Low Temperature Physics Division
Fachverband Tiefe Temperaturen (TT)

Stefan Kehrein
Georg-August University
Institute for Theoretical Physics
Friedrich-Hund-Platz 1
37077 Göttingen
stefan.kehrein@theorie.physik.uni-goettingen.de

Program Overview

(Lecture Halls H31, H32, H33, H36 and Poster P3 and P4)

Plenary Talks Chaired by the Low Temperature Physics Division

PLV VI	Wed	14:00–14:45	H1	**Topological spin-textures – from domain walls to Hopfions: Current innovations and future challenges** — •Stefan Blügel
PLV XI	Fri	8:30– 9:15	H1	**Exploring correlated phases and topology in van der Waals platforms** — •Roser Valenti

Symposia Coorganized by the Low Temperature Physics Division

Invited Talks of the joint SKM Dissertationspreis 2025 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	9:30–10:00	H2	**Nanoscale Chemical Analysis of Ferroic Materials and Phenomena** — •Kasper Aas Hunnestad
SYSD 1.2	Mon	10:00–10:30	H2	**Advanced Excitation Schemes for Semiconductor Quantum Dots** — •Yusuf Karli
SYSD 1.3	Mon	10:30–11:00	H2	**Aspects and Probes of Strongly Correlated Electrons in Two-Dimensional Semiconductors** — •Clemens Kuhlenkamp
SYSD 1.4	Mon	11:00–11:30	H2	**Mean back relaxation and mechanical fingerprints: simplifying the study of active intracellular mechanics** — •Till Münker
SYSD 1.5	Mon	11:30–12:00	H2	**Coherent Dynamics of Atomic Spins on a Surface** — •Lukas Veldman

Invited Talks of the joint Symposium Spins in Molecular Systems: Strategies and Effects of Hyperpolarization (SYMS)

See SYMS for the full program of the symposium.

SYMS 1.1	Wed	15:00–15:30	H1	**Exploring the Non-Perturbative Magnetic Resonance Drive Regime with spin selection rules in a π-Conjugated Polymer** — •Christoph Boehme
SYMS 1.2	Wed	15:30–16:00	H1	**The puzzle of spin and charge transport in the chirality induced spin selectivity effect** — •Bart van Wees
SYMS 1.3	Wed	16:00–16:30	H1	**Nano- and Microscale NMR spectroscopy with spin qubits in diamond** — •Nabeel Aslam
SYMS 1.4	Wed	16:45–17:15	H1	**Spin effects in adsorbed organometallic complexes** — •Richard Berndt
SYMS 1.5	Wed	17:15–17:45	H1	**Quantum Computing with Molecules** — •Mario Ruben

Invited Talks of the joint Symposium Nonequilibrium Collective Behavior in Open Classical and Quantum Systems (SYQS)

See SYQS for the full program of the symposium.

SYQS 1.1	Thu	15:00–15:30	H1	**Active quantum flocks** — •Markus Heyl
SYQS 1.2	Thu	15:30–16:00	H1	**Robust dynamics and function in stochastic topological systems** — •Evelyn Tang
SYQS 1.3	Thu	16:00–16:30	H1	**Nonequilibrium Dynamics of Disorder-Driven Ultracold Fermi Gases** — •Artur Widera
SYQS 1.4	Thu	16:45–17:15	H1	**Topological classification of driven-dissipative nonlinear systems** — •Oded Zilberberg
SYQS 1.5	Thu	17:15–17:45	H1	**Learning dynamical behaviors in physical systems** — •Vincenzo Vitelli

Invited Talks of the joint Symposium Electronic Structure Theory for Quantum Technology: From Complex Magnetism to Topological Superconductors and Spintronics (SYES)

See SYES for the full program of the symposium.

SYES 1.1	Fri	9:30–10:00	H1	**Ab-initio Design of superconductors** — •Lilia Boeri
SYES 1.2	Fri	10:00–10:30	H1	**Topological superconductivity from first principles** — •László Szunyogh
SYES 1.3	Fri	10:30–11:00	H1	**First-principles study and mesoscopic modeling of two-dimensional spin and orbital fluctuations in FeSe** — •Myrta Grüning
SYES 1.4	Fri	11:15–11:45	H1	**Non-collinear magnetism in 2D materials from first principles: Multiferroic order and magnetoelectric effects.** — •Thomas Olsen
SYES 1.5	Fri	11:45–12:15	H1	**Spin-phonon and magnon-phonon interactions from first principles** — •Marco Bernardi

Invited Talks in Focus Sessions

Invited Talks of the Focus Session "Magnetic Phenomena from Phonon Chirality and Angular Momentum" (joint session MA/TT)

TT 1.1	Mon	9:30–10:00	H20	**Driving Coherent Phonon-Phonon Angular Momentum Transfer via Lattice Anharmonicity** — •Sebastian Maehrlein
TT 1.2	Mon	10:00–10:30	H20	**Chiral phonons, phono-magnetism, and spin-rotation coupling** — •Matthias Geilhufe
TT 1.3	Mon	10:30–11:00	H20	**Geometry of temporal chiral structures and photoinduced chirality-spin coupling** — •Olga Smirnova
TT 1.4	Mon	11:15–11:45	H20	**Phonon thermal Hall effect** — •Kamran Behnia
TT 1.5	Mon	11:45–12:15	H20	**Giant effective magnetic moment of chiral phonons** — •Swati Chaudhary

Invited Talks of the Focus Session "Many-Body Phenomena in Nanomagnets: Kondo, Spinons, Spinarons and Beyond" (joint session O/TT)

TT 6.1	Mon	15:00–15:30	H24	**Kondo and Yu-Shiba-Rusinov resonances: transport and coupling** — •Laëtitia Farinacci
TT 6.2	Mon	15:30–16:00	H24	**Electron delocalization in a 2D Mott insulator** — •Amadeo L. Vazquez de Parga
TT 6.3	Mon	16:00–16:30	H24	**Kondo or no Kondo, that is the question** — •Alexander Weismann
TT 6.4	Mon	16:30–17:00	H24	**Evidence for spinarons in Co atoms on noble metal (111) surfaces** — •Artem Odobesko
TT 6.5	Mon	17:00–17:30	H24	**Spinarons: A new view on emerging spin-driven many-body phenomena in nanostructures** — •Samir Lounis

Invited Talks of the Focus Session "Strongly Correlated Quantum States in Moire Heterostructures" (joint session TT/HL/MA)

TT 18.1	Tue	9:30–10:00	H36	**The Thermoelectric Effect and Its Natural Heavy Fermion Explanation in Twisted Bilayer and Trilayer Graphene** — •Bogdan Andrei Bernevig
TT 18.2	Tue	10:00–10:30	H36	**Angle-Tuned Chiral Phase Transition in Twisted Bilayer Graphene** — •Laura Classen
TT 18.3	Tue	10:30–11:00	H36	**Quantum Optics of Semiconductor Moire Materials** — •Atac Imamoglu
TT 18.4	Tue	11:15–11:45	H36	**Probing the Band Structures of Multilayer Graphene Using the Quantum Twisting Microscope** — •Martin Lee
TT 18.5	Tue	11:45–12:15	H36	**Gate-Tunable Bose-Fermi Mixture in a Strongly Correlated Moiré Bilayer Electron System** — •Nathan Wilson

Invited Talks of the Focus Session "Nonlinear Spectroscopy of Collective Excitations in Quantum Magnets" (joint session TT/MA)

TT 27.1	Wed	9:30–10:00	H36	**Detecting Anyons Using Nonlinear Pump-Probe Spectroscopy** — •Max McGinley
TT 27.2	Wed	10:00–10:30	H36	**Two-Dimensional Nonlinear Dynamic Response of Frustrated Magnets** — •Wolfram Brenig
TT 27.3	Wed	10:30–11:00	H36	**Imaging Magnetization Dynamics and Collective Spin Excitations in Compensated Magnets on Ultrafast Timescales** — •Benjamin Stadtmüller
TT 27.4	Wed	11:15–11:45	H36	**Revealing Dynamics of Hidden Sectors with Nonlinear Spectroscopy** — •Yoshito Watanabe
TT 27.5	Wed	11:45–12:15	H36	**Theory of Nonlinear Spectroscopy of Quantum Magnets** — •Stefan Birnkammer

Invited Talks of the Focus Session "Ising Superconductivity in Monolayer Transition Metal Dichalcogenides" (joint session TT/HL/MA)

TT 44.1	Thu	9:30–10:00	H36	**Evidence of Unconventional Superconductivity in Monolayer and Bulk van der Waals Material TaS_2** — •Somesh Chandra Ganguli
TT 44.2	Thu	10:00–10:30	H36	**Signatures of Unconventional Superconductivity in Transition Metal Dichalcogenides** — •Miguel Ugeda
TT 44.3	Thu	10:30–11:00	H36	**Friedel Oscillations and Chiral Superconductivity in Monolayer $NbSe_2$** — •Magdalena Marganska
TT 44.4	Thu	11:15–11:45	H36	**Unconventional Pairing in Ising Superconductors** — •Andreas Kreisel
TT 44.5	Thu	11:45–12:15	H36	**High-Field Study of Ising Superconductivity in TMDs** — •Oleksandr Zheliuk

Individual Invited Talks

TT 15.1	Tue	9:30–10:00	H31	**Solving Many-Body Problems on Quantum Computers** — •Benedikt Fauseweh
TT 24.1	Wed	9:30–10:00	H31	**Possible Origin of High-Field Reentrant Superconductivity in UTe_2** — •Toni Helm
TT 24.7	Wed	11:30–12:00	H31	**Unconventional Superconductivity in Epitaxial $KTaO_3$-Based Heterostructures** — •Denis Maryenko
TT 31.1	Wed	15:00–15:30	H31	**Quantum Skyrmion Hall Effect** — •Ashley Cook
TT 33.8	Wed	17:00–17:30	H33	**Emergent Dynamical Gauge Fields in Generic Kitaev Spin Liquids: From Monolayer to Multilayers** — •Aprem Joy
TT 48.1	Thu	15:00–15:30	H32	**Optical Conductivity as a Probe for Chiral Majorana Edge Modes** — •Lina Johnsen Kamra

All Sessions

TT 1.1–1.8	Mon	9:30–13:00	H20	**Focus Session: Magnetic Phenomena from Phonon Chirality and Angular Momentum I (joint session MA/TT)**
TT 2.1–2.11	Mon	9:30–12:30	H31	**Nonequilibrium Quantum Systems (joint session TT/DY)**
TT 3.1–3.12	Mon	9:30–12:45	H32	**Correlated Magnetism – General**
TT 4.1–4.13	Mon	9:30–13:00	H33	**Topological Insulators**
TT 5.1–5.13	Mon	9:30–13:00	H36	**Superconductivity: Properties and Electronic Structure I**
TT 6.1–6.8	Mon	15:00–18:15	H24	**Focus Session Many-Body Phenomena in Nanomagnets: Kondo, Spinons, Spinarons and Beyond (joint session O/TT)**
TT 7.1–7.11	Mon	15:00–18:00	H31	**Correlated Electrons: Electronic Structure Calculations**
TT 8.1–8.10	Mon	15:00–17:45	H32	**Measurement Technology and Cryogenics**
TT 9.1–9.12	Mon	15:00–18:15	H33	**Correlated Magnetism – Low-Dimensional Systems**
TT 10.1–10.10	Mon	15:00–17:45	H36	**Topological Semimetals**
TT 11.1–11.67	Mon	15:00–18:00	P4	**Superconductivity: Poster**
TT 12.1–12.6	Mon	16:45–18:15	H15	**Quantum Transport and Quantum Hall Effects (joint session HL/TT)**
TT 13.1–13.12	Tue	9:30–12:45	H16	**Focus Session: Magnetic Phenomena from Phonon Chirality and Angular Momentum II (joint session MA/TT)**
TT 14.1–14.14	Tue	9:30–13:15	H18	**Spin Transport and Orbitronics, Spin-Hall Effects I (joint session MA/TT)**
TT 15.1–15.13	Tue	9:30–13:15	H31	**Quantum Coherence and Quantum Information Systems (joint session TT/DY)**
TT 16.1–16.12	Tue	9:30–12:45	H32	**Superconductivity: Properties and Electronic Structure II**
TT 17.1–17.14	Tue	9:30–13:15	H33	**Correlated Electrons: Method Development**
TT 18.1–18.9	Tue	9:30–13:15	H36	**Focus Session: Strongly Correlated Quantum States in Moiré Heterostructures (joint session TT/HL/MA)**
TT 19.1–19.13	Tue	9:30–13:00	H37	**Many-body Quantum Dynamics I (joint session DY/TT)**
TT 20.1–20.10	Tue	10:30–13:00	H8	**2D Materials: Electronic Structure and Exitations I (joint session O/HL/TT)**
TT 21.1–21.7	Tue	11:15–13:00	H13	**Quantum Dots and Wires: Transport (joint session HL/TT)**
TT 22.1–22.6	Tue	14:00–15:30	H37	**Many-body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)**
TT 23	Tue	14:15–15:45	H33	**Members' Assembly**
TT 24.1–24.11	Wed	9:30–13:00	H31	**Unconventional Superconductors**
TT 25.1–25.11	Wed	9:30–12:30	H32	**Superconductivity: Supercurrent Diode Effect**
TT 26.1–26.12	Wed	9:30–12:45	H33	**Correlated Magnetism – Frustrated Systems**
TT 27.1–27.7	Wed	9:30–12:45	H36	**Focus Session: Nonlinear Spectroscopy of Collective Excitations in Quantum Magnets (joint session TT/MA)**
TT 28.1–28.13	Wed	9:30–13:00	H37	**Many-body Quantum Dynamics II (joint session DY/TT)**
TT 29.1–29.8	Wed	10:30–12:45	H11	**2D Materials: Electronic Structure and Exitations II (joint session O/HL/TT)**
TT 30.1–30.3	Wed	15:00–15:45	H17	**Nanomechanical systems (joint session HL/TT)**
TT 31.1–31.6	Wed	15:00–16:45	H31	**Topology: Quantum Hall Systems**
TT 32.1–32.6	Wed	15:00–16:30	H32	**Superconductivity: Yu-Shiba-Rusinov and Andreev Physics**
TT 33.1–33.11	Wed	15:00–18:15	H33	**Correlated Magnetism – Spin Liquids**
TT 34.1–34.13	Wed	15:00–18:30	H36	**Superconductivity: Theory**
TT 35.1–35.9	Wed	15:00–18:00	P3	**Topology: Poster**
TT 36.1–36.9	Wed	15:00–18:00	P3	**Nanotubes, BEC, Cryocoolers: Poster**
TT 37.1–37.62	Wed	15:00–18:00	P4	**Correlated Electrons: Poster**
TT 38.1–38.7	Wed	16:45–18:30	H32	**Superconducting Electronics: SQUIDs, Qubits, Circuit QED I**
TT 39.1–39.6	Wed	17:00–18:30	H31	**Twisted Materials / Systems (joint session TT/HL)**
TT 40.1–40.6	Wed	17:30–19:00	H19	**Spin Transport and Orbitronics, Spin-Hall Effects II (joint session MA/TT)**
TT 41.1–41.12	Thu	9:30–12:45	H31	**Quantum-Critical Phenomena (joint session TT/DY)**
TT 42.1–42.14	Thu	9:30–13:15	H32	**Superconductivity: Tunneling and Josephson Junctions**
TT 43.1–43.13	Thu	9:30–13:00	H33	**Correlated Electrons: Other Theoretical Topics**

TT 44.1–44.7	Thu	9:30–12:45	H36	**Focus Session: Ising Superconductivity in Monolayer Transition Metal Dichalcogenides (joint session TT/HL/MA)**
TT 45.1–45.8	Thu	10:30–12:30	H11	**2D Materials: Electronic Structure and Exitations III (joint session O/HL/TT)**
TT 46.1–46.8	Thu	15:00–17:15	H13	**Transport Properties (joint session HL/TT)**
TT 47.1–47.13	Thu	15:00–18:30	H31	**Fluctuations, Noise and Other Transport Topics (joint session TT/DY)**
TT 48.1–48.5	Thu	15:00–16:30	H32	**Topology: Majorana Physics**
TT 49.1–49.13	Thu	15:00–18:30	H33	**Graphene and 2D Materials (joint session TT/HL)**
TT 50.1–50.13	Thu	15:00–18:30	H36	**Superconducting Electronics: SQUIDs, Qubits, Circuit QED II**
TT 51.1–51.6	Thu	16:45–18:15	H32	**Topological Superconductors**
TT 52.1–52.7	Fri	9:30–11:15	H31	**Nickelates and Other Complex Oxides**
TT 53.1–53.12	Fri	9:30–12:45	H32	**Topology: Other Topics**
TT 54.1–54.12	Fri	9:30–12:45	H33	**Correlated Electrons: Charge Order**
TT 55.1–55.13	Fri	9:30–13:00	H36	**Superconducting Electronics: SQUIDs, Qubits, Circuit QED III**
TT 56.1–56.7	Fri	9:30–11:15	H37	**Quantum Dynamics, Decoherence, and Quantum Information (joint session DY/TT)**
TT 57.1–57.7	Fri	10:30–12:15	H25	**Topology and Symmetry-protected Materials (joint session O/TT)**
TT 58.1–58.6	Fri	11:30–13:00	H31	**f-Electron Systems and Heavy Fermions**
TT 59.1–59.6	Fri	11:30–13:00	H37	**Quantum Chaos (joint session DY/TT)**

Members' Assembly of the Low Temperature Physics Division

Tuesday 14:15–15:45 H33

- Report
- Outlook 2025
- Miscellaneous

TT 1: Focus Session: Magnetic Phenomena from Phonon Chirality and Angular Momentum I (joint session MA/TT)

The magnetic moment of the electron lies at the heart of magnetism and spintronics. However, recent research has unveiled the angular momentum and magnetic moment of chiral phonons as fundamental quantities in their own right. These chiral phonons give rise to a plethora of novel lattice phenomena analogous to electronic effects, such as the phonon Hall and phonon Zeeman effects. Moreover, they play a critical role in angular momentum transfer on ultrafast timescales, as seen in the Einstein-de Haas effect. Chiral phonons can also generate effective magnetic fields reaching the tesla scale, inducing magnetization in antiferromagnetic, paramagnetic, and even nonmagnetic materials - a phenomenon reminiscent of the Barnett effect. These advancements showcase phonon chirality and angular momentum as powerful emerging tools for generating and controlling magnetism. This focus session aims to highlight the latest breakthroughs in chiral-phonon magnetism and foster connections between the rapidly evolving field of chiral phononics and the broader magnetism research community.

Coordinators: Dominik M.Juraschek, Eindhoven University of Technology, d.m.juraschek@tue.nl; Martina Basini, ETH Zürich, m.basini@ethz.ch

Time: Monday 9:30–13:00 Location: H20

Invited Talk TT 1.1 Mon 9:30 H20
Driving Coherent Phonon-Phonon Angular Momentum Transfer via Lattice Anharmonicity — •Sebastian Maehrlein — Fritz Haber Institute of the Max Planck Society — Helmholtz Zentrum Dresden Rossendorf — TU Dresden

The discrete rotational symmetry of crystal structures leads to the conservation of quantized angular momentum in solids. Whereas the exchange of energy and linear momentum between lattice vibrations (phonons) via anharmonic coupling is a cornerstone of solid-state physics, conservation and transfer of angular momentum within the lattice remained a postulate, yet. Recently, phonon angular momentum, often in the form of chiral phonons, was linked to gigantic magnetic fields, dynamical ferroelectricity, ultrafast demagnetization, or magnetic switching. However, the fundamental process of phonon to phonon angular momentum transfer required for demagnetization and other spin-related relaxation phenomena remained elusive.

Here we drive coherent phonon-phonon angular momentum transfer by establishing helical nonlinear phononics. Thereby, we directly observe phonon helicity-switching dictated by (pseudo) angular momentum conservation and the discrete rotational symmetry of the lattice. Ab-initio modeling in conjunction with classical equations of motion confirm the experimentally observed anharmonic phonon-phonon coupling as the dominating lattice angular momentum transfer channel. Our results thus open the field of helical or chiral nonlinear phononics, turning lattice angular momentum into the long missing tuning knob for ultrafast material control.

Invited Talk TT 1.2 Mon 10:00 H20
Chiral phonons, phono-magnetism, and spin-rotation coupling — •Matthias Geilhufe — Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden

High-intensity THz lasers enable the coherent excitation of individual phonon modes. The ultrafast control of emergent magnetism through phonons and phonon angular momentum opens new avenues for tuning functional materials. Recent experiments suggest a substantial magnetization in various materials [1,2], presenting a challenge for theoretical modeling. I will provide an introduction to magnetization induced by phonon angular momentum via the phonon inverse Faraday effect [3]. Additionally, I will discuss a coupling mechanism based on inertial effects, which facilitates the interaction between rotational degrees of freedom and electron spin [4].

[1] Basini et al., Nature, 628, 534 (2024)
[2] Davies et al., Nature, 628, 540 (2024)
[3] Shabala, Geilhufe, Physical Review Letters, arXiv:2405.09538
[4] Geilhufe, Physical Review Research, 4, L012004 (2022)

Invited Talk TT 1.3 Mon 10:30 H20
Geometry of temporal chiral structures and photoinduced chirality-spin coupling — •Olga Smirnova[1,2,3], Philip Flores[1], Aycke Roos[1], David Ayuso[4], Piero Decleva[5], Stefanos Carlstroem[1], Serguei Patchkovskii[1], and Andres Ordonez[4] — [1]Max-Born Institute, Berlin — [2]Technische Universität Berin — [3]Technion - Israeli Institute of Technology, Haifa, Israel — [4]Imperial College London, UK — [5]CNR IOM and Dipartimento di Scienze Chimiche e Farmaceutiche, Universita degli Studi di Trieste, Italy

In non-relativistic physics the concepts of geometry and topology are usually applied to characterize spatial structures, or structures in momentum space. We introduce the concept of temporal geometry [1], which encompasses geometric and topological properties of temporal shapes, e.g. trajectories traced by a tip of a time-dependent vector on sub-cycle time scale, and apply it to light-driven ultrafast electron currents in chiral molecules. The geometric concepts: curvature and connection emerge as ubiquitous features of photoexcited chiral electron dynamics. To demonstrate the link between the geometric fields and spin, we extend the concept of curvature to spin-resolved photoionization, and show that it is responsible for enantio-sensitive locking of the cation orientation to the photoelectron spin. This translates into chirality induced spin selectivity in photoionization of oriented chiral molecules both in one photon and two-photon processes.

[1] Geometry of temporal chiral structures, A. F. Ordonez, A. Roos, P. Mayer, D.Ayuso, O. Smirnova, arXiv preprint arXiv:2409.02500, 2024

15 min. break

Invited Talk TT 1.4 Mon 11:15 H20
Phonon thermal Hall effect — •Kamran Behnia — Ecole Supérieure de Physique et de Chimie Industrielles, Paris, France

In insulating solids and liquids, heat is carried by phonons. The phonon scattering time is close to the so-called Planckian time near the melting temperature. It increases with cooling, as phonon-phonon Umklapp scattering events rarefy. A rigorous determination of thermal conductivity of insulators from first principles has been a major accomplishment of the quantum theory of solids. In contrast, our understanding of momentum and energy exchange between phonons at low temperatures is imperfect. In this context, the experimental detection of phonon thermal Hall effect in a growing number of insulators is a challenge to the condensed matter theory. The list now includes elemental insulators, such as black phosphorus, silicon and germanium, in which the spin degree of freedom is irrelevant and the atomic bonds are covalent. We will examine how magnetic field can influence anharmonicity.

Invited Talk TT 1.5 Mon 11:45 H20
Giant effective magnetic moment of chiral phonons — •Swati Chaudhary[1,3], Dominik Juraschek[2], Martin Rodriguez-Vega[3], and Gregory A Fiete[4] — [1]The Institute for Solid State Physics, The University of Tokyo, Japan — [2]Eindhoven University of Technology, Eindhoven, Netherlands — [3]The University of Texas at Austin, Austin, USA — [4]Northeastern University, Boston, USA

Chiral phonons carry angular momentum and lead to magnetic responses in applied magnetic fields or when resonantly driven with ultrashort laser pulses. On the basis of purely circular ionic motion, these phonons are expected to carry a magnetic moment of the order of a few nuclear magnetons. However, some recent experiments have demonstrated a phonon magnetic moment of the order of a few Bohr magnetons. This kind of giant magnetic response points towards the electronic contribution to the magnetic moment of phonons. Many diverse mechanisms have been discovered for this enhanced magnetic response of chiral phonons. The orbital-lattice coupling is one such mechanism where low-energy electronic excitations on a magnetic ion hybridize with phonons and endow a large magnetic moment to phonons. In this talk, I'll present a microscopic model for the effective magnetic moments of chiral phonons based on this mechanism. We apply our model to two types of materials: rare-earth halide paramagnets and transition-metal oxide magnets. In both cases, we find that chiral phonons can carry giant effective magnetic moments of the order of a Bohr magneton, orders of magnitude larger than previous predictions.

TT 1.6 Mon 12:15 H20

Extrinsic Phonon Thermal Hall Effect — •Dimos Chatzichrysafis[1], Robin Richard Neumann[1,2], and Alexander Mook[1] — [1]Johannes Gutenberg-Universität, Mainz, Germany — [2]Martin-Luther-Universität Halle-Wittenberg, Germany

The thermal Hall effect is a developing tool to investigate charge-neutral excitations, exposing the quantum many-body ground state of correlated materials. Since a sense of chirality for the energy carriers is necessary for the generation of a thermal Hall effect, it is natural to expect that quasiparticles of magnetic excitations are responsible for the Hall transport. This conventional wisdom has been recently challenged in experiments [1] which revealed a universal character of the thermal Hall effect independent on the magnetic texture and the lattice structure, even in systems where magnetism is completely absent. This finding asks for the re-investigation of the role of phonons in the thermal Hall effect.

Here, we develop a theory for a phononic thermal Hall effect where the source of chirality is given by the presence of the molecular Berry phase. As a toy model we study a non-magnetic system on a Bravais square lattice. We go beyond the intrinsic mechanism [2] usually studied in literature and consider the contribution of different possible extrinsic sources of phonon Hall transport. Our results demonstrate that phonon thermal Hall effects can be native to very generic systems.

[1] Xiaobo Jin et al, arXiv:2404.02863
[2] Takuma Saito et. al, Phys. Rev. Lett. 123, 255901, December 2019

TT 1.7 Mon 12:30 H20

Signatures of chiral phonons in $MnPS_3$ — •Banhi Chatterjee and Peter Kratzer — Faculty of Physics, University of Duisburg-Essen, Lotharstr. 1, 47057, Duisburg, Germany

Chiral phonons can exist in two-dimensional transition metal dichalcogenide (TMDC) monolayers without inversion symmetry. They can be observed in the non-equilibrium state triggered by optical excitations using circularly polarized light. In existing literature a detailed theoretical calculation of the circular phonons production rate has already been done for the TMDC MoS_2. We investigate the antiferromagnetic semiconductor $MnPS_3$ with a similar hexagonal crystal structure and band-structure like MoS_2 but a larger unit cell as a novel candidate material that may allow for excitation of circular phonons. In $MnPS_3$, although the total magnetic moment is zero in the ground state, exciting the system using circularly polarized light induces a net magnetic moment. The damping of the magnons observed experimentally points to the transfer of orbital angular moment to combined phonon-magnon excitations. Using DFT+U and density functional perturbation theory (DFPT) we obtain in-plane chiral phonon modes at the valley-points of a monolayer $MnPS_3$ and for these modes the S atoms make circular motions. We further study the electron-phonon coupling between these chiral phonon modes and the excited electronic states carrying orbital angular momentum, particularly the dominant d-electrons, in order to theoretically investigate the experimentally observed damping of magnons.

TT 1.8 Mon 12:45 H20

Elliptically polarized coherent phonons in a degenerate mode — Arne Ungeheuer, Mashood T. Mir, Ahmed Hassanien, Lukas Nöding, Thomas Baumert, and •Arne Senftleben — Institut für Physik, Universität Kassel

Controlled excitation of phonons in crystalline solids is an emerging way to alter the property of a material to create phenomena such as transient magnetic polarization [1,2]. Here, we want to focus on controlling the polarization properties of coherent optical phonons that can be launched by ultrashort laser pulses. we demonstrate the excitation of elliptically polarized coherent optical phonons of the E_{2g} shearing mode in graphite. This is achieved by exciting the superposition of two orthogonally polarized phonon modes using a tailored pair of time-delayed optical pulses with tilted polarization. The elliptically polarized coherent phonons are detected by ultrafast electron diffraction [3], where we determine the amount of ellipticity and the sense of rotation.

[1] D. M. Juraschek, et al. *Phys. Rev. Lett.* **118**, 054101 (2017).
[2] A. S. Disa, et al. *Nature Phys.* **16**, 937–941 (2018).
[3] C. Gerbig, et al. *New J. Phys.* **17**, 043050 (2015).

TT 2: Nonequilibrium Quantum Systems (joint session TT/DY)

Time: Monday 9:30–12:30 Location: H31

TT 2.1 Mon 9:30 H31

Solving the nonequilibrium Dyson equation with quantics tensor trains — •Ken Inayoshi[1], Maksymilian Środa[2], Anna Kauch[3], Philipp Werner[2], and Hiroshi Shinaoka[1] — [1]Department of Physics, Saitama University, Saitama, Japan — [2]Department of Physics, University of Fribourg, Fribourg, Switzerland — [3]Institute of Solid State Physics, TU Wien, Vienna, Austria

The nonequilibrium Green's function (NEGF) method is a powerful tool to investigate dynamical phenomena in quantum many-body systems. However, the time-translational symmetry breaking of Green's functions (GFs) makes the simulation of long-time dynamics computationally and memory-intensive. To overcome these, various memory compression techniques have been proposed for the NEGF method [1,2]. Among these, quantics tensor trains (QTT) have been attracting a focus for its ability to exponentially compress the data size of GFs [3]. While a prototype NEGF method with QTT has been developed [4], its benchmarks were limited to the short-time dynamics due to technical challenges such as the slow convergence of self-consistent calculations. We propose an improved implementation to reach the longer time regions, using a variational method for solving the Dyson equation and a causality-based divide-and-conquer algorithm [5,6]. In this contribution, we benchmark our method in relevant test cases [6].

[1] J. Kaye and D. Golež, SciPost Phys. **10**, 091 (2021).
[2] M. Eckstein, arXiv:2410.19707.
[3] H. Shinaoka *et al.*, Phys. Rev. X **13**, 021015 (2023).
[4] M. Murray *et al.*, Phys. Rev. B **109**, 165135 (2024).
[5] M. Środa *et al.*, in preparation
[6] K. Inayoshi *et al.*, in preparation

TT 2.2 Mon 9:45 H31

Fractionalized prethermalization in the one-dimensional Hubbard model — •Anton Romen[1,2], Johannes Knolle[1,2,3], and Michael Knap[1,2] — [1]Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]Blackett Laboratory, Imperial College London, London, United Kingdom

Prethermalization phenomena in driven systems are generally understood via a local effective Floquet Hamiltonian. It turns out that this picture is insufficient for systems with fractionalized excitations. A first example is a driven Kitaev spin liquid which realizes a quasistationary state with vastly different temperatures of the matter and flux sectors, a phenomenon dubbed fractionalized prethermalization. In our work we argue that similar heating dynamics also occur in driven 1D tJ-models. In the weak doping limit of this model, the electron fractionalizes into quasiparticles carrying charge and spin. We show that the nonequilibrium heating dynamics of this model feature a quasistationary state characterized by a low spin and high charge temperature. We argue that the lifetime of this quasistationary state is determined by two competing processes depending on the specific drive chosen: A Fermi Golden Rule that describes the lifetime of the quasiparticles and the exponential lifetime of a Floquet prethermal plateau. Using a time dependent variant of the Schrieffer-Wolff transformation we systematically analyze the different classes of drives emerging from the respective Hubbard model. Lastly, we discuss potential ways towards an experimental realization in cold atom experiments.

TT 2.3 Mon 10:00 H31

Computing the lifetime of spin-orbital excitations in TiOCl using Lanczos techniques — •Paul Fadler[1,2], Philipp Hansmann[1], Kai Phillip Schmidt[1], Angela Montanaro[1,3], Filippo Glerean[4], Enrico Maria Rigoni[1,3], Daniele Fausti[1,3], and Martin Eckstein[2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Universität Hamburg — [3]University of Trieste — [4]Harvard University, Cambridge

TiOCl is a spin-Peierls compound with optically active d-d-transitions at 0.7 eV and 1.5 eV. A pump-push-probe spectroscopy experiment on this system revealed a nonlinear signal asymmetric with respect to the order in which these transitions are pumped. This asymmetry could arise from differing lifetimes of the excitations due to multi-magnon and orbital-fission decay processes. To test this hypothesis we derive a spin-orbital Hamiltonian from ab-initio calculation. Within this description the pumped excitations are orbitons, i.e., hybrid spin-orbital quasiparticles, that can be understood as orbital excitations surrounded by a magnon cloud. We evaluate their lifetimes using Fermi's golden rule for all spin-orbital decay channels, which we compute on a large cluster using Lanczos techniques. Comparing the theoretical prediction to the asymmetry and absolute decay times of the nonlinear signal in the experiment we conclude, that multi-magnon and orbital-fission decay processes could be the dominant decay channels for the 0.7 eV excitation. On the other hand for the 1.5 eV excitation other types of processes such as phonon-assisted decays or nonlinearities in the double-pump scheme have to be taken into account.

TT 2.4 Mon 10:15 H31

Comprehensive analysis of electronic relaxation in one dimension Kondo lattice model — •Arturo Perez Romero, Mica Schwarm, and Fabian Heidrich-Meisner — Institut for Theoretical Physics, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany

Recent advancements in laser technology have made it possible to create non-equilibrium conditions on timescales that outpace energy exchange across a wide range of degrees of freedom. The above represents a challenge not only for condensed matter experimental physicist, but also for theoretical physicist who are motivated to describe a great variety of far-from-equilibrium systems. In this paper, we study the real-time dynamics of two paradigmatic models: the Kondo lattice model (KLM) and Kondo-Heisenberg model (KHM) in one dimension. We analyze the role of exchange couplings for the relaxation of a single charge carrier via the time-dependent Lanczos method. We conduct a comprehensive study of the time evolution by evaluating the z-spin component of the conduction electron, the local spin-spin correlation between localized and conduction electron, the spin-spin correlation between localized spins, and the electronic momentum distribution momentum. The study includes a comparison with statistical mechanics predictions for steady state and a research of the effect of diagonal disorder.

This work was funded by the Deutsche Forschungsgemeinschaft (DPG, German Research Foundation) via CRC 1073

TT 2.5 Mon 10:30 H31

An attempt to extend the adiabatic theorem — •Sarah Damerow[1,2] and Stefan Kehrein[1] — [1]Institut für Theoretische Physik, Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen — [2]I. Institut für Theoretische Physik, Universität Hamburg, Notkestraße 9-11, 22607 Hamburg

A conjectured extension of the adiabatic theorem to quantum quenches, i.e., maximally non-adiabatic changes, is presented.The proposed extension is framed as follows: "as long as quenched states within the same magnetic phase are concerned, the overlap between the initial and final ground states is the largest possible." This conjecture is investigated analytically and is tested numerically using Exact Diagonalisation in two models: the Transverse Field Ising Model (TFIM) and the Axial Next Nearest Neighbour Ising Model (ANNNI).

TT 2.6 Mon 10:45 H31

Towards Floquet-GW: interacting electrons in time-periodic potentials — •Ayan Pal[1,2], Erik G. C. P. van Loon[1,2], and Ferdi Aryasetiawan[1] — [1]Division of Mathematical Physics, Department of Physics, Lund University, Professorsgatan 1, 223 63, Lund, Sweden — [2]NanoLund, Lund University, Professorsgatan 1B, 223 63, Lund, Sweden

The Floquet theory of time-periodic systems provides a middle ground between equilibrium and completely non-equilibrium physics. Here, we study interacting electrons in time-periodic potentials using the combination of Floquet theory and many-body methods such as RPA and GW. We apply these techniques to the electron gas and to lattice models and study the electronic and dielectric properties, for example the appearance of side bands in the spectral functions. These methods have the potential to describe the impact of periodic laser pulses on the plasmonic and optical properties of (moderately) correlated materials.

15 min. break

TT 2.7 Mon 11:15 H31

Universal quench dynamics in Yukawa-Sachdev-Ye-Kitaev models — •Haixin Qiu and Stefan Kehrein — Institute for Theoretical Physics, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Understanding the non-equilibrium properties of non-Fermi liquids without quasiparticles is essential for exploring the dynamics of strongly correlated systems. Here we investigate the quantum quench of a non-Fermi liquid model, the Yukawa-Sachdev-Ye-Kitaev model with interactions involving one boson and q fermions and its lattice extensions. We compute various in and out of equilibrium quantities for general q within the large-N dynamical mean field scheme by integrating the Kadanoff-Baym equations. We find transient oscillations and relaxation dynamics are insensitive to the quench amplitudes deep inside the non-Fermi liquid phase. Notably, the relaxation dynamics involve two distinct transient temperatures and relaxation rates for bosonic and fermionic degrees of freedom, both of which show non-Fermi liquid or universal behaviors. Signatures of prethermalization are also found when quenching near the Fermi liquid phase.

This work is supported by Deutsche Forschungsgemeinschaft (DFG) SFB 1073 (217133147) and FOR 5522 (499180199).

TT 2.8 Mon 11:30 H31

Long-range induced synchronization of Higgs oscillations in topological superconductors — Andreas Alexander Buchheit[1], Benedikt Fauseweh[2,3], and •Torsten Kessler[4] — [1]Saarland University, Department of Mathematics and Computer Science, Germany — [2]TU Dortmund University, Department of Physics, Germany — [3]German Aerospace Center (DLR), Cologne, Germany — [4]Eindhoven University of Technology, Department of Mechanical Engineering, Netherlands

We investigate the impact of long-range electron-electron interactions on the non-equilibrium dynamics of unconventional superconductors. Using recently developed mathematical tools for the efficient treatment of longe-range interactions on lattices, we simulate the time evolution of a triplet superconductor with arbitrary power law interaction. Owing to the long-range interaction, a chiral phase with d+p symmetry emerges. We find that the long-range interaction stabilizes the Higgs oscillation in this phase. While the d-wave's initial mode decays rapidly, it begins to mirror the stable Higgs oscillation of the p-wave condensate part. Eventually, the two parts oscillate with a joint frequency. We demonstrate that this behavior can also be observed in the optical conductivity resulting from an external probe pulse.

TT 2.9 Mon 11:45 H31

Tuning of slow dynamics in quantum East Hamiltonians motivated by Graph theory — •Heiko Georg Menzler[1], Mari Carmen Bañuls[2,3], and Fabian Heidrich-Meisner[1] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany — [2]Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schelling Strasse 4, D-80799 München

In-between fully ergodic/localized quantum system there exist many systems with atypical relaxation behaviors. One of these systems is the quantum East (QE) model. The classical East model is a central, exemplary model for glassy dynamics and kinetic constraints. Also its quantum counterpart features slow dynamics without conservation laws or disorder. However, the presence of slow dynamics has not yet been fully understood from a quantum perspective. Introducing an interpretation of constrained dynamics based on graph theory, we theoretically demonstrate control over the slow dynamics of QE models. As a general hypothesis, we propose that strong hierarchies between nodes on the Fock space graph are related to the presence of slow dynamics. To quantify hierarchical structures, we develop a measure of centrality for generic Hamiltonian matrices, reminiscent of established centrality measures from graph theory. Based on these ideas, we show how we can introduce detuning to alter the hierarchical structure in the QE model and acutely change the resulting constrained dynamics, evidenced by eigenstate structure in the detuned QE models.

Supported by DFG, German Research Foundation via FOR 5522

TT 2.10 Mon 12:00 H31

Optical signatures of dynamical excitonic condensates — •Alexander Osterkorn[1], Yuta Murakami[2], Tatsuya Kaneko[3], Zhiyuan Sun[4], Andrew J. Millis[5,6], and Denis Golež[1,7] — [1]Jožef Stefan Institute, Ljubljana, Slovenia — [2]RIKEN, Wako, Japan — [3]Osaka University, Toyonaka, Japan — [4]Tsinghua University, Beijing, P.R. China — [5]Columbia University, New York, USA — [6]Flatiron Institute, New York, USA — [7]University of Ljubljana, Ljubljana, Slovenia

Excitons, or bound electron-hole pairs, can condense into an excitonic insulator state, similarly to Cooper pairs in superconductors. A non-equilibrium carrier concentration, such as the one transiently induced by photo-doping or sustained by a tuneable bias voltage in bilayers, can create a dynamical excitonic insulator state, yet proving phase coherence in such setups remains challenging. We examine the condensate phase behavior theoretically and show that optical spectroscopy can distinguish between phase-trapped and phase-delocalized dynamical regimes. In the weak-bias regime, trapped phase dynamics result in an in-gap absorption peak nearly independent of bias voltage, while at higher biases its frequency increases approximately linearly. In the large bias regime, the response current grows strongly under the application of a weak electric probe leading to negative weight in the optical response, which we analyze relative to predictions from a minimal model for the phase. This work opens new avenues for experimentally probing coherence in excitonic condensates and the detection of their dynamical regimes.

TT 2.11 Mon 12:15 H31

Visualizing dynamics of charges and strings in (2+1)D lattice gauge theories — Tyler A. Cochran[1,2], •Bernhard Jobst[3,4], Eliott Rosenberg[1], Yuri D. Lensky[1], Adam Gammon-Smith[5], Michael Knap[3,4], Frank Pollmann[3,4], and Pedram Roushan[1] — [1]Google Research, CA, USA — [2]Princeton University, NJ, USA — [3]Technical University of Munich, 85748 Garching, Germany — [4]MCQST, 80799 München, Germany — [5]University of Nottingham, NG7 2RD, UK

Lattice gauge theories (LGTs) can be employed to understand a wide range of phenomena. Studying their dynamical properties can be challenging as it requires solving many-body problems that are generally beyond perturbative limits. We investigate the dynamics of local excitations in a $\mathbb{Z}_2$ LGT using a two-dimensional lattice of superconducting qubits. We first construct a simple variational circuit which prepares low-energy states that have a large overlap with the ground state; then we create particles with local gates and simulate their quantum dynamics via a discretized time evolution. As the effective magnetic field is increased, our measurements show signatures of transitioning from deconfined to confined dynamics. For confined excitations, the magnetic field induces a tension in the string connecting them. Our method allows us to experimentally image string dynamics in a (2+1)D LGT from which we uncover two distinct regimes inside the confining phase: for weak confinement the string fluctuates strongly in the transverse direction, while for strong confinement transverse fluctuations are effectively frozen.

TT 3: Correlated Magnetism – General

Time: Monday 9:30–12:45 Location: H32

TT 3.1 Mon 9:30 H32

The zoo of states in the 2D Hubbard model — •Robin Scholle[1], Pietro Bonetti[1,2], Demetrio Vilardi[1], and Walter Metzner[1] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Harvard University, Cambridge, USA

We use real-space Hartree-Fock theory to construct a magnetic phase diagram of the two-dimensional Hubbard model as a function of temperature and doping. We are able to detect various spin- and charge order patterns including Néel, stripe and spiral order without biasing the system towards one of them. For an intermediate interaction strength we predominatly find Néel order close to half-filling, stripe order for low temperatures or large doping, and an intermediate region of spiral order.

I will give a short summary of the method followed by a presentation of our current results and an outlook for possible further applications.

TT 3.2 Mon 9:45 H32

Hidden quantum correlations in the ground states of quasi-classical spin systems — •Levente Rózsa[1,2], Dennis Wuhrer[3], Sebastián A. Díaz[3], Ulrich Nowak[3], and Wolfgang Belzig[3] — [1]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary — [2]Budapest University of Technology and Economics, Budapest, Hungary — [3]University of Konstanz, Konstanz, Germany

Entanglement is a unique property of quantum systems, which is widely studied in strongly correlated materials and in quantum information theory. Here, we investigate the entanglement between magnons, the quanta of spin waves, around a classical spin-spiral ground state stabilized by frustrated exchange interactions [1]. We find that the entanglement between pairs of sites completely vanishes in certain parameter regimes, where quantum correlations can only be observed in multi-site clusters. We analyze the magnitude and the spatial dependence of the entanglement in the vicinity of classical phase transitions, and discuss the role of the symmetries of the ground state.

[1] L. Rózsa et al., arXiv:2411.08394.

TT 3.3 Mon 10:00 H32

Measurement of magnetic anisotropy in CsV_3Sb_5 using torque magnetometry — •Tobi Gaggl[1], Toshiki Kiyosue[2], Ryo Misawa[3], Tomoya Asaba[2], Max Hirschberger[3], and Yuji Matsuda[2] — [1]Technical University of Munich, Germany — [2]Kyoto University, Japan — [3]The University of Tokyo, Japan

Materials with a kagome lattice have emerged as a fertile ground for exploring nontrivial electronic states arising from the interplay between band topology and magnetic frustration. The kagome metals AV_3Sb_5 (A=K, Cs or Rb), which exhibit charge density wave ordering (CDW), may host such exotic states. It is believed that the CDW in kagome metals is of unconventional nature, thus advanced techniques for precise measurements are required for characterization.

This study investigates the CDW phase transition in CsV_3Sb_5 using a piezoresistive cantilever rotating in a magnetic field as an angular-dependent torquemeter. This method enables precise measurements of magnetization in single crystals and a powerful setup sensitive to changes in rotational symmetry. The results show a distinct two-fold out-of-plane magnetic anisotropy, which is due to the two-dimensional nature of the kagome lattice and consistent with previous calculations. The progression of the measured temperature-dependent magnetic anisotropy shows a clear kink at 94 K, confirming previously published results for the onset of CDW. My current work focuses on the development of novel kagome materials that could exhibit CDWs.

TT 3.4 Mon 10:15 H32

Detection of skyrmion lattices by dilatometric measurements — •Mathias Doerr[1], Justus Grumbach[1], Sergey Granovsky[1], Martin Rotter[1], and Max Hirschberger[2,3] — [1]Technische Universität Dresden, Institut für Festkörper- und Materialphysik, 01062 Dresden, Germany — [2]Department of Applied Physics and Quantum-Phase Electronics Center, University of Tokyo, Tokyo 113-8656, Japan — [3]RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan

Magnetic skyrmion lattices (SkL) with a characteristic structure size smaller than 3 nm in metallic $Gd_3Ru_4Al_{12}$ with a planar breathing kagome lattice, already demonstrated by X-ray diffraction and topological Hall effect studies [1], open up new possibilities for the effective transmission of information. The interplay between helically determined skyrmion patterns and underlying crystallographic structures offers the possibility to clearly determine the stability region of skyrmions by dilatometric measurements. We report high-precision measurements of magnetostriction and thermal expansion on

$Gd_3Ru_4Al_{12}$ and construct the magnetic phase diagram. Additional MonteCarlo simulations with *McPhase* confirm an asymmetric magnetic triple-$\boldsymbol{q}$ structure without symmetry breaking at the ordering temperature. The relationship between crystallographic distortion and formation of the SkL is also discussed.

[1] M. Hirschberger *et al.*, Nat. Commun. 10, 5831 (2019).

TT 3.5 Mon 10:30 H32

Electronic structure of the noncentrosymmtric tetragonal antiferromagnet $EuPtSi_3$ — •Katharina Müller[1], André Deyerling[1], Andreas Bauer[1,2], Wolfgang Simeth[1,3], Christian Franz[1,4], Christian Pfleiderer[1,2,5,6], and Marc A. Wilde[1,2] — [1]Physik Department, TUM School of Natural Sciences, TUM, Germany — [2]Zentrum für Quantum Engineering (ZQE), TUM, Germany — [3]Los Alamos National Laboratory, Los Alamos, NM, USA — [4]Jülich Centre for Neutron Science (JCNS) at MLZ, Forschungszentrum Jülich GmbH, Germany — [5]Munich Center for Quantum Science and Technology (MCQST), TUM, Germany — [6]Heinz Maier-Leibnitz Zentrum (MLZ), TUM, Germany

The localized Eu^{2+} moments of the rare-earth compound $EuPtSi_3$ were reported to show magnetic ordering below the Néel temperature $T_N = 17$ K [1]. With a magnetic field applied in the magnetically hard basal plane, four different types of noncollinear antiferromagnetic order emerge, one of which is commensurate with the lattice [2]. This coplanar canted magnetic structure breaks the crystal symmetry such that Berry curvature contributions are allowed and electronic transport phenomena may be affected. We study this link between the magnetic and the electronic structure with ab initio calculations, in particular highlighting the effect of changing the canting angle from the antiferromagnetic towards the spin-polarized state.

[1] A. Bauer et al., PRM **6**, 034406 (2022).
[2] W. Simeth et al., PRL **130**, 266701 (2023).

TT 3.6 Mon 10:45 H32

Thermal Hall transport driven by spin fluctuations — •Ignacio Salgado-Linares[1,2], Alexander Mook[3], and Johannes Knolle[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]Johannes Gutenberg University Mainz, Institute of Physics, Staudingerweg 7, Mainz 55128, 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 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 thermal currents due to chiral spin fluctuations in a square lattice model with Heisenberg interaction and DMI. The results are expected to shed new light on the topological thermal transport in systems where topology does not arise from static spin textures, but from spin fluctuations.

TT 3.7 Mon 11:00 H32

Pressure tuning of ferromagnetism in the Kagome metal CrNiAs — •Bin Shen[1], Franziska Breitner[1], Victoria A. Ginga[2], Philipp Gegenwart[1], and Alexander A. Tsirlin[2] — [1]EP VI, EKM, University of Augsburg, Germany — [2]Felix Bloch Institute, University of Leipzig, Germany

Ferromagnetic Kagome metals attract considerable interest as quantum materials with nontrivial topological electronic states. Here, we present our extensive study on single crystals of CrNiAs, crystallizing in a hexagonal structure with space group of $P\overline{6}2m$, featuring a distored kagome lattice of magnetic Cr. CrNiAs undergoes a ferromagnetic phase transition at $T_C = 135$ K, where the c-axis is the easy axis. At $T^\star = 90$ K another phase transition is found, likely driven by magnetism, associated with a shrinkage of the c-axis while the ab-plane expands. Anomalous Hall effect is observed in the magnetically ordered state of CrNiAs. We also report the pressure tuning of ferromagnetism.

