054145
[2] M. Kempa et al., in preparation

TT 69.2 Thu 9:45 H 3025

Cluster Truncated Wigner Approximation: Long-range bond disordered interacting spin-1/2 models — Adrian Braemer[1], •Javad Vahedi[1,2], and Martin Gärttner[1,2] — [1]Physikalisches Institut, Heidelberg, Germany — [2]Friedrich-Schiller-University, Jena, Germany

Phase-space methods, like Truncated Wigner Approximation (TWA), effectively simulate quantum system dynamics near classical limits by simplifying complexity and preserving initial noise information. However, TWA has limitations in finite times and classical/non-interacting scenarios. For strongly interacting systems far from the classical limit, conventional methods may provide unreliable approximations. The Cluster Truncated Wigner Approximation (cTWA) is an alternative approach introducing additional degrees of freedom to represent correlations independently, using classical equations of motion with initial conditions sampled from Gaussian distributions [1].

Our investigation focuses on quench dynamics in a spin chain with long-range interactions and disordered couplings[2]. Initializing the system in a Néel state, we compute dynamical observables, such as the staggered magnetization and Renyi entropy S_2 for a two-spin subsystem, using cTWA with different choices for the clustering and compare these to results from exact diagonalization. We find that a clustering strategy inspired by real-space renormalisation group argument matches the exact dynamics almost perfectly for a wide range of both interaction range and disorder strength.

TT 69.3 Thu 10:00 H 3025

Current-Voltage Characteristics of the Normal Metal-Insulator-PT-Symmetric Non-Hermitian Superconductor Junction as a Probe of Non-Hermitian Formalisms — •Viktoriia Kornich — Universität Würzburg

We study theoretically a junction consisting of a normal metal, PT-symmetric non-Hermitian superconductor, and an insulating thin layer between them. We calculate current-voltage characteristics for this junction using left-right and right-right bases and compare the results. We find that in the left-right basis, the Andreev-scattered particles move in the opposite direction compared with the right-right basis and conventional Andreev scattering. This leads to profound differences in current-voltage characteristics. Based on this and other signatures, we argue that the left-right basis is not applicable in this case. Remarkably, we find that the growth and decay with time of the states with imaginary energies in the right-right basis are equilibrated.

TT 69.4 Thu 10:15 H 3025

A Conjecture Regarding Ground State Overlaps — •Sarah Damerow and Stefan Kehrein — Institut für Theoretiche Physik, Friedrich-Hund-Platz 1, 37077 Göttingen, Georg-August Universität Göttingen, Germany

A conjectured extension of the adiabatic theorem to quantum quenches, i.e. non-adiabatic changes, is presented. Using Exact Diagonalisation and the Lanczos method, we study the Axial Next Nearest Neighbour Ising Model (ANNNI). We numerically test the following conjecture: A system is prepared in its ground state. Under adiabatic time evolution of the Hamiltonian this initial ground state evolves under the time-dependent Schrödinger equation. The overlap between the initial and the final ground state will be larger than any other overlap, if both states are in the same magnetic phase.

TT 69.5 Thu 10:30 H 3025

Constructing nonequilibrium steady states from equilibrium correlation functions in generic nonintegrable systems — •Markus Kraft[1], Jonas Richter[2,3], Fengping Jin[4], Sourav Nandy[5], Zala Lenarčič[5], Jacek Herbrych[6], Kristel Michielsen[4], Hans De Raedt[7], Jochen Gemmer[1], and Robin Steinigeweg[1] — [1]U Osnabrück — [2]U Stanford — [3]U Hannover — [4]FZ Jülich — [5]U Ljubljana — [6]U Wroclaw — [7]U Groningen

State-of-the-art approaches to extract transport coefficients of many-body quantum systems broadly fall into two categories: (i) they target the linear-response regime in terms of equilibrium correlation functions of the closed system; or (ii) they consider an open-system situation typically modeled by a Lindblad equation, where a nonequilibrium steady state emerges from driving the system at its boundaries. While quantitative agreement between (i) and (ii) has been found for selected model and parameter choices, also disagreement has been pointed out in the literature. Studying magnetization transport in the spin-1/2 XXZ chain, we here demonstrate that at weak driving the nonequilibrium steady state in an open system, including its buildup in time, can remarkably be constructed just on the basis of correlation functions in the closed system. We numerically illustrate this direct correspondence of closed-system and open-system dynamics.
[1] T. Heitmann et al., arXiv:2303.00430
[2] T. Heitmann et al., Phys. Rev. E 108 (2023) 024102
[3] M. Kraft et al., in preparation

TT 69.6 Thu 10:45 H 3025

A Mixed Quantum-Classical Approach to Nonequilibrium Charge Transport in Strongly Interacting Molecular Junctions — •Samuel Rudge, Christoph Kaspar, and Michael Thoss — University Freiburg, Freiburg im Breisgau, Deutschland

Electronic friction and Langevin dynamics (EF-LD) is a popular mixed quantum-classical approach to modeling the dynamics of molecules near metal surfaces [1]. We have recently shown that, using the numerically exact hierarchical equations of motion (HEOM) transport method, one can calculate the electronic friction of systems containing electron-electron correlations or high-frequency quantum vibrational modes [2].

In this contribution, we use, for the first time, the combined EF-LD and HEOM approach to explore nonequilibrium charge transport in molecular junctions containing strong interactions. The analysis is performed for a broad parameter regime and uncovers interesting transport behavior arising from the strong interactions. The method opens the door for the analysis of realistic multimode molecular models containing anharmonic vibrational modes and nonlinear electronic-vibrational interactions, which fully quantum methods currently struggle to treat [3].
[1] J. T. Lü *et al.*, Prog. Surf. Sci. **94** (2019) 21
[2] S. L. Rudge *et al.*, Phys. Rev. B **107**, (2023) 115416
[3] C. Schinabeck *et al.*, Phys. Rev. B **97**(2018) 235429

TT 69.7 Thu 11:00 H 3025

Transport resonances in systems with time periodic impurities — •Jan Mathis Giesen and Sebastian Eggert — Department of Physics and Research Center Optimas, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Periodically driven impurities in tight binding chains can lead to the complete breakdown of transport even at infinitesimal small driving amplitudes due to a Fano-like resonance [1]. We now go beyond the simple model to analyse effects of time-periodic impurities in general setups like electronic systems, magnons in thin ferromagnetic films, photonic waveguides and the scattering of cold atoms. More specifi-

cally we examine single particle transport resonances in models featuring long range coupling and generally more complicated band structures as well as multiple channels, modes or bands.
We extend the Floquet scattering ansatz using plane waves to include multiple modes and also apply a generalization in form of a Floquet-S-matrix scattering approach. We find that transport resonances are highly susceptible to changes in the band structure. Depending on the driving parameters and energy of incoming states new transport resonances can appear while others might become completely suppressed.
[1] S. A. Reyes *et al.*. New J. Phys. **19** (2017) 043029

15 min. break

TT 69.8 Thu 11:30 H 3025

Numerically exact simulation of photo-doped Mott insulators — •Fabian Künzel[1], André Erpenbeck[2], Daniel Werner[3], Enrico Arrigoni[3], Emanuel Gull[2], Guy Cohen[4], and Martin Eckstein[1] — [1]University of Hamburg, 20355 Hamburg, Germany — [2]University of Michigan, Ann Arbor, Michigan 48109, USA — [3]Graz University of Technology, 8010 Graz, Austria — [4]Tel Aviv University, Tel Aviv 6997801, Israel

A description of long-lived photo-doped states in Mott insulators is challenging, as it needs to address exponentially separated timescales. These photo-doped states simultaneously host strongly correlated electron-like and hole-like carriers and can show instabilities into various non-thermal orders. In our recent work (arXiv:2311.13933 [cond-mat.str-el]) we demonstrate how properties of such quasi-steady states can be accessed using numerically exact techniques, in particular the steady state Quantum Monte Carlo inchworm framework, by establishing a time-local ansatz for the distribution function with separate Fermi functions for the electron and hole quasiparticles. We compare the results to non-perturbative steady state solvers and validate the consistency of this approach upon comparison with real-time simulations in a quenched Hubbard model. The simulations show that the Mott gap remains robust to large photo-doping, and the photo-doped state has hole and electron quasiparticles with strongly renormalized properties. By combining the steady state ansatz with Quantum Boltzmann Equation schemes, they open up new avenues for characterizing the slow dynamics of Mott insulators.

TT 69.9 Thu 11:45 H 3025

Fractonic Dynamics in Breathing Quantum-Spin Ice — •Gloria Isbrandt[1,2], Frank Pollmann[1,2], and Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany

Fracton quantum matter is characterized by excitations with constrained mobility. It remains an open challenge to identify suitable material candidates for such systems. Recently, breathing pyrochlore lattices have been argued as potential candidates for realizing fractonic constraints. Here, we study the dynamics of excitations in such a breathing pyrochlore lattice. We derive an effective Hamiltonian for excitations in the fractonic ground state manifold, by resorting to the rank-2 U(1) gauge theory formulation and the rank-2 Gauss law of fractons. We show both by analytical considerations and by numerical simulations based on cellular automaton circuit dynamics, that excitations in these systems are confined to two-dimensional planes within the three-dimensional breathing pyrochlore lattice. We derive a height-field theory for the effective two-dimensional dynamics, which exhibits diffusive dynamics with slow modes at finite momenta, resulting from effective subsystem symmetries. Coined as "Fractonic Quantum-Spin Ice," this system offers a physically realizable platform for fractonic excitations predicted by higher-rank gauge theories

TT 69.10 Thu 12:00 H 3025

Dynamical Spectral Response of Fractonic Quantum Matter — •Philip Zechmann[1,2], Julian Boesl[1,2], Johannes Feldmeier[3], and Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Department of Physics, Harvard University, Cambridge, MA 02138, USA

Quantum many-body systems with fractonic excitations can realize fascinating phases of matter. Here, we study the low-energy excitations of a constrained Bose-Hubbard model in one dimension, which conserves the center of mass or, equivalently, the dipole moment in addition to the particle number. This model is known to realize fractonic phases, including a dipole Mott insulator, a dipole Luttinger liquid, and a metastable dipole supersolid. We use tensor network methods to compute spectral functions from the dynamical response of the system and verify predictions from low-energy field theories of the corresponding ground state phases. We demonstrate the existence of gapped excitations compatible with strong coupling results in a dipole Mott insulator, linear sound modes characteristic of a Luttinger liquid of dipoles, and soft quadratic modes at both zero and finite momenta in a supersolid state with charge density wave order and phase coherence at non-integer filling.

TT 69.11 Thu 12:15 H 3025

Deconfinement Dynamics of Fractons in Tilted Bose-Hubbard Chains — •Julian Boesl[1,2], Philip Zechmann[1,2], Johannes Feldmeier[3], and Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Department of Physics, Harvard University, Cambridge, MA 02138, USA

Fractonic constraints can lead to exotic properties of quantum many-body systems. Here, we investigate the dynamics of fracton excitations on top of the ground states of a one-dimensional, dipole-conserving Bose- Hubbard model. We show that nearby fractons undergo a collective motion mediated by exchanging virtual dipole excitations, which provides a powerful dynamical tool to characterize the underlying ground state phases. We find that in the gapped Mott insulating phase, fractons are confined to each other as motion requires the exchange of massive dipoles. When crossing the phase transition into a gapless Luttinger liquid of dipoles, fractons deconfine. Their transient deconfinement dynamics scales diffusively and exhibits strong but subleading contributions described by a quantum Lifshitz model. We examine prospects for the experimental realization in tilted Bose-Hubbard chains by numerically simulating the adiabatic state preparation and subsequent time evolution, and find clear signatures of the low-energy fracton dynamics.

TT 69.12 Thu 12:30 H 3025

Current-induced excitonic condensation in bilayer systems — •Alexander Osterkorn and Denis Golež — Institut "Jožef Stefan", Jamova cesta 39, 1000 Ljubljana, Slovenia

Excitons are correlated electron-hole pairs in multi-band electron systems, which can condense and form ordered phases of matter called excitonic insulators. These are expected to display novel and interesting features like superfluid energy transport and perfect Coulomb drag. While it is experimentally challenging to identify real materials hosting equilibrium excitonic order, out-of-equilibrium protocols open up an independent route to stabilize excitonic condensates. Ma et.al. [1] proposed a gated semiconductor bilayer architecture, in which an applied voltage bias allows for the continuous creation of interlayer excitons by means of an induced electrical current. We model the setup starting from the quasi-stationary situation [2] within the Hartree-Fock and second order Born approximations and discuss the strong impact of dimensionality on the formation of the excitonic state. In order to go beyond the static picture, we demonstrate the dynamical formation of a steady-state subsequent to a switch-on of the voltage bias within real-time DMFT. We discuss how the formation of an excitonic condensate depends on steady-state temperature and doped carrier concentration.
[1] L. Ma et al., Nature 598 (2021) 585
[2] M. Xie, A.H. MacDonald, Phys. Rev. Lett. 121 (2018) 067702

TT 69.13 Thu 12:45 H 3025

Semi-classical analysis of HHG in pseudo-relativistic materials — •Wolfgang Hogger[1], Vanessa Junk[1], Alexander Riedel[1], Cosimo Gorini[2], Angelika Knothe[1], Juan-Diego Urbina[1], and Klaus Richter[1] — [1]Institute for theoretical physics, University of Regensburg, Germany — [2]Université Paris-Saclay, CEA, CNRS, SPEC, 91191, Gif-sur-Yvette, France

The study of high-order harmonic generation (HHG) in solids by virtue of intense laser pulses provides a fascinating platform to study ultrafast electron dynamics as well as material properties. We theoretically investigate HHG on the basis of massive Dirac Fermions, serving as a prototypical model for topologically non-trivial matter and other systems with pseudo-relativistic dispersion. A successful and intuitive

picture for HHG in gases is the three-step model[1], which was also generalized and brought to the realm of semiconductors and 2D materials[2]. We study the emergence of this semi-classical model from a LZS-transfer-matrix method[3] which can account for the characteristic transition dynamics of Dirac Fermions and thus may provide a way to understand the physical mechanism of HHG in these systems.

[1] M. Lewenstein, P. Balcou, M. Y. Ivanov, A. L. Huillier, P. B. Corkum, Phys. Rev. A 49 (1994) 2117
[2] G. Vampa, C. R. Mcdonald, G. Orlando, D. D. Klug, P. B. Corkum, T. Brabec, Phys. Rev. Lett. 113 (2014) 073901
[3] S. N. Shevchenko, S. Ashhab, F. Nori, Phys. Rep. 492 (2010) 1

TT 70: Focus Session: Nanomechanical Systems for Classical and Quantum Sensing III (joint session HL/DY/TT/QI)

Nanomechanical and cavity-optomechanical systems have been recently established as a controllable and configurable platform that can be engineered to tackle outstanding sensing challenges both in the classical and in the quantum regime. With this focus session, experts from different but synergetically overlapping fields of nanomechanical sensing pursuing classical, non-linear and quantum approaches are brought together. The session shall provide an overview over the recent exciting developments of the techniques explored in micro- and nanomechanical systems and sensing concepts exploring quantum measurement schemes.

Organized by Eva Weig, Hubert Krenner, and Hans Hübl.

Time: Thursday 9:30–13:00 Location: EW 202

Invited Talk TT 70.1 Thu 9:30 EW 202
Quantum sensors and memories based on soft-clamped phononic membrane resonators — •Albert Schliesser — Niels Bohr Institute, Copenhagen University, Denmark

Soft-clamping of membrane resonators using a phononic pattern enables Q-factors above 1 billion and coherence times exceeding 100 ms at low temperature. We monitor the motion of such membranes with optical interferometry. This allows us to measure force and displacement at and beyond the standard quantum limit, and control the motional quantum state, even at room temperature. This platform lends itself for sensing applications; as an example, we image individual viruses and nanoparticles using the membrane as a force sensor. In a different set of experiments, we demonstrate mechanical storage and subsequent retrieval of optical pulses with an efficiency of 40%, suggesting applications as quantum memory for light.

Invited Talk TT 70.2 Thu 10:00 EW 202
Quantum mechanics-free subsystem with mechanical oscillators — •Laure Mercier de Lepinay[1], Caspar Ockeloen-Korppi[1], Matthew Woolley[2], and Mika Sillanpää[1] — [1]Department of Applied Physics, Aalto University, P.O. Box 15100, FI-00076 Aalto, Finland — [2]School of Engineering and Information Technology, UNSW Canberra, ACT, 2600, Australia

Quantum mechanics sets a limit on the precision of the continuous measurement of an oscillator's position. However, with an adequate coupling configuration of two oscillators, it is possible to build an oscillator-like subsystem of quadratures isolated from quantum and classical backaction which therefore does not suffer from this limit. We realize such a quantum mechanics-free subsystem using two micromechanical drumheads coupled to microwave cavities. Multitone phase-stable microwave pumping of the system allows to implement the necessary effective coupling configuration. We first demonstrate the measurement of two collective quadratures, evading backaction simultaneously on both of them, obtaining a total noise within a factor of 2 of the full quantum limit. Secondly, this measurement technique is directly adapted to the detection of continuous variable entanglement which is based, according to the Duan criterion, on variance estimates of two collective quadratures. We therefore verify the stabilized quantum entanglement of the two oscillators deeper than had been possible before for macroscopic mechanical oscillators.

Invited Talk TT 70.3 Thu 10:30 EW 202
Electrothermally tunable metal-graphene-siliconnitride membrane mechanical device — •Elke Scheer, Mengqi Fu, and Fan Yang — Department of Physics, University of Konstanz, 78457 Konstanz

Controlling the properties of mechanical devices over a wide range is important for applications as well as for fundamental research. In this work, we demonstrate an on-chip tunable device composed of a suspended siliconnitride (SiN) membrane with a graphene (G) layer on top which is connected to Au electrodes. Taking advantage of the electrical and thermal conductance properties of G and the difference in the thermal expansion coefficients of SiN and Au, we developed a device in which the G-Au interface serves as local heater by injecting a dc current. The force induced by the thermal expansion difference tunes the residual stress in the SiN membrane and deflects the membrane when the loading power overcomes the threshold to the buckling transition. With this device we realize an extreme large eigenfrequency tuning (more than 50 %) of the vibration mode. By injecting an ac voltage instead, and thus applying a periodic force to the membrane, we achieve strong excitation of the membrane resonator into the nonlinear vibration. This device may act as proof-of-principle for a compact on-chip excitation scheme for multidimensional and composite nanomechanical resonators.

15 min. break

Invited Talk TT 70.4 Thu 11:15 EW 202
From Nanomechanics to Spins — •Christian Degen — ETH Zurich, Switzerland

Nanomechanical resonators are exquisite sensors for weak magnetic forces, with exciting prospects in nanoscale detection and imaging of nuclear and electronic spins. In this talk, I will give an overview of our laboratory's activities in this field, including force detection with optomechanical membranes and strings, and nuclear spin imaging with the technique of magnetic resonance force microscopy.

Invited Talk TT 70.5 Thu 11:45 EW 202
Enhanced cooling efficiency in nonlinear cavity optomechanics — •Anja Metelmann[1], Nicolas Diaz-Naufal[2], David Zoepfl[3], Lukas Deeg[3], Christian Schneider[3], Mathieu Juan[4], and Gerhard Kirchmaier[3] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Free University Berlin, Berlin, Germany — [3]University of Innsbruck, Innsbruck, Austria — [4]Universite de Sherbrooke, Sherbrooke, Canada

Unlocking the quantum potential of mechanical resonators hinges on achieving ground state cooling, a key milestone for quantum information processing and ultra-precise quantum measurements. In the vibrant field of cavity optomechanics, dynamical backaction cooling and feedback protocols have successfully nudged macroscopic mechanical elements toward the quantum ground state. While linear regime cooling is well-explored, recent theoretical insights suggest that a nonlinear cavity could amplify cooling efficiency. We explore this intriguing nonlinear regime, focusing on the cooling dynamics of a mechanical resonator coupled to a nonlinear cavity, embodying the characteristics of a high-Q Duffing oscillator. In this talk we present a comparative analysis between theoretical predictions and experimental results from a magnetomechanical platform. The findings unveil a captivating enhancement in cooling efficiency attributed to the Duffing nonlinearity. This breakthrough not only enriches our understanding of optomechanical interactions but also holds promise for advancing cooling strategies in quantum technologies.

TT 70.6 Thu 12:15 EW 202

Brillouin scattering selection rules in elliptical optophononic resonators — •Anne Rodriguez[1,2], Priya Priya[1], Edson Cardozo de Oliveira[1], Abdelmounaim Harouri[1], Isabelle Sagnes[1], Florian Pastier[3], Martina Morassi[1], Aristide Lemaître[1], Loic Lanco[1], Martin Esmann[1], and Daniel Lanzillotti-Kimura[1,4] — [1]Centre de Nanosciences et de Nanotechnologies, Université Paris-Saclay, CNRS, Palaiseau, France — [2]present address: Chair for Nano and Quantum Sensors, Technische Universität München, Garching, Germany — [3]Quandela SAS, Palaiseau, France — [4]Institut für Physik, Universität Oldenburg, Germany

The selection rules of spontaneous Brillouin scattering in bulk crystalline solids are intrinsic material properties that formally constrain the energy, direction and polarization of the scattered photons for a given input state. In this work, we manipulate the polarization states of the input laser and Brillouin signal independently using polarization-sensitive optical micropillar cavities. The ellipticity of the micropillars lifts the degeneracy of the optical cavity modes, and induces a wavelength-dependent rotation of polarization [1,2], altering the Brillouin scattering selection rules. We developed a Brillouin spectroscopy scheme based on polarization filtering, allowing to measure acoustic phonon resonances with frequencies in the range of 20-100 GHz [3], with background-free spontaneous Brillouin scattering spectra.

[1] H. Wang et al., Nat. Phot. 13, 770 (2019). [2] B. Gayral et al., APL 72, 1421 (1998). [3] A. Rodriguez et al., ACS Photonics 10, 1687 (2023).

TT 70.7 Thu 12:30 EW 202

3D Microwave Cavity-Assisted Detection of High-Q Silicon Nitride Nanomechanical String Resonators — •Run Fa Jonny Qiu, Anh Tuan Le, Avishek Chowdhury, and Eva Weig — Technical University of Munich, Chair of Nano- and Quantum Sensors, Hans-Piloty Str. 1, 87548 Munich, Germany

Amorphous, low-pressure chemical vapor deposition (LPCVD)-grown silicon nitride (Si3N4) is a highly pre-stressed material due to its thermal-coefficient mismatch and is exploited in our fabrication of doubly-clamped freely suspended nanomechanical string resonators with superjacent electrodes for dielectric drive and detection. High-quality factor (Q-factor) nanomechanical string resonators with a Q-factor of roughly 300000 were fabricated. Two large gold-coated antennas connected to the electrodes are deposited on-chip which permits for a direct coupling of the mechanical displacement-induced change of the capacitance between the electrodes to the electric field of the three-dimensional (3D) rectangular cavity. Research on the quarter-wave coaxial cavity together with a capacitive loop and disk coupling revealed the possibility of both coupling schemes for the detection of mechanical modes. Applying direct current (DC) voltage to the electrodes allows for a frequency tuning of the mechanical flexural modes in the opposite direction, which due to the inherent coupling of the two in-plane (ip) and out-of-plane (oop) modes leads to an avoided crossing.

TT 70.8 Thu 12:45 EW 202

Optomechanical acceleration beats in confined polariton condensates — Alexander Kuznetsov, Klaus Biermann, and •Paulo Ventura Santos — Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e. V., Hausvogteiplatz 5-7, 10117 Berlin, Germany

High-frequency optomechanics involving optoelectronic systems with long temporal coherences enable access to the regime of non-adiabatic modulation, where the optomechanical modulation quantum $\hbar\Omega_M$ exceeds the typical energy decoherence rate of the optoelectronic resonances. Characteristic for this regime is the appearance of modulation sidebands around the optoelectronic resonance line displaced by energy multiples $m\Omega_M$,$(m = 0, \pm 1, \dots)$ with amplitude and number determined by the energy modulation amplitude ΔE_M. Here, we experimentally demonstrate a novel regime of temporal coherence invoked by the harmonic modulation of an optomechanical resonance at extreme energy modulation amplitudes $\Delta E_M/(\hbar\Omega_M) > 150$. We show that the resonance energy of a confined exciton-polariton Bose-Einstein condensate harmonically driven at these high relative modulation amplitudes exhibit temporal correlations with time-scales much shorter than the modulation period [Kuznetsov et al., DOI:10.21203/rs.3.rs-3197243/v1]. These correlations manifest themselves as comb of spectral resonances with energy scale determined by the ratio $\Delta E_M/(\hbar\Omega_M)$. We show that they arise from accelerated rates of energy change during the harmonic cycle and are, thus, termed the acceleration beats.

TT 71: Many-Body Quantum Dynamics I (joint session DY/TT)

Time: Thursday 9:30–13:00 Location: A 151

TT 71.1 Thu 9:30 A 151

Topological synchronization of fractionalized spins — •Christopher Wächtler[1] and Joel Moore[1,2] — [1]University of California, Berkeley, USA — [2]Lawrence Berkeley National Laboratory, Berkeley, USA

The gapped symmetric phase of the Affleck-Kennedy-Lieb-Tasaki (AKLT) model exhibits fractionalized spins at the ends of an open chain. We show that breaking SU(2) symmetry and applying a global spin-lowering dissipator achieves synchronization of these fractionalized spins. Additional local dissipators ensure convergence to the ground state manifold. In order to understand which aspects of this synchronization are robust within the entire Haldane-gap phase, we reduce the biquadratic term which eliminates the need for an external field but destabilizes synchronization. Within the ground state subspace, stability is regained using only the global lowering dissipator. These results demonstrate that fractionalized degrees of freedom can be synchronized in extended systems with a significant degree of robustness arising from topological protection.

TT 71.2 Thu 9:45 A 151

Understanding NMR signals by cluster dynamic mean-field theory — •Timo Gräßer[1], Thomas Hahn[2], and Götz S. Uhrig[1] — [1]Condensed Matter Theory, TU Dortmund University, Otto-Hahn Straße 4, 44221 Dortmund, Germany — [2]School of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, United Kingdom

A recently developed dynamic mean-field theory for spins at infinite temperature (spinDMFT)[1] is used to understand NMR signals quantitatively. The underlying idea is to couple a spin to a dynamic Gaussian mean-field with second moments that are self-consistently linked to the spin's autocorrelations. We improve the approach by considering clusters of spins quantum-mechanically (CspinDMFT)[2]. The extended model is more accurate and it allows for computing multi-spin correlations. We show that generic NMR signals comprise contributions of such multi-spin correlations. The applicability and validity of this approach is shown by describing NMR data for calcium fluoride (Ca F2) and adamantane (C10 H16).

[1] T. Gräßer et al., Phys. Rev. Research 3, 043168 (2021).
[2] T. Gräßer et al., arXiv:2307.14188 (2023).

TT 71.3 Thu 10:00 A 151

Domain wall dynamics of a two dimensional quantum Ising model using tree tensor networks — •Wladislaw Krinitsin[1], Niklas Tausendpfund[1,2], Matteo Rizzi[1,2], and Markus Schmitt[1,3] — [1]Forschungszentrum, Jülich, Deutschland — [2]Institut für Theoretische Physik, Köln, Deutschland — [3]Fakultät für Informatik und Data Science, Regensburg, Deutschland

Many body systems out of equilibrium are notoriously difficult to solve due to the rapid growth of entanglement with time. In particular the expanding possibilities to address two-dimensional systems in quantum simulations turn a spotlight on the lack of reliable numerical methods in this regime. We explore an approach to solve the time evolution of two-dimensional quantum systems by applying the time-dependent variational principle to Tree Tensor Networks. As an application, we consider the relaxation of domain wall initial conditions in a quantum Ising model, where pre-thermal behavior leads to a slow relaxation of domain wall initial conditions.

TT 71.4 Thu 10:15 A 151

Edge modes of the random-field Floquet quantum Ising

model — •Harald Schmid[1], Alexander-Georg Penner[1], Kang Yang[1], Leonid Glazman[2], and Felix von Oppen[1] — [1]Dahlem Center for Complex Quantum, Freie Universität Berlin, 14195 Berlin, Germany — [2]Department of Physics, Yale University, New Haven, Connecticut 06520, USA

Motivated by a recent experiment on a superconducting quantum processor [Mi et al., Science 378, 785 (2022)], we study edge modes in the random-field Floquet quantum Ising model. The edge modes induce pairings in the many-body Floquet spectrum with splittings exponentially close to zero or π. We find that random transverse fields induce a log-normal distribution for both types of splittings. In contrast, random longitudinal fields affect the zero and π splittings in drastically different ways. While zero pairings are rapidly lifted, the π pairings are remarkably robust, or even strengthen, up to vastly larger disorder strengths. We explain our result within a self-consistent Floquet perturbation theory and study implications for boundary spin-spin correlations. The robustness of π pairings against longitudinal disorder may be useful for quantum information processing.

TT 71.5 Thu 10:30 A 151

A metronome spin stabilizes time-crystalline dynamics — •Niklas Euler[1,2], Adrian Braemer[2], and Martin Gärttner[1,2] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

We investigate a disorder-free quantum Ising chain subject to a time-periodic drive that rotates each spin by an angle $\pi(1-\epsilon_i)$. In case all spins experience the same deviation ϵ and the system starts from a fully magnetized state, the dynamics is known to be time crystalline: The magnetization exhibits stable, period-doubled oscillations for timescales that grow exponentially with system size. In this work, we study the effect of ϵ differing between the spins. We find that reducing ϵ for a single spin drastically enhances the lifetime of spatial-temporal order, suggesting the name "metronome" spin. Employing perturbative arguments, we explain this observation for initial states with macroscopic bulk magnetization. Furthermore, in the case of random bitstring initial states, we report enhancement of the lifetime of a topological edge mode. Here, we relate the presence of the metronome spin to the suppression of resonant processes. Finally, we discuss an altered geometry in which the metronome spin is not directly part of the chain, making the two described mechanisms clearly distinguishable. Our results illuminate the rich nature of spatially-varying Floquet driving, establishing it as a promising technique for fields like Floquet engineering.

TT 71.6 Thu 10:45 A 151

Non-equilibrium dynamics of bosons with dipole symmetry: Emergence of new symmetry broken steady states — •Md Mursalin Islam[1,3], Krishnendu Sengupta[2], and Rajdeep Sensarma[3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Indian Association for the Cultivation of Science, Kolkata, India — [3]Tata Institute of Fundamental Research, Mumbai, India

We study equilibrium and dynamical phase diagrams of an interacting system of N-component charged bosons with dipole symmetry. In the large N limit, the equilibrium phase diagram of these bosons shows a first-order transition between two phases. The first one is a localized normal phase where both the global U(N) and the dipole symmetries are conserved and the second one is a delocalized condensed phase where both the symmetries are broken. In contrast, the steady state after an instantaneous quantum quench from the condensed phase shows an additional, delocalized normal phase, where the global U(N) symmetry is conserved but the dipole symmetry is broken, for a range of the quench parameters. A study of the ramp dynamics of the model shows that the above-mentioned steady state exists only above a critical ramp rate.

TT 71.7 Thu 11:00 A 151

Symmetries as Ground States of Local Operators — •Sanjay Moudgalya[1,2] and Olexei Motrunich[3] — [1]Technical University of Munich, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Department of Physics, California Institute of Technology, Pasadena, California 91125, USA

Symmetry algebras of quantum many-body systems with locality can be understood using commutant algebras, which are defined as algebras of operators that commute with a given set of local operators. In this work, we show that these symmetry algebras can be expressed as frustration-free ground states of a local superoperator, which we refer to as a "super-Hamiltonian". We demonstrate that for conventional onsite unitary symmetries, the symmetry algebras map to various kinds of ferromagnetic ground states. We obtain a physical interpretation of this super-Hamiltonian as the superoperator that governs the operator relaxation in noisy symmetric Brownian circuits, which relates its low-energy excitations to approximate symmetries that determine slowly relaxing modes in symmetric systems. We find examples of gapped/gapless super-Hamiltonians indicating the absence/presence of slow-modes, which happens in the presence of discrete/continuous symmetries. In the gapless cases, we recover slow-modes such as diffusion in the presence of U(1) symmetry. We also demonstrate this framework for unconventional symmetries that lead to Hilbert space fragmentation and quantum many-body scars, which lead to novel kinds of slow-modes such as tracer diffusion and asymptotic quantum scars.

15 min. break

TT 71.8 Thu 11:30 A 151

Active quantum flocks — •Reyhaneh Khasseh[1], Sascha Wald[2], Roderich Moessner[3], Christoph A. Weber[1], and Markus Heyl[1] — [1]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, D-86135 Augsburg, Germany — [2]Statistical Physics Group, Centre for Fluid and Complex Systems, Coventry University, Coventry, England — [3]Max-Planck-Institut fur Physik komplexer Systeme, 01187 Dresden, Germany

In the captivating overlap of quantum physics and biophysics, our research seeks to reveal how characteristics intrinsic to living systems can manifest within quantum matter. Flocks of animals in the macroscopic classical world are iconic representations of collective behavior, where constituents move in harmony as though a singular entity. The intriguing intersection between quantum physics and biophysics prompts the exploration of whether such flocks can manifest in the microscopic quantum realm. Introducing the concept of active quantum matter through a series of models on a one-dimensional lattice, we present analytical and numerical evidence pointing to the emergence of quantum flocks.

TT 71.9 Thu 11:45 A 151

Quantum motility-induced phase separation — •Laurin Brunner[1], Reyhaneh Khasseh[1], Federico Carollo[2], Igor Lesanovsky[2], Juan Garrahan[3], and Markus Heyl[1] — [1]University of Augsburg, Augsburg, Germany — [2]Universität Tübingen, Tübingen, Germany — [3]University of Nottingham, Nottingham, United Kingdom

Active matter is a central concept in biophysics explaining key mechanisms of living organisms. Very recently, a quantum analogue in open quantum systems has been introduced for the first time. Here, we study a theoretical model showing evidence of a quantum counterpart of motility-induced phase separation. We solve the dynamics by means of neural quantum states and we furthermore discuss the quantum features of our model.

TT 71.10 Thu 12:00 A 151

Fluctuations Approach to Quantum Many-Body Systems and its Application to Density Correlations and the Dynamic Structure Factor — •Erik Schroedter, Jan-Philip Joost, and Michael Bonitz — CAU Kiel, Germany

The dynamics of quantum many-body systems following external excitation are of great interest in many areas, such as correlated solids or dense plasmas. Standard approaches used for the description of the dynamics of such systems include the formalisms of reduced density matrices (RDM) and nonequilibrium Green functions (NEGF). However, both approaches are limited in their applicability due to the numerical scaling of simulations with respect to the system size or propagation time. Here, an alternative approach to the dynamics of quantum systems is presented, which is based on fluctuations and their correlation functions [1]. While this new approach is closely related to NEGF and RDM theory [2], it has interesting complementary features, such as the capability to simulate many-body effects using stochastic methods [3,4], which reduce the computational complexity and additionally increase numerical stability for stronger coupling. Moreover, this approach provides direct access to spectral two-particle quantities, such as the density response function or dynamic structure factor, for systems in and far from equilibrium.

[1] E. Schroedter, *et al.*, Cond. Matt. Phys. **25**, 23401 (2022)
[2] E. Schroedter, and M. Bonitz, phys. stat. sol. (b) (2024)
[3] D. Lacroix, *et al.*, Phys. Rev. B **90**, 125112 (2014)
[4] E. Schroedter, *et al.*, Phys. Rev. B **108**, 205109 (2023)

TT 71.11 Thu 12:15 A 151

Conserved Superoperators and Non-Universality in Unitary Circuits — •Marco Lastres[1,2], Frank Pollmann[1,2], and Sanjay Moudgalya[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany

An important result in the theory of quantum control is the "universality" of 2-local unitary gates, i.e. the fact that any global unitary evolution of a system of L qudits can be implemented by composition of 2-local unitary gates. Surprisingly, recent results show that universality can break down in the presence of symmetries: in general, not all globally symmetric unitaries can be constructed using k-local symmetric unitary gates. This also restricts the dynamics that can be implemented by symmetric local Hamiltonians.

In this study, we show that these obstructions to universality can in general be understood in terms of unconventional superoperator symmetries associated with unitary evolution by k-local gates. We demonstrate this explicitly in several examples by systematically deriving the superoperator symmetries using the framework of commutant algebras, which has recently been applied to derive the unconventional symmetries responsible for weak ergodicity breaking phenomena, such as quantum many body scars and Hilbert space fragmentation. In all, our work establishes a new comprehensive approach to explore the universality of unitary circuits and derive physical consequences of its absence.

TT 71.12 Thu 12:30 A 151

Exploring Quantum Dynamics of hard disks on a lattice — •Vighnesh Dattatraya Naik, Fabian Ballar Trigueros, and Markus Heyl — Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, 86135 Augsburg, Germany

Recent strides in quantum simulators have propelled the investigation of quantum matter with local constraints to the forefront of research. This study delves into the hard-disk problem, a paradigmatic class of constrained matter, by introducing its quantum version on lattices, which exhibits a natural realization in Rydberg atom arrays due to the Rydberg blockade mechanism. While static properties align with classical cases, dynamical properties are fundamentally different. In one dimension, we identify genuine quantum features in the melting process of a finite-size crystal displaying ballistic behavior, whereas the classical scenario exhibits sub-diffusion governed by the Kardar-Parisi-Zhang universality class. On two-dimensional square lattices, we show that in the quantum domain, crystals remain intact against most defects, whereas classically the initial crystal structure is washed out completely. We link this peculiar quantum behavior to the presence of quantum many-body scars, breaking conventional expectations of ergodicity. Our study highlights the potential of constrained two-dimensional quantum matter to display unique dynamical behaviors.

TT 71.13 Thu 12:45 A 151

Non-ergodic dynamical phenomena in lattice gauge theories — •Nilotpal Chakraborty[1], Markus Heyl[2], and Roderich Moessner[1] — [1]Max Planck Institute for physics of complex systems, Dresden — [2]University of Augsburg

Lattice gauge theories are paradigmatic examples of constrained many-body interacting systems. Such theories, while ubiquitous in nature, emerge in condensed matter settings as effective low-energy theories for certain classes of topological magnets. More recently such theories have also been at the forefront of a large quantum simulation effort using ultra cold atoms. With the advent of such simulation efforts and novel dynamical methods for solid state systems, the dynamics of such constrained interacting theories becomes an important theoretical question with physical relevance. In this talk I shall present lattice gauge theories as an ideal testbed for exploring a plethora of non-ergodic dynamical phenomena - ranging from fragmentation to scars as well as many-body localization. In particular, I shall focus on the occurrence of an interference induced many-body localization transition in two dimensional U(1) lattice gauge theories. Such a transition occurs for the problem of a single matter field hopping on a disordered background of interacting gauge fields. I will explore the problem both at the classical and quantum level and highlight interesting dynamical phenomena for both - such as sub-diffusion for the classical and many-body localization for the quantum problem.

TT 72: $SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor II (joint session TT/KFM/MA/O)

Strontium titanate ($SrTiO_3$) is a paradigmatic material that plays an important role in various fields of solid-state physics, surface science and catalysis: The pure bulk phase is a wide-band-gap semiconductor that upon cooling becomes a textbook quantum paraelectric. When slightly doped, $SrTiO_3$ turns into a Fermi-liquid-type metal that becomes superconducting at extremely low charge carrier density. $SrTiO_3$-based surfaces and interfaces host un-conventional electronic states such as quasi-two-dimensional electron liquid, magnetism and superconductivity. Despite intensive studies over the past decades, $SrTiO_3$ continues to reveal surprising new phenomena that challenge the established views on this material. To this end achieving light-induced nonequilibrium states and the recent preparation of a 2D oxide based on $SrTiO_3$ opens new playgrounds for research. This Focus Session will present exciting developments in the study of electronic states that are based on the peculiar properties of $SrTiO_3$.

Please note that this Focus Session comprises four parts: Posters are presented within the TT poster session TT58 (Wed 15:00-18:00, poster area E). Invited talks are compiled in the session TT62 (Thursday, 9:30 to 12:45, H0104), Contributed talks will be presented in sessions TT72 (Thursday 15:00-18:00, H0104) and TT83 (Fri 9:30-12:30, H0104).