Supported by DFG-TRR 360-492547816 and the Alexander von Humboldt Foundation.

15 min. break

TT 3.8 Mon 11:30 H32

Electronic transport measurements in Kagome metal $Yb_{0.5}Co_3Ge_3$ — •Zhiyuan Cheng[1], Heng Wu[2], Yaojia Wang[2], Peter van Veldhuizen[1], Federica Galli[1], Mazhar Ali[2], Julia Chan[3], and Semonti Bhattacharyya[1] — [1]Leiden University, Leiden, the Netherlands — [2]Delft University of Technology, Delft, the Netherlands — [3]Baylor University, Waco, United States

Kagome lattice has a unique geometry that gives rise to interesting band structures. As a result, Kagome lattices exhibit various properties, such as superconductivity, topological surface states, and complex magnetism. However, it is still yet to be well understood how these quantum properties intertwine with each other. Electrical doping, strain, and pressure can be utilized as powerful tools to modulate and investigate the rich physics of such complex systems.

In this project, we investigate a Kagome metal $Yb_{0.5}Co_3Ge_3$ that is known to exhibit charge density wave and complex magnetism. Susceptibility measurements performed in this material demonstrate the presence of Yb^{3+} moments with anti-ferromagnetic interactions and an onset of a week magnetic transition below 25 K. Yet, this complex magnetism is not completely understood.

We carried out magnetotransport measurements on $Yb_{0.5}Co_3Ge_3$ to study the interplay of its quantum properties at both ambient pressure (0 GPa) and high pressure (up to 2.0 GPa). Our ambient-pressure measurement shows that this complex magnetism gives rise to Kondo effect. High-pressure measurements reveal a clear signature of an enhancement of the Kondo effect with respect to the pressure.

TT 3.9 Mon 11:45 H32

Altermagnetism from interaction-driven itinerant magnetism — Samuele Giuli[1], •Carlos Mejuto-Zaera[1,2], and Massimo Capone[1,3] — [1]International School for Advanced Studies (SISSA), Trieste, Italy — [2]Current: Laboratoire de Physique Théorique (LPT), Toulouse, France — [3]CNR-IOM Democritos, Trieste, Italy

Altermagnetism is a phase of collinear spin-ordering presenting anisotropic magnetic properties, leading to great interest in its potential application for spintronic and thermoelectric devices. Realizing this promise will likely hinge on the design of tunable altermagnetic platforms, in which the magnetic and electric responses can be reliably controlled. A viable path towards this goal concerns leveraging electron interactions for the stabilization of altermagnetism, a strategy which is developing increasing traction in the field. In this work, we propose a mechanism driven by the interplay between a local Hubbard repulsion and the presence of a van Hove singularity in a two-band model. Here, the itinerant magnetism caused by the van Hove singularity colludes with the exchange mechanism driven by the Hubbard repulsion to generate an altermagnetic state in a sizeable portion of the phase diagram. Importantly, this correlated altermagnetic phase exhibits a tuneable spin-current, whose sign can be changed by tuning the interaction strength and/or particle doping. We study the role of strong electronic correlations in the stabilization of this phase by leveraging on the ghost rotationally invariant slave boson embedding. Further, we comment on the stability of the phase, and potential material realizations.

TT 3.10 Mon 12:00 H32

Investigation of the magnetoelastic coupling in $CaMn_2P_2$ and $SrMn_2P_2$ — •Sven Graus, Ashiwini Balodhi, N. S. Sangeetha, Teslin R. Thomas, Maximilian van de Loo, Andreas Kreyssig, and Anna E. Böhmer — Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum, Germany

Mn-based 122-compounds exhibit complex magnetic ordering in the antiferromagnetic state. In contrast to other related materials $CaMn_2P_2$ shows a strong first-order and $SrMn_2P_2$ a weak first-order antiferromagnetic phase transition [1]. Since the antiferromagnetic ordering breaks the three-fold symmetry of the lattice, one expects lattice distortions, which we investigated by high-resolution thermal expansion measurements. Thermal-expansion data of $CaMn_2P_2$ show a significant decrease of the sample length upon entering the antiferromagnetic state. Applying different uniaxial pressures along the [1 1 0] and [1 -1 0] directions alters the transition in qualitatively distinct ways. Increasing uniaxial pressure shifts the transition temperature upwards which shows magnetoelastic coupling and is consistent with the interpretation of an orthorhombic lattice distortion in the antiferromagnetic phase. In $SrMn_2P_2$, an anomaly in the thermal expansion is clearly resolvable upon entering the antiferromagnetic state. From

300 K to 6 K the linear thermal expansion coefficient α continuously decreases, reaching negative values below ∼100 K.

We acknowledge support by the Deutsche Forschungsgemeinschaft (DFG) under CRC/TRR 288 (Project A02).

[1] Sangeetha et al., PNAS **118**, e2108724118 (2021).

TT 3.11 Mon 12:15 H32

Synthesis of $CsMn_2P_2$ and study of its low temperature physical properties — •Matthias Kroll, N. S. Sangeetha, Sven Graus, Maik Golombiewski, Andreas Kreyssig, and Anna E. Böhmer — Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum, Germany

The growth of $CsMn_2P_2$ single crystals is challenging due to the high vapor pressure of cesium and phosphorus and the high melting point of manganese. We optimized the growth conditions for the reproducible synthesis of $CsMn_2P_2$ single crystals by systematically studying various growth techniques. The quantity and quality of the phase of interest in the resulting samples was characterized by x-ray powder diffraction, electron microscopy and energy-dispersive x-ray analysis. We perform thermal-expansion and magnetic field-dependent resistivity measurements at low temperatures to analyze the nature of the three phase transitions at 64, 17 and 11 K that cannot be explained conclusively so far [1,2]. At 17 K, a dramatic change of the electrical-transport behavior as well as a large thermal-expansion anomaly are observed.

We acknowledge support by the Deutsche Forschungsgemeinschaft (DFG) under CRC/TRR 288 (Project A02).

[1] F. Hummel, Magnetism and superconductivity in layered manganese and iron pnictides. Diss. LMU (2015).
[2] H. G. von Schnering et al., ZAAC 628, 2772 (2002)

TT 3.12 Mon 12:30 H32

Strain-tuning of magnetic properties of $Ca_{1-x}Sr_xCo_{2-y}As_2$ and elastoresistance measurements in different symmetry channels — •Teslin Rose Thomas, Michael Paul, N. S. Sangeetha, Sven Graus, Max Brückner, Andreas Kreyssig, and Anna E. Böhmer — Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum, Germany

The $Ca_{1-x}Sr_xCo_{2-y}As_2$ system belongs to the well-studied $ThCr_2Si_2$ structural family where Sr substitution induces a crossover from a collapsed tetragonal (cT) phase to an uncollapsed tetragonal (ucT) phase, along with different magnetic anisotropies [1,2].

In this study, we investigate how the cT-ucT crossover and the associated magnetic orders respond to in-plane symmetric and asymmetric strain in different configurations. We show that large in-plane symmetric strain can effectively tune the magnetic properties of the system. We also find a significant response of the resistance to in-plane symmetric strain with a temperature dependence that varies dramatically based on the doping level. The resistance response to symmetric strain dominates the response to asymmetric strain.

We acknowledge support from the Deutsche Forschungsgemeinschaft (DFG) under CRC/TRR 288 (Project A02).

[1] N. S. Sangeetha et al., Phys. Rev. Lett. 119, 257203 (2017).
[2] Bing Li et al., Phys. Rev. B 100, 024415 (2019).

TT 4: Topological Insulators

Time: Monday 9:30–13:00 Location: H33

TT 4.1 Mon 9:30 H33

Magnetotransport measurements on magnetic topological insulator nanostructures fabricated with shadow wall epitaxy — •Jan Karthein[1,2], Gion Toehgiono[1,2], Max Vassen-Carl[1,2], Taizo Kawano[3], Sosuke Otsubo[3], Makoto Kohda[3], Peter Schüffelgen[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, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, 52425 Jülich, Germany — [3]Department of Materials Science, Graduate School of Engineering, Tohoku University, 6-6-02 Aramaki-Aza Aoba, Aoba-ku, 980-8579 Sendai, Japan

We present a novel way to fabricate magnetic topological insulator nanostructures based on digital alloying and shadow wall epitaxy. The combination of these two techniques allows the preparation of structures in the micrometer and nanometer range without the need for lithography and etching steps on the material under investigation. The magnetotransport properties of micro and nano Hall bars fabricated in this way are investigated at cryogenic temperatures and in high magnetic fields. Different sizes of Hall bars are measured and their magnetic properties are studied. An anomalous Hall effect is observed, indicating the successful preparation of Hall bars based on magnetic topological insulator thin films. The Curie temperature of Hall bars with different widths is extracted and found to be systematically dependent on the dimensions.

TT 4.2 Mon 9:45 H33

Thermopower and resistivity of the topological insulator Bi_2Te_3 in the amorphous and crystalline phase — •Ena Osmic[1,2], Jose Barzola Quiquia[3], Stephan Winnerl[4], Winfried Böhlmann[5], Peter Häussler[3], and Joachim Wosnitza[1,2] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Division of Thin Film Physics, TU Chemnitz, Germany — [4]Institut für Ionenstrahlphysik und Materialforschung, HZDR, Dresden, Germany — [5]Felix-Bloch Institute for Solid-state Physics, Universität Leipzig, Germany

We investigated the temperature dependence of the thermopower $S(T)$ and resistance $R(T)$ in thin films of the topological insulator Bi_2Te_3, prepared *in situ* by sequential flash-evaporation at 4 K. In the amorphous phase, $S(T)$ is negative and significantly larger than in other amorphous materials, while in the crystalline phase, it remains negative and shows a linear temperature dependence. The resistivity $\rho(T)$ transitions from semiconducting behavior in the amorphous state to linear metallic behavior upon crystallization. For $T > 15$ K, the linear $\rho(T)$ reflects metallic surface states typical of topological insulators, while for $T < 10$ K, the conductivity shows a logarithmic temperature dependence dominated by electron-electron interactions. Raman spectroscopy confirms crystallization in the trigonal $R3m$ space group, and energy-dispersive X-ray spectroscopy indicates high compositional homogeneity with no magnetic impurities.

TT 4.3 Mon 10:00 H33

Phonon thermal Hall effect in weakly compensated topological insulators — •Rohit Sharma[1], Yongjian Wang[1], Yoichi Ando[1], Achim Rosch[2], and Thomas Lorenz[1] — [1]II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

The phonon thermal Hall effect has recently been observed in various classes of insulating materials, yet its origin remains unresolved [1-3]. In a series of well-compensated $Bi_{2-x}Sb_xTe_{3-y}Se_y$ samples, the thermal Hall conductivity $\kappa_{xy}(B)$ exhibits a linear and negative field dependence, with a thermal Hall ratio κ_{xy}/κ_{xx} on the order of 10^{-3}, consistent with observations in other insulating materials. Conversely, weakly compensated samples of $TlBi_{0.15}Sb_{0.85}Te_2$ exhibit a nonlinear dependence of $\kappa_{xy}(B)$, with κ_{xy}/κ_{xx} exceeding 2% across an extended temperature range. The electronic contribution to thermal transport, $\kappa^{el}_{xy} = \sigma_{xy}L_0T$, was calculated using the Wiedemann-Franz law and compared to the measured κ_{xy}. Remarkably, the measured κ_{xy} is significantly larger than κ^{el}_{xy} throughout the temperature range investigated. Possible mechanisms driving the nonlinear $\kappa_{xy}(B)$ and the large thermal Hall ratio in $TlBi_{0.15}Sb_{0.85}Te_2$ will be discussed.

Funded by the DFG via CRC 1238 Projects A04, B01, and C02.

[1] R. Sharma *et al.*, Phys. Rev. B **109**, 104304 (2024).
[2] R. Sharma *et al.*, Phys. Rev. B **110**, L100301 (2024).
[3] X. Li *et al.*, Nat. Commun.**14**, 1027 (2023).

TT 4.4 Mon 10:15 H33

Scattering theory of chiral edge modes in topological magnon insulators — •Stefan Birnkammer[1,2], Michael Knap[1,2], Johannes Knolle[1,2], Alexander Mook[3], and Alvise Bastianello[1,2] — [1]Technical University Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Johannes Gutenberg Universtät, Mainz, Germany

Topological magnon insulators exhibit robust edge modes with chiral properties similar to quantum Hall edge states. However, due to their strong localization at the edges, interactions between these chiral edge magnons can be significant, as we show in a model of coupled magnon-conserving spin chains in an electric field gradient. The chiral edge modes remain edge-localized and do not scatter into the bulk, and we characterize their scattering phase: for strongly-localized edge modes we observe significant deviation from the bare scattering phase. This renormalization of edge scattering can be attributed to bound bulk modes resonating with the chiral edge magnons, in the spirit of Feshbach resonances in atomic physics. We argue a real-time measurement protocol using spin-polarized scanning tunneling spectroscopy to study their scattering dynamics. Our result show that interaction among magnons can be encoded in an effective edge model of reduced dimensionality, where the interactions with the bulk renormalize the effective couplings. This work paves the way to develop a many-body effective theory for chiral edge magnons.

TT 4.5 Mon 10:30 H33

Multiplicative Chern insulators — •Archi Banerjee[1,2] and Ashley M. Cook[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute for the Chemical Physics of Solids, Dresden, Germany

Extending on the previous work on multiplicative topological phases, here we study bulk-boundary correspondence and response signatures of multiplicative Chern insulators (MCIs). Constructing the MCI Bloch Hamiltonian as a symmetry-protected tensor product of two topologically non-trivial parent Chern insulators (CIs), we study 2D MCIs and introduce 3D MCIs, constructed by requiring the two 2D parent Hamiltonians share only one momentum component, rather than both as in the case of the 2D MCI. We study the robustness of bulk-boundary correspondence against bulk perturbations breaking the tensor product structure of the child Hamiltonian, and find the bulk-boundary correspondence remains gapless and evolves to that of a topological skyrmion phase in cases considered here. We also study the response of the 2D MCI to time reversal symmetric flux insertion through two spatially-separated locations in the lattice. We observe a 4π periodic Aharonov-Bohm (AB) effect in which unpaired Majorana zero-modes and associated spin angular momentum are transferred between these two locations. We interpret the AB effect from the perspective of the effective field theories of the quantum skyrmion Hall effect as corresponding to a generalised $\nu = 1/2$ FQHE.

TT 4.6 Mon 10:45 H33

Probing the tomographic regime by nonlinear thermoelectric and magneto-transport in topological Fermi liquids — •Habib Rostami[1] and Johannes Hofmann[2] — [1]Department of Physics, University of Bath, United Kingdom — [2]Department of Physics, Gothenburg University, Sweden

In 2D Fermi liquids, odd-parity Fermi surface deformations [PRL. 123, 116601 (2019)] exhibit anomalously slow relaxation rates, suppressed as $\tau_{\rm AN}^{-1} \sim T^4$ with temperature T, deviating from the standard Fermi-liquid scaling, $\tau_{\rm FL}^{-1} \sim T^2$. This near ballistic (tomographic) regime currently lack a precise experimental probes. We link light-induced nonlinear thermoelectric currents to prolonged relaxation times, $\tau_{\rm AN}$ [Phys. Rev. Research 6, L042042 (2024)]. These currents, arising in topological Fermi liquids, depend on novel heat capacities, including the Berry curvature capacity $C_\Omega = \partial_T \langle \Omega^2 \rangle$ and velocity-curvature capacity $C_{\rm v} = \partial_T \langle v\Omega \rangle$. Quantified in Bi_2Te_3, these effects predict non-monotonic thermoelectric responses, providing features for experimental testing. In another study [arXiv:2411.08102v1], we show that weak magnetic fields suppress tomographic transport signatures by breaking time-reversal symmetry, a prerequisite for the odd-parity collisional relaxation effect. This suppression, occurring at much lower fields than those needed to disrupt hydrodynamic transport, suggests a practical experimental method to extract the odd-parity mean free path.

TT 4.7 Mon 11:00 H33

Finite size topology in magnetic topological insulators — •Joe Winter[1,2], Michał Pacholski[1], and Ashley Cook[1] — [1]MPI PKS, Dresden, Germany — [2]University of St Andrews, St Andrews, Scotland

The antiferromagnetic topological insulator phase is a foundational realization of three-dimensional topological phases of matter with magnetic order. It is furthermore an example of an axion insulator and condensed matter platform for realizing exotic axion dynamics of high-energy physics. At systems sizes where the sample size is comparable with the correlation length of the topological surface states, it is expected for these states to hybridise. We however show the strength of this hybridisation is oscillatory with respect to system parameters and resonances occur where the surface states can reform. We then confirm the defining response signature of the underlying 3D AFM TI phase persists in this geometry, at these resonances. We then open boundary conditions in a second direction to confirm the additional bulk-boundary correspondence of the finite-size topological phases spectral flow, finding q(3-2)D topologically-protected, gapless edge modes. The co-existence of the q(3-2)D topologically non-trivial edge states with a topological response associated with the 3D bulk topological invariant, the magnetoelectric polarizability, confirms finite-size AFM topological phases occur. This further demonstrates that finite-size topology is a generic feature of topological phases and very relevant experimentally.

15 min. break

TT 4.8 Mon 11:30 H33

Genuine topological Anderson insulator from impurity induced chirality reversal — •Avedis Neehus, Frank Pollmann, and Johannes Knolle — Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany

We investigate a model of Dirac fermions with topological mass impurities which open a global topological gap even in the dilute limit. Surprisingly, we find that the chirality of this mass term, i.e., the sign of the Chern number, can be reversed by tuning the magnitude of the single-impurity scattering. Consequently, the disorder induces a phase disconnected from the clean topological phase, i.e., a genuine topological Anderson insulator. In seeming contradiction to the expectation that mass disorder is an irrelevant perturbation to the Dirac semimetal, the tri-critical point separating these two Chern insulating phases and a thermal metal phase is located at zero impurity density and connected to the appearance of a zero energy bound state in the continuum corresponding to a divergent topological mass impurity. Our conclusions based on the T-matrix expansion are substantiated by large scale Chebyshev-Polynomial-Green-Function numerics. We discuss possible experimental platforms.

TT 4.9 Mon 11:45 H33

Topological phases of arbitrary numbers of coupled Su-Schrieffer-Heeger wires — •Anas Abdelwahab — Leibniz Univesität Hannover, Institut für Theoretische Physik, Hannover

The phase diagrams of arbitrary number $N_{\rm w}$ of Su-Schrieffer-Heeger (SSH) wires have been identified, with respect to the dimerization and the single particle wire-wire coupling, where the latter is either perpendicular or diagonal between adjacent wires. Even number of perpendicularly coupled wires exhibit either gapless or trivial topological phases. Odd number of perpendicularly coupled wires can exhibit gapless, trivial or nontrivial topological phases with winding number $w = 1$. The diagonally coupled wires reveal topological phases with winding numbers in the range $0 \leq w \leq N_{\rm w}$. The critical lines in their phase diagrams can reveal topological critical phases [1]. Each band of the diagonally coupled wires becomes a comletely flat band at specific lines in the phase diagram. The presence of W states [2] at the edges of coupled SSH wires with open boundary conditions will be dicussed.

[1] R.Verresen, R.Thorngren, N.G.Jones,F.Pollmann, Phys. Rev. X, 120, 057001 (2018).
[2] W.Dür, G.Vidal, J.I.Cirac, Phys. Rev. A 62, 062314 (2000).

TT 4.10 Mon 12:00 H33

Local and energy-resolved topological invariants for Floquet systems — •Arnob Kumar Ghosh, Rodrigo Arouca, and Annica M. Black-Schaffer — Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden

Periodically driven systems offer a perfect breeding ground for out-of-equilibrium engineering of topological boundary states at zero energy (0-mode), as well as finite energy (π-mode), with the latter having no static analog. The Floquet operator and the effective Floquet Hamiltonian, which encapsulate the stroboscopic features of the driven system, capture both spectral and localization properties of the 0- and π-modes but sometimes fail to provide complete topological characterization, especially when 0- and π-modes coexist. In this work [1], we utilize the spectral localizer, a powerful local probe that can provide numerically efficient, spatially local, and energy-resolved topological characterization. In particular, we apply the spectral localizer to the effective Floquet Hamiltonian for driven one- and two-dimensional topological systems with no or limited symmetries and are able to assign topological invariants, or local markers, that characterize the 0- and the π-boundary modes individually and unambiguously. Due to the spatial resolution, we also demonstrate that the extracted topological invariants are suitable for studying driven disordered systems and can even capture disorder-induced phase transitions.

[1] A.K.Ghosh, R.Arouca, A.M.Black-Schaffer, arXiv:2408.08548.

TT 4.11 Mon 12:15 H33

Characterizing exceptional topology through tropical geometry — •Ayan Banerjee[1], Rimika Jaiswal[2], Madhusudan Manjunath[3], and Awadhesh Narayan[4] — [1]Max Planck Institute for the Science of Light, Erlangen — [2]University of California Santa Barbara, USA — [3]Indian Institute of Technology Bombay, India — [4]Indian Institute of Science, Bangalore

Non-Hermitian Hamiltonians describing open quantum systems have been widely explored in platforms ranging from photonics to electric circuits [1]. A defining feature of non-Hermitian systems is exceptional points (EPs), where both eigenvalues and eigenvectors coalesce. The study of EPs has become an exciting frontier at the crossroads of optics, photonics, acoustics, and quantum physics. Tropical geometry is an emerging field of mathematics at the interface between algebraic geometry and polyhedral geometry, with diverse applications to science [2]. Here, we introduce Newton's polygon method and adopt the notion of a geometrical object known as amoeba in developing a unified tropical geometric framework to characterize different facets of non-Hermitian systems [3]. We introduce a framework linking tropical geometry to non-Hermitian physics, enabling the study of EPs, skin effects, and disorder properties.

[1] E.J.Bergholtz, J.C.Budich, F.K.Kunst, Rev.Mod.Phys.93, 015005 (2021).
[2] D.Maclagan, B.Sturmfels, Graduate Stud. Math.161, 75 (2009).
[3] A.Banerjee, R.Jaiswal, M.Manjunath, A.Narayan, Proc. Natl. Acad. Sci. U.S.A. 120, e2302572120 (2023).

TT 4.12 Mon 12:30 H33

Operator approach to quantum geometry and semi-classical dynamics — •Chen Xu[1,2], Andreas Haller[1], Suraj Hegde[3], Tobias Meng[2], and Thomas Schmidt[1] — [1]Department of Physics and Materials Science, University of Luxembourg, Luxembourg — [2]TU Dresden, Department of Physics — [3]IISER-Thiruvananthapuram, India

We develop an operator-based approach for computing the quantum geometric contributions to the equations of motion of the position and momentum operators in an multiband system, without resorting to semiclassical wave-packet approximations. We identify contributions such as the Berry curvature and the quantum metric tensor induced anomalous velocity as fundamentally effective multiband effects. We show using this approach that in general higher-order operator-valued geometric quantities emerge in studying the dynamics in the presence of inhomogeneous external fields. 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 4.13 Mon 12:45 H33

Exciton condensation driven by bound states of Green's function zeros — •Ivan Pasqua, Andrea Blason, and Michele Fabrizio — International School for Advanced Studies (SISSA), Via Bonomea 265, I-34136 Trieste, Italy

The spectral properties of electronic systems are encoded in the single-particle Green's function, with theoretical efforts traditionally focusing on the position and nature of its poles. Only recently, Green's function zeros have been recognized as important hallmarks of non-symmetry breaking strongly correlated insulators and, possibly, of fractionalized excitations. The analysis of the zeros offers a new perspective on the increasingly studied topic of excitonic insulators (EI), typically understood as the condensation of bound states between the valence and conduction bands of poles of the Green's function. Indeed this picture appears paradoxical in Mott insulators (MI), where the large gap between the Hubbard bands seemingly precludes the formation of such bound states. Yet, a continuous transition from a MI and an EI is observed in the Bernevig-Hughes-Zhang model using the dynamical cluster approximation. We find that a nontopological EI intrudes between the QSH and MI regimes. Our analysis suggests that excitons in the MI, which soften at the transition to the EI, could be bound states between valence and conduction bands of Green's function zeros. Our work proposes a novel mechanism for exciton condensation and highlights the role of Green's function zeros in diagnosing the properties of correlated phase of matter.

TT 5: Superconductivity: Properties and Electronic Structure I

Time: Monday 9:30–13:00 Location: H36

TT 5.1 Mon 9:30 H36

Superconducting properties of $[(SnSe)_{1+\delta}]_m[NbSe_2]$ superlattices with varying $NbSe_2$ interlayer spacing — •Linus P. Grote[1], Wieland G. Stoffel[1], Tom Herter-Lehmann[1], Willi Vallant[1], Alina Dietrich[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 layered superconductors understanding and controlling the coupling of superconducting layers is crucial due to its strong impact on their properties [1]. We examine the properties of $[(SnSe)_{1+\delta}]_m[NbSe_2]$ superlattices, which allow for nearly arbitrary stacking sequences due to the growth technique [2]. Given this degree of freedom we study how coupling mechanisms enable the occurance of superconductivity. Temperature-dependent resistance measurements revealed superconductivity for $NbSe_2$ interlayer distances of 2.4 nm or smaller. This behaviour is explained by the interplay of grain boundaries, cross-plane tunneling and systematical variation of the $NbSe_2$ interlayer distances. Additionally, magnetoresistance hysteresis measurements were conducted to investigate the charge carrier states and microscopic superconducting structures. The results provide new insights into the coupling mechanisms of 2D superconductors.

[1] O. Chiatti et al., J. Phys.: Condens. Matter **35**, 215701 (2023);
[2] C. Grosse et al., Sci. Rep. **6**, 33457 (2016).

TT 5.2 Mon 9:45 H36

Atomic-scale mapping of superconductivity in the incoherent CDW mosaic phase of a transition metal dichalcogenide — •Sandra Sajan[1], Haojie Guo[1], Tarushi Agarwal[2], Irián S. Ramírez[1], Chandan Patra[2], Maia G. Vergniory[1], Fernando de Juan[1], Ravi P. Singh[2], and Miguel M. Ugeda[1] — [1]Donostia International Physics Center, Paseo Manuel de Lardizábal 4, 20018 San Sebastián, Spain — [2]Department of Physics, Indian Institute of Science Education and Research Bhopal, Bhopal 462066, India

The emergence of superconductivity in the 1T phase of TaS_2 is preceded by the intriguing loss of long-range order in the charge density wave (CDW). Such decoherence, attainable by different methods, results in the formation of nm-sized coherent CDW domains bound by a two-dimensional network of domain walls (DW)-mosaic phase, which has been proposed as the spatial origin of the superconductivity. We report the atomic-scale characterization of the superconducting state of 1T-TaSSe, a model 1T compound exhibiting the CDW mosaic phase. We use high-resolution scanning tunneling spectroscopy and Andreev spectroscopy to probe the microscopic nature of the superconducting state in connection with the electronic structure of the DW network. Spatially resolved conductance maps at the Fermi level reveal a uniform landscape, independent of domain structure, indicating no link to superconductivity. This is confirmed at 340mK within the superconducting dome, where the gap's subtle inhomogeneity remains unconnected to DWs providing new insights into the fundamental interplay between SC and CDW in these relevant strongly correlated systems.

TT 5.3 Mon 10:00 H36

Ab-initio investigation of transition metal – superconductor interfaces — •Adamantia Kosma[1], Stefan Blügel[1], and Philipp Rüssmann[1,2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany

The realisation of Majorana-based topologically protected qubits requires a careful design and optimization of material interfaces for superconductor (SC)/topological insulator (TI) heterostructures. To this end, we perform ab-initio simulations to investigate the superconducting properties at the interface of transition metal overlayers (M = Os, Ir, Pt, Au) deposited on a Nb(110) film. Our density functional theory calculations are based on the full-potential Korringa-Kohn-Rostoker (KKR) Green function method and its Kohn-Sham Bogoliubov-de Gennes (KS-BdG) extension [1,2]. In our study we explore the possibility to control the work function mismatch through the overlayer, and we uncover the proximity induced superconductivity. Our findings show that some of these structures might be promising material candidates for interfacing a TI with a superconductor without unwanted band bending effects at SC/M/TI interfaces.

We thank the ML4Q (EXC 2004/1 – 390534769) for funding.

[1] JuDFTteam/JuKKR (2022). doi: 10.5281/zenodo.7284738
[2] P. Rüßmann, and S. Blügel, Phys. Rev. B **105**, 125143 (2022).

TT 5.4 Mon 10:15 H36

Local limit disorder characteristics of superconducting radio frequency cavities I. Frequency shift — •Matúš Hladký, Anastasiya Lebedeva, Marcel Polák, and František Herman — Comenius University in Bratislava

Negative resonant frequency shift abnormalities in the vicinity of the critical temperature have been observed in recent experiments on Superconducting Radio Frequency cavities.

We present a simple, straightforward approach using the Dynes superconductor theory [1] and discuss its results. In the ideal dirty limit, we analytically elaborate on the width and depth of the resulting dip. Studying the sign of the slope of the resonant frequency shift at crit. temperature in the moderately clean regime reveals the role of the pair-breaking and pair-conserving disorder. Next, we compare and also fit our results with the recent experimental data from the N-doped Nb sample presented in Ref. [2]. Our analysis remarkably complies with the experimental findings, especially concerning the dip width. We offer straightforward, homogeneous-disorder-based interpretation within the moderately clean regime.

This work has been supported by the APVV-23-0515 grant and by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478.

[1] A. Lebedeva, M. Hladký, M. Polák, F. Herman, arXiv:2409.04203v1.
[2] M. Zarea, H. Ueki, J. A. Sauls, Frontiers in Superconducting Materials, 3: 1-7, arXiv:2307.07905v1 (2023).

TT 5.5 Mon 10:30 H36

Local limit disorder characteristics of superconducting radio frequency cavities II. Quality factor — Anastasiya Lebedeva, Matúš Hladký, Marcel Polák, and •František Herman — Comenius University in Bratislava

Nowadays superconducting radio frequency (SRF) cavities represent fundamental tools used for (Standard Model) particle acceleration, (beyond Standard Model) particle probing, and long-lifetime photon preservation. We study their Quality factor properties mainly at low temperatures within the Dynes superconductor model [1]. We scrutinize and use the local limit response to the external electromagnetic field. Assuming the same regime at low temperatures, we address details of the high-quality plateaus. This work presents (and studies the limits of) the simple effective description of the complex problem corresponding to the electromagnetic response in the superconductors combining homogeneous conventional pairing and two different kinds of disorder scattering.

This work has been supported by the Slovak Research and Development Agency under the Contract no. APVV-23-0515, by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478.

[1] A. Lebedeva, M. Hladký, M. Polák, F. Herman, arXiv:2409.04203v1.

TT 5.6 Mon 10:45 H36

THz response of ultra thin NbN films grown by atomic layer deposition — •Frederik Bolle[1], Yayi Lin[1], Heidemarie Schmidt[2], Martin Dressel[1], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Leibniz IPHT, Jena

Most elementary excitations and collective modes of superconductors lie in the THz frequency range, making THz spectroscopy an ideal tool to directly measure the superconducting energy gap and superfluid density. By combining the spectral ranges from continuous, coherent backward wave oscillators and time-domain methods we can investigate a broad frequency range from $1.6\,\mathrm{cm}^{-1}$ (0.2 meV) up to $100\,\mathrm{cm}^{-1}$ (12.4 meV). We characterize the superconducting state of grown NbN films in particular concerning the behavior of its energy scales as the film becomes increasingly two dimensional approaching the superconductor insulator transition (SIT). We investigate films with thickness ranging from 4.5 nm and 20 nm and find a continuous suppression of the superconducting energy gap and superfluid density with reduced film thickness. These results enable a quantitative device design for various applications of NbN thin films such as high kinetic inductance circuitry.

TT 5.7 Mon 11:00 H36

Superfluid stiffness in strongly disordered NbN superconducting films — •Alexander Weitel Weitzel[1], Lea Pfaffinger[1], Matthias Stosiek[2], Animesh Panda[3], Ferdinand Evers[3], and Christoph Strunk[1] — [1]Inst. of Exp. a. Appl. Phys., University of Regensburg, D-93040 Regensburg, Germany — [2]TUM Sch. of Nat. Sci., Dep. of Phys. PH-I, D-85748 Garching bei München — [3]Inst. of Theoretical Phys., University of Regensburg, D-93040 Regensburg, Germany

In BCS-superconductors, the spectral gap, E_g, the pairing amplitude, Δ, and the mean-field critical temperature T_{c0} are essentially identical. At strong disorder, close to the superconductor-insulator transition (SIT), this is no longer the case. Moreover, in BCS-theory the superfluid stiffness, J_s, is determined by Δ and normal state resistance R_N. Also this relation typically no longer holds close to SIT. Recently, we have experimentally determined $J_s(T)$ in ultra-thin NbN films by measuring kinetic inductance and found a sharp Berezinski-Kosterlitz-Thouless (BKT) transition. Our latest experimental data cover $J_s(T)$ over a wide range of disorder strength, up to normal state resistance $\sim h/e^2$. We find a sharp BKT-transition right up to the SIT and independently measure the characteristic scales E_g, J_s, T_{c0} and T_{BKT} over two orders of magnitude in R_N. We present complementary numerical calculations of the superfluid stiffness, obtained from the Boguliubov-de Gennes (BdG) theory of disordered samples in a very broad range of disorder strengths. A detailed comparison of our measurements with the computational results will be presented.

15 min. break

TT 5.8 Mon 11:30 H36

Molecular hydrogen in the N-doped LuH_3 system as a possible path to superconductivity — •Cesare Tresca[1], Pietro Forcella[2], Andrea Angeletti[3], Luigi Ranalli[3], Cesare Franchini[3,4], Michele Reticcioli[3], and Gianni Profeta[1,2] — [1]CNR-SPIN L'Aquila, Italy — [2]University of L'Aquila, L'Aquila, Italy — [3]University of Vienna, Vienna, Austria — [4]University of Bologna, Bologna, Italy

The discovery of ambient superconductivity would mark an epochal breakthrough long-awaited for over a century, potentially ushering in unprecedented scientific and technological advancements. The recent findings on high-temperature superconducting phases in various hydrides under high pressure have ignited optimism, suggesting that the realization of near-ambient superconductivity might be on the horizon. However, the preparation of hydride samples tends to promote the emergence of various metastable phases, marked by a low level of experimental reproducibility. Identifying these phases through theoretical and computational methods poses a considerable challenge, often resulting in contentious outcomes. In this contribution, we consider N-doped LuH_3 as a prototypical complex hydride: By means of machine-learning-accelerated force-field molecular dynamics, we have identified the formation of H_2 molecules stabilized at ambient pressure by nitrogen impurities. Importantly, we demonstrate that this molecular phase plays a pivotal role in the emergence of a dynamically stable, low-temperature, experimental-ambient-pressure superconductivity.

TT 5.9 Mon 11:45 H36

Challenges in identifying nematic superconductivity of CsV_3Sb_5 kagome metal via transport measurements — •Yu-

Chi Yao[1,2], Fei Sun[1], José Guimarães[1,2], and Haijing Zhang[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany — [2]School of Physics and Astronomy, University of St Andrews, St Andrews, KY16 9SS, UK

Nematicity refers to the spontaneous symmetry breaking beyond the crystal-imposed anisotropy in the electron wavefunction. On the other hand, understanding the interplay between nematicity and superconductivity could be crucial for determining the underlying pairing mechanism in various correlated systems, such as cuprates [1] and iron-based [2] unconventional superconductors. In this study, we focus on the recently discovered kagome metal CsV_3Sb_5, which is famous for its multiple competing or coexisting orders [3,4]. By using CsV_3Sb_5 as the prototypical system, we address the challenges of identifying nematic superconductivity in transport measurements and systematically disentangle the extrinsic factors, such as imperfections in field alignment, from intrinsic nematic supercondcuting behavior.

[1] R. Daou *et al.* Nature **463**, 519-522 (2010).
[2] J. H. Chu *et al.* Science, **329**(5993), 824-826 (2010).
[3] B. R. Ortiz *et al.* Phys. Rev. Lett. **125**(24), 247002 (2020).
[4] F. Sun, H. Zhang *et al.* arXiv:2408.08117.

TT 5.10 Mon 12:00 H36

Unique electronic transport characteristics in superconducting MgB_2 films — •Clemens Schmid[1], Markus Gruber[1], Corentin Pfaff[2], Theo Courtois[2], Anton Pokusinskyi[3], Alexander Kasatkin[4], Karine Dumesnil[2], Stephane Mangin[2], Thomas Hauet[2], and Oleksandr Dobrovolskiy[3] — [1]Faculty of Physics and Vienna Doctoral School in Physics, University of Vienna, Austria — [2]Institute Jean Lamour, Université de Lorraine-CNRS, Nancy, France — [3]Cryogenic Quantum Electronics, EMG and LENA, Technische Universität Braunschweig, Germany — [4]G.V. Kurdyumov Institute for Metal Physics, NAS Ukraine, Kyiv, Ukraine

Maximizing the velocity of Abrikosov vortices in superconductors and characterizing the associated energy relaxation times is essential for possible applications like single photon detectors. Here, we investigate the current-voltage curves of MgB_2, a material whose thin film structures remain superconducting at temperatures up to 30 K. Furthermore, capabilities of a single photon response have been observed previously in MgB_2 films. Our experiments reveal peculiar shapes of the current-voltage curves, showing multiple steps in their transitions to the normal state. While the microscopic mechanisms underlying these steps are a topic of current debates, one explanation could imply the occurrence of composite and fractional vortices associated with the two-band nature of the superconductivity in MgB_2, a property which is in-line with the presence of two slopes in the temperature-magnetic-field phase diagram. We compare our findings across multiple layered structures and for varying thicknesses of the MgB_2.

TT 5.11 Mon 12:15 H36

Single-crystal growth and superconducting properties of $Sr_xBi_2Se_3$ — •Max Brückner[1], Jule Kirschke[1], Fatih Cetin[1], Sven Graus[1], Maik Golombiewski[1], Fotios Maragkos[2,3], Varvara Foteinou[2], Shibabrata Nandi[4,5], Haneen Abushammala[1], Andreas Kreyssig[1], and Anna E. Böhmer[1] — [1]Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum — [2]Central Unit for Ion Beams and Radionuclides, Ruhr-Universität Bochum, 44801 Bochum — [3]Department of Physics, National Technical University of Athens, 15780 Athens, Greece — [4]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science and Peter Grünberg Institut, JARA-FIT, 52425 Jülich — [5]Experimentalphysik IVc, JARA-FIT, RWTH Aachen, 52074 Aachen

Bi_2Se_3 is a topological insulator in which Sr-intercalation induces superconductivity with an unexpected two-fold anisotropy of H_{c2} in the basal plane. We examine how its properties relate to different single-crystal growth conditions, including self-flux growth of free-standing single crystals from a Bi-rich melt. The Sr-content was determined by proton-induced x-ray emission spectroscopy in our as-grown crystals with a resolution of up to 30 ppm. Transport measurements in magnetic fields showed superconductivity with $T_c \sim$ 2-3 K at surprisingly low Sr-content. In addition, we identified $SrBi_2Se_4$ as a secondary phase in our growth. Its superconducting properties were found to be similar to the ones of $Sr_xBi_2Se_3$.

This work is supported by the ERC grant Distort-to-Grasp (No. 101040811).

TT 5.12 Mon 12:30 H36

Tuning superconducting properties in 3D nanoarchitectures — •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], Uri Vool[1], and Claire Donnelly[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Nöthnitzer Str. 40, 01187, Dresden, Germany — [2]Institute of Applied Physics, TU Wien, Wiedner Hauptstr. 8-10/134,1040 Vienna, Austria — [3]University of Vienna, Vienna, Austria — [4]Leibniz IFW Dresden, Dresden, Germany

Introducing 3D nanoconfinement into the superconducting system can open a path for local geometrical control and the possibility of going beyond intrinsic properties. However, the fabrication of such intricate nanoarchitectures remains challenging.

In this context, we present an extended approach to creating superconducting 3D nanoarchitectures through focused electron-beam-induced deposition of tungsten. This method allows the realisation of 3D superconducting nanostructures with arbitrary geometries within a wide range of critical temperatures, providing local geometrical control of critical fields and, for example, the realisation of reconfigurable weak links. With transport measurements, we demonstrate the motion of superconducting vortices within these 3D superconducting nanostructures. Therefore, three-dimensional superconducting nanostructures offer new horizons for experimental investigations of the dynamics of vortices, anisotropy and possible applications of curvilinear 3D nanoarchitectures.

TT 5.13 Mon 12:45 H36

Vortex mass observed in far-infrared circular dichroism of high-T_c superconductors — •Roman Tesař[1], Michal Šindler[1], Pavel Lipavský[2], Jan Koláček[1], Christelle Kadlec[1], Wen-Yen Tzeng[3], Chih-Wei Luo[4], and Jiunn-Yuan Lin[4] — [1]Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic — [2]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic — [3]National Formosa University, Yunlin, Taiwan — [4]National Yang Ming Chiao Tung University, Hsinchu, Taiwan

The effective mass of the Abrikosov vortex (fluxon) in type-II superconductors remains an open and still not fully solved problem. Only a few experimental techniques are currently known to examine the fluxon mass, while numerous theoretical models have been developed that predict inconsistent values scattered over several orders of magnitude. We present an experimental method to determine fluxon mass based on the interaction with circularly polarized FIR/THz laser radiation. A rotating electric field induces the motion of fluxons along cyclotron trajectories, which leads to magnetic circular dichroism at terahertz frequencies. The modified Kopnin-Vinokur theory with experimentally established parameters provides a sufficient framework for estimating fluxon mass at low temperatures. We demonstrate the proposed method on thin films of $YBa_2Cu_3O_{7-\delta}$ with different doping levels. We also briefly mention other applications of the experimental technique used, such as probing cyclotron resonance in semiconductors and magnon modes in magnetic materials.

[1] Sci. Rep. 11, 21708 (2021).
[2] IEEE Trans. Appl. Supercond. 34, 0601005 (2024).

TT 6: Focus Session Many-Body Phenomena in Nanomagnets: Kondo, Spinons, Spinarons and Beyond (joint session O/TT)

The electron spin, a fundamental quantum mechanical property, plays a crucial role in determining the electronic and magnetic properties as well as the dynamics of matter. Its role becomes even more important at surfaces, 2D materials and nanomagnets as the low-dimensionality increases electron correlation. A fundamental understanding of spin excitations is significant for both fundamental science and modern applications. For decades, the interpretation of experimental signatures of spin excitations were focused on the Kondo effect paradigm, with Co atoms on the (111) surface of noble metals as the prototypical example. However, recent first-principles predictions and spin-polarized scanning tunnelling spectroscopy in high magnetic fields have demonstrated the existence of many-body states, called spinarons. These states arise from the binding of electronic states to spin excitations in the presence of spin-orbit coupling. Such findings, along with other studies, challenge the Kondo interpretation. Furthermore, related non-trivial many-body states may emerge in thin-film geometries, as shown by photoemission spectroscopy and first-principles manybody investigations or in quantum spin liquids. These examples testify that many-body phenomena are not only critically important for the fundamental understanding of spin excitations, they also impact a wide range of material characteristics, including electronic, magnetic, thermodynamic, and transport properties. This focus session will provide a forum to discuss intriguing many-body states driven by spin excitations, and serve as a forum to discuss the current knowledge on their origins, unique properties, and implications.

Organized by
Matthias Bode (Würzburg University), Yujeong Bae (Swiss EMPA), and Stefan Blügel (FZ-Jülich).

Time: Monday 15:00–18:15 Location: H24

Invited Talk TT 6.1 Mon 15:00 H24

Kondo and Yu-Shiba-Rusinov resonances: transport and coupling — •Laëtitia Farinacci[1,2,3], Gelavizh Ahmadi[3], Gaël Reecht[3], Benjamin W. Heinrich[3], Contanstin Czekelius[3], Felix von Oppen[3], and Katharina J. Franke[3] — [1]University of Stuttgart, Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany — [2]Carl-Zeiss-Stiftung Center for Quantum Photonics Jena-Stuttgart-Ulm, Germany — [3]Fachbereich Physik, Freie Universität Berlin, Germany

The exchange coupling between a magnetic impurity and a superconducting substrate leads to the formation of magnetic bound states, known as Yu-Shiba-Rusinov (YSR) states, inside the superconducting gap, as well as a Kondo resonance outside the gap. Studying these two many-body phenomena in parallel provides valuable insights into their characteristic properties.

We observed striking correlations between the asymmetries of the YSR state and the Kondo effect induced by FeTPyP molecules on Pb(111) in a scanning tunneling microscope (STM) [1]. We show that both asymmetries originate from interfering tunneling paths via a spin-carrying orbital and the highest occupied molecular orbital.

Additionally, we studied the formation of YSR bands in a self-assembled kagome lattice of magnetic molecules on Pb(111) and track YSR hybridization from kagome precursors to larger islands [2]. This work will motivate further studies to resolve possible spin-liquid or Kondo-lattice-type behavior.

[1] PRL 125, 256805 (2020). [2] Nat. Comm. 15, 6474 (2024).

Invited Talk TT 6.2 Mon 15:30 H24

Electron delocalization in a 2D Mott insulator — •Amadeo L. Vazquez de Parga[1,2,4,5], Cosme G. Ayani[1,2], Michele Pisarra[3], Iván M. Ibarburu[1], Clara Rebanal[1], Manuela Garnica[2,4], Fabián Calleja[2], and Fernando Martín[1,2] — [1]Universidad Autónoma de Madrid, Madrid, Spain — [2]IMDEA Nanociencia, Madrid, Spain — [3]Universitá della Calabria, Rende, Italy — [4]Instituto Nicolás Cabrera, Madrid, Spain — [5]Condensed Matter Physics Center (IFIMAC), Madrid, Spain

We follow by means of low temperature Scanning Tunneling Microscopy and Spectroscopy, the buildup of a 2D Kondo lattice in a system composed by a 2D Mott insulator, a single 1T-TaS2 layer, stacked on the surface of a metallic crystal, 2H-TaS2. When the sample temperature is lower than 27K, the magnetic moments present in the Mott insulator experience the Kondo screening by the conduction electrons of the metal, leading to the appearance of a Kondo resonance at the Fermi level. Below 11 K, a gap opens within the Kondo resonance, which is the signature of the formation of a coherent quantum state that extends all over the sample, i.e., a Kondo lattice [1]. Quasi particles interference maps reveal the emergence of a Fermi contour in the 2D Mott insulator when the temperature drops below 11K, indicating the delocalization of the highly correlated Mott electrons [2]. The observed modifications in the LDOS are well explained by state-of-the-art Density Functional Theory calculations.

[1] Small 20, 2303275 (2024) [2] Nat. Commun. 15, 10272 (2024)

Invited Talk TT 6.3 Mon 16:00 H24

Kondo or no Kondo, that is the question — •Alexander Weismann, Neda Noei, Niklas Ide, and Richard Berndt — Institut für experimentelle und angewandte Physik, Christian-Albrechts-Universität zu Kiel, Kiel, Germany

The spin properties of individual atoms and molecules can produce distinctive spectral features in tunneling spectra near zero bias. Among these features, Kondo resonances and inelastic spin-flip excitations are often challenging to distinguish, despite their markedly different spectral line shapes. A Kondo resonance indicates a non-magnetic ground state, where the atomic spin is screened by conduction band electrons. In contrast, spin-flip excitations observed in zero-field tunneling spectra require magnetic anisotropy, which arises from spin-orbit coupling (SOC), to play a significant role. In this study, we demonstrate that the well-known Co/Cu(111) system, long believed to exhibit a Kondo resonance, instead adopts a magnetic ground state that is protected from Kondo screening by substantial magnetic anisotropy. The zero-bias anomaly in scanning tunneling spectra undergoes significant modification when Co atoms are attached to monoatomic Cu chains. Measurements conducted at 340 mK in a magnetic vector field reveal clear signatures of inelastic spin-flip excitations, with the anisotropy axis tilted away from the surface normal. The magnitude and orientation of this anisotropy are consistent with density functional theory (DFT) calculations. Moreover, quantum Monte Carlo many-body simulations confirm that the Kondo effect is suppressed when SOC is properly accounted for.

Invited Talk TT 6.4 Mon 16:30 H24

Evidence for spinarons in Co atoms on noble metal (111) surfaces — •Artem Odobesko — Physikalisches Institut, Universität Würzburg, Am Hubland, 97074 Würzburg

The zero-bias anomaly in the tunnelling differential conductance of Co atoms on Au(111) [1], long attributed to the Kondo effect, has recently been reinterpreted [2] as evidence of the spinaron – a novel many-body excitation arising from the interplay between spin excitations and conduction electrons. In our study, we used spin-polarized scanning tunneling spectroscopy (STS) on Co atoms on Cu(111) and Au(111) under high magnetic fields, revealing field-induced energy shifts and spin-resolved spectral features that challenge the conventional Kondo interpretation. Instead, our findings provide the first experimental confirmation of the spinaron [3].

We also investigated the role of hybridization with the substrate in spinaron formation, focusing on the reconstructed Au(111) surface. The unique local electronic environments created by the herringbone reconstruction strongly influence the hybridization strength and spectral features of Co adatoms, revealing a clear link between adsorption site, hybridization, and spinaronic excitations. Our results shed light on the fundamental mechanisms driving spinaron formation.

[1] V. Madhavan, et al., Science 280, 567 (1998)
[2] J. Bouaziz, et al., Nat. Comm. 11, 6112 (2020)
[3] F. Friedrich, et al., Nat. Phys. (2023)

Invited Talk TT 6.5 Mon 17:00 H24

Spinarons: A new view on emerging spin-driven many-body phenomena in nanostructures — •Samir Lounis — Peter Grünberg Institut, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany — Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany — Institute of Physics, Martin Luther University Halle-Wittenberg, 06120 Halle (Saale), Germany

Many-body phenomena are crucial in physics, particularly in condensed matter, influencing electronic, magnetic, thermodynamic, and transport properties. They leave distinct spectroscopic signatures, such as Kondo, excitonic, and polaronic features, arising from specific degrees of freedom. Since more than two decades Cobalt atoms on the (111) surfaces of noble metals have been a paradigm for the Kondo effect in scanning tunnelling spectroscopy experiments [1]. However, our recent first-principles predictions [2] followed by STS experiments in high magnetic fields [3,4] challenge this notion. Our findings reveal that the observed transport anomalies stem from spin excitations of Co atoms, forming a new many-body state – the spinaron – distinct from the Kondo resonance. I will delve into the spinaron origins, their unique properties, and implications explored through the recent atomic manipulation experiments. This work opens pathways to investigate and engineer these hybrid states in nanostructures, offering new insights into fundamental many-body states.

[1] V. Madhavan et al., Science 280, 567 (1998); [2] J. Bouaziz et al., Nat. Commun. 11, 6112 (2020); [3] F. Friedrich et al., Nat. Phys. 20, 28 (2024); [4] N. Noei et al., Nanoletters 23, 8988 (2023)

TT 6.6 Mon 17:30 H24

Emergence of spinaronic states in Fe adatoms — Ilias Klepetsanis[1,2], Juba Bouaziz[4], •Philipp Rüssman[1,3], and Samir Lounis[1,2] — [1]Forschungszentrum Jülich & JARA, Germany — [2]University of Duisburg-Essen and CENIDE, Germany — [3]University of Würzburg, Germany — [4]Research Center for Advanced Science and Technology, University of Tokyo, Japan

In recent years, spinarons, predicted from first-principles calculations [1], have been observed in Co adatoms on the Cu(111) surface, using spin-polarized scanning tunnelling spectroscopy (STS) in high magnetic fields [2]. Spinarons leave a non-trivial spectroscopic signature, for long interpreted to originate from the Kondo effect [3]. Here, we employ relativistic time-dependent density functional and many-body perturbation theory, to investigate the case of Fe adatoms on the Cu(111) surface, which carry a large magnetic moment of $3.25\mu_B$ preferring an out-of-plane orientation as dictated by a magnetic anisotropy energy of 2meV. In contrast to the Co adatom, the spinarons in Fe do not overlap with trivial spin-excitations. We discuss the spinaronic response to an out-of-plane magnetic field, the orbital character and the impact of spin-orbit coupling. [1] J. Bouaziz et al., Nat. Commun. 11, 6112 (2020); [2] F. Friedrich et al., Nat. Phys. 20, 28 (2024); [3] V. Madhavan et al., Science 280, 567 (1998)

TT 6.7 Mon 17:45 H24

Revising the Superconductivity in Iron Based Superconductors from the Perspective of Electron Phonon Coupling — •Lanlin Du[1,2] and Sheng Meng[1,2,3] — [1]Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, Beijing, China — [2]School of Physical Sciences, University of Chinese Academy of Sciences, Beijing, China — [3]Songshan Lake Materials Laboratory, Dongguan, Guangdong, China

There are currently two mainstream superconducting pairing mechanisms, namely electron phonon coupling and spin fluctuation, which are believed to play a dominant role in conventional superconductors like simple metal superconductors and unconventional superconductors like Copper oxides, respectively. Iron based superconductors are believed to connect these two aspects, that is, both mechanisms are important in it. In fact, some studies have shown that electron phonon coupling is also important in cuprates, and even provide evidence for s-wave pairing symmetry in them. Therefore, it is important to consider the role of electron phonon coupling in unconventional superconductors. Here, we revise the superconductivity in Iron based superconductors using Migdal-Eliashberg formalism and electron phonon coupling strength corrected by many body method from the two perspectives of doping and pressurization. Our results are in good agreement with the experiments. Based on this, we predict a new two-dimensional high-Tc Iron based superconductor.

TT 6.8 Mon 18:00 H24

Theoretical model for multiorbital Kondo screening in strongly correlated molecules with several unpaired electrons — •Manish Kumar[1], Aitor Calvo-Fernandez[2], Diego Solar-Polo[1], Asier Eiguren[2], Maria Blanco-Rey[3], and Pavel Jelinek[1] — [1]Institute of Physics, Academy of Sciences of the Czech Republic , Cukrovarnicka 10, Prague 6, CZ 16200, Czech Republic — [2]Department of Physics, University of the Basque Country UPV-EHU, 48080 Leioa, Spain — [3]Department of Polymers and Advanced Materials: Physics, Chemistry and Technology, University of the Basque Country UPV-EHU, 20018 Donostia-San Sebastián, Spain

The mechanism of Kondo screening in strongly correlated molecules with several unpaired electrons on a metal surface is still under debate. Here, we provide a theoretical framework that rationalizes the emergence of Kondo screening involving several extended molecular orbitals with unpaired electrons. We introduce a perturbative model, which provides simple rules to identify the presence of antiferromagnetic spin-flip channels involving charged molecular multiplets responsible for Kondo screening. The Kondo regime is confirmed by numerical renormalization group calculations. In addition, we introduce the concept of Kondo orbitals as molecular orbitals associated with the Kondo screening process, which provide a direct interpretation of experimental dI/dV maps of Kondo resonances. We demonstrate that this theoretical framework can be applied to different strongly correlated open-shell molecules on metal surfaces, obtaining good agreement with previously published experimental data.

TT 7: Correlated Electrons: Electronic Structure Calculations

Time: Monday 15:00–18:00 Location: H31

TT 7.1 Mon 15:00 H31

Wannier interpolation of reciprocal-space periodic and non-periodic matrix elements in the optimally smooth subspace — •Giulio Volpato, Stefano Mocatti, Giovanni Marini, and Matteo Calandra — Department of Physics, University of Trento, Via Sommarive 14, 38123 Povo, Italy

Maximally localized Wannier functions use the gauge freedom of Bloch wavefunctions to define the optimally smooth subspace with matrix elements that depend smoothly on crystal momentum. The associated Wannier functions are real-space localized, a feature often used to Fourier interpolate periodic observables in reciprocal space on ultradense momentum grids. However, Fourier interpolation cannot handle non-periodic quantities in reciprocal space, such as the oscillator strength matrix elements, which are crucial for the evaluation of optical properties. We show that a direct multidimensional interpolation in the optimally smooth subspace yields comparable accuracy with respect to Fourier interpolation at a similar or lower computational cost. This approach can also interpolate and extrapolate non-periodic observables, enabling the calculation of optical properties on ultradense momentum grids. Finally, we underline that direct interpolation in the optimally smooth subspace can be employed for periodic and non-periodic tensors of any order without any information on the position of the Wannier centers in real space.

Funded by the European Union (ERC, DELIGHT, 101052708).

TT 7.2 Mon 15:15 H31

LCAO fragment orbital projectors for DFT+U — •Christoph Freysoldt, Hao Chen, and Jörg Neugebauer — Max-Planck-Institut für Nachhaltige Materialien GmbH, Max-Planck-Str. 1, 40237 Düsseldorf

DFT+U is an efficient approach to describe correlated mixed-valence transition metal oxides such as $Fe_3O_4=Fe^{II}Fe_2^{III}O_4$. The correlated orbitals are derived from, but not identical to the metal d-orbitals. Most DFT+U implementations employ local projectors with d-orbital symmetry centered on the transition metal atoms to extract the on-site occupation matrix of the correlated orbitals. Unfortunately, such projectors pick up not only intended occupations of localized orbitals, but also contributions from the extended metal-oxygen bonding states involving the O-2p orbitals. The spurious occupations are sensitive to the projector definition and the M-O bond length, and lead to artifacts in energies and structures. To arrive at a more reliable scheme, one must account for inter-atomic orbital overlap when defining the projectors. We propose using fragment orbitals from a linear combination of atomic orbitals (LCAO) that include the orbital mixing with the first ligand shell of each transition metal ion. To obtain analytic Pulay-like forces when atoms are displaced, the projectors are constructed from a simplified tight-binding model that reflects the atomic positions, but does not rely on the self-consistent electronic structure. We present preliminary results for iron oxides that exhibit improved occupations (closer to 0 and 1) and a reduced sensitivity to bonding distances.

TT 7.3 Mon 15:30 H31

Single- and two-particle observables in the Emery model: A dynamical mean-field perspective — •Yi-Ting Tseng[1], Mario Malcolms[2], Henri Menke[1,2], Marcel Klett[2], Thomas Schäfer[2], and Philipp Hansmann[1] — [1]Friedrich-Alexander-University Erlangen-Nürnberg — [2]Max Planck Institute for Solid State Research, Stuttgart

We investigate dynamical mean-field calculations of the three-band Emery model at the one- and two-particle level for material-realistic parameters of high-T_c superconductors[1]. Our study shows that even within dynamical mean-field theory, which accounts solely for temporal fluctuations, the intrinsic multi-orbital nature of the Emery model introduces effective non-local correlations. These correlations lead to a non-Curie-like temperature dependence of the magnetic susceptibility, consistent with nuclear magnetic resonance experiments in the pseudogap regime. By analyzing the temperature dependence of the static dynamical mean-field theory spin susceptibility, we find indications of emerging oxygen-copper singlet fluctuations, explicitly captured by the model. Despite correctly describing the hallmark of the pseudogap at the two-particle level, such as the drop in the Knight shift of nuclear magnetic resonance, dynamical mean-field theory fails to capture the spectral properties of the pseudogap.

[1] YiTing Tseng *et al.*, arXiv:2311.09023.

TT 7.4 Mon 15:45 H31

Origin of transitions inversion in rare-earth vanadates — •Xuejing Zhang[1], Erik Koch[2], and Eva Pavarini[1] — [1]Peter Grünberg Institute, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Jülich Supercomputing Centre, Forschungszentrum Jülich, 52425 Jülich, Germany

The surprising inversion of the orbital- and magnetic-order transitions in the RVO_3 series with increasing the rare-earth radius makes the series unique among orbitally-ordered materials [1]. Here, augmenting dynamical mean-field theory with order-parameter irreducible-tensor decomposition [2], we show that this anomalous behavior emerges from an unusual hierarchy of interactions. First, increasing the rare-earth radius, orbital physics comes to be controlled by xz-xz quadrupolar super-exchange rather than by lattice distortion. Next, for antiferromagnetic spin order, orbital super-exchange terms with different spin rank compete, so that the dipolar spin-spin interaction dominates. Eventually, G-type magnetic order (anti-ferro in all directions) can appear already above the orbital ordering transition and C-type order (anti-ferro in the ab plane) right around it. The strict constraints we found also explain why the inversion is rare, and give at the same time criteria to look for similar behavior in other materials [3].

[1] S. Miyasaka, Y. Okimoto, M. Iwama, Y. Tokura, Phys. Rev. B 68, 100406(R) (2003).
[2] X.J.Zhang, E.Koch, E.Pavarini, Phys.Rev.B 105, 115104 (2022).
[3] X. J. Zhang, E. Koch, E. Pavarini, arXiv:2411.16351 (2024).

TT 7.5 Mon 16:00 H31

Engineering correlated Dirac fermions and flat bands on SiC with transition metal adatom lattices — •Niklas Enderlein[1], Henri Menke[1,2], Yi-Ting Tseng[1], Michel Bockstedte[3], Janina Maultzsch[1], Giorgio Sangiovanni[4], and Philipp Hansmann[1] — [1]Friedrich-Alexander-University Erlangen-Nürnberg — [2]Max Planck Institute for Solid State Research, Stuttgart — [3]Johannes Kepler University Linz — [4]Julius-Maximilian-University of Würzburg

In our recent study [1] we propose three transition-metal adatom systems on 3C-SiC(111) surfaces as a versatile platform to realize massless Dirac fermions and flat bands with strong electronic correlations. Using density functional theory combined with the constrained random phase approximation and dynamical mean-field theory, we investigate the electronic properties of Ti, V, and Cr adatoms. The triangular surface lattices exhibit narrow bandwidths and effective two-band Hubbard models near the Fermi level, originating from partially filled, localized d-orbitals of the adatoms. Our study reveals a materials trend from a flat band Fermi liquid (Cr) via a paramagnetic Mott insulator with large local moments (V) to a Mott insulator on the verge to a heavy Dirac semimetal (Ti) showcasing the diverse nature of these strongly correlated systems. Specifically, the flat bands in the Cr and the well-defined Dirac cones in the strained metallic Ti lattice indicate high potential for realizing topological and correlated phases.

[1] H.Menke, N.Enderlein *et al.*, arXiv:2410.17165.

TT 7.6 Mon 16:15 H31

Antiferromagnetism in iridates revisited: Mott versus Slater physics — Francesco Cassol, Michele Casula, and •Benjamin Lenz — IMPMC, Sorbonne University - CNRS, Paris, France

Since its discovery, the antiferromagnetic low-temperature phase of the iridates Ba_2IrO_4 and Sr_2IrO_4 has been subject to numerous studies. Whereas their underlying spin-orbit entangled ground state of a half-filled $j_{\rm eff} = 1/2$ orbital is well accepted, the origin and nature of the antiferromagnetism is still debated. Are the materials classical Mott insulators or is the antiferromagnetism rather of Slater type? In this talk, we will revisit the question based on dynamical mean-field theory (DMFT) calculations that include the $j_{\rm eff} = 1/2$ and $j_{\rm eff} = 3/2$ states within the DMFT self-consistency. Comparing to both experiment and *ab initio* simulations from literature, we will depict a complex phase diagram at the crossroads between Slater and Mott physics.

15 min. break

TT 7.7 Mon 16:45 H31

Optical conductivity of Sr_2IrO_4 and Ba_2IrO_4: beyond the traditional interpretation of the double peak structure — •Francesco Cassol, Michele Casula, and Benjamin Lenz — IMPMC, Sorbonne University - CNRS, Paris, France

Since the discovery of their exotic spin-orbital entangled insulating ground state, Sr_2IrO_4 and Ba_2IrO_4 have attracted considerable attention. Spurred by the structural similarities with cuprate high T_C superconductors, numerous studies have explored their magnetic and electronic properties. Herein, we investigate the optical transport properties, by computing the optical conductivity beyond the Peierls substitution scheme within dynamical mean-field theory (DMFT) for both compounds. By explicitly including both $j_{\text{eff}} = 1/2$ and $j_{\text{eff}} = 3/2$ states in the DMFT self-consistency, we characterize the nature of the double peak structure found in the optical conductivity at low energy. In contrast with the traditional interpretation, we assign a mixed j_{eff} character to both peaks. Moreover, we accurately capture their temperature dependence, further corroborating our findings.

TT 7.8 Mon 17:00 H31

Non-flat bands and chiral symmetry in magic angle twisted bilayer graphene — •Miguel Sánchez[1], José González[2], and Tobias Stauber[1] — [1]Insituto de Ciencia de Materiales de Madrid ICMM-CSIC. Madrid, Spain — [2]Insituto de Estrrcutura de la Materia IEM-CSIC. Madrid, Spain)

We find that in any effective theory of magic angle twisted bilayer graphene (MATBG) that integrates out high-energy modes, the flat bands are prone to a significant increase in bandwidth. This effect from the Coulomb interaction is comparable to and even exceeding the perturbations due to strain and electron-phonon coupling.

As a result of this band widening, we identify a pattern of explicit symmetry breaking in MATBG from the ideal $U(4) \times U(4)$ symmetry down to the chiral non-flat $U(4)$ group, in contrast to the flat $U(4)$ symmetry that prevails when the bands are very flat.

Our work builds upon and extends a previous study [1]. For instance, we employ an atomistic model of MATBG that treats the full bandwidth accurately. Moreoever, we discuss the implications of our results for the latest experimental and theoretical findings.

[1] Phys. Rev. Lett. **125**, 257602 (2020).

TT 7.9 Mon 17:15 H31

Electronic structure of CrB_2 and implications for the incommensurate antiferromagnetic order — •André Deyerling[1], Alexander Regnat[1], Schorsch Sauther[1], Christian Pfleiderer[1,2,3,4], and Marc A. Wilde[1,2] — [1]Physik Department, TUM School of Natural Sciences, Technische Universität München, Germany — [2]Zentrum für Quantum Engineering (ZQE), Technische Universität München, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Technische Universität München, Germany — [4]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, Germany

CrB_2 exhibits antiferromagnetic order below $T_N = 89\,K$ [1]. Applying pressure leads to the suppression of magnetic order and the onset of superconductivity [2,3,4]. We report ab initio calculations of CrB_2 for different pressures and discuss possible mechanisms leading to the suppression of magnetic order and the onset of superconductivity. In addition we discuss the electronic structure for different possible magnetic ground states and their compatibility with neutron scattering experiments [4] and quantum oscillation measurements [5,6].

[1] A. Bauer et al., PRB 90, 064414 (2014).
[2] C. Pei et al., arXiv:2109.15213 (2021).
[3] S. Biswas et al., PRB 108, L020501 (2023).
[4] A. Regnat, PhD thesis, TUM (2019).
[5] M. Brasse et al., PRB 88, 155138 (2013).
[6] S. Sauther, PhD thesis, TUM (2021).

TT 7.10 Mon 17:30 H31

Calculating core-hole valence electron interactions from *ab initio* — •Felix Sorgenfrei[1], Olle Eriksson[1,2], and Patrik Thunström[1] — [1]Department of Physics and Astronomy, Uppsala University, Sweden — [2]Wallenberg Initiative Materials Science for Sustainability (WISE), Uppsala University, Uppsala Sweden

One common approach to simulating X-ray absorption spectra (XAS) for strongly correlated systems is the cluster model, where a model Hamiltonian is described with numerous free parameters. However, when different parameter sets yield the same spectra, drawing definitive conclusions becomes challenging. To overcome this, approaches integrating density functional theory (DFT) or DFT+ methods with the cluster model have been developed, allowing most parameters to be determined *ab initio*. Nonetheless, the Coulomb interaction between the core-hole and valence electrons (U_{cv}) remains undetermined from *ab initio* calculations. In this talk, I will present a method to calculate the screened core-valence interaction using *ab initio* linear response DFT, offering a more rigorous and predictive framework for XAS simulations.

TT 7.11 Mon 17:45 H31

SOLAX: A Python solver for fermionic quantum systems with neural network support — Louis Thirion[1], Philipp Hansmann[1], and •Pavlo Bilous[2] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany

We present a new Python library SOLAX [1] designed for configuration interaction (CI) calculations of fermionic quantum many-body systems which require high dimensional expansions in Slater determinant bases. The provided Python classes allow to conveniently encode basis sets, quantum states, and operators within the second quantization formalism. The JAX-based GPU-accelerated back-end performs efficiently the quantum mechanical operations necessary to determine many-body quantum states in finite-size Hilbert spaces.

Along with these core functionalities, SOLAX integrates a neural-network (NN) support for the CI calculation for otherwise prohibitively large expansions in Slater determinant basis sets. We show how NN can be used in SOLAX to identify a priori unknown subsets of the most important Slater determinants and iteratively obtain high-quality approximative many-body quantum states. Our recent developments include also NN-supported construction of spectral functions, which we plan to provide in future versions of SOLAX.

[1] L. Thirion, P. Hansmann, and P. Bilous, arXiv:2408.16915 (2024).

TT 8: Measurement Technology and Cryogenics

Time: Monday 15:00–17:45 Location: H32

TT 8.1 Mon 15:00 H32

64-pixel Magnetic Micro-Calorimeter array to study X-ray transitions in muonic atoms — •Daniel Kreuzberger, Andreas Abeln, Christian Enss, Andreas Fleischmann, Loredana Gastaldo, Daniel Hengstler, Andreas Reifenberger, Adrian Striebel, Daniel Unger, Julian Wendel, and Peter Wiedemann — for the QUARTET Collaboration, Kirchhoff Institute for Physics, Heidelberg University

The QUARTET collaboration aims to improve the knowledge on the absolute nuclear charge radii of light nuclei from Li to Ne. 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 up to 100 keV. Conventional solid-state detectors do not provide sufficient accuracy in this energy range. A high statistics measurement with lithium, beryllium and boron has recently been performed at the Paul Scherrer Institute. We present the experimental setup and the performance of the detector used. We discuss the first preliminary spectra and systematic effects in this measurement. The high statistics data in combination with the achieved energy resolution and calibration accuracy 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 8.2 Mon 15:15 H32

Magnetocaloric upgrade for the Quantum Design PPMS® — •Marvin Klinger, Jorginho Villar Guerrero, Anna Klinger, Tim Treu, Anton Jesche, and Philipp Gegenwart — EP VI, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg

Achieving millikelvin temperatures presents significant challenges in experimental physics. While many laboratories operate liquid helium cryostats at 2 K, reaching very low temperatures traditionally requires dilution refrigeration - a technique demanding both specialized expertise and substantial resources. We developed an upgrade for the Quantum Design Physical Property Measurement System (PPMS®) that overcomes these limitations. Our system employs adiabatic demagnetization refrigeration (ADR) to achieve temperatures well below 50 mK for multiple hours. The exceptional performance stems from novel quantum ADR materials that overcome disadvantages of traditional hydrated paramagnetic salts [1]. The upgrade consists of a user-friendly insert that integrates seamlessly with existing PPMS® systems. Its modular design allows researchers to easily swap the low-temperature assembly to accommodate different experimental needs, currently supporting electrical transport, stress/strain, and heat capacity measurements. This versatility and accessibility can make sub-50 mK measurements available to a broader scientific community without the complexity of dilution refrigeration.

[1] T. Treu et al., J. Phys. Condens. Matter 37, 013001 (2025)

TT 8.3 Mon 15:30 H32

The noise-o-meter: A novel device to disentangle noise sources in superconducting devices — •Lukas Münch, Daniel Hengstler, Matthew Herbst, David Mazibrada, Andreas Reifenberger, Markus Renger, Christian Ständer, Rui Yang, Andreas Fleischmann, Loredana Gastaldo, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University

In many applications of superconducting devices, different intrinsic noise sources are limiting the ultimate performance of the device. Our new device allows to conveniently disentangle the noise of the read-out chain, and to distinguish between magnetic flux noise and other noise sources. It consists of a microfabricated Wheatstone-like bridge of four superconducting inductors, two of which are filled with a sample material, which is read out via a pair of two-stage dc-SQUID read-out chains. The device can be operated in two modes. In the passive mode, the output signals of both read-out chains are cross-correlated, which allows the measurement of the total noise of all intrinsic noise sources within a sample material. In the active mode, the bridge is driven by an AC current to measure the samples complex susceptibility and, therefore, specifically the samples magnetic noise via the fluctuation-dissipation theorem. We used this setup to characterize SiO_2, Ag:Er and Au:Er films in a large temperature range from 20 to 800 mK. We discuss our design considerations and present the results of these measurements. Furthermore, we address the current performance limits of $S_\Phi = 30\,\mathrm{n}\Phi_0/\sqrt{\mathrm{Hz}}$ in passive mode and around 10 ppm for the concentration of magnetic impurities in active mode.

TT 8.4 Mon 15:45 H32

Broadband EPR Spectroscopy of $LiYF_4$ doped with Rare-Earth Ions — •Ana Strinic[1,2,3], Patricia Oehrl[1,2,3], Georg Mair[1,2], 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 Technology, Munich, Germany

We report on the study of hyperfine transitions of rare-earth ions doped into the host crystal $LiYF_4$ (RE^{3+}:$^7LiYF_4$) using broadband EPR spectroscopy at millikelvin temperatures. While the studied crystals are intentionally doped with ^{167}Er or ^{143}Nd, we identify impurity traces of other rare-earth ions from their EPR-transitions, based on previously published spin Hamiltonian parameters [1]. Taking into account the electron Zeeman, the hyperfine, and the quadrupole interactions, the high resolution spectra allow for the determination of refined spin Hamiltonian parameters for ^{167}Er and ^{143}Nd, as well as for the identified impurities. Our results demonstrate the advantage of using broadband EPR for material research, not only because precise information on the interactions of the spin system can be obtained, but also because the material purity can be tested. This study is relevant for quantum memory applications, as high purity materials are associated with achieving long coherence times [2].

[1] J. P. Sattler, J. Nemarich, Phys. Rev. B 4, 1, (1971);
[2] M. Le Dantec et al., Sci. Adv. 7, eabj9786 (2021).

TT 8.5 Mon 16:00 H32

Electro-optic cavities: Towards local measurement of light-matter coupling — •Michael S. Spencer[1], Joanna M. Urban[1], Maximilian Frenzel[1], Niclas S. Mueller[1], Olga Minakova[1], Martin Wolf[1], Alexander Paarmann[1], and Sebastian F. Maehrlein[1,2,3] — [1]FHI Berlin — [2]HZDR — [3]TU Dresden

Cavity quantum electrodynamics is expected to provide a unique direction for tailoring ground- and excited-state properties in correlated materials. Bringing this together with high-field driving in the terahertz (THz) spectral range opens the door to explore low-energy, field-driven cavity electrodynamics. Despite this potential, leveraging field-driven material control in bulk cavities is hindered by the lack of direct retrieval of intra-cavity fields. Here, we demonstrate novel active cavities, consisting of a Fabry-Pérot cavity filled with an electro-optic crystal, which measure their intra-cavity electric fields on ultrafast timescales. With these, we demonstrate quantitative retrieval of the cavity modes in amplitude and phase. We furthermore design a tunable multi-layer cavity, enabling deterministic design of hybrid cavities for future field-resolved polaritonic systems. Our theoretical modeling reveals the origin of the avoided crossings embedded in the intricate mode dispersion upon cavity tuning and enable fully-switchable polaritonic effects within arbitrary materials hosted by the hybrid cavity. Electro-optic cavities will therefore serve as in-situ probes of light-matter interactions across all coupling regimes, laying the foundation for field-resolved intra-cavity quantum electrodynamics.

15 min. break

TT 8.6 Mon 16:30 H32

Two-stage Pulse Tube Cryocooler with intermediate heat exchanger for accessing regenerator cooling capacity — •Bernd Schmidt[1,2], Jack-André Schmidt[1,2], Xaver Herrmann[1,2], Jens Falter[1], Dirk Dietzel[1,2], and André Schirmeisen[1,2] — [1]TransMIT GmbH, Center for Cryotechnology and Sensors, Giessen, Germany — [2]Institute of Applied Physics, University of Giessen, Germany

Two-stage PTCs achieve minimum temperatures of 2.2 K and have found their way even into sensitive applications where they compete with conventional LHe-bath cryostats. The 1st stage of a PTC is providing quite large cooling power at higher temperatures, ideal to cool radiation shields and precool peripheral elements. In addition, the cooling capacity of the regenerator is often used for precooling. This raises the question how the cooling capacity of a regenerator can best be harnessed. We present a cryocooler design [1], where an additional heat exchanger was incorporated into the 2nd stage regenerator.

This intermediate cooling stage allows to extract 4-5 W of cooling power at temperatures of 8-9 K for a standard two-stage PTC with a cooling capacity of 1.6 W at 4.2 K. The experimental data shows that applying the additional heating power does not adversely influence the performance of the second stage cold flange. The achieved cooling powers and temperatures are, for instance, ideally suited to cool superconducting wires in current quantum systems.

[1] J. Falter et al., submitted to Cryogenics (preprint: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4814535)

TT 8.7 Mon 16:45 H32

Experimental investigations of a frequency optimized Pulse Tube Cryocooler cooldown — •Jack Schmidt[1,2], Bernd Schmidt[1,2], and Andre Schirmeisen[1,2] — [1]Justus-Liebig-Universität Gießen — [2]TransMIT GmbH

Working in research often requires lower temperatures to achieve material effects such as superconductivity. This is achieved by using cryogenic liquids or closed cycle cryocoolers. Later have sub genres of working principle and provide different positive and negative aspects. We focus on the usage of Gifford-McMahon-type pulse tube cryocoolers which provide temperatures down to 2.2 K with the usage of Helium. The cooling power at 4.2 K scales up to 5 Watts nowadays with an electrical input power of the compressor around 25 kW. [1] As for mechanical stability the cryostats often become bulky and heavy. Including temperature isolation of the cold parts the cooldown times become very large. As the cryocoolers are mostly optimized for ongoing low temperature operation the cooling process lacks adaptations for an ideal cooldown. Other findings on this topic suggest to adjust valves and frequency. [2] Here we present our findings on the cooling process of a cryocooler to reduce cooldown time while adjusting the frequency. We were able to reduce the cooling time of the cryocooler by 9 % , applying electrical heat the cooldown is reduced by 10 %.

[1] X. Hao et al., Development of a 5 W/4.2 K two-stage pulse tube cryocooler. CEC/ICMC, C2Or3A-03 (2023);
[2] R. Snodgrass et al., Nat. Commun. 15, 3386 (2024).

TT 8.8 Mon 17:00 H32

Photoelectron characterization of a Cold field emitter for Ultrafast TEM — •Tim Dauwe[1,2], Nora Bach[1,2], Rudolf Haindl[1,2], Armin Feist[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Germany

Ultrafast transmission electron microscopy (UTEM) combines high spatial resolution with capabilities to image structures in the ultrafast temporal regime. This development was substantially advanced by creating femtosecond photoelectron pulses at modified Schottky tip emitters [1]. Further progress is expected by utilizing cold field emission guns (CFEG), which offer particularly high brightness and a narrower kinetic energy spectrum. In this contribution, we present a characterization of laser-triggered photoemission from a CFEG. We use a recent gun design allowing for laser access to the emitter (see Ref. [2]) and analyze beam characteristics in the linear photoemission regime. The CFEG is shown to support sub-nanometer probes and allows for photoelectron energy widths below 0.3eV. We emphasize the characterization of the spectral shape as a function of gun settings and compare it to theoretical models. Our experiments provide new insights for implementing and understanding photoemission from a CFEG, which will promote UTEM experiments at high resolution.

[1] A. Feist et al., Ultramicroscopy, 176 (2017)
[2] A. Schröder et al., arXiv:2410.23961 (2024)

TT 8.9 Mon 17:15 H32

Erbium dopants as luminescence thermometers in nanophotonic silicon waveguides — •Kilian Sandholzer, Stephan Rinner, Justus Edelmann, and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences, and Munich Center for Quantum Science and Technology (MCQST), Garching, Germany

The demand for fast and accurate temperature measurements in nanophotonic silicon devices grows as integrated structures for applications become more complicated and denser in classical and quantum technologies. Established approaches use sensors attached close to the components, which limits spatial resolution and increases the footprint of devices [1]. We propose and implement luminescence-based thermometry using directly integrated erbium emitters within nanophotonic silicon waveguides [2]. Coverage from 2 K to 295 K is achieved using two different effects: The thermal activation of non-radiative decay channels via impurities is used for temperatures above 200 K, and the population dynamics of crystal field and spin levels caused by phononic thermalization at lower temperatures. We achieve relative thermal sensitivities of 0.22(4) %/K at room temperature, increasing to 420(50) %/K at 2 K. Combined with spatially selective implantation, our method promises precise thermometry from ambient to cryogenic temperatures with a few-nanometer resolution.

[1] Y. Ma, B. Dong, and C. Lee, Nano Convergence 7, 12 (2020)
[2] K. Sandholzer et al., arXiv (2024)

TT 8.10 Mon 17:30 H32

Fast, accurate and local temperature control using qubits — •Riya Baruah[1], Pedro Portugal[1], Joachim Wabnig[2], and Christian Flindt[1,3] — [1]Department of Applied Physics, Aalto University, 00076 Aalto, Finland — [2]Nokia Bell Labs, Cambridge, United Kingdom — [3]RIKEN Center for Quantum Computing, Wakoshi, Saitama 351-0198, Japan

Many quantum technologies operate in the subkelvin regime. It is therefore desirable to develop practical tools and methods for the precise control of the temperature in nanoscale quantum systems. Here, we present a proposal for fast, accurate, and local temperature control using qubits, which regulate the flow of heat between a quantum system and its thermal environment [1,2]. The qubits are kept in a thermal state with a temperature that is controlled in an interplay between work done on the qubits by changing their energy splittings and the flow of heat between the qubits and the environment. Using only a few qubits, it is possible to control the thermal environment of another quantum system, which can be heated or cooled by the qubits. As an example, we show how a quantum system at subkelvin temperatures can be significantly and accurately cooled on a nanosecond timescale.

[1] P.Portugal, F.Brange, C.Flindt, Phys. Rev. Res. 4, 043112 (2022).
[2] R.Baruah, P.Portugal, J.Wabnig, C.Flindt, arXiv:2410.04796 (2024).

TT 9: Correlated Magnetism – Low-Dimensional Systems

Time: Monday 15:00–18:15 Location: H33

TT 9.1 Mon 15:00 H33

Pressure and quantum magnetism: Insights from brochantite $Cu_4SO_4(OH)_6$ — •Victoria Ginga[1], Bin Shen[2], Ece Uykur[3], Nico Giordano[4], and Alexander Tsirlin[1] — [1]Felix Bloch Institute, University of Leipzig, Germany — [2]EP VI, EKM, University of Augsburg, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [4]Deutsches Elektronen-Synchrotron DESY, Germany

Brochantite $Cu_4SO_4(OH)_6$, a widespread natural copper sulfate mineral, exemplifies a low-dimensional quantum magnet due to its geometrically frustrated $S = 1/2$ Cu^{2+} chains. The crystal structure of brochantite ($P2_1/n$) consists of edge-sharing zigzag double chains forming corrugated sheets in the *ab*-plane, with dissimilar Cu-O-Cu bridges fostering complex magnetic interactions. Ferromagnetic ordering within the Cu1-Cu2 and Cu3-Cu4 chains coexists with antiferromagnetic coupling between the chains, thus creating a delicate balance that can be affected by external pressure. We show that brochantite develops antiferromagnetic ordering below $T_N \approx 6$ K at ambient pressure. High-pressure X-ray diffraction data show that the monoclinic structure of brochantite remains stable up to at least 33 GPa, but individual structural parameters and especially bond angles are modified by pressure, thus affecting magnetic frustration in the compound. Magnetization measurements under pressure reveal changes in the Neel temperature and in the position of the susceptibility maximum. Our findings highlight brochantite as a platform for studying the interplay of structural and magnetic properties under extreme conditions.

TT 9.2 Mon 15:15 H33

μSR-investigation of clinoatacamite $Cu_2Cl(OH)_3$ — •Carolin Kastner[1], Fabrice Bert[2], Thomas J. Hicken[3], Jonas A. Krieger[3], Hubertus Luetkens[3], Aaron Schulze[1], Dirk Menzel[1], F. Jochen Litterst[1], Leonie Heinze[4], Kirrily C. Rule[5], Anja U. B. Wolter[6], and Stefan Süllow[1] — [1]IPKM, TU Braunschweig, Braunschweig, Germany — [2]SQM, Université Paris-Saclay, Orsay, France — [3]PSI, Villigen, Switzerland — [4]FZ Jülich GmbH, JCNS at MLZ, Garching, Germany — [5]ANSTO, Kirrawee, Australia — [6]IFW Dresden, Dresden, Germany

Interest in the natural mineral clinoatacamite $Cu_2Cl(OH)_3$ arose due to its chemical and structural relationship to herbertsmithite, a candidate material featuring a quantum spin liquid state on the kagome lattice. In clinoatacamite, the Cu^{2+} spins form a system of distorted kagome layers with three inequivalent antiferromagnetic in-plane couplings and weaker ferromagnetic interlayer exchange. This gives rise to a complex magnetic phase diagram which contains a sequence of magnetic transitions of unknown symmetry.

Here, we present a study of the magnetic phase diagram of single-crystalline clinoatacamite using muon spin spectroscopy (μSR) to gain insight into the microscopic details of the different magnetic phases. For our investigation, the natural, single-crystalline samples were extensively pre-characterized by magnetization and specific heat. We will discuss our findings in the context of the local site symmetry of the different Cu ions.

TT 9.3 Mon 15:30 H33

Complex magnetic excitations in the alternating ferro-antiferromagnetic chain vompound $Cu_2(OH)_3Br$ — •Kirill Povarov[1], Yurii Skourskii[1], J. Wosnitza[1,2], David Graf[3], Zhiying Zhao[4], and Sergei Zvyagin[1] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence ct.qmat, HZDR, Dresden — [2]Institut für Festkörper- und Materialphysik, TU Dresden — [3]National High Magnetic Field Laboratory, Tallahassee — [4]Fujian Institute of Research of Structure of Matter, Fujian

We report the intricate spectrum of magnetic excitations in the mixed-chain quantum magnet $Cu_2(OH)_3Br$. Electron spin resonance (ESR) measurements in the frequency range between 0.1 and 1 THz reveal two distinct types of excitations: Low-energy modes of antiferromagnetic resonance (AFMR), and a high-energy excitation multiplet. The latter was argued to stem from mixing between the spinons and magnons, based on the results of zero-field neutron spectroscopy [1]. Peculiarities of their behavior in magnetic fields up to 16 T are discussed.

This work was supported by the Deutsche Forschungsgemeinschaft through the Würzburg-Dresden Cluster of Excellence on Complexity and Topology in Quantum Matter - *ct.qmat* (EXC 2147, project No. 390858490) and the SFB 1143, as well as by HLD at HZDR, member of the European Magnetic Field Laboratory (EMFL).

[1] Zhang *et al.*, PRL **125**, 037204 (2020).

TT 9.4 Mon 15:45 H33

Synthesis and physical properties of the quasi-spin chain compound Li_2CuO_2 — •Ashiwini Balodhi[1,2] and Min Gyu Kim[2] — [1]Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum, Germany — [2]Department of Physics, University of Wisconsin-Milwaukee, Milwaukee, WI 53201, USA

Li_2CuO_2 serves as an excellent model system for investigating low-dimensional magnetism, owing to its simple $CuOi_4$ square planar coordination along the b-axis (orthorhombic structure). Previous studies on both polycrystalline and single-crystal samples have revealed an antiferromagnetic (AFM) transition at $T_N \sim 9$ K, accompanied by a canted AFM spin structure at T = 2.6 K. To probe the intrinsic magnetic properties of Li_2CuO_2, we synthesized this material using the flux method. We will present detailed magnetic, and heat capacity measurements on flux-grown samples. Magnetization and heat capacity data confirm a long-range antiferromagnetic transition at T_N = 9.3 K. In contrast to earlier studies reporting ferromagnetic components at low temperatures, our results do not indicate any evidence of ferromagnetic ordering in low temperature regime.

This work is supported by the University of Wisconsin-Milwaukee.

[1] A. Balodhi, M. G. Kim, Crystals 14, 288 (2024).
[2] A. Balodhi, M. G. Kim. J.Magn.Magn.Mater. 611, 172617 (2024).

TT 9.5 Mon 16:00 H33

Sub-Kelvin magnetic susceptibility insights into the spin chain system $YbAlO_3$ — •Lipsa Behera[1,2], Javier Landaeta[2], Konstantin Semeniuk[2], and Elena Hassinger[1,2] — [1]TUD Dresden University of Technology, Dresden, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

Low dimensional quantum magnets offer a rich platform to explore intriguing physics such as Tomonaga-Luttinger liquid, incommensurate phases and quantum phase transitions. What makes them special is the constraint in dimensionality leading to strong correlations. $YbAlO_3$ is an example of a quasi-one-dimensional spin chain system that can be described as a S = 1/2 Heisenberg chain with smaller Ising-like interchain interactions. At 1K it shows a typical spinon spectrum. At low temperature, the phase diagram presents an antiferromagnetic phase below 0.9 K, that changes into a longitudinal spin density wave including a MS/3 plateau, transverse antiferromagnetic phase and the field polarised state with H ||a. Recent thermal conductivity and magnetostriction measurements uncovered a previously unobserved MS/5 plateau phase at B = 0.7 T, motivating detailed sub-kelvin magnetic susceptibility studies. Here, we report ac susceptibility measurements down to 25 mK, which not only reproduces the known phase diagram to a good extent, but also confirm the presence of the magnetization plateau Ms/5. Furthermore, it reveals additional anomalies, embedded in the incommensurate phase, adding up to the complex magnetic behavior of this material.

TT 9.6 Mon 16:15 H33

Evidence of spin-phonon charge coupling in the quasi-1D Ising spin chain system α-CoV_2O_6 — •Debismita Naik and Pradip Khatua — Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur, West Bengal 741246, India

The quasi-one-dimensional Ising spin chain system α-CoV_2O_6 exhibits fascinating magnetic properties at lower temperatures. The DC magnetization and specific heat confirm the antiferromagnetic long-range ordering temperature T_N = 15 K. From the specific heat, the calculated magnetic entropy above T_N suggests short-range ordering in this low-dimensional compound. The temperature-dependent XRD supports the key finding of magnetoelastic coupling, which is crucial for linking the electrical and magnetic dipoles. Temperature-dependent Raman spectroscopy reveals the presence of spin-phonon coupling below T_N. Additionally, the study highlights an unusual evolution of the Raman modes above T_N which appears to be linked to short-range magnetic ordering. The renormalization of Raman modes and lattice anomalies near T_N illustrate spin-lattice coupling via magne-

toelastic and spin-phonon interactions leads to interplay between spin, charge, and phonon degrees of freedom in α-CoV_2O_6. To support the intriguing phenomena, the theoretical charge density difference maps suggest the formation of electrical dipoles between Co and O atoms below T_N arises from p-d hybridization.

15 min. break

TT 9.7 Mon 16:45 H33

Crystal structure, electronic structure and magnetism in the binary compound Cr_3Se_4 — •Helge Rosner[1], Seojin Kim[1], Yurii Prots[1], Vincent Morano[2], Oksana Zaharko[2], Jörg Sichelschmidt[1], Marcus Schmidt[1], and Michael Baenitz[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, 01187 Dresden, Germany — [2]Laboratory for Neutron Scattering and Imaging, 5232 Villigen PSI, Switzerland

Cr_3Se_4 crystallises in a monoclinic lattice, structurally closely related to the rhombohedral chalcogenite delafossite-like systems $ACrX_2$ with A = Na, Cu, Ag and X = S, Se. In contrast to these intrinsically semiconducting materials with a nonmagnetic monovalent A site, in Cr_3Se_4 the distorted triangular $CrSe_2$ layers are separated by a formally trivalent and magnetic ion. In consequence, the inter-layer distance is strongly reduced, making the system more three dimensional, and thus strongly increasing the magnetic ordering temperature.
Here, we present a joint experimental and theoretical study of the binary material Cr_3Se_4, including thermodynamic measurements, high resolution XRD, neutron scattering and density functional band structure calculations. Our data consistently demonstrate that the metallic system undergoes an antiferromagnetic ordering at about 160 K which is strongly coupled to the crystal lattice. The band structure calculations show that the conduction bands originate from strongly hybridised Cr-Se states with sizeable spin-orbit interaction. In a detailed comparison, we will highlight the similarities and differences between Cr_3Se_4 and the chalcogenite delafossites.

TT 9.8 Mon 17:00 H33

First-principles phonon study of $AgCrS_2$, $AgCrSe_2$, and $AgCrTe_2$ — •Seo-Jin Kim, Jörg Sichelschmidt, Michael Baenitz, Yurii Prots, Markus Schmidt, and Helge Rosner — Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

We study the elastic and dynamic stability of layered triangular lattice systems $AgCrS_2$, $AgCrSe_2$, and $AgCrTe_2$ using density functional theory (DFT). These systems share the same structure but exhibit different properties. Multiferroic $AgCrS_2$ undergoes an additional structural transition to a monoclinic phase and exhibits a collinear double-stripe antiferromagnetic ground state below $T_N = 42$ K. $AgCrSe_2$ shows noncollinear cycloidal magnetic ordering below $T_N = 32$ K. To investigate the interplay between magnetism and structure, we analyze the elastic constants and phonon dispersions of these compounds. Our findings reveal that the on-site Coulomb repulsion and additional symmetry alterations in the Cr layer are crucial for achieving dynamical stability in $AgCrS_2$. Furthermore, we analyze $AgCrSe_2$ and $AgCrTe_2$ to understand the general trends in elastic and dynamic properties with chalcogen variation.

TT 9.9 Mon 17:15 H33

Magnetic-field tuning of the spin dynamics in the van der Waals antiferromagnet $CuCrP_2S_6$ (CCPS) — •Joyal John Abraham[1,2], Sebastian Selter[1], Yuliia Shemerliuk[1,2], Saicharan Aswartham[1], Bernd Büchner[1,2,3], Vladislav Kataev[1], and Alexey Alfonsov[1] — [1]Leibniz IFW Dresden, D-01069 — [2]Institute for Solid State and Materials Physics, TU Dresden, D-01062 Dresden — [3]Institute for Solid State and Materials Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, D-01062

Magnetic van der Waals (vdW) materials have recently attracted significant attention due to their tunable magnetic properties, easy exfoliation, and possible integration into spintronic devices. In this work, we explore with electron spin resonance (ESR) spectroscopy the spin dynamics of the vdW antiferromagnetic (AFM) compound CCPS featuring interpenetrating antipolar Cu^{1+} and (AFM) Cr^{3+} sublattices. Above the AFM ordering temperature $T_N \approx 30$ K ESR reveals prominent ferromagnetic (FM) spin correlations that persist far above T_N, suggesting an intrinsically two-dimensional character of the spin dynamics in CCPS. At $T < T_N$, a complex field dependence of collective excitations of the AFM-ordered spin-lattice was observed featuring two non-degenerate magnon gaps at $H = 0$. A remarkable tuning of the excitations from the AFM-type to the FM-type with increasing field strength was demonstrated. Application of the linear spin wave theory enabled us to quantify the exchange and anisotropic constants. Furthermore, this unusual crossover of AFM-FM excitations is explained using the obtained energy parameters.

TT 9.10 Mon 17:30 H33

Investigation of the insulator to metal transition in the 2d van der Waals magnet $FePSe_3$ — •Saicharan Aswartham, Masoumeh Rahimkhani, Andreas Kreyssig, and Anna Böhmer — Experimentalphysik IV, Ruhr- Universität Bochum, 44801 Bochum, Germany

Layered magnetic van der Waals (vdW) materials offers an interesting playground for the investigation of correlated electronic ground states in two dimensions. $FePSe_3$ belongs to the family of transition metal phosphorus trichalcogenides $TMPX_3$ with an antiferromagnetic ground state with T_N=108 K. Interestingly, under the application of external pressure FePSe3 undergoes insulator to metal transition. Here, we present detailed synthesis and physical properties of $Fe_{1-x}TM_xPSe_3$ with different transition metal substitution. We furtheraim to investigate spin cross over behaviour with the application of chemical pressure in $FePSe_3$.

[1] Wang et al., Nat. Commun. 9, 1914 (2018).
[2] Selter et al., Phys. Rev. Mater. 5, 073401 (2021).

TT 9.11 Mon 17:45 H33

Modelling low-energy spin excitation measurements in field-induced phases of the spin-ladder antiferromagnet $BiCu_2PO_6$ — Patrick Pilch[1], Kirill Amelin[2], •Gary Schmiedinghoff[3], Anneke Reinold[1], Changqing Zhu[1], Kirill Yu. Povarov[4], Sergei Zvyagin[4], Hans Engelkamp[5], Yin-Ping Lan[6], Guo-Jiun Shu[6], Fang-Cheng Chou[7], Urmas Nagel[2], Toomas Rõõm[2], Götz S. Uhrig[1], Benedikt Fauseweh[1,3], and Zhe Wang[1] — [1]TU Dortmund, 44227 Dortmund, Germany — [2]NICPB, 12618 Tallinn, Estonia — [3]DLR, 51147 Cologne, Germany — [4]HZDR, 01328 Dresden, Germany — [5]Radboud University, 6525 ED Nijmegen, The Netherlands — [6]Taipei Tech, Taipei 10608, Taiwan — [7]NTU, Taipei 10617, Taiwan

We report on terahertz spectroscopic measurements and subsequent theoretical modelling of quantum spin dynamics on single crystals of a spin-1/2 frustrated spin-ladder antiferromagnet $BiCu_2PO_6$ as a function of applied external magnetic fields. Anisotropic spin triplon excitations are observed, which split in applied magnetic fields with a quantum phase transition at $B_{c1} = 21.4\,T$ for fields applied along the crystallographic a axis.

We theoretically model the magnetic field dependence of the triplon modes by using continuous unitary transformations to determine an effective low energy Hamiltonian. Through an exhaustive parameter search we find numerically optimized parameters to very well describe the experimentally observed modes, which corroborate the importance of significant magnetic anisotropy in the system.

The talk focuses on the theoretical analysis of the experimental data.

TT 9.12 Mon 18:00 H33

Evidence of multiple phase transition in $Sr_2BB'O_6$ — •Aprajita Joshi, Shalini Badola, Akriti Singh, and Surajit Saha — Indian Institute of Science Education and Research Bhopal, India

The manifestation of phase transition is well mimicked by the lattice, thus by phonons, which requires its correlation with other degrees of freedom (spins, phonons etc.). Often, one can study the behavior of associated phonons with external perturbation to get more insight into the ground state of the material. Thus, any changes in the phase can be tracked with the external stimuli. Keeping this in mind, we explored the structural and magnetic attributes of $Sr_2BB'O_6$ with the help of Raman spectroscopy, using temperature as an external perturbation. The obtained phonon parameter shows the signature of a series of structural phase transitions. Magnetic measurements reveal that it also stabilizes in an antiferromagnetic ground state. An apparent deviation in Raman modes was seen around both the magnetic transitions, acting as a signature of spin-phonon coupling in the system. Additionally, temperature-dependent Raman gave insight into the local distortion in the lattice arising in the magnetically ordered state. This was also corroborated by temperature-dependent XRD measurements.