Organizers: Rossitza Pentcheva, University of Duisburg-Essen, Marc Scheffler, University of Stuttgart

Time: Thursday 15:00–18:00 Location: H 0104

TT 72.1 Thu 15:00 H 0104

Origin of unconventional normal-state transport and superconductivity in electron-doped $SrTiO_3$ — •Stephen Rowley — Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge, CB3 0HE, United Kingdom

Quantum phase transitions may be reached in many ferroelectric systems by supressing the Curie temperature to absolute zero using a control parameter such as chemical substitution or hydrostatic pressure. In electron-doped specimens of quantum critical ferroelectrics such as $SrTiO_3$, unconventional superconductivity and unusual normal-state transport have been detected. In the latter case, a resistivity varying as temperature-squared is observed over a wide range of temperatures above the Fermi temperature. We present new experimental and model results that provide insight into the nature of the mechanisms for both superconductivity and normal-sate transport. We find in experiments and quantitative models without adjustable parameters, that both effects are connected and enhanced in samples tuned to the ferroelectric quantum critical point. Superconductivity appears to arise near the critical point due to the virtual exchange of longitudinal hybrid-polar-modes, even in the absence of a direct coupling to the transverse-optical phonon modes.

TT 72.2 Thu 15:15 H 0104

Dilute superconductivity in the vicinity of a ferroelectric quantum critical point coupled via the "vector coupling": The case of $SrTiO_3$ — •Sudip Kumar Saha[1,2], Avraham Klein[1], Jonathan Ruhman[2], and Maria Navarro Gastiasoro[3] — [1]Ariel University, Israel — [2]Bar-Ilan University, Israel — [3]Donostia International Physics Center, Spain

Lightly doped $SrTiO_3$ (STO) is one of the most studied examples of quantum ferroelectric metal (QFEMs), where superconductivity coexists with ferroelectric order. Pristine STO is paraelectric naturally close to a ferroelectric quantum critical point (QCP). Strain or chemical substitution (for example, doping with Ba/Ca instead of Sr) drives STO through the QCP to the ferroelectric phase, which manifests itself in the softening of the transverse optical (TO) phonon mode. Doped samples are superconducting, where the T_c vs. density dome extends to very low density. To date, there is no consensus on the mechanism leading to superconductivity at such low density. Edge et al. have proposed that the ferroelectric QCP and dilute superconductivity are related [Phys. Rev. Lett. 115, 247002 (2015)]. In this work we explore the possible origin of low-density superconductivity from coupling linearly to the TO mode via a "vector coupling". We solve the critical-Eliashberg theory numerically, including fermionic and bosonic self-energy corrections, which allows us access all the way to the QCP. Notably, all our calculations are justified within standard approaches. We find the existence of a superconducting dome with magnitude and dependence on the distance from the QCP that resembles experiments.

TT 72.3 Thu 15:30 H 0104

Dislocation-based filamentary superconductivity in reduced $SrTiO_3$ — •Christian Rodenbücher[1], Gustav Bihlmayer[2], Carsten Korte[1], and Kristof Szot[3] — [1]Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK-14), 52425 Jülich, Germany — [2]Forschungszentrum Jülich GmbH, Peter Grünberg Institut (PGI-1), 52425 Jülich, Germany — [3]University of Silesia, Institute of Physics, 41-500 Chorzów, Poland

Exposure of $SrTiO_3$ single crystals to reducing conditions at elevated temperatures leads to the generation of metallic filaments forming along of dislocations, which act as preferential reduction sites. This effect can be enhanced when stimulating the local deoxidation by electric fields. This results in an agglomeration of metallic filaments in nano-bundles, which are embedded in the insulating surrounding crystal matrix. Despite removing only 10^{14-15} oxygen atoms from the dislocation network, electro-reduced crystals are superconducting with a transition temperature of 0.2 K, and their residual resistance is lower than that of purely thermally-reduced crystals. As the total amount of oxygen removed during electro-reduction is much smaller than the smallest reported carrier concentration for superconducting $SrTiO_{3-x}$ so far, our findings challenge traditional explanations of superconductivity in metal oxides. Combining conductivity characterization by atomic force microscopy with theoretical analysis of the dislocation cores, we propose a model explaining the superconducting properties by the coexistence of metallic dislocation cores with polar insulating regions allowing for polaronic coupling in the bundles.

TT 72.4 Thu 15:45 H 0104

Dislocation-Induced Photoconductivity Enhancement in Fe-Doped $SrTiO_3$: compensation of low mobility by high carrier density through the emergence of a sub-band gap level — •mehrzad soleimany[1,2], till frömling[1], jürgen rödel[1], and marin alexe[2] — [1]Department of Materials and Earth Sciences, Technical University of Darmstadt, Darmstadt, Germany — [2]Department of Physics, University of Warwick, Coventry, UK

Owing to the remarkable properties of $SrTiO_3$ (STO), such as quantum paraelectric state below 37 K, negative differential resistance under illumination, and significant alteration of properties by doping, STO stands out among perovskite oxides. Until recently, little attention had been paid to the tunability of its properties - especially optical properties -via the introduction of dislocations. In this study, we introduce the method of dislocation imprint, which allows us to induce high densities of dislocations ($> 1 \times 10^{14}$ m^{-2}) into a large volume of Fe-doped STO. Low-temperature I-V measurements indicated an about one order of magnitude increase in the photoconductivity of dislocation-rich samples. Photo-Hall measurements revealed that while dislocations might decrease the mobility, they could enhance the photoconductivity by increasing the number of carriers. Spectral responsivity measurements demonstrated that the higher carrier density could stem from the emergence of a sub-band gap level. Complementary C-AFM measurements conducted under illumination confirmed the local enhancement of photoconductivity at dislocations, which fitted well to the Electron Channeling Contrast Images of dislocations.

TT 72.5 Thu 16:00 H 0104

IR and THz studies on $(Ba_{0.45}Sr_{0.55}TiO_3)_{24}Ba_{0.45}Sr_{0.55}O$ and $(Ba_{0.45}Sr_{0.55}TiO_3)_8Ba_{0.45}Sr_{0.55}O$ thin films — Veronica Goian[1], Matthew Barone[2], Natalie Dawley[2], Christelle Kadlec[1], •Darrell Schlom[2,3], and Stanislav Kamba[1] — [1]Institute of Physics ASCR, Prague, Czech Republic — [2]Department of Materials Science and Engineering, Cornell University, Ithaca, NY, USA — [3]Kavli Institute at Cornell for Nanoscale Science, Ithaca, NY, USA

$(SrTiO_3)_nSrO$ and (n=1..6) films crystallizing in the Ruddlesdden-Popper (RP) structure are well known for low dielectric loss and large microwave permittivities which are highly tunable with electric field.[1,2] Bulk $(SrTiO_3)_nSrO$ is paraelectric, but the tensile strained thin films deposited on (110)$DyScO_3$ with n≥3, become ferroelectric at low temperatures. $(ATiO_3)_{24}AO$ and $(ATiO_3)_8AO$, A= $Ba_{0.45}Sr_{0.55}$ films deposited on (110)$DyScO_3$ exhibit no strain and yet become ferroelectric. Here we performed infrared and THz studies of phonon dynamics down to 10 K and compared it with above mentioned thin films and (Sr,Ba)TiO_3. The effect of soft mode and central mode on microwave dielectric properties and electric field tunability of permittivity will be discussed.

[1] C. H. Lee et al., Nature, 502 (2013) 532
[2] N. M. Dawley et al., Nat. Mater. 19 (2020) 176

TT 72.6 Thu 16:15 H 0104

Polar phonon behaviour in polycrystalline Bi-doped strontium titanate thin films — •Oleksandr Tkach[1], Olena Okhay[2], Dmitry Nuzhnyy[3], Jan Petzelt[3], and Paula M. Vilarinho[1] — [1]Department of Materials and Ceramic Engineering, CICECO, University of Aveiro, Aveiro, Portugal — [2]TEMA-Centre for Mechanical Technology and Automation, Department of Mechanical Engineering, University of Aveiro, Aveiro, Portugal — [3]Institute of Physics of the Czech Academy of Sciences, Prague, Czechia

Among strontium titanate (STO) based materials, Bi-doped STO have been intensively studied as for dielectric as for resistance-switching memory and thermoelectric applications. Here, we enhance the dielectric characterisation by a lattice dynamics study of sol-gel-derived $Sr_{1-1.5x}Bi_xTiO_3$ thin films with x = 0.0053 and 0.167, deposited on Al_2O_3 substrates, using a variable-temperature far-infrared spectroscopy in a transmittance mode. Bi doping, known to induce a low-frequency dielectric relaxation in STO ceramics and films, due to off-centre dopant ion displacements generating electric dipoles, is shown to affect the polar phonon behaviour of thin films. We show that in weakly Bi-doped films, the low-frequency polar TO1 mode softens on cooling but less than in undoped STO. In heavily Bi-doped STO films, this mode displays no significant frequency variation with temperature from 300 to 10 K. The polar phonon behaviour of polycrystalline Bi-doped STO thin films is comparable with that of Bi-doped STO ceramics, which exhibit dielectric relaxations and harden soft-mode behaviour instead of the ferroelectric phase transition.

15 min. break

TT 72.7 Thu 16:45 H 0104

Emergence of strain-Induced magnetism in plastically-deformed SrTiO3 at low temperature — •Anirban Kundu[1], Xi Wang[2], Avraham Klein[1], and Beena Kalisky[2] — [1]Department of Physics, Ariel University, Israel — [2]Institute of Nanotechnology & Advanced Materials, Bar-Ilan University, Israel

It is well established that SrTiO3 (STO) can possess ferroelectric states alongside observed superconducting states. However, so far, the phenomena of magnetism have not been established. In our collaborative work, in a plastically deformed bulk STO sample; SQUID measurements reveal strong magnetic signals which are completely absent in pristine samples. This strain-induced magnetism has two salient features. First, the magnetic moment is seen only with applied strain and increases with applied strain. Second, it also increases with temperature. Using Ginzberg Landau theory we show that these properties may be the result of coupling terms between strain, polar, and magnetic orders centered around dislocation walls induced by the plastic deformation. Our analysis implies that deformed STO is a quantum multiferroic.

TT 72.8 Thu 17:00 H 0104

Mobility in $SrTiO_3$ Mediated by Machine Learning Predicted Anharmonic Phonons — •Luigi Ranalli[1], Carla Verdi[2], and Cesare Franchini[1] — [1]University of Vienna, Vienna, Austria — [2]University of Queensland: Brisbane, Queensland, Australia

The anharmonic corrections to ionic motion play a crucial role in influencing the electron-phonon interaction, a phenomenon typically addressed through harmonic dynamical matrices at the ground state. By combining machine learning methodologies [1] and the stochastic self-consistent harmonic approximation [2], we achieve a precise depiction of the temperature-dependent evolution of phonon frequencies and the onset of ferroelectricity in the quantum paraelectric perovskites $SrTiO_3$ [3] and $KTaO_3$ [4]. In this presentation, anharmonic dynamical matrices are incorporated into the Boltzmann transport equation calculations for $SrTiO_3$ up to 300K using the EPW code [5] and fixing the derivatives of the Kohn-Sham potential computed through density functional perturbation theory [6]. This approach yields a coherent interaction vertex, ensuring that the temperature-dependent ferroelectric soft mode explains and recovers the observed trend in experimental mobility, akin to the behavior observed in $KTaO_3$.

[1] R. Jinnouchi et al., Phys. Rev. Lett. 122 (2019) 225701
[2] L. Monacelli et al., J. Phys.: Condens. Matter 33 (2021) 363001
[3] C. Verdi et al., Phys. Rev. Materials 7 (2023) L030801
[4] L. Ranalli et al., Adv. Quantum Technol. 6 (2023) 2200131
[5] H. Lee et al., 10.1038/s41578-021-00289-w (2023)
[6] J. Zhou et al., Phys. Rev. Research 1 (2019) 033138

TT 72.9 Thu 17:15 H 0104

Machine-learning-backed evolutionary exploration of the $SrTiO_3(110)$ surface phase diagram — •Ralf Wanzenböck[1], Florian Buchner[1], Michele Riva[2], Jesús Carrete[3,1], and Georg K. H. Madsen[1] — [1]Institute of Materials Chemistry, TU Wien, A-1060 Vienna, Austria — [2]Institute of Applied Physics, TU Wien, A-1040 Vienna, Austria — [3]Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, 50009 Zaragoza, Spain

We use Clinamen2, a modern functional-style Python implementation of the covariance matrix adaptation evolution strategy (CMA-ES), to gain insights into the lesser-known regions of the complex $SrTiO_3(110)$ surface phase diagram. To speed up the process, we leverage the transferability of a neural-network force field (NNFF) implemented on top of the state-of-the-art JAX framework.

Starting from smaller reconstructions in well-explored phases, such as the 4×1 surface reconstruction [Wanzenböck et al., Digit Discov 1, 703-710 (2022)], the NNFF is iteratively refined using an active learning workflow that relies on uncertainty estimation techniques [Carrete et al., J. Chem. Phys 158, 204801 (2023)]. We show how this workflow and the underlying uncertainty metric lead to a flexible NNFF, highlighted by the exploration of out-of-sample $SrTiO_3(110)$-$(2 \times n)$ reconstructions.

TT 72.10 Thu 17:30 H 0104

Quasiparticle and excitonic properties of monolayer $SrTiO_3$ — •Lorenzo Varrassi[1], Peitao Liu[2], and Cesare Franchini[1,3] — [1]Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna — [2]Shenyang National Laboratory for Materials Science, Institute of Metal Research — [3]University of Vienna, Faculty of Physics and Center for Computational Materials Science, Vienna.

Recently, a breakthrough has been achieved with the synthesis of freestanding $SrTiO_3$ ultrathin films down to the monolayer limit[1]; its optical and excitonic properties remain however largely unexplored. This talk will provide insights on the quasiparticle and excitonic properties of monolayer $SrTiO_3$, employing many-body perturbation theory.

Our analysis[2] emphasizes the need to go beyond the diagonal GW approximation and include off-diagonal self-energy elements in order to obtain correct description of the orbital hybridizations. A fully satisfying description is achieved by treating non-locality in both exchange and correlation.

The optical properties are studied through the solution of the Bethe-Salpeter equation. We observe a significant enhancement of the excitonic effects with respect to the bulk phase, with a binding energy at the optical gap about four times greater. Furthermore, the two-dimensional polarizability at the long wavelength limit is dominated by two strongly bound excitonic peaks; their character is determined through the analysis of the excitonic wavefunctions.

[1] D. Ji et al., Nature 570 (2019) 87
[2] L. Varrassi et al., arxive:2303.14830 (2023)

TT 72.11 Thu 17:45 H 0104

$SrTiO_3$: Thoroughly investigated but still good for surprises — •Annette Bussmann-Holder[1], Reinhard K. Kremer[1], Krystian Roleder[2], and Ekhard K. H. Salje[3] — [1]Max-Planck-Institute for Solid State Research, Heisenbergstr. 1, D-70569 Stuttgart, Germany — [2]Institute of Physics, University of Silesia, ul. 75 Pułku Piechoty 1, 41-500 Chorzów, Poland — [3]Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, United Kingdom

For decades $SrTiO_3$ is in the focus of research with seemingly neverending new insights regarding its ground state properties, its application potentials, its surface and interface properties, the superconducting state, the twin boundaries and domain functionalities, etc. Here, we focus on the already well-investigated lattice dynamics of STO and show that four different temperature regimes can be identified which dominate the elastic properties, the thermal conductivity and the birefringence. These regimes are the low-temperature quantum fluctuation dominated one, followed by an intermediate regime, the region of the structural phase transition at 105 K and its vicinity, and at high temperatures a regime characterized by precursor and saturation effects. They can all be elucidated by lattice dynamical aspects. The relevant temperature dependencies of the soft modes are discussed and their relationship to lattice polarizability is emphasized.

TT 73: Superconducting Electronics: Qubits II (joint session TT/QI)

Time: Thursday 15:00–16:15 Location: H 2053

TT 73.1 Thu 15:00 H 2053

Frequency-conversion loss in three-wave-mixing traveling-wave parametric amplifiers — •Christoph Kissling, Victor Gaydamachenko, Marat Khabipov, Alexander B. Zorin, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Traveling-Wave Parametric Amplifiers (TWPAs) enable near-quantum-limited amplification of weak microwave signals with several GHz bandwidths and saturation powers above -100 dBm. One aspect of current research is the reduction of microwave loss in TWPAs, which is seen as one reason why the added noise of TWPAs stays repeatedly above the quantum limit. Typically, most of the microwave loss is attributed to lossy dielectric layers. However, in this talk we address another loss mechanism which can occur in three-wave-mixing TWPAs. We discuss how frequency-conversion of a probe tone by the presence of noise in the kHz to MHz range can dominate the insertion loss. This potentially-overlooked nonlinear loss mechanism appears like linear loss and can therefore lead to false conclusions in the characterization and optimization of TWPAs.

TT 73.2 Thu 15:15 H 2053

Generating on-chip ac radiation for high impedance electronics — •David Scheer and Fabian Hassler — Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany

Superconducting circuits with high impedances have promising applications in qubit design and quantum metrology. It is however difficult to supply external ac signals to a high impedance environment due to impedance mismatching and parasitic capacitances. The ac Josephson effect can provide a solution to this problem since it generates oscillating currents from an external dc bias. Here we present the use of Josephson junctions as an on chip radiation source as a way to avoid external driving of high impedance circuits.

TT 73.3 Thu 15:30 H 2053

High-impedance resonators based on granular aluminum — •Mahya Khorramshahi, Martin Spiecker, Patrick Paluch, Ritika Dhundhwal, Nicolas Zapata, Ioan M. Pop, and Thomas Reisinger — Karlsruhe Institute of Technology, Karlsruhe, Germany

High-impedance resonators in superconducting quantum circuits are important in the advancement of quantum computing technologies. In particular, impedances surpassing the resistance quantum can be realized, enabling the development of protected qubits and strong coupling to small-dipole-moment systems with exciting prospects for interfacing to spin qubits or donor spins. Utilizing granular aluminum (GrAl), we have developed compact resonators operating in the few GHz regime and characteristic impedances as high as 80 kOhm. We characterized the resonators, with GrAl resistivity increasingly close to the superconducting to insulating transition, and report on single photon quality factors, non-linearity, and noise-spectral density.

TT 73.4 Thu 15:45 H 2053

Longitudinal coupling between a molecular spin ensemble and a superconducting resonator — •Simon Günzler[1,2], Dennis Rieger[2], Thomas Koch[2], Kiril Borisov[2], Patrick Winkel[2], Grigore Timco[3], Richard E.P. Winpenny[3], Ioan M. Pop[1,2], and Wolfgang Wernsdorfer[1,2] — [1]IQMT, Karlsruhe Institute of Technology, Germany — [2]PHI, Karlsruhe Institute of Technology, Germany — [3]PSI and School of Chemistry, The University of Manchester, UK

Hybrid quantum architectures coupling electronic spin ensembles to superconducting circuits have advanced remarkably in the past decade. So far, however, they rely on transverse coupling schemes, tuning the spin transition in close proximity to the circuit's frequency. Here, we demonstrate longitudinal coupling between spins in a microcrystal of Cr_7Ni and the kinetic inductance of a granular aluminum superconducting microwave resonator. Remarkably, this enables the measurement of the crystal's magnetization independent of the detuning between the spin and resonator mode. Separate resonators fabricated from niobium on the same chip allow us to excite and measure the relaxation of the spins more than 2 GHz detuned from the readout resonator.

TT 73.5 Thu 16:00 H 2053

Fermionic quantum computation with Cooper pair splitters — Kostas Vilkelis[1,2], •Antonio Manesco[2], Juan Daniel Torres Luna[1,2], Sebastian Miles[1,2], Michael Wimmer[1,2], and Anton Akhmerov[2] — [1]Qutech, Delft University of Technology, Delft 2600 GA, The Netherlands — [2]Kavli Institute of Nanoscience, Delft University of Technology, Delft 2600 GA, The Netherlands

We propose a practical implementation of a universal quantum computer that uses local fermionic modes (LFM) rather than qubits. Our design consists of quantum dots tunnel coupled by a hybrid superconducting island together with a tunable capacitive coupling between the dots. We show that coherent control of Cooper pair splitting, elastic cotunneling, and Coulomb interactions allows us to implement the universal set of quantum gates defined by Bravyi and Kitaev. Finally, we discuss possible limitations of the device and list necessary experimental efforts to overcome them.

TT 74: Topological Insulators

Time: Thursday 15:00–18:00 Location: H 3005

TT 74.1 Thu 15:00 H 3005

Gapped Dirac cones in thin film topological insulator — •Alireza Akbari[1] and Peter Thalmeier[2] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44801 Bochum, Germany — [2]Max Planck Institute for the Chemical Physics of Solids, 01187 Dresden, Germany

Topological insulators (TIs) have gapless Dirac cones with helical spin polarization in their surface states. Warping introduces snowflake Fermi surfaces, observed in materials like Bi_2Se_3 and Bi_2Te_3 . Quasiparticle interference (QPI) experiments on isolated TI surfaces reveal distinct features. In thin film geometries with finite tunneling between surface states, the QPI spectrum undergoes significant changes, leading to gap formation and altered spin texture. We explore variations with film thickness and their impact on backscattering processes. Introducing a step in the TI film, achieved by profiling the substrate, results in one-dimensional bound states within the hybridization gap. In an s-wave superconductor substrate, Majorana zero modes appear at step ends within the superconducting gap. Thus this simple configuration of a stepped interface between a superconductor and a TI may host Majorana zero modes effectively.

[1] Phys. Rev. Research 2 (2020) 033002.
[2] Phys. Rev. B 104 (2021) 184511.

TT 74.2 Thu 15:15 H 3005

Topological Green's function zeros — Steffen Bollmann[1], Chandan Setty[2], Urban Seifert[3], and •Elio König[1] — [1]Max-Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]Department of Physics and Astronomy, Rice Center for Quantum Materials, Rice University, Houston, Texas 77005, USA — [3]Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA

The interplay of topology and strong correlations manifests itself in a plethora of exotic phenomena. Specifically, topological bands of Green's function zeros have recently attracted substantial interest. Here, we present an analytically tractable model displaying such topological bands of zeros in the fermionic Green's function when the system is tuned to a topologically ordered phase. We further demonstrate the existence of "edge states" of zeros and discuss their experimental implications, in particular when proximitized to edge states of non-interacting topological insulators. If time permits, we will also discuss transport signatures.

TT 74.3 Thu 15:30 H 3005

Nonreciprocal charge transport in nanowires of MBE-grown topological insulator /superconductor heterostructure — •Roozbeh Yazdanpanah, Jens Brede, Alexey Taskin, and Yoichi Ando — University of Cologne, Cologne, Germany

In systems with broken inversion and time reversal symmetry, magnetochiral anisotropy (MCA) leads to such nonreciprocal transport which depends both on the current amplitude and the applied magnetic field. The MCA effect in gated nanowires of a topological insulator (TI) leads to considerable current nonreciprocity[1]. Additionally, the MCA in a superconductor (SC) in the fluctuation regime also results in nonreciprocal effects, which is also the case for stacks of TI/SC[2]. We studied the combination of these two effects. For this purpose, thin films of $(Bi_{1-x}Sb_x)_2Te_3$ on $PdTe_2$ were grown in an MBE chamber and nanowires of different widths were fabricated. Second harmonics measurements were performed to study the nonreciprocal charge transport in these nanowires. A clear enhancement of the MCA was observed in a nanowire with 100-nm width even without gating.

[1] H.F. Legg et al., Nat. Nanotechnol. 17 (2022) 696.
[2] M. Masuko et al., npj Quantum Materials 7 (2022) 104.

TT 74.4 Thu 15:45 H 3005

Optical spectroscopy study of the magnetic topological insulators $Mn(Bi_{1-x}Sb_x)_2Te_4$ at ambient and high pressure — •M. Köpf[1], S. H. Lee[2,3], Z. Q. Mao[2,3,4], and C. A. Kuntscher[1] — [1]Experimentalphysik II, Institute of Physics, Augsburg University, 86159 Augsburg, Germany — [2]2D Crystal Consortium, Materials Research Institute, Pennsylvania State University, University Park, Pennsylvania 16802, USA — [3]Department of Physics, Pennsylvania State University, University Park, Pennsylvania 16802, USA — [4]Department of Materials Science and Engineering, Pennsylvania State University, University Park, Pennsylvania 16802, USA

The magnetic topological insulator $MnBi_2Te_4$ and the related materials $Mn(Bi_{1-x}Sb_x)_2Te_4$ are promising candidates for the realization of rare quantum mechanical effects due to the coexistence of topological surface states and magnetic ordering. We studied the optical response of $Mn(Bi_{1-x}Sb_x)_2Te_4$ with various Sb doping levels x at ambient and under hydrostatic pressure. Both Sb doping and pressure application cause strong effects on the electronic band structure, strongly influencing the free charge carrier dynamics, according to infrared reflectivity measurements. In the Sb-doped compounds the metallic strength decreases from x=0 to x=0.26, followed by an increase for higher x. Under hydrostatic pressure, $MnBi_2Te_4$ and the least metallic material $Mn(Bi_{0.74}Sb_{0.26})_2Te_4$ (x=0.26) show an unusual decrease in metallic character up to ∼10 GPa.

TT 74.5 Thu 16:00 H 3005

Finite Size Effects in Magnetic Topological Insulators — •Joe Winter[1,2], Bernd Braunecker[2], and Ashley Cook[1] — [1]MPI PKS 38 Nöthnitzer Straße 01187 Dresden German — [2]School of Physics and Astronomy, North Haugh, St Andrews KY16 9SS

The antiferromagnetic topological insulator phase is a foundational realization of three- dimensional topological phases of matter with magnetic order. Experimental evidence of the axion insulator phase in MnBi2Te4 for thin-film samples, a quasi-(3-1)-dimensional (q(3-1)D) geometry, therefore motivates investigation of finite-size topo- logical (FST) phases derived from the axion insulator phase. Here, we show the AFM TI does realize finite-size topological phases for the q(3-1)D geometry, with open-boundary conditions and small system size in one direction. We first characterize the FST phase diagram in the q(3-1)D bulk using Wannier spectral flow. We also confirm the defining response signature of the underly- ing 3D AFM TI phase, due to the topologically non-trivial magnetoelectric polarizability, persists in this geometry but only for the topologically non-trivial finite-size topological regions. We then open boundary conditions in a second direction to confirm the additional bulk-boundary corre- spondence of the finite-size topological phases, finding q(3-2)D topologically-protected, gapless edge modes. The co-existence of the q(3-2)D topologically nontrivial edge states with a topological response associated with the 3D bulk topological invariant, the magnetoelectric polarizability, further demonstrates that finite-size topology is a generic feature of topological phases and very relevant experimentally.

TT 74.6 Thu 16:15 H 3005

Magnetic Topological Transistor — •Hai-Peng Sun[1,5], Chang-An Li[1,5], Sang-Jun Choi[1,5], Song-Bo Zhang[2], Hai-Zhou Lu[3,4], and Björn Trauzettel[1,5] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg 97074, Germany — [2]Department of Physics, University of Zürich, Winterthurerstrasse 190, Zürich 8057, Switzerland — [3]Shenzhen Institute for Quantum Science and Engineering and Department of Physics, Southern University of Science and Technology (SUSTech), Shenzhen 518055, China — [4]Shenzhen Key Laboratory of Quantum Science and Engineering, Shenzhen 518055, China — [5]Würzburg-Dresden Cluster of Excellence ct.qmat, Germany

We propose a magnetic topological transistor based on MnBi2Te4, in which the "on" state (quantized conductance) and the "off" state (zero conductance) can be easily switched by changing the relative direction of two adjacent electric fields (parallel vs. antiparallel) applied within a two-terminal junction. We explain that the proposed magnetic topological transistor relies on a novel mechanism due to the interplay of topology, magnetism, and layer degrees of freedom in MnBi2Te4. Its performance depends substantially on film thickness and type of magnetic order. We show that "on" and "off" states of the transistor are robust against disorder due to the topological nature of the surface states. Our work opens an avenue for applications of layer-selective transport based on the topological van der Waals antiferromagnet MnBi2Te4.

15 min. break

TT 74.7 Thu 16:45 H 3005

Topological-insulator spin transistor — •Linh T. Dang[1], Oliver Breunig[1], Zhiwei Wang[1,3], Henry F. Legg[2], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne, D-50937 Köln, Germany — [2]Department of Physics, University of Basel, CH-4056 Basel, Switzerland — [3]School of Physics, Beijing Institute of Technology, Beijing 100081, China

A net spin polarization can be induced by injecting charge current into the spin-momentum-locked surface state of topological insulators (TIs). Due to the helical spin structure of this surface state, only one sign of spin polarization is expected from a fixed current direction. However, both signs that agree and disagree with this prediction have been observed in the past. Although the origin of the opposite sign is unclear, it suggests that the spin polarization can be switched from one sign to the other. In this talk, we report our experiment in which we observed both signs of spin polarization in the same device at different back-gate voltages, which demonstrates the ability to switch between the two signs by electrostatic gating; which gives a proof of principle of a spin transistor based on TI [1]. We observed a complicated switching behaviour which can be explained by a minimal model taking into account the competing contributions of the topological surface state and trivial Rashba-split bands.

[1] L. T. Dang, O. Breunig, Z. Wang, H. F. Legg, Y. Ando, Phys. Rev. Appl. 20 (2023) 024065.

TT 74.8 Thu 17:00 H 3005

Structure-driven phase transitions in paracrystalline topological insulators — Victor Regis[1], Victor Velasco[2], Marcello Silva Neto[2,3], and •Caio Lewenkopf[4] — [1]Jožef Stefan Institute, Ljubljana, Slovenia — [2]Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil — [3]Laboratório Nacional de Nanotecnologia - CNPEM, Campinas, Brazil — [4]Instituto de Física, Universidade Federal Fluminense, Niterói, Brazil

We study phase transitions driven by structural disorder in noncrystalline topological insulators. We use a procedural generation algorithm, the Perlin noise, typically used in computer graphics, to introduce disorder in a two-dimensional lattice, allowing a continuous interpolation between a pristine and a random gas system, going through all different intermediate structural regimes, such as the paracrystalline and the amorphous phases. We apply a two-band model, including intraorbital and interorbital mixings, to the structures generated by the algorithm and we find a sequence of structure-driven topological phase transitions characterized by changes in the topological Bott index, at which the insulating gap dynamically closes while evolving from the Bragg planes of the Brillouin zone towards the center. We interpret our results within the framework of Hosemann's paracrystal theory, according to which distortion is included in the lattice structure factor and renormalizes the band-splitting parameter. Based on these results, we ultimately demonstrate the phenomenon of topological protection at its extreme.

TT 74.9 Thu 17:15 H 3005

Physical consequence of edge zeros in topological Mott in-

sulators — •Niklas Wagner[1], Daniele Guerci[2], Andrew J. Millis[2,3], and Giorgio Sangiovanni[1] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, 97074 Würzburg, Germany — [2]Center for Computational Quantum Physics, Flatiron Institute, New York, USA — [3]Department of Physics, Columbia University, New York, USA

Recently, Green's function zeros and their relation to topology have attracted considerable interest [1-4]. Using slave-rotor calculations I will demonstrate a connection between gapless zeros and gapless spinons – both in the bulk and at the boundary. I will then apply these results to interfaces between topological insulators and topological Mott insulators, showing that the previously observed annihilation of edge zeros and egde poles [4] can be interpreted using the spinon language. This approach reveals the occurance of a spin-charge separation at the interface.

[1] A. Blason and M. Fabrizio, arxiv:2304.08180(2023)
[2] J. Zhao, P. Mai, B. Bradlyn, P. Phillips, arXiv:2305.02341 (2023)
[3] C. Setty et al., arXiv:2309.14340 (2023)
[4] N.Wagner et al., Nat. Commun. 14, 7531 (2023)

TT 74.10 Thu 17:30 H 3005

A gate-tunable bosonic Su-Schrieffer-Heeger chain — •Lukas Johannes Splitthoff[1,2], Miguel Carrera Belo[1,2], Guliuxin Jin[2], Eliska Greplova[2], and Christian Kraglund Andersen[1,2] — [1]QuTech, Delft University of Technology, Delft 2628 CJ, The Netherlands — [2]Kavli Institute for Nanoscience, Delft University of Technology, Delft 2628 CJ, The Netherlands

Metamaterials engineered to host topological states of matter in controllable quantum systems hold promise for quantum simulations and the advancement of quantum computing technologies. In this context, the Su-Schrieffer-Heeger (SSH) chain, a textbook example of topological matter, has gained prominence due to its simplicity and practical applications, including entanglement stabilization in superconducting quantum circuits. In this talk, we present the implementation of a five-unit-cell bosonic SSH chain on a one-dimensional lattice of superconducting resonators. Our approach offers precise and independent in-situ tuning of coupling parameters a feature that has eluded previous work. We achieve electrostatic control over the inductive intercell coupling using semiconductor nanowire junctions, which enables the spectroscopic observation of a trivial-to-topological phase transition in the engineered topological metamaterial. In particular, we will discuss the robustness of the topological edge state against various disorder realizations, including local perturbations and noise originating from electrostatic gate control. Our results pave the way for larger controllable bosonic lattices to facilitate quantum simulations.

TT 74.11 Thu 17:45 H 3005

Transport channels in the two-dimensional, Floquet-driven Qi-Wu-Zhang model — •Aya Abouelela[1], Haixin Qiu[2], and Johann Kroha[1,3] — [1]Universität Bonn, Germany — [2]Georg August Universität Göttingen, Germany — [3]University of St. Andrews, U.K

This presentation explores the realm of topological phases, with a specific focus on topological insulators and their edge states. Over the past decade, the field has witnessed rapid developments in the external drive of these systems, with periodically driven or Floquet systems standing out for their ability to induce diverse topological phases through a seemingly simple dynamical control. Our talk centers on anomalous Floquet topological phases within a hopping-driven Qi-Wu-Zhang model. We showcase the impact of drive parameters such as amplitude, frequency, and on-site potential on band Chern numbers, unveiling the emergence of anomalous edge states. Utilizing Chern number phase diagrams, we present edge states with vanishing dynamical winding numbers or Chern numbers. Additionally, we propose experimentally realizable slab geometry of our model with finite bias voltage and predict dI/dV spectroscopy exhibiting quantized transport carried by the zero and anomalous modes. Finally, we map out the spatial structure of the transport channels and highlight the transmission along the system's physical edge. Notably, the slab geometry exhibits corner sites with a high density of states, which may originate from higher order corner states.

TT 75: Low Dimensional Systems

Time: Thursday 15:00–17:45 Location: H 3007

TT 75.1 Thu 15:00 H 3007

First-order electronic phase transition in α-(BEDT-TTF)$_2$I$_3$ revealed by temperature-dependent generalized ellipsometry — •Achyut Tiwari, Bruno Gompf, Dieter Schweitzer, and Martin Dressel — Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

The nature of correlation-driven metal-insulator transitions remains a longstanding puzzle in solid-state physics. While some theories suggest a second-order character, various experimental observations in these materials indicate first-order phase transitions. Despite considerable progress over the last decades in understanding the underlying driving mechanisms of metal-insulator transitions, in particular the phase coexistence remains poorly understood on a microscopic scale. Here, we employ Mueller matrix spectroscopic and temperature-dependent ellipsometry to determine the anisotropic dielectric functions of the two-dimensional charge-transfer salt α-(BEDT-TTF)$_2$I$_3$ across its charge-order metal-insulator transition. Our results offer valuable insights into temperature-dependent changes of the dielectric functions along the different crystallographic axes. Furthermore, we apply an effective-medium approximation to quantify the correlation between the metal-to-insulator transition and the volume fraction of the metallic phase embedded within the insulating phase. Through this comprehensive approach, generalized ellipsometry unravels the nature of the correlation-driven metal-insulator transition.

TT 75.2 Thu 15:15 H 3007

Quantum spin dynamics across field-induced phase transitions in the spin-chain compound $Cu_2(OH)_3Br$ — •Anneke Reinold[1], Kirill Amelin[2], Zhiying Zhao[3], Changqing Zhu[1], Patrick Pilch[1], Hans Engelkamp[4], Toomas Rõõm[2], Urmas Nagel[2], and Zhe Wang[1] — [1]TU Dortmund University, Germany — [2]National Institute of Chemical Physics and Biophysics, Tallinn, Estonia — [3]Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou, China — [4]Radboud University, Nijmegen, The Netherlands

In low-dimensional quantum magnets, exotic magnetic phenomena can emerge due to strong spin fluctuations. Here we investigate quantum spin dynamics of the spin-1/2 chain compound $Cu_2(OH)_3Br$ by high-resolution terahertz spectroscopy as a function of temperature and in high magnetic fields. Below a Néel temperature of $T_N = 9.3\,K$, this compound exhibits a unique magnetic structure consisting of alternating ferromagnetically and antiferromagnetically aligned chains of Cu^{2+} spins. In this ordered phase we observe magnetic excitations, which are characteristic for this unique spin structure and consistent with previous results of inelastic neutron scattering experiments. Crossing a field-induced quantum phase transition, we reveal different characteristics of spin dynamics for the high-field phase.

TT 75.3 Thu 15:30 H 3007

Temperature-dependence of 2D electron transport in presence of different scattering mechanisms — •Philipp Heilmann[1] and Björn Trauzettel[1,2] — [1]Institute of Theoretical and Astrophysics, University of Würzburg, Germanny — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Germany

We examine 2D electron transport through a long narrow channel driven by an external electric field in presence of diffusive boundary scattering. At zero temperature, electron scattering leads to a transition from the ballistic to the diffusive regime with characteristic current density profiles. At finite temperature, the phase space for transport and particle scattering is enlarged. We study the influence of finite temperature on current densities and average current in this system. We are particularly interested in temperature-dependent scattering, for instance, electron-electron scattering, and its observable signatures.

TT 75.4 Thu 15:45 H 3007

Mean-field theory for the thermodynamics of quantum spin systems — •Andreas Honecker — Laboratoire de Physique Théorique et Modélisation, CNRS UMR 8089, CY Cergy Paris Uni-

versité, France

Many quantum-spin compounds realize a complex –typically higher-dimensional– exchange geometry. This poses a challenge for the theoretical description of their thermodynamic properties. Mean-field theory suggests itself as a flexible tool in this context. However, accuracy of simple single-site mean-field theory turns out to be disappointing for certain antiferromagnetic compounds with a low saturation field that are of potential interest for adiabatic demagnetization refrigeration [1]. We therefore revisit the mean-field approximation for the thermodynamic properties of the spin-1/2 Heisenberg ferro- and antiferromagnets on prototypical lattices such as the square, triangular, and simple cubic ones and benchmark it against numerical results obtained by quantum Monte Carlo simulations and exact diagonalization. We also discuss perspectives for improving the accuracy of mean-field methods.

[1] M. Tiwari, *Mean-Field Theory for Quantum Spin Systems and the Magnetocaloric Effect*, Ph.D. thesis, CY Cergy Paris Université (2022)

TT 75.5 Thu 16:00 H 3007

Fractional spin excitations and conductance in the spiral staircase Heisenberg ladder — •Flavio Ronetti[1,2], Daniel Loss[2], and Jelena Klinovaja[2] — [1]Aix-Marseille Univ, Université de Toulon, CNRS, CPT, Marseille, France — [2]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

In this talk, we present some theoretical investigation of the spiral staircase Heienberg spin-1/2 ladder in the presence of antiferromagnetic long-range spin interactions and a uniform magnetic field. If the magnetizations of the two chains forming the ladder satisfy a certain resonance condition, involving interchain couplings as perturbations, the system is in a partially gapped magnetic phase hosting excitations characterized by fractional spins, whose values can be changed by the magnetic field. We obtain our results with the help of bosonization and numerical density matrix renormalization group methods.