TT 10: Topological Semimetals

Time: Monday 15:00–17:45 Location: H36

TT 10.1 Mon 15:00 H36

Uniaxial pressure tuning of the anomalous Hall effect in Mn_3Ge — •Gustavo Lombardi[1], Leonardo Oparacz Kutelak[2], Mario Moda Piva[1], Vinicius Estevo Silva Frehse[3], Guilherme Calligaris[2], Ricardo Donizeth dos Reis[2], and Michael Nicklas[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany — [2]Brazilian Synchrotron Light Laboratory, 13083-100, Campinas, Brazil — [3]Center for Electronic Correlations and Magnetism, 86159, Augsburg, Germany

The hexagonal Heusler compound Mn_3Ge exhibits an antiferromagnetic structure in which the Mn spins are arranged in a 120° triangular configuration characteristic of a Kagome lattice in the *ab* plane. These Kagome layers are periodically stacked along the *c* axis. This structure gives rise to a large anomalous Hall effect (AHE) due to a non-vanishing Berry curvature. Uniaxial pressure provides an effective method for tuning the AHE in Mn_3Ge. Our results reveal that applying stress along the *a* direction, which induces a distortion in the *ab* plane, significantly modifies the Hall signal. In contrast, stress applied along the *c* axis has no visible effect on the Hall signal. These results, combined with previous hydrostatic pressure data [1], suggest that the strong variations in the AHE are due to changes in the magnetic order in the *ab* plane. We also find that the application of hydrostatic and uniaxial pressure leads to different modifications of the magnetic order, the former inducing an out-of-plane tilt of the Mn spins, while the latter induces rotations of the Mn spins within the *ab* plane.

[1] R. D. Dos Reis et al., Phys. Rev. Mater. **4**, 51401 (2020).

TT 10.2 Mon 15:15 H36

Terahertz-light induced dynamics in the magnetic Weyl semimetal Mn_3Sn — •Anneke Reinold[1], Sergey Kovalev[1], Tomohiro Uchimura[2], Shunsuke Fukami[2], and Zhe Wang[1] — [1]Department of Physic, TU Dortmund University, Germany — [2]Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University, Sendai, Japan

We present a time-resolved spectroscopic study of the strong terahertz (THz) field-driven dynamics in the chiral-structured non-collinear Kagome antiferromagnet Mn_3Sn, a material renowned for anomalous transport properties, topological effects, and promising spintronic applications [1]. The driven charge and spin nonequilibrium dynamics are probed by optical transmission and Faraday rotation with a subpicosecond time resolution for various experimental conditions. By varying THz and optical polarization, sample orientation, and sample temperature, we carry out a comprehensive investigation of the THz field-driven nonequilibrium dynamics, in order to figure out the contributions due to different mechanisms. Our findings provide insight into the THz field-driven spin dynamics in this Kagome antiferromagnet and demonstrate its potential for THz spintronic applications.

[1] J. Han, T. Uchimura et al., Nat. Phys. **20**, 1110 (2024).

TT 10.3 Mon 15:30 H36

Anomalous Hall and Nernst effect in the Weyl semimetal $Ta_{1+x}Ru_{1-x}Te_4$ — •Mahdi Behnami[1,2,3], Dmitri Efremov[1], Grigory Shipunov[1], Saicharan Aswartham[1], Vilmos Kocsis[1], Marina Putti[3,4], Bernd Büchner[1,2], Helena Reichlova[1,2,5], and Federico Caglieris[4] — [1]IFW Dresden, P.O. Box 270116, 01171 Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01062 Dresden, Germany — [3]Department of Physics, University of Genoa, 16146 Genova, Italy — [4]CNR-SPIN, 16152 Genova, Italy — [5]Institute of Physics ASCR, v.v.i., Cukrovarnick a 10, 162 53, Praha 6, Czech Republic

The anomalous Nernst effect is a transverse thermoelectric phenomenon driven by a temperature gradient perpendicular to both the heat current and the magnetic order vector. This effect is particularly valuable for probing the topological nature of materials, as it exhibits greater sensitivity to the Berry curvature near the Fermi energy compared to the anomalous Hall effect. In this study, we report that the type-II Weyl semimetal $Ta_{1+x}Ru_{1-x}Te_4$ exhibits both anomalous Hall and Nernst effects. These phenomena can be attributed to the finite Berry curvature generated by the Weyl points in this material.

TT 10.4 Mon 15:45 H36

Electronic transport and classification for topological nodal planes — •Moritz M Hirschmann[1,2], Kirill Alpin[1], Raymond Wiedmann[1], Niclas Heinsdorf[1,3], Wan Yee Yau[1,4], Andreas Leonhardt[1], Douglas H Fabini[5], Johannes Mitscherling[1,6,7], and Andreas P Schnyder[1] — [1]MPI FKF, Stuttgart, Germany — [2]RIKEN CEMS, Wako, Japan — [3]UBC, Vancouver, Canada — [4]MPI CBG, Dresden, Germany — [5]MIT, Cambridge, USA — [6]UC, Berkeley, USA — [7]MPI PKS, Dresden, Germany

Nodal planes are the two-dimensional generalization of nodal points/lines [1], and like them, they may carry a topological charge, for which we devise a symmetry-based classification. When a single or a pair of two nodal planes are topological, Fermi arcs connect the pockets of Weyl points and nodal planes on the surface. While this is similar to Weyl semimetals, their transport properties differ. We find that the large degeneracy of nodal planes is susceptible to a time-reversal breaking that contributes to the anomalous Hall effect. Further, perturbed nodal planes generically enhance the quantum metric contributing to the interband part of the optical conductivity. As an application, we study the hexagonal van der Waals material $CoNb_3S_6$, which exhibits such topological nodal planes. Recently, this compound has gained interest due to its All-in-All-out magnetic order that exhibits a nontrivial spin-space symmetry [2]. Here, the topological nodal planes dominate the anomalous Hall and Nernst effects.

[1] Nature 594, 374 (2021).
[2] arXiv:2403.01113 (2024).

TT 10.5 Mon 16:00 H36

Quantum geometry of topological nodal planes in Kondo systems — •Yannis Ulrich[1], Andreas Schnyder[1], and Laura Classen[1,2] — [1]Max Planck Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany — [2]Department of Physics, Technical University of Munich, D-85748 Garching, Germany

The geometric properties of the Hilbert space of Bloch states, such as the Berry curvature or quantum metric, play an important role in understanding topological semimetals. They are also fundamental for the understanding of various physical responses, including the (non-)linear Hall effect and (magneto-)optical conductivities. In this talk, I investigate the quantum geometry of two-dimensional topological band degeneracies, i.e., topological nodal planes, with a flat dispersion. Such nodal planes naturally arise in Kondo materials with screw rotation symmetries. Using a periodic Anderson model, I show how nodal planes in these Kondo materials can be tuned via pressure or temperature to be close to the Fermi level with a nearly flat dispersion. I show that such flat nodal planes exhibit a substantial quantum geometry, which in turn leads to nontrivial signatures in the (non-)linear Hall responses. Derivations of the Hall conductivities are presented in the manifestly gauge-invariant language of projectors, emphasizing their advantages in this type of calculation.

TT 10.6 Mon 16:15 H36

Finite-size topological phases from semimetals — •Adipta Pal[1,2] and Ashley M. Cook[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute for the Chemical Physics of Solids, Dresden, Germany

Topological semimetals are some of the topological phases of matter most intensely-studied experimentally. The Weyl semimetal phase, in particular, has garnered tremendous, sustained interest given fascinating signatures such as the Fermi arc surface states and the chiral anomaly, as well as the minimal requirements to protect this three-dimensional topological phase. Here, we show that thin films of Weyl semimetals (which we call quasi-(3-1)-dimensional, or q(3-1)d) generically realize finite-size topological phases distinct from 3d and 2d topological phases of established classification schemes: response signatures of the 3d bulk topology co-exist with topologically-protected, quasi-(3-2)d Fermi arc states or chiral boundary modes due to a second, previously-unidentified bulk-boundary correspondence. We show these finite-size topological semimetal phases are realized by Hamiltonians capturing the Fermiology of few-layer Van der Waals material MoTe2 in experiment. Given the broad experimental interest in few-layer Van der Waals materials and topological semimetals, our work paves the way for extensive future theoretical and experimental characterization of finite-size topological phases.

15 min. break

TT 10.7 Mon 16:45 H36

Phonon-mediated surface superconductivity in Weyl semimetals — •Kristian Maeland and Björn Trauzettel — Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany

Recent experiments show that Weyl semimetals can host surface superconductivity in the Fermi arcs, while remaining metallic in the bulk. We study a lattice model of a Weyl semimetal to see if phonons are a candidate pairing mechanism to explain this phenomenon. Specifically, we study the pairing mechanism in detail on the surface and in the bulk. Furthermore, we make predictions about the critical temperature and the momentum dependence of the gap function.

TT 10.8 Mon 17:00 H36

The Weyl-Mott point: Topological and non-Fermi liquid behavior from an isolated Green's function zero — •Rafael Alvaro Flores Calderon[1] and Chris Hooley[2] — [1]Max Planck Institute for the Physics of Complex Systems, Noethnitzer Strasse 38, 01187 Dresden, Germany — [2]Centre for Fluid and Complex Systems, Coventry University, Coventry CV1 2TT, United Kingdom

We present a model in which a Hatsugai-Kohmoto interaction is added to a system of fermions with a Weyl point in their non-interacting dispersion relation, and analyze its behavior as a function of the chemical potential. We show that the model exhibits a Weyl-Mott point, a single isolated Green's function zero, and that this implies an emergent non-Fermi-liquid state at the border of the metallic regime and a gapped topological state for the insulating one. The Weyl-Mott point inherits the topological charge from the original Green's function pole, and is therefore naturally associated with a strongly correlated chiral anomaly.

TT 10.9 Mon 17:15 H36

Observation of quasiparticle lifetime oscillations in WSi_2 — •Ivan Volkau[1], Nico Huber[1], Leo Maximov[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

The observation of quasiparticle lifetime oscillation (QPLOs) in CoSi [1] raises the question whether they are a generic feature observable in many materials or if they require a specific band structure. Here, we report the observation of QPLOs in WSi_2, which has recently generated great interest due to its remarkable characteristics in its transport properties, such as axis-dependent conduction polarity [2] and extremely large magnetoresistance [3]. We present Shubnikov-de Haas (SdH) and de Haas-van Alphen measurements, performed at different orientation of magnetic field up to 18 T and temperatures down to 1.5 K. We analyze the oscillation frequencies, their angular dependence, and their temperature dependence. The detected combination frequencies in the SdH effect exhibit characteristics consistent with QPLOs theory providing another example where the influence of QPLOs is observed.
[1] Nature 621, 276 (2023).
[2] Chem. Mater. 35, 4228 (2023).
[3] Phys. Rev. B 102, 115158 (2020).

TT 10.10 Mon 17:30 H36

Anomalous photo-Nernst effect and impact of disorder in $HfTe_5$ films — Maanwinder Singh[1,2], Tobias Meng[3], and •Christoph Kastl[1,2] — [1]Walter-Schottky-Institute, Technical University of Munich, Germany — [2]Munich Center for Quantum Science and Technology — [3]Institute of Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

We discuss optoelectronic transport in thin films of $HfTe_5$, which is a non-magnetic, weakly gapped semimetal at the border of a weak to strong topological insulator transition. We find that focused photoexcitation results in strong a transversal response at finite magnetic field, which we describe in terms of a Berry curvature driven anomalous photo-Nernst effect of three-dimensional massive Dirac fermions [1]. We further use Raman microscopy to reveal significant microscale disorder and strain in contacted films, which has important implications for the interpretation of transport experiments in $HfTe_5$ due to the sensitivity of its electronic structure to external strain [2].
[1] Singh et al., Adv. Phys. Res. 3, 2300099 (2024).
[2] Singh et al., ACS Nano 18, 18327 (2024).

TT 11: Superconductivity: Poster

Time: Monday 15:00–18:00 Location: P4

TT 11.1 Mon 15:00 P4

Chiral and nematic superconductivity in monolayer $NbSe_2$ — •Anton Bleibaum[1], Julian Siegl[1], Wen Wan[2], Marcin Kurpas[3], John Schliemann[1], Miguel M. Ugeda[2,4,5], Magdalena Marganska[1], and Milena Grifoni[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany — [2]Donostia International Physics Center, Paseo Manuel de Lardizábal 4, 20018 San Sebastián, Spain — [3]Institute of Physics, University of Silesia in Katowice, 41-500 Chorzów, Poland — [4]Centro de Física de Materiales, Paseo Manuel de Lardizábal 5, 20018 San Sebastián, Spain — [5]Ikerbasque, Basque Foundation for Science, Bilbao 48013, Spain

Superconductivity emerges when there is an effective attractive electron-electron interaction. As proposed by Kohn and Luttinger in 1965, screening of the Coulomb interaction can give rise to long-range Friedel oscillations providing regions of attractive interaction which allow for Cooper pairing. In $NbSe_2$, Coulomb repulsion is sufficient to induce superconductivity, when accounting for screening on the triangular lattice. Using momentum resolved gap equations, we find two quasi-degenerate nematic solutions near the critical temperature T_c. In agreement with tunneling spectroscopy experiments, a complex linear combination forms a fully gaped chiral phase well below T_c. When we allow for an in-plane magnetic field, we find an equal spin pairing component.

TT 11.2 Mon 15:00 P4

Exfoliation and STM/STS Investigations of Monolayer $NbSe_2$ S/F Systems — •Tiark Tiwary[1], Marcel Strohmeier[1], Elke Scheer[1], and Angelo Di Bernardo[1,2] — [1]University of Konstanz, 78457 Konstanz, Germany — [2]University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano (SA), Italy

Two dimensional materials have become of great interest in the recent years, because of their promise to enable novel electronic functionality by choosing suitable material combinations. A typical feature of 2D superconductors is their anisotropy of the critical field which is most pronounced in the monolayer limit. To understand more about the behaviour of Ising superconductivity in monolayer $NbSe_2$, STM/STS measurements were performed. To this end, gold-assisted exfoliation was used to obtain large monolayer on a Ti/Au surface. The measurements largely confirmed the previous reports [1, 2] on monolayer $NbSe_2$. To develop devices for superconducting spintronics, the interplay between a ferromagnet and monolayer $NbSe_2$ is investigated. Multiple techniques to gain $NbSe_2$ monolayer were explored. The exfoliation of small monolayers on a Co surface could be achieved.
[1] Wan et al., Adv. Mater. 34, 2206078 (2022);
[2] Kuzmanović et al., Phys. Rev. B **106**, 184514 (2022).

TT 11.3 Mon 15:00 P4

Cavity Mediated Control on Study of Transient THz Field on Superconductors — Angela Montanaro, Giacomo Jarc, •Nitesh Khatiwada, and Daniele Fausti — Friedrich-Alexander-Universität Erlangen-Nürnberg

Cavity QED has emerged as a new stimulus for studying phase transition in quantum materials. A recent study[1] demonstrating changes in critical temperature for metal insulator phase transition mediated by cavity electrodynamics in $1T\text{-}TaS_2$ has inspired us to investigate cavity mediated phase transition in superconductors.
[1] Nature 622, 487 (2023).

TT 11.4 Mon 15:00 P4

THz spectroscopy on superconducting ZrN thin films — •Ozan Saritas[1], Frederik Bolle[1], Martin Dressel[1], Roman

Potjan[2], Marcus Wislicenus[2], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Fraunhofer Institute for Photonic Microsystems (IPMS), Center Nanoelectronic Technologies (CNT), Dresden, Germany

The recent large-scale preparation of superconducting ZrN thin films is of interest for potential quantum technology applications [1]. Therefore, here we use THz frequency domain spectroscopy to investigate the superconducting electrodynamics of ZrN thin films, with thickness between 20 nm and 50 nm, grown on 300 mm-standard silicon substrates. We have measured the transmission and phase shift of THz radiation passing through the ZrN films, and we have obtained the frequency-dependent dielectric function. We thus acquired characteristic material quantities such as the temperature-dependent superconducting energy gap $2\Delta(T)$ and superfluid density $n_\mathrm{s}(T)$. With decreasing thickness, there is a clear trend towards a lower critical temperature T_c, a reduced $2\Delta(T=0)$, and a lower $n_\mathrm{s}(T=0)$. While the overall behavior is similar to BCS predictions, thinner films exhibit values for the ratio $2\Delta(T=0)/(k_BT_c)$ that deviate more from the canonical value.

Additionally, a novel analysis of the temperature-dependent shift of Fabry-Perot transmission resonance frequencies of superconducting thin-film samples was performed.

[1] R. Potjan *et al*, Appl. Phys. Lett. **123**, 172602 (2023)

TT 11.5 Mon 15:00 P4

Terahertz investigations on superconducting nitride thin films — •Yayi Lin[1], Frederik Bolle[1], Janine Lorenz[2], Marcello Guardascione[2], Marc Neis[2], Thomas J. Smart[2], Martin Dressel[1], Rami Barends[2], Pavel Bushev[2], F. Stefan Tautz[2], Felix Lüpke[2], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Peter Grünberg Institut, Forschungszentrum Jülich, Jülich, Germany

In recent years, superconducting nitride thin films have garnered significant attention, for example for applications in quantum electronics. Due to the wide range of accessible kinetic inductance, high critical temperature, and correspondingly large energy gap, these materials are readily utilized in microwave resonators, low-temperature amplifiers, and quantum circuits.

We use terahertz (THz) spectroscopy to probe the electrodynamics of superconducting NbTiN ($T_c > 10$ K) and TiN ($T_c > 3$ K) thin films at frequencies below and above their superconducting energy gaps. We combine THz frequency-domain spectroscopy and THz time-domain spectroscopy to cover the frequency range from 100 GHz to 3 THz. We present key properties of several nitride thin films such as critical temperature (T_c), complex optical conductivity ($\hat{\sigma}$), energy gap (2Δ), superfluid density (n_s), and kinetic inductance (L_k). Of particular interest is the absolute value of the superconducting energy gap, which allows comparison with other spectroscopic techniques and predictions based on BCS theory.

TT 11.6 Mon 15:00 P4

Nanoscale Characterization of Defects in Superconducting Nitrides — •Janine Lorenz[1,2,3], Amin Karimi[1], Yorgo Hadad[1], Rami Barends[1], F. Stefan Tautz[1,2,3], and Felix Lüpke[1,4] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA) - Fundamentals of Future Information Technology, Germany — [3]Institut für Experimentalphysik IV A, RWTH Aachen Universität, Germany — [4]II. Physikalisches Institut, Universität zu Köln, Germany

Due to their elevated critical temperature and high kinetic inductance, Nitride supercondcutors are promising candidates for microwave resonators and low-noise amplifiers that are essential for useful quantum computing. We aim to improve structural and superconducting properties of our 11 nm NbTiN thin films grown by sputter deposition. By implementing a post-deposition thermal annealing protocol in Nitrogen/Hydrogen gas atmosphere we achieve an increase in critical temperature from initially 11.5 K to 18 K. In this work, we apply scanning probe techniques to investigate surface superconductivity and defects that appear as Yu-Shiba-Rusinov states of treated and untreated thin films.

TT 11.7 Mon 15:00 P4

Superconductivity of Reduced Indium Tin Oxide — •Luca Hofmeister, Jan Pusskeiler, Gabriele Untereiner, Martin Dressel, and Marc Scheffler — 1. Physikalisches Institut, Universität Stuttgart, Deutschland

Indium tin oxide (ITO) is a transparent semiconductor commonly used in photovoltaics and flat screen displays. It is possible to induce low temperature superconductivity in ITO via electrochemical reduction in a NaCl solution. [1,2]

We reduced multiple ITO samples at a constant reduction current and measured the temperature dependence of their two-point resistance with a microwave Corbino spectrometer. Depending on the reduction time, the $\mathrm{T_c}$ ranges from 2.2 K to 3.7 K, forming a superconducting dome.

Reduction induces a color change of the ITO, which loses some of its transparency for increasing reduction times. Nevertheless, ITO retains some transparency even after very long reduction, thereby making ITO a candidate for usage as a transparent superconducter.

[1] A. E. Aliev *et al.*, Appl. Phys. Lett. **101**, 252603 (2012);
[2] E. Batson *et al.*, Supercond. Sci. Technol. **36**, 055009 (2023).

TT 11.8 Mon 15:00 P4

Structural properties of $YBa_2Cu_3O_7$ thin film nanopatterns generated by focused He-ion-beam irradiation — •Robin Hutt[1], Cesar Magen[2], Christoph Schmid[1], Jan Ullmann[1], Simon Koch[1], Javier Pablo-Navarro[2], Ross Carter[1], Paul Zimmermann[1], Frank Schreiber[1], Dieter Koelle[1], Reinhold Kleiner[1], Ivan Zaluzhnyy[1], and Edward Goldobin[1] — [1]Universität Tübingen, Germany — [2]INMA, Universidad de Zaragoza - CSIC, Spain

Irradiation of a $YBa_2Cu_3O_7$ (YBCO) thin film with a focused He ion beam (He-FIB) with spot size $\lesssim 10$ nm changes its properties on the nanoscale. A moderate irradiation dose D supresses the critical temperature T_c locally, thus allowing us to "draw", e.g., Josephson barriers, while a high D destroys (amorphizes) the crystal locally, letting us create highly resistive walls (edges of devices and holes) in one fabrication run. We report on the irradiation of YBCO thin films by He-FIB using single lines and rectangular areas with different doses and investigate the result using transmission electron microscopy (TEM). We visualize the crossover to amorphization at the critical dose D_c and the growth of the amorphous track width with D. Using a simple model, we obtain the value of D_c and FIB spot size with a good accuracy. In the areas irradiated by $D < D_c$ we use strain analysis of the TEM images to detect subtle changes in the crystal structure. This is complemented by spatially-resolved X-ray diffraction data that indicate the swelling of the film in c-direction in irradiated regions. Finally, these observations are correlated with electric transport properties of irradiated areas.

TT 11.9 Mon 15:00 P4

$YBa_2Cu_3O_7$ thin films on Si substrates for SQUID-on-lever scanning probe microscopy — •Simon Koch, Alexander Koller, Christoph Schmid, Reinhold Kleiner, and Dieter Koelle — Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, Universität Tübingen, 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 atomic force microscopy (AFM) cantilevers could enable SSM in the Tesla range and at temperatures up to ~ 80 K with 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. In recent years, epitaxial $SrTiO_3$ (STO) with perovskite crystal structure has been realized on Silicon [1] and epitaxial STO-on-Si commercial substrates are now available. STO is lattice-matched to YBCO, and therefore provides an ideal starting point for the project.

We present our process for the fabrication of YBCO thin films on STO-on-Si substrates, based on pulsed laser deposition (PLD) and discuss the optimization of growth conditions. We further present our preliminary results regarding film quality and electrical characterization of fabricated structures.

[1] Abel *et al.*, Nature Mater. **18**, 42-47 (2019).

TT 11.10 Mon 15:00 P4

Disorder dependent properties of superconductors — •Marvin Zibula and Götz Seibold — Institut für Physik B-TU Cottbus-Senftenberg, Erich-Weinert Straße 1, 03046 Cottbus

We study the properties of disordered superconductors within the attractive Hubbard model and a disorder potential which interpolates between diluted impurities and Anderson-type disorder with a random potential at each lattice site. In the latter case, we reproduce the

results from Ghosal et al. [1], corresponding to the formation of superconducting islands that are not correlated to the underlying charge distribution. However, such a correlation becomes effective upon reducing the impurity concentration. Our results are important for recent optical experiments related to the nonlinear first harmonic response which are more compatible with the diluted model.
[1] A.Ghosal, M.Randeria, N.Trivedi, Phys.Rev.B 65, 014501 (2001)

TT 11.11 Mon 15:00 P4

Influence of strong correlations on impurity-induced TRSB in a (s+id)-wave superconductor — •Marius Paul and Götz Seibold — BTU Cottbus

In numerical simulations of the extended Hubbard model with nearest-neighbor attraction, which is an actively investigated model for high-Tc-superconductors, there has been made observations of time reversal symmetry breaking in the form of loop currents in the last few years [1,2]. Those loop currents emerge mainly in the vicinity of an $s + id$-state when nonmagnetic disorder is present in the superconductor. While previous work has focused on the investigation of this phenomenon within the Bogoljubov-de Gennes approximation, we will discuss here the influence electronic correlations on the stability of the loop currents. This is accomplished via the time-dependent Gutzwiller approximation extended towards the inclusion of pairing correlations.
[1] Z.-X.Li, S. Kivelson, D.-H.Lee, npj Quantum Mater. 6, 12 (2021).
[2] C.N.Breiø, P.J.Hirschfeld, B.M.Andersen, PRB 105, 014504 (2022).

TT 11.12 Mon 15:00 P4

Constraints on the theoretical modeling of hole-doped La_2CuO_4 — •Qiwei Li, Xuejing Zhang, and Eva Pavarini — Peter Grünberg Institute-2, Forschungszentrum Jülich, Jülich, Germany

The low-energy electronic properties of hole-doped La_2CuO_4 are believed to be well captured by the single-band Hubbard model describing x^2-y^2 electrons. This finds support, e.g., on Fermi surface and angle resolved photoemission experiments. Here we show that this imposes constraints on the microscopic description of the system.

TT 11.13 Mon 15:00 P4

Nonlinear THz-spectroscopy of $PdCoO_2$ and LBCO: Probing c-axis dynamics and collective excitations — •Shuhan Wang[1], Tim Priessnitz[2], Min-Jae Kim[1,2], Liwen Feng[1,2], Gideok Kim[2], Bernhard Keimer[2], and Stefan Kaiser[1,2] — [1]TUD Dresden University of Technology, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany

Layered quantum materials offer a unique platform for studying anisotropic transport and collective excitations. Using THz-High-Harmonics Generation, we investigate the c-axis responses of $PdCoO_2$ and $La_{2-x}Ba_x$ CuO_4 (LBCO) grown on offcut substrates. $PdCoO_2$ shows exceptionally large THz second harmonic and third harmonic generation [1] while LBCO shows distinct features linked the superconducting Higgs response and the Josephson plasma resonance. We will discuss the features referenced to the linear response of these systems measures with THz time domain spectroscopy.
[1] T. Priessnitz et al., arXiv:2409.07872

TT 11.14 Mon 15:00 P4

Higgs collective mode in superconductors: in- and out-of equilibrium — •Sida Tian[1], Rafael Haenel[1,2], and Dirk Manske[1] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart — [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. We present a theory of non-equilibrium response based on Keldysh formalism, and introduce a recent developed experimental technique of Non-equilibrium Antistokes Raman Scattering. We further comment on the influence of higher-order fluctuations to collective modes, which will change the collective mode mass. This implies that in circumstances where quantum corrections become relevant such as strong coupling, the Higgs mode will move inside the pair breaking gap.

TT 11.15 Mon 15:00 P4

Nematic susceptibility in heavily hole-doped iron based superconductors — •Franz Eckelt[1], Xiaochen Hong[2], Vilmos Kocsis[3], Vadim Grinenko[4], Bernd Büchner[2], Christian Hess[1], Chul-Ho Lee[5], and Kunihiro Kihou[5] — [1]Bergische Universität Wuppertal, 42097 Wuppertal, Germany — [2]College of Physics and Center of Quantum Materials and Devices, Chongqing University, 401331 Chongqing, China — [3]Leibnitz-Institut for Solide State and Materials Research, 01069 Dresden, Germansy — [4]Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai 201210, China — [5]National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki, 305-8568, Japan

We investigate the elastoresistivity of 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 the amplitude of which possesses a strong non-montonic doping dependence. We discuss our results in terms of nematic fluctuations, Fermi surface effects near a Lifshitz transition, and a potential orbital-selective Mott transition.

TT 11.16 Mon 15:00 P4

The Search for 1144 Phases under Pressure — •Leonard Essich, Kristin Kliemt, and Cornelius Krellner — Institute of Physics, Goethe University Frankfurt, Germany

Alternative stacking of 122 Fe-based pnictides has enabled the synthesis of the 1144 phase $AB\mathrm{Fe_4As_4}$ (A = alkali, B = alkaline earth). Examples include $CaKFe_4As_4$, where a *half-collapsed* tetragonal phase emerges under pressure, and $EuRbFe_4As_4$ or $EuCsFe_4As_4$, where Eu magnetism coexists with superconductivity [1,2]. Theoretical studies predict the stability of further 1144 Fe-arsenides and an extension to phosphides ($AB\mathrm{(TM)_4P_4}$ where TM = Fe, Ru, Co, or Ni). Notably, $CaKRu_4P_4$ has been successfully synthesised [1]. This work investigates the synthesis of other 1144 phases under high-pressure conditions, designed to support the incorporation of smaller phosphorus atoms on arsenic lattice positions. Multi-anvil presses offer precise pressure and temperature control, large sample sizes, and adaptable setups for crystal growth research. In this contribution, we present the capabilities of a multi-anvil press, the challenges encountered during sample preparation, and outline the pathway to synthesising 1144 phases. A Walker-type module, previously utilized in our laboratory, contains a 6-8 anvil configuration within a steel cylinder [3]. The choice of pressure-transmitting medium and internal configuration is crucial to achieving the desired outcome in these experiments.
[1] B. Q. Song *et al.*, Phys. Rev. Materials **5**, 094802 (2021)
[2] U. S. Kaluarachchi *et al.*, Phys. Rev. B **96**, 140501 (2017)
[3] A. A. Haghighirad *et al.*, Cryst. Growth Des. **8**, 1961 (2008)

TT 11.17 Mon 15:00 P4

Two-Gap Superconductivity in the Noncentrosymmetric La_3Se_4 — f košuth[1,2], n potomová[2], z pribulová[1], j kacmarcík[1], •m naskar[3], d s inosov[3], s ash[4], a k ganguli[5], j soltýs[6], v cambel[6], p szabó[1], and p samuely[1] — [1]Centre of Low Temperature Physics, Institute of Experimental Physics, Slovak Academy of Sciences, SK04001 Košice, Slovakia — [2]Centre of Low Temperature Physics, Faculty of Science, P. J. Šafárik University, SK-04001 Košice, Slovakia — [3]Institut für Festkörper und Materialphysik, Technische Universität Dresden, D-01069 Dresden, Germany — [4]Institute for Solid State Research, Leibniz IFW Dresden, D-01069 Dresden, Germany — [5]Department of Chemistry, Indian Institute of Technology Delhi, New Delhi 110016, India — [6]Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava SK84104, Slovakia

Point-contact Andreev reflection spectroscopy at low temperatures and high magnetic field has been carried out on the noncentrosymmetric superconductor La_3Se_4 (T_c = 8 K). Two superconducting energy gaps Δ_1 and Δ_2, with $2\Delta_1/k_BT_c = 5.8$ and $2\Delta_2/k_BT_c = 2.3$, are directly observed in certain spectra. The effects of temperature and magnetic fields help to distinguish a two-gap structure, even in the more common spectra where only a single gap is visible at low temperatures, indicated by a pair of maxima around zero bias. The presence of two-gap superconductivity, consistent with the results from point-contact Andreev reflection spectroscopy, is further confirmed by heat capacity and Hall probe magnetization measurements.

TT 11.18 Mon 15:00 P4

Positive Evidence for Bogoliubov-Fermi Surfaces in Al/InAs Hybrids — •Simon Feyrer[1], Ignacio Lobato[1], Vjeko Dimic[1], Michael Prager[1], Dominique Bougeard[1], Matthias Kronseder[1], Giorgio Biasiol[4], Carlos Balseiro[2], Liliana Arrachea[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: Physic des Solides, Université Paris-Saclay, France — [4]IOM CNR, Laboratorio TASC, Area Science Park Basovizza, Trieste, Italy

We present measurements 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 a change of behavior as the magnetic field becomes larger than B*, consistent with a contribution of the superconducting 2DEG in the InAs affected by the spin-orbit coupling [1]. Using resonators with different geometries we discuss the correlation between the observed anisotropy and the crystal orientation.

[1] D. Phan et al., Phys. Rev. Lett. 128, 107701 (2022).

TT 11.19 Mon 15:00 P4

Proximity induced superconductivity in non-collinear antiferromagnets (NCAFMs) — •Anshuman Padhi[1], Prajwal Rigvedi Madhusudan Rao[1], Ajin Joy[2], Ajesh K Gopi[1], Jiho Yoon[1], Jae-Chun Jeon[1], Banabir Pal[1], and Stuart S. P. Parkin[1] — [1]Max Planck Institute of Microstructure Physics, 06120, Halle (Saale), Germany — [2]Indian Institute of Science, 560012, Bengaluru, India

Conversion of spin-singlet Cooper pairs to spin-polarised triplet Cooper pairs has been a significant achievement of proximity induced superconducting hybrids. But they often require multilayed stack of mismatched magnetisation interfacing the superconducting condensate, leading to lower tunability, less flexibility on the choice of materials and lesser densities of converted triplet Cooper pairs. Recently, usage of non-collinear antiferromagents have been shown to host long-ranged supercurrents and owing to their atomic distribution of spins in a Kagome lattice are a prime candidate for triplet superconductivity. In this study we aim to fundamentally understand the proximity effect into two-phases of a Mn-based antiperovskite, by analysing the field-dependence of the critical temperature of the superconducting thin-film interfacing them. The unique spin-texture of such materials, with broken inversion symmetry and the presence of uncompensated moments too, can lead to interesting physics w.r.t. the Andreev levels. Thus we fabricate S/I/NCAFM tunneling devices and perform electrical tunneling measurements to study the probable Andreev levels and the impact of the spin-states on them. This exploratory work aims at a deeper level of understanding of Cooper pair interactions in NCAFMs.

TT 11.20 Mon 15:00 P4

Interaction of supercurrents in multiterminal graphene Josephson junctions — •Paul Maier, Romain Danneau, and Detlef Beckmann — Institut für Quantenmaterialien und Technologien, Karlsruher Institut für Technologie

Topological states are predicted to exist in the Andreev bound state spectrum of multiterminal Josephson junction with four or more terminals [1]. Superconductor graphene hybrid structures are especially suitable to realize such devices due to the gate tunability of graphene and the low contact resistance necessary to form Andreev bound states. Understanding the distribution of supercurrent in graphene multiterminal Josephson junctions is one step in the search for these states. We report on the experimental investigation of transport in a four-terminal graphene Josephson junction. We observe magnetic interference patterns in two-terminal measurements and critical current contours in multiterminal measurements, and compare the results to theoretical simulations.

[1] R.-P. Riwar et al., Nat. Commun. 7, 11167 (2016).

TT 11.21 Mon 15:00 P4

Control of Andreev Reflection via a Single-Molecule Orbital — •Lorenz Meyer[1], Jose L. Lado[2], Nicolas Néel[1], and Jörg Kröger[1] — [1]Institut für Physik, Technische Universität Ilmenau, D-98693 Ilmenau, Germany — [2]Department of Applied Physics, Aalto University, 02150 Espoo, Finland

Charge transport across a single-molecule junction fabricated from a normal-metal tip, a phthalocyanine, and a conventional superconductor in a scanning tunneling microscope is explored as a function of the gradually closed vacuum gap. The phthalocyanine (2H-Pc) molecule and its pyrrolic-hydrogen-abstracted derivative (Pc) exhibit vastly different behavior. Andreev reflection across the 2H-Pc contact exhibits a temporary enhancement that diminishes with increasing conductance. The hybridization of 2H-Pc with the tip at contact formation gives rise to a molecular magnetic moment that is Kondo-screened in the tip. In contrast, the single-Pc junction lacks Andreev reflection in the same conductance range. Spectroscopy experiments and supporting nonequilibrium Green function calculations highlight the importance of a molecular orbital close to the Fermi energy for rationalizing the observations.

Funding by the DFG through KR 2912/18-1 and KR 2912/21-1 is acknowledged.

TT 11.22 Mon 15:00 P4

Real-space mapping of Yu-Shiba-Rusinov states around magnetic defects on superconducting surfaces — •Raffaele Aliberti[1,2], Samir Lounis[1,4], Philipp Rüssmann[1,3], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [2]RWTH Aachen, Aachen, Germany — [3]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany — [4]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

Interfacing magnetic impurities with superconductors generally gives rise to Yu-Shiba-Rusinov (YSR) bound states. Using first-principles, we study the case of Mn impurities deposited on a superconducting Ta (110) surface. We explore both the orbital nature and amplitude of the induced YSR states while investigating their spatial extent, which is characterized by an oscillatory and anisotropic behavior as function of distance with respect to the Mn impurities.In particular, we study the interplay of intrinsic electronic structure properties of the hosting superconductor and that of the impurities, which impacts the resulting "cloud" of YSR states.

We employ the Kohn-Sham Bogoliubov-de Gennes method within the all-electron full-potential relativistic Korringa-Kohn-Rostoker Green function method [1] interfaced with the AiiDA infrastructure for high-throughput automation [2].

TT 11.23 Mon 15:00 P4

Stochastic resonance realized with a superconducting magnetic impurity state — •Philipp Maier[1], Björn Kubala[1,2], Joachim Ankerhold[1], and Ciprian Padurariu[1] — [1]Institute for Complex Quantum Systems and IQST, Ulm University — [2]German Aerospace Center (DLR), Ulm

The phenomenon of stochastic resonance was originally studied in the context of climatic changes and has since been observed in a variety of systems, both classical and quantum. Here, we employ this phenomenon to infer the rates of tunneling processes in the course of quantum electronic transport [1,2]. We theoretically investigate the emergence of stochastic resonance in superconducting junctions, focusing on a system where one electrode hosts a Yu-Shiba-Rusinov state – a discrete bound state within the superconducting gap induced by the magnetic exchange interaction between a magnetic impurity and its superconducting host. Applying the framework of full counting statistics, we demonstrate that stochastic resonance manifests as the reduction of the Fano factor and a resonance of the tunneling current. The frequency of the resonance reveals information about the rate of microscopic electronic processes, e.g. the process responsible for quasiparticle-occupation parity breaking.

[1] M. Hänze et al., Sci. Adv. 7 (2021)
[2] T. Wagner et al., Nat. Phys. 15 (2019)

TT 11.24 Mon 15:00 P4

Dynamical simulations of single photon detection in superconducting nanowires — •Carlos Alberto Diaz Lopez[1], Joachim Ankerhold[1], Björn Kubala[1,2], and Ciprian Padurariu[1] — [1]Institute of Complex Quantum Systems, University of Ulm, Ulm, Germany — [2]German Aerospace Center (DLR), Ulm, Germany

We use a Python simulation package py-TDGL [1] based on modified Ginzburg-Landau theory [2] to simulate the dynamics of the superconducting condensate in a thin nanowire during the detection of a single-photon. The detection event is modeled phenomenologically as a hot-spot formation: the photon is modeled as an initially localized increase in the electronic temperature, with a Gaussian spatial profile that diffuses outwards while also dissipating in time. Our simulations successfully reproduce the characteristic time-dependent voltage peaks measured in superconducting nanowire single-photon detectors, while providing an accompanying movie-like dynamics of the superconducting order parameter. We propose a method to enhance the prominence of the voltage peaks by optimizing the applied DC current and the intensity of an externally-applied perpendicular magnetic field, with the goal of enabling the detection of single-photons in a broader frequency spectrum.

[1] L.Bishop-Van Horn, Comput.Phys.Commun**291**, 108799 (2023).
[2] L. Kramer, R. J. Watts-Tobin, Phys. Rev. Lett. **40**, 1041 (1978).

TT 11.25 Mon 15:00 P4

Simulations of heating effects in dual Shapiro step circuits — •Matthias Meiring, Fabian Kaap, Sergey Lotkhov, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

So-called dual Shapiro steps are quantised current steps separated by $2ef$, with e the elementary charge and f the rf drive frequency. They have recently gained renewed interest due to successful experimental demonstrations [1,2,3]. These dual Shapiro steps could bear the potential for a novel quantum current standard. Our measurements of dual Shapiro steps in an $Al/AlO_x/Al$ dc-SQUID connected to a circuit made of high-kinetic-inductance granular aluminium and high-ohmic oxidised titanium revealed an electron temperature, which is substantially higher compared to the case without rf drive. We evaluate thermal heating phenomena in the measured chip layout and present adapted circuit designs, which should reduce heating effects and enhance the step size. Achieving this will lead to more prominent dual Shapiro steps and could thus pave the way to a new quantum current standard based on superconducting circuits.

[1] R.S.Shaikhaidarov et al., Nature 608 (2022).
[2] N. Crescini et al., Nat. Phys. 19 (2023).
[3] F. Kaap et al., Nat. Commun. 15 (2024).

TT 11.26 Mon 15:00 P4

Broadband kinetic inductance of high impedance superconductors — •Jan Pusskeiler[1], Martin Dressel[1], Thomas Valentin[2], Ameya Nambisan[2], Simon Geisert[2], Ioan Pop[1,2], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Physikalisches Institut and IQMT, KIT

Kinetic inductance quantifies the intrinsic phase-shifted electrodynamics of superconductors and lies at the heart of superconducting quantum electronics operating at microwave frequencies. Determining the complex impedance Z of disordered and granular superconductors in a frequency range from 10 kHz to 20 GHz using a broadband Corbino reflectometer allows direct observation of the kinetic inductance as a linear contribution to the reactance, $\mathrm{Im}(Z) = L_{\mathrm{kin}} \cdot \omega$. By obtaining the broadband kinetic inductance at temperatures deep in the superconducting state, from 1.15 K up to the critical temperature T_c, we can extrapolate the zero-temperature kinetic inductance.

We study granular aluminum as a high-kinetic inductance superconductor featuring a superconducting dome in the low-temperature phase diagram as a function of normal-state resistivity ρ_{dc}. We report kinetic inductances ranging from 20 pH/sq to 2 nH/sq for granular aluminum thin films with resistivities between 120 $\mu\Omega$cm and 6100 $\mu\Omega$cm. We calculate the superfluid stiffness and observe a $1/\rho_{dc}$ dependance, as also reported in [1]. Furthermore, we observe absorption features that we interpret as signatures of collective modes of the superfluid condensate.

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

TT 11.27 Mon 15:00 P4

Characterization of photoresists for deep UV 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]Kirchhoff Institute for Physics, Heidelberg University — [2]Heidelberg Instruments Mikrotechnik GmbH

Photoresists are integral to the precise pattern transfer processes required for fabricating micro- and nanoscale devices. The structuring of photoresists with optical maskless lithography systems has proven to be extremely versatile and efficient in research and development. Within the framework of the SuperLSI project, Heidelberg Instruments is developing a maskless lithographic platform incorporating a 266 nm Deep UV optical system, designed to achieve patterning resolutions as fine as 200 nm. Identification and thorough characterization of photoresists compatible with the lithographic platform is required. We focus on the performance of a positive (DuPont UV5-0.6) and negative (micro resist technology ma-N 2405) photoresist for the fabrication of superconducting sub-500 nm features. Structural fidelity, etch resistance, and developer compatibility with superconducting materials, such as niobium and aluminum, are evaluated. Achieving reduced linewidths advances quantum sensors like SQUIDs by enabling smaller Josephson junctions (JJs). Initial results for cross-type JJs with areas below 1 μm^2 highlight the potential of optical maskless lithography for flexible wafer-scale fabrication of superconducting devices.

TT 11.28 Mon 15:00 P4

Chemical-mechanical polishing process for the fabrication of cross-type Nb/Al-AlOx/Nb Josephson tunnel junctions — •A. Stoll, N. Fiedler, L. Münch, D. Hengstler, A. Reifenberger, A. Fleischmann, and C. Enss — KIP, Heidelberg University

Josephson tunnel junctions (JJs) are the basic elements of many superconducting electronic devices such as qubits or superconducting quantum interference devices (SQUIDs). Since many applications demand numerous JJs, a reliable wafer-scale fabrication process yielding reproducible, high-quality junctions is essential.
We present the microfabrication process of cross-type Nb/Al-AlOx/Nb Josephson tunnel junctions, emphasizing chemical-mechanical polishing (CMP) for planarization within SiO_2. A layer of SiO_2 is deposited over the structured trilayer, and CMP is used to polish away excess SiO_2, resulting in a planar, smooth, and uniform surface that enhances the accuracy and reliability of the junctions. Quality checks were conducted on junctions of various sizes, as well as the influence of support-like structures around junctions, to evaluate performance and scalability. Electrical characterizations demonstrate high-quality superconducting properties, validating the efficacy of CMP in the planarization of Josephson junction trilayers
This method enhances the scalability and integration of Josephson junctions in complex superconducting circuits, contributing to advancements in quantum computing and superconducting electronics.

TT 11.29 Mon 15:00 P4

High-quality niobium Josephson junctions for superconducting mm-wave qubits — •Urs Strobel[1], Benedict Rothmund[1], Lucas Radke[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Institut for Quantum Materials and Technologies (IQMT), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany

Millimeter-wave quantum circuits require a superconductor with an energy gap above 100 GHz , which exceeds the energy gap of the widely used aluminum. Niobium offers much more suitable properties in this frequency range. Implemented in thin film technology on low loss substrates, high quality niobium Josephson junctions should complement the capacitors and inductors required for quantum circuits. We have developed $Nb/Al\text{-}AlO_x/Nb$ trilayer Josephson junctions suitable for quantum circuits and characterized them at cryogenic temperatures. We present dc and mm-wave measurement data obtained with these junctions. In addition, we discuss design considerations for prospective mm-wave transmon qubits.

TT 11.30 Mon 15:00 P4

Building a Quantum Wheatstone Bridge — •Thilo Krumrey[1], Alex Kreuzer[1], Hossam Tohamy[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]IQMT, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany

Today's qubits, while still quite noisy, are sufficiently coherent for non-computing applications. We are exploring the possibility of using an arrangement of superconducting qubits to study the quantum version of the Wheatstone resistance bridge[1]. It would allow for comparative measurements of coupling energies using the interference of an excitation gradient across strongly coupled qubits. We propose an implementation of a quantum Wheatstone bridge using superconducting quantum circuits with quarton flux qubits. Here, the large positive anharmonicity and the tunability [2] of the operating frequency are beneficial for our application. We will present circuit simulations results based on the proposed design and compare them with measurements of the circuit at mK temperatures.

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

TT 11.31 Mon 15:00 P4

Charge Sensitivity of a Quantum Phase Slip Transistor — •Marius Frohn[1], Jan Nicolas Voss[1], Hannes Rotzinger[1,2], and Alexey Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Institut für Quantenmaterialien und Technologien (IQMT), Karlrsruher Institut für Technologie, Karlsruhe, Germany

Superconducting quantum phase slip (QPS) devices are high-impedance circuits that are promising for quantum sensing applications or the realisation of a current standard. For example, the QPS transistor is a dual circuit to the SQUID and is therefore sensitive to charge rather than flux. We study QPS transistors fabricated from two strongly coupled granular aluminium nanowires. This allows us to use intrinsic electromigration[1] to fine-tune the Coulomb blockade voltage in situ. The current-voltage characteristics at different gate biases and wire resistances provide insight into the charge sensitivity and operating range of the QPS transistor. We present the results of experiments on superconducting nanowire circuits at mK temperatures.

[1] J. N. Voss, Y. Schön, M. Wildermuth, D. Dorer, J. H. Cole, H. Rotzinger and A. V. Ustinov, ACS Nano **15** (2021)

TT 11.32 Mon 15:00 P4

Characterization of Nb Air Bridges for Superconducting Quantum Computing — •Amanda Scoles[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Ivan Tsitsilin[1,2], David Bunch[1,2], Julius Feigl[1,2], Lea Richard[1,2], Vera Bader[1,2], Lasse Södergren[1,2], Christian Schneider[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

Superconducting qubits are a promising platform for the realization of practical quantum computing. The short gate times, comparatively long lifetimes, and relatively straightforward fabrication process, when compared to other systems, indicate an encouraging future for superconducting quantum circuits. Nevertheless, further optimization of both the fabrication and calibration processes is necessary to fully realize the potential of this platform. In particular, there is a need to enhance qubit coherence, reliability and scalability, which are the current main limitations of this technology.

In this work we investigate Nb air bridges, which provide flexibility in routing of control lines and facilitate the scaling of qubit numbers in planar geometries. We investigate the optimal fabrication parameters in order to maximize the yield of such structures. Additionally, we assess the quality factors of superconducting resonators in the vicinity of air bridges as well as daisy chains of air bridges, to determine the additional loss induced by the air bridge process.

TT 11.33 Mon 15:00 P4

Chiral High-Fidelity State Transfer with Thouless Pumping in Superconducting Circuits — •Lukas Vetter[1,2], Federico Roy[1,2], Jacquelin Luneau[1,2], João H Romeiro[1,2], Max Werninghaus[1,2], Christian MF Schneider[1,2], Peter Rabl[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Scienes, Department of Physics — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften

Efficient and robust techniques for state transfer and entanglement generation are vital for the progress of quantum technologies. Thouless pumping enables the topologically protected chiral transfer of excitations in quantum systems, however, dispersion during the protocol leads to losses in transfer fidelity. Here, we introduce a protocol for high-fidelity state transfer based on Thouless Pumping with Bloch Oscillations to suppress dispersion. Our protocol enables the transfer of single and multi-excitation Fock states and Bell states with high fidelity while being robust against perturbations of the Hamiltonian. We describe the effect of Bloch Oscillations using semi-classical equations of motion and show that changing the pumping cycle enables the generation of distant Bell pairs. We experimentally implement our results on a superconducting qubit device by realizing the pumping on a tunable coupler architecture. Our work paves the way for using Thouless pumping in quantum information processing, with applications in topologically robust entanglement generation and multi-qubit gates.

We acknowledge financial support from GeQCoS, MUNIQC-SC, MCQST, OpenSuperQPlus100, and the Munich Quantum Valley.

TT 11.34 Mon 15:00 P4

Vacuum Correlations in Superconducting Quantum Circuits — •Gesa Dünnweber[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

When the quantum vacuum is subjected to time-varying boundary conditions, its inherent fluctuations can be parametrically amplified to create photonic excitations. This phenomenon, known as the dynamical Casimir effect, has been experimentally realized in superconducting quantum devices. Building on these results, we theoretically investigate the correlations induced in such circuits by quantum vacuum interactions. In particular, we analyze a system featuring controlled time-dependence across multiple components and consider potential technological applications.

TT 11.35 Mon 15:00 P4

Gate tunable superconductivity in Al/STO hybrid structures — •Jay Schmidt, Simon Reinhardt, Matthias Kronseder, Nicola Paradiso, and Christoph Strunk — Deptartment of Exp. and Appl. Physics, University of Regensburg, Germany

We present a systematic study on the gate-tunable superconducting properties of Al thin films epitaxially deposited on STO substrates. As a quantum paraelectric, STO exhibits an exceptionally high $\varepsilon \approx 7000$, enabling substantial charge modulation at the Al/STO interface. Metal deposition on STO induces oxygen vacancy formation within the substrate, contributing double electron donors that create an interface 2DEG. Based on measurements of the Hall-effect we extract charge carrier densities in the Al/STO system that are comparable to those in pristine Al films and significantly surpass those observed in LAO/STO 2DEGs. This finding indicates that charge transport is predominantly mediated by Al carriers. $T_C(n)$ and $B_C(T,n)$ exhibit strong tunability under an applied gate voltage with variations up to 15% and 50%, respectively. Notably, the observed T_C values ($\approx$ 0.92 - 1.06 K) are lower than those of pristine Al thin films ($\approx$ 1.4 K) but exceed those of STO, suggesting a bilayer system of superconductors with distinct gap energies coupled through proximity effects. We further investigate the superfluid stiffness, which turns out to be also highly gate-tunable with variations up to 15%. These results underline the potential of Al/STO heterostructures as a versatile platform for studying tunable superconducting phenomena.

TT 11.36 Mon 15:00 P4

Design of a Gate Tunable $\lambda/4$ Josephson Parametric Amplifier in an Al/InAs Hybrid Superconductor/Semiconductor Heterostructure — •Vjeko Dimić[1], Simon Feyrer[1], Alexander Kirchner[1], Giorgio Biasiol[2], Christoph Strunk[1], and Leandro Tosi[1,3] — [1]Institute of Experimental and Applied Physics, University of Regensburg, Germany — [2]CNR-Istituto Officina dei Materiali Laboratorio TASC, Italy — [3]Centro Atomico Bariloche, Comision Nacional de Energia Atomica, Argentina

We present the design of a Josephson parametric amplifier based on a distributed $\lambda/4$ microwave resonator fabricated on a hybrid Al/InAs heterostructure. The 2DEG hosted in the InAs is used to tailor SNS junctions which terminate the resonator and can be tuned using an electrostatic gate deposited on top [1]. We characterize the microwave response of $\lambda/4$ resonators, the losses and the tunability of the resonance frequency resulting from the gate modulation of the Josephson inductance. We show how amplification can be obtained by pumping the gate electrode at twice the resonance frequency.

[1] W. Strickland et al., Phys. Rev. Appl. 19, 034021 (2023).

TT 11.37 Mon 15:00 P4

Design of granular aluminum based kinetic inductance traveling wave parametric amplifiers — Daniel Valenzuela, Christoph Kissling, •Victor Gaydamachenko, Fabian Kaap, Sergey Lotkhov, and Lukas Grünhaupt — Physikalisch-Technische Bundensanstalt, Bundesallee 100, 38116 Braunschweig

Superconducting traveling wave parametric amplifiers (TWPA) are a key ingredient in readout chains, which benefit greatly from lowest possible added noise and several GHz of bandwidth. In the case of kinetic inductance based TWPAs (KI-TWPA), the non-linear kinetic inductance of disordered superconducting thin films is used to enable three- and four-wave mixing processes for signal amplification. A key challenge for the design of KI-TWPAs is to ensure an impedance of 50 Ohm. In addition, unwanted frequency conversion processes have to be phase mismatched, while those generating amplification need to be retained. We tackle both challenges using so-called artificial coplanar waveguides with a multiperiodic capacitance variation. Here, we discuss the design of granular aluminum (grAl) KI-TWPA, our fabrication and process, and show initial experimental results.

TT 11.38 Mon 15:00 P4

Advanced Josephson travelling wave parametric amplifyer analysis with non-linear circuit simulations — •Lars Aaron Anhalt[1,2,3], Daniil Bazulin[1,2], Gleb Krylov[1,2], Yongjie Yuan[4], Diego Contreras[1,2,3], Christian Gnandt[1,2,3], Michael Haider[4], Kirill Fedorov[1,2,5], and Stefan Filipp[1,2,5] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching — [2]School of Natural Sciences, Technical University of Munich, 85748 Garching — [3]Ludwig-Maximilians-Universität in Munich, 80539 Munich — [4]TUM School of Computation, Information and Technology, Technical University of Munich, 85748 Garching — [5]Munich Center for Quantum Science and Technology, 80799 Munich

Broadband, quantum-limited microwave amplifiers are crucial for efficient and fast readout, which enables scaling of superconducting quantum processors. Josephson travelling wave parametric amplifiers (JTWPAs) are the most common solution in the field, providing amplification via copropagation of a pump tone with a signal in a nonlinear medium composed of Josephson junctions. Unwanted conversion processes, as well as stringent requirements on the fabrication processes, still pose challenges to their successful implementation. Here, we demonstrate how circuit simulation with WRSpice can help with the interpretation of experimental measurements of particular JTWPA designs and facilitate further improvements. Our simulations prove to be applicable to a wide range of circuit designs and varying parameters, reproducing competing conversion processes that go beyond analytical results from commonly used coupled mode equations.

TT 11.39 Mon 15:00 P4

Observing measurement-induced transitions in a transmon qudit — •Philippe Gigon[1,2], Zihao Wang[3], Benjamin D'Anjou[1], Alexandre Blais[1], and Machiel Blok[3] — [1]Université de Sherbrooke — [2]Walther-Meißner-Institut — [3]University of Rochester

Numerous experiments have shown that high-power dispersive transmon readout can lead to unexpected state transitions. Significant theoretical efforts have been made to describe these transitions using a simplified model, avoiding the need to account for the full Lindbladian dynamics of the coupled resonator-transmon system [1,2,3,4]. In this study, we employ a semi-classical effective drive model combined with Floquet theory and compare its predictions with experimental results from a transmon qudit. The high controllability and the readout capabilities of the qudit make it the perfect tool to study measurement-induced transitions. Our findings reveal that the semi-classical model accurately predicts critical photon numbers, identifies the states involved in the transitions, and quantifies the affected population.

[1] D. Sank et al., Phys. Rev. Lett. 117, 190503 (2016).
[2] M. Khezri et al., Phys. Rev. Appl. 20, 054008 (2023).
[3] R. Shillito et al., Phys. Rev. Appl. 18, 034031 (2022).
[4] M. F. Dumas et al., Phys. Rev. X 14, 041023 (2024).

TT 11.40 Mon 15:00 P4

Collective behavior of qubits coupled to a common waveguide — •Johannes Friedrich[1,2], Gerhard Huber[1,2], Joan Agustí[1,2], Gesa Dünnweber[1,2], Christian Schneider[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften

The behavior of multiple qubits coupled to a common waveguide cannot be understood as the additive behavior of single qubits. Since the waveguide can mediate an all-to-all interaction between qubits via propagating photons, collective radiant states, such as superradiant, subradiant, and twilight states, can be formed [1,2]. Using superconducting qubits offers control over multiple system parameters such as individual qubit frequency, coupling and spacing and enables the realization of 1D waveguides with large coupling to decoherence ratios, parameters difficult to achieve in atomic systems. Here, we explore parameter regimes beyond time and spatial uniform couplings, providing insights into designing quantum devices with controllable radiative properties.

We acknowledge financial support from GeQCoS, MUNIQC-SC, MCQST, OpenSuperQPlus100, the Munich Quantum Valley and the Deutsche Forschungsgemeinschaft.

[1] Y. Ke, et al., Phys. Rev. Lett. 123, 253601 (2019).
[2] B. Kannan et al., Nature 583 (2020).

TT 11.41 Mon 15:00 P4

Design of fluxonium qubits inductively coupled to granular aluminum based readout resonators — •Li-Wei Chang, Asen Georgiev, Fabian Kaap, Sergey Lotkhov, Mark Bieler, and Lukas Gruenhaupt — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The fluxonium qubit is a specific type of superconducting qubit, which has garnered significant interest due to its coherence time in the millisecond range, high gate fidelities on the order of 99.9%, and a large anharmonicity up to several GHz. Recent years have also seen a surge in material studies related to this type of qubit, with a particular focus on high kinetic inductance materials such as granular aluminum (grAl). Three basic components form a fluxonium qubit: a Josephson junction, a capacitor, and a so-called superinductor with an impedance larger than the resistance quantum $R_Q = \hbar/4e^2$. We discuss our circuit parameters chosen via numerical simulations to implement a fluxonium with a transition frequency of 0.6 GHz $\sim$ 12 GHz depending on the external magnetic field. To enable dispersive readout, we employ a granular aluminum based readout resonator. This configuration not only provides substantial inductance but also allows inductive coupling to the qubit. We present our methodology to design the circuit parameters, including the dispersive shift, quality factor, and T1 Purcell decay

TT 11.42 Mon 15:00 P4

Understanding loss channels in fluxonium qubits through high-impedance LC resonators — •Matthias Zetzl[1,2,3], Johannes Schirk[1,2,3], Florian Wallner[1,2,3], Ivan Tsitsilin[1,2,3], Niklas Bruckmoser[1,2,3], Christian Schneider[1,2,3], and Stefan Filipp[1,2,3] — [1]Walther-Meißner-Institut, Garching, Germany — [2]Technische Universität München, Munich, Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

Current quantum systems based on superconducting qubits are limited by their rate of information loss. Therefore, identifying and mitigating the sources of decoherence of individual qubits is key to improve the performance of these systems. Here, we investigate loss mechanisms in Josephson junction arrays, which are commonly used to implement protected qubits such as "fluxonium" or "zero-pi" qubits. To probe these loss channels, we characterize high-impedance lumped-element LC resonators, comprised of two charge islands connected by a Josephson junction array. While this architecture closely resembles that of "fluxonium" qubits, it allows for a more straightforward characterization by direct transmission measurements of the resonators. By extracting the internal quality factor of the resonators, we can assess the fabrication quality of the junctions in a fast and efficient way, providing a useful tool for all junction based components.

TT 11.43 Mon 15:00 P4

dc-SQUIDs with distributed lossy lines to damp LC resonances — •Nicolas Kahne, Anna Ferring-Siebert, Daniel Hengstler, Fabian Krämer, David Mazibrada, Lukas Münch, Alexander Stoll, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, 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 for single dc-SQUIDs and two-stage dc-SQUID setups, 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 11.44 Mon 15:00 P4

Mapping Locations of Two Level Defects in Superconducting Quantum Circuits — •David Mazibrada[1], Johannes Schwenk[1], Jürgen Lisenfeld[1], Hannes Rotzinger[1,2], Philip Willke[1], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, 76131 Karlsruhe, Germany — [2]Institut for Quantum Materials and Technologies, 76131 Karlsruhe, Germany

The development of superconducting quantum circuits has drawn attention to the study of microscopic two-level systems (TLS), as they are a source of decoherence and instability of qubits. Individual TLS can be manipulated using microwave signals, but their specific locations in quantum circuits remain largely unclear. We intend to manipulate the TLS using the electric field of an atomic force microscope tip [1]. This approach should allow us to gain insights into the microscopic nature of the TLS. We will present the assembled atomic force microscope setup and show characterisation data of quantum circuits measured at millikelvin temperatures.

[1] M. Hegedüs, et al., arXiv:2408.16660v1 (2024)

TT 11.45 Mon 15:00 P4

Fully tunable C-shunted Flux Qubits for TLS Research — •Benedikt Berlitz[1], Alexey V. Ustinov[1,2], and Jürgen Lisenfeld[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]IQMT, 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 fully tunable, capacitively shunted superconducting flux qubits specifically to be used as TLS detectors, aiming for good coherence in a wide accessible qubit frequency range. The goal is to gather comparable data of many defects located within the same device. We 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 11.46 Mon 15:00 P4

Identification of Noise Sources in Superconducting Microstructures — •Markus Renger, Anton Jarecka, Daniel Hengstler, Matthew Herbst, David Mazibrada, Lukas Münch, Andreas Reifenberger, Christian Ständer, Rui Yang, Andreas Fleischmann, Loredana Gastaldo, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University

Improving the performance of superconducting devices often means identifying and eliminating different noise sources. Many 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 with which we can analyze specific noise sources in a representative manner. This device consists of a Wheatstone-like bridge of four microfabricated superconducting inductors, two of which filled with sample material, and a pair of two-stage dc-SQUID read-out chains. We can use the method of cross-correlation, to derive the total noise contribution of our device, or AC-drive the Wheatstone bridge to measure the complex AC susceptibility of the sample material. Our experiments are performed at temperatures between $T = 20\,\mathrm{mK}$ and $T = 800\,\mathrm{mK}$ in the frequency range from $f = 100\,\mathrm{mHz}$ to $f = 100\,\mathrm{kHz}$. We discuss the design of the experimental holder with excellent thermal coupling and shielding. We present the results of multiple measurements on thin films of SiO_2, Ag:Er, as well as Au:Er and perform a detailed comparison. In addition, we demonstrate our device's ability to probe the dynamics of magnetic moments in the sample material.

TT 11.47 Mon 15:00 P4

Dual Tone Spectroscopy of Atomic Tunneling Systems — •Jan Blickberndt, Anton Jarecka, Moritz Maur, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University

Atomic Tunneling Systems (TSs) are intrinsic to disordered structures and thin films, inevitably impacting microstructured devices by causing noise and decoherence in all kinds of applications ranging from Josephson Junctions to cryogenic detector readout chains. Understanding the dynamics of these random fluctuators is essential to mitigate their deteriorative effects on superconducting quantum devices. To investigate the non-equilibrium dielectric behavior of TSs under electric bias, we developed a novel LC resonator setup based on a Wheatstone bridge design. This configuration features two resonance branches that share a common dielectric host material in their capacitors, thereby probing the exact same ensemble of TSs. By applying an external bias field via a cover electrode, we can modulate the energy states of the TSs, enabling their transition between the two resonance modes which allows us to explore ensemble properties as well as the non-linear dynamics of two-level systems. Our current experiments confirm the functionality of the device. To complement the experimental work, we developed a Monte Carlo simulation framework to validate and extend our findings.

TT 11.48 Mon 15:00 P4

Dynamic Control of Dielectric Loss in Amorphus Solids at Low Temperatures — •Marc Hyps, Christian Ständer, Jan Blickberndt, Andreas Fleischmann, Andreas Reiser, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University

The main influence on the low temperature behaviour of amorphous solids is determined by atomic tunneling systems (TSs). TSs can be described by the phenomenological standard tunneling model (STM). The STM assums the TSs to be broadly distributed in their energy splitting. Experimental investigations of atomic tunneling systems gained recent interest due to their deteriorative effects in superconducting quantum devices, such as increased noise and decoherence.
We use newly designed and microfabricated superconducting LC-resonator to study the dielectric rf-response of an amorphous sample in the presence of an electric bias field. The bias field is applied via an electrode placed above the resonator chip wich modifies the energy splitting of the TSs. With this setup we are able to prove the non-equillibrium Landau-Zener dynamics with two different measurement protocols. Aditionally we apply two symetrically detuned pump tones. These resulted in an inversion of the population difference between ground and exited state, hence gain. Also an additional loss contribution was found, hinting towards a coupling to nuclear quadrupol moments.

TT 11.49 Mon 15:00 P4

Enhancement of Low Temperature Dielectric Loss through Vibrational Bias — •Jonathan Herbrich, Christian Ständer, Andreas Fleischmann, Andreas Reiser, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University

At low temperatures low energy excitations are present in amourphous solids, due to atomic tunneling systems (TSs), leading to different properties compared to their crystalline counterparts. These TSs can be expressed as two level systems with a flatly distributed energy splitting. These properties are well described by the phenomenological standard tunneling modell (STM). Due to their negative influence like noise and decoherance on superconducting quantum devices, these TSs are a subject of recent investigations.
Lately we investigated the dielectric rf-response of an amourphous sample while slowly varying an electric bias field. A microfabricated superconducting LC-resonator, using the sample as a substrate, was used for these measurements. In recent measurements a mechanical strain field was used instead of the electric one. The field is applied by bending the sample with a piezoelectric actuator. As a result, the energy splitting of the TSs is modified, as these couple to the strain field via the deformation potential. Our measurements can be described in a framework based on Landau-Zener transition, origianally developed for the description of electrically biased resonators.

TT 11.50 Mon 15:00 P4

Superconducting Qubits for Measurements with Infrared Photons — •Jonathan Huschle[1], Markus Griedel[1,2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruhe Institut for Technology (KIT) — [2]Institut for Quanten Materials and Technologies (IQMT), Karlsruhe Institut for Technology (KIT)

In superconductors, the impact of photons with energy higher than the energy gap leads to breaking of Cooper pairs, which increases noise level and introduces additional dissipation at microwave frequencies. The coherence of superconducting qubits is particularly sensitive to this influence and can be used as a detector. In the qBriqs project, we develop a setup and measurement protocol for far-infrared photons and identify the influence of broken Cooper pairs using a modified transmon qubit[1]. Here, the capacitance of the qubit is reduced, resulting in an increased charge noise sensitivity. We present the qubit design and measurements at mK temperatures.

[1] B. G. Christensen *et al.*, Phys. Rev. B 100, 140503 (2019).

TT 11.51 Mon 15:00 P4

Round Robin of the European "Metrology for Superconducting Qubits" (MetSuperQ) Project — •Paul Kugler — KIT, Karlsruhe, Deutschland

Project presentation: The MetSuperQ project addresses the urgent need for metrology support in superconducting circuits, a leading technology for practical quantum computers. The qubit round robin aims to enhance qubit coherence times by studying external influences through round robin measurements at multiple institutes and laboratory settings. This initiative will demonstrate qubit readout and benchmarking, disentangle intrinsic from external sources of decoherence, and raise awareness about the reliability of qubit characterization. By closing the gap in metrology support, this project paves the way for fault-tolerant quantum computers and their scalability.

TT 11.52 Mon 15:00 P4

Quantum Secret Sharing in Multipartite Microwave Networks — •Karolina Weber[1,2], Wun Kwan Yam[1,2], Simon Gandorfer[1,2], Florian Fesquet[1,2], Kedar E. Honasoge[1,2], Maria-Teresa Handschuh[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, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Quantum secret sharing (QSS) is a quantum cryptography scheme that provides an unconditionally secure way to exchange information in multipartite networks. Here, information about a secret quantum state is shared with n receivers, where the original secret state can be reconstructed if and only if a sufficient number of receivers collaborate. The remaining receivers do not acquire enough information for reconstruction, thereby protecting the secret state from losses, noise, or malicious conspiracies. We experimentally implement the QSS protocol with coherent states in a microwave network with $n = 3$ parties using continuous-variable entanglement and analyze the achieved reconstruction fidelities for different scenarios. We observe that the reconstruction fidelity with 2 collaborating parties exceeds the no-cloning limit, thus, proving the unconditional security of the QSS protocol. Finally, we consider an extension of this experiment towards sharing of qubit states and its applications to blind quantum computing.

TT 11.53 Mon 15:00 P4

Simulation of Non-Markovian Waveguide QED Systems with Tensor-Network Techniques — •Ze Xu — Walther-Meißner-Institute

The coupling of atoms or other two-level emitters to the quantized electromagnetic field is typically modeled using a Markovian master equation, which accounts for both dissipative and coherent photon-mediated interactions. However, this description breaks down in extended optical networks or slow-light waveguides, where significant propagation delays lead to strongly retarded, i.e., non-Markovian, interactions between the emitters. This regime of light-matter interactions remains largely unexplored due to the complexity of modeling non-Markovian effects in a fully quantized framework. In this poster, I will discuss the application of tensor-network techniques for simulating non-Markovian waveguide QED systems with strongly driven emitters, focusing specifically on the case of so-called giant atoms under critical coupling conditions.

TT 11.54 Mon 15:00 P4

Evaluating Spin Ensembles Based on Phosphorus Donors for Quantum Memory Applications — •Andreas Dunaev[1,2], Patricia Oehrl[1,2], 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, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Solid-state spin ensembles show great potential for applications in quantum memory devices due to their long coherence times and compatibility with superconducting quantum circuits [1]. Crucial requirements for the application as a memory platform are that the stored information can be accessed and the storage capacity can actively be reset [2]. Here, we discuss an electron spin ensemble of phosphorus donors in silicon coupled to a superconducting resonator in this context. In detail, we present the characterization of this coupled system and demonstrate the storage of classical pulses using a Hahn-echo pulse sequence at temperatures of 4K, moderate magnetic fields, and GHz frequencies. In addition, we introduce the concept of an active reset of the spin ensemble using infrared light. We compare our findings to an input-output model.

[1] A. Morello *et al.*, Adv. Quantum Technol. **3**, 2000005 (2020)
[2] J. O'Sullivan *et al.*, Phys. Rev. X **12**, 041014 (2022)

TT 11.55 Mon 15:00 P4

Remote Cooling of Spin-ensembles through a Spin-mechanical Hybrid Interface — •Wang Yang[1], Durga Dasari[1], and Joerg Wrachtrup[1,2] — [1]3. Physikalisches Institut, ZAQuant, University of Stuttgart, Allmandring 13, 70569 Stuttgart, Germany — [2]Max Planck Institute for solid state research, Heisenbergstraße 1, 70569 Stuttgart, Germany

We present a protocol for the ground-state cooling of a tripartite hybrid quantum system, in which a macroscopic oscillator acts as a mediator between a single probe spin and a remote spin ensemble. In the presence of weak dispersive coupling between the spins and the oscillator, cooling of the oscillator and the ensemble spins can be achieved by exploiting the feedback from frequent measurements of the single probe spin. We explore the parameter regimes necessary to cool the ensemble, the oscillator, or both to their thermal ground states. This novel cooling protocol shows that, even with only weak dispersive coupling, energy transfer-like effects can be obtained by simply manipulating the probe spin. These results not only contribute to the development of a practical solution for cooling/polarizing large spin ensembles, but also provide a relatively simple means of tuning the dynamics of a hybrid system. The proposed protocol thus has broader implications for advancing various quantum technology applications, such as macroscopic quantum state generation and remote sensing.

TT 11.56 Mon 15:00 P4

Towards SQUID Optomechanical Devices based on $YBa_2Cu_3O_7$ — •Timo Märklin, Kenny Fohmann, Michael Schöllhorn, Mohamad El Kazouini, Christoph Schmid, Benedikt Wilde, Dieter Koelle, Reinhold Kleiner, and Daniel Bothner — Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, Universität Tübingen, Germany

Integrating a superconducting quantum interference device (SQUID) into a superconducting microwave resonator yields a circuit with a flux-tunable resonance frequency. By additionally releasing a part of the SQUID loop from the substrate such that it can oscillate mechanically, one obtains a SQUID optomechanical device in which microwave photons interact with phonons of the mechanical oscillator. If their interaction rate is sufficiently high, one can prepare non-classical states in the mechanical resonator which could build the foundation for experiments testing quantum gravity.

Today's standard material for superconducting frequency-tunable resonators is aluminum. However, the low critical field of aluminum in the range of some 10 mT severely limits the interaction rates achievable in SQUID optomechanical devices, as the interaction rate is directly proportional to an externally applied magnetic field. Therefore, we investigate the high-T_c superconductor $YBa_2Cu_3O_7$ (YBCO) regarding its suitability for SQUID optomechanics, since its high critical field beyond 10 T promises interaction rates higher than those achieved so far. This poster presents our recent progress along the path towards SQUID optomechanical devices based on YBCO.

TT 11.57 Mon 15:00 P4

Analysis of the Mechanical Properties of Nanomechanical String Resonators based on NbTiN — •Burak Bülbüloğlu[1,2], Korbinian Rubenbauer[1,2], Thomas Luschmann[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 Technology, Munich, Germany

Opto- and electromechanical systems play an intricate part in the fields of quantum sensing and transduction. Aluminum (Al) is a popular material platform in the field of cavity-optomechanics due to its low internal loss rates at microwave frequencies and self-limiting oxide. However, the operation of Al is limited by its critical temperature ($T_c \approx 1.2\,K$ in the bulk). We explore Niobium Titanium Nitride (NbTiN) as an alternative candidate for opto- and electromechanical systems based on thin film technology. NbTiN has a T_c of up to $17\,K$ in bulk and can be used as a material for planar superconducting microwave quantum circuits. Moreover, it has a higher critical current density compared to Al and, thus, can support a larger photon number or microwave drive power. Here, we present doubly-clamped NbTiN nanomechanical string resonators and investigate their mechanical properties. We find stress levels on par with annealed Al, positioning NbTiN strings as a promising platform for the implementation of nano-electromechanical circuits operating at elevated temperatures.

TT 11.58 Mon 15:00 P4

Cavity Optomechanics with a Carbon Nanotube Nanomechanical Resonator — •Katrin Burkert, Akong Loh, Furkan Özyigit, Fabian Stadler, Anton Weber, 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 resonators. Suspended between Ti/Au electrodes and gated, they can act simultaneously as beam resonators with large Q and as quantum dots. We have realized optomechanical coupling of a SWCNT nanomechanical resonator to a microwave cavity and quantified it through optomechanically induced transparency measurements [1,2]. The nonlinearity of Coulomb blockade in the CNT was exploited to significantly enhance the coupling strength, reaching g_0 ∼100 Hz [1,2]; also back-action of the CNT on the microwave cavity has been demonstrated [1,2]. Ongoing work is directed towards strong coupling and ground state cooling of the nanomechanical resonator. This requires improvements of the microwave cavity [3] and the transfer assembly procedure. Suspended CNTs have been proposed as long-lived nanoelectromechanical qubits [4], a topic of high current research interest [5].

[1] S. Blien et al., Nat. Commun. 11, 1636 (2020).
[2] N. Hüttner et al., PR Appl. 20, 064019 (2023).
[3] N. Kellner et al., PSSB 260, 2300187 (2023).
[4] F. Pistolesi et al., PRX 11, 031027 (2021).
[5] Y. Yang et al., Science 386, 783 (2024).

TT 11.59 Mon 15:00 P4

Dissipative Microwave Optomechanics with a Carbon Nanotube — •Anton Weber, Katrin Burkert, Akong Loh, Niklas Hüttner, and Andreas K. Hüttel — Institut for Experimental and Applied Physics, University of Regensburg, 93053 Regensburg, Germany

High-frequency nanomechanical resonators are valuable for many measurement applications. We investigate a high quality factor mechanical resonator consisting of a suspended carbon nanotube. The nanotube is actuated by applying an external radiofrequency signal. Its motion can modulate its conductance, allowing for electrical detection [1]. In order to transfer this type of experiment from time-averged, dc measurement to fast GHz detection, the nanotube can be integrated into a microwave reflectometry setup at low temperature. A Quartz tuning-fork based carbon nanotube transfer is used to insert the bottom-up grown CNTs into the top-down designed circuit geometry [2]. The specific electronic and mechanical properties of CNTs require adaptation to the microwave circuit; a stub tuner, formed from coplanar waveguides (CPWs), is used for this purpose. They are particularly suitable for high impedance CNTs, as their resonant frequencies and impedance behavior can be precisely controlled by their geometry. The nanotube vibration modulates the signal reflection, effectively resulting in a dissipatively coupled microwave optomechanical system [3].

[1] G. A. Steele et al., Science 325, 5944 (2009).
[2] S. Blien et al., PSSB 255, 180018 (2018).
[3] F. Elste et al., Phys. Rev. Lett. 102, 207209 (2009).

TT 11.60 Mon 15:00 P4

Simulation model on the trigger time in superconducting single-photon detectors — •Tim Janocha, Someshvaran Udayakumar, Stefan Kaiser, and Riccardo Bassoli — Technische Universität Dresden, Dresden, Deutschland

Superconducting nanowire single-photon detectors (SNSPDs) are promising quantum communication devices due to their high efficiency, low dark count rates and minimal timing jitter. Here we present a simulation model on the trigger time between photon absorption and detection triggering. Within the framework of the proposed model, the influence of the photon energy, bias current, and strip width are investigated and their influence on the device performance is discussed.

TT 11.61 Mon 15:00 P4

Towards X-ray Spectroscopy with sub-eV Absolute Energy Calibration up to 100 keV — •A. Striebel, A. Abeln, A. Brunold, D. Kreuzberger, D. Unger, D. Hengstler, A. Reifenberger, A. Fleischmann, L. Gastaldo, and C. Enss — Kirchhoff Institute for Physics, Heidelberg University

Metallic magnetic calorimeters (MMCs) are energy-dispersive X-ray detectors which provide an excellent energy resolution over a large dynamic range combined with a very good linearity. MMCs convert the energy of each incident photon into a temperature pulse which is measured by a paramagnetic temperature sensor. The resulting change of magnetisation is read out by a SQUID magnetometer.

To investigate electron transitions in U^{90+} within the framework of the SPARC collaboration, we developed the 2-dimensional maXs-100 detector array. It features 8x8 pixels with a detection area of $1\,cm^2$, an absorber thickness of $50\,\mu m$, a photo efficiency of 18 % at 100 keV, an energy resolution of 40 eV at 60 keV and was successfully operated in a recent beamtime at CRYRING@FAIR. To increase the photo efficiency to above 35 % at 100 keV we develop a new maXs-100 detector with $100\,\mu m$ thick absorbers.

Currently, the absolute energy calibration is limited not by the detector itself, but by the Struck SIS3316 analog-to-digital converter. We present a technique to precisely determine the ADCs' non-linearity using an Analog Devices EVAL-ADMX1002B ultra low-distortion sine wave generator. This allows to correct for the non-linearity. We discuss the effect of this correction on actual MMC spectra.

TT 11.62 Mon 15:00 P4

Towards Large-Area 256-Pixel MMC Arrays for High Resolution X-ray Spectroscopy — •Andreas Abeln, Daniel Hengstler, Daniel Kreuzberger, Andreas Reifenberger, Andreas Fleischmann, Loredana Gastaldo, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University

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.

In this contribution we present a detector setup featuring a novel dense-packed 16×16 pixel MMC array. The pixels provide a total active area of $4\,mm \times 4\,mm$ and are equipped with $5\,\mu m$ 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 1.4 eV (FWHM) at an operating temperature of 20 mK. For the cost-effective read-out of the 128 detector channels we envisage the flux-ramp multiplexing technique. We present first results of the detector characterization obtained utilizing parallel 2-stage dc-SQUID read-out chains. We discuss the detector performance, focusing on the thermal behavior within the detector as well as to the thermal bath.

TT 11.63 Mon 15:00 P4

MMC-Based Photon and Phonon Detector for Scintillating Crystals at mK Temperatures — •Ioana-Alexandra Nitu, Christian Enss, Andreas Fleischmann, Daniel Hengstler, Ashish Jadhav, Cagla Mahanoglu, Andreas Reifenberger, Christian Ritter, and Loredana Gastaldo — Kirchhoff Institute for Physics, Heidelberg University

Scintillating crystals at mK temperatures are used in the search for neutrinoless double beta decay ($0\nu\beta\beta$) and Dark Matter, because they provide the means to discern the interaction of heavy particles, such as α particles, from light ones, such as electrons. The discrimination is achieved by measuring the temperature increase of the crystal and the emitted light simultaneously. This approach is used in the AMoRE experiment where $LiMoO_4$ crystals are employed to search for $0\nu\beta\beta$.

We present the design concept of an integrated photon and phonon (P2) detector, based on low temperature metallic magnetic calorimeters (MMCs). This detector is to be microfabricated on a 3-inch Si wafer; the central wafer area is used for the detection of the scintillation light, while the outer area contains three double-meander MMC detectors to monitor temperature changes in the crystal. We pursue the optimisation of the design and discuss the challenges in the microfabrication of the photon and phonon detector. Preliminary results are presented and compared to the expected performance.

TT 11.64 Mon 15:00 P4

MMC-based X-ray Detector for Transitions in light Muonic Atoms — •Peter Wiedemann, Andreas Abeln, Christian Enss, Andreas Fleischmann, Loredana Gastaldo, Daniel Hengstler, Daniel Kreuzberger, Andreas Reifenberger, Adrian Striebel, Daniel Unger, and Julian Wendel — for the QUARTET Collaboration, Kirchhoff Institute for Physics, Heidelberg University

High energy resolution X-ray spectroscopy of muonic atoms is used for the determination of charge nuclear radii. The QUARTET collaboration aims to improve the accuracy of nuclear charge radii of light elements from Li to Ne up to one order of magnitude by using Metallic Magnetic Calorimeter (MMC) arrays. These Detectors have already demonstrated excellent energy resolution and energy calibration with sub-ev prevision. We present the result obtained with the newly developed MMC array optimized to reach a quantum efficiency of 98% at 19 keV with 4 eV ΔE_{FWHM} We Discuss the performance achieved with this new MMC array at the light of precision X-ray spectroscopy of muonic lithium, beryllium and boron.

TT 11.65 Mon 15:00 P4

Towards Phonon Detection in Superfluid Helium with MMCs — •Axel Brunold, Andreas Fleischmann, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University

The search for light dark matter requires innovative detection techniques that can probe weakly interacting particles with exceptional sensitivity. One promising approach involves studying elastic scattering interactions between dark matter particles and helium atoms at millikelvin temperatures.
As part of the "Direct search Experiment for Light dark matter", DELight, a pilot experiment is conducted to investigate the behavior of metallic magnetic calorimeters (MMCs) submerged in liquid helium. MMCs have previously demonstrated the capability to detect photons with high energy resolution and linearity; this experiment seeks to explore how these properties translate to the detection of phonons. In this setup, a small copper cell (300 ml) is cooled to below 1 K within a $^3He/^4He$ dilution refrigerator and filled with ^4He. The liquid helium level, while filling and later on operating the MMC, is monitored with an LC circuit-based level meter. At these millikelvin temperatures, ^4He is deep in its superfluid phase, enabling a long mean free path for phonons and rotons. A resistive heater is used to excite phonons, which are then collected by an MMC on a 5 mm x 5 mm silicon substrate. This contribution presents the setup and first results.

TT 11.66 Mon 15:00 P4

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 Novotný[2], Andreas Reifenberger[1], Dennis Schulz[1], and Andreas Wolf[2] — [1]Kirchhoff Institute for Physics, 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.
For readout, the signals of the 64 pixels of each row are added up and a triggered pixel is identified by its unique signal decay time. Two pixel rows are connected to the same SQUID with opposite polarity. This allows the use of only 32 SQUID channels to read out all 4094 pixels of the detector. We present an improved readout scheme using an exponential decay time spacing. In addition, we compare simulations of this scheme to measured data.

TT 11.67 Mon 15:00 P4

Characterization of Ti/Au Bilayer at mK — •Martin Schwendele, Chrsitain Enss, Andreas Fleischmann, Daniel Hengstler, Ashish Jadhav, Lukas Münch, Andreas Reifenberger, and Loredana Gastaldo — Kirchhoff Institute for Physics, Heidelberg University

Low temperature microcalorimeters reach high energy resolution in a wide energy range thanks to very sensitive thermometers. Magnetic penetration depth thermometers (MPTs) would represent a very interesting alternative with respect to commonly used metallic magnetic calorimeteres (MMCs) and transition edge sensors (TESs).
We present the study of Ti/Au bilayers, typically used in TES as sensible material for MPTs. Films with different ratios between the superconducting layer and the normal conducting layers have been produced using sputtering technique. We discuss the dependence of the transition temperature as a function of the thickness ratio as well as the estimation of the penetration depth as a function of temperature.

TT 12: Quantum Transport and Quantum Hall Effects (joint session HL/TT)

Time: Monday 16:45–18:15 Location: H15

TT 12.1 Mon 16:45 H15

kdotpy: A Python application for k·p band structure simulations of zincblende semiconductors — •Wouter Beugeling[1,2], Florian Bayer[1,2], Christian Berger[1,2], Jan Böttcher[3], Leonid Bovkun[1,2], Christopher Fuchs[1,2], Maximilian Hofer[1,2], Saquib Shamim[1,2], Moritz Siebert[1,2], Li-Xian Wang[1,2], Ewelina M. Hankiewicz[3], Tobias Kiessling[1,2], Hartmut Buhmann[1,2], and Laurens W. Molenkamp[1,2] — [1]Physikalisches Institut (EP3), Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institute for Topological Insulators, Am Hubland, 97074 Würzburg, Germany — [3]Institut für Theoretische Physik und Astrophysik (TP4), Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

The software project kdotpy aims at simulations of electronic band structures of semiconductor devices with k·p theory. The application implements the widely used Kane model, capable of reliable predictions of transport and optical properties for a large variety of topological and non-topological materials with a zincblende crystal structure.

In this presentation, I present the core functionality and features of kdotpy. I will explain how we have implemented principles of modern software engineering and good scientific practice in this project.

TT 12.2 Mon 17:00 H15

End states in zigzag Haldane model nanoribbons — Simone Traverso, Maura Sassetti, and •Niccolò Traverso Ziani — Physics Department, University of Genova, Italy

As topological materials based on the graphene lattice become experimentally realizable in materials such as germanene, the physics of the bound states that characterize them at step edges and in quasi one-dimensional settings becomes relevant.

In this context, the appearance of topological bound states in zigzag Haldane nanoribbons will be addressed [1]. A reentrant topological phase diagram is found. Together with numerical results, a low energy theory extending the Jackiw-Rebbi paradigm will be presented.

[1] S. Traverso, M.Sassetti, N. Traverso Ziani, NPJ Quantum Materials 9, 9 (2024).

TT 12.3 Mon 17:15 H15

Time-reversal invariant Chalker-Coddington model and the real-space renormalisation group — •Syl Shaw and Rudolf A. Römer — Department of Physics, University of Warwick, Coventry, CV4 7AL, UK

The Chalker-Coddington model has been utilised to great success in understanding the plateau transitions in the quantum Hall effect. Since the model's inception, it has been extended to a time-reversal invariant symmetry class to describe the quantum-spin Hall effect. Here we adapt a real-space renormalisation group method[1] to respect time-reversal symmetry and use it investigate the phase diagram of the quantum-spin Hall effect. We aim to find distinct phases as a function of both saddle-point height, z and spin-mixing angle ϕ. At the phase boundary between insulator and metal, we compute the value of the critical exponent of the localisation length, ν, with the same real-space renormalisation technique. [1] S. Shaw, R. A. Römer Physica E 165, 116073 (2025)

TT 12.4 Mon 17:30 H15

Utilizing Silicon Qubit Devices for Quantum Electrical Metrology — •Dustin Wittbrodt[1], Johannes Christian

Bayer[1], Lars Schreiber[2,3], Janne Lehtinen[4], Marcelo Jaime[1], and Frank Hohls[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]RWTH Aachen University, Aachen, Germany — [3]Forschungszentrum Juelich, Juelich, Germany — [4]SemiQon Technologies Oy, Espoo, Finland

The 2019 redefinition of the SI system established fixed values for fundamental constants such as the elementary charge (e) and the Planck constant (h), enabling the quantum realization of the units of Ampere, Volt, and Ohm. While the quantum realization of Volt and Ohm is well-established, the realization of the Ampere, whether directly through Single Electron Pumps (SEPs) or indirectly via the Volt and Ohm, has yet to achieve the same level of accuracy. Moreover, further device applications in practical circuits require paralelization approaches to achieve higher current outputs. The international project "Advanced Quantum Technology for Metrology of Electrical Currents" (AQuanTEC) aims to upscale SEPs beyond the 1 nA threshold. To achieve this, AQuanTEC explores several strategies, including the use of silicon devices first designed for spin qubit realization. These devices are highly promising due to their potential scalability, driven by ongoing advancements in integrating large numbers of qubits.

TT 12.5 Mon 17:45 H15

Surface state dominated transport in HgTe topological insulator devices — •Maximilian Hofer[1,2], Christopher Fuchs[1,2], Lena Fürst[1,2], Tobias Kiessling[1,2], Wouter Beugeling[1,2], Hartmut Buhmann[1,2], and Laurens W. Molenkamp[1,2] — [1]Physikalisches Institut, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institute for Topological Insulators, Am Hubland, 97074 Würzburg, Germany

Recently grown three dimensional topological insulators based on tensile strained HgTe exhibit an exceptionally high mobility and very low intrinsic carrier density. The high quality material has made it possible to study the Landau level dispersion at low magnetic fields and identify four distinct transport regimes. We demonstrate that while a contribution from the topological surface states to transport measurements is expected across the full experimentally accessible density range, there exists only a narrow density regime for which the electronic transport is exclusively carried by the topological surface states. We present the corresponding phase diagram for pure topological surface state transport depending on layer thickness and carrier concentration. For thick HgTe films grown pseudomorphically strained on CdTe, the total carrier density needs to be kept between $1.8 \times 10^{11}\,\mathrm{cm}^{-2}$ and $2.6 \times 10^{11}\,\mathrm{cm}^{-2}$ to remain in the pure surface state region and avoid contributions from bulk states. The experimental observations are supported by eight band $\boldsymbol{k} \cdot \boldsymbol{p}$ band structure calculations.

TT 12.6 Mon 18:00 H15

Designing a quantum sorter based on two-dimensional topological insulators — •Amanda Teodora Preda[1,2], Iulia Ghiu[2], Lucian Ion[2], Andrei Manolescu[3], and George Alexandru Nemnes[1,2] — [1]Horia Hulubei National Institute for Physics and Nuclear Engineering, Reactorului 30, Magurele- Ilfov, 077125, Romania — [2]University of Bucharest, Faculty of Physics, Atomistilor 405, Magurele-Ilfov, 077125, Romania — [3]Department of Engineering, Reykjavik University, Menntavegur 1, Reykjavik IS-102, Iceland

The idea of a quantum sorter emerged in quantum information, a field that aims to exploit quantum effects and manipulate qubits for information processing. In theory, it was proven that one can propose a universal quantum sorter for any arbitrary observable. To this point, suitable experimental schemes of implementation for this proposal were explored mainly in quantum optics. In our study, we introduce a solid-state version of a quantum sorter, based on a multi-terminal mesoscopic device with multiple output ports, that aims to separate the incoming states by both their spin and transversal mode. In order to maximize the state-separation efficiency of such a device, we chose to exploit the unique transport properties of topological insulators. Employing the tight-binding based simulation package Kwant, we modeled a device that meets the criteria of an irreversible quantum sorter, using the well-established BHZ Hamiltonian to simulate a multi-terminal quantum system made up of both trivial and topological materials.

TT 13: Focus Session: Magnetic Phenomena from Phonon Chirality and Angular Momentum II (joint session MA/TT)

The magnetic moment of the electron lies at the heart of magnetism and spintronics. However, recent research has unveiled the angular momentum and magnetic moment of chiral phonons as fundamental quantities in their own right. These chiral phonons give rise to a plethora of novel lattice phenomena analogous to electronic effects, such as the phonon Hall and phonon Zeeman effects. Moreover, they play a critical role in angular momentum transfer on ultrafast timescales, as seen in the Einstein-de Haas effect. Chiral phonons can also generate effective magnetic fields reaching the tesla scale, inducing magnetization in antiferromagnetic, paramagnetic, and even nonmagnetic materials - a phenomenon reminiscent of the Barnett effect. These advancements showcase phonon chirality and angular momentum as powerful emerging tools for generating and controlling magnetism. This focus session aims to highlight the latest breakthroughs in chiral-phonon magnetism and foster connections between the rapidly evolving field of chiral phononics and the broader magnetism research community.

Coordinators: Dominik M.Juraschek, Eindhoven University of Technology, d.m.juraschek@tue.nl; Martina Basini, ETH Zürich, m.basini@ethz.ch

Time: Tuesday 9:30–12:45 Location: H16

TT 13.1 Tue 9:30 H16

Continuous-wave terahertz spectroscopy on chiral phonons — •Ji Eun Lee, Luca Eisele, Artem Pronin, and Martin Dressel — 1. Physikalisches Institut, Universität Stuttgart, Germany

We apply continuous-wave frequency-domain terahertz spectroscopy to study chiral phonons at low frequencies. As samples, we use thin films of materials with soft phonon modes, such as SrTiO3 and (doped) PbTe. Our experimental method utilizes both, measurements of transmission with circular-polarized light and Faraday-rotation experiments. In the talk, our approach to the measurements and preliminary results will be summarized.

TT 13.2 Tue 9:45 H16

Spin-lattice coupling in multiscale modeling: from angular momentum transfer to chiral phonons — •Markus Weissenhofer[1,2], Philipp Rieger[1], Sergiy Mankovsky[3], Akashdeep Kamra[5], MS Mrudul[1], Hubert Ebert[3], Ulrich Nowak[4], and Peter M. Oppeneer[1] — [1]Uppsala University, Uppsala, Sweden — [2]Freie Universität Berlin, Berlin, Germany — [3]Ludwig Maximilian Universität, München, Germany — [4]Universität Konstanz, Konstanz, Germany — [5]Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Kaiserslautern, Germany

Transfer and manipulation of angular momentum is a key aspect in spintronics. Recently, it has been shown that angular momentum transfer between spins and lattice is possible on ultrashort timescales [1]. To contribute to the understanding of this transfer, we have developed a theoretical multiscale framework for spin-lattice coupling, which is linked to ab-initio calculations on the one hand and magnetoelastic continuum theory on the other [2], allowing for the study of a wide range of magnetomechanical phenomena. Here I will discuss how this framework can be used to calculate magnon-phonon coupling parameters, emphasizing the importance of a Dzyaloshinskii-Moriya type interaction for angular momentum transfer [2] and revealing the existence of chiral phonons in iron arising from a chirality-selective coupling [3]. [1] Tauchert al., Nature 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). [3] Weißenhofer et al., arXiv:2411.03879.

TT 13.3 Tue 10:00 H16

Chiral phonon-induced magnetization reversal in 2D ferromagnets — •Daniel Bustamante Lopez[1] and Dominik Juraschek[2] — [1]Department of Physics, Boston University, Boston, Massachusetts 02215, USA — [2]Department of Applied Physics and Science Education, Eindhoven University of Technology, Eindhoven, Netherlands

In our previous work, we explored magnonic rectification, where a coherently excited chiral phonon generates an effective magnetic field capable of inducing quasistatic magnetization in antiferromagnetic materials. In this study, we extend this concept to ferromagnetic materials, demonstrating that phononic magnetic fields can achieve permanent magnetization reversal. We focus on two-dimensional chromium-based ferromagnetic crystals, including CrI3, CrGeTe3, and CrCl3, and investigate reversal mechanisms such as damping switching and precessional switching. Our findings reveal that phononic magnetic fields enable robust and permanent magnetization reversal within nanoseconds, highlighting their potential for ultrafast magnetic control.

TT 13.4 Tue 10:15 H16

Chiral phonons in coupled magnon-phonon band structure — •Yelyzaveta Borysenko, Daniel Schick, and Ulrich Nowak — University of Konstanz, Konstanz, Germany

Coupling of spin and lattice degrees of freedom in magnetic materials is a key aspect for angular momentum based information processing. During ultrafast demagnetization, spin angular momentum can be transferred into the lattice creating chiral phonons even in simple centrosymmetric materials [1]. Spin-lattice coupling mechanisms involved in such processes can be approached using first principles calculations, which allow to determine leading energy terms for angular momentum exchange for different materials [2, 3]. Coupled spin-lattice dynamics is then described constructing angular momentum-conserving Hamiltonian linked to ab initio calculated model parameters [4].

Here, we linearize the equations of motion and calculate coupled magnon-phonon dispersions. We discuss how different coupling terms, e.g., of anisotropy or Dzyaloshiskii-Moriya type, can modify magnon and phonon dispersions, open up energy gaps, lift the degeneracy of modes, and lead to avoided crossings in the band structure.

[1] S. R. Tauchert et al., Nature 602, 73 (2022); [2] S. Mankovsky et. al., Phys. Rev. Lett. 129, 067202 (2022); [3] J. Hellsvik et al., Phys. Rev. B 99, 104302 (2019); [4] M. Weißenhofer et al., Phys. Rev. B 108, L060404 (2023)

TT 13.5 Tue 10:30 H16

Phonon Inverse Faraday effect from electron-phonon coupling — •Natalia Shabala and Matthias Geilhufe — Department of Physics, Chalmers University of Technology, 412 96 Gothenburg, Sweden

The phonon inverse Faraday effect describes the emergence of a DC magnetization due to circularly polarized phonons. From time-dependent second order perturbation theory and electron-phonon coupling we develop a microscopic formalism for phonon inverse Faraday effect. We arrive at a general and material-independent equation [1]. Using this equation for ferroelectric soft mode in $SrTiO_3$ gives an estimate of effective magnetic field which is consistent with recent experiments [2]. Hence, our approach is promising for shedding light into the microscopic mechanism of angular momentum transfer between ionic and electronic angular momentum, which is expected to play a central role in the phononic manipulation of magnetism.

[1] N. Shabala and R. M. Geilhufe, Accepted to PRL, arXiv:2405.09538, 2024

[2] M. Basini et al., Nature 628, 534 (2024)

TT 13.6 Tue 10:45 H16

Temperature dependent magnon-phonon coupling in YIG/GGG heterostructures — •J. Weber[1,2], M. Cherkasskii[3], F. Engelhardt[3,4,5], S.T.B. Goennenwein[6], S.Viola Kusminskiy[3,5], 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, Munich, Germany — [3]Institute for Theoretical Solid State Physics, RWTH Aachen University, Aachen, Germany — [4]Department of Physics, University Erlangen-Nuremberg, Erlangen, Germany — [5]Max Planck Institute for the Science of Light, Erlangen, Germany — [6]Department of Physics, University of Konstanz, Konstanz, Germany — [7]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Magnon-phonon coupling in heterostructures has recently gained interest in the context of angular momentum conversion and angular momentum transport via phonons. A typical experimental setting is a bilayer system, where the magnetization dynamics of a magnetic thin film interacts with the elastic standing wave excitations of a non-magnetic bulk crystal. So far, bulk acoustic wave resonators consisting of a ferrimagnetic yttrium iron garnet (YIG) film deposited on a crystalline gadolinium gallium garnet (GGG) substrate have been studied at room temperature due to the favorable magnetic damping properties of YIG [1]. We present a temperature dependent analysis of the magnon-phonon coupling of a YIG/GGG bulk acoustic wave resonator.

[1] K. An et al., Phys. Rev. B **101**, 060407, (2020).

15 min. break

TT 13.7 Tue 11:15 H16

Modeling of the preparation and conservation of coherent phonon (pseudo) angular momentum — •Olga Minakova[1], Maximilian Frenzel[1], Carolina Paiva[2], Joanna M. Urban[1], Michael S. Spencer[1], Martin Wolf[1], Dominik M. Juraschek[2,3], and Sebastian F. Maehrlein[1,4,5] — [1]FHI Berlin — [2]Tel Aviv University — [3]Eindhoven University of Technology — [4]HZDR — [5]TU Dresden

The angular momentum of lattice vibrations - phonon angular momentum - is an underexplored degree of freedom in solid-state systems. Recent experiments have shown that circularly-polarized THz pulses can coherently excite degenerate phonon modes, enabling the preparation of phonon angular momentum states. THz-Kerr effect spectroscopy provides a means to monitor these states by directly measuring vectorial phonon trajectories. To interpret such experiments, it is essential to understand the symmetry properties of the phonon modes that influence the driving and probing processes, as well as the conservation of angular momentum in the crystal lattice. Here, we model the generation and detection of coherent phonon angular momentum, revealing how crystal symmetry dictates the selection rules in the lattice. We show that the form of the Raman tensors associated with the phonon explains the phonon helicity observed in experiments, linking the discrete rotational symmetry of the material to the conservation of pseudo angular momentum in lattice vibrations.