TT 75.6 Thu 16:15 H 3007

All product eigenstates in Heisenberg models from a graphical construction — •Felix Gerken[1,2], Ingo Runkel[3], Christoph Schweigert[3], and Thore Posske[1,2] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [3]Fachbereich Mathematik, Universität Hamburg, Germany

Recently, large degeneracy based on product eigenstates has been found in spin ladders, Kagome-like lattices, and motif magnetism, connected to spin liquids, anyonic phases, and quantum scars. In this talk, we present a unified description of these systems by a complete classification of product eigenstates of Heisenberg XXZ Hamiltonians with Dzyaloshinskii-Moriya interaction on general graphs in the form of Kirchhoff rules for spin supercurrent. The Kirchhoff rules imply a graphical construction procedure for a yet unknown class of potentially strongly, in some cases even extensively, degenerate spin models. The algebraic problem of determining the degeneracy is translated into a graph-theoretic problem. Thus, we find an intriguing connection between graph topology, degeneracy and entanglement. Further, there are hints that the degeneracy is linked to exotic condensates which could be studied in atomic gases and quantum spin lattices.

[1] F. Gerken, I. Runkel, C. Schweigert, T. Posske, arXiv:2310.13158 (2023)

15 min. break

TT 75.7 Thu 16:45 H 3007

Tuneable band topology and non-reciprocal response in 2D altermagnets — •Peng Rao[1], Alexander Mook[2], and Johannes Knolle[1,3,4] — [1]Department of Physics, Technische Universität München, Garching, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, Mainz, Germany — [3]Blackett Laboratory, Imperial College London, London, United Kingdom — [4]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Non-reciprocal response due to time-reversal-symmetry (TRS) breaking in condensed matter platforms is an active field of research with broad theoretical and experimental interests, due to its application in building electrical devices, i.e. quantum circulators. In this work, we study the optical response of a newly proposed class of TRS-breaking materials called 'altermagnets', where TRS is broken by collinear antiferromagnetic order. Unlike usual antiferromagnets, in an altermagnetic metal (i.e. RuO_2) the spin-polarized Fermi surfaces are split by the order of the Fermi energy, exhibiting strong TRS breaking in its electronic properties. We first consider the altermagnet bandstructure and band topology using a 2D band Hamiltonian with spin-orbit coupling and magnetic field. We then investigate the non-reciprocal optical response by computing the optical conductivity tensor and anomalous Hall response. In particular, we estimate the Faraday angle using parameters that are quantitatively correct for RuO_2.

TT 75.8 Thu 17:00 H 3007

Thermal Hall transport in Semi-classical Magnets — •Ignacio Salgado-Linares[1,2], Alexander Mook[3], and Johannes Knolle[1,2] — [1]Physics Department, TUM School of Natural Sciences, Technical University of Munich, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany

In recent years, the thermal Hall effect has emerged as a powerful tool for probing topological phenomena of magnetic systems. At low temperatures, the thermal Hall transport of long-range ordered magnets can be described in the framework of linear spin-wave theory (LSWT). However, how to treat regimes with increased thermal fluctuations or non-linearities beyond LSWT is an outstanding question. Therefore, within this project, we developed a novel numerical technique to extract the thermal Hall transport properties, which intrinsically includes non-linear effects. In particular, we use semi-classical spin dynamics simulations to compute topological thermal edge currents in the Kitaev honeycomb model on a cylinder geometry. The results are expected to shed new light on the topological thermal transport in Kitaev spin liquid candidate materials.

TT 75.9 Thu 17:15 H 3007

Characterizing the entanglement of mixed states in anyonic systems — •Nico Kirchner[1,2], Wonjune Choi[1,2], and Frank Pollmann[1,2] — [1]Technical University of Munich — [2]Munich Center for Quantum Science and Technology (MCQST)

Entanglement of mixed quantum states can be quantified using the so-called partial transpose and its corresponding entanglement measure, the logarithmic negativity. Recently, the notion of partial transpose has been extended to systems of anyons, which are exotic quasiparticles whose exchange statistics go beyond the bosonic and fermionic case. Studying the fundamental properties of this anyonic partial transpose for non-abelian anyons and the bipartition geometry, we find a rich multiplet structure in the eigenvalues of the partial transpose, the so-called negativity spectrum, and reveal the possiblity of defining both a charge- and an imbalance-resolved logarithmic negativity. Focusing on low-energy properties, we find that the anyonic partial transpose captures both the correct entanglement scaling for gapless systems, as predicted by conformal field theory, and the phase transition between a topologically trivial and a nontrivial phase.

TT 75.10 Thu 17:30 H 3007

Current-phase relation in Fibonacci Josephson junctions — •Ignacio Sardinero[1], Jorge Cayao[2], Keiji Yada[3], Yukio Tanaka[3], and Pablo Burset[1] — [1]Department of Theoretical Condensed Matter Physics, Condensed Matter Physics Center (IFIMAC) and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain — [2]Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden — [3]Department of Applied Physics, Nagoya University, Nagoya 464-8603, Japan

Quasicrystals (QCs), lattices displaying long-range order without translational periodicity, have been shown to be topologically nontrivial. They feature energy gaps linked to topological invariants, harboring edge modes under specific conditions. The Fibonacci quasicrystal (FQC), a prototypical example of a one-dimensional QC, comprises an aperiodic sequence of two alternating parameters. We consider Josephson junctions where superconductors with a finite phase difference are subjected to chemical potentials arranged in a Fibonacci sequence. The FQC arrangement, which may be implemented using local gates, introduces gaps and edge modes above the superconducting energy gap. We show that these edge modes develop superconducting correlations, with an intriguing dependence on the superconducting phase difference. This effect gives rise to a finite Josephson current which can even dominate the contribution from common Andreev states. The interplay between FQCs and the Josephson effect opens up new avenues for exploring exotic phenomena with important consequences in topological superconductivity.

TT 76: Superconductivity: Tunnelling and Josephson Junctions II

Time: Thursday 15:00–17:45 Location: H 3010

TT 76.1 Thu 15:00 H 3010

Chiral adiabatic transmission protected by Fermi surface topology — Isidora Araya Day[1,2], •Kostas Vilkelis[1,2], Antonio Lucas Rigotti Manesco[2], Ahmet Mert Bozkurt[1,2], Valla Fatemi[3], and Anton Akhmerov[2] — [1]QuTech, Delft University of Technology, Delft 2600 GA, The Netherlands — [2]Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 4056, 2600 GA Delft, The Netherlands — [3]School of Applied and Engineering Physics, Cornell University, Ithaca, NY 14853 USA

We demonstrate that Andreev modes that propagate along a transparent Josephson junction have a perfect transmission at the point where three junctions meet. The chirality and the number of quantized transmission channels is determined by the topology of the Fermi surface and the vorticity of the superconducting phase differences at the trijunction. We explain this chiral adiabatic transmission (CAT) as a consequence of the adiabatic evolution of the scattering modes both in momentum and real space. We identify an effective energy barrier that guarantees quantized transmission. We expect that CAT is observable in nonlocal conductance and thermal transport measurements. Furthermore, because it does not rely on particle-hole symmetry, CAT is also possible to observe directly in metamaterials.

TT 76.2 Thu 15:15 H 3010

Magnetization dynamics and Peierls instability in topologicalJosephson structures — •Adrian Reich[1], Erez Berg[2], Jörg Schmalian[1,3], and Alexander Shnirman[1,3] — [1]Institute for Theoretical Condensed Matter Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Department of Condensed Matter Physics, Weizmann Insitute of Science, Rehovot 76100, Israel — [3]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany

We study a long topological Josephson junction with a ferromagnetic strip between two superconductors. The low-energy theory exhibits a nonlocal in time and space interaction between chiral Majorana fermions, mediated by the magnonic excitations in the ferromagnet. We show that sufficiently strong and long-ranged interactions may induce a Z_2-symmetry breaking, leading to a tilting of the magnetization and the opening of a fermionic gap, analogous to the Peierls instability in the commensurate Fröhlich model. Within a Gaussian fluctuation analysis, we estimate critical values for the temporal and spatial nonlocality of the interaction, beyond which the symmetry breaking is stable at zero temperature. We compare these results with a renormalization group analysis of closely related models and conclude that nonlocality, i.e., the stiffness of the magnetization in space and time, stabilizes the symmetry breaking. In the stabilized regime, we expect the current-phase relation to exhibit an experimentally accessible discontinuous jump. At nonzero temperatures, the long-range order is destroyed by solitons, which in our case carry each a Majorana zero mode.

TT 76.3 Thu 15:30 H 3010

Quartet Tomography in Multiterminal Josephson Junctions — •David Christian Ohnmacht[1], Marco Coraiola[2], Juan Jose García-Esteban[1,3], Deividas Sabonis[2], Fabrizio Nichele[2], Wolfgang Belzig[1], and Juan Carlos Cuevas[1,3] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]IBM Research Europe—Zurich, Säumerstrasse 4, 8803 Rüschlikon, Switzerland — [3]Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain

We investigate the detection of quartets in hybrid multiterminal Josephson junctions [1]. Using simple models of quantum dots coupled to superconducting leads, we find that quartets are ubiquitous and show how to rigorously extract their contribution to the current-phase relation (CPR). We also demonstrate that quartets are closely related to the hybridization of Andreev bound states (ABSs) in these systems and propose a method to identify quartets directly in ABS spectra. We illustrate our method by analyzing the spectroscopic measurements of the ABS spectrum in a threeterminal Josephson junction realized in an InAs/Al heterostructure [2]. Our analysis strongly suggests the existence of quartets in the studied hybrid system.

[1] D. C. Ohnmacht et. al., arXiv:2311.18544 (2023)
[2] M. Coraiola et. al., Nat. Commun. 14 (2023) 6784

TT 76.4 Thu 15:45 H 3010

Equal contribution of even and odd frequency pairing for normal metal metal/superconductor junctions — •Shun Tamura[1], Viktoriia Kornich[1], and Björn Trauzettel[1,2] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Würzburg, Germany

Odd-frequency pairings are odd under the exchange of the relative time or frequency of the superconducting pairing. Odd-frequency pairing emerges specifically at the surface or interface of superconductors. We calculate the conductance of normal metal/superconductor junctions based on the linear response theorem. We observe that the contributions to the conductance from odd and even frequency pairings are equal, even though the superconductor follows a conventional s-wave spin-singlet pairing.

TT 76.5 Thu 16:00 H 3010

Analysis of Inelastic Tunneling Spectrum of Lead Phthalocyanine Adsorbed on Superconducting Pb(100) — •Athanasios Koliogiorgos and Richard Korytár — Department of Condensed Matter Physics, Charles University in Prague, Czech Republic

A wealth of information can be gained from the vibrational spectrum of adsorbed molecules on metal surfaces. Such spectrum can be accessed by inelastic electron tunneling in scanning-tunneling microscopy. A recent experimental study has reported resonances in a lead phthalocyanine (PbPc) molecule on a superconducting Pb(100) which were attributed to vibrational excitations. These excitations appear as peaks in the first derivative of the current-voltage relation within the superconducting gap, in a scanning-tunneling setup. Here we introduce an innovative computational approach to analyze the inelastic tunneling spectra of PbPc adsorbed on Pb(100) surfaces. Our method focuses on the vibrational spectrum observed in the first derivative of the current-voltage relation. This spectrum provides insights into the adsorbate's vibrational transitions and the interplay of electronic and vibrational states in molecular systems. Our approach diverges from conventional methods by calculating vibrational transitions from isolated molecular electronic orbitals, thus avoiding issues related to the continuous density of states in metals. This refinement facilitates an accurate interpretation of the experimental spectra. Our results highlight the importance of considering two-vibron processes. We also explore the impact of charge transfer and molecular magnetism on the vibrational spectrum by comparing neutral and charged states of PbPc.

15 min. break

TT 76.6 Thu 16:30 H 3010

Resistivity tensor of vortex-lattice states in Josephson junction arrays — •Alexander Penner[1], Karsten Flensberg[2], Leonid Glazman[3], and Felix von Oppen[1] — [1]Freie Universität Berlin — [2]University of Copenhagen — [3]Yale University

Two-dimensional Josephson junction arrays frustrated by a perpendicular magnetic field are predicted to form a cascade of distinct vortex lattice states. Here, we show that the resistivity tensor provides both structural and dynamical information on the vortex-lattice states and intervening phase transitions, which allows for experimental identification of these symmetry-breaking ground states. We illustrate our general approach by a microscopic theory of the resistivity tensor for a range of magnetic fields exhibiting a rich set of vortex lattices as well as transitions to liquid-crystalline vortex states.

TT 76.7 Thu 16:45 H 3010

Fermionic versus bosonic description of dissipation in Josephson junctions — •Oleksiy Kashuba, Theodoulos A. Costi, and Roman-P. Riwar — Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich, D-52425 Jülich

The Caldeira-Leggett model is the commonly accepted go-to approach to describe dissipation in superconducting circuits [1]. However, this model predicts a superconductor-insulator transition whose experimental verification is still heavily debated. Starting with the microscopic picture of a Josephson junction coupled to a normal metal, we notice that it matters whether the limit of large superconducting gap is taken before or after the wideband limit (where bosonization applies). For the former, the interaction cannot be mapped exactly to the Caldeira-Leggett model [2]. Instead, we find a generalized Kondo model, which, for large charging energies, reduces to the standard anisotropic Kondo model. While this model features a phase transition of its own, the parameters that control the transition are different. In particular, the phase transition can only occur if the partial capacitance between the superconducting island and normal metal is allowed to be negative. In the same fashion, Langevin equation for quantum phase derived directly from the microscopic model has additional contributions to the ohmic term compared to the Caldeira-Leggett model. Our work thus indicates that different microscopic realizations of the bath may give rise to different phase diagrams.

[1] F. Guinea, V. Hakim, A. Muramatsu, Phys. Rev. Lett. 54 (1985) 263
[2] G. Schön, A. Zaikin, Phys. Reports 198 (1990) 237

TT 76.8 Thu 17:00 H 3010

Half-integer Shapiro steps in highly transmissive InSb nanoflag Josephson junctions — Andrea Iorio[1], Alessandro Crippa[1], Bianca Turini[1], Sedighe Salimian[1], Matteo Carrega[2], Luca Chirolli[1], Valentina Zannier[1], Lucia Sorba[1], Elia Strambini[1], Francesco Giazotto[1], and •Stefan Heun[1] — [1]NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Piazza San Silvestro 12, 56127 Pisa, Italy — [2]CNR-SPIN, Via Dodecaneso 33, 16146 Genoa, Italy

We investigate a ballistic InSb nanoflag-based Josephson junction with Nb superconducting contacts. The high transparency of the superconductor-semiconductor interfaces enables the exploration of quantum transport with parallel short and long conducting channels. Under microwave irradiation, we observe half-integer Shapiro steps that are robust to temperature, suggesting their possible nonequilibrium origin. Our results demonstrate the potential of ballistic InSb nanoflags Josephson junctions as a valuable platform for understanding the physics of hybrid devices and investigating their nonequilibrium dynamics.

This research activity was partially supported by the FET-OPEN project AndQC (H2020 Grant No. 828948), PNRR MUR Project No. PE0000023-NQSTI, and PRIN MUR (Grant No. 2022PH852L).

TT 76.9 Thu 17:15 H 3010

Fractional transconductance via nonadiabatic topological Cooper pair pumping — Hannes Weisbrich[1], •Raffael L. Klees[2], Oded Zilberberg[1], and Wolfgang Belzig[1] — [1]Universität Konstanz — [2]Universität Augsburg

Many robust physical phenomena, such as the integer quantum Hall effect, rely on topological invariants arising from geometrical and topological properties of the underlying quantum states. Furthermore, the interplay of many-body correlations and topology leads to the more exotic fractional quantum Hall effect, in which anyons, particles with fractional statistics, lead to a fractional quantized conductance. While the topology of the integer effect can be realized as a quantized transconductance in superconducting multiterminal systems [1-2], a proposal for its fractional counterpart is still missing. In this talk, we present such a proposal based on an engineered chain of Josephson junctions that fills this research gap and demonstrates how to generate a fractional quantized transconductance [3]. We show that this transconductance occurs at robust plateaus as a result of nonadiabatic Landau-Zener transitions. Our proposal paves the way for future quantum simulations of correlated exotic many-body out-of-equilibrium states in Josephson junction systems.

[1] R.-P. Riwar *et al.*, Nat. Commun. **7** (2016) 11167
[2] R. L. Klees *et al.*, Phys. Rev. Lett. **124** (2020) 197002
[3] H. Weisbrich *et al.*, Phys. Rev. Research **5** (2023) 043045

TT 76.10 Thu 17:30 H 3010

Evidence for multiple Andreev reflection (MAR) in a hybrid superconducting single-electron transistor — •Jens Siewert[1,2], Laura Sobral Rey[3], David C. Ohnmacht[3], Clemens B. Winkelmann[4], Wolfgang Belzig[3], and Elke Scheer[3] — [1]University of the Basque Country, 48080 Bilbao, Spain — [2]Ikerbasque, 48009 Bilbao, Spain — [3]University of Konstanz, 78457 Konstanz, Germany — [4]Université Grenoble Alpes & CNRS, 38000 Grenoble, France

MAR and Coulomb blockade (CB) are competing phenomena in superconducting single-electron transistors: While MAR tends to significantly change the number of island excess charges, CB excludes such processes at small bias voltages. Despite substantial experimental effort over the years, up to now no unambiguous evidence for MAR processes in superconducting CB devices has been reported. To study this problem we have experimentally investigated a novel device, a single-electron transistor with one superconductor-superconductor (S-S) junction and a superconductor-normal (S-N) junction [1]. The realization of the S-S junction is chosen as a mechanically controllable break junction, such that different conductance regimes and coupling strengths can be studied in the same device. We find clear evidence for the presence of MAR processes in the current-voltage characteristics of our SSN single-electron transistor, both in the subgab region as well as for bias voltages where single-quasiparticle tunneling is possible and MAR is suppressed in single junctions.

[1] L. Sobral Rey et al., Phys. Rev. Lett. 132, 057001 (2024)

TT 77: Frustrated Magnets: Strong Spin-Orbit Coupling II

Time: Thursday 15:00–16:30 Location: H 3025

TT 77.1 Thu 15:00 H 3025

Spin-orbit coupling in a half-filled t_{2g} shell: the case of $5d^3$ K_2ReCl_6 — •Philipp Warzanowski[1], Marco Magnaterra[1], Gereon Schlicht[1], Quentin Faure[2,3], Christoph J. Sahle[2], Petra Becker[4], Ladislav Bohatý[4], Marco Moretti Sala[5], Giulio Monaco[6], Maria Hermanns[7], Paul H. M. van Loosdrecht[1], and Markus Grüninger[1] — [1]Institute of Physics II, University of Cologne — [2]ERSF, Grenoble, France — [3]LLB, Paris-Saclay, France — [4]Sect. Crystallography, University of Cologne — [5]Politecnico di Milano, Italy — [6]Università di Padova, Italy — [7]Stockholm University, Sweden

Strong spin-orbit coupling ζ is typically a game changer in 5d transition-metal compounds. The half-filled t_{2g}^3 shell, however, stands out due to its quenched orbital moment. This viewpoint has been tackled by Streltsov and Khomskii for large ζ/J_H, i.e., in the jj-coupling limit [1]. Here, we present our results of resonant inelastic x-ray scattering (RIXS) and optical spectroscopy of the $5d^3$ Mott insulator K_2ReCl_6, studying on-site d-d excitations and overtones thereof, the Mott gap, and charge-transfer excitations [2]. From comparison with single-site multiplet calculations, we determine ζ/J_H and the cubic crystal field-splitting $10Dq$ for this compound and discuss the effect of ζ on the ground state.

[1] S. Streltsov and D. I. Khomskii, PRX 10, 031043 (2020)
[2] P. Warzanowski et al., arXiv:2311.11419

TT 77.2 Thu 15:15 H 3025

Magnetism in Kitaev Quantum Spin Liquid Candidate $RuBr_3$ — Tillmann Weinhold[1], Chennan Wang[2], Felix Seewald[1], Vadim Grinenko[3], Yoshinori Imai[4], Fuki Sato[4], Kenya Ohgushi[4], Hans Henning Klauss[1], and •Rajib Sarkar[1] — [1]Institute of Solid State and Materials Physics, TU Dresden, Germany — [2]Laboratory for Muon Spin Spectroscopy, PSI, Villigen, Switzerland — [3]Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai, China — [4]Department of Physics, Graduate School of Science, Tohoku University, Sendai, Japan

We present muon spin rotation (μSR) studies showing that long-range magnetic order takes place in $RuBr_3$ at ≈ 34 K. The observations of clear oscillations in the muon time spectra demonstrate the presence of well-defined internal fields at the muon sites. The magnetic ordering appears to be very robust and static suggesting a more conventional nature of magnetic ordering in the $RuBr_3$ system at zero field. Present investigations prove that in $RuBr_3$ the Kitaev interactions are likely to be weakened at zero field in comparison to the α-$RuCl_3$ system. This proves that it is possible to tune the Kitaev interactions by replacing Cl with heavier halogen elements such as Br.

TT 77.3 Thu 15:30 H 3025

Pressure- and temperature-induced structural evolution of $RuBr_3$ with honeycomb layers — •Victoria A. Ginga[1], Bin

Shen[2], Prashanta K. Mukharjee[2], Angel M. Arevalo-Lopez[3], Ece Uykur[4], Philipp Gegenwart[2], and Alexander A. Tsirlin[1,2] — [1]Felix Bloch Institute, University of Leipzig, Germany — [2]EP VI, EKM, University of Augsburg, Germany — [3]University of Lille, France — [4]Helmholtz-Zentrum Dresden-Rossendorf, Germany

$RuBr_3$ received recent attention as a close chemical analog of the Kitaev magnet α-$RuCl_3$. Here, we report on the structural transformations of $RuBr_3$ and the stability ranges of its different polymorphs as a function of pressure and temperature. At ambient pressure, β-$RuBr_3$ forms a chain-like structure where short Ru-Ru bonds prevent the Ru^{3+} ions from being magnetic. In turn, β-$RuBr_3$ can be transformed into layered BiI_3-type magnetic α-$RuBr_3$ (space group R-3) by a high-pressure high-temperature treatment and quenched to ambient conditions. We show that α-$RuBr_3$ is metastable and irreversibly transforms into β-$RuBr_3$ on heating. Additionally, there is a reversible R-3 to C2/m transformation before β-$RuBr_3$ is reached. Upon compression, α-RuBr3 shows a strong tendency toward Ru-Ru dimerization in the triclinic and nonmagnetic α*-$RuBr_3$ (space group P-1).

TT 77.4 Thu 15:45 H 3025

Pressure effect on several Kitaev materials — •Bin Shen[1], Faranak Bahrami[2], Fazel Tafti[2], Philipp Gegenwart[1], and Alexander A. Tsirlin[3] — [1]EP VI, EKM, University of Augsburg, Germany — [2]Department of Physics, Boston College, Chestnut Hill, MA 02467, USA — [3]Felix Bloch Institute, University of Leipzig, Germany

Kitaev quantum spin liquids host quantum entanglement and non-Abelian anyonic excitations. However, experimentally, the ground state of these Kitaev candidates is all magnetically ordered mainly thanks to other competing interactions beyond pure Kitaev exchange. Boosting the Kitaev term and driving the system towards Kitaev limit is a subject of current interest. Here, we present our pressure-tuning results on several Kitaev materials [β-Li_2IrO_3 (B. Shen et al., PRB 104, 134426), α-Li_2IrO_3 (B. Shen et al., PRB 105, 054412), and α-$RuBr_3$ (unpublished)] and reveal a generic behavior for the majority: a sudden suppression of the magnetic order due to structural dimerization. We also show one exception [$Ag_3LiRh_2O_6$ (unpublished)] in which the magnetic order is gradually suppressed without the interference of structural dimerization.

TT 77.5 Thu 16:00 H 3025

Band structure study of the magnetic ground state of pyrochlore iridates — •Alexander Yaresko, Aleksandra Krajewska, Tomohiro Takayama, and Hidenori Takagi — Max Plank Institute for Solid State Research, Stuttgart, Germany

Most of pyrochlore $R_2Ir_2O_7$ iridates, where R^{3+} is a rare-earth ion, undergo a transition to non-collinear magnetically ordered state with Ir moments pointing either to or from the center of a tetrahedron. This all-in-all-out (AIAO) order is thought to be stabilized by strong Dzyaloshinskii-Moriya interaction (DMI) allowed on the pyrochlore lattice. Recently, a new $In_2Ir_2O_7$ iridate was synthesized in which the trigonal distortion and Ir-O-Ir bond bending is even stronger than in $Lu_2Ir_2O_7$. Thus, one would expect that also in this compound strong DMI stabilizes AIAO order.

In order to verify this we performed LDA+U calculations for $In_2Ir_2O_7$ and $R_2Ir_2O_7$ (R=Y, Lu, Nd) with different non-collinear magnetic structures. For $R_2Ir_2O_7$, in agreement with neutron diffraction data the lowest energy was obtained for AIAO order. For $In_2Ir_2O_7$, however, non-collinear coplanar Palmer-Chalker order is found to be the most favorable one. This prediction is supported by recent neutron diffraction experiments. Comparison of exchange parameters estimated from the calculations suggests that the change of the magnetic ground state in $In_2Ir_2O_7$ may be caused by competition between DMI and local easy plane anisotropy which becomes allowed because of strong trigonal splitting of Ir d t_{2g} states.

TT 77.6 Thu 16:15 H 3025

Metallic conductivity on Na-deficient structural domain walls in the spin-orbit Mott insulator Na_2IrO_3 — •Franziska Breitner, Julian Kaiser, Anton Jesche, and Philipp Gegenwart — Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, 86159 Augsburg, Germany

Charge carrier doping of spin-orbit Mott insulators and Kitaev magnets is considered as promising route towards the realization of exotic quantum phases. Here we focus on the prototypical system Na_2IrO_3, for which previous ARPES and STM studies revealed indications of a high tunability of its electronic properties. We thus performed a combined structural and electrical resistivity study of Na_2IrO_3 single crystals [1]. Laue back-scattering diffraction indicates twinning with $\pm120°$ rotation around the c^*-axis while scanning electron microscopy displays nanothin lines parallel to all three b-axis orientations of twin domains. Energy dispersive x-ray analysis line-scans across such domain walls indicate no change of the Ir signal intensity, i.e. intact honeycomb layers, while the Na intensity is reduced down to $\sim 2/3$ of its original value at the domain walls, implying significant hole doping. The temperature dependent electrical resistance of individual domain walls contacted via focused-ion-beam microstructuring demonstrates the tuning through the metal-insulator transition into a correlated-metal ground state by increasing hole doping.

[1] F. A. Breitner, J. Kaiser, A. Jesche, Ph. Gegenwart, https://arxiv.org/abs/2311.07275

TT 78: Spin Transport and Orbitronics, Spin-Hall Effects II (joint session MA/TT)

Time: Thursday 15:00–16:00 Location: EB 107

TT 78.1 Thu 15:00 EB 107

Controlling the Interlayer Dzyaloshinskii-Moriya Interaction by Electrical Currents — •Fabian Kammerbauer[1], Won-Young Choi[1], Freimuth Frank[1,2], Robert Frömter[1], Yuriy Mokrousov[1,2], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University, Staudingerweg 7, 55128 Mainz, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The recently discovered interlayer Dzyaloshinskii-Moriya interaction (IL-DMI) in multilayers exhibiting perpendicular magnetic anisotropy induces a canting of spins in the in-plane direction, potentially stabilizing intriguing spin textures like Hopfions [1]. Nucleation control becomes pivotal, prompting our exploration into the impact of electric currents on IL-DMI strength–a phenomenon previously established for DMI [2]. To quantify IL-DMI, we use out-of-plane hysteresis loops, applying a static in-plane magnetic field at varied azimuthal angles. A notable observation emerges: a shift in azimuthal dependence with increasing current. This shift is attributed to an additional in-plane symmetry breaking introduced by the electrical current. Detailed fitting substantiates the presence of an additive current-induced term [3]. This unveils a practical avenue for manipulating 3D spin textures on-the-fly via a readily accessible method.

[1] Han et al., Nat. Mater. 18, 703-708 (2019)
[2] Karnad et al., Phys. Rev. Lett. 121, 147203 (2018)
[3] Kammerbauer et al, Nano Lett. 2023, 23, 15, 7070-7075 (2023)

TT 78.2 Thu 15:15 EB 107

Local violation of the reciprocity between the direct and inverse orbital Hall effects — •Dongwook Go[1,2], Tom S. Seifert[3,4], Tobias Kampfrath[3,4], Stefan Blügel[1], Hyun-Woo Lee[5], and Yuriy Mokrousov[1,2] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich, Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg Universität Mainz, Mainz, Germany — [3]Department of Physics, Freie Universität Berlin, Berlin, Germany — [4]Department of Physical Chemistry, Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [5]Department of Physics, Pohang University of Science and Technology, Pohang, Korea

We theoretically investigate the reciprocity between the direct and inverse orbital Hall effects [1]. We show that the reciprocal relation between charge and orbital transport can be rigorously established by adopting the definition of the *proper* current that takes non-conservation effects into account [2]. Importantly, we find that the local reciprocity of charge and orbital currents is violated in thin films, as we demonstrate for the case of W(110) from first principles. Our results explain a seemingly inconsistent behavior of direct and inverse orbital Hall effect observed in recent experiments, where the two phenomena are found to be dominant in bulk and at surfaces, respectively

[3,4]. References: [1] Go *et al.* In Preparation; [2] Shi *et al.* Phys. Rev. Lett. **96**, 076604 (2007); [3] Hayashi *et al.* Commun. Phys. **6**, 32 (2023); [4] Seifert *et al.* Nat. Nanotechnol. **18**, 1132 (2023).

TT 78.3 Thu 15:30 EB 107

Spin-orbitronics in two dimensional systems: Orbital magnetization, orbital Hall effect and orbital Edelstein effect — •Börge Göbel[1], Oliver Busch[1], Annika Johansson[2], Manuel Bibes[3], and Ingrid Mertig[1] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg — [2]Max-Planck-Institut für Mikrostrukturphysik, Halle — [3]Unité Mixte de Physique, CNRS, Thales, Paris

The orbital contribution to the magnetization is often quenched by the crystal field which is why it is typically significantly smaller than the spin contribution, in equilibrium. In this talk, I will present the generation of a large orbital magnetization and orbital currents.

In non-collinear spin textures, crystal symmetries are broken and the quenching is lifted. In topologically non-trivial skyrmion crystals, for example, the emergent field forces electrons on orbital trajectories which leads to the generation of a considerable orbital magnetization [1]. Likewise, an orbital Hall effect with orbital edge states arises in non-magnetic Kagome nanoribbons [2]. In two-dimensional electron gases (2deg), e.g. at the interface of STO/AlO [3,4] or KTO/AlO [5], the inversion symmetry is broken so that an (inverse) Edelstein effect arises. The application of a charge current leads to the generation of spin and orbital magnetization densities and vice versa.

[1] BG et al. PRB 99, 060406 (2019)
[2] Busch, Mertig, BG, PRResearch 5, 043052 (2023)
[3] Vaz, BG et al. Nature Materials 18, 1187 (2019)
[4] Johansson, BG et al. PRResearch 3, 013275 (2021)
[5] Varotto, BG et al. Nature Communications 13, 6165 (2022)

TT 78.4 Thu 15:45 EB 107

Spin Fluctuation Enhancement of Spin Hall Effect in Low-resistive Antiferromagnet — •Chi Fang and Stuart S.P. Parkin — Max Planck Institute of Microstructure Physics, Halle (Saale) 06120, Germany

The spin Hall effect (SHE) generates a pure spin current by a charge current, which is promisingly adopted to electrically manipulate magnetization. To reduce power consumption of such control, a giant spin Hall angle (SHA) in the SHE is expected in low-resistive systems for practical applications. Low resistive antiferromagnet Chromium(Cr) is reported with remarkble SHA. Here, critical spin fluctuation near the antiferromagnetic (AFM) phase-transition in Cr is proved as an effective mechanism to further create an additional part of SHE. The SHA is significantly enhanced when temperature approaches the Néel temperature of Cr and has a peak value of -0.36 near the Néel temperature. This value is higher than the room-temperature value by 153% and leads to a low normalized power consumption among known spin-orbit torque (SOT) materials. This study demonstrates the critical spin fluctuation as a prospective way of increasing SHA and enriches the AFM material candidates for spin-orbitronic devices.

TT 79: Quantum Chaos and Coherent Dynamics (joint session DY/TT)

Time: Thursday 15:00–17:45 Location: A 151

TT 79.1 Thu 15:00 A 151

Probing the anisotropic scattering model in ultrapure Delafossites — •Linus Holeschovsky, Carsten Putzke, and Philip Moll — Max-Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany

Anisotropic scattering models have been used to describe the strange metal phase of overdoped cuprates. They stem from the idea of two distinct, k-dependent live-times of quasi-particles. This description is one among many trying to explain the strange metal phase and remains highly debated. On the other hand, the ultrapure delafossite PdCoO2 and PtCoO2 show two distinct quantum coherence lengths that can be explained by two different scattering times. These delafossite are particularly interesting due to their extremely long mean free path and moderate electronic correlation. This gives access to underlying physical properties, which can be theoretically explained within well-established theoretical models.

In this study, angle-dependent magnetic oscillation is used to investigate the anisotropic scattering time in microstructured PdCoO2 and PtCoO2. Specifically, a two-axis rotator is used to probe the coherence peak of interlayer transport in different crystallographic directions, which is particularly sensitive to scattering times. The anisotropy and temperature dependence of the scattering time can therefore be mapped on the Fermi surface. In this talk, we emphasize how the relative simplicity and textbook-like behavior of the delafossite materials make them prime candidates to probe physical models otherwise difficult to verify but were proposed in more complex materials.

TT 79.2 Thu 15:15 A 151

Semiclassical structure of resonance states in chaotic scattering — Roland Ketzmerick, •Florian Lorenz, and Jan Robert Schmidt — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

We introduce a classical multifractal measure that describes resonance states with decay rate γ in the semiclassical limit. This measure (i) maximizes an entropy-like quantity and (ii) is conditionally invariant with the same decay rate γ. It is derived from a local random vector model and replaces previous approximate approaches. This supports the recently proposed factorization conjecture, that resonance states are a product of a classical measure and universal fluctuations [1]. These results are numerically demonstrated for optical microcavities.

[1] R. Ketzmerick, K. Clauß, F. Fritzsch, and A. Bäcker, Chaotic resonance modes in dielectric cavities: Product of conditionally invariant measure and universal fluctuations, Phys. Rev. Lett. **129**, 193901 (2022).

TT 79.3 Thu 15:30 A 151

Quasiclassical description of out-of-time-ordered correlators — •Thomas Michel[1], Juan Diego Urbina[2], and Peter Schlagheck[1] — [1]CESAM Research Unit, University of Liège, 4000 Liège, Belgium — [2]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

Out-of-time-ordered correlators (OTOCs) are quantum objects that can be used as a probe for quantum chaos. They characterise information scrambling, more specifically, how a local operator commute with another local operator that is time-evolved. We present a quasiclassical formalism of OTOCs using the semiclassical van Vleck-Gutzwiller propagator in combination with the diagonal approximation. For short time, we recover the same result as with the Wigner-Moyal formalism, yielding an initial exponential growth of the correlator. For long times and fully chaotic dynamics, this quasiclassical formalism yields a finite saturation value of the OTOC. However, as we verified in Bose-Hubbard systems, this quasiclassical saturation value is found to be small compared to the actual quantum OTOC saturation threshold. This finding shows the importance of effects beyond quasiclassical physics related to trajectory pairs with small-angle crossings, as was pointed out in Ref. [1].

[1] 1.Rammensee, J., Urbina, J.-D. & Richter, K. Many-Body Quantum Interference and the Saturation of Out-of-Time-Order Correlators. Phys. Rev. Lett. 121, 124101 (2018).

TT 79.4 Thu 15:45 A 151

A semiclassical approach to mode entanglement in Bose-Hubbard systems — •Sebastian Hörhold, Juan Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany

Entanglement is the fundamental mechanism behind phenomena as equilibration and decoherence [1] in many-body systems. Degrees of freedom of bosonic theories, describing for example cold atoms in optical lattices, are represented by complex matter fields at each lattice point and one speaks then of mode entanglement. In a semiclassical approach [2] based on interfering mean-field paths in Fock space, describing mode entanglement becomes rather cumbersome [3] as the path integral is constructed by using product states.

The aim of our work is to incorporate entanglement at the level of the path integral, similar to what has been done for matrix product states in spin systems [4]. We address then whether the effective classical description, closely related to the time-dependent variational approach [5], captures the emergence of entanglement.

[1] M. Rigol, V. Dunjko and M. Olshanii, Nature 452, 854-858
[2] K. Richter, J. D. Urbina and S. Tomsovic, J. Phys. A: Math. Theor. 55 453001
[3] S. Tomsovic et al., Phys. Rev. A 97, 061606(R)
[4] A. G. Green et al., arXiv:1607.01778v1
[5] J. Haegeman et al., arXiv:1103.0936v2

TT 79.5 Thu 16:00 A 151

Chaotic escape dynamics in the vicinity of hyperbolic fixed points — •Alexander Hempel, Jonas Stöber, and Arnd Bäcker — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

For an ensemble of orbits started in the vicinity of a hyperbolic fixed point in the area-preserving standard map, we find a slow, non-exponential decay of the survival probability. We show that this is governed by the stable and unstable manifolds which form a partial barrier enclosing a resonance zone. The re-entrance of orbits into the resonance zone and the statistics of transit times leads to a simple model, which explains the initial decay of the survival probability. Furthermore we briefly discuss quantum mechanical consequences.

15 min. break

TT 79.6 Thu 16:30 A 151

Higher-order exceptional points in waveguide-coupled microcavities — •Julius Kullig[1], Daniel Grom[1], Sebastian Klembt[2], and Jan Wiersig[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany — [2]Physikalisches Institut and Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems, University of Würzburg, Würzburg, Germany

Open quantum and wave systems exhibit fascinating and exotic behavior described by non-Hermitian physics. A key feature of such systems are exceptional points (EPs) in the parameter space. At these EPs the eigenvalues of the Hamiltonian become degenerate and simultaneously the corresponding eigenstates coalesce. Consequently, the system has interesting chiral eigenstates and is highly sensitive to external perturbations. A hot topic of current research is the creation of high-order EPs, where more than two eigenstates coalesce. In this talk, we present an intuitive and robust implementation of high-order EPs in photonic structures consisting of waveguide-coupled microring cavities. Combining the unidirectional coupling from the waveguide with mirror-induced asymmetric backscattering, we can increase the order of the EPs even further. Furthermore, we demonstrate that our setup allows for an easy realization of non-generic perturbation schemes.

TT 79.7 Thu 16:45 A 151

Non-Hermitian mesoscopic optics in coupled microcavities — •Tom Rodemund[1], Síile Nic Chormaic[2], and Martina Hentschel[1] — [1]Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany — [2]Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan

Coupled cavities are of interest as they expose qualitatively new effects, such as non-Hermitian properties, that are not accessible using an individual cavity. Here, we study two coupled two-dimensional microdisk cavities of circular and deformed (limaçon) shape, which are in the focus of interest due to their high emission directionality [1].

We investigate their coupling-induced properties as a function of intercavity distance and identify characteristic coupling regimes, with clear signatures of the presence of another cavity even deep in the weak couling regime. For deformed coupled microcavities, the asymmetry of the intercavity coupling implies non-Hermitian properties prominently evident in the chirality of the coupled cavity modes. We use an analytical model to explain our findings and reveal the direct connection between coupling asymmetry and the resulting sense of rotation of the coupled modes. This could prove useful for future applications such as far-field emission control of coupled cavities.

[1] Kreismann et al., *Phys. Rev. Res.* **1** 033171 (2019)

TT 79.8 Thu 17:00 A 151

Tuning phase space and far-field emission in anisotropic bilayer-graphene cavities — •Lukas Seemann[1], Angelika Knothe[2], and Martina Hentschel[1] — [1]Technische Universität Chemnitz, 09107 Chemnitz, Germany — [2]Universität Regensburg, 93040 Regensburg, Germany

Ray-wave correspondence is a well-known tool in optics. Its generalization to Fermi electron optics in 2D materials allows for the description of ballistic charge carrier transport, e.g. in gate-defined cavities [1]. Here we focus on bilayer graphene (BLG) with a trigonal warped Fermi line. Its anisotropic disperion relation with three preferred propagation directions implies an electron dynamics in BLG cavities that differs significantly from the optical case [2]. In this work we investigate the interplay of momentum and real space asymmetries by combining the anisotropic dispersion relation with a deformed cavity. We investigate the resulting charge carrier dynamics in o'nigiri shaped cavities where the latter provides the same C3 symmetry as the BLG Fermi line. We study its signatures in phase space and explain how it translates into the far-field. Its properties can be fine-tuned by choosing appropriate material parameters for the BLG system, by the cavity geometry, and the tilt angle between BLG lattice and cavity axis which opens a broad venue for applications.

[1] J.-K. Schrepfer, S. Chen, M.-H. Liu, K. Richter, and M. Hentschel, Phys. Rev. B 104, 155436 (2021)
[2] Lukas Seemann, Angelika Knothe, and Martina Hentschel Phys. Rev. B 107, 205404 (2023)

TT 79.9 Thu 17:15 A 151

Non-abelian invariants in periodically-driven quantum rotors — •Volker Karle, Areg Ghazaryan, and Mikhail Lemeshko — Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg

This presentation explores the role of topological invariants in the non-equilibrium dynamics of periodically-driven quantum rotors, inspired by experiments on closed-shell diatomic molecules driven by periodic, far-off-resonant laser pulses. This approach uncovers a complex phase space with both localized and delocalized Floquet states. We demonstrate that the localized states are topological in nature, originating from Dirac cones protected by reflection and time-reversal symmetry. These states can be modified through laser strength adjustments, making them observable in current experiments through molecular alignment and observation of rotational level populations. Notably, in scenarios involving higher-order quantum resonances leading to multiple Floquet bands, the topological charges become non-Abelian. This results in the remarkable finding that the exchange of Dirac cones across different bands is non-commutative, enabling non-Abelian braiding, paving the way for the study of controllable multi-band topological physics in gas-phase experiments with small molecules, as well as for classifying dynamical molecular states by their topological invariants.

TT 79.10 Thu 17:30 A 151

Unveiling out of time correlators in stochastic operator variance — •Aritra Kundu — Univeresity of Luxembourg

This study introduces the stochastic operator variance (SOV) as a tool for investigating quantum systems influenced by noise. We present a protocol that utilizes noise to probe out-of-time-order correlators and extract the Lyapunov exponent in a noisy quantum chaotic system. We demonstrate SOV in both quantum and classical realms by introducing a stochastic version of the Lipkin-Meshkov-Glick (LMG) model. We further examine analytical and numerical demonstrations of a stochastic LMG Hamiltonian undergoing energy dephasing. In the classical limit, we provide analytical results for the Lyapunov exponents. This research contributes to understanding the interplay between noise and quantum dynamics for benchmarking near-term noisy quantum devices.

TT 80: Correlated Electrons: Poster

Time: Thursday 15:00–18:00 Location: Poster E

TT 80.1 Thu 15:00 Poster E

Synthesis and Characterisation of Chemically tuned $CeRh_2As_2$ — •Sushma Lakshmi Ravi Sankar, Seunghyun Khim, Arushi Yadav, and Lea Richter — Max Planck Institute of Chemical Physics of Solids, Dresden

$CeRh_2As_2$ is an intriguing Kondo-lattice system which demonstrates novel phase diagrams involving superconductivity and an unknown ordered state. The unique multiple superconducting phases are suggested to be given by a combination of local inversion symmetry breaking and a localized nature of the Ce-4f electrons. Furthermore, the emergence of superconductivity within an ordered phase, suggested to be the quadrupole density wave state, remains to be understood regarding its nature and proposes a complex role of the Ce-4f electrons. To reach a deeper understanding of this pristine system, a doping study could be a promising experimental approach. Substituting the As site with the isovalent P is expected to decrease the lattice constants while doping the Ce atom with La would effectively modify electronic structures by introducing hole carriers. Here, we will report on preliminary works on single-crystal growth of P- and La-doped $CeRh_2As_2$. We utilized the Bi-flux method, previously used for growing the pristine crystal. Our characterization including crystal structures and basic properties such as resistivity, magnetization, and specific heat will be presented in order to find systematic changes in physical parameters.

TT 80.2 Thu 15:00 Poster E

Growth and characterisation of $PrCo_2P_2$ and $NdCo_2P_2$ single crystals — •Benjamin Helmer, Fabian Fiedler, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt am Main, Germany

Recently, long-lived spin waves in the THz regime were discovered in the metallic antiferromagnet $CeCo_2P_2$ [1], resulting from an intricate interplay of structural and magnetic degrees of freedom in this compound. Therefore it is of current interest to investigate similar compounds in the $LnCo_2P_2$ series. Here, we present the crystal growth of (Pr,Nd)Co_2P_2 in tin flux, using temperatures of up to 1400°C and a vertical temperature gradient, and the corresponding structural and physical characterization.

The structural characterization is performed by powder x-ray diffractometry, energy-dispersive x-ray spectroscopy and Laue diffraction. Magnetic properties of these systems, arising from the combination of the 4f-moments of $(Pr,Nd)^{3+}$-ions and the 3d-moments of Co^{3+}, are investigated by measurements of magnetization and heat capacity.

[1] G. Poelchen *et al.*, Nat. Commun. **14**, 5422 (2023)

TT 80.3 Thu 15:00 Poster E

Electron Spin Resonance of Eu on triangular layers in EuT_2P_2 (T=Mn, Zn, Cd). — •Jörg Sichelschmidt[1], Pierre Chailloleau[1], Sarah Krebber[2], Asmaa El Mard[2], Kristin Kliemt[2], and Cornelius Krellner[2] — [1]Max-Planck-Insitut für Chemische Physik fester Stoffe, 01187 Dresden — [2]Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt

Eu-based 122 systems in the trigonal $CaAl_2Si_2$ structure haven proven to show unusual transport properties such as anomalous Hall effect or colossal magnetoresistance, in the vicinity of an antiferromagnetically ordered state [1,2]. We investigated the electron spin resonance (ESR) of Eu^{2+} in EuT_2P_2 (T=Mn, Zn, Cd) single crystals. The temperature dependencies of ESR linewidth and resonance shift show a similar behaviour when approaching the Eu-ordered state – a divergence towards T_N, indicating the growing importance of magnetic correlations and the build-up of internal magnetic fields.

[1] S. Krebber et al. Phys. Rev. B **108**, 045116 (2023).
[2] X. Cao et al., Phys. Rev. Res. **4**, 023100 (2022).

TT 80.4 Thu 15:00 Poster E

Magnetism, heat capacity and electronic structure of $EuCd_2P_2$ in view of its colossal magnetoresistance — •Sarah Krebber[1], Dmitry Usachov[2], Charu Garg[1], Marvin Kopp[1], Jens Müller[1], Denis Vyalikh[3], Cornelius Krellner[1], and Kristin Kliemt[1] — [1]Physikalisches Institut, Goethe Universität Frankfurt, Germany — [2]Donostia International Physics Center (DIPC), 20018 Donostia-San Sebastian, Spain — [3]Iberasque, Basque Foundation for Science, Bilbao, Spain

Materials showing a colossal magnetoresistance (CMR) effect have been studied extensively over the last decades as they potentially form the materials basis for future applications. Recently, Eu-based 122 compounds in the trigonal $CaAl_2Si_2$ structure type have been shown to be promising candidates to study this CMR effect in antiferromagnetically ordered materials, where the underlying mechanism is still under investigation [1-3]. Recent studies propose the formation of ferromagnetic clusters to be the cause for these unusal transport properties in $EuCd_2P_2$ [2]. Here we present a detailed study of the magnetic properties of $EuCd_2P_2$ in connction with its heat capacity and electrical resistivity particulary in the view of its colossal magnetoresistance. Furthermore, we report on its electronic structure by ARPES measurements accompanied by DFT calculations.

[1] Z.C.Wang et al., Adv. Mater. 33, 2005755 (2021).
[2] V.Sunko et al., Phys. Rev. B 107, 144404 (2023).
[3] S.Krebber et al., Phys. Rev. B 108, 045116 (2023).

TT 80.5 Thu 15:00 Poster E

Unveiling novel interactions: hybridization variations in mixed-valent TmSe under negative pressure — •Chul Hee Min[1,2], Simon Müller[3], Michael Heber[4], Lenart Dudy[5], Woojae Choi[6], Yong Seung Kwon[6], Hendrik Bentmann[1], Friedrich Reinert[2], and Kai Rossnagel[2,4] — [1]FYI, NTNU, Norway — [2]IEAP, CAU Kiel, Germany — [3]EP7, Uni. Würzburg, Germany — [4]DESY, Germany — [5]SOLEIL, France — [6]DGIST, South Korea

In the 1980s, a range of interactions associated with the localized 4f states in rare earth compounds were contemplated, but the extent of their influence on physical properties remained unclear. Consequently, in most instances, these interactions were overlooked, and the standard Anderson model was commonly employed for such compounds. However, our recent investigations have uncovered spectroscopic evidence of a hitherto unrecognized interaction in the mixed-valent TmSe, particularly when subjected to negative pressure (the substitution of Se with Te). Our photoemission results reveal a distinct behavior: the 4f peak, previously considered singular, actually comprises two peaks that progressively separate with increasing the lattice parameter. Moreover, we demonstrate a correlated variation in the hybridization between the 4f states and other states. Consequently, our findings highlight a variable interaction that evolves with lattice expansion, with the bonding character transitioning from 5d to the cation p states. This discovery underscores the necessity of incorporating at least one additional hybridization into the Anderson model to effectively capture the mixed-valent characteristics.

TT 80.6 Thu 15:00 Poster E

Single crystal growth and characterization of $EuMn_2Si_2$ and $EuMn_2Ge_2$ — •Janina Strahl, Marwa Hussein Abdelhakam Abouelela, Kristin Kliemt, and Cornelius Krellner — Institute of Physics, Goethe-University, Frankfurt (Main), Germany

$EuMn_2Si_2$ exhibits a thermally driven valence transition at around 530 K of the europium ions above room temperature from Eu^{3+} at low temperatures to $Eu^{\sim 2.5+}$ at high temperatures [1]. The isoelectronic and isostructural substitution of silicon with germanium leads to a stabilization of the divalent state of Eu in $EuMn_2Ge_2$ without Eu ordering down to 1.5 K [1]. Both rare earth intermetallic 122 compounds crystallize in the tetragonal $ThCr_2Si_2$ structure type and show antiferromagnetic ordering of the manganese sublattices above room temperature. In literature [1,2] additional spin-reorientation transitions in polycrystalline samples at low temperatures were observed. In this contribution, we present the single crystal growth of these compounds and the results of our structural, chemical and magnetic characterization.

[1] M. Hofmann et al., Phys. Rev. B 69, 174432 (2004)
[2] I. Nowik et al., Phys. Rev. B 55, 3033 (1997)

TT 80.7 Thu 15:00 Poster E

Effect of substitutions and disorder on the valence transition in $YbIn_{1-x}(Ag/Au)_xCu_4$ single crystals — •Michelle Ocker, Bereket Ghebretinsae, Jan Niklas Zimmermann, Bernd Wolf, Kristin Kliemt, Michael Lang, and Cornelius Krellner — Physikalisches Institut, Goethe Universität Frankfurt, 60438 Frankfurt/Main, German

$YbInCu_4$ is one of the rare cases which exhibits a 1^{st}-order valence transition at ambient pressure as a function of temperature around $T_v = 42$ K [1]. The first-order valence transition line is terminated at a second-order critical endpoint (CEP) [2] where strong fluctuations together with strong coupling effects can be expected. In order to identify these effects and to study them in more detail, single crystalline samples were prepared in In-Cu flux [3]. To tune the material to a point close to the CEP in the valence cross-over region single crystals substituted with silver and gold were prepared. To fine-tune the substituted samples measurements under He-gas pressure were performed. We report on the single crystal growth with different substitution levels and different initial compositions. We present the results of our structural, chemical and physical characterization for the various samples. We show the elastic constant $c_L(T,p)$ and discuss the behaviour of the magneto-elastic coupling constant near the CEP.

[1] I. Felner et al., Physical Review B 35, (1987) 6956.
[2] Y. Onuki et al., J. Phys. Soc. Japan 89, (2020) 102001.
[3] J. L. Sarrao et al., Physical Review B 54, (1996) 12207.

TT 80.8 Thu 15:00 Poster E

Electric Field Gradient influenced by Rare Earth Elements in *R*AlSi Weyl Semimetals — •Tillmann Weinhold[1], Hank Wu[2], Rajib Sarkar[1], Vadim Grinenko[3], Fazel Tafti[4], Stephen Blundell[2], and Hans-Henning Klauss[1] — [1]TU Dresden, Germany — [2]University of Oxford, Great Britain — [3]Shanghai JiaoTong University, China — [4]Boston College, MA, USA

Weyl semimetals exhibit topologically non-trivial band-structures with Weyl nodes that can host massless fermionic quasiparticles (Weyl fermions). These can give rise to exotic electronic properties such as anomalous Hall effect and a chiral anomaly in the transverse magnetoresistance.

We used NMR and μSR experiments to gain information about local static and dynamic magnetic properties of RAlSi ($R = \{La, Ce, Nd\}$). Surprisingly, we observe an Electric Field Gradient (EFG) at the *Al* position, which is dependent on the rare earth element present in the compound. The EFG is most pronounced for NdAlSi and vanishes for LaAlSi.

TT 80.9 Thu 15:00 Poster E

Heat capacity and magnetization studies of the kagome intermetallic compound YbCr6Ge6 — •Kilian Srowik[1], Laura T. Corredor[1], Bernd Büchner[1,2], Sabine Wurmehl[1], and Vitaliy Romaka[1] — [1]Leibniz Institute for Solid State and Materials Science Dresden (IFW Dresden), 01069 Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01062, Dresden, Germany

Intermetallic compounds, with their mixed bonding character show a wide variety of physical properties, particularly electric and magnetic phenomena. Between them, compounds with rare-earth elements and transition metals owe their varied properties to the relationship between the localized f electrons of the rare-earth elements and the itinerant d electrons of the transition elements. Examples include the kagome metal candidate YCr6Ge6, incommensurate antiferromagnetism and successive spin reorientation in YMn6Ge6 and YbFe6Ge6, and the recent heavy fermion system YbV6Sn6. In this work, a newly synthesized YbCr6Ge6 bearing hexagonal MgFe6Ge6 structure, consisting of a triangular ytterbium sublattice and a kagome chromium sublattice, is investigated. Here, we report on heat capacity and magnetization measurements of this new compound at low temperatures and high magnetic fields. Contrary to most of its RECr6Ge6 sister compounds, a clear antiferromagnetic transition around 4 K is observed. Our results are discussed in the light of structural data.

TT 80.10 Thu 15:00 Poster E

$Ce_2Ir_3Ga_5$: A new locally non-centrosymmetric heavy fermion system — •Arushi Arushi, Raul Cardoso-Gil, and Christoph Geibel — Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

Recently, a new type of unconventional superconductivity with a field-induced transition between two different superconducting (SC) states was discovered in the heavy fermion system $CeRh_2As_2$. This unusual SC state was proposed to be based on specific symmetries of the underlying structure, i.e., a globally centrosymmetric layered structure, but where the Ce-layers themselves lack inversion symmetry. This new type of SC state has attracted strong interest, prompting the search for further heavy fermion systems crystallizing in structures with appropriate symmetries. Here, I will present the discovery and the study of a new Ce-based heavy fermion system with a globally centrosymmetric structure but without inversion symmetry on the Ce-site, $Ce_2Ir_3Ga_5$. A single crystal X-ray diffraction study revealed an orthorhombic $U_2Co_3Si_5$ type structure. Resistivity, specific heat, and magnetization measurements indicate a moderate-heavy fermion behavior with a Kondo energy scale of the order of 40 K. Most experimental results suggest the absence of magnetic order, but a tiny anomaly in the specific heat opens the possibility for a very weak, itinerant type of ordering.

TT 80.11 Thu 15:00 Poster E

Phase diagram study of the Falicov-Kimball Model on the two-dimensional Kagome lattice — •Ammar Nejati[1] and Younes Javanmard[2] — [1]Jülich Centre for Neutron Science (JCNS) — [2]Leibniz Universität Hannover

The Falicov-Kimball Model (FKM) is a relatively simple model of coupled quantum and classic degrees of freedom, in the middle of the spectrum between the Hubbard and the Anderson models.

A number of studies have revealed its rich phase diagram in two-dimensional lattices, e.g. square and triangular lattices [1,2].

In a square lattice with half-filling, depending on the interaction strength and temperature, FKM exhibits a rich variety of phases: At sufficiently low temperatures, there is a charge density wave (CDW) phase; at high temperatures and weak interactions, a weakly localized phase appears which becomes an Anderson-localized phase in the thermodynamic limit; at high temperatures and strong interactions, a Mott insulating phase emerges [1]. In addition, there are two other phases called 'quantum liquid' and 'classical liquid' in triangular lattices and away from halffilling at sufficiently low temperatures and weak interactions [2]. We set up a Monte Carlo algorithm for the two-dimensional FKM away from the half-filling regime on a kagome lattice to study this model's rich phase diagram, and to extend the previous studies regarding the consequences of geometry on the emegent quantum phases and the corresponding phase transitions.

[1] Phys. Rev. Lett. 117, 146601
[2] Phys. Rev. Lett. 122, 197601

TT 80.12 Thu 15:00 Poster E

Specific heat and magnetocaloric effect measurements as probe of field-induced states in the Cobalt based honeycomb compound $BaCo_2(AsO_4)_2$ — •Sebastian Erdmann[1], Prashanta Mukharjee[1], Philipp Gegenwart[1], and Alexander A. Tsirlin[2] — [1]Experimentalphysik VI, Universität Augsburg, Germany — [2]Felix Bloch Institute for Solid State Physics, Universität Leipzig, Germany

In recent years the honeycomb Kitaev model has attracted much interest, because it can be analytically solved and displays a quantum spin liquid (QSL) state. Realization of the Kitaev interaction requires spin-orbit magnetic moments. Thus, mainly 4d and 5d honeycomb materials, like α-$RuCl_3$ and Na_2IrO_3 were studied in this context. However, recently the $3d^7$ Cobalt based honeycomb compounds such as $BaCo_2(AsO_4)_2$, $Na_2Co_2TeO_6$, and $Na_3Co_2SbO_6$ were predicted as suitable alternatives. Although the Kitaev interaction may be weaker in these materials due to the weaker spin-orbit coupling, it was theoretical predicted, that the QSL state might be more accessible because of the easy suppression of the antiferromagnetic Heisenberg coupling. Among these materials $BaCo_2(AsO_4)_2$ is a suitable candidate as it is free from structural imperfections and has a low critical field required to tune from the ordered to the paramagnetic state. We report specific heat and magnetic Grüneisen parameter measurements on $BaCo_2(AsO_4)_2$ down to the millikelvin range and study the details of the H-T phase diagram. Several field-induced anomalies are observed, whose origin will be discussed.

TT 80.13 Thu 15:00 Poster E

Coherent and screening properties of Dirac electrons — •Max Fischer[1], Arianna Poli[2], Niklas Wagner[1], Alessandro Toschi[3], Sergio Ciuchi[2], and Giorgio Sangiovanni[1] — [1]Universität Würzburg, Würzburg, Germany — [2]Università dell'Aquila, Coppito-L'Aquila, Italy — [3]TU Wien, Vienna, Austria

We investigate the quasi-particle transport properties of a model describing interacting Dirac and Weyl semimetals in the presence of local Hubbard repulsion U, where we explicitly include a deviation from the linearity of the energy-momentum dispersion through an intermediate-energy scale Λ.

In particular we analyze the screening processes affecting the local moments in such correlated Dirac semimetals and compare their physics to corresponding Anderson impurity models.

TT 80.14 Thu 15:00 Poster E

Chiral quantum phase transition in moiré Dirac materials — •Ana García-Page[1] and Laura Classen[1,2] — [1]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany — [2]Department of Physics, Technical University of Munich, D-85748 Garching, Germany

Strong enough interactions induce a semimetal-to-insulator transition in Dirac materials, which can be viewed as the solid-state analogue of the chiral phase transition in quantum chromodynamics. Moiré Dirac materials such as twisted bilayer graphene offer a new opportunity to study this transition because they facilitate tuning the effective interaction via a twist angle. Motivated by this, we explore the quantum phase transition of a 2D Dirac material which spontaneously develops a gap that breaks an Ising symmetry. We model it via an effective Gross-Neveu-Yukawa theory and employ the functional renormalisation group method to map out the phase diagram. We analyse the quantum critical behavior at the transition and investigate the effect of a chemical potential which introduces a finite charge density.

TT 80.15 Thu 15:00 Poster E

Perturbative approach to the quantum phase transition in the Dicke-Ising chain — •Jonas Leibig, Anja Langheld, Max Hörmann, and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

For the first time, we calculate high-order series expansions of the Dicke-Ising chain in the strong-coupling limit. We achieve this by applying a conditional displacement transformation and mapping to a self-consistent matter problem. We improve former results [1, 2] and are now able to derive the exact series results in the thermodynamic limit. We solve the self-consistent equations up to order 20 for ground-state energy and magnetization and analyze the phase diagram.

We examine ferromagnetic and antiferromagnetic Ising interactions, including the Dicke model and quantized transverse-field Ising chain as limiting cases. For ferromagnetic interactions, a second-order quantum phase transition occurs up to J = 0.5h from the Dicke limit and a first-order transition until J = 2h from the other limit. In the range between 0.5h and 2h, distinguishing between a first- and second-order phase transition is challenging. Quantum Monte Carlo simulations support the series approach, particularly for antiferromagnetic Ising interactions.

[1] J. Rohn et al., Phys. Rev. Res. 2, 023131 (2020)
[2] Y. Zhang et al., Sci Rep 4, 4083 (2014)

TT 80.16 Thu 15:00 Poster E

Spin-orbit coupled states arising in the half-filled t_{2g} shell — •Marco Schönleber and Maria Daghofer — Insitut für Funktionelle Materie und Quantentechnologien, Universität Stuttgart

Strongly correlated and spin-orbit coupled t_{2g} systems have been extensively investigated. By coupling orbital and spin angular momentum into one quantity, spin-orbit coupling (SOC) tends to reduce orbital degeneracy, e.g. for the widely studied case of one hole in the t_{2g} shell. However, the opposite has to be expected at half filling. Without spin-orbit coupling, all orbitals are half filled, no orbital degree of freedom is left and coupling to the lattice can be expected to be small. At dominant spin-orbit coupling, in contrast, one of the j=3/2 states is empty and the system couples to the lattice. We investigate this issue. One finding is that the low-energy manifold evolves smoothly from the four S=3/2 states in the absence of SOC to the four j=3/2 states with dominant SOC. These four states are always separated from other states by a robust gap. We then discuss a relevant superexchange mechanism to assess the interplay between spin-orbit coupling and coupling to the lattice.

TT 80.17 Thu 15:00 Poster E

Emergence of magnetism by structural engineering in a spin-orbit coupled oxide — •Ji Soo Lim[1], Martin Kamp[1], Merit Spring[1], Axel Lubk[2], Johannes Schultz[2], Ivan Soldatov[2], Rudolf Schäfer[2], Amar Fakhredine[3], Carmine Autieri[3], Fadi Choueikani[4], Philippe Ohresser[4], Bernd Büchner[2], Giorgio Sangiovanni[1], Michael Sing[1], and Ralph Claessen[1] — [1]Physikalisches Institut and Würzburg-Dresden Cluster of Excellence ct.qmat, Würzburg, Germany — [2]Leibniz Institute for Solid State and Materials Research and Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany — [3]Institute of Physics, Polish Academy of Sciences, Poland — [4]Synchrotron SOLEIL, Ormes les Merisiers, Saint-Aubin, BP 48, Gif-sur-Yvette, France

Iridates exhibit an interesting emergent phenomena due to the interplay of short-range Coulomb interaction, spin-orbit coupling and crystal-field. Here, we manipulate the structural properties of SrIrO3 films by using SrTiO3 (111) substrates. A spontaneous twinned superstructure with a periodicity of 3 unit cells (uc) and unexpected magnetism is found. The interfaces between the 3 uc stacks are distinguished by face-sharing octahedra. We observe two transitons at about 30 and 7 K, linked to magnetism. Below 30 K, the anomalous Hall effect appears, with hysteresis loops below 7 K. X-ray circular magnetic dichroism and magneto-optic Kerr effect microscopy prove the emergence of magnetism below 30 K. Calculations indicate a different electronic band structure due to face-sharing octahedra and two-dimensional ferromagnetism of the interfaces.

TT 80.18 Thu 15:00 Poster E

$TlYbSe_2$ a new member of the $J = 1/2$ triangular lattice Yb delafossite family: from spin liquid to field - induced magnetic order — T. Fujii[1], M. Pillaca[3], F. Bärtl[2], J. Sichelschmidt[1], S. Luther[2], E. Häussler[3], H. Yasuoka[1], J. Wosnitza[2], H. Kühne[2], Th. Doert[3], and •M. Baenitz[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden — [2]Hochfeld-Magnetlabor Dresden, HZDR — [3]Faculty of Chemistry and Food Chemistry, TU Dresden

$TlYbSe_2$ is a new member of the Yb delafossite family [1], which differs strongly from the previous alkali metal Yb delafossites. It is characterized by a much larger saturation field (about 25 T) and a higher transition temperature (about 2 K) of the ordered state. As for the other Yb delafossites, long ranged magnetic order is absent down to low temperatures in zero field. We report detailed macroscopic and microscopic measurements as a function of magnetic field and temperature on polycrystalline samples. Besides bulk methods such as magnetization and specific heat, spectroscopic methods such as ESR and NMR are applied.

[1] B. Schmidt, J. Sichelschmidt, K. M. Ranjith, Th. Doert, and M. Baenitz, Phys. Rev. B 103, 214445 (2021).

TT 80.19 Thu 15:00 Poster E

Magnetic dilution of a frustrated triangular-lattice spin system — •S. Luther[1], F. Bärtl[1,2], E. Häussler[3], T. Doert[3], J. Sichelschmidt[4], T. Kotte[1], J. Wosnitza[1,2], M. Baenitz[4], and H. Kühne[1] — [1]Hochfeld-Magnetlabor Dresden, HZDR — [2]Institut für Festkörper- und Materialphysik, TU Dresden — [3]Fakultät für Chemie und Lebensmittelchemie, TU Dresden — [4]MPI-CPfS, Dresden

Among the Yb-based triangular-lattice antiferromagnets, the delafossite $NaYbS_2$ is one of the candidates for realizing a quantum-spin-liquid (QSL) ground state. The magnetic phase diagram was probed by several experimental methods. The proposed QSL ground state of $NaYbS_2$ is suppressed at fields of several tesla, and long-range order with various spin configurations is manifested. As a next step, we investigated possible changes to this phenomenology by diluting the magnetic lattice of $NaYbS_2$ by means of Lu substitution. We synthesized a series of $NaYb_{1-x}Lu_xS_2$ single crystals, with $0 \leq x \leq 1$, and characterized these crystals by various probes, where the ESR spectroscopy data reveal a systematic reduction of the Weiss temperature as x is increased [1]. Further, we present recent specific-heat, magnetization and NMR measurements for samples with $x = 0.2$, which reveal a reduction of the transition temperature to the field-induced long-range magnetic order. An unchanged enhancement of the nuclear spin-lattice relaxation rate $1/T_1$ at low fields and temperatures indicates the stability of the putative QSL ground state against small levels of magnetic dilution.

[1] E. Häußler et al., Phys. Rev. Mater. **6**, 046201 (2022)

TT 80.20 Thu 15:00 Poster E

Quantum Phase Transitions of Kitaev's Toric Code on a Honeycomb lattice — •Viktor Kott, Matthias Mühlhauser, and Kai Phillip Schmidt — FAU, Erlangen-Nürnberg, Deutschland

We investigate the robustness of the topological phase of Kitaev's toric code in a uniform magnetic field on the honeycomb lattice through perturbative linked cluster expansions using a hypergraph decomposition. This approach allows us to correctly account for the non-trivial mutual exchange statistics of elementary anyonic excitations. By extracting the ground-state energy and excitation energies of the topological phase, we can determine the quantum phase transitions out of this topologically ordered state. In contrast to the conventional toric code on a square lattice, the ground-state phase diagram is dependent on the magnetic field's sign, which distinguishes between unfrustrated and frustrated parameter regimes. Consequently, this leads to distinct quantum-critical properties and a richer phase diagram.

TT 80.21 Thu 15:00 Poster E

Linear and non-linear response of the extended Kitaev model in a magnetic field — •Olesia Krupnitska — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany — Institute for Condensed Matter Physics, National Academy of Sciences of Ukraine, 1 Svientsitskii Street, Lviv, 79011, Ukraine

Investigation of elementary excitations of the generalized Kitaev model plays an important role for understanding the dynamic properties of its solid-state realization. In the present study, we consider linear and non-linear response of the extended Kitaev model induced by an external magnetic field. Linear and non-linear response susceptibilities will be calculated within the Majorana mean-field approach. We discuss how the obtained results can be used for the interpretation of the experimental study of Kitaev-like compounds.

TT 80.22 Thu 15:00 Poster E

Kondo screening in Kitaev-type spin-orbitals liquids — •Christos Kourris and Matthias Vojta — Institut für Theoretische Physik, TU Dresden, Dresden, Germany

In systems of itinerant fermions interacting with local moments, the competition between Kondo screening and various types of symmetry breaking and topological order can give rise to rich phenomenology. The existence and type of screening depend crucially on the low-energy properties of the host system. Here we use suitable mean-field schemes to study situations where a single Kondo impurity is coupled to a Kitaev-type spin-orbital liquid, whose excitations are itinerant Majorana fermions.

TT 80.23 Thu 15:00 Poster E

Thermodynamic and magnetic characterization of the 3D magnetically frustrated langbeinite material $Tl_2Mn_2(SO_4)_3$ — •Alexander Bäder[1], Lucas Berger[1], Ladislav Bohaty[2], Petra Becker-Bohaty[2], Oliver Breunig[1], and Thomas Lorenz[1] — [1]II. Physikalisches Institut, Universität zu Köln — [2]Institut für Kristallographie, Universität zu Köln

According to theory, a 3D antiferromagnetic Heisenberg model with strong geometric frustration can be realized on the so-called trillium lattice [1]. Magnetic trillium lattices can be found in cubic materials of the low-symmetry space group $P2_13$, which is realized by several members of the langbeinite family, but up to now the magnetic properties of such materials have been hardly explored. In a recent study, signatures of a field-driven quantum spin-liquid behavior have been reported for the langbeinite material $K_2Ni_2(SO_4)_3$ with S=1 Ni^{2+} ions on a trillium lattice [2]. Here, we report the thermodynamic and magnetic characterization of the analogous $Tl_2Mn_2(SO_4)_3$ langbeinite with S=5/2 Mn^{2+} ions. From specific heat, magnetocaloric-effect, and magnetization measurements we derive a B–T phase diagram, indicating the presence of at least 3 magnetic phases below a temperature of about 1.5 K. The low ordering temperature in combination with a large field of 15 T to reach magnetic saturation indicates pronounced magnetic frustration.

This work was supported through CRC1238 (projects A02 and B01).

[1] J. Hopkinson, Phys. Rev. B **74**, 224441 (2006)
[2] I. Živković *et al.*, Phys Rev. Lett. **127**, 157204 (2021)

TT 80.24 Thu 15:00 Poster E

Evidence for low temperature magnetic ordering in triangular $YbBO_3$ — •Marvin Klinger[1], Prachi Telang[1], Tim Treu[1], Anna Moser[1], Ramesh Nath[2], Surya Mohanty[2], Gediminas Simutis[3], Anton Jesche[1], and Philipp Gegenwart[1] — [1]EP VI, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg — [2]School of Physics, Indian Institute of Science Education and Research Thiruvananthapuram — [3]Laboratory for Neutron and Muon Instrumentation, Paul Scherrer Institut

The triangular magnet $YbBO_3$ attracted considerable attention as a quantum spin liquid candidate material with absent magnetic long-range order as well as spin freezing down to 20 mK in muon spin rotation (μSR) experiments [1]. In the course of investigating the suitability of this material for millikelvin adiabatic demagnetization refrigeration, we prepared a phase pure $YbBO_3$ powder, mixed it with fine silver powder for optimizing thermal contact and pressed pellets for standardized ADR performance test in the PPMS, similar as in [2]. The heat capacity, determined from the warming curve, indicates a clear and sharp magnetic phase transition at 400 mK, also confirmed by μSR on the same pellet. This indicates that silver is required to bind the grains together for thermal contact, otherwise the sample temperature could be significantly increased leading to wrong conclusions.

Work supported by the German Research Foundation through project 514162746 (GE 1640/11-1).

[1] K. Somesh et al., Phys. Rev. B 107, 064421 (2023).
[2] A. Jesche et al., Phys. Rev. B 107, 104402 (2023).

TT 80.25 Thu 15:00 Poster E

How to: Mean-field calculations with long-range interactions — •Jan Alexander Koziol[1], Giovanna Morigi[2], and Kai Phillip Schmidt[1] — [1]Department of Physics, Staudtstraße 7, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany — [2]Theoretical Physics, Saarland University, Campus E2.6, D-66123 Saarbrücken, Germany

We introduce an approach to set up mean-field calculations for lattice models with long-range interactions. The basic idea of our method is to perform mean-field calculations on all possible unit cells up to a given extend. The long-range interaction is treated without truncation using resummed couplings. One further advantage of the method we present is that all phases with ordering vectors fitting on any of the considered unit cells can be detected within out framework. We describe in detail the underlying theoretical ideas behind the method, the technicalities on how to implement the unit cell generation, and several results we obtained for spin-1/2 degrees of freedom and bosons on the two-dimensional square and triangular lattice.

TT 80.26 Thu 15:00 Poster E

Continuous similarity transformation for Antiferromagnetic Heisenberg model on a honeycomb lattice — •Dag-Björn Hering[1], Matthias R. Walther[2], Kai P. Schmidt[2], and Götz S. Uhrig[1] — [1]Technische Universität Dortmund, Department of Physics, Condensed Matter Theory, Otto-Hahn-Str. 4, 44227 Dortmund — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Institut für Theoretische Physik I, Staudtstraße 7, 91058 Erlangen

In [1,2] Sala et al. showed that YbCl3 realizes the antiferromagnetic spin 1/2 Heisenberg model on the honeycomb lattice by comparing neutron scattering results with linear and self-consistent spin wave theory. However, deviations of the experimental data to the spin wave theory results occurred, namely an anomaly in the one-magnon dispersion at the K-point and in features of the the two-magnon continuum. This suggests that a treatment beyond self-consistent spin wave theory is needed. Continuous similarity transformations (CSTs) quantitively reproduced neutron scattering results for the antiferromagnetic Heisenberg model on a square lattice [3,4,5], where 1/S expansions were not sufficient for quantitative results. Here, we apply to the (CSTs) spin 1/2 Heisenberg model on the honeycomb lattice. The CST flow equations are truncated in momentum space by the scaling dimension d so that all contributions with $d \leq 2$ are taken into account. The resulting quartic magnon-conserving effective Hamiltonian is analyzed in the zero-, one-, and two-magnon sector.

[1] Nat. Commun. 12, 171 (2021)
[2] Commun. Phys. 6, 234 (2023)
[3] Rev. Lett. 115, 207202 (2015)
[4] SciPost Phys. 4, 001 (2018)
[5] Phys. Rev. Res. , 013132 (2023)

TT 80.27 Thu 15:00 Poster E

Thermodynamic properties of the triangular lattice XXZ model — •Alexander Schwenke and Wolfram Brenig — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany

Motivated by its rich ground-state phase diagram, we investigate the triangular lattice XXZ model as a prime example to benchmark the numerical linked cluster expansion (NLCE) as a method for the study of geometrically frustrated quantum magnets. We employ a single-site representation in order to evaluate thermodynamic properties in a finite magnetic field $\vec{B}$. To this end we present results for the internal energy, the specific heat, the magnetization, and the magnetic susceptibility for clusters of sizes up to $\sim \mathcal{O}(11)$ sites. Supplementing these

calculations with exact diagonalization results, we discuss various cuts in the $J-\vec{B}$ plane.

TT 80.28 Thu 15:00 Poster E

Significant suppression of the lattice softening close to the QCP in $CoNb_2O_6$ — •Andreas Hauspurg[1,2], S. Zherlitsyn[1], K. Matsuura[3], T.-H. Arima[4], and J. Wosnitza[1,2] — [1]Hochfeld-Magnetlabor Dresden, HZDR, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]RIKEN Center for Emergent Matter Science, Japan — [4]Department of Advanced Materials Science, University of Tokyo, Japan

$CoNb_2O_6$ is a model system for the spin-$\frac{1}{2}$ one-dimensional transverse field Ising model and shows a quantum critical point (QCP) at 4.75 T for $H \parallel b$. Neutron-diffraction experiments have revealed a set of discrete collective spin modes in $CoNb_2O_6$, which follow the long-sought E8 symmetry at the QCP. This proposition is supported by investigations with THz spectroscopy and NMR, which suggest that a one-dimensional QCP might lie within the 3D ordered phase [1, 2, 3].

We studied $CoNb_2O_6$ by means of the ultrasound pulsed-echo technique and investigated the in field magnetoelastic properties down to lowest temperatures of 0.3 K. In our contribution we present and discuss a significant suppression of the elastic softening related to the QCP. We studied this behavior to much lower temperatures than done before [4].

[1] Coldea *et al.*, Science 327, 177 (2010).
[2] Amelin *et al.*, Phys. Rev. B 102, 104431 (2020).
[3] Kinross *et al.*, Phys. Rev. X 4, 031008 (2014).
[4] Matsuura *et al.*, Phys. Rev. Lett. 124, 127205 (2020).

TT 80.29 Thu 15:00 Poster E

Unconventional magnetic excitation in novel frustrated spin-1/2 triangular antiferromagnets — •Fanjun Xu[1,2], Nazmul Islam[1], and Bella Lake[1,2] — [1]Helmholtz-Zentrum Berlin, DE — [2]Technische Universität Berlin, DE

In frustrated magnets, many exotic quantum phenomena can appear as a consequence of the competing interaction. One of the most celebrated examples is the highly degenerated ground state of unsatisfied spins on the triangular lattice antiferromagnet (TLAF). Theoretical studies suggest spin-1/2 TLAF develops long-range magnetic order at the ground state, combined with broadened and renormalized downward magnon excitations.

Surprisingly, a recent inelastic neutron scattering experiment on the spin-1/2 TLAF $Ba_3CoSb_2O_9$ reveals unconventional multiband higher energy excitations. To clarify whether this unconventional higher energy excitation continuum is universal for spin-1/2 triangular antiferromagnets or not, an inelastic neutron scattering experiment on high-quality polycrystalline $Ba_3CoNb_2O_9$ and $Ba_3CoTa_2O_9$ was performed.

In this poster, the magnetic excitations of the novel spin-1/2 TLAF $Ba_3CoNb_2O_9$ and $Ba_3CoTa_2O_9$ will be presented. The strong quantum fluctuations of the effective S-1/2 cobalt moments are evident by the higher energy continuum qualitatively observed in both compounds. The single-magnon scattering will be discussed in detail with a Heisenberg model.

TT 80.30 Thu 15:00 Poster E

Crystal growth and investigation of metallic kagome magnet $GdMn_6Ge_6$ — •Katharina M. Zoch, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt am Main, Germany

Metallic kagome systems show topologically nontrivial magnetic and electronic structures with the AT_6X_6-compounds counting as one of the prototypes of this material class [1]. The unique magnetism and interesting band structure makes them an ideal family to tune exotic magnetic and topological states using external parameters. So far, most work is based on polycrystalline samples, especially for the AMn_6Ge_6 (A = lanthanide) compounds. The typical self-flux crystal growth is challenging and has only been successfully performed for compounds with AMn_6Ge_6 (A = Tb-Lu) [2]. Here, we present the growth of $GdMn_6Ge_6$ crystals using a self-flux method as well as their chemical and physical characterization.