TT 13.8 Tue 11:30 H16

Spin-spin interaction via chiral phonons — •Daniel Schick[1], Markus Weissenhofer[2,3], Akashdeep Kamra[4], and Ulrich Nowak[1] — [1]University of Konstanz, Konstanz, Germany — [2]Uppsala University, Uppsala, Sweden — [3]Free University of Berlin, Berlin, Germany — [4]University of Kaiserslautern-Landau, Kaiserslautern, Germany

Coupling between the magnetic degrees of freedom and phonons has emerged as a topic of great importance for explaining various magnetic phenomena, like ultrafast demagnetization processes [1], and the possibility to affect magnetization dynamics via phonon pumping [2]. We develop a tool to study spin-lattice coupling in atomistic simulations, which conserves total angular momentum. This allows us to precisely retrace the transfer of angular momentum between the spin and lattice systems. We demonstrate the emergence of an effective spin-spin interaction mediated by chiral phonons. This effect can arise from thermal phonons as follows. A spin may precess after coupling to a phonon, with this precession producing chiral phonons, which in turn, affect other spins. A similar effect can be achieved by driving a spin to induce chiral phonons. We discuss the dependence of this interaction on the temperature and strength of the spin-lattice interaction and discuss our findings within the context of phonon-enhanced magnon transport phenomena.

[1] S. R. Tauchert, et. al., Nature **602**, 73 (2022)

[2] R.Schlitz et. al. Phys. Rev. B **106**, 014407 (2022)

TT 13.9 Tue 11:45 H16

Ultrafast generation of multicolor chiral phonons in magnetic

and ferroelectric materials — •Omer Yaniv[1] and Dominik M. Juraschek[2] — [1]Tel Aviv University, Tel Aviv, Israel — [2]Eindhoven University of Technology, Eindhoven, Netherlands

Terahertz pulses are powerful tools capable of initiating coherent vibrational motions in solids. Circularly polarized pulses can further excite chiral phonons. Such phonons carry an angular momentum and are able to generate magnetic moments leading to a varying range of phenomena, including the phonon Hall, phonon Zeeman, and phonon inverse Faraday effects. Our study investigates the coherent driving of phonons using multicolor laser pulses, leading to Lissajous trajectories of the atoms. We demonstrate the generation of such multicolor chiral phonons in BaTiO3, a task that presents significant challenges due to the requirement of an exact 1:2 phonon frequency ratio. Achieving this precise ratio is crucial for the generation of closed atomic Lissajous loops. However, we overcome this challenge by creating phonon polaritons with shifted frequencies through the use of optical cavities. This approach allows us to surpass the limitations imposed by the strict phonon frequency ratio. By carefully tuning the cavity parameters, we demonstrate a new pathway for controlling lattice vibrations at ultrafast timescales. We also explore how multicolor phonons tune magnetic properties in monolayer CrI3, a 2D material with strong spin-orbit coupling and ferromagnetism. By manipulating phonon dynamics, we examine the interaction between lattice vibrations and magnetic order.

TT 13.10 Tue 12:00 H16

Chiral Phonons induced by Magnon-Phonon Coupling — •Hannah Bendin[1], Alexander Mook[2], Ingrid Mertig[1], and Robin R. Neumann[1,2] — [1]Martin Luther University Halle-Wittenberg, Halle (Saale), Germany — [2]Johannes Gutenberg University, Mainz, Germany

Chiral phonons, the quasiparticles of circularly polarized lattice vibrations, have recently been investigated due to a range of emerging phenomena. Notably, chiral phonons carry nonzero angular momentum. However, the systems in which they occur still require extensive research. Chiral phonons may, for example, be found in lattices with broken inversion symmetry. Alternatively, they can be induced by the coupling to magnons, the quasiparticles of spin excitations, thereby lifting time-reversal symmetry.

Here, we analyze how magnetoelastic coupling gives rise to magnon-phonon hybridization, which, in turn, generates phonon angular momentum. Conversely, we show how the phonon angular momentum and the spin of the magnons affects their coupling strength. This interplay between magnons and chiral phonons allows for the tunability of the phonon angular momentum.

TT 13.11 Tue 12:15 H16

Ultrafast laser-induced carrier and magnetization dynamics in $SrTiO_3$ from real-time time-dependent DFT — •Andri Darmawan, Markus E. Gruner, and Rossitza Pentcheva — Department of Physics, University of Duisburg-Essen

Recent experimental studies indicate electric-field-driven ferroelectricity [1] and multiferroicity [2] in the paradigmatic nonmagnetic band insulator $SrTiO_3$ in the terahertz regime. Following a comprehensive study of the optical [3] and x-ray absorption [4] spectra including quasiparticle and excitonic effects, here we explore the response of $SrTiO_3$ to laser excitation. Using real-time time-dependent density functional theory (RT-TDDFT) as implemented in the Elk code, we investigate both linear and circular polarized laser pulses. A complex site- and orbital-dependent temporal dynamics is observed with opposite sign of fluctuations at O and Ti sites and charge transfer from O $2p$ to Ti $3d$ states for linearly polarized light, that breaks dynamically inversion symmetry. Notably, circularly polarized pulses induce a finite transient magnetic moment which is absent for linearly polarized pulses. Funding by DFG within CRC1242 (project C02) and computational time at magnitUDE, amplitUDE and the Leibniz Supercomputer Center (project pr87ro) are gratefully acknowledged.

[1] T.F. Nova et al., Science 364, 1075 (2019)
[2] M. Basini et al., Nature 628, 534 (2024)
[3] V. Begum, M.E. Gruner and R. Pentcheva, Phys. Rev. Mater. 3, 065004 (2019)
[4] V. Begum-Hudde et al., Phys. Rev. Res. 5, 013199 (2023)

TT 13.12 Tue 12:30 H16

Phonon pumping in ferromagnet/nonmagnetic insulator hybrid systems — •Richard Schlitz[1], Luise Holder[1], Johannes Weber[2,3], Mikhail Cherkasskii[4], Fabian Engelhardt[4], Julie Střihavková[5], Matthias Althammer[2,3], Silvia V. Kusminskiy[4,6], Hans Huebl[2,3,7], and Sebastian T. B. Goennenwein[1] — [1]Department of Physics, University of Konstanz, Konstanz, Germany — [2]Walther-Meißner-Institut, BAdW, Garching, Germany — [3]School of Natural Sciences, TUM, Garching, Germany — [4]Institute for Theoretical Solid State Physics, RWTH Aachen University, Aachen, Germany — [5]Faculty of Mathematics and Physics, Charles University, Prague — [6]Max Planck Institute for the Science of Light, Erlangen, Germany — [7]Munich Center for Quantum Science and Technology, München, Germany

In ferromagnetic thin films, magnetization dynamics, e.g., driven by ferromagnetic resonance, can coherently couple to phonons. If a ferromagnetic film is deposited on a crystalline substrate with polished parallel faces, the sample stack forms a bulk acoustic resonator, leading to characteristic modifications of the magnetic resonance signal.

In this work, we show that the magnetoelastic coupling can mediate the hybridization of the coherent magnetization dynamics with longitudinal and transverse phonons, with a particular dependence on the orientation of the magnetic field. We extract the magnetoelastic coupling parameters and compare them with theoretical expectations. Our results show that both longitudinal and transverse phonons can be efficiently excited, depending on the magnetic field orientation.

TT 14: Spin Transport and Orbitronics, Spin-Hall Effects I (joint session MA/TT)

Time: Tuesday 9:30–13:15 Location: H18

TT 14.1 Tue 9:30 H18

Topological orbital Hall effect caused by skyrmions and antiferromagnetic skyrmions — •Lennart Schimpf, Ingrid Mertig, and Börge Göbel — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg

The topological Hall effect is a hallmark of topologically non-trivial magnetic textures such as magnetic skyrmions. It quantifies the transverse electric current once an electric field is applied and occurs as a consequence of the emergent magnetic field of the skyrmion. Likewise, an orbital magnetization is generated. Here we show that the charge currents are orbital polarized even though the conduction electrons couple to the skyrmion texture via their spin [1]. The topological Hall effect is accompanied by a topological orbital Hall effect even for s electrons without spin-orbit coupling. As we show, antiferromagnetic skyrmions and antiferromagnetic bimerons that have a compensated emergent field [2], exhibit a topological orbital Hall conductivity that is not accompanied by charge transport and can be orders of magnitude larger than the topological spin Hall conductivity.

[1] B. Göbel, L. Schimpf, I. Mertig, arXiv pre-print: 2410.00820
[2] B. Göbel, I. Mertig, O. Tretiakov, Physics Reports 895, 1 (2021)

TT 14.2 Tue 9:45 H18

Optimization of orbital torques in ferrimagnets and their relationship with Gilbert damping — •shilei ding, william legrand, hanchen wang, mingu kang, paul noel, and pietro gambardella — Department of Materials, ETH Zurich, 8093 Zurich, Switzerland

Application of an electric field can induce a non-equilibrium orbital angular momentum in conductive materials whose electronic bands have a k-dependent orbital character. This phenomenon can lead to the current-induced accumulation of orbital momenta in nonmagnetic layers, which can then diffuse into neighboring magnetic layers and interact with the local magnetization through spin-orbit coupling, giving rise to orbital torques. Conversely, the excitation of spin precession in a magnetic layer can give rise to an orbital current, resulting in orbital pumping and dissipation of angular momentum in the nonmagnetic layer. In the first part, I will present the efficacy of converting orbital to spin momenta in ferrimagnetic materials, specifically in the RE-TM ferrimagnet GdyCo100-y. This work underscores the mechanisms that facilitate orbital-to-spin conversion within a magnetic layer at the atomic level. In the second part, I will discuss how the Gilbert damping parameter correlates to spin and orbital torques in magnetic layers adjacent to Pt and CuOx layers, respectively. I will show that CoFe/CuOx bilayers exhibit a favorable combination of efficient orbital torque and minimal increase in Gilbert damping, which is promising for the implementation of orbital torque oscillators with reduced damping compared to spin torque oscillators.

TT 14.3 Tue 10:00 H18

Orbital magnetoresistance in insulating antiferromagnets — •Christin Schmitt[1], Sachin Krishnia[1], Edgar Galíndez Ruales[1], Takashi Kikkawa[2], Duc Tran[1], Timo Kuschel[1], Eiji Saitoh[2], Yuriy Mokrousov[1,3], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, 55128 Mainz, Germany — [2]Department of Applied Physics, The University of Tokyo, Tokyo 113-8656, Japan — [3]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Insulating antiferromagnetic and ferrimagnetic materials are promising candidates for spintronic devices due to their intrinsic properties such as low damping [1]. Recently, orbital angular momentum (OAM) has emerged as a crucial concept in condensed-matter physics. Theoretical and experimental studies have highlighted that the orbital Hall effect (OHE) can enable orbital currents with efficiency orders of magnitude higher than that of spin Hall effects [2]. Here, we investigate magneto-resistance effects in magnetic systems [2,3]. We find that in TmIG the transverse magnetoresistance signal is increased significantly upon replacing Pt, a spin-current generator, by Cu*, a pure orbital-current generator. Further, we explore antiferromagnets with orbital magnetoresistance effects as pure orbital current is crucial for next generation pure orbitronics devices using abundant, cheap and environmentally friendly materials. [1] R. Lebrun, et al., Nature, 561, 222-225 (2018). [2] S. Ding, et al., Phys. Rev. Lett. 125, 177201 (2020). [3] S. Ding et al., Phys. Rev. Lett. 128, 067201 (2022).

TT 14.4 Tue 10:15 H18

Non-reciprocity in magnon mediated charge-spin-orbital current interconversion — •Sachin Krishnia[1], Omar Ledesma-Martin[1], Edgar Galindez-Ruales[1], Felix Fuhrmann[1], Duc Tran[1], Rahul Gupta[1], Marcel Gasser[1,2], Dongwook Go[1,2], Gerhard Jakob[1], Yuriy Mokrousov[1], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

In magnetic systems, angular momentum is carried by the spin and orbital degrees of freedom. Non-local devices can be used to study angular momentum transport. They consist of parallel heavy-metal nanowires placed on top of magnetic insulators like yttrium iron garnet (YIG), facilitating the transmission of information by magnons, generated by the accumulation of spin at the interface, created via the spin Hall effect (SHE) and detected via the inverse SHE (iSHE). It has been demonstrated that these processes have comparable efficiencies when the role of the detector and injector is reversed, which points to reciprocity of the processes. However, we show that by adding Ru as a source of direct and inverse orbital Hall effect (OHE), the system no longer exhibits this reciprocity. Specifically, the generation of magnons via the combination of SHE and OHE and detection via the iSHE is found to be about 35% more efficient than the inverse process for our system [1]. [1] O. Ledesma et al., arXiv:2411.07044 (2024).

TT 14.5 Tue 10:30 H18

Detection of dynamic x-ray magnetic linear dichroism in NiO — •Timo Kuschel[1], Johannes Demir[1], Olga Kuschel[2], Joachim Wollschläger[2], and Christoph Klewe[3] — [1]Bielefeld University, Germany — [2]Osnabrück University, Germany — [3]Advanced Light Source (ALS), Berkeley, USA

Spin transport through thin antiferromagnetic layers such as NiO has been studied by ferromagnetic resonance (FMR) spin pumping [1], spin Seebeck effect [2], non-local magnon spin transport [3] and x-ray detected FMR (XFMR) [4]. In all these experiments, the spin current has been identified in an adjacent Pt layer [1-3] or FeCo film [4] via inverse spin Hall effect or dynamic x-ray magnetic *circular* dichroism, respectively, after having the NiO layer already passed.

In this contribution, we study Fe_3O_4/NiO/Pt [5] by XFMR and present the identification of dynamic x-ray magnetic *linear* dichroism (XMLD) [6] at the Ni L edges directly in the NiO layer for FMR spin pumping in the adjacent Fe_3O_4 layer. We will analyze the XFMR response depending on the NiO thickness. Further, we will discuss coupling phenomena at the NiO-Fe_3O_4 interface vs. spin transport through the NiO layer as the origin of the dynamic XMLD response.

[1] H. L. Wang et al., Phys. Rev. Lett. 113, 097202 (2014)
[2] W. Lin et al., Phys. Rev. Lett. 116, 186601 (2016)
[3] G. R. Hoogeboom et al., Phys. Rev. B 103, 144406 (2021)
[4] M. Dabrowski et al., Phys. Rev. Lett. 124, 217201 (2020)
[5] L. Baldrati et al., Phys. Rev. B 98, 014409 (2018)
[6] C. Klewe et al., New J. Phys. 24, 013030 (2022)

TT 14.6 Tue 10:45 H18

Manipulating the sign of the interlayer exchange coupling — •Nathan Walker — The Open University, Milton Keynes, UK

We demonstrate, using computer simulations and a non-equilibrium Greens function approach, that the sign of the out-of-equilibrium interlayer exchange coupling (ooeIEC) changes in the presence of an external bias. The system consists of a double barrier connected to an exchange coupled ferromagnetic tri-layer. We find a strongly non-linear dependence of the spin current on voltage which results in the exchange coupled tri-layer switching between parallel and antiparallel configurations. Our results are in excellent agreement with earlier theoretical calculations, which predict an approximately 2π topological phase change of the (equilibrium) IEC. We believe that this could act as an energy efficient mechanism for magnetic switching which does not rely on spin-transfer torque (STT). There are potential applications to magnetoresistive random-access memory (MRAM), one of the principal contenders for a universal memory.

TT 14.7 Tue 11:00 H18

Harnessing Orbital Hall Effect in Spin-Orbit Torque MRAM — •J. Omar Ledesma Martin[1,2], Rahul Gupta[1], Chloé Bouard[2], Fabian Kammerbauer[1], Iryna Kononenko[1], Sylvain Martin[2], Gerhard Jakob[1,3], Marc Drouard[2], and Mathias Kläui[1,3] — [1]1 Institute of Physics, Johannes Gutenberg University Mainz, 55099, Mainz, Germany — [2]Staudingerweg 7 — [3]Department of Physics, Center for Quantum Spintronics, Norwegian University of Science and Technology, 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 the spin Hall conductivity of Pt. [1] 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]x3/Co/MgO/CoFeB/Ta/Ru, where the OHE materials are Ru, Nb, and Cr. Additionally, a sample with Pt instead of OHE serves as a reference. The results demonstrate an improvement for the Ru samples, exhibiting higher damping-like torque and significantly 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.

[1] R. Gupta et al., arXiv:2404.02821 (2024). Nature Comm. In press (2024)

15 min. break

TT 14.8 Tue 11:30 H18

Spin and orbital Hall effect in metal systems: extrinsic vs. intrinsic contributions — •Sergiy Mankovsky and Hubert Ebert — LMU of Munich, 81377 Munich, Germany

Kubo's linear response formalism has been used to study the orbital Hall effect (OHE) for non-magnetic undoped and doped metallic systems, focusing on the impact of different types of disorder. Corresponding first-principles calculations of the orbital Hall conductivity (OHC) were performed making use of the KKR Green function method that allows in particular to monitor the impact of the vertex corrections on the OHC. The doping- and temperature-dependence of the OHC have been investigated and compared with corresponding results for the spin Hall conductivity (SHC). The temperature dependent properties of the OHC and SHC determined by thermally induced lattice vibrations (in non-magnetic materials) and spin fluctuations (in magnetic systems) have been accounted for making use of the alloy analogy model. For elemental systems at finite temperature a dominating role of the intrinsic contribution to the temperature-dependent OH and SH conductivities is found. In contrast, the OH and SH conductivities of doped systems at low temperatures are dominated by the SOC-driven extrinsic contributions strongly decreasing at higher temperatures due to the increasing impact of the electron-phonon scattering.

TT 14.9 Tue 11:45 H18

Simulations of spin transport in YIG — •Ben Schwanewedel, Moumita Kundu, and Ulrich Konstanz — Fachbereich Physik, Universität Konstanz, Konstanz, Germany

Being synthesized first in 1957, YIG has the lowest Gilbert damping among all known materials. This makes it interesting for spintronic applications and long-range spin transport. In YIG's complex unit cell Fe atoms occupy 20 sublattices leading to 20 magnon bands between 0 and 25 THz. We develop an atomistic spin model for YIG based on exchange interactions from Ref. [1], which were determined through neutron scattering. Further parameters were adapted from Ref. [2]. We varify our study through investigation of the magnon dispersion and comparing it to the results of Ref. [1].

We use atomistic spin dynamics simulations for the model above based on the stochastic Landau-Lifshitz-Gilbert equation to unravel its spin dynamics and spin transport properties. The spin transport is triggered by thermal gradients and and local magnetic fields and it is analyzed using an observable which is proportional to the magnon population. Also, magnon dispersions far from equilibrium are evaluated and discussed.

[1] Princep, Andrew J., et al. "The full magnon spectrum of yttrium iron garnet." npj Quantum Materials 2.1 (2017): 63.

[2] Barker, Joseph, and Gerrit EW Bauer. "Thermal spin dynamics of yttrium iron garnet." Physical review letters 117.21 (2016): 217201.

TT 14.10 Tue 12:00 H18

Orbital Hall effect accompanying quantum Hall effect — •Börge Göbel and Ingrid Mertig — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg

The quantum Hall effect emerges when two-dimensional samples are subjected to strong magnetic fields at low temperatures: Topologically protected edge states cause a quantized Hall conductivity in multiples of e^2/h. Here we show that the quantum Hall effect is accompanied by an orbital Hall effect [1]. Our quantum mechanical calculations fit well the semiclassical interpretation in terms of "skipping orbits". The chiral edge states of a quantum Hall system are orbital polarized akin to an orbital version of the quantum anomalous Hall effect in magnetic systems. The orbital Hall resistivity scales quadratically with the magnetic field making it the dominant effect at high fields.

The discussion can be generalized to systems with effective magnetic fields: The topological Hall effect caused by the emergent field of topological spin textures, such as magnetic skyrmions, is accompanied by an orbital Hall effect, as well [2].

[1] B. Göbel, I. Mertig, Phys. Rev. Lett. 133, 146301 (2024)

[2] B. Göbel, L. Schimpf, I. Mertig, arXiv pre-print: 2410.00820

TT 14.11 Tue 12:15 H18

Large Spin Hall Angle in Mn-based Antiferromagnetic Alloys — •Nabil Menai[1], Martin Gradhand[2], and Derek Stewart[3] — [1]H. H. Wills Physics Laboratory, University of Bristol, Tyndall Ave, BS8-1TL, UK — [2]Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany — [3]Western Digital Research Center, San Jose, California 95119, USA

Antiferromagnets (AFMs) have emerged as crucial materials for spintronic technologies for their ability to host spin-dependent transport phenomena, despite their zero net magnetization. Their robustness against external magnetic fields and ultrafast spin dynamics make them ideal for efficient spin-charge interconversion. In this theoretical study, we use density functional theory and Greens function methods to investigate the transport properties of Mn-based binary alloyed AFMs. Our focus is on the total spin Hall conductivity (SHC), accounting for both the intrinsic contributions from Berry curvature and the extrinsic effects from skew scattering and side-jump mechanisms. The objective is to identify AFM materials that exhibits a high spin Hall angle (SHA); with an efficient charge-to-spin Hall current conversion ratio. Our results reveal that doping MnPt with Ir significantly enhances the SHA, achieving a value of 8% at room temperature. In contrast, doping with Pd offers temperature stability with lower SHA values. Additionally, we examine the effects of substituting Mn atoms with magnetic transition metals such as Fe and Ni. These findings underscore the potential of antiferromagnetic alloys for efficient spin current generation.

TT 14.12 Tue 12:30 H18

Competing ordinary and Hanle magnetoresistance in Pt and Ti thin films — •Sebastian Sailler[1], Giacomo Sala[2], Denise Reustlen[1], Richard Schlitz[1], Min-Gu Kang[2], Pietro Gambardella[2], Sebastian T.B. Goennenwein[1], and Michaela Lammel[1] — [1]Department of Physics, University of Konstanz — [2]Department of Materials, ETH Zurich

One of the key elements in spintronics research is the spin Hall effect, allowing to generate spin currents from charge currents. A large spin Hall effect is observed in materials with strong spin orbit coupling, e.g. Pt. Recent research suggests the existence of an orbital Hall effect, the orbital analogue to the spin Hall effect, which also arises in weakly spin orbit coupled materials like Ti, Mn or Cr. In any of these materials, a magnetic field perpendicular to the spin or orbital accumulation leads to additional Hanle dephasing and thereby the Hanle magnetoresistance. Here, we studied the magnetoresistance (MR) of Pt thin films over a wide range of thicknesses. Careful evaluation shows that the MR of our textured samples is dominated by the so-called ordinary MR, while the Hanle effect does not play a significant role. Analyzing the intrinsic properties of Pt films deposited by different groups, we find that next to the resistivity, also the structural properties of the film influence which MR dominates. We further show that this correlation can also be found in orbital Hall active materials like Ti. We conclude that in all materials exhibiting a spin or orbital Hall effect, the Hanle MR and the ordinary MR coexist, and that the sample's purity and crystallinity determines which MR dominates.

TT 14.13 Tue 12:45 H18

Orbital Hanle magnetoresistance in Mn thin films — •Min-Gu Kang, Federica Nasr, Giacomo Sala, and Pietro Gambardella — Department of Materials, ETH Zurich, 8093 Zurich, Switzerland

Momentum-space orbital texture, or orbital character of electrons, enables the orbital Hall effect (OHE), a current-induced flow of nonequilibrium orbital angular momentum in centrosymmetric systems with negligible spin-orbit coupling. This orbital current, which can be orders of magnitude larger than its spin counterpart, offers transformative potential for spin-orbitronics, yet the mechanisms of orbital relaxation remain unclear. In this work, we present temperature-dependent orbital Hanle magnetoresistance and associated orbital relaxation mechanisms in Mn thin films. The results clearly show that the orbital Hanle magnetoresistance depends on the structure of the Mn thin films and can be associated with competing Dyakonov-Perel and Elliott-Yafet orbital relaxation effects. Our study highlights the critical role of orbital relaxation in determining the magnitude of current-induced orbital effects in 3d transition metal films.

TT 14.14 Tue 13:00 H18

Tuning of spin transport properties in 2D ferromagnet VSe_2 by structural polytypes of TaS_2 electrodes — •Biplab Sanyal and Masoumeh Davoudiniya — Department of Physics & Astronomy, Ångströmlaboratoriet, Uppsala University, Box-516, 75120 Uppsala, Sweden

2D magnets and their heterostructures are promising materials for future spintronic applications. Here, we present a study of spin transport through a ferromagnetic monolayer of 1T-VSe_2 with two structural polytypes of TaS_2 electrodes stacked in van der Waals heterostructures. Using density functional theory coupled with the nonequilibrium Green function framework, we explore the impact of TaS_2 electrode polytypes on the device's quantum transport properties. We observe that devices with 1T-TaS_2 electrodes exhibit higher spin-dependent transmission compared to 2H-TaS_2 electrodes. Incorporating MoS_2 as a tunnel barrier, anisotropic tunnel magnetoresistance enhances significantly, reaching 168% for the 1T-device and 1419% for the 2H-device. Spin-transfer torque (STT) analysis shows that its magnitude is highest at $90°$ (-702 μeV/V for 1T and -1561 μeV/V for 2H devices) and decreases towards $180°$. The 1T-device shows superior performance with lower Gilbert damping, reduced critical current density and voltage for magnetization switching, compared to the 2H-device, which requires significantly higher current and voltage. Our predictions reveal the potential of 1T-VSe_2-based heterostructures for advanced spintronic applications.

TT 15: Quantum Coherence and Quantum Information Systems (joint session TT/DY)

Time: Tuesday 9:30–13:15 Location: H31

Invited Talk TT 15.1 Tue 9:30 H31

Solving Many-Body Problems on Quantum Computers — •Benedikt Fauseweh — TU Dortmund University, Otto-Hahn-Str 4, 44227 Dortmund

In this talk, I will provide an overview on the state-of-the art in digital quantum simulations (DQS) for many-body systems [1]. Modern quantum computers present challenges due to the noisy nature of these systems. Novel quantum algorithms, especially hybrid classical-quantum algorithms [2], have been developed to fit the specifications of such devices. For DQS, the prevailing question today is: What problems are amenable to be simulated on noisy quantum computers? I will discuss recent work on simulating quantum many-body dynamics [3], algorithmic advances to detect ground state phase transitions and the potential of stabilizing exotic non-equilibrium phases of matter, e.g., discrete time crystals [4], using quantum-classical feedback.

[1] B. Fauseweh, Nat. Comm. 15, 2123 (2024).
[2] B. Fauseweh and J.-X. Zhu, Quantum 7, 1063 (2023).
[3] B. Fauseweh and J.-X. Zhu, Quantum Inf. Process. 20, 138 (2021).
[4] G. Camacho and B. Fauseweh, Phys. Rev. Res. 6, 033092 (2024).

TT 15.2 Tue 10:00 H31

Fast Initialisation of Bell States in Kerr Cat Qubits — •Miriam Resch[1], 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

Schrödinger cat states play an important role for applications in continuous variable quantum information technologies. As macroscopic superpositions they are inherently protected against certain types of noise making cat qubits a promising candidate for quantum computing [1]. It has been shown recently that cat states occur naturally in driven Kerr parametric oscillators (KPOs) as degenerate ground states with even and odd parity that are adiabatically connected to the respective Fock states by switching off the drive [2]. To perform operations with several cat qubits one crucial task is to create entanglement between them. This can be done by initializing the cats from entangled Fock states or by performing operations directly in cat space. Here we show efficient transformations of multi mode cat states through adiabatic and diabatic switching between Kerr-type Hamiltonians with degenerate ground state manifolds and show how those transformations can be used to directly initialize the cat states as entangled Bell states.

[1] Réglade et al., Nature 629, 778 (2024);
[2] Puri et al., npj Quantum Inf. 3, 18 (2017).

TT 15.3 Tue 10:15 H31

Impurity models in waveguide QED — •Adrian Paul Misselwitz[1,2,3], Jacquelin Luneau[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 this talk I will discuss photonic impurity models, which emerge from the coupling of two-level atoms to a 1D photonic waveguide in the presence of strong photon-photon interactions. Such models appear, for example, in the context of superconducting microwave circuits, where Josephson junctions give rise to strong Kerr-nonlinearities at the few-photon level. In this case, the resulting competition between photon-photon repulsion and the attractive atom-photon interaction leads to the formation of localized bound states with a well-defined photon number and, under certain conditions, the build-up of long-range, algebraically decaying correlations between the impurity sites. I will show how these strongly-correlated phases of light and matter can be simulated efficiently with the help of large-scale tensor network simulations and discuss a possible explanation of the observed long-range correlations in terms of a simpler, effective Bose-Hubbard model.

TT 15.4 Tue 10:30 H31

Voltage without current — Christina Koliofoti and •Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

Superconductors famously give rise to equilibrium currents without voltages. But can the converse exist? We argue that voltage-dependent Josephson effects generically provide exactly such a classical time crystal behaviour – bringing with them known conceptual issues, such as discontinuous "brick-wall" trajectories, and ill-defined canonical quantization. With the example of quantum phase slip junctions in the presence of electro-motive forces, we resolve these lingering problems. Decoherence provokes a phase transition from a quantum Hamiltonian (non-Lagrangian) system with nonlinear Cooper-pair tunneling to a Lagrangian (non-Hamiltonian) classical time crystal. Our work illustrates that direct canonical quantization of low-energy theories may fail, and that the nonadiabaticity of brick-wall trajectories leads to a temporary break down of the classical theory even for strong decoherence.

TT 15.5 Tue 10:45 H31

Of gyrators and anyons I - Anyons — •Oleksiy Kashuba, Ram Mummadavarapu, and Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

In recent years there have emerged various ideas to create and control topological excitations in superconducting devices. Notably, nontrivial Chern bands were predicted to exist in conventional multiterminal Josephson junctions, but the Chern number is yet to be experimentally verified, and the pathway towards feasible quantum hardware applications is unclear. In this talk, we show how generic multiterminal circuits can be expressed as gyrator networks with quantized gyration conductance, giving rise to anyonic excitations carrying q/p fractional fluxes (q, p integer), measurable via a fractional Aharonov-Casher phase. We further present concepts for error correction protocols, and quantum simulations of interacting fermionic (or generally anyonic) many-body systems—notably, introducing the possibility to mimic fractional quantum Hall physics or to implement local fermionic models that explicitly break the Wigner superselection rule. The latter indicates that a full understanding of multiterminal circuits will require grappling with a virtually unexplored class of parity-breaking quantum field theories.

TT 15.6 Tue 11:00 H31

Of gyrators and anyons II - Gyrators — •Ram Mummadavarapu, Oleksiy Kashuba, and Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

In recent years, significant progress has been made in developing methods to create and control topological excitations in superconducting devices. Among these, the prediction of nontrivial Chern bands in conventional multiterminal Josephson junctions stands out as a particularly promising development. However, despite theoretical predictions, the experimental verification of the non-trivial Chern number remains an open challenge. Based on the realization that multiterminal junctions generically map on special gyrator networks hosting anyons (see also talk "Of gyrators and anyons I"), we here present circuit-specific band-engineering techniques to minimize parasitic anyon interactions. We show in particular how circular scattering in three-terminal quantum dot chains gives rise to a flat topological ground state, where disorder mitigates Chern number fluctuations and the quasiparticle continuum provides a work-around for known limitations to create nontrivial flat bands. Further band-engineering strategies are presented where the superconducting phase is scrambled either via parallelization or dissipative phase transitions.

15 min. break

TT 15.7 Tue 11:30 H31

Minimal SU(2) models for analog simulation in small-scale superconducting quantum devices — •Lucia Valor[1,2,3], Jacquelin Luneau[1,2,3], Klaus Liegener[1,2,3], Stefan Filipp[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

Lattice gauge theories (LGTs) are essential tools for studying fundamental interactions in particle physics and have broad applications in condensed matter physics and quantum information. Quantum simulation of non-Abelian theories remains challenging. Recent research on the analog simulation of LGTs has focused on scalable atomic quantum platforms. In contrast, we propose minimal SU(2) LGT models for analog simulation, tailored for small-scale superconducting quantum hardware. By adopting concepts from quantum optics, our approach emphasises coarse-grained systems that capture internal degrees of freedom and relevant non-Abelian properties with just a few qubits, bypassing the scalability demands of fine-grained models. We explore unique features of these non-Abelian systems and provide a circuit design for their experimental realisation. This work advances the study of non-Abelian gauge theories and introduces a novel method for implementation of LGTs using superconducting qubits.

TT 15.8 Tue 11:45 H31

Secure squeezed state microwave quantum communication with spin ensembles (part 1) — •Florian Fesquet[1,2], Patricia Oehrl[1,2], Kedar E. Honasoge[1,2], Maria-Teresa Handschuh[1,2], Achim Marx[1], Rudolf Gross[1,2,3], Hans Huebl[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 (MCQST), 80799 Munich, Germany

Quantum key distribution (QKD) holds the promise of delivering unconditionally secure distribution of classical keys between remote parties. So far, its implementation in the microwave regime, which is frequency-compatible with superconducting quantum circuits, has been missing. Here, we present the realization of a continuous-variable QKD protocol using propagating squeezed microwave states and demonstrate a finite-size security. In order to store these states for quantum memory applications, we investigate a scheme based on the excitation of high-coherence spin ensembles by microwave quantum signals. Here, we focus on a phosphorus donor electron spin ensemble hosted in isotopically engineered silicon. Our measurements indicate a successful coupling of microwave squeezed states to the spin ensemble with an estimated efficiency of 36%.

TT 15.9 Tue 12:00 H31

Secure squeezed state microwave quantum communication with spin ensembles (part 2) — •Patricia Oehrl[1,2], Florian Fesquet[1,2], Tahereh Parvini[1,2,3], Maria-Teresa Handschuh[1,2], Kedar E. Honasoge[1,2], Achim Marx[1], Nadezhda Kukharchyk[1,2,3], Rudolf Gross[1,2,3], Kirill G. Fedorov[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 Technology (MCQST), Munich, Germany

Solid-state spin ensembles offer exceptional coherence times at low temperatures and transition frequencies in the GHz range, which makes them ideal for interfacing with superconducting quantum circuits. Moreover, they are promising candidates for the storage of microwave quantum states, providing great potential for quantum memory and quantum sensing applications. Here, we investigate a phosphorus donor electron spin ensemble hosted in silicon. It is coupled to a superconducting microwave resonator and probed at millikelvin temperatures as well as moderate magnetic fields. We investigate the efficiency of photon absorption for coherent and squeezed microwave signals. To this end, we use continuous wave and pulsed electron spin resonance protocols. We verify our results with an input-output model of our hybrid system and discuss the storage efficiency of microwave signals.

We acknowledge financial support from the Federal Ministry of Education and Research of Germany (project number 16KISQ036).

TT 15.10 Tue 12:15 H31

Quantum thermodynamics of non-Markovian Otto cycles using the principle of minimal dissipation — •Salvatore Gatto[1], Alessandra Colla[2], Heinz-Peter Breuer[1], and Michael Thoss[1] — [1]University of Freiburg — [2]Università degli Studi di Milano

A central challenge in quantum thermodynamics revolves around establishing a consistent and universally accepted definition for work, heat, and entropy production in open quantum systems subjected to thermal reservoirs. A recently developed approach, known as principle of minimal dissipation [1,2], 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 the quantum Otto cycle[3] of a single-impurity Anderson model, with a particular focus on memory effects and strong system-bath couplings. The study uses the hierarchical equations of motion approach (HEOM), which allows a numerically exact simulation of nonequilibrium transport in general open quantum systems involving multiple bosonic and fermionic environments [4].

[1] A.Colla and H.-P.Breuer, Phys Rev.A 105, 052216 (2022).
[2] S.Gatto,A.Colla,H.-P.Breuer,M.Thoss,Phys.Rev.A110,032210(2024)
[3] I.A.Picatoste,A.Colla,H.-P.Breuer, Phys.Rev.Res.6,013258 (2024).
[4] J.Bätge, Y.Ke, C.Kaspar, M.Thoss, Phys.Rev.B 103, 235413 (2021).

TT 15.11 Tue 12:30 H31

Non-Hermitian dynamics close to exceptional points — •Aisel Shiralieva, Grigorii Starkov, and Björn Trauzettel — University of Würzburg, Würzburg, Germany

Exceptional points (EPs), which are degeneracies occurring in both open classical and quantum systems, play a crucial role across numerous areas of physics. This work examines the behavior of dissipative systems with N levels, with a particular emphasis on non-Hermitian qubits and qutrits. These systems are of interest due to recent experimental studies involving a driven non-Hermitian superconducting qubit embedded within a three-level structure, where the ground state serves as an "effective bath". Although significant progress have been made in understanding EPs, the precise connection between their occurrences in non-Hermitian Hamiltonians and in the Lindblad formalism remains unclear, especially if quantum jumps are treated as perturbations. Our results reveal how EPs in these two frameworks relate to each other and illustrate how perturbations can either lift the degeneracy or eliminate the EPs entirely in the Lindblad formalism.

TT 15.12 Tue 12:45 H31

Post-measurement Quantum Monte Carlo — •Kriti Baweja[1], David Luitz[1], and Samuel Garratt[2] — [1]Institute of Physics, Nussalle 12 53115, Bonn, Germany — [2]Department of Physics, University of California, Berkeley, CA 94720, USA

We study the effects of extensive measurements on many-body quantum ground and thermal states using Quantum Monte Carlo (QMC). Measurements generate density matrices composed of products of local nonunitary operators, which we expand into operator strings via a generalized stochastic series expansion (SSE). This 'post-measurement SSE' employs importance sampling of operator strings contributing to a measured thermal density matrix. Our algorithm is applied to the spin-1/2 Heisenberg antiferromagnet on a square lattice. Thermal states of this system exhibit SU(2) symmetry, which is preserved through SU(2)-symmetric measurements. We identify two classes of post-measurement states: one where correlations can be efficiently computed using deterministic loop updates, and another where SU(2)-symmetric measurements induce a QMC sign problem in any site-local basis. Using this approach, we demonstrate measurement-induced phenomena, including the creation of long-range Bell pairs, symmetry-protected topological order, and enhanced antiferromagnetic correlations. This method offers a scalable way to simulate measurement-induced collective effects, providing numerical insights to complement experimental studies. Our work opens the door to exploring how measurements influence many-body quantum systems, enabling deeper understanding of their dynamics. [1] arXiv:2410.13844

TT 15.13 Tue 13:00 H31

Zero-temperature magnon-mediated long-range entanglement in Heisenberg chain with magnetic impurity — •Marius Melz and Jamal Berakdar — Martin-Luther-Universität Halle - Wittenberg

The understanding of many-body entanglement in solid-state systems is of interest both for fundamental and practical reasons. In this work, a spin-1/2 Heisenberg chain is coupled to a chiral magnetic impurity, acting as a magnon scatterer. The spatial entanglement structure of the ground state and its effect on the propagation of local magnons is characterized by the spatially resolved bipartition entropy and logarithmic negativity. The ground state exhibits an entanglement transition at a critical magnetic bias field. We find that magnon scattering generates steady-state long-range entanglement between two scattering regions. Furthermore, it is demonstrated that this effect is significantly amplified in the high-entanglement phase.

TT 16: Superconductivity: Properties and Electronic Structure II

Time: Tuesday 9:30–12:45 Location: H32

TT 16.1 Tue 9:30 H32

Layer-thickness and substrate effects on superconductivity in epitaxial FeSe films on BLG/SiC(0001) — •yongsong wang[1], haojie guo[1], ane etxebarria[2], sandra sajan[1], sara barja[1,2,3,4], and miguel moreno ugeda[1,3,4] — [1]Donostia International Physics Center, San Sebastián, Spain — [2]Department of Polymers and Advanced Materials, University of the Basque Country, San Sebastián, Spain — [3]Centro de Física de Materiales, San Sebastián, Spain — [4]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

The layered nature and simple structure of FeSe reveal this iron-based superconductor as a unique building block for the design of artificial heterostructure materials. While superconductivity develops in ultrathin films of FeSe on $SrTiO_3$ substrates, it remains unclear whether it can be developed on more chemically inert, layered materials such as graphene. Here, we report on the characterization of the structural, chemical and electronic properties of few-layer FeSe on bilayer graphene grown on SiC using low-temperature scanning tunneling microscopy/spectroscopy (STM/STS) and X-ray photoelectron spectroscopy (XPS). STM imaging of our FeSe films with thicknesses up to three layers exhibit the tetragonal crystal structure of bulk FeSe, which is supported by XPS spectra consistent with the FeSe bulk counterpart. While our STS measurements at 340 mK reveal a metallic character for few-layer FeSe on BLG/SiC, they show an absence of superconductivity, as the low-lying electronic structure exhibits a spatially anisotropic dip-like feature robust against magnetic fields. Superconductivity in FeSe/BLG/SiC, however, emerges for thicker films with T_c = 6 K.

TT 16.2 Tue 9:45 H32

Lattice dynamical studies in the unconventional superconductor: LiFeAs — •Akshay Tewari[1], Sabine Wurmehl[2], Bernd Büchner[2], Andrea Piovano[3], and Markus Braden[1] — [1]II.Physics Institute, Universität zu Köln, Zülpicher Strasse 77, 50937 Köln, Germany — [2]IFW Dresden, D-01171 Dresden, Germany — [3]ILL, 71 avenue des Martyrs, 38000 Grenoble, France

LiFeAs crystallizes in a tetragonal structure(P4/nmm) and is superconducting below T_c=18K. Unlike other iron pnictides, LiFeAs does not exhibit long-range magnetic order, but has AFM fluctuations at incommensurate positions. Studies suggest that superconductivity in LiFeAs is driven by electronic correlations but a contribution from electron phonon coupling is still debated. We have studied the phonon dispersion of LiFeAs using inelastic neutron scattering on large single crystals to search for anomalies in the dispersion which are signatures of electron phonon coupling. We could determine almost all branches along main symmetry directions by analyzing the data with force-model lattice dynamical calculations. Temperature dependencies of specific phonon modes were also examined. Our experimental results provide significant differences to the DFT calculations previously reported[1,2]. No pronounced instability was observed but strong relative energy shifts of 6% were detected for specific modes in the temperature dependent scans. The overall dispersion fits the lattice dynamical model and is also supported by more recent DFT calculations.

[1] G.Q. Huang et al. PRB 82, 014511 (2010).
[2] R.A. Jishi et al., Adv. in Cond.Mat.Phys. 804343(2010).

TT 16.3 Tue 10:00 H32

NMR evidence of pseudogap and against spin magnetism in the time-reversal symmetry breaking state of $Ba_{1-x}K_xFe_2As_2$ — •F. Bärtl[1], F. Caglieris[2,3,4], Y. Li[5], Q. Hu[5], Y. Zheng[5], C.-H. Yim[5], J. Wosnitza[1,6], R. Sarkar[2], H.-H. Klauss[2], E. Babaev[7], J. Garaud[8], H. Kühne[1], and V. Grinenko[5] — [1]HLD-EMFL, HZDR, Dresden — [2]University of Genoa — [3]CNR-SPIN, Genoa — [4]IFW, Dresden — [5]TDLI, Shanghai Jiao Tong University — [6]IFMP, TU Dresden — [7]Department of Physics, KTH, Stockholm — [8]Institut Denis Poisson, Université de Tours

Recently, we focused on the investigation of samples from the narrow doping range of $0.7 \leq x \leq 0.8$ in the hole-doped superconductor $Ba_{1-x}K_xFe_2As_2$. Here, the proximity to a Lifshitz transition results in a multiband $s + is$ superconducting state, which spontaneously breaks time-reversal symmetry (BTRS), manifested as spontaneous currents around non-magnetic impurities. This is theoretically predicted and was experimentally revealed by μ^+SR measurements, where the depolarization rate below T_c is only non-zero in the mentioned narrow doping regime. Moreover, the μ^+SR together with Nernst-effect measurements suggest the emergence of the BTRS already at a temperature $T_c^{Z_2} > T_c$, which indicates a behavior beyond mean-field approximation, described by a four-fermion order parameter, hence termed quartic metal. Here, we present ^{75}As NMR spectroscopy and relaxometry measurements of a sample with $x = 0.77$, which contradict the presence of conventional spin magnetism and hint at pseudogap behavior in the critical regime.

TT 16.4 Tue 10:15 H32

Observation of saddle point nesting driven charge order on the surface of a 122-type iron-based superconductors — •Yu Zheng — Tsung Dao Lee Institute, Shanghai Jiao Tong University, 1 Lisuo Road, Shanghai, 201210

Unconventional superconductivity is known for intertwining with other correlated states, making the exploration for new intertwined orders highly important for understanding the mechanism of unconventional superconductivity. Spin and nematic orders are widely observed in the iron-based superconductors (FeSCs). However, evidence for charge order in the phase diagrams of FeSCs is rarely found. Employing STM and DFT, here we demonstrate,through expanding the phase diagram of $Ba_{1-x}K_xFe_2As_2$ to the heavily hole doped regime by surface doping, the formation of a CDW order on the As-terminated surface of $Ba_{0.23}K_{0.77}Fe_2As_2$, whose emergence suppresses superconductivity completely, indicating direct competition between the two. Notably, the wavevector of the charge order matches with the nesting vector between the near-EF saddle points, suggesting saddle-point nesting as its driving mechanism.

TT 16.5 Tue 10:30 H32

Long-term stability of irradiation-induced defects in $YBa_2Cu_3O_{7-\delta}$ thin films — •Bernd Aichner[1], Sandra Keppert[2], Philip Rohringer[1], Marius-Aurel Bodea[2], Benedikt Müller[3], Max Karrer[3], Reinhold Kleiner[3], Edward Goldobin[3], Dieter Koelle[3], Johannes David Pedarnig[2], and Wolfgang Lang[1] — [1]Faculty of Physics, University of Vienna, Wien, Austria — [2]Institute of Applied Physics, Johannes Kepler University Linz, Linz, Austria — [3]Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, University of Tübingen, Tübingen, Germany

Helium ion irradiation is the method of choice for creating sub-100 nm structures in cuprate superconductors suitable for pinning magnetic flux quanta.

In this presentation, we address the stability of irradiation-induced defects for irradiation performed in an ion implanter as well as in a helium ion microscope. Annealing experiments allow us to extract the activation energy for the diffusion of displaced oxygen atoms back to their original sites in the material's crystal structure. Additionally, a long-term study indicates that vortex-matching features caused by a regular array of irradiation-induced defect columns are still present after about six years of sample storage, a strong hint for the stability of the defects created by irradiation. These findings may be an important ingredient for future applications of helium ion irradiation in the production process of superconducting electronics.

TT 16.6 Tue 10:45 H32

Two-fluid model analysis of the terahertz conductivity of YBaCuO samples: Optimally doped, underdoped and overdoped cases — •Christelle Kadlec[1], Wen-Yen Tzeng[2], Chih-Wei Luo[3], Jiunn-Yuan Lin[3], and Michal Šindler[1] — [1]Institute of Physics, Prague, Czech Republic — [2]National Formosa University, Yunlin, Taiwan — [3]National Yang Ming Chiao Tung University, Hsinchu, Taiwan

The conductivity of a high-quality overdoped $Y_{0.7}Ca_{0.3}Ba_2Cu_3O_{7-\delta}$ film and of underdoped and optimally doped films of its parent compound $YBa_2Cu_3O_{7-\delta}$ was measured using time-domain terahertz spectroscopy. In the normal state, the frequency dependence of the complex conductivity is described by the Drude model. Below the critical temperature T_c, the two-fluid model was successfully employed to fit all the spectra, from 5 K up to T_c. The temperature behaviour of fundamental parameters such as the scattering rate $1/\tau$, the superfluid (normal) fraction f_s (f_n) and the complex conductivity σ was investigated at given frequencies. We observed that a fifth of the electrons do not condense to the superfluid fraction even at 5 K for the optimally doped and overdoped samples. The real part of the conductivity $\sigma_1(T)$ exhibits a peak for low frequencies. It can be observed for all three compounds and its exact shape depends on the quality of the sample. A further analysis shows that this peak is a consequence of the competition between the scattering time $\tau(T)$ and the superfluid fraction $f_s(T)$.

For further details, see https://arxiv.org/pdf/2309.17408

15 min. break

TT 16.7 Tue 11:15 H32

Higgs spectroscopy on the interplay of superconductivity and charge density waves — •Liwen Feng[1,2], Tim Priessnitz[2], Thales De Oliveira[3], Jan-Christoph Deinert[3], Sergey Kovalev[3], Hao Chu[4], and Stefan Kaiser[1] — [1]TUD Dresden University of Technology, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [4]Shanghai Jiao Tong University, China

Superconductivity (SC) and charge density wave (CDW) often coexist. In the framework of Higgs Spectroscopy, we use high-field terahertz pulses to coherently drive the corresponding Higgs and CDW amplitude modes and investigate their interplay directly in the third harmonic generation (THG) signals. Our findings reveal that the interaction between CDW fluctuations and Higgs oscillations lead to a Fano resonance [1]. We will show that we can characterize the interplay by directly investigating the relative phase responses of these modes in the time-domain THG signal [1]. We will discuss competing interactions of SC with long-range CDW order in 2H-$NbSe_2$ [1] and hole-doped cuprate $La_{2-x}Sr_xCuO_4$, interaction with short-range CDW order in the electron-doped cuprate $La_{2-x}Ce_xCuO_4$, and a noninteracting scenario in the Bismuthate superconductor $Ba_{1-x}Rb_xBiO_3$.

[1] H. Chu et al., Nat Commun. 14 (2023) 1343.