[1] N. J. Ghimire et al., Sci. Adv. 6, eabe2680 (2020)
[2] H. Zhou et al., Phys. Rev. Materials 7, 024404 (2023)

TT 80.31 Thu 15:00 Poster E

Optical conductivity of the kagome magnets FeSn and Fe_3Sn_2: search for Weyl cone and flat band excitations — •Jihaan Ebad-Allah[1,2], Fabian Meggle[1], Raphael Borkenhagen[1], Lilian Prodan[3], Vladimir Tsurkan[3], Felix Schilberth[3], István Kézsmárki[3], and Christine Kuntscher[1] — [1]Experimentalphysik II, Universität Augsburg, 86159 Augsburg, Germany — [2]Department of Physics, University of Tanta, 31527 Tanta, Egypt — [3]Experimentalphysik V, Center for Electronic Correlations and Magnetism, Institute for Physics, Universität Augsburg, D-86135 Augsburg, Germany

Magnetic materials with kagome-lattice arrangement have recently attracted considerable interest due to their remarkable electronic and magnetic properties such as topological Weyl semimetal state, topological superconductivity, and anomalous Hall effect. Kagome magnets FeSn and Fe_3Sn_2 belong to this material class, where theoretical calculations predict the existence of flat bands, nodal points, and helical nodal-lines in the vicinity of the Fermi energy, which motivated us to search for their fingerprints in the optical conductivity. Thus, we performed temperature-dependent reflectivity measurements on single crystals of both compounds. Our results reveal a similar profile of the optical conductivity spectrum for both materials, namely, intraband contributions at low energy, a dip below 0.16 eV, and a pronounced absorption band at around 0.4 eV followed by an increase of σ_1 towards higher energies. We relate the observed excitations to possible transitions between electronic bands predicted by theoretical calculations.

TT 80.32 Thu 15:00 Poster E

Magnetic phase diagram of the frustrated kagome system clinoatacamite — •Aaron Schulze[1], Carolin Kastner[1], Leonie Heinze[1], Dirk Menzel[1], Manfred Reehuis[2], Ralf Feyerherm[2], Kirrily Rule[3], Anja Wolter[4], and Stefan Süllow[1] — [1]IPKM, TU Braunschweig, Germany — [2]HZB, Berlin, Germany — [3]ANSTO, Australia — [4]IFW, Dresden, Germany

The natural mineral clinoatacamite ($Cu_2Cl(OH)_3$) has been discussed as geometrically frustrated magnet. The Cu^{2+} ions form a system of kagome layers with an antiferromagnetic in-plane coupling. This type of geometrical frustration leads to exotic quantum states at low temperatures. Here, we present an extensive study using single crystalline material that reveal a complex magnetic phase diagram of the material at low temperatures.

The measurements of the specific heat, magnetic susceptibility and magnetization as well as neutron scattering experiments indicate the existence of several magnetic phases. It is known that the uppermost magnetic phase has an ordering temperature of 18.1 K. The microscopic details of this phase are unknown. The lowest temperature phase exhibits signs of canted antiferromagnetism. Several exotic intermediate phases, whose microscopic behaviour is unclear, exist between these phases. From our data we construct the magnetic phase diagram for magnetic fields parallel and perpendicular to the kagome planes.

TT 80.33 Thu 15:00 Poster E

μm-beam LEED study of the charge density wave in the kagome metal CsV_3Sb_5 — •Lukas Jehn[1], Felix Kurtz[1], Alp Akbiyik[1], Gevin von Witte[2], Amir Haghighirad[3], Dong Chen[4], Chandra Shekhar[4], Hannes Böckmann[1], Matthieu Le Tacon[3], Claudia Felser[4], and Claus Ropers[1,5] — [1]Max Planck Institute for Multidisciplinary Sciences, D-37077 Göttingen — [2]Department of Information Technology and Electrical Engineering, ETH Zürich, CH-8093 Zürich — [3]Institute for Quantum Materials and Technologies, KIT, D-76344 Eggenstein-Leopoldshafen — [4]Max Planck Institute for Chemical Physics of Solids, D-01187 Dresden — [5]4th Physical Institute, University of Göttingen, D-37077 Göttingen

The discovery of the novel kagome metal CsV_3Sb_5 [1] sparked broad interest due to the coexistence of a charge density wave (CDW) phase and possible unconventional superconductivity [2]. We used low-energy electron diffraction (LEED) with a μm-sized electron beam [3] to study the structural CDW phase transition. We recorded high-quality backscattering diffraction patterns in ultrahigh vacuum from multiple cleaved samples. Surprisingly, we did not find superstructure reflexes at intensity levels predicted from dynamic LEED calculations based on the lattice distortion in the bulk. Therefore, we conclude that the periodic lattice distortion accompanying the CDW in CsV_3Sb_5 is less pronounced at surfaces than in the bulk.

[1] B. R. Ortiz et al., Phys. Rev. Mater. 3, 094407 (2019)
[2] B. R. Ortiz et al., Phys. Rev. Lett. 125, 247002 (2020)
[3] G. Storeck et al., Struct. Dyn. 4, 044024 (2017)

TT 80.34 Thu 15:00 Poster E

NMR of the Ising-type spin chain $BaCo_2V_2O_8$ at pulsed mag-

netic fields — D. Opherden[1], Z. Wang[2], Y. Ihara[3], K. Matsui[4], T. Kotte[1], S. Yamamoto[1], J. Wosnitza[1], S. Luther[1], T. Lorenz[5], and •H. Kühne[1] — [1]HLD-HZDR, Dresden — [2]Department of Physics, TU Dortmund — [3]Department of Physics, Hokkaido University — [4]Institute for Solid State Physics, Tokio — [5]Institute of Physics II, University of Cologne

NMR measurements at pulsed magnetic fields have been developed at dedicated large-scale research facilities for some time and are becoming increasingly available for user experiments. We will present our new results on the Ising-type spin-chain system $BaCo_2V_2O_8$, which hosts a quantum critical point at 40 T for magnetic fields applied transverse to the Ising axis. We studied $BaCo_2V_2O_8$ using ^{51}V NMR with pulsed magnetic fields up to about 60 T. The resulting NMR spectra probe the local uniform magnetization up to and across the regime of the quantum critical point. In the saturated regime, the field-induced suppression of electronic-moment fluctuations enables the detection of otherwise undetectable ^{59}Co NMR spectra, providing complementary insight into the field-driven polarization process of the Co^{2+} moments.

TT 80.35 Thu 15:00 Poster E

Charge-Density wave in a two-band model of infinite-layer nickelates — •Tharathep Plienbumrung[1], Maria Daghofer[1], Jean-Baptiste Morée[2], and Andrzej Oleś[3] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Stuttgart, Germany — [2]Waseda Research Institute for Science and Engineering, Waseda University, Tokyo, Japan — [3]Institute for Theoretical Physics, Jangiellonian University, Krakow, Poland

Recent measurements on infinite-layer (IL) nickelate compounds have found a charge-ordered state in the undoped compound as well as, short-range magnetic behavior. These measurements highlight the significant role of the rare-earth orbitals on nickelate compound, and the importance of nonlocal correlations in studying IL nickelate. Here, we study the two-band model of IL nickelate, including intersite Coulomb interaction, at quarter-filling on cubic lattice. We employ variational cluster approach (VCA) to study the spin and charge properties of the model at thermodynamics limit. The short-range correlations within cluster size are solved exactly while the long-range interactions beyond the cluster are included via mean-field approximation. We show that the intersite Coulomb interactions are substantial, creating the interplay between the spin and charge fluctuations in the IL nickelate. Furthermore, we explore the effect of doping on the charge and magnetic properties of the model. The single-particle spectral functions of the model at different doping level will be presented.

TT 80.36 Thu 15:00 Poster E

Transport properties and magnetization of $Sr_4Ru_3O_{10}$ — •Lara Pätzold[1], Zahra Ghazinezhad[1], Agustinus A. Nugroho[2], Markus Braden[1], and Thomas Lorenz[1] — [1]II. Physikalisches Institut, Universität zu Köln, Germany — [2]Bandung Institute of Technology, Indonesia

The layered transition metal oxide $Sr_4Ru_3O_{10}$ is a member of the Ruddlesden-Popper series and crystallizes in an orthorhombic structure. It is a ferromagnetic metal with $T_c \approx 105$ K and an additional metamagnetic transition at 50 K, where a deeper understanding of the magnetism is still missing. We present a study of single crystals of $Sr_4Ru_3O_{10}$ in terms of magnetization and electrical transport properties. We measured in-plane and out-of-plane magnetization and also investigated a possible anisotropy in the ab plane. Additionally we measured longitudinal ρ_{xx} and Hall resistivity ρ_{xy} with the magnetic field applied in the c direction. We observe a normal and anomalous Hall effect, whereby the latter shows a non-monotonic temperature dependence. In addition, the magnetoresistance changes sign at low temperatures. Analogous behavior of ρ_{xx} and ρ_{xy} is seen in the sister compound $SrRuO_3$, which in addition shows a anomalous spin dynamics [1]. All of these observations are associated to Weyl points in the bandstructure [2].

Funded by the DFG via CRC 1238 Projects A02, B01 and B04

[1] K. Jenni et al., Phys Rev Lett. **123**, 017202 (2019)
[2] K. Takiguchi et al., Nat. Commun. **11**, 4969 (2020)

TT 80.37 Thu 15:00 Poster E

Experimental signatures of gate tunable superconductivity in Al/STO heterostructures — •Jaydean Schmidt, Matthias Kronseder, Nicola Paradiso, and Christoph Strunk — Department of Exp. and Appl. Physics, University of Regensburg (Germany)

We demonstrate the effect of strong electric fields on aluminum (Al) thin films epitaxially grown on strontium titanite (STO) substrates. As a quantum paraelectric, STO has a large dielectric constant ($\varepsilon \approx 7000$), causing strong charge accumulation at the interface. STO based heterostructures have gained significant attention in the context of interface superconductivity [1]. The growth of certain metals onto STO induces the formation of oxygen vacancies in STO, acting as double electron donors in the highly conductive interface layer.

By applying an external electric field, we obtain a hole density of the combined Al/STO system $n \approx 2$ - $7\times10^{20}/\mathrm{m}^2$. These values are similar to Al films ($\approx 10^{21}/\mathrm{m}^2$) but much higher than the values measured for LAO/STO interface 2DEGs ($\approx 10^{18}/\mathrm{m}^2$), indicating a charge flow dominated by Al charge carriers. Furthermore, both $T_c(n)$ and $B_c(T,n)$ are gate tunable, up to 15% and 50%, respectively. We found that $T_c \approx 0.92$ - 1.06 K is much lower compared to isolated thin Al films (≈ 1.4 K) yet higher than in STO. The system thus behaves like a bilayer of two superconductors with different gap that forms one proximity coupled system. It is surprising that the hybrid film remains gate tunable, despite the high carrier density of Al.

[1] N. Reyen et. al, Science, **317**, 1196 (2007)

TT 80.38 Thu 15:00 Poster E

High-pressure study of CDW in 2H-TaSe$_2$ — •Yuliia Tymoshenko[1], Amir-Abbas Haghighirad[1], Tom Lacmann[1], Alsu Ivashko[1], Gaston Garbarino[2], Luigi Paolasini[2], and Frank Weber[1] — [1]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [2]European Synchrotron Radiation Facility, 71 avenue des Martyrs, CS 40220, Grenoble 38043, France

The study of charge density wave (CDW) materials is one of the most intriguing areas of modern solid state physics, since CDW often appears close to superconductivity (SC). The relationship between these phenomena, whether it be cooperation, competition, or simply coexistence, has been a subject of long-standing controversy. 2H-TaSe$_2$, a prototypical transition metal dichalcogenide (TMD) in which CDW and SC are intertwined, serves as a promising material to shed light on the interplay of both cooperative electron phenomena. Here we present our recent high-pressure x-ray diffraction (XRD) and spectroscopy (IXS) measurements showing a full suppression of the CDW by pressure, revealing a quantum critical point (QCP). The data shows a close connection between the QCP and the emegnent superconducting phase.

TT 80.39 Thu 15:00 Poster E

Interplay between the coupled electronic and lattice orders in unconventional CDW systems $BaNi_2As_2$ studied by collective mode spectroscopy — •Chandra Vardhan Kotyada[1], Priyanka Yogi[1], Amon P. Lanz[1], Amrit R. Pokharel[1], Amir A. Haghighirad[2], Matthieu Le Tacon[2], and Jure Demsar[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany — [2]Institute for Quantum Materials and Technologies, KIT, 76344 Karlsruhe, Germany

Time-resolved reflectivity studies of in $BaNi_2As_2$, a non-magnetic analogue of the parent compound of a pnictide superconductor $BaFe_2As_2$, reveal the existence of several charge-density-wave (CDW) amplitude modes[1], as in prototype CDW systems[2]. Their temperature and excitation density dependence suggest the charge-order driven nematicity in $BaNi_2As_2$ and support the idea of orthorhombic-triclinic structural symmetry phase transition being mediated by the stabilization of the CDW order[1]. We extend our studies to cover a large range in P-substituted $BaNi_2(As_{1-x}P_x)_2$[3]. Beyond the triclinic critical point (x 0.07), where also six-fold enhancement of superconducting T_c is observed[3], only two strongly damped sub-THz amplitude modes are resolved. The fact that diffraction and spectroscopic data[3] imply the absence of orthorombic distortions in samples beyond x 0.07 suggests the changes in the collective mode spectrum may be linked to variation in nematicity.

[1] A.R. Pokharel et. al., Comm. Phys. 5, 141 (2022)
[2] K. Warawa et al., Phys. Rev. B 108, 045147 (2023)
[3] Y. Yao et al., Nat. Commun. 13, 4535 (2022)

TT 80.40 Thu 15:00 Poster E

Optical investigation of altering correlation strength driven phase transition in 2D correlated molecular conductors — •Savita Priya, Dieter Schweitzer, and Martin Dressel — 1. Physikalisches Institut, Universität Stuttgart, Germany

Two-dimensional molecular electron systems are considered model systems for studying low-dimensional physics; exhibiting interesting phase diagrams with exotic charge and magnetic ordering phenomena, electronic correlations and coupling of the electron system with the underlying molecular and lattice system. The quasi-two-dimensional BEDT-TTF charge transfer salts can be tuned by chemical means, i.e. change of counter anion or partial atomic substitution in the organic layers, leading to a subtle modification of the coupling. Here we partialy substitute sulfur with selenium atoms in the organic framework of α-(BEDT-TTF)$_2$I$_3$, known for its metal-insulator phase transition at 135 K, forming α-(BEDT-STF)$_2$I$_3$ and α-(BEDT-TSF)$_2$I$_3$. We investigate changes in electronic behavior on the phase transition from the metallic to low temperature insulating phase in the substituted counterparts of α-(BEDT-TTF)$_2$I$_3$ (below 66 K for BEDT-STF and 40 K for BEDT-TSF). The chemical modification affects the molecular orbital overlap asymmetrically in BEDT-STF and symmetrically in BEDT-TSF. Our approach combines wide-ranged infrared spectroscopy with temperature variation (down to 12 K) to analyze changes in electronic response, focusing on order and temperature change of phase transition.

TT 80.41 Thu 15:00 Poster E

Unveiling the optical behavior of a doped molecular quantum spin liquid candidate — Savita Priya[1], Sudip Pal[1], Christian Prange[1], Hiromi Taniguchi[2], and •Martin Dressel[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Germany — [2]Graduate School of Science and Engineering, Saitama University, Japan

Quantum spin liquid (QSL) materials, identified by antiferromagnetic spin arrangement in a triangular lattice, have attracted attention ever since it was theorized. Study of the experimentally challenging QSL state, described by absence of long-range magnetic order due to geometric frustration involves techniques such as thermodynamic methods and magnetic probes to elucidate the magnetic properties. Among molecular QSLs, the κ-phase BEDT-TTF salts are notably significant as their triangular lattice points consist of BEDT-TTF dimer, in contrast to the atomic arrangement in inorganic QSL candidates. Owing to the incommensurate interpenetrating sublattice structure, a quasi-two dimensional organic conductor, κ-(BEDT-TTF)$_4$Hg$_{2.89}$Br$_8$ has gained attention as a doped QSL candidate. The unconventional stoichiometry results in 11complexity and plausible inhomogeneity. It is interesting to compare the electronic properties with the isostructural QSL candidate, κ-(BEDT-TTF)$_2$Cu$_2$(CN)$_3$. Here we present the results of our detailed infrared investigations of the correlated electron system κ-(BEDT-TTF)$_4$Hg$_{2.89}$Br$_8$ in a wide temperature and spectral range revealing insights into charge dynamics, vibrational properties, subtle temperature-induced changes in the electronic behavior and the anisotropic optical response.

TT 80.42 Thu 15:00 Poster E

Unusual magnetic anisotropy of the near-room-temperature ferromagnet Fe_4GeTe_2 — Riju Pal[1,2,3], Joyal J. Abraham[1,2], Suchanda Mondal[4], Prabhat Mandal[3], Atindra Nath Pal[3], Bernd Büchner[1,2], Vladislav Kataev[1], and •Alexey Alfonsov[1] — [1]Leibniz IFW Dresden, 01069 Dresden, Germany — [2]TU Dresden, 01062 Dresden, Germany — [3]S. N. Bose National Centre for Basic Sciences, 700106 Kolkata, India — [4]Saha Institute of Nuclear Physics, 700064 Kolkata, India

The representative of the family of two-dimensional conducting materials with high ferromagnetic ordering temperature, the Fe_4GeTe_2 compound features a peculiar spin reorientation transition at $T_{SR} \sim 110$ K suggesting a non-trivial temperature evolution of the magnetic anisotropy (MA). Here, we report an electron spin resonance (ESR) study of MA in this compound. We found that above a characteristic temperature of $T_{shape} \sim 150$ K the total magnetic anisotropy is mostly given by the demagnetization effect. Below T_{shape} we observed the growth of the intrinsic magnetic anisotropy that counteracts the shape anisotropy, rendering the sample seemingly isotropic at T_{SR}. At all temperatures from 3 K up to 300 K the main contribution to the intrinsic magnetic anisotropy is found to be of an easy-axis type. Below another characteristic temperature $T_d \sim 50$ K the anisotropy becomes even more complex than a simple easy-axis type. The temperatures characteristic for the evolution of intrinsic magnetic anisotropy match those observed in transport measurements, suggesting an inherent coupling between magnetic and electronic degrees of freedom in Fe_4GeTe_2.

TT 80.43 Thu 15:00 Poster E

Multipartite entanglement in the spin-1 bilinear-biquadratic chain — •Malo Rouxel and Andreas Honecker — Laboratoire de Physique Théorique et Modélisation, CNRS UMR 8089, CY Cergy Paris Université, France

The spin-1 bilinear-biquadratic chain represents the most general model for an isotropic exchange interaction in a spin-1 chain. In this model, the Hamiltonian can be expressed as a function of θ:

$$H = \sum_i (\cos(\theta)(S_i S_{i+1}) + \sin(\theta)(S_i S_{i+1})^2).$$

The chain exhibits several phases depending on the value of θ: the Haldane phase, a dimerized phase, a ferromagnetic phase, and a gapless phase. We show that proper multipartite entanglement measures enable the differentiation of various behaviors of the ground state depending on θ, and thus the identification of the corresponding phases. This ground state is obtained by diagonalizing the Hamiltonian using the Lanczos algorithm and the divide-and-conquer eigenvalue algorithm. As the ground state can be degenerate, symmetries and conservation laws are also studied.

TT 80.44 Thu 15:00 Poster E

A Combinatorial Method for Calculating Moments of Many-Body Operators — •Elaheh Adibi and Erik Koch — Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

We introduce an approach for calculating the moments for many-electron systems defined as $\langle E^M \rangle = \mathrm{Tr}\, H^M$ where H denotes the Hamiltonian in second quantization. Working in a basis of Slater determinants, $|I\rangle$, matrix elements $\langle I|H^M|I\rangle$ can only be non-zero if the orbital indices of the creation operators are a permutation of those of the annihilation operators. Classifying all permutations in terms of cycles enables us to calculate $\sum_I \langle I|H^M|I\rangle$ for different classes of cycles which is proportional to a binomial involving the number of orbitals and electrons. This binomial is then simply multiplied by the appropriate Eulerian number, which determines the number of permutations of a cycle with a given number of ascents.

TT 80.45 Thu 15:00 Poster E

Efficient Spin-Structure Estimation through Flavor-Specific Twisted Boundary Conditions — •Benjamin Heinrich — Institut für funktionelle Materie und Quantentechnologie, Universität Stuttgart

The challenge of constrained cluster sizes arising from the escalating computational demand of exact diagonalization (ED) can be addressed by extending periodic with twisted boundary conditions. By employing flavor-specific twisted boundary conditions, wherein each spin gains a distinct phase during hopping, additional points in momentum space become accessible when computing the spin excitation spectrum. In this study, we explore the viability of this approach by applying it to the Hubbard model on one- and two-dimensional lattices. Our findings indicate that this method produces reliable results in scenarios where the pertinent physics is predominantly captured by a single quasiparticle (e.g., one magnon), even if the relevant magnetic order is incommensurate with the bare lattice. However, its reliability diminishes in more intricate situations (e.g., two spinons). For the former case, this methodology provides a valuable initial insight into excitation spectra with minimal computational demands and can be easily integrated into existing ED code.

TT 80.46 Thu 15:00 Poster E

Hypergraph Decompositions — •Matthias Mühlhauser and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

A crucial element of graph-based linked-cluster expansions is to identify structurally equivalent clusters. To this end the clusters are typically represented by graphs, where the vertices represent the sites and the edges represent the couplings between the sites. The structural equivalence of clusters corresponds to isomorphism of the respective graphs.

However, if (possibly oriented) many-site couplings exist such a graph representation is typically not obvious, whereas hypergraphs naturally capture this structure. Interestingly, it is known that hypergraphs can be unambigously represented by bipartite graphs. We exploit this representation to distinguish equivalence classes of clusters and set up linked-cluster expansions via full hypergraph decompositions [1].

[1] Phys. Rev. E 105, 064110

TT 80.47 Thu 15:00 Poster E

Accelerating nonequilibrium Green function simulations with embedding self-energies — •Jan-Philip Joost[1], Karsten Balzer[2], Hannes Ohldag[1], and Michael Bonitz[1] — [1]Kiel University, Institute for Theoretical Physics and Astrophysics, 24098 Kiel, Germany — [2]Computing Center of Kiel University, 24118 Kiel, Germany

Real-time nonequilibrium Green functions (NEGFs) have been very successfully used to simulate the dynamics of correlated many-particle systems far from equilibrium. However, NEGF simulations are computationally expensive since the effort scales cubically with the simulation duration. Recently, we introduced the G1-G2 scheme that allows for a dramatic reduction to time-linear scaling [1]. While previous applications focused on isolated systems, here we extend the G1-G2 scheme to open systems applying the NEGF-concept of an embedding selfenergy. We demonstrate how this concept can be transformed into a time linear system of equations and present results for the charge transfer between correlated 2D materials and an external ion [2].

[1] N. Schlünzen, J.-P. Joost and M. Bonitz, Phys. Rev. Lett. 124, 076601 (2020)
[2] K. Balzer, N. Schlünzen, H. Ohldag, J.-P. Joost, and M. Bonitz, Phys. Rev. B 107, 155141 (2023)

TT 80.48 Thu 15:00 Poster E

Green's functions of quantum impurity systems from MPS-based band Lanczos — •Coraline Letouzé[1], Guillaume Radtke[1], Benjamin Lenz[1], and Sebastian Paeckel[2] — [1]Sorbonne Université, Muséum National d'Histoire Naturelle, UMR CNRS 7590, Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, IMPMC, 75005 Paris, France — [2]Department of Physics, Arnold Sommerfeld Center for Theoretical Physics (ASC), Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, 80333 München, Germany

Quantum impurity models are important both on their own (see e.g. Kondo effect or quantum dots) and as solvers for embedding techniques such as the dynamical mean-field theory (DMFT). Accurately calculating the Green's functions of such interacting quantum many-body systems is still a challenging problem. To that aim, we implement the (band) Lanczos algorithm for matrix-product states (MPS). It allows us to compute real-frequency Green's functions by diagonalizing the Krylov projection of the Hamiltonian, while efficiently compressing the many-body wavefunctions. We present results for the 2D Hubbard model and DMFT-based impurity models of transition metal oxides.

TT 80.49 Thu 15:00 Poster E

The Orthonormalized Kernels Representation: a semi-analytic compression algorithm for imaginary axis Greens functions — •Andreas Hausoel[1,2], Max Fischer[3,2], Giorgio Sangiovanni[3,2], Jeroen van den Brink[1,2], and Oleg Janson[1,2] — [1]Institute for Theoretical Solid State Physics, Leibniz IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence Ct.qmat, Technische Universität Dresden, 01062, Dresden, Germany — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Recently there were introduced two novel and exciting representations (= quantum mechanical basis sets) of Greens functions on the imaginary axis: the intermediate representation (IR) and the discrete Lehmann representation (DLR). They optimally compress the physical information (removing all the noise and redundant data) in two very different ways. However, both have a drawback, preventing them from becoming 'the' new basis for quantum mechanical calculations: the analytical form of the IR is not known, and the DLR is not orthonormal.

The Orthonormalized Kernels Representation (OKR) manages to cure their drawbacks and unite their advantages. However, this construction creates a severe problem at an entirely different place: nonlinear diagrammatic equations become intracable.

With our poster we explain this new perspective on the subject and put the manifold possibilities for further advance up for discussion.

TT 80.50 Thu 15:00 Poster E

Convergence behaviour of numerical linked-cluster expansions — •Harald Leiser, Max Hörmann, and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

An important step in understanding dynamical properties of quantum many-body systems is the investigation of one-particle properties in the thermodynamic limit. For a Hamiltonian $H = H_0 + xV$ we derive an effective block-diagonal Hamiltonian $H_{\text{eff}} = T^{\dagger}HT$ with the projective cluster-additive transformation [1]. We calculated numerical linked-cluster expansions (NLCEs) for the antiferromagnetic transverse-field Ising model on a chain, ladder, triangular stripe and a sawtooth chain and obtained $S = \log(T)$ and H_{eff}. Moreover, we compared the convergence of the NLCE for the models under study with regards to the used unit cell expansion. Especially for the saw-tooth chain, a comparison with an expansion into triangles showed better agreements with extrapolations of existing series expansion [2]. Apart from that, we expand the framework to obtain one-particle properties more efficiently. To be concrete, we use the information on S of a cluster expansion up to a cluster-size with N spins to calculate $\exp(-S)H\exp(S)$ in the thermodynamic limit and compare this with the usual NLCE up to the same cluster-size.

[1] M. Hörmann et al., SciPost Phys. 15 (2023) 097
[2] D. J. Priour et al., Phys. Rev. B 64 (2001) 134424

TT 80.51 Thu 15:00 Poster E

Actively moving domain in a driven ferrimagnet — •Reza Doostani, Achim Rosch, Dennis Hardt, and Nina del Ser — Institute for Theoretical Physics, University of Cologne, Germany

We investigate the behavior of a ferrimagnet driven by a weak oscillating staggered magnetic field. The undriven system can be described by Heisenberg energy term and magnetocrystalline anisotropy. Numerical and analytical studies of this classical spin model using Landau-Lifshitz-Gilbert equation show the existence of a rotational Goldstone mode. We Also study the long-range order of the system in presence of thermal fluctuation in one and three dimension. Further analysis can be done by inserting a domain wall into the system. Driving the system results in the movements of domain wall with speed v which interestingly is linear to the field amplitude. This claim is realized both analytically and numerically.

TT 80.52 Thu 15:00 Poster E

Transverse Ising model in curved 2D geometries — •Grigorios Makris[1], Ion Cosma Fulga[2,3], and Fabian Hassler[1] — [1]Institute for Quantum Information, RWTH Aachen University, Germany — [2]Institute for Theoretical Solid State Physics, IFW Dresden, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany

The transverse field Ising model is a prime example of a quantum phase transition. The one dimensional model has been solved analytically as it maps to a free fermion system and rigorous results for its scaling properties have been obtained. The two dimensional model has been evaluated numerically in two dimensional flat space.

Here, we study the transverse field Ising model in a curved two dimensional geometry. We investigate the finite size effects near the infinite critical point and its scaling in the thermodynamic limit.

TT 80.53 Thu 15:00 Poster E

Understanding the supercritical phase of the Hubbard model with timescales of the local moment screening — •Léo Gaspard[1,2] and Jan M. Tomczak[2,3] — [1]Laboratoire de Chimie et Physique Quantiques, Université Toulouse III - Paul Sabatier, Toulouse, France — [2]Institut für Festkörperphysik, Technische Universität Wien, Wien, Austria — [3]King's College London, London, United Kingdom

A material's phase diagram typically indicates the types of realized long-range orders, corresponding to instabilities in static response functions. In correlated systems, however, key phenomena crucially depend on dynamical processes, too: In a Mott insulator, the electrons' spin moment fluctuates in time, while it is dynamically screened in Kondo systems. Here, we introduce a timescale "t_m" characteristic for the screening of the local spin moment and demonstrate that it fully characterizes the dynamical mean-field phase diagram of the Hubbard model: The retarded magnetic response delineates the Mott transition and provides a new perspective on its signatures in the supercritical region above. We show that "t_m" has knowledge of the Widom line and that it can be used to demarcate the Fermi liquid from the bad metal regime. Additionally, we identify a region with preformed local moments that we suggest to have a thermodynamic signature.

TT 80.54 Thu 15:00 Poster E

Dynamically generated quadrupole polarization using Floquet adiabatic evolution — •Gonzalo Camacho, Christoph Karrasch, and Roman Rausch — Technische Universität Braunschweig, Institut für Mathematische Physik, Mendelssohnstrasse 3, 38106 Braunschweig, Germany

We investigate the nonequilibrium dynamics of the S = 1 quantum spin chain subjected to a time-dependent external drive, where the driving frequency is adiabatically decreased as a function of time (Floquet adiabatic evolution). We show that, when driving the rhombic anisotropy term (known as the two-axis countertwisting in the context of squeezed spin states) of a Néel antiferromagnet, we can induce an overall enhancement in the quadrupole polarization, while at the same time suppressing the staggered magnetization order. The system evolves into a new state with a net quadrupole moment and antiferroquadrupolar correlations. This state remains stable at long times once the driving frequency is kept constant. On the other hand, we find that we cannot achieve a quadrupole polarization for the symmetry-protected Haldane phase, which remains robust against such driving.

[1] C. Camacho et al., Phys. Rev. Res. 5, 023015 (2023)

TT 80.55 Thu 15:00 Poster E

Formation and stability of Floquet-Bloch bands in a quasi-1D model of interacting spinless fermions. — •Manuel Buriks, Karun Gadge, and Salvatore R. Manmana — Institut für Theoretische Physik, Georg-August-Universität Göttingen, Deutschland

Motivated from the search of Floquet side bands (FBs) in experiments on different materials, we study the time evolution of periodically driven interacting spinless fermions on a quasi-1D system resembling a graphene stripe. Using matrix product states (MPS), we compute the time-evolution of the spectral function and study the formation and stability of FBs for different setups.

TT 80.56 Thu 15:00 Poster E

Relaxation dynamics in the one-dimensional Kondo lattice model — •Arturo Perez Romero and Fabian Heidrich-Meisner — Institut for Theoretical Physics, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany

We study the real-time dynamics of optically excited electrons coupled in a paradigmatic model describing the coupling between localized and conduction electrons, the Kondo lattice model. In particular, we analyze the role of localized electrons interacting with a highly excited carrier at low density for an antiferromagnetic coupling ($J > 0$) via the time-dependent Lanczos method. We implement a ferromagnetic orden for the localized electrons and an opposite spin for the itinerant electron as our initial state. We perform an extensive analysis of the time evolution by calculating the spin-spin correlation between localized electrons and between delocalized and localized electrons and the electronic momentum distribution function. We discuss several dynamical properties, such as the magnetization transfer from the charge carrier to localized spins, the approach of the system to the steady state, and the transient dynamics by considering long and short time scales.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) via CRC 1073.

TT 80.57 Thu 15:00 Poster E

Application of the TraSPI Method to Aharonov-Bohm Interferometers with Interacting Quantum Dots. — •Alexander Hahn, Jürgen König, and Fred Hucht — Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany

Utilizing the "Transfer-matrix Summation of Path Integrals" (TraSPI) approach[1], we extend the method's application to the study of quantum transport in an Aharonov-Bohm interferometer accommodating two quantum dots. Here, the usage of the TraSPI method allows for the calculation of the current influenced by the enclosed magnetic flux and on-site Coulomb interactions. The numerical accuracy and efficiency of the TraSPI method allow for a detailed exploration of the interplay between quantum coherence and dot interactions.

[1] S. Mundinar, A. Hahn, J. König, and A. Hucht, Phys. Rev. B **106**, 165427 (2022)

TT 80.58 Thu 15:00 Poster E

Exploring magnetic pairing mechanisms in the *t*-*J* model on mixed-dimensional ladder systems using high-order series expansion — •Jakob Heidweiler, Patrick Adelhardt, Paul Fadler, and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

For many years, the t-J model has been suggested as the basis upon which to discuss high-T superconducting systems. Over the last decades the t-J model has become a paradigmatic model to understand the physics of high-T_c superconductors in a minimal setting. Nevertheless, pinpointing the exact pairing mechanism in these systems has not been accomplished. In recent works on mixed-dimensional t-J ladders [1,2] a magnetic pairing mechanism between holes on opposite legs of the ladder has been suggested. Here we extend these investigations by applying perturbative continuous unitary transformations (pCUTs) about the isolated rung limit in the thermodynamic limit. We investigate the effective low-energy Hamiltonian with special attention towards the properties of the emergent bound states.

[1] H. Lange et al. arXiv:2309.13040
[2] H. Lange et al. arXiv:2309.15843

TT 80.59 Thu 15:00 Poster E

Cooperative effects in dense cold atomic gases including magnetic dipole interaction — •Nico Bassler[1,2], Ishan Varma[3], Marvin Proske[3], Patrick Windpassinger[3], Kai Phillip Schmidt[1], and Claudiu Genes[2,1] — [1]Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany — [3]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55122 Mainz, Germany

We theoretically investigate cooperative effects in cold atomic gases exhibiting both electric and magnetic dipole-dipole interactions, such as occurring for example in clouds of dysprosium atoms. We distinguish between the quantum degenerate case, where we take a many-body physics approach, and the quantum non-degenerate case, where we use the formalism of open system dynamics. For quantum non-degenerate gases, we illustrate the emergence of tailorable spin models in the high-excitation limit. In the low-excitation limit, we provide analytical and numerical results detailing the effect of magnetic interactions on the directionality of scattered light and characterize sub- and superradiant effects. For quantum degenerate gases, we study the interplay between sub- and superradiance effects and the fermionic or bosonic quantum statistics nature of the ensemble.

TT 81: Frustrated Magnets: General II

Time: Thursday 16:30–18:00 Location: H 2053

TT 81.1 Thu 16:30 H 2053

Order-by-disorder scenarios in the antiferromagnetic J_1-J_2-J_3 transverse-field Ising model on the ruby lattice — •Antonia Duft, Jan Koziol, Patrick Adelhardt, Matthias Mühlhauser, and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

We investigate the highly frustrated J_1-J_2-J_3 transverse-field Ising model on the ruby lattice. We derive effective models in the low-field limit and determine the gap closing of the high-field polarized phase by series expansions. The extensive ground-state degeneracy at zero field is lifted by two different order-by-disorder mechanisms. For $J_2 > J_3$, we find an emergent clock-ordered phase at low fields stabilized by resonating plaquettes and a 3d-XY quantum phase transition to the polarized phase similar to the triangular lattice. For $J_3 > J_2$, a diagonal order-by-disorder mechanism stabilizes a distinct $k = (0, 0)$ order and the phase transition to the high-field phase is in the 3d-Ising universality class. The special case $J_2 = J_3$ displays an enhanced ground-state degeneracy in the zero-field limit and no gap closing of the high-field gap can be detected reliably. The physics of the clock-ordered phase for $J_2 > J_3$ can be implemented in Rydberg atom arrays.

TT 81.2 Thu 16:45 H 2053

Signatures of Domain-Wall Confinement in Raman Spectroscopy of Ising Spin Chains — •Stefan Birnkammer[1,2], Johannes Knolle[1,2,3], and Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany — [3]Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom

Mesonic bound states of domain walls can be stabilized in quasi one-dimensional magnetic compounds. Here, we theoretically study the Raman light scattering response of a twisted Kitaev chain with tilted magnetic fields as a minimal model for confinement in $CoNb_2O_6$. By both numerical matrix product states and few-domain wall variational states, we show that confinement-induced bound states directly manifest themselves as sharp peaks in the Raman response. Near quantum criticality the Raman spectrum exhibit the famous E_8 symmetry. Remarkably, by tuning the polarization of the incident light field, we demonstrate that the Raman response offers new insights into the intrinsic structure of the bound state wavefunction.

TT 81.3 Thu 17:00 H 2053

Magneto- and barocaloric properties of the ferro-antiferromagnetic sawtooth chain — •Nico Reichert[1], Henrik Schlüter[1], Tjark Heitmann[2], Johannes Richter[3], Roman Rausch[4], and Jürgen Schnack[1] — [1]Fakultät für Physik, Universität Bielefeld — [2]Fachbereich Mathematik/Informatik/Physik, Universität Osnabrück — [3]Institut für Physik, Otto-von-Guericke-Universität Magdeburg; Max-Planck-Institut für Physik komplexer Systeme, Dresden — [4]Institut für Mathematische Physik, Technische Universität Braunschweig

Materials that are susceptible to pressure and external magnetic fields allow the combined use of both for caloric processes. Here we report investigations of the ferromagnetic-antiferromagnetic sawtooth chain that due to its critical behavior not only allows for both barocaloric as well as magnetocaloric processes but also features very large cooling rates in the vicinity of the quantum critical point [1].

[1] N. Reichert, H. Schlüter, T. Heitmann, J. Richter, R. Rausch, J. Schnack, Z. Naturforsch. A (2023) accepted

TT 81.4 Thu 17:15 H 2053

Quantum criticality in the sawtooth chain compound atacamite — •Leonie Heinze[1,2], Tommy Kotte[3], Albin Demuer[4], Sven Luther[3], Ralf Feyerherm[5], Andrew Ammerlaan[6], Uli Zeitler[6], Dirk Menzel[1], Kirrily C. Rule[7], Anja U. B. Wolter[8], Hannes Kühne[3], and Stefan Süllow[1] — [1]IPKM, TU Braunschweig, Braunschweig, Germany — [2]FZ Jülich GmbH, JCNS at MLZ, Garching, Germany — [3]HLD-EMFL, HZDR, Dresden-Rossendorf, Germany — [4]LNCMI, CNRS, Grenoble, France — [5]HZB, Berlin, Germany — [6]HFML-EMFL, Nijmegen, The Netherlands — [7]ANSTO, Kirrawee, Australia — [8]IFW Dresden, Dresden, Germany

We present an extensive high-field heat capacity study of the natural mineral atacamite, a material realization of the non-uniform quantum sawtooth chain in a very weak 3D coupling network [1]. For applied magnetic fields up to 35 T, we have mapped out the highly distorted entropy landscape of this frustrated material for $\mathbf{H} \parallel c$ axis. We found evidence for a field-induced quantum critical point in the phase diagram of atacamite, which appears to separate the field region of the antiferromagnetic phase present in lower magnetic fields and a field region without long-range magnetic order in higher magnetic fields—but far away from the saturation field.

[1] L. Heinze *et al.*, Phys. Rev. Lett. **126** (2021) 207201

TT 81.5 Thu 17:30 H 2053

Quantum-criticality of transverse-field Ising models with quenched disorder extracted by quantum Monte-Carlo methods — •Calvin Krämer, Anja Langheld, Jan Alexander Koziol, Max Hörmann, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik, Staudtstraße 7, Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We study the one- and two-dimensional transverse-field Ising model with quenched disorder at $T = 0$ by quantum Monte Carlo simulations. Using averaged binder ratios and a sample-replication method, we can extract critical points and correlation length exponents ν by finite-size scaling. Scaling of the averaged magnetisation at the critical point is used further to determine the order-parameter critical exponent β. The dynamical scaling in the Griffiths phase is investigated by measuring the local susceptibility in the disordered phase and the dynamical exponent z' is extracted.

TT 81.6 Thu 17:45 H 2053

Cooling and heating in the Bose-Hubbard model by parameter tuning — •Axel Pelster[1], Sven Stawinski[2], and Sebastian Eggert[1] — [1]University of Kaiserslautern-Landau, Landesforschungszentrum OPTIMAS — [2]Universität Bonn

We investigate short-range interacting Bosons in an optical lattice at finite temperature. It is well known that the system shows a Mott-Superfluid transition when changing the repulsion U, the hopping t and/or the filling. However, it is much less clear how the temperature is affected by those changes, assuming the parameter t and/or U are tuned adiabatically. We now present for the full Free energy in a higher-order mean field theory and derive the temperature and entropy in a large parameter space. We discuss where significant heating or cooling effects can be expected in the superfluid phase, in the Mott region and near the phase transition lines.

TT 82: Members' Assembly

- Status Report on current meeting
- Outlook 2024, 2025
- Miscellaneous

Time: Thursday 18:05–19:30 Location: H 3005

All members of the Low Temperature Physics Division are invited to participate.

TT 83: $SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor III (joint session TT/KFM/MA/O)

Strontium titanate ($SrTiO_3$) is a paradigmatic material that plays an important role in various fields of solid-state physics, surface science and catalysis: The pure bulk phase is a wide-band-gap semiconductor that upon cooling becomes a textbook quantum paraelectric. When slightly doped, $SrTiO_3$ turns into a Fermi-liquid-type metal that becomes superconducting at extremely low charge carrier density. $SrTiO_3$-based surfaces and interfaces host un-conventional electronic states such as quasi-two-dimensional electron liquid, magnetism and superconductivity. Despite intensive studies over the past decades, $SrTiO_3$ continues to reveal surprising new phenomena that challenge the established views on this material. To this end achieving light-induced nonequilibrium states and the recent preparation of a 2D oxide based on $SrTiO_3$ opens new playgrounds for research. This Focus Session will present exciting developments in the study of electronic states that are based on the peculiar properties of $SrTiO_3$.

Please note that this Focus Session comprises four parts: Posters are presented within the TT poster session TT58 (Wed 15:00-18:00, poster area E). Invited talks are compiled in the session TT62 (Thursday, 9:30 to 12:45, H0104), Contributed talks will be presented in sessions TT72 (Thursday 15:00-18:00, H0104) and TT83 (Fri 9:30-12:30, H0104).

Organizers: Rossitza Pentcheva, University of Duisburg-Essen, Marc Scheffler, University of Stuttgart

Time: Friday 9:30–12:30 Location: H 0104

TT 83.1 Fri 9:30 H 0104

High-mobility two-dimensional electron gases based on strain engineered ferroelectric $SrTiO_3$ thin films — •Ruchi Tomar[1], Tatiana Kuznetsova[2], Srijani Mallik[1], Luis M. Vicente-Arche[1], Fernando Gallego[1], Maximilien Cazayous[3], Roman Engel-Herbert[2,4], and Manuel Bibes[1] — [1]Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, 91767 Palaiseau, France. — [2]Pennsyvlania State University, University Park, PA 16802, USA. — [3]Laboratoire Matériaux et Phénomènes Quantiques (UMR 7162 CNRS), Université de Paris, 75205 Paris Cedex 13, France. — [4]Paul Drude Institute for Solid State Electronics, Leibniz Institute within Forschungsverbund Berlin eV, Hausvogteiplatz 5-7, 10117, Berlin, Germany.

Two-dimensional electron gases (2DEGs) based on the quantum paraelectric $SrTiO_3$ display fascinating properties such as large electron mobilities, superconductivity, and efficient spin-charge interconversion owing to their Rashba spin-orbit coupling. Here, we use oxide molecular beam epitaxy to grow high-quality strain-engineered $SrTiO_3$ films that are ferroelectric up to 170 K. We then generate a 2DEG by sputtering a thin Al layer and demonstrate an increase in mobilities compared to earlier literature. Furthermore, through Raman spectroscopy and magneto-transport measurements, we show that the ferroelectric character is retained after 2DEG formation. These results thus qualify our samples as ferroelectric 2DEGs up to temperatures well above previous results based on Ca-$SrTiO_3$ substrates, opening the way towards ferroelectric 2DEGs operating at room temperature.

TT 83.2 Fri 9:45 H 0104

Two-dimensional electron liquids at truly bulk-terminated $SrTiO_3$ — •Igor Sokolović[1,2], Eduardo B. Guedes[3], Thomas van Waas[4], Samuel Poncé[4,5], Craig M. Polley[6], Michael Schmid[2], Ulrike Diebold[2], Milan Radović[3], Martin Setvín[2,7], and J. Hugo Dil[3,8] — [1]Institute of Microelectronics, TU Wien, Vienna, Austria — [2]Institute of Applied Physics, TU Wien, Vienna, Austria — [3]Photon Science Division, PSI, Villagen, Switzerland — [4]ETSF, Institute of Condensed Matter and Nanosciences, UCLouvain, Louvain-la-Neuve, Belgium — [5]WEL Research Institute, Wavre, Belgium — [6]MAX IV laboratory, Lund University, Lund, Sweden — [7]Faculty of Mathematics and Physics, Charles University, Prague , Czech Republic — [8]Institut de Physique, ÉPFL, Lausanne, Switzerland

A truly bulk-terminated $SrTiO_3(001)$ surface prepared by cleaving *in situ* was investigated with angle-resolved photoemission spectroscopy (ARPES) and noncontact atomic force microscopy (ncAFM). The (1×1) $SrTiO_3(001)$ surfaces were achieved through our cleaving procedure that exploits the strain-induced ferroelectric transition in $SrTiO_3$, and provides both possible surface terminations, TiO_2 and SrO. Each hosts a specific two-dimensional electron liquid (2DEL): the first with split and the other with degenerate bands. The origin of the 2DELs and the band-splitting mechanisms are elucidated by correlating the observed reciprocal- and real-space electronic and atomic structure.

TT 83.3 Fri 10:00 H 0104

Low-energy excitations at $SrTiO_3(001)$ surfaces in absence and presence of a two-dimensional electron gas — •Hannes Herrmann, Anne Oelschläger, and Wolf Widdra — Martin-Luther-Universität Halle-Wittenberg, 06120 Halle, Germany

The low-energy excitations of $SrTiO_3$, a large-bandgap oxide perovskite, are dominated by phonons and phonon polaritons. At the surface they couple to dipole-active surface phonon polaritons that are bound to the $SrTiO_3$-vacuum interface. These excitations can be addressed by surface vibrational spectroscopy techniques as, e.g., high-resolution electron energy loss spectroscopy (HREELS).
Here we will present HREELS studies that identify all $SrTiO_3(001)$ dipole-active excitations, including their specific line shapes and will discuss the electron-phonon coupling to a two-dimensional electron gas. The latter are prepared with variable charge-carrier concentrations either by annealing under ultrahigh-vacuum condition or by growth of an ultrathin layers of EuO on top. With formation of the 2DEGs, the discrete surface phonon polaritons couple to the electron-hole pair continuum as is witnessed by a substantial line broadening and asymmetric Fano-like line shapes. A quantitative description that accounts for all details of the line shape paves the way for an in-situ analysis of the 2DEG charge carrier dynamics.

TT 83.4 Fri 10:15 H 0104

Confined ionic-electronic systems based on $SrTiO_3$ — •Felix Gunkel, Marcus Wohlgemuth, Moritz L. Weber, and Regina Dittmann — Peter Gruenberg Institute, Forschungszentrum Juelich

$SrTiO_3$ reflects a a prototype ionic-electronic oxide, in which the physical properties are significantly affected by the ionic defect structure. [Gunkel et al., APL 2020] At the same time, spatial confinement of electronic charge carries led to unexpected electronic and magnetic phenomena, including 2DEG formation, magnetoresistance and localization phenomena. Here we will discuss, how spatial confinement also affects the ion-dynamics and defect-equilibria of SrTiO3, yielding interfacial defect structures and ion-dynamics that significantly differ from the bulk. [Rose et al., Adv. Mater. (2023); Weber et al., Nature Mater., to be published (Jan 2 2024)]. New opportunities to tailor such confined ionic-electronic systems arise from synthesis advances in generating transferable, free-standing $SrTiO_3$ sheets. These reflect ideally-confined nanosheets of $SrTiO_3$ and can serve as model system for ionic-electronic confinement phenomena as well as template for the synthesis of functional bilayer structures. We discuss the state-of-the-art of controlled bilayer synthesis and derive the required finite-size corrections in the thermodynamic description of the defect chemistry of $SrTiO_3$, indicating that the average reduction enthalpy of $SrTiO_3$ can be effectively reduced via confinement.

TT 83.5 Fri 10:30 H 0104

Origin of spin-polarized 2DEG at the $EuTiO_3(001)$ surface and $LaAlO_3/EuTiO_3/SrTiO_3(001)$ interface — •Manish Verma and Rossitza Pentcheva — Department of Physics, Universität Duisburg-Essen

Since the discovery of a two-dimensional electron gas (2DEG) at the interface between the $LaAlO_3$ and $SrTiO_3$ band insulators, studies on oxide surfaces and interfaces uncovered an intriguing and rich physics, such as possible magnetism in 2DEG. Using density functional theory with an on-site Coulomb repulsion term U, we find a spin-polarized 2DEG at the $EuTiO_3(001)$ surface arising from the interplay of ferromagnetic (FM) order of Eu-4f magnetic moments and the localization of electrons released from oxygen divacancies at the surface Ti sites, in agreement with in situ high-resolution angle-resolved photoemission [1]. The 2DEG at the $LaAlO_3/EuTiO_3/SrTiO_3(001)$ interface is formed due to the polar discontinuity. The spin-polarization is due to the FM exchange interaction between Eu 4f and Ti 3d states and steers the occupation of d_{xz}/d_{yz} orbitals [2].

[1] R. Di Capua *et al.*, Phys. Rev. Research **3** (2021) L042038
[2]. R. Di Capua *et al.*, npj Quantum Mater. **7** (2022) 41

TT 83.6 Fri 10:45 H 0104

A multiferroic STO-based 2D-electron gas — •Marco Salluzzo[1], Yu Chen[1], Martando Rath[1], Daniela Stornaiuolo[2], Julien Brehin[3], Manuel Bibes[3], Julien Varignon[4], and Cinthia Piamonteze[5] — [1]Cnr-Spin Complesso Monte S. Angelo via Cinthia 80126, Napoli, Italy — [2]Università "Federico II" di Napoli, Dipartimento di Fisica "Ettore Pancini", Complesso Monte S. Angelo via Cinthia 80126, Napoli, Italy — [3]Unité Mixte de Physique, CNRS, Thales, Université Paris Saclay, Palaiseau, France — [4]Crismat, CNRS , Ensicaen, Normandie Université, Caen, France — [5]Swiss Light Source, Paul Scherrer Institut, Villigen, Switzerland.

The fabrication of artificial materials combining different functional properties is a powerful method to create novel quantum states. Here we demonstrate the realization of a 2D electron gas exhibiting a coexistence of ferroelectric and ferromagnetic order parameters, by heteroepitaxy.

The novel 2DEG is realized by inserting few unit cells of the antiferromagnetic insulator $EuTiO_3$ between a $LaAlO_3$ band insulating thin film (10 unit cells) and a Ca-doped $SrTiO_3$ single crystal.

By using Ti-$L_{2,3}$ and Eu $M_{4,5}$ edges x-ray linear dichroism and x-ray magnetic circular dichroism, we provide evidences of a switchable polarization, non-volatile tuning of Ti3d orbital splitting, and of a modulation of Eu-4f magnetic moment of the 2DEG by the FE-polarization[1]. The result is of interest for quantum spin-orbitronic applications.

[1] J. Bréhin et al., Nat. Phys. 19 (2023) 823

TT 83.7 Fri 11:00 H 0104

Magnetotransport properties of a spin polarized STO-based 2D electron system tuned by visible light — Maria D'Antuono[1,2], Yu Chen[2], Roberta Caruso[1,2,3], Benoit Jouault[4], Marco Salluzzo[2], and •Daniela Stornaiuolo[1,2] — [1]Department of Physics, University of Naples Federico II, Italy. — [2]CNR-SPIN, Naples, Italy. — [3]Condensed Matter Physics and Materials Science Division, Brookhaven National Laboratory, NY, USA. — [4]Laboratoire Charles Coulomb, CNRS,Université de Montpellier, France

Two-dimensional electron systems (2DES) developing in STO-based heterostructures possess a wide range of properties which are largely tunable thanks to the systems band structure and carrier density. In $LaAlO_3/EuTiO_3/SrTiO_3$ (LAO/ETO/STO) heterostructure, for instance, the charge carriers, above a critical value, start to fill Ti-3d bands with $d_{xz,yz}$ character, leading to the stabilization of a ferromagnetic order of Ti and Eu magnetic moments, and to a spin polarization of the 2DES. In this work we show that such mechanism can be achieved not only using electric field effect, but also using visible light irradiation. Furthermore, the analysis of the Anomalous Hall effect and of magnetocodnuctance curves demonstrate that visible light irradiation leads to enhanced stabilization of ferromagnetic correlations in the 2DES. Our results establishs the combined use of visible light and gate voltage as a straightforward way to access unexplored regions of the LAO/ETO/STO 2DES phase diagram.

15 min. break

TT 83.8 Fri 11:30 H 0104

All-electrical measurement of the spin-charge conversion effect in nanodevices based on $SrTiO_3$ two-dimensional electron gases — •Fernando Gallego[1], Felix Trier[1,2], Srijani Mallik[1], Julien Brehin[1], Sara Varotto[1], Luis Moreno[1], Tanay Gosavy[3], Chia-Ching Lin[3], Jean-René Coudevylle[4], Lucía Iglesias[1], Fèlix Casanova[5,6], Ian Young[3], Laurent Vila[7], Jean-Philippe Attané[7], and Manuel Bibes[1] — [1]Unité Mixte de Phys, CNRS-Thales, Univ. Paris-Saclay, 91767 Palaiseau, France. — [2]Dept of Energy Conservation and Storage, Univ. of Denmark, 2800 Kgs. Lyngby, Denmark. — [3]Comp. Res. Intel Corp., Hillsb., OR 97124, USA. — [4]Centre de Nanosciences et de Nanotech., CNRS, Université Paris-Sud, Université Paris-Saclay, France. — [5]CIC nanoGUNE BRTA, 20018 Donostia, Spain. — [6]IKERBASQUE, Basque Foundation for Science, 48009 Bilbao, Spain. — [7]Univ. Grenoble Alpes, CNRS, CEA, SPINTEC, Grenoble, France.

We report all-electrical spin-injection and spin-charge conversion experiments in nanoscale devices harnessing the inverse Edelstein effect of $SrTiO_3$ 2DEGs. We have designed, patterned and fabricated nanodevices in which a spin current injected from a cobalt layer into a $LaAlO_3/SrTiO_3$ 2DEG is converted into a charge current. We optimized the spin-charge conversion signal by back-gating. We further disentangled the inverse Edelstein contribution from spurious effects. The combination of non-volatility and high energy efficiency of these devices could potentially lead to new technology paradigms for beyond-CMOS computing architectures.

TT 83.9 Fri 11:45 H 0104

Effect of confinement and coulomb interactions on the electronic structure of the (111) $LaAlO_3/SrTiO_3$ interface — •Mattia Trama[1,2,3], Vittorio Cataudella[4,5], Carmine Antonio Perroni[4,5], Francesco Romeo[1], and Roberta Citro[1,2] — [1]Universitá degli Studi di Salerno, Fisciano, Italy — [2]INFN Sezione di Napoli, Naples, Italy — [3]Institute for Theoretical Solid State Physics, IFW Dresden, Dresden, Germany — [4]Universitá degli Studi di Napoli Federico II, Naples, Italy — [5]CNR-SPIN Napoli Unit, Naples, Italy

A tight-binding supercell approach is used for the calculation of the electronic structure of the (111) $LaAlO_3/SrTiO_3$ interface. The confinement potential at the interface is evaluated solving a discrete Poisson equation by means of an iterative method. In addition to the effect of the confinement, local Hubbard electron-electron terms are included at the mean-field level within a fully self-consistent procedure. The calculation carefully describes how the two dimensional electron gas arises from the quantum confinement of electrons near the interface due to the band bending potential. The resulting electronic sub-bands and Fermi surfaces show full agreement with the electronic structure determined by angle-resolved photoelectron spectroscopy experiments. In particular, we analyse how the effect of local Hubbard interactions change the density distribution over the layers from the interface to the bulk. Interestingly, the two-dimensional electron gas at the interface is not depleted by local Hubbard interactions which indeed induce an enhancement of the electron density between the first layers and the bulk.

TT 83.10 Fri 12:00 H 0104

Enhanced Non-linear Response by Manipulating the Dirac Point in the (111) $LaTiO_3/SrTiO_3$ Interface — •Yoram Dagan, Gal Tuvia, Amir Burshtein, Itai Silber, Amnon Aharony, Ora Entin-Wohlman, and Moshe Goldstein — School of Physics and Astronomy, Tel Aviv University

Tunable spin-orbit interaction (SOI) is an important feature for future spin-based devices. In the presence of a magnetic field, SOI induces an asymmetry in the energy bands, which can produce non-linear transport effects ($V \sim I^2$). Here, we focus on such effects to study the role of SOI in the (111) $LaTiO_3/SrTiO_3$ interface. This system is a convenient platform for understanding the role of SOI since it exhibits a single-band Hall-response through the entire gate-voltage range studied. We report a pronounced rise in the non-linear longitudinal resistance at a critical in-plane field H_{cr}. This rise disappears when a small out-of-plane field component is present. We explain these results by considering the location of the Dirac point formed at the crossing of the spin-split energy bands. An in-plane magnetic field pushes this point outside of the Fermi contour, and consequently changes the symmetry of the Fermi contours and intensifies the non-linear transport. An out-of-plane magnetic field opens a gap at the Dirac point, thereby significantly diminishing the non-linear effects. We propose that magnetoresistance effects previously reported in $SrTiO_3$-based interfaces could be comprehended within our suggested scenario.

TT 83.11 Fri 12:15 H 0104

Tunable 2D Electron- and 2D Hole States Observed at Fe/$SrTiO_3$ Interfaces — •Pia Maria Düring[1], Paul Rosenberger[1,2], Lutz Baumgarten[3], Fatima Alarab[4], Frank Lechermann[5], Vladimir N. Strocov[4], and Martina Müller[1] — [1]FB Physik, Universität Konstanz, 78457 Konstanz — [2]TU Dortmund, 44221 Dortmund — [3]FZ Jülich, PGI-6, 52425 Jülich — [4]PSI, SLS, CH-5232 Villingen — [5]TP III, RU Bochum, 44780 Bochum

Oxide electronics provide the key concepts and materials for enhancing silicon-based semiconductor technologies with novel functionalities. However, a crucial property of semiconductor devices remains undisclosed in their oxide counterparts: the ability to set or even switch between negatively (n) charged electrons or positively (p) charged holes. Using resonant angle-resolved photoelectron spectroscopy, we provide direct evidence for individually emerging n- or p-type 2D band dispersions in $SrTiO_3$ (STO)-based heterostructures [1]. The key to setting the carrier character is the oxidation state of a Fe-based interface layer: For Fe and FeO, hole bands emerge in the empty band gap region of STO, while for Fe_3O_4 overlayers, an 2D electron system (2DES) is formed. Unexpected oxygen vacancy characteristics arise for the hole-type interfaces, which as of yet had been exclusively assigned to the emergence of 2DESs. In general, this study unveils the potential to seamlessly alter the conductivity type at STO interfaces by manipulating the oxidation state of a redox overlayer.

[1] P. M. Düring et al., Adv. Mater. (accepted)

TT 84: Focus Session: Emerging Magnetic Phenomena from Chiral Phonons II (joint session MA/TT)

Contemporary efforts in spintronics focus on utilizing and controlling electronic angular momentum for possible applications in data storage and processing. Only recently, an alternative has arisen in the form of angular momentum generated by circularly polarized (chiral) phonons. Chiral phonons have been shown to lead to a variety of novel magnetic phenomena, including a phonon Hall, phonon Einstein-de Haas, phonon Barnett, and phonon Zeeman effect. Phonon angular momentum can be utilized to control the magnetic state of solids and even to induce magnetization in nonmagnetic materials. These discoveries make the angular momentum of chiral phonons a promising tool for the control of magnetic materials and an emerging quantity of interest for spintronic applications. The goal of this focus session is to highlight topical research on novel magnetic phenomena arising from chiral phonons and to connect this rapidly developing field to the broader audience working in magnetism and spintronics.

Coordinators: Sebastian T. B. Goennenwein, Universität Konstanz, sebastian.goennenwein@uni-konstanz.de Ulrich Nowak, Universität Konstanz, ulrich.nowak@uni-konstanz.de

Time: Friday 9:30–11:30 Location: H 1058

TT 84.1 Fri 9:30 H 1058

Born effective charges in insulators and metals — •Paolo Fachin, Francesco Macheda, and Francesco Mauri — Sapienza, Università di Roma, Italia

The Born effective charges quantify the coupling of phonons with light, allowing to describe experimental spectra of crystals in infrared spectra. While in insulators the electrical polarization is well defined and the Born Effective charges are described in a Berry phase formulation in the context of the modern theory of polarization[1], in metals this quantity is more challenging to deal with. There are two different limits, the static [2] and the dynamical [1][3] one, concurring in the determination of the vibrational features in a combination depending on the phonon frequency and linewidth ratio [4]. The nature of these two limits is clarified using a low energy model for graphene compared with ab initio simulations. The effect of the recently predicted [5][6] intrinsic chiral phonons in crystals can be detected in infrared experiments in a way that is described by the Born effective charges.

[1] Bistoni,Mauri et al., 2D Materials, 6, 045015 (2019)
[2] Macheda, Barone and Mauri, Phys.Rev.Lett.,129(18),185902(2022)
[3] Dreyer,Coh, and Stengel, Phys. Rev. Lett., 128, 095901 (2022)
[4] Marchese, Macheda, Mauri and al., Nat. Phys. (2023)
[5] Bistoni, Mauri, and Calandra, Phys.Rev.Lett. 126,225703 (2019)
[6] Saparov, Niu et al., Phys. Rev. B 105, 064303 (2022)

TT 84.2 Fri 9:45 H 1058

Magnon-phonon coupling in $Co_{25}Fe_{75}$ thin film/crystalline substrate heterostructures — •J. Weber[1,2], M. Müller[1,2], F. Engelhardt[3,4,5], V. Bittencourt[6], T. Luschmann[1,2,7], M. Cherkasskii[5], S.T.B. Goennenwein[8], S.V. Kusminskiy[5,3], S. Geprägs[1], R. Gross[1,2,7], M. Althammer[1,2], and H. Huebl[1,2,7] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Max Planck Institute for the Science of Light, Erlangen, Germany — [4]Department of Physics, University Erlangen-Nuremberg, Erlangen, Germany — [5]Institute for Theoretical Solid State Physics, RWTH Aachen University, Aachen, Germany — [6]ISIS (UMR 7006), Université de Strasbourg, Strasbourg, France — [7]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [8]Department of Physics, University of Konstanz, Konstanz, Germany

The coupling between the quantized excitations of the spin system (magnons) and the lattice (phonons) regained interest due to potential applications in quantum devices. Here, we report the coherent excitation of elastic waves in a metallic ferromagnetic $Co_{25}Fe_{75}$ thin film by driving its Kittel modes, leading to the excitation of transverse acoustic phonons in the substrate forming a bulk acoustic wave resonator. Our results agree well with model calculations based on the magnetic and acoustic properties of the magnetic and elastic subsystems and allow to determine the effective magnetoelastic coupling strength.

TT 84.3 Fri 10:00 H 1058

Light induced magnetization in $SrTiO_3$ — •Natalia Shabala and R. Matthias Geilhufe — Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden

Dynamical multiferroicity refers to magnetization of a material caused by a temporally varying polarization [1]. Such phenomena can be light-induced. For example, Kerr-effect measurements on THz-pumped $SrTiO_3$ (STO) reveal significant magnetic moments in the sample of about 0.1 Bohr magneton per unit cell, while $SrTiO_3$ itself is non-magnetic [2]. Moreover, this value is significantly larger than the one expected from a circularly moving charge argument. We attempt to understand this discrepancy by finding a connection between magnetization resulting from optically driven chiral phonons and Berry connection. By extending the formalism of inverse Faraday effect to phonons and applying modern theory of polarization, we hope to develop a better understanding of the large difference between theoretical and experimental values of light induced magnetization. In the prospect of “phonon-enabled technology”, we apply our formalism to investigate a Hall effect in graphene/STO, mediated by light-induced chiral phonons in the STO substrate. We find that a laser field strength of 0.1 MV/m and a current of 1 mA will cause a transverse electric field of about 40 nV, which can be measured in state-of-the-art experiments.

[1] D. M. Juraschek et al., ”Dynamical multiferroicity”, *Phys. Rev. Mater.*, 1.1 (2017): 014401
[2] M. Basini et al., ”Terahertz electric-field driven dynamical multiferroicity in $SrTiO_3$”, *arXiv preprint arXiv:2210.01690* (2022)

TT 84.4 Fri 10:15 H 1058

Creating and observing elliptically polarized coherent optical shear phonons in graphite — Arne Ungeheuer, Mashood T. Mir, Ahmed S. Hassanien, Lukas Nöding, Thomas Baumert, and •Arne Senftleben — Institut für Physik, Universität Kassel

We present a scheme to create circularly or elliptically polarized coherent phonons of the degenerate inter-layer shear mode in graphite. The approach utilizes the time-delayed excitation of two coherent phonons linearly polarized in perpendicular directions by femtosecond laser pulses. We observe the resulting elliptically polarized coherent phonon using ultrafast electron diffraction [1], where they create a unique signature that allows us to determine the phonon's ellipticity and sense of rotation. Analyzing the atomic motion in the crystal, we find that the atoms in adjacent layers circulate in the same direction in a Hula hoop fashion. In magnetic materials, such elliptically polarized phonons can create a transient magnetization in an atomistic version of the Barnett effect [2].

[1] C. Gerbig, et al. *New J. Phys.* **17**, 043050 (2015).
[2] T. F. Nova, et al. *Nature Phys.* **13**, 132–136 (2017).

TT 84.5 Fri 10:30 H 1058

Chirality of spin and orbital dynamics in laser-induced demagnetization — •Junjie He — Charles University, Prague, Czech Republic

Despite spin (SAM) and orbital (OAM) angular momentum dynamics are well-studied in demagnetization processes, their components receive less focus. Here, we utilize the real-time ab initio theory to unveil significant x and y components of SAM and OAM induced by circularly left (σ+) and right (σ-) polarized laser pulse in Ferromagnetic metals. Our results show that the magnitude of OAM is an order of magnitude larger than that of SAM, highlighting a stronger optical response from the orbital degrees of freedom of electrons compared to spin. Additionally, we observe a marked dependency of the oscillations of the x and y components on the optical helicity. Intriguingly, σ+ and σ- pulses induce chirality in the precession of SAM and OAM, respectively, with clear associations with laser frequency and duration. Our results could be important to understand the polarized phonon in the demagnetization process.

TT 84.6 Fri 10:45 H 1058

Ultrafast symmetry breaking with multicolor chiral phonons — •Omer Yaniv and Dominik Juraschek — Tel Aviv University, Tel Aviv, Israel

In the field of ultrafast dynamics, terahertz pulses stand out as powerful tools capable of initiating coherent vibrational motions in crystal lattices. Circularly or elliptically polarized pulses can excite chiral phonons, which are the collective vibrational patterns of circular or elliptical orbital motions of atoms around their equilibrium lattice positions. Such phonons carry angular momentum and are able to generate magnetic fields leading to a varying range of phenomena. Our study explores the coherent driving of chiral phonons using multicolor laser pulses. Such driving allows us to generate different types of magnetic patterns. We focus on IR-active optical degenerate phonons in CsPbF3 with frequencies at 1.8 THz and 3.6 THz and look at three different features of this multicolor phonon driving. We dynamically induce inversion symmetry breaking in the centrosymmetric lattice structure. This can give rise to nonlinear phenomena, such as second harmonic generation (SHG). Additionally, we show the generation of atomic eight-curve motion, which leads to the generation of spatially distinct alternating phononic angular momentum. This gives rise to an antiferromagnetic pattern of the dynamical phonon magnetic moment. Furthermore, our findings indicate that coherent excitation can lead to the formation of new symmetries, such as a 3-fold rotation, arising from atomic cloverleaf motion. We expect our predictions to be realizable with state-of-the-art pulse shaping techniques.

TT 84.7 Fri 11:00 H 1058

Chiral phonons as dark matter detectors — •Carl Romao[1], Riccardo Catena[2], Nicola Spaldin[1], and Marek Matas[1] — [1]Department of Materials, ETH Zurich, CH-8093 Zurich, Switzerland — [2]Department of Physics, Chalmers University of Technology, SE-412 96 Goteborg, Sweden

We have proposed a method for detecting single chiral phonons using magnetometers. This would allow chiral phonons to be used as dark-matter detectors capable of exploring a multitude of unprobed dark-matter candidates. Metal*organic frameworks are potential candidate detector materials, as their flexibility yields low-energy chiral phonons with measurable magnetic moments, and their anisotropy leads to directional sensitivity, which mitigates background contamination. InF3(4,4'-bipyridine) has been identified as a candidate material; sensing of its phonon magnetic moments would extend detector reach by orders of magnitude below current limits.

TT 84.8 Fri 11:15 H 1058

Nuclear boost to pseudomagnetic fields from quantum geometry — •Lennart Klebl[1], Arne Schobert[1], Giorgio Sangiovanni[2], Alexander V. Balatsky[3,4], and Tim O. Wehling[1,5] — [1]Universität Hamburg, Germany — [2]Universität Würzburg, Germany — [3]University of Connecticut, Storrs, USA — [4]Nordita, Stockholm University and KTH Royal Institute of Technology, Stockholm, Sweden — [5]The Hamburg Centre for Ultrafast Imaging, Germany

Recent experiments demonstrate precise control over coherently excited phonon modes using high-intensity terahertz lasers, opening new pathways towards dynamical, ultrafast design of magnetism in functional materials. While in qualitative agreement with the observed dynamics in experiments, the theoretically predicted magnetic field strengths of circularly polarized phonon modes lack three orders of magnitude. In this work, we put forward a coupling mechanism based on electron-nuclear quantum geometry. This effect is rooted in the adiabatic evolution of the electronic wavefunction under a circular evolution of nuclear coordinates. The excitation pulse then induces a transient level splitting between electron orbitals that carry angular momentum. When converted to effective magnetic fields, values on the order of tens of Teslas are easily reached. We give criteria under which the evolution of nuclear degrees of freedom can be described adiabatically in the electronic sector and find that in the perovskite $SrTiO_3$, the adiabatic regime is in experimental reach.

TT 85: Topology: Majorana Physics II

Time: Friday 9:30–11:30 Location: H 3005

Invited Talk TT 85.1 Fri 9:30 H 3005

Majorana bound states in artificial Kitaev chains — •Srijit Goswami — QuTech, Delft University of Technology, The Netherlands

In the past decade superconductor-semiconductor hybrids have been studied intensively, with significant efforts towards studying Majorana bound states (MBSs). In this talk I will discuss a relatively new approach to realize MBSs using quantum dot-superconductor hybrids. I will focus on how MBSs can be systematically and reliably engineered in a two-dimensional electron gas by tuning the relative strengths of the different kinds of couplings between the quantum dots.

TT 85.2 Fri 10:00 H 3005

Magnet-superconductor hybrid systems, Majorana zero modes and topological quantum computing — •Stephan Rachel — School of Physics, University of Melbourne, Parkville, Australia

There has been significant experimental progress in recent years in establishing magnet-superconductor hybrid systems as a promising platform for Majorana physics. I will report about recent progress in this field and then explain how topological quantum computing can be enabled via braiding of Majorana zero modes. I will show examples of simple quantum algorithms that can be computed in a fault-tolerant way.

TT 85.3 Fri 10:15 H 3005

Exploiting the Dynamics of Majorana-Majorana Hybridisation — •Themba Hodge, Eric Mascot, Daniel Crawford, and Stephan Rachel — School of Physics, University of Melbourne, Parkville, Australia

Qubits built out of Majorana-Zero Modes (MZMs) have long been theorised as a potential pathway toward fault-tolerant topological quantum computation. However, almost unavoidable in these processes is the overlapping of the different Majorana wavefunctions that arise throughout the process. This leads to a qubit-error due to Majorana-Majorana hybridisation, changing the outcome of the computation. This work presents a method to track the dynamical evolution of the Majorana wavefunctions, allowing one to track transitions in the ground-state subspace and calculate time-dependent correlation functions that provide the output of quantum computations. This is compared to exact, time-dependent superconducting simulations utilising the method introduced in [1], to confirm the advantage of this approach to make accurate dynamical predictions without the need for full many-body calculations. We also show how Majorana-Majorana hybridisation enable arbitrary quantum gates, including the magic-gate.

[1] E. Mascot, T. Hodge, D. Crawford, J. Bedow, D. Morr, S. Rachel, Phys. Rev. Lett. 131 (2023) 176601

TT 85.4 Fri 10:30 H 3005

Poor man's zero modes in hybrid quantum dot devices — •Michael Wimmer, Chun-Xiao Liu, Mert Bozkurt, Sebastian Miles, Francesco Zatelli, Bas ten Haag, and Tom Dvir — QuTech, TU Delft, The Netherlands

We will give an overview of different types of Majorana zero modes that can appear in two quantum dots with tunable normal and superconducting couplings. In particular, we will discuss how their properties can be understood from the charge stability diagram, and how to identify them in transport properties. Finally, we will comment on the scaling to longer chains.

TT 85.5 Fri 10:45 H 3005

Protection of poor man's Majorana bound states in larger systems — •Viktor Svensson and Martin Leijnse — NanoLund and Solid State Physics, Lund University, Sweden

Majorana zero modes exhibit non-abelian properties that would be useful for quantum computation. In large systems the Majoranas can be well separated and thereby topologically protected, but this is difficult to realize experimentally. Small systems may be simpler to build, but as the Majoranas are closer together they are less robust. In a model with interacting quantum dots, we study how the protection of the Majorana bound states changes as the size of the system is varied.

TT 85.6 Fri 11:00 H 3005

Machine-learned tuning of artificial Kitaev chains to Majorana sweet spots — •Jacob Benestad[1], Athanasios Tsintzis[2], Rubén Seoane Souto[3], Martin Leijnse[2], and Jeroen Danon[1] — [1]Center for Quantum Spintronics, Norwegian University of Science and Technology — [2]Division of Solid State Physics and NanoLund, Lund University — [3]Instituto de Ciencia de Materiales de Madrid, Spanish Research Council

Artificial Kitaev chains have been proposed as a platform realising so-called "poor man's Majorana bound states" (PMMs), lacking the topological protection of genuine Majorana bound states but still retaining non-abelian properties. These PMMs are found at discrete "sweet spots" for the Hamiltonian parameters, and the challenge in an experimental setting would be to tune the system to such a sweet spot. A recent proposal for how to experimentally probe the quality of sweet spots in artificial Kitaev chains [1] opens the door for auto-tuning of such systems. We investigate the use of Machine Learning based on an evolutionary strategy to automatically tune the Hamiltonian parameters to a sweet spot that could host PMMs.

[1] Souto et al., Phys. Rev. Research 5 (2023) 043182

TT 85.7 Fri 11:15 H 3005

Exploration of topological states and multiple gaps in MgB_2 superconductors — •Nora Kucska[1], Andras Laszloffy[1], Laszlo Szunyogh[2], and Balazs Ujfalussy[1] — [1]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary — [2]Budapest University of Technology and Economics, Budapest, Hungary

Unfortunately, most known topological superconductors possess low transition temperatures, impeding the experimental observation of Majorana fermions. MgB_2, a widely recognized high-temperature superconductor would consequently be an ideal subject to study due to the suspected topological properties of its band structure. This gives light to its intriguing quantum phase characterized by protected gapless surface/edge states within a bulk superconducting gap, possibly hosting Majorana fermions.

Using fully relativistic first-principles calculations, a Dirac-nodal line structure is investigated through the bulk and surface band structure of MgB_2. Adding magnetic impurities to the surface, the interaction between the topological system with the impurities is explored.

MgB_2 is also known for having multiple gaps in the superconducting state. Numerous experimental and theoretical studies find either one or two distinct gaps in the density of states, while a third gap was found in thin films of MgB_2 and by theoretical non-relativistic ab initio calculations. The multiple gap structure of MgB_2 was analyzed giving more insights on the topic. We study the so-called Yu-Shiba-Rusinov states in the context of this multi gapped superconductor.

TT 86: Correlated Electrons: Method Development

Time: Friday 9:30–13:15 Location: H 3007

TT 86.1 Fri 9:30 H 3007

RKKY-induced Kondo suppression in heavy-fermion materials — •Ulli Pohl[1] and Johann Kroha[1,2] — [1]University of Bonn, DE — [2]University of St. Andrews, UK

In heavy-fermion (HF) systems, the interplay of the local Kondo exchange interaction and the long-range RKKY interaction, remains a difficult problem. It can control magnetic quantum phase transitions in these materials. Recently, a perturbative, selfconsistent renormalization group technique was developed to include the local Kondo exchange and the RKKY interaction on the same footing [1]. In particular, the RKKY interaction is generated from the local Kondo exchange in second order of perturbation theory, as in realistic systems. In the present work, we extend this theory from weak RKKY interaction, i.e., from the HF-liquid side of a magnetic quantum phase transition (QPT), to strong RKKY interaction, i.e. to the realm where the system orders magnetically at sufficiently low temperatures. While on the HF side of the QPT the Kondo spectral weight develops logarithmically with decreasing temperature T, we find that on the magnetic side of the QPT the Kondo spectral weight is suppressed already at T orders of magnitude higher than the ordering Néel temperature T_N. This indicates that the Kondo weight may be destructed not by critical magnetic order-parameter fluctuations, but by frustrating RKKY coupling active at all temperatures. The behavior may be observable in a certain class of HF materials [2].

[1] A. Nejati, K. Ballmann, J. Kroha, PRL **118**, 117204 (2017).
[2] C. Wetli. *et al.*, Nature Physics 14, 1103 (2018).

TT 86.2 Fri 9:45 H 3007

Compressed Models of Exact Many-Body Propagators — •Markus Wallerberger — TU Wien, Austria

Many-body propagators take centre stage in a multitude of theories and experiments of strongly correlated systems. Computing these propagators for small systems, one usually turns to the numerically exact Lanczos method or related configuration interaction techniques. However, the multi-point propagator is still challenging to compute efficiently.

In this contribution, we will show how to use the recently developed intermediate representation and sparse modelling, machine-learning inspired models for the many-body propagator, to significantly speed up and numerically stabilize the computation of these propagators.

TT 86.3 Fri 10:00 H 3007

Efficient Computation of Multidimensional Lattice Sums with Boundaries and Applications to Long-Range Interacting Topological Quantum Systems — •Andreas A. Buchheit[1], Torsten Kessler[2], and Kirill Serkh[3] — [1]Saarland University, 66123 Saarbrücken, Germany — [2]Eindhoven University of Technology, 5600 MB Eindhoven, Netherlands — [3]University of Toronto, Toronto, ON M5S 2E4, Canada

Topologically non-trivial quantum states exhibit protected edge modes at the material boundary with numerous applications. Recent theoretical results have shown that such states can emerge due to long-range interactions. However, computing the effect of long-range interactions on edge modes is challenging. Here, we lay out a robust framework designed to efficiently compute multidimensional lattice sums with long-range interactions on bounded lattices. We show that any lattice sum can be generated from a generalization of the Riemann zeta function to multidimensional non-periodic lattice sums and put forth a super-exponentially converging algorithm for these zeta functions for an extensive range of geometries. Combining these functions with an efficient algorithm for constructing band-limited function approximations yields a general and easy-to-use framework for evaluating arbitrary lattice sums over non-periodic subsets of lattices. Most importantly, we demonstrate that the runtime is solely influenced by the complexity of the structures that the particles form and not by the particle number. We benchmark our method by computing interaction energies in 3D crystals with 10^{23} particles.