TT 16.8 Tue 11:30 H32

Dynamics of non-thermal states in a cuprate superconductor revealed by mid-infrared three-pulse spectroscopy — •Angela Montanaro[1,2,3], Enrico Maria Rigoni[1,2], Giacomo Jarc[1,2], Viktor Kabanov[4], and Daniele Fausti[1,2,3] — [1]University of Trieste, 34127 Trieste, Italy — [2]Elettra Sincrotrone Trieste, 34127 Trieste, Italy — [3]University of Erlangen-Nürnberg, 91058 Erlangen, Germany — [4]Jožef Stefan Institute, 1000 Ljubljana, 25123 Brescia, Italy

Unconventional cuprate superconductors exhibit anomalous high-frequency electrodynamics compared to standard BCS systems. In BCS superconductors, spectral weight redistribution occurs only near the superconducting gap energy, but in cuprates, changes extend to energies two orders of magnitude higher. This implies that high-energy electronic excitations might influence the pairing mechanism.

In this work, we disentangle the effects of high- and low-photon energy excitations in a prototype cuprate system. We set up a technique which combines two pump pulses having substantially different photon energy: a visible pulse much more energetic than the superconducting gap and a mid-infrared pump with photon energy smaller than the gap. Our findings show that the two photoexcitations have a different effect on the condensate electrodynamics. Moreover, we found that the overall response of the system strongly depends on the time-order of the two photoexcitations. This allowed us to constrain the lifetime of photoinjected carriers and ultimately the recovery time of the condensate.

TT 16.9 Tue 11:45 H32

Hidden antiferromagnetism and pseudogap from fluctuating stripes — •Henning Schlömer[1], Annabelle Bohrdt[2], and Fabian Grusdt[1] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 — [2]University of Regensburg, Universitätsstr. 31, 93053 Regensburg

One of the central mysteries of hole-doped cuprates is the pseudogap phase, whose unusual properties are believed to be essential for understanding high-temperature superconductivity. While a broad variety of theoretical proposals have been put forward in the past decades, a unified view connecting the pseudogap to other observed phases, like antiferromagnetic (AFM) and stripe phases, has remained elusive. In this talk, I will propose a scenario in which the the AFM, stripe, and pseudogap phases all share a common origin: The spins in the material form an ordered AFM background, on top of which fluctuating domain walls exist that can obscure long-range order. I will argue that these fluctuating domain walls are at the heart of the pseudogap phase: They hide magnetic order in real space, leaving only short-range AFM correlations detectable in experiments. Furthermore, these fluctuations can give rise to a topological phase (an odd Z2 spin liquid) that supports a small Fermi surface, consistent with experimental data. At a (hidden) quantum critical point, hidden AFM order fully dissolves, restoring spin symmetry without a divergent correlation length.

TT 16.10 Tue 12:00 H32

Direct evidence of pairing up to the pseudogap energy in cuprate high-temperature superconductors — Jiasen Niu[1,2], Maialen Ortego Larrazabal[3], Thomas Gozlinski[1,2], •Yudai Sato[1,2], Koen M. Bastiaans[4], Tjerk Benschop[1], Jian-Feng Ge[1,5], Yaroslav M. Blanter[4], Genda Gu[6], Ingmar Swart[3], and Milan P. Allan[1,2] — [1]Leiden Institute of Physics, Leiden University — [2]Fakultät für Physik, Ludwig-Maximilians-Universität — [3]Debye Institute of Nanomaterials Science — [4]Kavli Institute of Nanoscience, Delft University of Technology — [5]Max Planck Institute for Chemical Physics of Solids — [6]Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory

In cuprate high-temperature superconductors, a pseudogap state is observed in a specific region of the phase diagram. Since it exists between the Mott insulating and superconducting phases, the origin of the pseudogap is thought to be associated with electron pairing and/or a locally ordered state. Despite extensive studies, however, a definitive explanation remains elusive. Shot-noise experiments, which can directly detect electron pairing, hold the potential to resolve this long-standing debate. In this presentation, I will report on local shot-noise measurements on the unconventional superconductor $Bi_2Sr_2Ca_2CuO_{8+\delta}$ using scanning tunneling microscopy. We found that the pseudogap energy is associated with electron pairing, with pairing energies reaching up to 70 meV. Our results exclude the possibility of the pseudogap arising solely from local orders, and instead indicate a clear relation between the pseudogap state and Cooper pair formation.

TT 16.11 Tue 12:15 H32

Spin susceptibility in a pseudogap state with spiral magnetic fluctuations — •Paulo Forni[1], Pietro M. Bonetti[1,2], Henrik Müller-Groeling[1], Demerio Villardi[1], and Walter Metzner[1] — [1]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany — [2]Department of Physics, Harvard University, Cambridge MA 02138, USA

We explore the spin susceptibility in the pseudogap phase of the 2D Hubbard model by introducing spin fluctuations into a spiral magnetic state. This analysis is based on an emergent SU(2) gauge theory following the fractionalization of the electron field into a fermionic chargon, carrying charge, and a bosonic spinon, encoding its spin. Chargons are treated within the random phase approximation in a spiral state. Deep in the pseudogap phase, spin fluctuations can be captured by a gradient expansion of the spinon field, leading to a nonlinear sigma model whose stiffnesses are computed from the underlying chargon order. Our results reveal a gapped, nematic, and SU(2)-symmetric spin susceptibility with a broad spectrum of magnetic excitations. These findings align with key features of the pseudogap phenomenology in cuprates, offering a unified theoretical framework to describe its spin and charge degrees of freedom.

TT 16.12 Tue 12:30 H32

Rise and fall of the pseudogap in the Emery model: Insights for cuprates — •Mario O. Malcolms[1], Henri Menke[1,2], Yi-Tin Tseng[2], Eric Jacob[3], Karsten Held[3], Philipp Hansmann[3], and Thomas Schaefer[1] — [1]Max-Planck-Institut für Festkörperforschung — [2]University of Erlangen-Nürnberg — [3]Institute of Solid State Physics, TU Wien

The intriguing properties of layered cuprate superconductors have not lost their fascination since their discovery. The physical mechanisms behind this rich phenomenology -after almost 40 years of intense community effort- are still highly debated. The reason for the latter is deeply routed in the fact that cuprates are strongly interacting quantum many-body systems, many of whose properties cannot be explained by a simple single-particle picture: their electrons are strongly correlated in space and in time. Adding to the complexity of this material class it has been realized early on, that due to the hybridization of copper $d_{x^2-y^2}$- and oxygen $p_{x/y}$-orbitals in the relevant two-dimensional layers, the undoped parent compounds are charge-transfer, rather than (single-orbital) Mott-Hubbard insulators. The adequate minimal theoretical modellization of cuprates, hence, has to include the oxygen p-orbitals on top of the copper-d ones, enabling, among other properties, (Zhang-Rice) singlet-formation between these orbitals. In this work we make significant progress in the universal description of the cuprates' phase diagrams by extending the powerful λ-corrected dynamical vertex approximation (DΓA) to the three-band Emery model.

TT 17: Correlated Electrons: Method Development

Time: Tuesday 9:30–13:15 Location: H33

TT 17.1 Tue 9:30 H33

Accuracy of embedded impurity methods for spin-polarized systems — •Kevin Ackermann and Maurits W. Haverkort — Institute for Theoretical Physics, Heidelberg, Germany

Ab-Initio embedded impurity approaches, such as DFT+DMFT, have proven to be a robust tool in understanding physical properties of materials for quite some time. Still the intersection between the employed mean field method, like Hartree-Fock or DFT, and the many-body impurity remains awkward. One of the issues can be exemplified for spin-polarised systems. For these materials spin is no longer a good quantum number in mean-field approximations and SU(2)-symmetry is explicitly broken by the usual spin-polarized mean-field methods. This automatically turns every spin-flip excitation into a *Hund's* coupling excitation, distorting the many-body spectral function in the process. Standard methods used in quantum chemistry to remedy this, such as restricted open shell Hartree-Fock/Kohn-Sham, average over the different spin potentials or densities. However, there are many flavors of realizing the needed spin averaging. To examine the impact of this choice, we compare ground state properties, such as bond lengths, as well as excitation spectra among a multitude of spin averaging schemes for a range of molecules.

TT 17.2 Tue 9:45 H33

Neural-network-supported Configuration Interaction as impurity solver for DMFT — •Alexander Kowalski[1], Philipp Hansmann[2], Giorgio Sangiovanni[1], and Adriana Pálffy[1] — [1]Institute for Theoretical Physics and Astrophysics, Universität Würzburg, 97074 Würzburg, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

Solving a strongly correlated lattice model by means of DMFT involves mapping it to interacting auxiliary Anderson impurity models (AIM) whose solution consumes the majority of computational resources. For the solution, algorithms such as QMC, NRG, DMRG or exact diagonalization can be used, where the latter in particular has the advantage of being able to compute exact results on the real frequency axis but is constrained to a small number of bath sites due to the exponential growth of the Hilbert space. Selected configuration interaction (CI) based approaches that operate in only a subspace of the total Hilbert space can greatly alleviate this problem while still including the most relevant contributions. Recently, a neural network has been shown to improve basis selection in ground state AIM calculations [1]. Here we investigate the use of a similar neural-network-supported CI solver to select the Hilbert space basis for the auxiliary AIM in DMFT.

[1] P. Bilous, L. Thirion, H. Menke, M. W. Haverkort, A. Pálffy, P. Hansmann, arXiv:2406.00151

TT 17.3 Tue 10:00 H33

Neural Quantum States as Dynamical Mean Field Theory solvers — •Jonas B. Rigo[1], Wladislaw Krinitsin[1,2], and Markus Schmitt[1,2] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control, 52425 Jülich, Germany — [2]University of Regensburg

Neural Quantum Sates (NQS) constitute a variational wave function ansatz, that can provably efficiently represent even highly entangled quantum many-body states. Beyond their representative power, NQS inherit the speed of modern neural networks (NN) and equally profit from the enormous development that NNs have recently received. In this work we show that NQS can efficiently find the ground state of quantum impurity models with large baths, allowing us to compute high quality real-frequency, zero-temperature Green's functions by means of a Krylov-like method. We demonstrate the capability of this approach and its potential as dynamical mean-field theory (DMFT) solver at the example of the Bethe lattice and other benchmarks.

TT 17.4 Tue 10:15 H33

Neural network supported Configuration Interaction calculations in quantum many-body clusters — •Louis Thirion[1], Pavlo Bilous[2], Yorick L. A. Schmerwitz[3,4], Gianluca Levi[3], Elvar Ö. Jónsson[3], Henri Menke[5], Maurits Haverkort[6], Adriana Pálffy-Buss[7], Hannes Jónsson[3], and Philipp Hansmann[1] — [1]University of Erlangen-Nürnberg — [2]Max Planck Institute for the Science of Light, Erlangen — [3]University of Iceland, Reykjavik — [4]Max Planck Institute for Coal Research, Mühlheim — [5]Max Planck Institute for Solid State Research, Stuttgart — [6]University of Heidelberg — [7]University of Würzburg

A novel method is presented for computing the ground state in finite-size quantum many-body systems using configuration interaction (CI) enhanced by machine learning. Our recently developed Python library Solax [1] is used for this purpose. A neural network classifier is trained to select an efficient many-body basis in an iterative procedure. It addresses the exponential growth of the Hilbert space while maintaining accuracy. Validation with the Single Impurity Anderson Model shows a basis reduction by at least an order of magnitude compared to standard truncation schemes [2]. Application to the N_2 molecule with $\leq 2 \times 10^5$ Slater determinants, gives results comparable to full CI calculations with nearly 10^{10} determinants [3]. We aim to extend this method to multi-tier embedding schemes for predicting critical energy scales in heterogeneous catalysis.

[1] L.Thirion, P.Hansmann, P.Bilous, arXiv:2408.16915v1;
[2] P.Bilous, L.Thirion *et al.*, arXiv:2406.00151;
[3] Y.L.A.Schmerwitz, L.Thirion *et al.*, arXiv:2406.08154.

TT 17.5 Tue 10:30 H33

Simulating two-dimensional fermionic systems with strong correlations using Neural Quantum States — •Hannah Lange[1,2,3], Annika Böhler[1,2], Christopher Roth[4], and Annabelle Bohrdt[5,2] — [1]LMU Munich — [2]Munich Center for QST, Munich — [3]Max-Planck-Institute for Quantum Optics, Garching — [4]Flatiron Institute, New York — [5]University of Regensburg

Simulating strongly interacting fermionic systems is crucial for understanding correlated phases like unconventional superconductivity, yet it remains a challenge for numerical and experimental methods in many cases. Here, I will discuss the efficiency and accuracy of fermionic neural quantum states (NQS), in particular hidden fermion determinant states (HFDS), for simulating doped quantum magnets. I will show results on the strongly interacting limit of the Fermi-Hubbard model across the entire doping regime. The HFDS achieve energies competitive with matrix product states (MPS) on lattices as large as 8 x 8 sites while using several orders of magnitude fewer parameters. This efficiency enables us to probe low-energy physics across the full doping range: Starting from the low-doping regime, where magnetic polarons dominate, we track their evolution with doping through spin and polaron correlations and compare them with experimental measurements. Furthermore, I will discuss different initializations of NQS, including a hybrid training scheme, which improves the training by incorporating experimental measurements. Our findings open the way for simulating large-scale fermionic systems at any particle filling.

TT 17.6 Tue 10:45 H33

Simulating Fermi Hubbard and t-J Models with Neural Quantum States — •Annika Böhler[1,2], Hannah Lange[1,2,3], Christopher Roth[4], and Annabelle Bohrdt[2,5] — [1]Department of Physics Ludwig-Maximilians-Universität München, Germany — [2]Munich Center for Quantum Science and Technology, Germany — [3]Max-Planck-Institute for Quantum Optics, Munich Germany — [4]Center for Computational Quantum Physics, Flatiron Institute, New York, USA — [5]University of Regensburg, Germany

Simulating strongly correlated electron systems remains a major challenge in condensed matter physics. While these systems offer a rich playground for studying emergent phenomena such as high-temperature superconductivity, they remain challenging to study both experimentally and theoretically, due to the exponential growth of the Hilbert space dimension. Neural Quantum States (NQS) offer a versatile variational framework to address this complexity. In this presentation, I will discuss the application of NQS to the strong interaction limit of the Fermi-Hubbard model. I will explore results obtained using different NQS architectures tailored to encode specific symmetry constraints. Hidden fermion determinant states are employed to efficiently capture fermionic antisymmetry, while other architectures incorporate lattice symmetries to improve accuracy and efficiency. I will show how these models can be extended to study higher SU(N) generalizations of the t-J model, providing a flexible approach to investigate a wide range of strongly correlated quantum systems and their emergent phases.

TT 17.7 Tue 11:00 H33

Investigating Quantum Many-Body Systems with Neural Quantum States — •Fabian Döschl[1,2], Felix A. Palm[1,2,3], Hannah Lange[1,2,4], Fabian Grusdt[1,2], and Annabelle Bohrdt[2,5] — [1]Ludwig-Maximilians-University Munich, Theresienstr. 37, Munich D-80333, Germany — [2]Munich Center for Quantum Science and Technology, Schellingstr. 4, Munich D-80799, Germany — [3]CENOLI, Universite Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium — [4]Max-Planck-Institute for Quantum Optics, Hans-Kopfermann-Str.1, Garching D-85748, Germany — [5]University of Regensburg, Universitätsstr. 31, Regensburg D-93053, Germany

Neural Quantum States (NQS) have shown to be a reliable and efficient method for numerically simulating the ground states of two-dimensional quantum systems. Of particular interest for current research are fractional quantum Hall models and lattice gauge theories, both of which present significant challenges for state-of-the-art numerics. In this study, we demonstrate that NQS are capable of effectively simulating such complex systems. We focus on evaluating the strengths and weaknesses of this Ansatz from a physical perspective, providing deeper insights into the potential difficulties encountered during optimization.

15 min. break

TT 17.8 Tue 11:30 H33

X-ray absorption meets Matrix Product States: Application of a MPS-based band Lanczos solver to impurity models with core levels — •Coraline Letouzé[1], Sebastian Paeckel[2], Guillaume Radtke[1], and Benjamin Lenz[1] — [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

In strongly correlated materials like transition metal (TM) oxides, core-level spectroscopies such as X-ray Absorption Spectroscopy (XAS) are usually solved on a small cluster made of the valence and core states of the TM ion and its oxygen ligands. This cluster is then diagonalized exactly via the Lanczos algorithm. In the quest to extend this cluster model into an impurity model, beyond the capabilities of Exact Diagonalization, we apply the band Lanczos algorithm on Matrix Product States (MPS). Compared to standard valence-only impurity models, the inclusion of core levels leads to more interacting orbitals connected by an intricate interaction network.

In this talk I will present our results on impurity models for simple TM oxides (NiO, MnO), with a focus on the numerical stability and convergence of the MPS-based band Lanczos solver.

TT 17.9 Tue 11:45 H33

Diagonal isometric tensor product states in two dimensions — •Benjamin Sappler[1,2], Masataka Kawano[3], and Frank Pollmann[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 Basic Science, University of Tokyo, Meguro-ku, Tokyo 153-8902, Japan

The numerical simulation of quantum many-body systems is a challenging problem due to the exponential growth of Hilbert space with system size. In one spatial dimension this challenge was answered by the Density Matrix Renormalization Group (DMRG) algorithm, which can be understood as a variational method over Matrix Product States (MPS). One of the reasons for the success of DMRG is the existence of a canonical form for MPS that simplifies and speeds up most algorithms. Isometric tensor product states (isoTPS) generalize the canonical form of MPS to tensor networks in two and higher dimensions and have shown first promising results. Here we introduce an alternative canonical form for isoTPS by rotating the lattice by $\pi/4$ and introducing auxiliary tensors. We implement the time evolving block decimation (TEBD) algorithm on this new canonical form and benchmark the method by computing ground states and the real time evolution of the transverse field Ising model in two dimensions on large square lattices.

TT 17.10 Tue 12:00 H33

Dual Fermion Approach to the Falicov-Kimball Model: a benchmarking of methods — •Akshat Mishra[1], Hugo U. R. Strand[2], and Erik G. C. P. van Loon[1] — [1]NanoLund and Division of Mathematical Physics, Department of Physics, Lund University, Lund, Sweden — [2]School of Science and Technology, Örebro University, SE-701 82 Örebro, Sweden

The Falicov-Kimball model is often said to be the simplest lattice model for electronic correlations. It consists of mobile electrons and immobile impurities and the competition between the kinetic and interaction energy governs the physics. As a function of interaction strength and doping, the model shows uniform metallic and insulating phases as well as charge-density waves. A numerically exact solution of the Falicov-Kimball model is possible using classical Monte Carlo. In this work, we use this as a benchmark for two approximate many-body methods, Dynamical Mean-Field Theory (DMFT) and Dual Fermion (DF). We explore the thermodynamic properties, the electronic structure and the momentum-dependent susceptibility.

TT 17.11 Tue 12:15 H33

Enabling accurate Quantum Chemistry on current and near-term Quantum Hardware with the Transcorrelated Method. — •Werner Dobrautz[1,2], Igor O. Sokolov[5], Ali Alavi[4], Martin Rahm[3], and Ivano Tavernelli[5] — [1]CASUS - HZDR, Görlitz, Germany — [2]ScaDS.AI - TU Dresden, Dresden, Germany — [3]Chalmers University, Gothenburg, Sweden — [4]MPI-FKF, Stuttgart, Germany — [5]IBM Research, Rüschlikon, Switzerland

In this talk I will present how to enable accurate and efficient quantum chemistry calculations on NISQ devices for relevant chemical and physical problems. This is achieved by the use of an exact explicitly correlated method in the form of the transcorrelated (TC) method.

TC methods provide an efficient way of partially transferring the description of electronic correlations from the ground state wavefunction directly into the underlying Hamiltonian. This reduces the necessary quantum resources two-fold:

(1) The TC Hamiltonian possesses a more compact ground state wavefunction, which facilitates electronic structure calculations and thus requires shallower quantum circuits.

(2) For ab initio quantum chemistry problems the TC method reduces the required number of qubits, by allowing to obtain highly accurate results with small basis sets.

I will present results on the Hubbard model and small chemical test systems, like the hydrogen molecule and lithium hydride, where results within chemical accuracy to the complete basis set limit and experimental results are within reach with only 4 to 10 qubits.

TT 17.12 Tue 12:30 H33

Cluster extension of the DMF^{2}RG and application to the 2d Hubbard model — •Marcel Krämer[1,2], Michael Meixner[1], Kilian Fraboulet[1], Pietro Bonetti[3], Demetrio Vilardi[1], Nils Wentzell[4], Thomas Schäfer[1], Alessandro Toschi[5], and Sabine Andergassen[2,5] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Institute of Information Systems Engineering, TU Wien, Vienna, Austria — [3]Department of Physics, Harvard University, Cambdrige, USA — [4]Center for Computational Quantum Physics, Flatiron Institute, New York, USA — [5]Institute for Solid State Physics, TU Wien, Vienna, 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 **non-**

local nonperturbative correlations can be also incorporated in the DMF^2RG 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 17.13 Tue 12:45 H33

How to stay on the physical branch of self-consistent many-electron schemes — •Herbert Essl, Matthias Reitner, and Alessandro Toschi — TU Wien

We precisely determine the mathematical condition under which the physical solution of the many-electron problem, obtained by self-consistent resummations becomes unstable by increasing interaction strength. The evaluation of the proposed criterion only requires the calculation of two-particle correlation functions. The validity of our predictions has been explicitly verified by performing self-consistent calculations of basic interacting models. Our findings eventually unveil the precise connection linking the misleading convergence of the self-consistent schemes to the multivaluedness of the Luttinger-Ward functionals and to the divergences of the irreducible vertex functions. Further, our analysis explains how the misleading convergence occurs even in parameter regions without vertex divergences. More importantly, it allows us to define a general scheme for stabilizing the physical solution, when it is unstable in conventional self-consistent schemes.

TT 17.14 Tue 13:00 H33

Mapping energy functionals and external potential of V- representable charge densities of interacting quantum systems — •Calin-Andrei Pantis-Simut[1,2], Amanda Teodora Preda[1,2], and George Alexandru Nemnes[1,2] — [1]Horia Hulubei National Institute for Physics and Nuclear Engineering, Reactorului 30, 077125 Magurele-Ilfov, Romania — [2]Faculty of Physics, University of Bucharest, Atomistilor 405, 077125 Magurele-Ilfov, Romania

Quantum systems are shaping the modern information processing technologies. Designing and analyzing these systems yields one of the most outstanding challenges in modern physics. These systems are fairly complex due to the Coulomb interaction between the particles. There are several methods for solving these problems, the most accurate providing solutions beyond mean-field approaches. Here the Exact Diagonalization is regarded as the gold standard for a system containing several particles. Recently, charge densities of such systems have been successfully mapped from randomly generated external potentials, using cGANs models. In this work, we intend to develop a machine learning based-model in order to obtain energy functionals E[n] for several classes of Hamiltonians (e.g. containing spin-orbit interaction), thus enabling the bypass of numerical intensive procedures like Exact Diagonalization. For this task, we employ CNNs to map the energy functionals from the ground state charge density. A more in depth analysis of the inverse problem is employed also in this work. Successfully mapping the external potential is not trivial since not every proposed charge density is V-representable.

TT 18: Focus Session: Strongly Correlated Quantum States in Moiré Heterostructures (joint session TT/HL/MA)

In recent years, significant progress has been made in realizing and exploring correlated quantum states in multilayer moiré heterostructures of graphene or transition metal dichalcogenides. These achievements have been made possible by the high level of control and tunability of these systems. Striking phenomena have been demonstrated experimentally, including unconventional superconductivity, fractional quantum anomalous Hall states, Mott-Wigner states and density waves, as well as kinetic ferromagnetism. Moreover, recently novel spectroscopic experimental techniques have been developed which allow for new ways to explore the dynamical response of these exotic states. This focus session will discuss recent experimental advancements as well as theoretical developments in the field of strongly correlated moiré heterostructures.

Organizers: Dmitri K. Efetov (LMU München), Michael Knap (TU München)

Time: Tuesday 9:30–13:15 Location: H36

Topical Talk TT 18.1 Tue 9:30 H36

The Thermoelectric Effect and Its Natural Heavy Fermion Explanation in Twisted Bilayer and Trilayer Graphene — Dumitru Calugaru[1], Haoyu Hu[2], Rafael Luque Merino[3], Nicolas Regnault[4], Frank Koppens[3], Dmitri K. Efetov[5], and •Bogdan Andrei Bernevig[1] — [1]Dept of Physics, Princeton University, Princeton, USA — [2]DIPC, San Sebastián, Spain — [3]ICFO, Barcelona, Spain — [4]Laboratoire de Physique de l'ENS, Paris, France — [5]LMU Munich, Munich, Germany

We study the interacting transport properties of twisted bilayer graphene (TBG) using the topological heavy-fermion (THF) model, where TBG comprises localized, correlated f-electrons and itinerant, dispersive c-electrons. The Seebeck coefficient of TBG exhibits unconventional traits: negative values with sawtooth oscillations at positive fillings, contrasting typical band-theory expectations. This behavior arises from the dichotomy between heavy (short-lived, correlated f-electrons) and light (long-lived, dispersive c-electrons), with transport dominated by c-electrons due to their stronger dispersion and longer lifetimes. At positive integer fillings, c- (f-)electron bands govern the electron (hole) doping side, resulting in an overall negative Seebeck coefficient. Sawtooth oscillations occur near each integer filling due to gap openings. Our results underscore the importance of electron correlations and lifetime asymmetry, naturally captured by the THF model, in understanding TBG transport properties. These findings align with experiments on twisted bilayer and trilayer graphene and highlight the interplay of heavy and light carriers.

Topical Talk TT 18.2 Tue 10:00 H36

Angle-Tuned Chiral Phase Transition in Twisted Bilayer Graphene — •Laura Classen[1,2], Nikolaos Parthenios[1,2], Cheng Huang[3], Xu Zhang[3], Maksim Ulybyshev[4], Fakher Assaad[3], and Zi Yang Meng[4] — [1]Max Planck Institute for Solid State Research — [2]Technical University of Munich — [3]University of Hong Kong — [4]University of Wuerzburg

The twist angle constitutes an important control knob in twisted bilayer graphene that has become accessible in-situ. It effectively tunes between weakly interacting, decoupled graphene layers and strongly correlated electrons at a magic angle of around 1.1 degree. We propose that this facilitates the realisation of a chiral phase transition of Dirac fermions at charge neutrality in twisted bilayer graphene. We argue that the transition can be described by the Gross-Neveu-Yukawa model that couples Dirac fermions and an XY order parameter field. The quantum critical behavior of this effective model is consistent with quantum Monte Carlo simulations of the continuum model for twisted bilayer graphene.

Topical Talk TT 18.3 Tue 10:30 H36

Quantum Optics of Semiconductor Moire Materials — •Atac Imamoglu — Institute of Quantum Electronics, ETH Zurich

Moire superlattices in two dimensional semiconductors have enabled the observation of a wealth of phenomena driven by strong electronic correlations, ranging from Mott-Wigner states to fractional quantum anomalous Hall effect. In this talk, I will present experiments exploring quantum optical control of strongly correlated electrons.

15 min. break

Topical Talk TT 18.4 Tue 11:15 H36

Probing the Band Structures of Multilayer Graphene Using the Quantum Twisting Microscope — •Martin Lee[1,2], Ipsita Das[1,2], János Papp[1,2], Marc Currle[1], Jiazhuo Li[1,2], Mudit Bhatt[1,2], Jonah Herzog-Arbeitman[3], Jiabin Yu[3], Zhiyuan Zhou[3], Markus Becherer[4], Philipp Altpeter[1], Christian Obermayer[1], Heribert Lorenz[1], Kenji Watanabe[5], Takashi Taniguchi[5], Bogdan Andrei Bernevig[3,6,7], and Dmitri Efetov[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, München, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]Department of Physics, Princeton University, Princeton, New Jersey, USA — [4]School of Computation Information and Technology, Technical University of Munich, Germany — [5]National Institute of Material Sciences, Tsukuba, Japan — [6]Donostia International Physics Center, Donostia-San Sebastian, Spain — [7]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

Understanding the band-structure is foundational in describing the behavior of electrons in crystalline systems. While the tight-binding model effectively captures the non-interacting band-structures in materials like graphene, it relies on analytically or numerically derived hopping parameters. In this talk, we present the development of a quantum twisting microscope (QTM), which allows the k-resolved tunneling spectroscopy between the electronic states at the 2D tip and the 2D sample by twisting in-situ. Our QTM measurements allow us to extract the hopping parameters that agree with theoretical predictions.

Topical Talk TT 18.5 Tue 11:45 H36

Gate-Tunable Bose-Fermi Mixture in a Strongly Correlated Moiré Bilayer Electron System — •Nathan Wilson[1], Amine Ben Mhenni[1], Wilhelm Kadow[2], Mikołaj Metelski[1], Adrian Paulus[1], Alain Dijkstra[1], Jonathan Finley[1], and Michael Knap[2] — [1]Walter Schottky Institute, TU Munich, Garching, Germany — [2]School of Natural Sciences, TU Munich, Garching, Germany

Quantum gases consisting of species with distinct quantum statistics, such as Bose-Fermi mixtures, can behave in a fundamentally different way than their unmixed constituents. This makes them an essential platform for studying emergent quantum many-body phenomena such as mediated interactions and unconventional pairing. Here, we realize an equilibrium Bose-Fermi mixture in a bilayer electron system implemented in a WS_2/WSe_2 moiré heterobilayer with strong Coulomb coupling to a nearby moiré -free WSe2 monolayer. Absent the fermionic component, the underlying bosonic phase manifests as a dipolar excitonic insulator. By injecting excess charges, we show that the bosonic phase forms a stable mixture with added electrons but abruptly collapses upon hole doping. We develop a microscopic model to explain the unusual asymmetric stability with respect to electron/hole doping. By monitoring excitonic resonances from both layers, we demonstrate stability of the phase over a wide range in the boson/fermion density phase space, in agreement with theoretical calculations. Our results further the understanding of phases stabilized in moiré bilayer electron systems and demonstrate their potential for exploring the exotic properties of equilibrium Bose-Fermi mixtures.

TT 18.6 Tue 12:15 H36

Theory for Optical Control of Correlated States in Moiré Transition Metal Dichalcogenide Heterostructures — •Haoyang Tian and Urban Friedrich Peter Seifert — Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77a, 50937 Köln, Germany

In recent years, moiré transition metal dichalcogenide (TMD) heterostructures have emerged as highly versatile platforms for investigating phases and phenomena of strongly correlated electrons on emergent lattice scales. However, experimental characterization of the precise nature of some interaction-driven long-range ordered states and their excitations has remained a challenge. Given strong light-matter couplings and valley selection rules in TMD materials, ultrafast optical methods may constitute a promising avenue for probing and controlling these states and their collective modes. In this work, we develop a theoretical framework to describe coherent light-matter interactions in moiré TMD heterostructures, and model the system's steady-state and non-equilibrium dynamics during and after photoexcitation with a laser pulse. Thus obtained characteristic signatures of the system's dynamics may allow for new experimental insights.

TT 18.7 Tue 12:30 H36

Single-Particle Spectral Function of Fractional Quantum Anomalous Hall States — •Fabian Pichler[1,2], Wilhelm Kadow[1,2], Clemens Kuhlenkamp[3,1,2], and Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Department of Physics, Harvard University, Cambridge, Massachusetts, USA

Fractional quantum Hall states are the most prominent example of states with topological order, hosting excitations with fractionalized charge. Recent experiments in twisted $MoTe_2$ and graphene-based heterostructures provide evidence of fractional quantum anomalous Hall (FQAH) states, which spontaneously break time-reversal symmetry and persist even without an external magnetic field. Understanding the unique properties of these states requires the characterization of their low-energy excitations. To that end, we construct a parton theory for the energy and momentum-resolved single-particle spectral function of FQAH states. We explicitly consider several experimentally observed filling fractions as well as a composite Fermi liquid in the half-filled Chern band. The parton description captures qualitatively our numerical exact diagonalization results. Additionally, we discuss how the finite bandwidth of the Chern band and the non-ideal quantum geometry affect the fractionalized excitations. Our work demonstrates that the energy and momentum-resolved electronic single-particle spectral function provides a valuable tool to characterize fractionalized excitations of FQAH states in moiré lattices.

TT 18.8 Tue 12:45 H36

Tuneability of Superconducting Properties in Transition Metal Dichalcogenide bilayers — •Michael Winter and Tim O. Wehling — I. Institut für Theoretische Physik, Universität Hamburg, Notkestraße 9-11, 22607 Hamburg

In recent years, rising interest sustained in van der Waals materials, particularly in transition metal dichalcogenides (TMDs or TMDCs). This work explores the potential for bilayer [hetero-]structuring in TMDs, which have garnered significant attention due to the discovery and prediction of exotic quantum phases, such as superconductivity and Mott insulating behaviour.

I present predictions derived from a minimal quantum lattice model, incorporating ab initio calculations based on plane-wave density functional theory (DFT), density functional perturbation theory (DFPT), and subsequent electron-phonon interaction calculations. The resulting model allows us to investigate the effects of different material combinations (e.g., MoS_2, $MoSe_2$, WS_2, WSe_2) and electron doping on superconductivity in such [hetero-]bilayer.

TT 18.9 Tue 13:00 H36

Proximity-Induced Spin-Triplet Superconducting Correlations in Transition Metal Dichalcogenides — •Florian Kayatz, Jorge Cayao, and Annica Black-Schaffer — Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden

The realization of spin-triplet Cooper pairs is a key ingredient for superconducting spintronics. One promising route to achieve this task is by exploiting the strong intrinsic spin-orbit coupling of transition metal dichalcogenides (TMDs). In this work, we consider a TMD layer coupled to a conventional spin-singlet s-wave superconductor and demonstrate the emergence of spin-triplet superconducting correlations. We find that these spin-triplet pair correlations form in the TMD as a proximity-induced effect but also appear in the superconductor as an inverse proximity effect and as a nonlocal phenomenon that exists between the TMD and superconductor. Furthermore, we relate these emergent superconducting correlations to experimentally observable features in the density of states and conductance.

TT 19: Many-body Quantum Dynamics I (joint session DY/TT)

Time: Tuesday 9:30–13:00 Location: H37

TT 19.1 Tue 9:30 H37

Controlling Many-Body Quantum Chaos — •Lukas Beringer[1], Mathias Steinhuber[1], Juan Diego Urbina[1], Klaus Richter[1], and Steven Tomsovic[1,2] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Department of Physics and Astronomy, Washington State University, Pullman, WA USA

Controlling chaos is a well-established technique that leverages the exponential sensitivity of classical chaotic systems for efficient control. This concept has been generalized to single-particle quantum systems [1] and, more recently, extended to bosonic many-body quantum systems described by the Bose-Hubbard model [2]. In direct analogy to the classical paradigm, a localized quantum state can be transported along a specific trajectory to a desired target state. In the latter context, this approach reduces to time-dependent control of the chemical potentials, making it suitable for implementation in optical lattice experiments. Highlighted potential applications are rapid, customizable state preparation and stabilization of quantum many-body scars in one-, two-, and three-dimensional lattices. Recent progress includes potential applications to large time-crystal platforms and preparation protocols for entangled states, such as cat-like states.

[1] S. Tomsovic, J. D. Urbina, and Klaus Richter, Controlling Quantum Chaos: Optimal Coherent Targeting, PRL 130.2 (2023): 020201.

[2] L. Beringer, M. Steinhuber, J. D. Urbina, K. Richter, S. Tomsovic, Controlling many-body quantum chaos: Bose-Hubbard systems, New J. Phys (2024): 26 073002.

TT 19.2 Tue 9:45 H37

Exact spectral function and nonequilibrium dynamics of the strongly interacting Hubbard model — Ovidiu I. Pâţu[1], •Andreas Klümper[2], and Angela Foerster[3] — [1]Institute for Space Sciences, Bucharest-Măgurele, R 077125, Romania — [2]Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, 42097 Wuppertal, Germany — [3]Instituto de Física da UFRGS, Av. Bento Gonçalves 9500, Porto Alegre, RS, Brazil

Analytical results on the correlation functions of strongly correlated many-body systems are rare in the literature and their importance cannot be overstated. We present determinant representations for the space-, time-, and temperature-dependent correlation functions of the strongly interacting one-dimensional Hubbard model in the presence of an external trapping potential. These representations are exact and valid in both equilibrium and nonequilibrium scenarios like the ones initiated by a sudden change of the confinement potential. In addition, they can be implemented numerically very easily significantly outperforming other numerical approaches. As applications of our results we investigate the single particle spectral functions of systems with harmonic trapping and show that dynamical quasicondensation occurs for both fermionic and bosonic spin-1/2 systems released from a Mott insulator state.

TT 19.3 Tue 10:00 H37

Quantum many-body scars beyond the PXP model in Rydberg simulators — Aron Kerschbaumer[1], Marko Ljubotina[1,2,3], Maksym Serbyn[1], and •Jean-Yves Desaules[1] — [1]Institute of Science and Technology Austria, Klosterneuburg, Austria — [2]Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

Persistent revivals recently observed in Rydberg atom simulators have challenged our understanding of thermalization and attracted much interest to the concept of quantum many-body scars (QMBSs). QMBSs are non-thermal highly excited eigenstates that coexist with typical eigenstates in the spectrum of many-body Hamiltonians, and have since been reported in multiple theoretical models, including the so-called PXP model, approximately realized by Rydberg simulators. At the same time, questions of how common QMBSs are and in what models they are physically realized remain open.

In our work, we demonstrate that QMBSs exist in a broader family of models that includes and generalizes PXP to longer-range constraints and states with different periodicity. We show that in each model, multiple QMBS families can be found. Each of them relies on a different approximate su(2) algebra, leading to oscillatory dynamics in all cases. However, in contrast to the PXP model, their observation requires launching dynamics from weakly entangled initial states rather than from a product state. The new QMBSs we unveil may be experimentally probed using Rydberg atom simulator in the regime of longer-range Rydberg blockades.

TT 19.4 Tue 10:15 H37

Roughening dynamics of quantum interfaces — Wladislaw Krinitsin[1,2], •Niklas Tausendpfund[1,3], Matteo Rizzi[1,3], Markus Heyl[4], and Markus Schmitt[1,2] — [1]Institute of Quantum Control (PGI-8), Forschungszentrum Jülich, Jülich, Germany — [2]Faculty of Informatics and Data Science, University of Regensburg, Regensburg, Germany — [3]Institute for Theoretical Physics, University of Cologne, Köln, Germany — [4]Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany

The roughening transition, known from three-dimensional classical spin systems, describes how fluctuations of interfaces transition from being bounded to being extensive when crossing the characteristic roughening temperature. We explore signatures of such phenomena in the dynamics of domain walls in the two dimensional quantum Ising model, where we observe pre-thermal steady states in their evolution well beyond the perturbative limit using Tree Tensor Networks. We formulate an effective model of the interface, which captures qualitative features of a roughening transition. Most notably, it exhibits a Berezinskii Kosterlitz Thouless quantum phase transition from smooth to rough interfaces, whose signatures extend to finite temperatures. These findings can be related to the observed slow thermalization in the full model, opening the way to a better understanding of prethermalization effects in interface dynamics, which can be easily implemented and tested in experimental setups such as Rydberg atom experiments.

TT 19.5 Tue 10:30 H37

Semigroup Influence Functionals for the Dynamics of Quantum Impurity Models — •Michael Sonner[1], Valentin Link[2], and Dmitry Abanin[3,4] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, D-01187 Dresden, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany — [3]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA — [4]Google Research, Brandschenkestrasse 150, 8002 Zürich, Switzerland

Quantum impurity models˜(QIM) consist of a local interacting impurity which is coupled to baths of free fermions. These models exhibit a range of non-trivial phenomena such as the Kondo effect. and play a central role in the dynamic mean field theory (DMFT) approach to correlated matter. However, despite their importance, computing the real time dynamics of QIM remains a challenge. Recently, approaches based on matrix product states (MPS) representation of influence functionals (IF) have been proven effective approaches to this problem. These method work by capturing the, generically non-markovian dynamical effects of the quantum environments on the local impurity in a multi time object, which then is compressed as MPS. Taking explicit advantage of time-translation invariance of the model, we find an infinite MPS or semigroup representation of the IF. I will demonstrate how these ideas can be used to predict QIM dynamics for very long times as well as give direct access to stationary non-equilibrium states.

TT 19.6 Tue 10:45 H37

Quantum Fisher information of monitored random circuits — •Arnau Lira Solanilla, Xhek Turkeshi, and Silvia Pappalardi — Universität zu Köln

We characterize the multipartite entanglement structure of monitored random quantum circuits using the quantum Fisher information. We show that, despite the known phase transition in bipartite correlations, the multipartiteness is bounded. On the other hand, we generate a phase with extensive multipartite entanglement under symmetry preserving random operations by introducing two-qubit measurements. We focus on the limit where no unitary operations are applied, but there is a competition between two noncommuting projective measurements. We exploit a map to bond percolation to precisely calculate the universal scaling of multipartite entanglement.

TT 19.7 Tue 11:00 H37

Entanglement in quantum circuits with SU(2) symmetry — •Tobias Dörstel and Michael Buchhold — Institute for Theoretical Physics, Cologne

Quantum circuits offer a robust framework for studying the out-of-equilibrium dynamics of quantum many-body systems. We investigate one-dimensional monitored quantum circuits with global SU(2) symmetry, serving as digital counterparts to the Heisenberg chain. These circuits consist of unitary qubit SWAPs and non-unitary SWAP-measurements. Entanglement in the chain is governed by the configuration of qubit singlet states, whose count is fixed by the symmetry sector. Varying the measurement rate, unitary operations, and singlet number reveals diverse entanglement behaviors, ranging from volume law to $\log^2(L)$ and $\log(L)$ scaling of half-chain entanglement. We explain these scaling regimes analytically using an SU(2)-symmetric "Page law" and a mapping to loop models with crossings.

15 min. break

TT 19.8 Tue 11:30 H37

Generalized dual-unitary circuits from biunitarity — •Michael A. Rampp, Suhail A. Rather, and Pieter W. Claeys — Max-Planck-Institut für Physik komplexer Systeme, Dresden

We present a general framework for constructing solvable lattice models of chaotic many-body quantum dynamics with multiple unitary directions using biunitary connections. We show that a network of biunitary connections on the Kagome lattice naturally defines a multi-unitary circuit, where three 'arrows of time' directly reflect the lattice symmetry. These models unify various constructions of hierarchical dual-unitary and triunitary gates and present new families of models with solvable correlations and entanglement dynamics. Using multi-layer constructions of biunitary connections, we additionally introduce multilayer circuits with monoclinic symmetry and higher level hierarchical dual-unitary solvability and discuss their (non-)ergodicity. Our work demonstrates how different classes of solvable models can be understood as arising from different geometric structures in spacetime.

TT 19.9 Tue 11:45 H37

Magic spreading in doped Clifford circuits — •Jiangtian Yao and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems

We study the spreading of magic, or nonstabilizerness, in Clifford circuits with doping by non-Clifford gates. We characterize the spatial extent of magic in classes of Clifford circuits where the growth behavior of entanglement entropy and operator strings are known. The dynamics of magic spreading in such circuits is compared to that of entanglement entropy, and quantitative measures for longer-ranged magic are also explored.

TT 19.10 Tue 12:00 H37

One magnon magnetization dynamics for the kagome lattice antiferromagnet — Henrik Schlüter, •Jannis Eckseler, and Jürgen Schnack — Faculty of Physics, Bielefeld University, Bielefeld, Germany

We present aspects of the one-magnon dynamics of the antiferromagnetic kagome lattice as an example of flat-band dynamics extending the work of [1] to two dimensional systems. We illustrate how localized eigenstates also called localized magnons [2] influence the dynamics of excitations and possibly prevent the system from thermalization. To this end we introduce a $J_1 - J_2$-model for the kagome lattice which guarantees the stability of one out of three localized magnons and lets us distinguish the different flat bands.

[1] F. Johannesmann, J. Eckseler, H. Schlüter, and J. Schnack, Phys. Rev. B 108, 064304 (2023).
[2] J. Schnack, H.-J. Schmidt, J. Richter, and J. Schulenburg, Eur. Phys. J. B 24, 475 (2001).

TT 19.11 Tue 12:15 H37

Towards a Many-Body Generalization of the Wigner-Smith Time Delay — •Georg Maier[1], Carolyn Echter[2], Juan Diego Urbina[1], Caio Lewenkopf[3], and Klaus Richter[1] — [1]Institut für Theoretische Physik Universität Regensburg, Regensburg, Germany — [2]Mathematische Fakultät Universität Regensburg, Regensburg, Germany — [3]Instituto de Física Universidade Federal Fluminense, Niterói RJ, Brazil

Many body systems with a large number of degrees of freedom are usually described by statistical physics on the theoretical side while experiments usually relay on scattering (e.g. particle physics). Is it possible to relate scattering and statistical physics, or to measure scattering-related observables which directly relate to quantities of statistical physics? At least for single particle systems a close relation exists between the well known Wigner-Smith delay time in scattering theory and the density of states of the scattering system.

I will present a novel ansatz relating a many-body version of dwell-/Wigner-Smith delay time and many body density of states based on the famous Birman-Krein-Friedel-Loyd formula connecting scattering theory and statistical observables in the many-body context. Due to the flexibility of this ansatz it can be used to investigate a wide variety of MB systems. I will discuss interesting scaling behaviors for different systems, like the harmonic trap[1] or the free particle together with the different behavior of bosons, fermions and indistinguishable particles.

[1] C. Echter et. al 2409.08696

TT 19.12 Tue 12:30 H37

Subleading logarithmic behavior in the parquet formalism — •Marcel Gievers[1,2], Richard Schmidt[3], Jan von Delft[1], and Fabian B. Kugler[4] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Universität Heidelberg — [4]CCQ, Flatiron Institute, New York

The Fermi-edge singularity in x-ray absorption spectra of metals is a paradigmatic case of a logarithmically divergent perturbation series. Prior work has thoroughly analyzed the leading logarithmic terms. Here, we investigate the perturbation theory beyond leading logarithms and formulate self-consistent equations to incorporate all leading and next-to-leading logarithmic terms. This parquet solution of the Fermi-edge singularity goes beyond the previous first-order parquet solution and sheds new light on the parquet formalism regarding logarithmic behavior. We present numerical results in the Matsubara formalism and discuss the characteristic power laws. We also show that, within the single-boson exchange framework, multi-boson exchange diagrams are needed already at the leading logarithmic level.

TT 19.13 Tue 12:45 H37

Ballistic transport in a disordered, boundary-driven XXZ spin chain. — •Johannes S Hofmann[1], Adam McRoberts[2], and Roderich Moessner[1] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]International Centre for Theoretical Physics, Strada Costiera 11, 34151, Trieste, Italy

Recent experiments on Google's sycamore NISQ device on spin transport realised ballistic transport in a edge-driven XXZ chain without disorder; and theoretical works on the classical variant demonstrated the survival of ballistic regime in the easy-plane upon the introduction of bond disorder. Here, we consider various generalisations of this set-up.

TT 20: 2D Materials: Electronic Structure and Exitations I (joint session O/HL/TT)

Time: Tuesday 10:30–13:00 Location: H8

TT 20.1 Tue 10:30 H8

Line-moiré phases of an epitaxial honeycomb monolayer AgTe/Ag(111) — •Romana Ganser, Muthu P. T. Masilamani, Begmuhammet Geldiyev, Maximilian Ünzelmann, and Friedrich Reinert — Experimentelle Physik VII and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Germany

We present angle-resolved photoemission spectroscopy (ARPES) measurements on tunable one-dimensional moiré phases of an epitaxial honeycomb monolayer AgTe/Ag(111) [1]. In this model system, the moiré structure can be tuned almost continuously in contrast to hardly controllable twist angles in bilayer van-der-Waals heterostructures [2]. We experimentally observe moiré minibands and band gaps of 120 - 170 meV suggesting sizable superlattice potentials. By comparing the experimental data to simple model calculations, we analyze the local character of the potential. This provides important information of interface hybridization effects on the band structure, which may not be limited to the system at hand but rather a broad range of moiré interfaces.

[1] Ünzelmann, M. et al. PRL. 124, 176401 (2020).
[2] Lisi, S. et al. Nat. Phys. 17, 189-193 (2021).

TT 20.2 Tue 10:45 H8

Photoemission Time Scale Determination: the Effect of Crystal Dimensionality and Electronic Correlation — •Fei Guo[1], Dmitrii Usanov[2], Eduardo B. Guedes[2], Mauro Fanciulli[3], Arnaud Magrez[1], Michele Puppin[1], and Hugo Dil[1,2] — [1]Institute of Physics, Ecole Polytechnique Federale de Lausanne, CH-1015 Lausanne, Switzerland — [2]Photon Science Division, Paul Scherrer Institut, CH-5232 Villigen, Switzerland — [3]Laboratoire de Physique des Matériaux et Surfaces, CY Cergy Paris Université, Cergy-Pontoise, 95031, France

Spin polarization of photoelectrons from spin-degenerate dispersive initial states originates from the interference of multiple photoemission channels, measuring the spin polarization with spin- and angle-resolved photoemission spectroscopy (SARPES) allows the estimation of the phases of the interfering channels, and hence the Eisenbud-Wigner-Smith (EWS) time delay of photoemission, which is the amount of time required by the photoelectron to evolve into a free particle final state. While not directly measurable for solid-state photoemission, this time scale has been measured for gaseous photoionization, which is generally in the attosecond (10^-18s) range.

We present investigations with multiple materials of different properties, and by comparing with previous studies, we propose a relationship between the EWS time delay, electronic correlation mechanism, and dimensionality.