TT 86.4 Fri 10:15 H 3007

Cluster extension of the DMF^{2}RG and application to the 2d Hubbard model — •Marcel Krämer[1], Michael Meixner[2], Kilian Fraboulet[1], Pietro M. Bonetti[2], Demetrio Vilardi[2], Nils Wentzell[3], Thomas Schäfer[2], Alessandro Toschi[4], and Sabine Andergassen[4,5] — [1]Institut für Theoretische Physik, Universität Tübingen, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]Center for Computational Quantum Physics, Flatiron Institute, New York, USA — [4]Institute for Solid State Physics, Vienna University of Technology, Austria — [5]Institute of Information Systems Engineering, Vienna University of Technology, Austria

The DMF^{2}RG has been introduced to overcome the weak-coupling limitation of the fermionic functional renormalization group (fRG). This approach builds on the idea to exploit the dynamical mean-field theory (DMFT) as starting point for the fRG flow, thus capturing **local nonperturbative** correlations via DMFT together with perturbative nonlocal correlations generated during the flow. We show how **nonlocal nonperturbative** correlations can be also incorporated in the DMF^{2}RG scheme by using cellular DMFT (CDMFT) for a 2×2 cluster instead of single-site DMFT as starting point of the flow. Both CDMFT and fRG implementations have been formulated within the single-boson exchange decomposition, which has already proven to be an insightful bosonization scheme. We illustrate the ability of this novel approach to efficiently capture nonlocal nonperturbative correlations to describe d-wave superconductivity in the 2d Hubbard model.

TT 86.5 Fri 10:30 H 3007

divERGe - an open source functional renormalization code for material calculations — •Jonas B. Hauck[1], Dante M. Kennes[2,3], and Lennart Klebl[4] — [1]Institute for Theoretical Physics, Goethe University Frankfurt, Frankfurt a.M., Germany — [2]Institute for Theory of Statistical Physics, RWTH Aachen University, and JARA Fundamentals of Future Information Technology, Aachen, Germany — [3]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, Hamburg, Germany — [4]I. Institute for Theoretical Physics, Universität Hamburg, Hamburg, Germany

We present divERGe, an open source, high-performance C/C++/Python library for functional renormalization group (FRG) calculations on lattice fermions. The versatile model interface is tailored to real materials applications and seamlessly integrates with existing, standard tools from the ab-initio community. The code fully supports multi-site, multi-orbital, and non-SU2 models in all of the three included FRG variants: TUFRG, N-patch FRG, and grid FRG. With this, the divERGe library paves the way for widespread application of FRG as a tool in the study of competing orders in quantum materials.

TT 86.6 Fri 10:45 H 3007

Functional renormalization group for the Hubbard model at infinite on-site repulsion via Hubbard X-operators — Andreas Rückriegel, •Jonas Arnold, Rüdiger Krämer, and Peter Kopietz — Institut für Theoretische Physik, Universität Frankfurt, Max-von-Laue Straße 1, 60438 Frankfurt, Germany

Exact functional renormalization group (FRG) flow equations for quantum systems can be derived directly within an operator formalism without using functional integrals. This simple insight opens new possibilities for applying FRG methods to models for strongly correlated electrons with projected Hilbert spaces, such as the t model, obtained from the Hubbard model at infinite on-site repulsion. By representing this model in terms of Hubbard X-operators, we derive exact flow equations for the time-ordered correlation functions of the X-operators (X-FRG), which allow us to calculate the electronic correlation functions in the projected Hilbert space. We use our approach to investigate the “hidden Fermi liquid” state of this model where the Hamiltonian consists only of the projected kinetic energy.

TT 86.7 Fri 11:00 H 3007

Single-boson exchange formulation of the Schwinger-Dyson equation and its application to the functional renormalization group — •Miriam Patricolo[1,2], Marcel Gievers[4,5], Kilian Fraboulet[3], Sarah Heinzelmann[3], Demetrio Vilardi[2], Pietro M. Bonetti[2], and Sabine Andergassen[1,6] — [1]Institute of Information Systems Engineering, Vienna University of Tec., Vienna, Austria — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany

— [3]Institut für Theoretische Physik and Center for Quantum Science, Universität Tübingen, Tübingen, Germany — [4]Ludwig-Maximilians-Universität München, München, Germany — [5]Max Planck Institute of Quantum Optics, Garching, Germany — [6]Institute for Solid State Physics, Vienna University of Technology, Vienna, Austria

We extend the recently introduced single-boson exchange (SBE) formulation to the computation of the self-energy from the Schwinger-Dyson equation. In particular, we derive its general expression both in diagrammatic and physical channels and show that the SBE formulation of the Schwinger-Dyson equation can be naturally applied also to non-local interactions. We furthermore discuss its implications in a truncated unity solver. As an application, we provide functional renormalization group results for the two-dimensional Hubbard model at weak coupling, where the use of the Schwinger-Dyson equation for the self-energy flow allows to capture the pseudogap opening. We illustrate how the SBE formulation proves particularly advantageous in identifying the relevant physical channels responsible for driving the physical behavior.

15 min. break

TT 86.8 Fri 11:30 H 3007

Inchworm quasi Monte Carlo for quantum impurities — •Hugo U. R. Strand[1,2], Joseph Kleinhenz[3], and Igor Krivenko[4] — [1]School of Science and Technology, Örebro University, SE-701 82 Örebro, Sweden — [2]Institute for Molecules and Materials, Radboud University, 6525 AJ Nijmegen, the Netherlands — [3]Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720-8229, USA — [4]Institut für Theoretische Physik, Universität Hamburg, Notkestraße 9, 22607 Hamburg, Germany

The inchworm expansion is a promising approach to solving strongly correlated quantum impurity models due to its reduction of the sign problem in real and imaginary time. We show that the imaginary time integration is amenable to quasi Monte Carlo, with enhanced N^{-1} convergence, compared to standard inchworm Monte Carlo calculations with $N^{-1/2}$ convergence. This extends the applicability of the inchworm method to, e.g., multi-orbital Anderson impurity models with off-diagonal hybridization, relevant for materials simulation, where continuous time hybridization expansion Monte Carlo has a severe sign problem. We also present an open source implementation of our Inchworm quasi Monte Carlo approach: "QInchworm.jl", implemented in the Julia programming language.

TT 86.9 Fri 11:45 H 3007

Numerical linked-cluster expansions applied to a problem with bound-state decay — •Max Hörmann and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

Using numerical linked-cluster expansions (NLCEs) we investigate the Hamiltonian $H = \sum_i -n_i n_{i+1} + x\,(a_i a_{i+1}^\dagger + \text{h.c.}) = H_0 + xV$ on a chain in the sector of two hardcore-bosons. For $x < 1/2$ the Hamiltonian has a bound-state solution $\omega_{\text{bs}}(k) = -1 - 2x^2(1+\cos(k))$ below the continuum for each momentum and a local quasi-particle picture, which decouples bound states and continuum, exists. The perturbative solution for the bound-state energies is exact in second order. For $x > 1/2$ these energies are only eigenstates for $\omega_{\text{bs}}(k_{\text{bs}}) < 4x\,|\cos(k_{\text{bs}})|$. We explain how the breakdown of this formula for $k < k_{\text{bs}}$ can be understood in the framework of NLCEs.
For $x > 1/2$ conventional NLCEs do not converge any more. We try to modify them to obtain a convergent expansion, that shall yield a continuation of the bound-state energy dispersion for $k < k_{\text{bs}}$. For $k > k_{\text{bs}}$ we want to still find the energies $\omega_{\text{bs}}(k)$, but for $k < k_{\text{bs}}$ we want those, where the finite lifetime of the bound states is maximal.

TT 86.10 Fri 12:00 H 3007

Analytic results for the two-particle vertex in the atomic limit of the Hubbard model — •Stefan Rohshap, Markus Wallerberger, Karsten Held, and Anna Kauch — Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria

Much of the physics of strongly correlated electrons contained in the Hubbard model can already be understood by studying its atomic limit. Although the exact analytical expressions for the atomic one- and two-particle Green's functions are easily obtained, this is not the case for the two-particle irreducible vertex functions. These are of particular interest due to the presence of vertex divergences that are also present in the full Hubbard model [1]. Analytic expressions for irreducible vertices were so far only found for the half-filled single-orbital atom, by means of a sophisticated matrix inversion procedure that to our knowledge cannot be generalized [2].

In this contribution, we will present a new generalized technique based on a pole expansion method that allows the derivation of a set of analytic algebraic equations for determining the irreducible vertex also in the multiorbital case at arbitrary filling. We will show that this system of algebraic equations can be solved by choosing a suitable ansatz and exemplify it on the case of the single-band Hubbard atom. Moreover, we will present a new method for identifying vertex divergences based on the calculation of the determinant of the generalized susceptibility.

[1] T. Schäfer et al., Phys. Rev. B 94 (2016) 235108
[2] P. Thunström et al., Phys. Rev. B 98 (2018) 235107

TT 86.11 Fri 12:15 H 3007

Thermodynamic stability at the two-particle level — •Alexander Kowalski[1], Matthias Reitner[2], Lorenzo Del Re[3,4], Maria Chatzieleftheriou[5,6], Adriano Amaricci[7], Alessandro Toschi[2], Luca de' Medici[5], Giorgio Sangiovanni[1], and Thomas Schäfer[4] — [1]Institut für Theoretische Physik und Astrophysik und Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg — [2]Institute for Solid State Physics, TU Wien — [3]Department of Physics, Georgetown University — [4]Max-Planck-Institut für Festkörperforschung — [5]Laboratoire de Physique et d'Étude des Matériaux, UMR8213 ESPCI — [6]CPHT, CNRS, École polytechnique — [7]CNR-IOM, Istituto Officina dei Materiali, Consiglio Nazionale delle Ricerche

We show how the stability conditions for a system of interacting fermions that conventionally involve variations of thermodynamic potentials can be rewritten in terms of local one- and two-particle correlators. We illustrate the applicability of this alternative formulation in a multi-orbital model of strongly correlated electrons at finite temperatures, inspecting the lowest eigenvalues of the generalized local charge susceptibility in proximity of the phase-separation region. Additionally to the conventional unstable branches, we analyze unstable solutions possessing a positive, rather than negative compressibility. Our stability conditions require no derivative of free energy functions with conceptual and practical advantages for actual calculations and offer a clear-cut criterion for analyzing the thermodynamics of correlated complex systems.

TT 86.12 Fri 12:30 H 3007

Engineering photon-mediated long-range spin interactions in Mott insulators — •Paul Fadler[1], Jiajun Li[2], Kai Phillip Schmidt[1], and Martin Eckstein[3] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Paul Scherrer Institut — [3]Universität Hamburg

We investigate the potential to induce long-range spin interactions in a Mott insulator via the quantum electromagnetic field of a cavity. The coupling between light and spins is inherently non-linear and occurs via multi-photon processes like Raman scattering and two-photon absorption/emission with electronically excited intermediate states. Based on this, in arXiv:2311.01339 we elucidate two pathways: (i) In the absence of external driving, long-range interactions are mediated by the exchange of at least two virtual cavity photons. We show that these vacuum-mediated interactions can surpass local Heisenberg interactions in mesoscopic setups, e.g., in small enough split-ring resonators. (ii) In a laser-driven cavity, interactions can be tailored through a hybrid scheme of both laser and cavity photons. This offers a versatile pathway for Floquet engineering of long-range interactions in macroscopic systems. In general, the derivation of these interactions requires careful consideration: We demonstrate that a simple phenomenological approach, based on an effective spin-photon Hamiltonian, can be used only if the cavity is resonantly driven. Outside of these narrow regimes and for the undriven case, a series expansion within the underlying electronic model is necessary, which we perform to obtain long-range four-spin interactions in the half-filled Hubbard model.

TT 86.13 Fri 12:45 H 3007

Quasi-particle Bound States at Mott-Semiconductor Interfaces — •Jan Verlage[1], Friedemann Queisser[2,3], Peter Kratzer[1], and Ralf Schützhold[2,3] — [1]Fakultät für Physik, Universität Duisburg-Essen — [2]Institut für Theoretische Physik, Helmholtz-Zentrum Dresden-Rossendor — [3]Institut für Theoretische Physik, Technische Universität Dresden

We investigate bound states at the interfaces between semiconductors and a strongly correlated Mott insulator. Employing a method exploiting the hierarchy of correlations we identify effective quasi-particle and hole excitations in the heterostructure. To leading order in the hierarchy, the modes satisfy an effective two-component evolution equation. This allows for the investigation of bound states at single interfaces and heterostructures with and without conctact potentials at the interfaces. A single interface necessitates a contact potential to support bound states while a heterstructure does not.

The project is funded by the DFG, grant # 278162697 (CRC 1242).

TT 86.14 Fri 13:00 H 3007

Engineering effective nearest neighbor hopping — •Nico Leumer — DIPC, San Sebastian, Spain

The complexity of condensed matter in general implies the need for simple effective models that are still capable of describing the real world physics accurately. One approach is based on non-interacting tight-binding (TB) models, where we restrict Hamiltonians typically to onsite energies and nearest-neighbor (nn) hopping terms since next nearest neighbor (nnn) hoppings are deemed unimportant. However, has it ever come to your mind that nnn processes can be willingly engineered to dominate their nn cousins?

Theory demonstrated recently that onsite and nn hopping t_1 are sufficient to realize effective nnn hoppings t_2 [1]. Here, the key feature is the ability to tune t_1/t_2 such that the strong nnn regime $t_2 \gg t_1$ becomes in fact accessible. Contrary to its potentially "unrealistic" appearance on first glance, this procedure of generating nnn hoppings was already successfully applied [2], actually without experimentalist's awareness.

In my contribution, I present how nnn hoppings emerge from a free particle Hamiltonian featuring only onsite and nn terms. Further, I state why onsite terms are essential in reaching the strong t_2 limit. The nnn hoppings are not only a curiosity, they also imply the presence of in general complex wavevectors and the existence of degenerate (finite) energy eigenvalues at well-defined parameter constraints.

[1] N. G. Leumer, J. Phys. A: Math. Theor. 56 435202 (2023)
[2] K. Qian et.al., Phys. Rev. Research 5, L012012 (2023)

TT 87: Frustrated Magnets: Spin Liquids

Time: Friday 9:30–13:15 Location: H 3010

TT 87.1 Fri 9:30 H 3010

Electrical transport probes of quantum spin liquids — •Raffaele Mazzilli[1], Alex Levchenko[2], and Elio J. König[1] — [1]Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany — [2]Department of Physics, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA

Quantum spin liquids are an exotic phase of matter characterized by the presence of fractionalized excitation(spinons) and emergent gauge fields. One of the difficulties in probing experimentally a QSL phase comes from the fact that the spinons do not carry an electric charge, ruling out the possibility of using conventional electrical probes. Going beyond conventional transport, we propose two setups of electric probes to characterize a QSL phase. First, we analyze a setup in which a QSL layer is interposed between two metallic layers. In this setup, we apply a current in the first metallic layer and measure the induced voltage on the second one. The momentum transfer is affected by the non-trivial behavior of momentum-carrying spinons and results in a response that will potentially be helpful for the future characterization of candidate QSL materials. The second probe we propose is an STM experiment on a Kondo lattice in which the local moments have non-trivial dynamics (hence forming a QSL phase). We provide the STM response in each of the phase configurations of this system allowing also for the possibility for the conduction electrons and for the spinons to form a superconducting phase. This last setup might find a concrete realization in materials such as TaS_2, $TaSe_2$, and $NbSe_2$ in the 1T, 2H, and 4Hb crystallographic phases.

TT 87.2 Fri 9:45 H 3010

Modifying Quantum Spin Liquid Candidate $NaYbS_2$ — •Rajib Sarkar[1], Ellen Häussler[3], Hubertus Luetjens[2], Christopher Baines[2], Thomas Hicken[2], Thomas Doert[3], and Hans Henning Klauss[1] — [1]Institute of Solid State and Materials Physics, TU Dresden, D-01062 Dresden, Germany — [2]Laboratory for Muon Spin Spectroscopy, PSI, Villigen, Switzerland — [3]Faculty of Chemistry and Food Chemistry, TU Dresden, D-01062 Dresden, Germany

$NaYbS_2$ is a candidate material for a pseudo-$S = 1/2$ based quantum spin liquid on the ideal triangular lattice. Single crystals of the solid solution series $NaYb_{1-x}Lu_xS_2$ could be synthesized over the entire substitution range $0 < x < 1$. The chemical and structural analysis of this series reveals the statistically homogeneous replacement of Yb^{3+} by Lu^{3+} ions. Long-range magnetic order has not been detected in magnetic susceptibility measurements at any x down to 2 K. This suggests $NaYb_{1-x}Lu_xS_2$ as a family of diluted triangular-lattice spin liquids. We started investigating this series at specific doping concentrations by means of zero field (ZF) and longitudinal field (LF) μSR experiments to test for the presence of static magnetism and to investigate the nature of the magnetic ground state.

TT 87.3 Fri 10:00 H 3010

Low-temperature spin state in an organic spin-liquid candidate κ-(BEDT-TTF)$_2$Cu$_2$(CN)$_3$ investigated by magnetization measurements — •Eria Imada[1,2], Yosuke Matsumoto[2], Pal Sudip[3], Naoki Yoneyama[4], Martin Dressel[3], Takahiko Sasaki[5], Kazushi Kanoda[1,2,3], and Hidenori Takagi[1,2,3] — [1]The University of Tokyo, Tokyo, Japan — [2]Max-Planck-Institute, Stuttgart, Germany — [3]University of Stuttgart, Stuttgart, Germany — [4]Yamanashi University, Kofu, Japan — [5]Tohoku University, Sendai, Japan

The ground state of the organic quantum spin liquid candidate, κ-(BEDT-TTF)$_2$Cu$_2$(CN)$_3$, is under debate. We report our detailed DC magnetization M measurements. $M(T)$ on cooling shows a rapid decrease with a clear kink at 6K but an appreciable residual contribution, nearly liner in magnetic field up to 7 T, remains even at 2 K. We discuss possible origin of the low temperature residual contribution.

TT 87.4 Fri 10:15 H 3010

Kondo screening in Kitaev spin liquids with a Fermi surface — •Michel M. J. Miranda[1,2] and Matthias Vojta[1] — [1]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany — [2]Max-Planck-Institut für Chemische Physik fester Stoffe, Nöthnitzer Straße 40, 01187 Dresden, Germany

Isolated magnetic impurities can be used to probe the low-energy properties of a host system, with the standard Kondo effect in metals being the paradigmatic example. Magnetic impurities have also been discussed as probes of quantum spin liquids and their excitations, and various approximate theoretical treatments have been put forward. In particular, it has been suggested that a spin liquid with a spinon Fermi surface would lead to Kondo screening akin to that in normal metals. Here we study this problem for a particular Kitaev model with a Majorana Fermi surface, realized on the square-octagon lattice. We present a numerically exact solution using Wilson's Numerical Renormalization Group (NRG) which generalizes previous work for the honeycomb-lattice Kitaev model. Our numerical data for the renormalization-group flow and for thermodynamic observables highlight important differences between the Kitaev system and a metal, related to the fractionalization scheme and the influence of the emergent gauge field.

TT 87.5 Fri 10:30 H 3010

2-Form U(1) Spin Liquids: Classical Model and Quantum Aspects — •Kristian Chung[1] and Michel Gingras[2] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, D-01187 Dresden, Germany — [2]Department of Physics and Astronomy, University of Waterloo, Ontario, N2L 3G1, Canada

In this talk I introduce the concept of 2-form U(1) spin liquids, described by emergent 2-form U(1) gauge fields and supporting fractionalized string excitations. I introduce a frustrated Ising model on the pyrochlore lattice dubbed the "spin vorticity model", constructed to enforce a microscopic zero-curl constraint. I demonstrate that the ground state manifold is a classical spin liquid, with algebraically decaying correlations and an extensive ground state entropy. Each ground state may be decomposed into a collection of closed 2-dimensional membranes, and spin-flips fractionalize into strings attached to open membranes. The emergent gauge structure of this spin liquid is given by the theory of 2-form electrodynamics, which describes 1-dimensional charged strings coupled to a rank-2 anti-symmetric gauge field. Perturbing the classical model with quantum exchange interactions results in an effective "membrane exchange" model of the quantum dynamics, which maps to a strongly-coupled frustrated 2-form U(1) lattice gauge theory. The string excitations are captured by coupling a 1-form string field to the 2-form U(1) gauge field, thus mapping a quantum spin model to a 2-form U(1) gauge-Higgs model. I discuss the possibility of realizing a novel class of quantum phases of matter: 2-form U(1) quantum spin liquids.

TT 87.6 Fri 10:45 H 3010

Spectral Functions in $S = \frac{1}{2}$ Antiferromagnetic Heisenberg Models on the Triangular Lattice — •Markus Drescher[1], Laurens Vanderstraeten[2], Roderich Moessner[3], and Frank Pollmann[1,4] — [1]Department of Physics, Technische Universität München, 85748 Garching, Germany — [2]Center for Nonlinear Phenomena and Complex Systems, Université Libre de Bruxelles, 1050 Brussels, Belgium — [3]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [4]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

We consider an extended spin-$\frac{1}{2}$ antiferromagnetic Heisenberg model on the triangular lattice with nearest- and next-nearest-neighbor interactions and an additional scalar chiral term that gives rise to a rich phase diagram comprising putative quantum spin-liquid phases alongside magnetically ordered states with a coplanar 120° order, stripe order and a noncoplanar tetrahedral order. Using large-scale matrix-product-state simulations, we obtain the spectral responses in distinct ordered and liquid regimes of the phase diagram and review our results in the light of analytical predictions such as mean-field theory and spin-wave calculations. We also discuss finite-size effects and the role of different cylinder geometries for the spectral function.

TT 87.7 Fri 11:00 H 3010

Disorder effects in spiral spin liquids: Long-range spin textures, Friedel-like oscillations, and spiral spin glasses — •Pedro Monteiro Cônsoli and Matthias Vojta — Technische Universität Dresden

Spiral spin liquids are correlated states of matter in which a frustrated magnetic system evades order by fluctuating between a set of (nearly) degenerate spin spirals. Here, we investigate the response of spiral spin liquids to quenched disorder in a J_1-J_2 honeycomb-lattice Heisenberg model. At the single-impurity level, we identify different order-by-quenched-disorder phenomena and analyze the ensuing spin textures. In particular, we show that the latter generally display Friedel-like oscillations, which encode direct information about the spiral contour, i.e., the classical ground-state manifold. At finite defect concentrations, we perform extensive numerical simulations and characterize the resulting phases at zero temperature. As a result, we find that the competition between incompatible order-by-quenched-disorder mechanisms can lead to spiral spin-glass states already at low to moderate disorder. Finally, we discuss extensions of our conclusions to nonzero temperatures and higher-dimensional systems, as well as their applications to experiments.

TT 87.8 Fri 11:15 H 3010

Dimensional reduction and incommensurate dynamic correlations in the spin-1/2 triangular lattice antiferromagnet $Ca_3ReO_5Cl_2$ — •S. A. Zvyagin[1], A. N. Ponomaryov[1], J. Wosnitza[1,2], D. Hirai[3], Z. Hiroi[3], M. Gen[3], Y. Kohama[3], A. Matsuo[3], Y. H. Matsuda[3], and K. Kindo[3] — [1]HZDR, Germany — [2]TU Dresden, Germany — [3]ISSP, Japan

The observation of spinon excitations in the spin-1/2 triangular antiferromagnet $Ca_3ReO_5Cl_2$ reveals a quasi-one-dimensional (1D) nature of magnetic correlations, in spite of the nominally 2D magnetic structure. This phenomenon is known as frustration-induced dimensional reduction. Here, we present high-field electron spin resonance spectroscopy and magnetization studies of $Ca_3ReO_5Cl_2$, allowing us to refine spin-Hamiltonian parameters and to investigate peculiarities of its low-energy spin dynamics. We argue that the presence of the uniform Dzyaloshinskii-Moriya interaction (DMI) shifts the spinon continuum in momentum space and, as a result, opens a zero-field gap in the Brillouin zone center. The observed gap is found to be consistent with the structural modulation in the ordered state, suggesting this material as a perfect model triangular-lattice system, where a pure DMI-spiral ground state can be realized.

[1] S.A. Zvyagin et al., Nat. Commun. 13, 6310 (2022)

15 min. break

TT 87.9 Fri 11:45 H 3010

A novel classical spin-liquid with fractionalized bionic charges and chiral field excitations in the pyrochlore lattice — •Daniel Lozano-Gómez[1,2], Yasir Iqbal[3,4], and Matthias Vojta[1,2] — [1]Technische Universität Dresden, Dresden, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany — [3]Indian Institute of Technology-Madras, Chennai, India — [4]The Quantum Centers in Diamond and Emerging Materials, Chennai, India

Classical spin-liquid phases are generally described by emergent low-temperature gauge symmetries with fractionalized excitations and a system-size-dependent degeneracy of the ground-state manifold. In the study of spin-liquids, the pyrochlore lattice has demonstrated to be fruitful ground in the theoretical and experimental realization of such phases. Indeed, recent work on bilinear spin models in this lattice has identified a variety of classical and quantum spin-liquids whose most prominent examples are spin-ice, quantum spin-ice, higher-rank, and a 2-form spin-liquid. In contrast, much less attention has been devoted to spin models with interactions beyond bilinear spin terms realizing such highly correlated phases. In this work, we present a Hamiltonian composed of a three-body spin term that realizes a novel classical spin-liquid phase. We demonstrate that the ground-state manifold of this Hamiltonian is described by a subspace of the so-called color-ice-state manifold and that a gauge field theory describing the ground-state manifold possesses a chiral term that constraints the emergent gauge fields to follow a right-hand-rule.

TT 87.10 Fri 12:00 H 3010

Signatures of fractionalization in phonon spectral functions — •Josef Willsher[1,2], Urban F. P. Seifert[3], and Johannes Knolle[1,2,4] — [1]TU Munich, Germany — [2]MCQST, Germany — [3]Kavili Institute, Santa Barbara, USA — [4]Imperial College London, UK

A complicating factor in the realization and observation of gapless quantum spin liquids in materials is the ubiquitous presence of other degrees of freedom which may relieve geometric frustration, in particular phonons. We study the U(1) Dirac spin liquid and investigate how the coupling between spin-singlet monopoles and phonons manifests in the spectral properties of the phonons. We find that the critical gauge fluctuations of the algebraic spin liquid lead to a continuum of excitations in the phonon spectrum. A finite-temperature scaling Ansatz predicts a T-dependent Kohn-like anomaly of the phonon dispersion which could provide a universal signature of the Dirac spin liquid. This framework is able to recover the phenomenology of the recently described spin-Peierls instability of this system. We discuss the extension of these results to ultrasound attenuation experiments, as well as their applicability to other gapless spin liquids.

TT 87.11 Fri 12:15 H 3010

Spin-Peierls instability of deconfined quantum critical points — •David Hofmeier[1], Josef Willsher[1,2], Urban Seifert[3], and Johannes Knolle[1,2,4] — [1]TU Munich, Germany — [2]MCQST, Germany — [3]Kavli Institute, UCSB, USA — [4]Imperial College London, UK

Deconfined quantum critical points (DQCPs) are possible phase transitions beyond the Landau paradigm. The original example of a DQCP is the spin-1/2 quantum antiferromagnet on the square lattice which features a second order transition between valence bond solid (VBS) and Néel order. The VBS order breaks a lattice symmetry which should naturally lead to a coupling between phonons and the VBS order parameter. We investigate a field-theoretic description of the DQCP in the presence of a monopole-lattice coupling. We show that treating phonons as classical lattice distortions leads to a relevant monopole-phonon interaction inducing an instability towards the plaquette VBS phase. Consequently, there is a breakdown of the DQCP which generally becomes a first-order transition. Taking into account the full quantum nature of the phonons may alleviate this, where we argue that the DQCP persists above a critical phonon frequency. This work provides an extension of the spin-Peierls instability of algebraic spin liquid phases to a beyond-Landau phase transition, a fact we justify by close analogy with the 1D analogs of deconfined criticality. We discuss the implications of our findings to recent experiments on the Shastry–Sutherland lattice, and indeed argue that this spin-lattice coupling can be used to explain the observed plaquette order.

TT 87.12 Fri 12:30 H 3010

Higher-Order Susceptibilities in Extended Kitaev Models Computed Via Krylov-Space Based Methods — •Marius Möller[1], David Kaib[1], Wolfram Brenig[2], and Roser Valentí[1] — [1]Institute for Theoretical Physics, Goethe University Frankfurt, Max-von-Laue-Strasse 1, 60438 Frankfurt am Main, Germany — [2]Institute for Theoretical Physics, Technical University Braunschweig, 38106 Braunschweig, Germany

Higher Harmonic Generation phenomena and the underlying susceptibilities were recently proposed to potentially provide new insights into fractionalized excitations by showing clearer signatures than the rather featureless continua appearing in linear response. We investigate the possibility of calculating the higher order susceptibilities numerically from Exact Diagonalization Techniques, proposing a Krylov-space based algorithm applicable to various lattice models.

M.M., D.K. and R.V. gratefully acknowledge funding by the DFG (German Research Foundation): TRR 288 – 422213477.

TT 87.13 Fri 12:45 H 3010

Two-dimensional spectroscopy of quantum spin ice using Husimi cacti — •Mark Potts[1], Roderich Moessner[1], and Owen Benton[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Queen Mary University of London, London, United Kingdom

Two-dimensional coherent spectroscopy (2DCS) is a non-linear optical technique that has attracted increasing interest in the search for clear signatures of fractionalisation in exotic quantum phases of matter. Quantum spin ice is an example of such a system, hosting fractionalised spinon excitations often referred to as magnetic monopoles.

We present work analysing the possible application of 2DCS to candidate quantum spin ices as a probe of their fractionalised excitations, in a regime with strong thermal excitation of the gauge field.

In this limit, monopole dynamics are heavily constrained, and can be modelled by effective hopping on dual Husimi cacti graphs. We predict that a sharp 2DCS response can be observed using probe fields with well-defined effective pseudo-momenta when mapped to the Husimi cacti; a zero-momentum real-space probe field does not respect this condition, and so is predicted to produce a broad 2DCS signal despite the presence of fractionalised excitations. These results are supported by exact diagonalisation computations on a 32-site cluster.

TT 87.14 Fri 13:00 H 3010

Treating anyonic statistics within a full hypergraph decomposition — •Matthias Mühlhauser, Viktor Kott, and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

We describe how to execute a full hypergraph decomposition[1] to set up a linked-cluster expansion for the topological phase of Kitaev's Toric Code in a uniform magnetic field. An important challenge for such an expansion is to correctly incorporate the non-local anyonic braiding statistics into the calculations on the clusters. Indeed, the anyonic statistics lead to counter-intuitive effects like clusters which contribute to irreducible one-quasiparticle matrix elements despite hosting no excitation. We explain how to incorporate the non-local statistics within hypergraph expansions for perturbative series expansions of the one-charge gap, the one-flux gap, and the ground-state energy in the thermodynamic limit.

[1] Phys. Rev. E 105, 064110

TT 88: 2D Materials and Heterostuctures: (Twisted) Bilayers (joint session HL/TT)

Time: Friday 9:30–12:15 Location: EW 201

TT 88.1 Fri 9:30 EW 201

Lattice relaxation, electronic structure and continuum model for twisted bilayer MoTe2 — •Ning Mao[1], Cheng Xu[2,3], Jiangxu Li[2], Ting Bao[3], Peitao Liu[4], Yong Xu[3], Claudia Felser[1], Liang Fu[5], and Yang Zhang[2,6] — [1]Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany — [2]Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA — [3]Department of Physics, Tsinghua University, Beijing 100084, China — [4]Institute of Metal Research, Chinese Academy of Sciences, 110016 Shenyang, China — [5]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA — [6]Min H. Kao Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, Tennessee 37996, USA

Our study delves into the effect of lattice relaxation on the moiré band structures of twisted bilayer MoTe2, implemented by large-scale first-principles calculations and transfer learning neural network. Throughout our study, we have incorporated two van der Waals correction methods: the Grimme D2 method and a density-dependent energy correction. Notably, the latter method demonstrates a continuous evolution of bandwidth with respect to twist angles. Our findings reveal the critical role of in-plane lattice displacements, which generate substantial pseudomagnetic fields, reaching up to 250 T. Building on these insights, we have developed a comprehensive continuum model with a single set of parameters for a wide range of twist angles, providing a useful starting point for many-body simulation.

TT 88.2 Fri 9:45 EW 201

Twist disorder in $tWSe_2$: Insights from Lateral Force Microscopy and Raman Spectroscopy — •Nicolai-Leonid Bathen[1], Rami Dana[2], Hendrik Lambers[1], Nihit Saigal[1], Julian Klein[2], Frances M. Ross[2], and Ursula Wurstbauer[1] — [1]University of Münster, Münster, Germany — [2]Massachusetts Institute of Technology, Cambridge, MA, United States

Bilayers of twisted transition metal dichalcogenides (TMDCs) form moiré hybridized lattices resulting in moiré minibands [1] which leads to the capability to host correlated quantum phases [2] and to simulate Mott-Hubbard physics [3]. These properties vary strongly with the local twist angle configuration due to changes in the moiré cell size, symmetry and long-range disorder. Here we unravel the formation of moiré lattices and local disorder in the twist angle in twisted WSe_2 homo-bilayers ($tWSe_2$) by lateral force microscopy in ambient providing atomic resolution. We studied several $tWSe_2$ bilayers with a large variety in the nominal twist angle of 3° to 11° and find a surprisingly large variation in twist angle up to 1° within less than a micrometer distance. We contrast those findings with low-frequency Raman measurements sensitive to interlayer coupling and we will discuss consequences of the local twist disorder for collective inter-moiré band excitations studied by resonant inelastic light scattering [1].

[1] N. Saigal et al., arXiv 2310 14417 (2023) [2] N. P. Wilson et al., Nature 599, 383-392 (2021) [3] S. Ryee and T. O. Wehling, Nano Lett. 23 (2), 573-579 (2023) [4] Y. Song and E. Meyer, ACS Langmuir 39, 15409 (2023)

TT 88.3 Fri 10:00 EW 201

Electrical tuning of moiré excitons in $MoSe_2$ bilayers — •Joakim Hagel[1], Samuel Brem[2], and Ermin Malic[2,1] — [1]Department of Physics, Chalmers University of Technology, 412 96 Gothenburg, Sweden — [2]Department of Physics, Philipps University of Marburg, 35037 Marburg, Germany

Recent advances in the field of vertically stacked 2D materials have revealed a rich exciton landscape. In particular, it has been demonstrated that out-of-plane electrical fields can be used to tune the spectral position of spatially separated interlayer excitons. Other studies have shown that there is a strong hybridization of exciton states, resulting from the mixing of electronic states in both layers. However, the connection between the twist-angle dependent hybridization and field-induced energy shifts has remained in the dark. Here, we investigate on a microscopic footing the interplay of electrical and twist-angle tuning of moiré excitons in homobilayers [1,2]. We reveal distinct energy regions in PL spectra that are clearly dominated by either intralayer or interlayer excitons, or even dark excitons [1]. Consequently, we predict twist-angle-dependent critical electrical fields at which the material is being transformed from a direct into an indirect semiconductor [1]. Our work provides new microscopic insights into experimentally accessible knobs to significantly tune the moiré exciton physics in atomically thin nanomaterials.

[1] J. Hagel, S. Brem, E. Malic, 2023 2D Mater. 10 014013
[2] Tagarelli, F., Lopriore, E., Erkensten, D. et al. Nat. Photon. 17, 615-621 (2023)

TT 88.4 Fri 10:15 EW 201

Exciton-polaritons in twisted-bilayer heterostructures — •Francesco Troisi[1], Hannes Huebener[1], Angel Rubio[1,3], and Simone Latini[2] — [1]MPSD, Hamburg, Germany — [2]Department of Physics, DTU, Lyngby, Denmark — [3]Center for Computational Quantum Physics, Flatiron Institute, Simons Foundation, NYC, USA

2D materials, such as TMDs, have attracted significant attention due to their unique electronic properties, such as tunable bandgap, high emission efficiency, and a strong excitonic binding allowing the formation of stable excitons at room temperature. Excitons in multilayer TMD structures are the object of great interest, as we find both inter- and intra-layer excitons, which give rise to a response at different energies. Previous works show that it is possible to tune the Moiré potential to control their localization, which influences the optical properties.

In the quest to understand and control excitons in novel environments, this study focuses on excitonic behavior for a twisted bilayer MoSe2/WSe2 heterostructure in an optical cavity. Our goal is to produce an all-optical Moiré-like exciton confinement by tuning the cavity. Optical cavities provide a promising approach to controlling material properties by coupling the electronic transitions in the material to the confined photons inside the cavity, which implies photonic and excitonic states cannot be separated. The so-called exciton-polariton states are obtained. In the strong coupling regime, one needs to go beyond the perturbative approach to treat the light-matter problem.

This study utilizes the full diagonalization of the QED problem built from the Wannier equation in k-space and the Moiré potential.

TT 88.5 Fri 10:30 EW 201

Investigating the orbital dependence of the superlattice potential in Moiré semiconductors with NanoARPES — •Gianmarco Gatti[1], Julia Issing[1], Dario Rossi[2], Louk Rademaker[2], Anna Tamai[1], and Felix Baumberger[1] — [1]Department of Quantum Matter Physics, University of Geneva, Geneva, 1211, Switzerland — [2]Department of Theoretical Physics, University of Geneva, Geneva, 1211, Switzerland

Moiré semiconductors emerged as tunable quantum simulators for strongly correlated phases. The single-particle low-energy physics is ruled by the moiré-periodic superpotential that develops by twisting or stacking layers with different lattice parameters. Signatures of this modulation are observed in the spectral function measured by angle-resolved photoemission spectroscopy (ARPES) in the form of replicas and gaps opening at the nascent zone boundary. In twisted bilayer transition metal dichalcogenides (TMDs), flat bands are reported at the Brillouin zone center and their dispersion is associated to the effective moiré potential experienced by electronic states with large out-of-plane orbital character. Here, we extend this analysis and present the orbital and wave vector dependence of this interaction over the whole Brillouin zone by comparing quantitatively our ARPES data on a TMD heterobilayer with an extended tight-binding model. Our results set the fundaments for future spectroscopic studies of the electronic correlations in moiré systems.

TT 88.6 Fri 10:45 EW 201

Confocal SHG microscopy of twisted bilayers of MoS_2 — •Nikita V. Siverin[1], Daniel J. Gillard[2], Dmitri R. Yakovlev[1], Alexander I. Tartakovskii[2], and Manfred Bayer[1] — [1]TU Dortmund, Dortmund, Germany — [2]The University of Sheffield, Sheffield, UK

We investigate the crystal and exciton symmetries in twisted MoS_2 bilayer flakes using second harmonic generation (SHG). By measuring and modeling the full dependence of the SHG signal on the linear polarization angles of incident and emitted light we reveal the underlying mechanisms of SHG. Our method employs a confocal microscopy setup, allowing for spectroscopic investigations of different excitonic resonances.

Twisting layers of 2D materials is a familiar technique that produces a superlattice and gives rise to the phenomena called moiré structure inducing changes in optical properties.

We measured different regions of overlapping flakes: monolayer, twisted monolayers, bilayer and twisted bilayers. We observe strong SHG signal from monolayers and we can measure twisted angle by polarization anisotropies of the SHG signal. According to group theory, SHG is forbidden in bilayers, but we observe small signal with rotational anisotropy deviating from the one for monolayers.

15 min. break

Invited Talk TT 88.7 Fri 11:15 EW 201

Correlated phases in the vicinity of tunable van Hove singularities in Bernal bilayer graphene — •Anna Seiler[1], Nils Jacobsen[1], Martin Statz[1], Fabian Geisenhof[2], Felix Winterer[2], Isabell Weimer[1], Tianyi Xu[3], Zhiyu Dong[4], Leonid Levitov[4], Fan Zhang[3], and Thomas Weitz[1] — [1]University of Göttingen — [2]Ludwig-Maximilians-Universität München — [3]University of Texas at Dallas — [4]Massachusetts Institute of Technology

The bandstructure of naturally occurring Bernal bilayer graphene exhibits four linearly-dispersed Dirac cones but changes drastically when large electric displacement fields are applied across the two layers. Here, tunable van Hove singularities lead to the emergence of complex correlated states. We observe experimental signatures consistent with various interaction-driven phases, including the fractional metals of Stoner type [1, 2]. More prominently, we find competing nontrivial insulating and metallic phases at hole doping that exhibit intriguing temperature dependences and nonlinear I-V characteristics at zero magnetic fields [1]. In addition, we report a novel interaction-driven behaviour in the Stoner phases in the electron-doped regime electric-field gapped Bernal bilayer graphene [2]. Specifically, we reveal that the spin- and valley-polarized phases exhibit an insulator-like temperature dependence of the conductance that challenges the conventional picture of metallic Stoner magnetism.

[1] A. M. Seiler et al., Nature 608, 298-302 (2022)
[2] A. M. Seiler et al., arXiv:2308.00827 (2023)

TT 88.8 Fri 11:45 EW 201

Valley transport assisted by Fermi surface warping — Josep Ingla-Aynés[1], •Antonio L. R. Manesco[1], Talieh S. Ghiasi[1], Serhii Volosheniuk[1], Kenji Watanabe[2], Takashi Taniguchi[3], and Herre S. J. van der Zant[1] — [1]Kavli Institute of Nanoscience, Delft University of Technology, Netherlands — [2]Research Center for Electronic and Optical Materials, National Institute for Materials Science, Japan — [3]Research Center for Materials Nanoarchitectonics, National Institute for Materials Science, Japan

Valleys are distinct energy extrema in a band structure. Graphene has a band structure with two valleys at distinct high-symmetry points. The large momentum separation of these points suppresses intervalley scattering in ballistic devices. However, even in ballistic devices, valley coherence is limited by atomically-sharp edge disorder. Gate-defined bilayer graphene devices overcome this limitation and enable the observation of valley coherent phenomena. In this work, we explored ballistic electron transport in multiterminal bilayer graphene devices. We observed specular electron-focusing between gate-defined quantum point contacts, suggesting that smooth edges preserve valley polarization. Moreover, trigonal warping of the Fermi surface causes valley-dependent electron jetting, which we detected with magnetic collimation. Our results show two current peaks in the collector signal at opposite magnetic fields, consistent with the injection of two valley-polarized electron jets. Since the valley polarization of the electron current depends on the magnetic field, collimation devices are current sources with tuneable valley polarization.

TT 88.9 Fri 12:00 EW 201

Gate screening of Coulomb interactions in Bernal bilayer graphene — •Isabell Weimer[1], Anna Seiler[1], Dong Zhao[2], Jurgen Smet[2], and R. Thomas Weitz[1] — [1]1st Institute of Physics, Faculty of Physics, Georg-August-University Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]MPI for Solid State Research, Heisenbergstraße 1, 70569 Stuttgart, Germany

Measurements on dual gated, hexagonal Boron Nitride (hBN) encapsulated Bernal bilayer graphene samples, have revealed a complex phase space for Bernal bilayer graphene, including numerous Stoner metals, a correlated insulator consistent with a Wigner-Hall crystal [1] and superconducting behavior [2].

We have investigated the influence of the gate induced Coulomb interaction screening [3] on the appearance of previously reported correlated phases in gated Bernal bilayer graphene devices, using the thickness of the dielectric hBN spacing layers as variable parameter. In direct comparison of devices studied here, which are characterized by a comparably thin h-BN layer, with the data of Seiler et. al. , we observed behavior, which is supportive of an effectively lowered magnitude of Coulomb interactions. Additionally, three features in the transport data were identified, which could potentially be indicative of phases, not reported in [1] and [2].

References: [1] Seiler, Anna M., et al. Nature 608.7922 (2022): 298-302. [2] Zhou, Haoxin, et al. Science 375.6582 (2022): 774-778. [3] Kim, Minsoo, et al. Nature communications 11.1 (2020): 2339.

TT 89: Focus Session: Evolution of Topological Materials into Superconducting Nanodevices (joint session HL/TT)

The focus session intends to span the arc between topological materials and superconducting nanodevices, both experimentally and theoretically. Such structures are interesting for applications in future topological quantum circuits. In recent years, the number of topological materials and the knowledge about them has rapidly increased. As part of the focus session, material properties of layered systems made of topological materials, especially in combination with superconductors, are discussed. On the other hand, the special challenges in the nanofabrication of these materials for use in future topological quantum processors are addressed. Another focus is the quantum transport in nanoscale hybrid structures.

Organized by Thomas Schäpers, Philipp Rüßmann, and Peter Schüffelgen

Time: Friday 9:30–12:45 Location: EW 202

Invited Talk TT 89.1 Fri 9:30 EW 202
Tunneling spectroscopy of a phase-tunable topological insulator Josephson junction — •Jakob Schluck[1], Ella N. Nikodem[1], Anton Montag[2], Alexander Ziesen[2], Mahasweta Bagchi[1], Zhiwei Wang[1], Fabian Hassler[2], and Yoichi Ando[1] — [1]Institute of Physics II, University of Cologne — [2]JARA-Institute for Quantum Information, RWTH Aachen University

Topological superconductivity is predicted to be realized in a topological insulator proximitized by an s-wave superconductor [1]. In such a system, vortices host Majorana zero modes - quasiparticle excitations obeying non-Abelian exchange statistics that could have important applications as topological qubits.

Here we present our experimental findings concerning the bound state spectrum of topological insulator Josephson junctions. We locally probe the density of states through tunnel contacts made on top of the junction, while tuning the phase difference across it by applying an external magnetic field.

We find a periodic filling of the induced gap, with states reaching zero energy for a local phase difference of π. Taking the phase gradient along the junction into account, we interpret those as signatures of Majorana zero modes bound to the π-phase boundary [2]. We will discuss their stability with respect to the chemical potential and possible trivial origins.

[1] Liang Fu and C. L. Kane, Phys. Rev. Lett. 100, 096407 (2008) [2] A. C. Potter and L. Fu, Phys. Rev. B 88, 121109 (2013).

Invited Talk TT 89.2 Fri 10:00 EW 202
Robust Majorana modes in topological material-based nanoelectronic hybrid devices — •Kristof Moors — Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany — JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany

Majorana modes have the potential to be used as robust carriers of quantum information for future fault-tolerant quantum information processing applications. While their realization in various condensed matter systems is well understood in principle, realistic conditions (with, e.g., disorder or imperfections) can complicate their formation as well as experimental verification in practice. I will present recent modeling and simulation results on two promising platforms for Majorana devices: magnetic and nonmagnetic topological insulator nanoribbons with proximity-induced superconductivity, respectively. These platforms have distinct advantages for a robust realization of Majorana modes by forming them out of their proximitized and topologically protected surface or edge states. In this way, a higher tolerance with respect to disorder and less finetuned conditions can be obtained as compared to alternative platforms. I will discuss the topological phase with well-separated Majorana modes in such systems under realistic conditions, the robustness against disorder, and distinct signatures in spectroscopy and transport experiments. I will also comment on the latest status regarding the experimental development.

Invited Talk TT 89.3 Fri 10:30 EW 202
Thermal and electric response of superconducting topological materials; are Majorana states more widespread than expected? — •Ewelina Hankiewicz — Institute for Theoretical Physics, Uni Würzburg, Germany

In this talk, we will discuss different Josephson junctions based on semimetals, metals and topological insulators proximitized with s-wave superconductors. We show that thermal response can be more sensitive to Majorana bound states than an electrical response [1,2]. Moreover, due to the 4pi periodicity of topological Josephson junctions, the thermal engines built on them are more efficient as the ones on the classical Josephson junctions [3].

Furthermore, we predict that the s-wave superconductivity proximitized j=3/2 particles in 2D Luttinger materials are able to host Majorana bound states even in the absence of Dresselhaus and Rashba spin-orbit couplings [4]. This originates from the hybridization of the light and heavy hole bands of the j=3/2 states in combination with the superconducting pairing. We predict that Majorana bound states should be seen in many classes of materials like p-doped GaAs and bulk HgTe [4].

[1] A. G. Bauer et al. Phys. Rev. B 104, L201410 (2021). [2] R. L. Klees, D. Gresta, J. Sturm, L. W. Molenkamp, and E. M. Hankiewicz arXiv:2306.17845 (2023). [3] B. Scharf, A. Braggio, E. Strambini, F. Giazotto, E. M. Hankiewicz, Communications Physics 3, 198 (2020). [4] J.-B. Mayer, M. A. Sierra, and E. M. Hankiewicz, Phys. Rev. B 105, 224513 (2022).

15 min. break

Invited Talk TT 89.4 Fri 11:15 EW 202
Tunable Josephson coupling in HgTe nanodevices — •Martin P. Stehno — Physikalisches Institut EP3 und Institut für Topologische Isolatoren, Julius-Maximilians-Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Mercury telluride offers access to a variety of topological phases in a single material system. This opens up opportunities for disentangling the complex interplay of band structure effects, interface preparation, and phase dynamics that characterize the Josephson effect in topological insulator nanodevices. We study a new generation of gate-tunable Josephson junctions with weak links fabricated from 2D and 3D topological insulator HgTe. These devices feature ballistic transport over a wide range of carrier densities and allow us to map out the Josephson coupling of topological states and bulk modes using a combination of quantum transport methods, supercurrent interference, and microwave spectroscopy. By adding a gated constriction into a 2D topological insulator weak link, we create a quantum point contact (QPC) that allows us to study the ac Josephson effect as a function of the number of open channels. As we deplete the constriction further, we explore proximity-induced superconductivity in the quantum spin Hall edge channels and in the regime of the recently discovered 0.5-anomaly in HgTe QPC devices.

Invited Talk TT 89.5 Fri 11:45 EW 202

Superconducting proximity effect in topological Dirac materials — •Chuan Li[1], Anqi Wang[2], Caizhen Li[2], Chhunguang Chu[2], Zhimin Liao[2], and Alexander Brinkman[1] — [1]MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands. — [2]State Key Laboratory for Mesoscopic Physics and Frontiers Science Center for Nano-optoelectronics, Peking University, 100871 Beijing, China

Inducing superconductivity in topological materials stimulates the formation of novel quantum states of matter. Besides the original prediction in 3D topological insulators, the notion of topological phases has been generalized to different dimensions and extended to the higher-order states.

In the last few years, our research has demonstrated the possibility of realizing the topological superconductivity in engineered 3D topological insulators, 3D Dirac semimetals [1,2], and their 1D hinge states. Particularly, Cd3As2 is predicted to be a higher-order topological semimetal, possessing three-dimensional bulk Dirac fermions, two-dimensional Fermi arcs [3], and one-dimensional hinge states [4] or non-Hermitian states [5]. These topological states have different characteristic length scales in electronic transport. We show that the superconducting proximity effect can be a sensitive probe for distinguishing these states.

[1] Li, C. et al. Nat. Mater. 17, 875 (2018). [2] Wang, A. Q. et al. PRL (2018). [3] Li, C.-Z. et al. Nat. Commun.(2020). [4] Li, C.-Z. et al. PRL (2020). [5] C. G. Chu, et al., Nat. Commun. (2023).

Invited Talk TT 89.6 Fri 12:15 EW 202

Exploring Josephson Junctions made of Topological Insulator Wires and Superconductors — •Dieter Weiss — Experimentelle und Angewandte Physik, Universität Regensburg, 93040 Regensburg

Topological insulator (TI) nanowires in proximity to conventional superconductors provide a tunable platform to realize topological superconductivity and Majorana bound states (MBS) [1]. Tuning is achieved by an axial magnetic flux ϕ which transforms the system from trivial at ϕ =0 to topologically non-trivial when a magnetic flux quantum $\phi_0 = h/2e$ threads the wire cross section. Here we study the supercurrent I_C and its periodicity on the superconducting phase as a function of the axial magnetic field using Josephson junctions made of strained HgTe wires (the TI) with Nb contacts. Depending on the transparency of the contacts we observe either a monotonically decreasing I_C with increasing B for high transparency or $h/2e$, $h/4e$, and even $h/8$e periodic oscillations of the supercurrent for samples with lower transparency [2]. Samples with high transparency exhibit 4π periodic supercurrents, a signature of MBS [3]. I will discuss the significance of these signatures and the origin of the flux-periodic oscillations.

Work done in collaboration with Ralf Fischer, Wolfgang Himmler, Jordi Picó-Cortés, Jacob Fuchs, Michael Barth, Cosimo Gorini, Klaus Richter, Gloria Platero, Milena Grifoni, Dmitriy A. Kozlov, Nikolay N. Mikhailov, Sergey A. Dvoretsky, and Christoph Strunk.

[1] A. Cook and M. Franz, Phys. Rev. B 84, 201105(R) (2011)
[2] W. Himmler et al., Phys. Rev. Res. 5, 043021 (2023)
[3] R. Fischer et al., Phys. Rev. Res. 4, 013087 (2022)

TT 90: Many-Body Quantum Dynamics II (joint session DY/TT)

Time: Friday 9:30–10:30 Location: A 151

TT 90.1 Fri 9:30 A 151

Cavity control of quantum materials — •Daniele Fausti — Friedrich Alexander University of Erlangen-Nuremberg

This seminar will focus on the potential of cavity electrodynamics in shaping material properties, opened by on our recent investigation into cavity-mediated thermal control of the metal-to-insulator transition in 1T-TaS2, which demonstrated the feasibility of reversible cavity manipulation of a phase transition in a correlated solid-state material. By immersing the charge density wave material 1T-TaS2 into cryogenic tunable terahertz cavities, we unveil a remarkable shift between conductive states. This transition, triggered by a substantial alteration in sample temperature, is controlled by mechanical adjustments of the distance between cavity mirrors and their alignment[1]. The discussion will extend to unpublished data on vibrational strong coupling within higher frequency cavities, emphasizing the position-dependent coupling strength that underscores the influence of the mode structure on the observed effects. Our findings rationalized in a scenario reminiscent of the Purcell effects, wherein the spectral profile of the cavity significantly shapes the energy exchange between the quantum material and the external electromagnetic field unfolds promising opportunities for tailoring the thermodynamics and macroscopic transport properties of quantum materials through strategic engineering of their electromagnetic surroundings. The seminar will discuss some perspectives for cavity control of material functionalities in correlated complex quantum materials.

[1] Nature 622, pages 487*492 (2023)

TT 90.2 Fri 9:45 A 151

Phase transition driven by ultrashort laser pulses in the charge-density-wave material $K_{0.3}MoO_3$ — •Rafael T. Winkler[1,2], Larissa Boie[1], Yunpei Deng[2], Matteo Savoini[1], Serhane Zerdane[2], Abhishek Nag[2], Sabina Gurung[1], Davide Soranzio[1], Tim Suter[1], Vladimir Ovuka[1], Janine Zemp-Dösseger[1], Elsa Abreu[1], Simone Biasco[1], Roman Mankowsky[2], Edwin J. Divall[2], Alexander R. Oggenfuss[2], Mathias Sander[2], Christopher Arrell[2], Danylo Babich[2], Henrik T. Lemke[2], Paul Beaud[2], Urs Staub[2], Jure Demsar[3], and Steven L. Johnson[1,2] — [1]Institute for Quantum Electronics, Physics Department, ETH Zurich, Zurich, Switzerland. — [2]SwissFEL, Paul Scherrer Institute, Villigen, Switzerland. — [3]Faculty - Institute of Physics, Johannes Gutenberg-University Mainz

Blue Bronze ($K_{0.3}MoO_3$) is a quasi 1D material exhibiting a charge density wave with a periodic lattice distortion (PLD). In a time resolved x-ray experiment at SwissFEL, we study the dynamics of the PLD by pumping $K_{0.3}MoO_3$ with short laser pulses and probing it using x-ray diffraction. We construct reciprocal space maps (RSM) of superlattice reflections at different delays. The RSM along the surface normal gets broader at the delay equal to half the amplitude mode oscillation period, indicating a transient inversion of the PLD. For longer delays, this broadening is not visible. However, the diffracted x-ray intensity drops below the unpumped value indicating a molten CDW near the surface.

TT 90.3 Fri 10:00 A 151

Equilibrium parametric amplification in Raman-cavity hybrids — •Hector Pablo Ojeda Collado[1,2], Marios H. Michael[3], Jim Skulte[1,2], Angel Rubio[3,4], and Ludwig Mathey[1,2] — [1]Center for Optical Quantum Technologies and Institute for Quantum Physics, University of Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Max Planck Institute for the Structure and Dynamics of Matter, Luruper Chausse 149, 22761 Hamburg, Germany — [4]Center for Computational Quantum Physics, The Flatiron Institute, 162 Fifth Avenue, New York, New York 10010, USA

Parametric amplification have led to extraordinary photo-induced phenomena in recent pump-probe experiments. While these phenomena manifest themselves in out-of-equilibrium settings, in this work, we present the striking result of parametric amplification in equilibrium. We demonstrate that quantum and thermal noise of a Raman-active mode amplifies light inside a cavity when the Raman mode frequency is twice the cavity frequency. This noise-driven amplification leads to the creation of an unusual parametric Raman polariton with smoking gun signatures in Raman spectroscopy. We show distinctive properties of this polariton, including localization and static shift of the Raman mode, together with an increase of quantum light fluctuations within the cavity. Our study suggests a resonant mechanism for controlling Raman modes and thus matter properties by cavity fluctuations. We conclude by outlining how to compute the Raman-cavity coupling, and suggest possible experimental realizations.

TT 90.4 Fri 10:15 A 151

Real-time transport of short electron pulses trough an impurity on a 1D quantum wire — •Thomas Kloss[1,2], Yuriel Nunez Fernandez[1,2], and Xavier Waintal[2] — [1]Univ. Grenoble Alpes, CNRS, Institut Néel, 38000 Grenoble, France — [2]Université Grenoble Alpes, CEA, Grenoble INP, IRIG, Pheliqs, F-38000 Grenoble, France

We study the transmission of pulses which are propagating through a weakly coupled impurity site, which is located on an infinitely long 1D tight-binding chain. For short pulses, the number of transmitted charges deviates from the adiabatic regime and shows a periodic dependence on the number of injected charges. In the limit of ultrashort pulses an analytic formula can be derived which matches perfectly the results obtained by numerical simulations using the Tkwant software. In a next step, a Hubbard-like interaction with strength U is added on the impurity site. Onside density and currents are obtained in a perturbative expansion in U using a real-time Green function approach. We apply a tensor-train technique to integrate over the high-dimensional integrals, which has been shown to outperform diagrammatic quantum Monte Carlo by orders of magnitude in speed an accuracy. The results are compared to self-consistent mean-field calculations and to the non-interacting limit.

TT 91: 2D Materials VII: Heterostructures (joint session O/TT)

Time: Friday 10:30–12:45 Location: MA 005

TT 91.1 Fri 10:30 MA 005

Defect-free two-dimensional core-shell heterostructures: MoS_2-TaS_2/Au(111) — Kai Mehlich[1,2], Mahdi Ghorbani-Asl[3], Daniel Sahm[4], Thais Chagas[4], Daniel Weber[1], Catherine Grover[1], Daniela Dombrowski[1,2], Arkady Krasheninnikov[3], and •Carsten Busse[1,2] — [1]Department Physik, Universität Siegen, Germany — [2]Institut für Materialphysik, Universität Münster, Germany — [3]Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [4]Department Bauingenieurwesen, Universität Siegen, Germany

We prepared two-dimensional core-shell heterostructures of the monolayer transition metal dichalcogenides (TMDCs) MoS_2 and TaS_2 by reactive molecular beam epitaxy (MBE) on chemically inert and weakly interacting Au(111). The heterostructures are in a size regime where quantum confinement can be expected. Despite large lattice mismatch a seamless interconnection of the two materials has been achieved, confirming successful encapsulation of the semiconducting core by a metallic shell. The resulting strain is analyzed on the atomic scale using scanning tunneling microscopy (STM) and compared to continuum models as well as simulations unsing empirical potentials.

TT 91.2 Fri 10:45 MA 005

Growth and nanomanipulation of ultrathin Bismuthene nanoflakes on h-BN monolayers — •Antonio J. Martínez-Galera[1,2,3] and José M. Gómez-Rodríguez[2,3,4] — [1]Departamento de Física de Materiales, Universidad Autónoma de Madrid, E-28049 Madrid, Spain — [2]Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain — [3]Instituto de Ciencia de Materiales Nicolás Cabrera, Universidad Autónoma de Madrid, E-28049 Madrid, Spain — [4]Departamento de Física de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain

Bismuthene, a young member of the family of 2D Materials, exhibits unique electronic properties when reduced to a single layer [1,2]. This study explores the growth of thin bismuth nanoflakes on h-BN monolayers under ultrahigh vacuum conditions. High-resolution scanning tunneling microscopy (STM) images unveil a stacking arrangement of Bi atoms within the nanoflakes, similar to the structure of Bi(110) planes in bulk material. Precise control of nanoflakes thickness, down to the lower limit of a bilayer, has been achieved by adjusting the deposited Bi amount on the h-BN surfaces. In addition to the structural characterization, well-controlled nanomanipulation experiments by using the STM tip have been conducted with these nanoflakes.

References:

[1] F. Reis et al. Science 357, 287-290 (2017).
[2] S. Zhang et al. Chem. Soc. Rev. 47, 982-1021 (2018).

TT 91.3 Fri 11:00 MA 005

Optical properties of van der Waals TMD heterostructures from first-principles — •Riccardo Reho[1,2] and Zeila Zanolli[1,2] — [1]Chemistry Dept., Debye Institute for Nanomaterials Science, Utrecht University, Utrecht, The Netherlands — [2]ETSF

Van der Waals (VdW) heterostructures of two-dimensional transition metal dichalcogenides (TMDs) provide a unique platform to investigate rich phenomena stemming from the intricate interactions of charge, spin, and moiré superlattice with many-body effects. Controlling and predicting their optical properties with precision remains challenging.

Employing the ab initio GW-BSE method, we will offer an in-depth microscopic description of the optical properties of TMDs heterostructures. Beyond conventional electronic and absorption analyses, we also delve into the Photoluminescence spectra, leveraging a recent implementation we introduced in the Yambo code. We discuss on the roles of various degrees of freedom, such as mechanical strain and twist alignment. Our findings underscore the importance of structural properties, especially geometrical relaxation and computational subtleties, in ensuring accurate predictions of the band structure and absorption spectra for MoS_2/WS_2 and $MoSe_2/WSe_2$ heterostructures. Notably, we report a pronounced excitonic shift attributed to twisting and strain, shedding light on their profound impact on optical properties.

TT 91.4 Fri 11:15 MA 005

Complexity of excitons at the TMD-Graphene interface — •Amir Kleiner, Daniel Hernangómez Pérez, and Sivan Refaely-Abramson — Weizmann Institute of Science, Rehovot, Israel

The complex optical characteristics of heterostructures composed of layered 2D materials are of great importance and interest. Specifically, the interaction between light and matter at the interface of layered transition metal dichalcogenides (TMDs) and graphene draw significant interest, facilitating the understanding of related energy-transfer mechanisms and their structural roots. We use state-of-the-art first principles calculations to study the dependence of the excitonic composition and absorption properties of the representative WS_2 - Graphene heterostructures on the structural details of these structures. Examining the cases of 0° and 30° degrees of interlayer twist angle, we find that the induced Brillouin zone mismatch, and concomitantly the energy level alignment between the graphene Dirac cone and the TMD bands, dictate the excitonic properties resulting in significant variation between the two systems. In particular, these set the charge-separation of nature of low-energy interlayer excitons and the state hybridization of optically active intralayer excitonic peaks. We use our results to numerically quantify the graphene-induced homogeneous broadening as a function of heterostructure alignment. Our findings provide guidelines for optical excitations based on the composition of the heterostructure, indicating a direct connection between the stacking of the layers, the separation of charges within the excitons, and the broadening of optical features.

TT 91.5 Fri 11:30 MA 005

Electronic Characterization of Magnetic $CrCl_3$ Monolayers on $NbSe_2$ — •Jan Cuperus, Anna Reinhold, Daniel Vanmaekelbergh, and Ingmar Swart — Debye Institute for Nanomaterials Science, Utrecht University, The Netherlands

Electronic devices today suffer from a considerable loss of energy in the form of heat. With the ever increasing scale of information processing, it is essential to develop devices that are more efficient either in power usage or in information processing. In both cases, new materials are required to enable this. Van der Waals heterostructures are a class of materials that are well suited to offer the required properties. By combining materials with different properties in a heterostructure with a high quality interface, a plethora of properties can be obtained. Recently, this strategy was used to obtain topological superconductivity by combining superconducting $NbSe_2$ with ferromagnetic $CrBr_3$ [1].

We have conducted STM experiments on a similar heterostructure, replacing the out-of-plane ferromagnetism of CrBr3 by the in-plane ferromagnetism of $CrCl_3$. We present the MBE growth of $CrCl_3$ on $NbSe_2$ and structural insight into the formed heterostructure by STM measurements. In addition, the electronic structure is investigated using differential conductance measurements, both with and without an externally applied magnetic field. We show that the superconductivity of $NbSe_2$ couples to the in-plane ferromagnet, thereby introducing in-gap states.

[1] S. Kezilebieke, et al. Nature 588, 424-428 (2020).

TT 91.6 Fri 11:45 MA 005

Interplay of tunnelling gap and Faraday-like screening in graphene heterostructures — •Tobias Wichmann[1,2,3], Keda Jin[1,2,4], Jose Martinez Castro[1,4], Honey Boban[5], Lukasz Plucinski[5], Tom G. Saunderson[6,7], Yuriy Mokrousov[6,7], Markus Ternes[1,2,4], F. Stefan Tautz[1,2,3], and Felix Lüpke[1,2] — [1]Peter-Grünberg-Institut (PGI-3), Forschungszentrum Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA) - Fundamentals of Future Information Technology, Germany — [3]Institut für Experimentalphysik IV A, RWTH Aachen, Germany — [4]Institut für Experimentalphysik II B, RWTH Aachen, Germany — [5]Peter-Grünberg-Institut (PGI-6), Forschungszentrum Jülich, Germany — [6]Institute of Physics, Johannes Gutenberg University, Mainz, Germany — [7]Peter-Grünberg-Institut (PGI-1) and Institute for Advanced Simulations (IAS), Forschungszentrum Jülich, Germany

Scanning tunneling spectroscopy of graphene shows a gap around the Fermi energy, as tunnelling channels to the graphene Dirac states are suppressed due to their finite momentum in the graphene plane. Until now, applications of this phenomenon have been lacking. We report the interplay of the tunnelling gap and Faraday-like screening in graphene placed on Fe_3GeTe_2 (FGT). By tunnelling through the electronic gap of the graphene into the underlying FGT surface, we directly access the electronic properties of the graphene/FGT van der Waals interface. Studying the magnetoelectric tunability of the heterostructure properties, we find Faraday-like screening of the electric field exerted by the tunnelling probe by the graphene.

TT 91.7 Fri 12:00 MA 005

Probing the phase transition to a coherent 2D kondo lattice — •Cosme Gonzalez Ayani[1,2,3], Michele Pisarra[4], Ivan M. Ibarburu[2,3], Manuela Garnica[2], Rodolfo Miranda[2,3,5], Fabian Calleja[2], Fernando Martin[2,3], and Amadeo L. Vazquez de Parga[2,3,5] — [1]Institute of Physics, Zagreb, Croatia — [2]Universidad autonoma madrid, Madrid, Spain — [3]Imdea Nanociencia, Madrid, Spain — [4]Universita della Calabria, Rende, Italy — [5]IFIMAC, Madrid, Spain

Kondo screening occurs when a magnetic impurity is embedded in a metal, below a given temperature, known as the Kondo temperature, a singlet state forms between the spin of the impurity and the spins of the conduction electrons. When the distance between the magnetic impurities is small enough the physics of the system is expected to be modified. The first experimental evidence was obtained in the 1970s in systems containing rare earths. By means of scanning tunneling microscopy (STM) and spectroscopy (STS) at low temperatures we explore a van der Waals heterostructure consisting in a single layer of 1T-TaS2 on a 2H-TaS2 crystal. The 1T-TaS2 layer presents a (13x13)R13.9 charge density wave (CDW) with a localized electron at the center of every unit cell of the CDW. For temperatures below 28 K the spatially resolved STS shows the presence of a Kondo resonance in the Mott-Hubbard gap. For temperatures below 11 K the system develops a quantum coherent state called Kondo lattice, resembling the physics of 3D heavy fermion metals.

TT 91.8 Fri 12:15 MA 005

Engineering quantum dot nanoarrays in van der Waals heterostructures — •Keda Jin[1,2], Lennart Klebl[3], Junting Zhao[1,2], Tobias Wichmann[1,5], F. Stefan Tautz[1,5], Felix Lüpke[1], Dante Kennes[4], Jose Martinez-Castro[1,2], and Markus Ternes[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Institut für Experimentalphysik II B, RWTH Aachen, 52074 Aachen, Germany — [3]I.Institute for Theoretical Physics, Universität Hamburg, 22607 Hamburg, Germany — [4]Institut für Theorie der statistischen Physik, RWTH Aachen, 52074 Aachen — [5]Institut für Experimentalphysik IV A, RWTH Aachen, 52074 Aachen, Germany

Superlattice engineering in graphene has generated interest for their ability to mimic the moiré potential observed in twistronics. While the moiré potential is sensitive to the twist angle, we present a method to periodically modulate the graphene potential by stacking graphene on 1T/2H-$NbSe_2$. The doping effect from the charge density wave of 1T-$NbSe_2$ allows for the formation of quantum dot nanoarrays. Using scanning tunneling microscopy/spectroscopy, we visualized the localized electronic structures to be independent of the twist angle between graphene and $NbSe_2$. Furthermore, we observed a bias-dependent strip pattern, breaking the six-fold rotational symmetry, which indicates an emergence of correlated states in the quantum dot nanoarrays. Our research paves the way for the fabrication of quantum dot nanoarrays in van der Waals heterostructures, extending beyond graphene to other 2D van der Waals heterostructures that are not limited by twist angle.

TT 91.9 Fri 12:30 MA 005

Mechanical Characterization of Molecular Sieving Polymers — •Jakob Kreie[1], André Beyer[1], Yonghang Yang[2], Zhikun Zheng[2], and Armin Gölzhäuser[1] — [1]Physics of Supramolecular Systems and Surfaces, Bielefeld University, Germany — [2]School of Chemistry, Sun Yat-sen University, Guangzhou, Guangdong, Republic of China

To enable the practical use of molecular sieves on a larger scale, it is crucial to achieve a certain mechanical stability and elasticity. Our study deals with the analysis of polymer membranes as molecular sieves, these 2D imine-linked covalent organic frameworks are periodic and porous networks. The focus of the research is on their permeability as well as their mechanical properties.

Through the application of an atomic force microscope, we conducted comprehensive evaluations using free-standing nanoindentation and the bulge test. The results revealed a Young's modulus of 55 GPa and a breaking strength of 83 N/m for a membrane thickness of 45 nm. Moreover, our observations demonstrated remarkable elasticity during repeated tests, even after localized damage to the free-standing membrane had occurred.

TT 92: Quantum Dynamics, Decoherence and Quantum Information (joint session DY/TT)

Time: Friday 10:45–13:00 Location: A 151

TT 92.1 Fri 10:45 A 151

Photon-Resolved Floquet Theory and its Application to Quantum Communication — •Georg Engelhardt[1], Sayan Choudhury[2,3], W. Vincent Liu[2,1], JunYan Luo[4], Victor M. Bastidas[5,6], and Gloria Platero[7] — [1]Southern University of Science and Technology, Shenzhen, China — [2]University of Pittsburgh, Pittsburgh, USA — [3]Harish Chandra Research Institute, UttarPradesh, India — [4]Zhejiang University of Science and Technology, Hangzhou, China — [5]NTT Research, Sunnyvale, USA — [6]Massachusetts Institute of Technology, Cambridge, USA — [7]Instituto de Ciencia de Materiales de Madrid ICMM-CSIC, Madrid, Spain

The semiclassical analysis of Floquet systems can not account for quantum-optical phenomena that rely on the quantized nature of light. Here, we go beyond the semiclassical description by unifying Floquet theory with quantum optics using the framework of Full-Counting Statistics. This formalism, which we dub 'Photon-resolved Floquet theory' (PRFT), is based on two-point tomographic measurements, instead of the two-point projective measurements used in standard Full-Counting Statistics [1,2]. The PRFT predicts the generation of macroscopic light-matter entanglement when atoms interact with multimode electromagnetic fields, thereby leading to complete decoherence in the Floquet-state basis. Employing the PRFT, we propose a quantum communication protocol that may outperform the state-of-art few-photon protocols by two orders of magnitude or better.

[1] G. Engelhardt et al., arXiv:2207.08558 [2] G. Engelhardt et al., arXiv:2311.01509

TT 92.2 Fri 11:00 A 151

Information currents in disordered region — •Nicolas Bauer and Björn Trauzettel — Julius Maximilians Universität Würzburg, Würzburg, Germany

The information lattice is a tool to organize quantum information into different scales and allows the definition of local information and information currents. Hence, it allows to study the flow of information in various systems. We apply the information lattice to a hybrid quench-probe setup, where one part of the system undergoes a quench while another part remains inert. The quench creates a propagating entanglement wave packet, visible in the information lattice, and we study how a disordered region in the probe affects this information current, i.e. scattering and localization of information within the disordered region. In addition, the hybrid setup has an energy selective coupling feature, which allows us to analyze and compare the scattering/localization properties of e.g. fermions at varying energy levels or topological excitations like Majorana zero modes.

TT 92.3 Fri 11:15 A 151

Single-Qubit Error Mitigation by Simulating Non-Markovian Dynamics — •Mirko Rossini, Dominik Maile, Joachim Ankerhold, and Brecht Donvil — Institute for Complex Quantum Systems and IQST, Ulm, Germany

Quantum simulation is a powerful tool to study the properties of quantum systems. The dynamics of open quantum systems are often described by completely positive (CP) maps, for which several quantum simulation schemes exist. Such maps, however, represent only a subset of a larger class of maps: the general dynamical maps which are linear, Hermitian preserving, and trace-preserving but not necessarily positivity preserving. In this talk, I show a simulation scheme for these general dynamical maps, which occur when the underlying system-reservoir model undergoes entangling (and thus non-Markovian) dynamics. Such maps also arise as the inverse of CP maps, which are commonly used in error mitigation. Our simulation scheme is illustrated on an IBM quantum processor, demonstrating its ability to recover the initial state of a Lindblad evolution. This paves the way for a novel form of quantum error mitigation. Our scheme only requires one ancilla qubit as an overhead and a small number of one and two-qubit gates. Consequently, we expect it to be of practical use in near-term quantum devices.

TT 92.4 Fri 11:30 A 151

Generalisation of the Landauer-Buettiker theory onto the case of dissipative contacts — •Andrey Kolovsky — Krasnoyarsk, Russia

We revisit the problem of two-terminal transport of non-interacting Fermi particles in a mesoscopic device by employing the semi-microscopic model for the contacts, where we mimic the self-thermalisation property of the contacts by using the Lindblad relaxation operators. It is argued that the dissipative dynamics of the contacts causes partial decoherence of the quantum states of fermionic carriers in the device which, in its turn, can essentially modify the system conductance as compared to predictions of the standard Landauer-Buettiker theory.

TT 92.5 Fri 11:45 A 151

Iterative construction of conserved quantities in dissipative nearly integrable systems — •Iris Ulčakar[1,2] and Zala Lenarčič[1] — [1]Jožef Stefan Institute, 1000 Ljubljana, Slovenia — [2]University of Ljubljana, Faculty for physics and mathematics, 1000 Ljubljana, Slovenia

Integrable systems offer rare examples of solvable many-body problems in the quantum world. Due to the fine-tuned structure, their realization in nature and experiment is never completely accurate, therefore effects of integrability are observed only transiently. One way to surpass that is to couple nearly integrable systems to baths and driving: these will stabilize integrable effects up to arbitrary time, as encoded in the time dependent, and eventually, the stationary state of form of a generalized Gibbs ensemble. However, the description of such driven dissipative nearly integrable models is challenging and no exact analytical methods have been proposed so far. Here we develop an iterative scheme in which integrability breaking perturbations (baths) determine the most necessary conserved quantities to be added into a truncated generalized Gibbs ensemble description. Our scheme significantly reduces the complexity of the problem, paving the way for thermodynamic results.

TT 92.6 Fri 12:00 A 151

Quantum thermodynamics of impurity models using the principle of minimal dissipation — •Salvatore Gatto, Alessandra Colla, Heinz-Peter Breuer, and Michael Thoss — University of Freiburg

Quantum thermodynamics has witnessed significant attention and advancement in recent years. A central challenge in this field revolves around establishing a consistent and universally accepted definition for work, heat, and entropy production in open quantum systems subjected to thermal reservoirs. Despite numerous proposals, the absence of generally accepted definitions, particularly in scenarios involving strong interactions between the system and reservoirs, remains a contentious issue. A recently developed approach, known as principle of minimal dissipation [1], leads to a unique decomposition of the quantum master equation into coherent and dissipative dynamics, allowing to identify uniquely the contributions describing work and heat.

In this contribution, we apply this approach to investigate the thermodynamic characteristics of impurity models, with a particular focus on memory effects and strong system-bath couplings. The study uses the hierarchical equations of motion approach, which allows a numerically exact simulation of nonequilibrium transport in general open quantum systems involving multiple bosonic and fermionic environments [2].

[1] A. Colla and H. Breuer, Phys. Rev. A 105, 052216 (2022)

[2] J. Bätge, Y. Ke, C. Kaspar, and M. Thoss, Phys. Rev. B 103, 235413 (2021)

TT 92.7 Fri 12:15 A 151

Control phase transitions analysis in the quantum control landscape — •Nicolò Beato, Pranay Patil, and Marin Bukov — Max Planck Institute for the Physics of Complex Systems, Noethnitzer Str. 38, 01187 Dresden, Germany

In recent years, the presence of control phase transitions emerged while numerically surveying the quantum control landscape associated with population-transfer problems in few-qubit systems [10.1103/PhysRevX.8.031086]. Despite all efforts, an analytical understanding of quantum optimal control landscapes is largely missing.

In this work, we present a set of perturbative methods that allow for the analytical characterization of various control phase transitions. These methods provide an explicit mapping between quantum control problems and classical many-body systems at thermal equilibrium (exhibiting long-range, multi-body interactions). We demonstrate the effectiveness of these approaches by explicitly considering the single- and two- qubit state-preparation problems, previously extensively studied via numerical optimization algorithms [10.1103/PhysRevA.97.052114]. Through this approach, control phase transitions are connected to dramatic changes in the topological and geometrical properties of the near-optimal part of the control landscape.

The methods developed are largely independent from the quantum systems underlying the control problem and can be easily adapted to more complicated settings. Our work shed new light on the close connection between optimal quantum control and (spin) glassy systems.

TT 92.8 Fri 12:30 A 151

Engineering unsteerable quantum states with active feedback — •Samuel Morales[1], Yuval Gefen[2], Igor Gornyi[3,4], Alex Zazunov[1], and Reinhold Egger[1] — [1]Institut für Theoretische Physik, Heinrich-Heine-Universität, 40225 Düsseldorf, Germany — [2]Department of Condensed Matter Physics, Weizmann Institute, 7610001 Rehovot, Israel — [3]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [4]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

We propose active steering protocols for quantum state preparation in quantum circuits where each system qubit is connected to a single detector qubit, employing a simple coupling selected from a small set of steering operators. The decision is made such that the expected cost-function gain in one time step is maximized. We apply these protocols to several many-qubit models. Our results are underlined by three remarkable insights. First, we show that the standard fidelity does not give a useful cost function; instead, successful steering is achieved by including local fidelity terms. Second, although the steering dynamics acts on each system qubit separately, entanglement in the generated target state is introduced, and can be tuned at will, by performing Bell measurements on detector qubit pairs after every time step. This implements a weak-measurement variant of entanglement swapping. Third, numerical simulations suggest that the active steering protocol can reach arbitrarily designated target states, including passively unsteerable states such as the N-qubit W state.

TT 92.9 Fri 12:45 A 151

Extended Hilbert Space for Discontinuous Floquet Drives in the Walsh Basis — •James Walkling and Marin Bukov — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The form of the Floquet counterdiabatic protocol has recently been found and formulated in terms of a variational principle. While good convergence is achieved in a number of systems for harmonic drives, for step drives, the convergence of the numerics is poorly behaved. As a result, we explore a reformulation of Floquet Hilbert space in terms of a more natural basis for step drives: the Walsh basis. Among other nice properties, this basis forms a group for certain finite truncations. We investigate the results of this change of basis on the overall Hamiltonian in the extended space.