TT 20.3 Tue 11:00 H8

Disorder effects in the Band Structure of Transition Metal Dichalcogenide alloys $A_xB_{1-x}Se_2$ (A, B= Cr, Mo, W) — •Sarath Sasi[1], Aki Pulkkinen[1], Laurent Nicolaï[1], Raphaël Salazar[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, Neuville-sur-Oise, France — [3]Université Paris-Saclay, CEA, CNRS, LIDYL, Gif-sur-Yvette, France

Recent advances in materials synthesis have enabled the creation of 2D TMDC alloys, which offer unique opportunities for tailoring electronic and optoelectronic properties to meet diverse application demands.[1].This study investigates the band structure evolution of $A_xB_{1-x}Se_2$ alloys (A, B = Cr, Mo, W) across varying composition fractions (x). Using the Coherent Potential Approximation (CPA)[2], which accurately models scattering in disordered systems, theoretical calculations were performed with the *SPR-KKR* package[3]. Results reveal that some of the TMDC alloys maintain their band structures without significant disorder effects. Angle-Resolved Photoemission Spectroscopy (ARPES) measurements align closely with one-step model photoemission calculations, confirming theoretical predictions. These insights provide a foundation for tailoring electronic properties, advancing their applicability in next-generation devices.

[1] Zhou, J., Lin, J., Huang, X., et al. Nature, 556, 355-359 (2018).
[2] Soven, P., Phys. Rev., 156, 809(1967).
[3] Braun, J., Minar, J., Ebert, H. Physics Reports, 740 (2018).

TT 20.4 Tue 11:15 H8

Unveiling Doping-Induced Electronic Modifications in Antiferromagnetic MPS_3 van der Waals Materials — •Till Willershausen[1], Jonah Elias Nitschke[1], Patrick Merisescu[2], David Janas[1], Lasse Sternemann[1], Michele Capra[1], Mira Arndt[1], Valentin Mischke[1], and Mirko Cinchetti[1] — [1]TU Dortmund University — [2]Bath University

Antiferromagnetic van der Waals (vdW) materials, with scalability to monolayer thickness, semiconducting properties, and intrinsic antiferromagnetic ordering, hold promise for spintronic and quantum technology applications. We investigate alkali metal doping effects on the MPS_3 family (M = Mn, Ni, Co, Fe) of 2D antiferromagnetic vdW materials, revealing doping-induced changes in their electronic structure. X-ray Photoelectron Spectroscopy (XPS) shows shifts in oxidation states in $NiPS_3$, $CoPS_3$, and $FePS_3$, while $MnPS_3$ displays no significant changes, indicating distinct charge transfer. Further investigation with Angle-Resolved Photoelectron Spectroscopy (ARPES) reveals new alkali-metal induced bands appearing above the previous valence band maximum. This analysis highlights doping-induced modifications and contrasts in transition metal behavior in MPS_3, providing insights into doping mechanisms and electronic tunability.

TT 20.5 Tue 11:30 H8

Enhanced electron-phonon coupling in few-layer $MoTe_2$ from micro-ARPES — •Thomas P. van Waas[1], Julia Issing[2], Marco Gibertini[3], Christophe Berthod[2], Anna Tamai[2], Felix Baumberger[2,4], and Samuel Poncé[1,5] — [1]European Theoretical Spectroscopy Facility, Institute of Condensed Matter and Nanosciences, Université catholique de Louvain, Belgium — [2]Department of Quantum Matter Physics, University of Geneva, Switzerland — [3]Dipartimento di Scienze Fisiche, Informatiche e Matematiche, University of Modena and Reggio Emilia, Italy — [4]Swiss Light Source, Paul Scherrer Institut, Switzerland — [5]WEL Research Institute, Belgium

Bulk orthorhombic T_d-$MoTe_2$ is a type-II Weyl semimetal with a superconducting critical temperature of $T_c = 0.1$ K. Transport measurements show a monotonic increase in T_c as the thickness of multilayer $MoTe_2$ is reduced, reaching $T_c = 7.6$ K in the monolayer. We investigate photoemission kinks in the electron pocket of exfoliated mono-bi-, and trilayer $MoTe_2$ from micro-focused angle-resolved photoemission spectroscopy. We use a custom code to quantify the electron self-energy $\Sigma_n(E)$ for a parabolic non-interacting dispersion, and obtain from $\Sigma_n(E)$ the Eliashberg spectral function $\alpha^2F_n(\omega)$ using the maximum entropy method. We find two dominant phonon modes in $\alpha^2F_n(\omega)$ for the mono- and trilayer, with a large enhancement of the lower-frequency phonon mode in the former. We also provide tentative results for the bilayer, where quantification is more challenging due to a small splitting of the electronic bands.

TT 20.6 Tue 11:45 H8

Electronic structure of V-doped WSe_2 — •Jana Kähler[1,2], Florian K. Diekmann[1,2], Matthias Kalläne[1,2,3], Tim Riedel[1,2], Adina Timm[1,2], Anja Yalim[1,2], Jens Buck[1,2], Meng-Jie Huang[2], Jules M. Knebusch[1,2], Luka Hansen[1,3], Jan Benedikt[1,3], and Kai Rossnagel[1,2,3] — [1]Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, 24098 Kiel, Germany — [2]Ruprecht Haensel Laboratory, Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg — [3]Kiel Nano, Surface and Interface Science KiNSIS, Christian-Albrechts-Universität zu Kiel, 24098 Kiel, Germany

Spintronics represents a promising and energy-efficient alternative to conventional electronics, with significant potential applications, e.g., in areas such as classical and quantum computing. The vanadium-doped layered transition metal dichalcogenide $2H$-WSe_2 is a promising candidate to fulfill the desired properties as a room-temperature magnetic semiconductor with gating tunability. Here, we present a comprehensive electronic structure study of chemical vapor transport-grown pristine and V-doped WSe_2 by soft X-ray, VUV and 11eV-laser ARPES, highlighting the influence of a low V doping concentration on the electronic structure of WSe_2.

TT 20.7 Tue 12:00 H8

Unraveling magnetic ordering in a van der Waals correlated

material — Tommaso Pincelli[1,2], •Tania Mukherjee[1,2], Lawson Lloyd[2], Shuo Dong[2,3], Yoav William Windsor[1,2], Martin Wolf[2], Laurenz Rettig[2], and Ralph Ernstorfer[1,2] — [1]Technische Universität Berlin, 10623 Berlin, Germany — [2]Fritz-Haber-Institute of the Max Planck Society, 14195 Berlin, Germany — [3]Beijing National Laboratory for Condensed Matter Physics, China

Layered van der Waals (vdW) materials offer a compelling platform to investigate various emergent quantum properties in low dimensions. Fe_3GeTe_2 (FGT), a vdW ferromagnetic metal, is well-known for exhibiting exotic phenomena, ranging from skyrmion formation to heavy fermion behavior. However, an understanding of the magnetic ordering, a key feature for spintronic applications, still remains elusive in this material. In particular, the interplay of both local magnetic moments and an itinerant mechanism in the formation of ferromagnetic ordering in FGT, a non-f-electron correlated system, remains to be clarified. Using time- and angle-resolved photoemission spectroscopy (trARPES) and first-principles calculations, we provide evidence for an ordering mechanism in FGT by observing a pronounced reduction in the Stoner exchange gap. This stands in contrast to earlier temperature-dependent ARPES studies of the electronic structure of FGT, which favored a localized excitation model over the weak-coupling itinerant picture. We also observe the impact of phononic excitations which further confirm our findings.

TT 20.8 Tue 12:15 H8

Spin structure of the unoccupied surface state at AgTe/Ag(111) — •Carolin Benfer, Marcel Holtmann, and Markus Donath — Physikalisches Institut, Universität Münster, Germany

The AgTe/Ag(111) surface alloy has recently been investigated as a model system for the role of orbital angular momentum in the formation of spin effects in the electronic structure [1]. Two p-like surface states were detected in ARPES measurements, one shows a Rashba-type spin splitting, while the other one does not. This behavior is attributed to the symmetries of the orbital wave functions of the electrons. For the unoccupied states a third surface state has been predicted. Following the symmetry arguments given in [1], a Rashba-type spin splitting of the state is expected.

We use inverse photoemission (IPE) to directly study the unoccupied state of the surface alloy. Low-energy electron diffraction and scanning tunneling microscopy measurements confirm a homogeneous monolayer film of the surface alloy, which is growing in a honeycomb structure. Angle-resolved IPE measurements detect the predicted surface state with free electron-like dispersion. Spin-resolved IPE measurements reveal a Rashba-type spin structure.

[1] M. Ünzelmann *et al.*, Phys. Rev. Lett. **124**, 176401 (2020)

TT 20.9 Tue 12:30 H8

Orbital mixing as key mechanism for ferromagnetism in van der Waals CrI3 — •Alessandro De Vita[1,2], Srdjan Stavrič[3], Roberto Sant[4], Nicholas B. Brookes[4], Giancarlo Panaccione[5], Silvia Picozzi[3], Ralph Ernstorfer[1,2], and Tommaso Pincelli[1,2] — [1]Institut für Optik und Atomare Physik, Technische Universität Berlin, Straße des 17 Juni 135, 10623 Berlin, Germany — [2]Fritz Haber Institute of the Max Planck Society, Faradayweg 4-6, 14195 Berlin, Germany — [3]Consiglio Nazionale delle Ricerche CNR-SPIN, c/o Università degli Studi G. D'Annunzio, 66100 Chieti, Italy — [4]ESRF, The European Synchrotron, 71 Avenue des Martyrs, CS40220, 38043 Grenoble Cedex 9, France — [5]Istituto Officina dei Materiali (IOM)-CNR, Laboratorio TASC, in Area Science Park, S.S.14, km 163.5, I-34149 Trieste, Italy

Van der Waals ferromagnets constitute a versatile platform where exotic quantum states can be realized; among them, CrI3 is a prototypical and widely studied 2D ferromagnet, with promising applications in spin- and orbitronics. Despite that, key information on its electronic occupation and stabilization of the magnetic configuration are missing. By means of complementary absorption and photoemission spectroscopies, and density functional theory calculations, we give a description of the orbital character of bulk CrI3, and demonstrate that the emergence of ferromagnetism in this material is underpinned by the orbital mixing between I p and Cr eg states. Our results have clear impact on the understanding of how microscopic interactions at the orbital level stabilize ordered states in van der Waals ferromagnets.

TT 20.10 Tue 12:45 H8

Resonant Photoemission Studies of Transition Metal Sulfides and Selenides — •Yashasvi Mehra[1,2,3], Samuel Beaulieu[4], Mauro Fanciulli[1,2], Olivier Heckmann[1,2], Karol Hricovini[1,2], Aki I.O. Pulkkinen[3], Jan Minar[3], and Maria Christine Richter[1,2] — [1]Université Paris-Saclay, CEA, LIDYL, Gif-sur-Yvette, France — [2]CY Cergy Paris Université, CEA, LIDYL, Gif-sur-Yvette, France — [3]University of West Bohemia, NTC, Pilsen, Czech Republic — [4]Universite de Bordeaux CNRS CEA, CELIA, UMR5107, F33405 Talence, France

By performing resonant ARPES measurements and SPR-KKR photoemission calculations on Transition Metal Selenide, Sulfide and the Vanadium intercalated NbS2 systems, we study the interplay between different decay mechanisms in resonant conditions, radiation-less Raman Auger and Classical Auger emissions. Through a method proposed by Cini and Sawatzky we can determine the on-site Coulomb interaction per element in some cases. On the theoretical front the calculations are performed using the SPR-KKR method, which is based on one-step model, that incorporates the effect of all matrix elements which accounts for the photoemission process. Furthermore, we analyze calculated ARPES, XAS, element and orbital resolved band structure underlining agreement with experimental results and helping with its interpretation.

TT 21: Quantum Dots and Wires: Transport (joint session HL/TT)

Time: Tuesday 11:15–13:00 Location: H13

TT 21.1 Tue 11:15 H13

Transport properties of quantum dots for single-electron pumps — •Johannes C. Bayer, Thomas Gerster, Dario Maradan, Frank Hohls, and Hans W. Schumacher — Physikalisch-Technische Bundesanstalt, 31668 Braunschweig, Germany

A single-electron pump (SEP) is a device emitting a well-defined number of n electrons per cycle of an external drive. With driving frequency f and elementary charge e, this results in a current of $I = nef$. Since the revision of the SI system, the elementary charge e hereby is an exact value, so that SEPs provide a suitable basis for a quantum current standard. The accuracy of this current is directly related to erroneous cycles, where the emitted number of electrons deviates from n. Our SEP devices are based on electrostatically defined quantum dots in GaAs/AlGaAs two-dimensional electron gases. In such devices, the tunnel barriers as well as the energy levels are controllable via gate voltages. Based on multiple quantum dot devices we here investigate relations between transport properties and SEP operation characteristics.

TT 21.2 Tue 11:30 H13

Non-Markovian higher-order electron pump: improvement of efficiency — •Lukas Litzba, Jürgen König, and Nikodem Szpak — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, Duisburg 47057, Germany

We consider an electron pump that consists of a non–interacting quantum dot and electron baths. Our pumping setup utilizes only higher–order tunneling processes, which are purely quantum mechanical and have no classical analog. In order to study higher order tunneling–mechanism and non–Markovian effects, we extend the exact Heisenberg equation and the Laplace transform technique to time–dependent Hamiltonians and apply this technique to our model. Thereby, we identify parameter ranges which lead to a significant increase of the current flowing through the quantum dot and an improvement of the energetic efficiency of these processes.

TT 21.3 Tue 11:45 H13

Fast Machine-Learning assisted characterisation of current quantisation — •Wang Ngai Wong[1], Yannic Rath[1], Nikolaos Schoinas[1], Shota Norimoto[1], Masaya Kataoka[1], Alessandro Rossi[1,2], and Ivan Runnger[1,3] — [1]National Physical Laboratory, Teddington, TW11 0LW, UK — [2]Department of Physics, SUPA, University of Strathclyde, Glasgow G4 0NG, UK — [3]Department of Computer Science, Royal Holloway, University of London, Egham, TW20 0EX, UK

Characterisation of single-electron pumps (SEPs) has long been bottlenecked by the process of fine-tuning measurement parameters to study their novel properties. This limits potential experimental parameters to those that can remain static throughout the fine-tuning process. We demonstrate a novel method assisted by machine learning which has led to an eightfold speedup in the measurement process (see Appl. Phys. Lett. 125, 124001 (2024)), and in so doing opens the door to further characterisation experiments which are impossible using conventional methods. Our method is based around an active learning cycle to navigate the information landscape of the gate voltage parameter space, while also significantly reducing the number of measurement points required. This is paired with a post-processing approach which allows us to accurately predict and characterise the small operational regimes significantly more efficiently than conventional sweeps across the parameter space. We exploit the framework to characterise the behaviour of multiplexed GaAs multi-pump devices across a range of magnetic fields.

TT 21.4 Tue 12:00 H13

Novel Mixed-Dimensional Reconfigurable Field Effect Transistors — •Sayantan Ghosh[1,2], Muhammad Bilal Khan[1], Phanish Chava[1], Kenji Watanabe[3], Takashi Taniguchi[3], Slawomir Prucnal[1], René Hübner[1], Thomas Mikolajick[2], Artur Erbe[1,2], and Yordan M Georgiev[1,4] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Technische Universität Dresden, Dresden, Germany — [3]National institute for Material Science, Tsukuba, Japan — [4]Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria

The limitations of CMOS downscaling drive the exploration of alternative device concepts like reconfigurable FETs (RFETs), which can dynamically switch between n- and p-polarity through electrostatic gating. This work introduces a novel mixed-dimensional RFET utilizing 1D silicon (Si) nanowires combined with 2D hexagonal boron nitride (hBN) as a dielectric and encapsulating layer. hBN*s insulating properties, chemical stability, and absence of dangling bonds make it ideal for its use as a dielectric in 1D electronics. The RFET fabrication employs electron beam lithography, reactive ion etching, and flash lamp annealing for precise silicide formation. Mechanically exfoliated hBN flakes (5-10 nm) were integrated using dry stamping transfer, with thickness characterized by microscopy techniques. Device characterization reveals improved subthreshold swing, on-current, and ION/IOFF ratio due to hBN*s 2D passivation, highlighting its potential for advanced nanowire-based RFET architectures.

TT 21.5 Tue 12:15 H13

Kondo effect for half-filling of the third shell of a quantum dot — •Olfa Dani[1], Johannes C. Bayer[1], Timo Wagner[1], Gertrud Zwicknagl[2], and Rolf J. Haug[1] — [1]1Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany — [2]2Institut für Mathematische Physik, Technische Universität Braunschweig, Braunschweig, Germany

In this work, we investigate the electrical transport in the third shell [1] of a gate-defined GaAs quantum dot. The exact number of electrons in the quantum dot (N_e) is determined using a quantum point contact as a sensitive charge detector, detecting single-electrons tunneling through the system [2]. N_e is varied by changing the applied gate voltage.

The addition energy E_c for $N_e = 7$ - 11 shows a triangular behavior with a maximum at half-filling of the shell. This observed behavior is described analytically with Hund's rule exchange interaction. Besides, for successive numbers of electrons occupying the quantum dot $N_e = 7$ to 11, a Zero-bias anomaly (ZBA) characteristic for the Kondo effect is observed [3]. The width of the ZBA exhibits a triangular behavior, with a maximum at $N_e = 9$, similar to E_c. The broadening of the ZBA is attributed to the contribution of the Kondo resonance as well as Hund's satellite peaks, originating from the degenerate orbitals observed in the spectral function.

[1] L. P. Kouwenhoven, et. al., Rep. Prog. Phys. 64, 701-736 (2001).
[2] T. Wagner, et. al., Nat. Phys.15, 330-334 (2019).
[3] J. Schmid, et. al., Phys. Rev. Lett. 84, 5824 (2000).

TT 21.6 Tue 12:30 H13

Beyond full counting statistics and Langevin theory: The quantum polyspectra approach to multi-detector measurements — •Armin Ghorbanietemad, Markus Sifft, and Daniel Hägele — Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI, Germany

The quantum polyspectra approach to quantum measurements has recently been shown to cover the full range between weak and strong quantum measurements [1 - 3]. It provides thus a more general approach to quantum measurements than the full counting statistics used in nano-electronics or the Langevin-approach used in spin noise spectroscopy. This approach draws its strength from comparing higher order spectra of the measurement record with model spectra calculated from quantum expressions that are calculated on the level of a Lindblad master equation. Here, we generalize the polyspectra approach to include the case of the simultaneous measurements of more than one quantity of a quantum system. The approach regards measurement induced damping, measurement backaction, and the quantum Zeno effect. We give a few examples of multi-detector polyspectra that were calculated by a multi-detector extension of our SignalSnap and QuantumCatch library [4, 5].

[1] Hägele et al., PRB 98, 205143 (2018)
[2] Sifft et al., PRR 3, 033123 (2021)
[3] Sifft et al., PRA 109, 062210 (2024)
[4] https://github.com/MarkusSifft/SignalSnap
[5] https://github.com/MarkusSifft/QuantumCatch

TT 21.7 Tue 12:45 H13

Revealing Hidden States in Quantum Dot Array Dynamics: Quantum Polyspectra Versus Waiting Time Analysis — •Markus Sifft[1], Johannes C. Bayer[2], Daniel Hägele[1], and Rolf J. Haug[2] — [1]Faculty of Physics and Astronomy, Ruhr University Bochum, GER — [2]Institute of Solid State Physics, Leibniz Universität Hannover, GER

We show how by virtue of the recently introduced quantum polyspectral analysis of transport measurements [1,2], the complex transport measurements of multi-electron QD systems can be analyzed. This method directly relates higher-order temporal correlations of a raw quantum point contact (QPC) current measurement to the Liouvillian of the measured quantum system. By applying this method to a two-electron double QD system, we uncover dynamics between singlet and triplet states, indistinguishable in the QPC current, without requiring the identification of quantum jumps or prior assumptions about the number of quantum states involved. Our findings demonstrate that system models in such cases of hidden dynamics are inherently non-unique. Furthermore, we compare our method to a traditional analysis via the waiting-time distribution. Our method achieves parameter estimates with up to 50% lower errors, while also being applicable in scenarios with low signal-to-noise, where traditional counting methods falter. Our approach challenges previous assumptions and models, offering a more nuanced understanding of QD dynamics and paving the way for the optimization of quantum devices. [1] Hägele et al., PRB 98, 205143 (2018), [2] Sifft et al., PRR 3, 033123 (2021)

TT 22: Many-body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)

Time: Tuesday 14:00–15:30 Location: H37

TT 22.1 Tue 14:00 H37

Power-law banded random matrices as models for quantum many-body Hamiltonians — •Wouter Buijsman[1], Masudul Haque[2,1], and Ivan M. Khaymovich[3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]TU Dresden, Institute of Theoretical Physics, Dresden, Germany — [3]Nordita, Stockholm, Sweden

Hamiltonians of one-dimensional, disordered single-particle sytems with long-range hoppings can naturally be modeled by power-law banded random matrices. In this picture, the phase diagram of power-law banded random matrices show an ergodic, weakly ergodic, and localized phase. Motivated by modern developments on ergodicity breaking and localization in interacting quantum many-body systems, we study many-body interpretations of such random matrices. We discuss a number of ways to label the basis states with many-body configurations, and compare the physical properties of the resulting Hamiltonians. Specifically, we study the scaling of the many-body entanglement entropy with system size for eigenstates at both the bulk and the edge of the spectra. Using a scaling analysis on the full sets of eigenstates, we subsequently provide a quantitative picture of the phase diagram. We elaborate on the physical relevance of this interpretation of random matrix models for quantum many-body systems.

TT 22.2 Tue 14:15 H37

Escaping the Krylov space during reorthogonalization — •Max Pieper, Jannis Eckseler, and Jürgen Schnack — Universität Bielefeld

Krylov complexity [1] is often used as a measure of complexity in quantum many-body-systems. During its calculation, the Lanzcos algorithm is used to construct an operator basis. Due to the poor orthogonality of the resulting basis reorthogonalization is often employed [2]. We investigate how using reorthogonalization causes the Lanczos algorithm to accumulate non-Krylov basis elements. We suspect this to negatively affect the Krylov algorithm.

[1] D. E. Parker et al. Phys. Rev. X 9, 041017 (2019)
[2] E. Rabinovici et al. JHEP 06, 062 (2021)

TT 22.3 Tue 14:30 H37

An estimate of the equilibration time based on the operator growth hypothesis — •Merlin Füllgraf, Jiaozi Wang, and Jochen Gemmer — Universität Osnabrück

We study the equilibration times T_{eq} of local observables in quantum chaotic systems by considering their auto-correlation functions. Based on the recursion method, we suggest a scheme to estimate T_{eq} from the corresponding Lanczos coefficients. We numerically find that, if an observable follows the *operator growth hypothesis*, a finite number of Lanczos coefficients is sufficient for a reasonable estimate of the equilibration time. This implies that equilibration occurs on a realistic time scale much shorter than the life of the universe. The numerical findings are further supported by analytical arguments.

TT 22.4 Tue 14:45 H37

Effects of chaos in Bose-Hubbard systems with few degrees of freedom. The smallest possible heat engine? — •Viviane Bauer, Nico Fink, and James Anglin — Physics Department and Research Center OSCAR, RPTU Kaiserslautern-Landau

Microscopic engines are a research focus in both biochemistry and nanotechnology. While other forms of engines besides heat engines are also being considered, the fully microscopic limit of a heat engine is a fundamentally important problem in physics. What happens to thermodynamics when not only the working fluid and mechanism of a heat engine, but even the hot and cold reservoirs are microscopic?

To realize such microscopic heat baths, we turn to the process of chaotic ergodization, studied in Bose-Hubbard dimers and trimers.

One realization we currently study is based on two Bose-Hubbard trimers, which allow energy and particle transport between them. The particle transport is furthermore coupled to a mass, so our engine works against a force to lift it. Moreover, we have identified a dynamic mechanism which can stabilize this lifting process. The result is a system which operates just like a heat engine, except for being fully microscopic. The structure of coupled chaotic subsystems both supports and requires an understanding of the fully microscopic heat engine in terms of open-system control.

TT 22.5 Tue 15:00 H37

Impurity coupled to the SYK bath — •Anastasia Enckell and Stefan Kehrein — Institute for Theoretical Physics, Georg-August-Universität Göttingen, Germany

System-plus-bath models play an important role in addressing fundamental questions in condensed matter physics. One challenging aspect is modelling the bath, which is often approached using free-particle or open quantum system frameworks. Here, we explore the Sachdev-Ye-Kitaev (SYK) model as a new kind of quantum bath with unique properties, including the absence of quasiparticles, maximal chaos, and non-integrability, which make it a valuable framework for studying system-plus-bath interactions. We study the time evolution of the occupation of an impurity coupled to the SYK bath following a quench. From the Kadanoff-Baym equations for a noninteracting impurity, we see that the only relevant property for the impurity occupation is a combination of hybridisation and density of states of the bath. These parameters can be adjusted in order to model the impurity coupled to any bath of interest. Using this approach, we can study the impurity dynamics coupled to the SYK bath by making suitable changes to the hybridisation in impurity plus Fermi bath setting, which significantly simplifies the task. We observe oscillatory dynamics of the impurity at zero temperature, with the oscillations decreasing as the temperature increases. This behaviour contrasts with that of a free-particle bath and suggests interesting underlying physics.

TT 22.6 Tue 15:15 H37

Thermal-relaxation asymmetry in fluctuating hydrodynamics — •Felipe Pereira-Alves and Aljaž Godec — Mathematical bio-Physics Group, Max Planck Institute for Multidisciplinary Sciences, 37077 Göttingen, Germany

It was theoretically predicted and recently experimentally confirmed that small systems, such as trapped colloidal particles quenched far from equilibrium, heat up faster than they cool down. The phenomenon was coined thermal-relaxation asymmetry. The proposed physical explanation of the asymmetry instigated intriguing questions about its existence in the thermodynamic limit. Here we investigate thermal relaxation dynamics in far-from-equilibrium temperature quenches on the level of fluctuating hydrodynamics of short- and long-range (logarithmically) interacting many-body systems. We prove the existence of a strict asymmetry for any temperature quench for both, short- and long-range interactions. Remarkably, in contrast to small systems, there is no “close-to-equilibrium” regime of quenches for which heating and cooling are symmetric. Notably, we find that relaxation is self-similar up to the relaxation time, and uncover intricate differences between short- and long-range interactions.

TT 23: Members’ Assembly

Time: Tuesday 14:15–15:45 Location: H33

All members of the LT Division are heartfully invited to join!
Topics:

- **Report**
- **Outlook 2025**
- **Miscellaneous,**

TT 24: Unconventional Superconductors

Time: Wednesday 9:30–13:00 Location: H31

Invited Talk TT 24.1 Wed 9:30 H31

Possible Origin of High-Field Reentrant Superconductivity in UTe_2 — •Toni Helm — Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence ct.qmat, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

Due to its potentially spin-triplet-superconducting ground state, UTe_2 (fondly called Ute) has triggered a wave of enthusiasm among condensed-matter researchers since the discovery of superconductivity below 1.6 K in this anisotropic heavy-fermion paramagnet. As the quality of single crystals improved, e.g., Tc was pushed to 2.1 K, some of the fog about Ute's mysterious properties has cleared. Nevertheless, the excitement has only become stronger as Ute exhibits signatures of multiple superconducting phases with distinct order parameters stabilized by different tuning parameters such as pressure, magnetic field, or field orientation. Particularly, strong magnetic fields applied to Ute appear to not only suppress superconductivity, as expected for a textbook superconductor, but also enhance and enable additional phases in a rare and very unconventional phase diagram.

In this talk, we will look at Ute's high-field properties and review recent results concerned with the field-induced superconducting phases in this special compound. In particular, we will focus on what is known so far about the reentrant superconductivity that sets in for specific field orientations at field values beyond approximately 40 T. Latest results from experiments in fields up to 70 T have certain implication to the possible origin of the extremely field-robust reentrant superconductivity in UTe_2.

[1] T. Helm et al., Nat. Commun. 15 (2024).

TT 24.2 Wed 10:00 H31

Fermi surface studies on UTe_2 — •F. Husstedt[1,2], B. V. Schwarze[1], J. P. Brison[3], G. Knebel[3], G. Lapertot[3], M. Kimata[4], D. Aoki[4], T. Helm[1], and J. Wosnitza[1,2] — [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 presence of three-dimensional (3D) Fermi surfaces in the heavy-fermion superconductor UTe_2 is strongly debated. We had access to high-quality UTe_2 single crystals with $T_c = 2\,K$ to perform angle-dependent measurements of the magnetic torque, magnetotransport, and Hall effect. The observed quantum oscillations provide further insight into the electronic structure of UTe_2. We measured de Haas-van Alphen frequencies that show a very good agreement with previous reports. Consistent with two-dimensional Fermi-surface cylinders, we also observed a 100 T Shubnikov-de Haas (SdH) frequency for field oriented along the crystallographic a axis. We investigated the angular dependence of this frequency in the a-b plane as well as in the a-c plane to clarify if it may originate from a 3D Fermi surface. The temperature dependence of the 100 T SdH frequency reveals an effective mass much lower than the ones reported for the fundamental frequencies.

TT 24.3 Wed 10:15 H31

Investigating the strain dependence of the lower and upper superconducting critical fields in Sr_2RuO_4: A novel approach using elastocaloric effect measurements — •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

Elastocaloric measurements under uniaxial stress are an extremely sensitive technique that provides rich thermodynamic information. This is especially true when studying materials, such as the unconventional superconductor Sr_2RuO_4 [1]. In particular, the investigation of the elastocaloric effect in an applied magnetic field is challenging and pioneering, but highly relevant.

We have performed high resolution elastocaloric measurements on Sr_2RuO_4 in a magnetic field along the [001] axis with uniaxial stress applied in the [100] direction at low temperatures. We have studied the strain dependence of the lower and upper superconducting critical fields. Both show a dome-like shape with a maximum close to the Van Hove strain. We discuss the advantages and limitations of the elastocaloric technique compared to conventional probes such as electrical resistivity and susceptibility, highlighting its contribution to the understanding of unconventional superconductivity in Sr_2RuO_4.

[1] Y. S. Li *et al.*, Nature 607, 276 (2022).

TT 24.4 Wed 10:30 H31

Why scanning tunneling spectroscopy of Sr_2RuO_4 sometimes does not see the superconducting gap — •Adrian Valadkhani[1], Jonas Profe[1], Andreas Kreisel[2], Peter Hirschfeld[3], and Roser Valenti[1] — [1]Goethe University, Frankfurt am Main, Germany — [2]University of Copenhagen, Copenhagen, Denmark — [3]University of Florida, Gainesville, USA

Scanning tunneling spectroscopy (STS) and scanning tunneling microscopy (STM) are perhaps the most promising ways to detect the superconducting gap size and structure in the canonical unconventional superconductor Sr_2RuO_4 directly. However, in many cases, researchers have reported being unable to detect the gap at all in STM conductance measurements, while in others they were able to find the gap. Recently, an investigation of this issue on various local topographic structures on a Sr-terminated surface found that superconducting spectra appeared only in the region of small nanoscale canyons, corresponding to the removal of one RuO surface layer. In this talk, we analyze the electronic structure of various possible surface structures using ab initio density functional theory (DFT), and argue that bulk conditions, favorable for superconductivity, can be achieved, when removal of the RuO layer suppresses the RuO4 octahedral rotation locally. Our findings are supported by a paper recently published using numerical methods beyond DFT-random phase approximation (RPA) and functional renormalization group (FRG). We further propose alternative terminations to the most frequently reported Sr termination where superconductivity surfaces should be observed.

TT 24.5 Wed 10:45 H31

Complex impedance scanning tunneling microscopy as a probe for unconventional superconductors — •Amber Mozes[1], Sanghun Lee[2], Tjerk Benschop[1], Koen Bastiaans[1], and Milan Allan[1,2] — [1]Leiden University, Leiden, The Netherlands — [2]LMU, Munich, Germany

In many unconventional superconductors, the superconducting state is spatially inhomogeneous, and macroscopic superconductivity is suppressed. To understand what causes this suppression of superconductivity, we are developing a probe to measure the local complex impedance. We combine scanning tunneling microscopy (STM) with microwave microscopy. This could, in principle, allow to locally probe the impedance response and relate this to inhomogeneity in free carrier density whenever macroscopic homogeneity is suppressed. More specifically, it would be possible to measure the kinetic inductance of a superconductor, governed by the Meissner effect, as well as local resistivity from non superconducting carriers. Implementation of complex impedance measurements in STM requires a microwave impedance matching circuit to enable simultaneous DC and AC readout of the tip-sample response. I will present our recently developed chip circuits that are in situ replaceable, enabling sample specific circuit design, with the aim to impedance match for superconducting sample properties.

TT 24.6 Wed 11:00 H31

Tunneling spectroscopy on superconducting thin films of noncentrosymmetric niobium rhenium — •Marcel Strohmeier[1], Carla Cirillo[2], Andriy Smolyanyuk[3], Karsten Held[3], Carmine Attanasio[4], Angelo Di Bernardo[1,4], and Elke Scheer[1] — [1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [2]CNR-Spin, c/o University of Salerno, 84084 Fisciano (SA), Italy — [3]Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria — [4]Department of Physics 'E.R. Caianiello', University of 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-type spin-orbit coupling (SOC) a mixed spin-singlet and spin-triplet pairing state is predicted in these materials. In our talk, we focus on the non-centrosymmetric compound $Nb_{0.18}Re_{0.82}$, whose superconducting order parameter remains under debate. Its favorable combination of material properties such as structural disorder, strong SOC and relatively high critical current densities makes NbRe an promising candidate for applications in superconducting single-photon detection and gate-controlled supercurrent devices. We present low-temperature scanning tunneling microscopy measurements on polycrystalline NbRe fabricated by magnetron sputtering. Using high-energy resolution N-I-S spectroscopy, we probe the local density of states in thin films of varying thickness and crystallinity to gain insights into the intrinsic pairing symmetry of the superconductor.

15 min. break

Invited Talk TT 24.7 Wed 11:30 H31

Unconventional Superconductivity in Epitaxial $KTaO_3$-Based Heterostructures — •Denis Maryenko — RIKEN Center for Emergent Matter Science, Wako, Japan

Spin-orbit coupling (SOC) is a driving force behind the emergence of novel quantum phenomena. Among these, superconductivity is particularly exciting due to its potential to form unconventional superconducting states that challenge conventional theories. The perovskite $KTaO_3$, with its inherently strong SOC, has recently gained attention as a promising material platform for exploring these phenomena. However, achieving precise control over interfacial electronic states to realize a conductive layer in $KTaO_3$ remains a significant challenge.

In this work, we present out recent progress on epitaxially grown $KTaO_3$-based heterostructures, with a focus on the $LaTiO_3$-$KTaO_3$ (110) interface[1]. Our findings reveal a systematic emergence of superconductivity in these structures. We demonstrate that the superconducting state, signaling unconventional Cooper pairing, can be tuned by electric and magnetic fields. This study sheds light on the interplay between superconductivity and SOC in low-dimensional systems, contributing to the broader understanding of quantum materials with strong spin-orbit interaction.

[1] D. Maryenko et al., APL Materials 11, 61102 (2023).

TT 24.8 Wed 12:00 H31

Topological Fermi Arcs and Surface Superconductivity in $PtBi_2$ — •Julia Besproswanny[1], Sebastian Schimmel[1], Sven Hoffmann[1], Gregory Shipunov[2], Saicharan Aswartham[2], Joaquin Puig[3], Yanina Fasano[3], Danny Baumann[2], Ricardo Vocaturo[2], Jorge I. Facio[3], Oleg Jansen[2], Jeroen van den Brink[2], 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

t-$PtBi_2$ is a topological Weyl semimetal, as evidenced by band structure and quasiparticle interference (QPI) investigations [1]. It also exhibits unconventional surface superconductivity [2,3], with ARPES revealing a superconducting energy gap only on the Fermi arc states [3]. Low-temperature scanning tunneling microscopy and spectroscopy (STM/STS) reveals locally varying sample-dependent superconductivity revealed by the energy gap. In some cases the scale of the gap suggests BCS critical temperatures as high as 70-130 K. We study the temperature and magnetic field dependence of the the energy gap, demonstrating its persistence up to 50 K. Furthermore, QPI measurements in the superconducting state indicate an interplay between topological Fermi arcs and superconductivity.

[1] S. Hoffmann et. al., Adv. Phys. Res. 2400150 (2024);
[2] S. Schimmel et. al., Nat. Commun. 15, 9895 (2024);
[3] A. Kuibarov et. al., Nature 626, 294(2024).

TT 24.9 Wed 12:15 H31

Unconventional Superconductivity in Trigonal $PtBi_2$: Ginzburg–Landau Theory — Harald Waje[1], Ion Cosma Fulga[2], Jeroen van den Brink[2,3], and •Carsten Timm[1,3] — [1]TU Dresden, 01062 Dresden, Germany — [2]Leibniz Institute for Solid State and Materials Research Dresden (IFW), 01069 Dresden, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

Trigonal $PtBi_2$ is a Weyl semimetal that exhibits unconventional surface superconductivity carried by the Fermi arcs [1]. Recent results indicate that the superconducting gap might be nodal, i.e., exhibiting topologically protected Majorana cones. There are three possible superconducting order parameters, corresponding to the three irreducible representations A_1, A_2, and E of the noncentrosymmetric point group C_{3v}. The gap has s-wave ($l = 0$), i-wave ($l = 6$), or d-wave ($l = 2$) symmetry, respectively. We set up a Ginzburg–Landau theory for these order parameters, which also includes coupling to an applied magnetic field. Finally, we discuss some effects described by this theory, such as field-induced pair-density waves.

[1] A. Kuibarov *et al.*, Nature **626**, 294 (2024).

TT 24.10 Wed 12:30 H31

Symmetry-Preserving First-Order Superconductor-to-Superconductor Transition in Heavy-Fermion $CeRh_2As_2$ — •Fabian Jakubczyk[1,2], Julia Link[1,2], and Carsten Timm[1,2] — [1]TU Dresden, 01062 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

Locally noncentrosymmetric materials are attracting significant attention due to the unique phenomena associated with sublattice degrees of freedom. The recently discovered heavy-fermion superconductor $CeRh_2As_2$ has emerged as a compelling example of this class, garnering widespread interest for its remarkable H-T phase diagram, which features field-induced multi-phase superconductivity with non-trivial angular dependencies and large critical fields, as well as antiferromagnetic order, and potential higher multipole orders. To investigate the complex interplay of the ordered phases in $CeRh_2As_2$ including the impact of a magnetic field, we develop a theoretical framework based on group-theoretical considerations, combined with Bogoliubov–de Gennes and Ginzburg–Landau methods. This approach enables us to propose probable symmetries of the superconducting states and elucidate their close relationship with magnetism in this material. Intriguingly, we find that the dominant first-order transition can be interpreted as a transition between coexistence phases of the same symmetry but with distinct admixtures of individual order parameters. Our approach accurately reproduces current experimental phase diagrams, both if the transition to a magnetic phase occurs below the superconducting critical temperature and if it occurs above.

TT 24.11 Wed 12:45 H31

Cause and Effect - Understanding the Fundamental Principles Determining the Gap Structure in Fluctuation Driven Superconductors — •Jonas Profe[1], Olivier Gingras[2], Antoine Georges[3,2,4,5], and Roser Valenti[1] — [1]Institut für Theoretische Physik, Goethe-Universität Frankfurt, Max-von-Laue-Str. 1, 60438 Frankfurt am Main, Germany — [2]Center for Computational Quantum Physics, Flatiron Institute, 162 Fifth Avenue, New York, New York 10010, USA — [3]College de France, 11 place Marcelin Berthelot, 75005 Paris, France — [4]Centre de Physique Theorique, Ecole Polytechnique, CNRS, Institut Polytechnique de Paris, 91128 Palaiseau Cedex, France — [5]DQMP, Universite de Geneve, 24 quai Ernest Ansermet, CH-1211 Geneve, Suisse

Describing and understanding unconventional superconductors is one of the major challenges of modern condensed matter physics. Here, central questions are, what determines which symmetry the superconducting order will have in a material and how can we engineer specific superconducting orders? In this talk, we disentangle how the effective pairing interaction and the electronic structure influence the resulting superconducting order for attractive interactions mediated by fluctuations. For this, we analytically dissect the linearized gap equation in order to extract as much information as possible. We then exemplify how one can utilize this understanding to design models showing specific ordering tendencies in both a single and a multi-orbital setting.

TT 25: Superconductivity: Supercurrent Diode Effect

Time: Wednesday 9:30–12:30 Location: H32

TT 25.1 Wed 9:30 H32

Gate Tunable Anomalous Josephson and Supercurrent Diode Effect — •Johanna Berger[1], Simon Reinhardt[1], Christian Baumgartner[1], Lorenz Fuchs[1], Tim Ascherl[1], Andreas Costa[2], Sergei Gronin[3], Geoff Gardner[3], Tyler Lindemann[3], Michael Manfra[3], Jaroslav Fabian[2], Denis Kochan[2,4], Christoph Strunk[1], and Nicola Paradiso[1] — [1]Institut für Experimentelle und Angewandte Physik, University of Regensburg, 93040 Regensburg, Germany — [2]Institut für Theoretische Physik, University of Regensburg, 93040 Regensburg, Germany — [3]Purdue University, West Lafayette, Indiana 47907 USA — [4]Institute of Physics, Slovak Academy of Sciences, 84511 Bratislava, Slovakia

The discovery of the supercurrent diode effect by Ando et al. [1] and its observation in a rich variety of systems caused an increasing interest in the physics of non-reciprocal superconductivity.
Here, we study Josephson junctions in hybrid Al/InGaAs/InAs structures, which harbor strong Rashba spin-orbit interaction. In combination with a Zeeman field, this gives rise to an anomalous phase shift φ_0 in the current-phase relation (CPR). The presence of high harmonics in the CPR gives rise, in addition, to the supercurrent diode effect [2,3,4]. Using an asymmetric superconducting quantum interferometer we simultaneously measure the φ_0-shift and supercurrent diode effect on a single junction [5]. By electrostatic gating of the junction, we reveal the link between the φ_0-shift and supercurrent diode effect.

TT 25.2 Wed 9:45 H32

Unconventional Josephson Supercurrent Diode Effect Induced by Chiral Spin-Orbit Coupling — •Andreas Costa[1], Osamu Kanehira[2], Hiroaki Matsueda[2], and Jaroslav Fabian[1] — [1]University of Regensburg, Germany — [2]Tohoku University, Japan

First-principles calculations have recently predicted that chiral materials lacking mirror symmetries—such as twisted van-der-Waals homobilayers—can feature unconventional radial Rashba coupling with spins aligned fully parallel (instead of tangentially) to momentum.

In this talk, we will address Josephson transport through vertical superconductor/ferromagnet/superconductor junctions hosting crossed (radial and tangential) Rashba fields at the interfaces and demonstrate that their interplay with ferromagnetic exchange can lead to supercurrent rectification even when the magnetization is collinear with the current. This so-called unconventional supercurrent diode effect (SDE) originates from spin precessions inside the ferromagnet, which imprint polarity-dependent transmission probabilities on the Cooper pairs being well-distinct from the conventional SDE, and provides a sensitive probe of chiral spin textures.

This work has been supported by DFG Grants 454646522 and 314695032 (SFB 1277).

TT 25.3 Wed 10:00 H32

Tunable Field-Free Unidirectional Diode Effect in Single-Crystal Superconducting Device — •Tobias Faeth[1], Damien Berube[2], Killian Rigaux[2], Yuqiang Fang[3], Anyuan Gao[2], Thao Dinh[2], Yufei Liu[2], Jianxiang Qiu[2], Houchen Li[2], Charles Reichhardt[4], Cynthia Reichhardt[4], Fuqiang Huang[3], and Suyang Xu[2] — [1]Max Plack Instiute for Microstructure Physics, Halle (Saale), Germany — [2]Harvard University, Cambridge, USA — [3]Bejing University, Beijing, China — [4]Los Alamos National Laboratory, Los Alamos, USA

Superconducting diodes could become critical components of multiple technologies, from energy-efficient superconducting computing to large scale effective quantum computing, memories and switches. In this talk, we report a device made out of a 2D superconductor, that exhibits field-free, tunable, and perfectly rectifying diode effect. Starting from finite field differential conductance experiments, we demonstrate diode efficiencies up to 30% at 100mT. Measuring nonlinear resistances, we characterize magnetochiral anisotropy (MCA) and calculate a MCA coefficient of $\gamma = 6.0 \times 10^8$ $T^{-1}A^{-1}$, the highest ever reported. Setting the field back to 0, we investigate a novel geometry, while carrying out differential conductance measurements. In the new geometry, we find $I_c^+ = 0$ while $I_c^- = 2\mu A$, a 100% diode efficiency. We hypothesize this effect is attributed to uneven vortex flow under opposite biases. We substantiate this model with computations that confirm increased diode efficiency under the novel geometry.

TT 25.4 Wed 10:15 H32

Tunable Diode effect in a Superconducting Tunnel Junction with Biharmonic Drive — •David Scheer[1], Rubén Seoane Souto[2], Fabian Hassler[1], and Jeroen Danon[3] — [1]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [2]Instituto de Ciencia de Materiales de Madrid, Consejo Superiorde Investigaciones Científicas (ICMM-CSIC), 28049, Madrid, Spain — [3]Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

A Josephson diode is a superconducting circuit element that enables non-reciprocal transport, allowing a dissipationless supercurrent to preferentially flow in a single direction. Existing methods for achieving the required symmetry breaking mostly rely on specifically-designed materials or carefully-engineered circuits composed of multiple Josephson junctions. In this talk, we demonstrate that applying a biharmonic drive to a conventional superconducting tunnel-junction induces a diode effect through harmonic mixing processes that shift the supercurrent region. We show that, in a conventional tunnel junction, unit efficiency is achievable while maintaining a large supercurrent. Moreover, the relative phase between the two driving tones determines the directionality of the diode, which can be tuned in situ.

TT 25.5 Wed 10:30 H32

Spin-Resolved Josephson Diode Effect in Strongly Polarized SFS Junctions — •Danilo Nikolić, Niklas L. Schulz, and Matthias Eschrig — Institut für Physik, Universität Greifswald, Felix-Hausdorff-Strasse 6, 17489 Greifswald, Germany

We present a systematic study of equal-spin Cooper pair formation at the interface between a superconductor (S) and a helical ferromagnet (F) [1]. The theory is done in the framework of the quasiclassical Green's function formalism [2-4]. However, assuming the large splitting between the spin bands in F, the standard quasiclassical approach cannot be applied directly and requires a modified description [5-8]. Applying this approach, we account for the long-ranged (equal-spin) Josephson current-phase relation (CPR) in an SFS weak link considering a helimagnetic state in F. Remarkably, the CPR takes a nontrivial form leading to both the anomalous and Josephson diode effects. These effects have clear physical interpretations based on the coupling between the superconducting phase and the adiabatic spin gauge field (geometric phase) induced by inhomogeneous magnetization of F.

[1] A. Spuri *et al.*, Phys. Rev. Res. **6**, L012046 (2024).
[2] G. Eilenberger, Z. Phys. **214**, 195 (1968).
[3] A.I.Larkin, Yu.N.Ovchinnikov, Sov. Phys. JETP **28**, 1200 (1969).
[4] A. I. Buzdin, Rev. Mod. Phys. **77**, 935 (2005).
[5] M. Eschrig, Phys. Rev. B **80**, 134511 (2009).
[6] R. Grein *et al.*, Phys. Rev. Lett. **102**, 227005 (2009).
[7] M. Eschrig, Rep. Prog. Phys. **78**, 104501 (2015).
[8] I. V. Bobkova *et al.*, Phys. Rev. B **96**, 094506 (2017).

TT 25.6 Wed 10:45 H32

Spin and Charge Josephson Diode Effect in Diffusive Superconductor-Ferromagnet Heterostructures — •Niklas L. Schulz, Danilo Nikolić, and Matthias Eschrig — Institut für Physik, Universität Greifswald, Felix-Hausdorff-Strasse 6, 17489 Greifswald, Germany

Long-range equal-spin triplet supercurrents in the presence of a nontrivial spin texture are of fundamental importance for applications of superconducting spintronics [1]. In this work we investigate quantum geometric phases in a Josephson trilayer consisting of a strongly spin-polarized ferromagnet connected to BCS superconductors by ferromagnetic insulating barriers. For non-coplanar spin textures of the device, spin-geometric phases arise, which enter the current-phase relation additionally to the superconducting phase difference [2]. In general, such spin-geometric phases are induced by gauge fields entering the transport equation [3] and in the considered case these are caused by spin-dependent U(1) gauge fields. The resulting current-phase relation in such devices allows for the observation of a Josephson diode effect in the charge current for symmetric systems and a diode effect in the spin current for asymmetric configurations. In certain cases, the device also allows to switch between fully spin-polarized supercurrents across the ferromagnet by reversing the Josephson phase.

[1] M. Eschrig, Rep. Prog. Phys. **78**, 104501 (2015)

[2] R. Grein et al., Phys. Rev. Lett. **102**, 227005 (2009)
[3] I. V. Bobkova et al., Phys. Rev. B **96**, 094506 (2017)

15 min. break

TT 25.7 Wed 11:15 H32

Josephson diode fabricated by a focused He-Ion beam in a $YBa_2Cu_3O_7$ thin film. — •Edward Goldobin, Alireza Jozani, Christoph Schmid, Reinhold Kleiner, and Dieter Koelle — Universität Tübingen, Germany

We report on the fabrication of a Josephson diode with high asymmetry and size $\approx 1\,\mu m^2$. The device is fabricated from $YBa_2Cu_3O_7$ thin films by creating nano-patterns using a focused He-ion beam (He-FIB). He-FIB irradiation of different doses allows us to "write" both Josephson barriers as well as amorphous resistive walls (circuit boundaries) on a sub-micron scale [1]. We have fabricated sub-μm Josephson junctions of in-line geometry that have rather skewed $I_c(H)$ dependences. At the optimal value of the applied magnetic field H, the ratio of positive and negative critical current I_c reaches ≈ 7. Such a high asymmetry is key for achieving good figures of merit, e.g. a wide rectification window, large stopping forces and a high rectification efficiency [2]. The rectification of an ac current into an average dc voltage $\langle V\rangle$ was investigated experimentally by measuring rectification curves $\langle V\rangle(I_{ac})$ at $T = 4.2$ K. Average dc voltages as high as $212\,\mu$V were achieved for the optimum value of the driving amplitude I_{ac}. Further, the diode was loaded, which allowed us to measure the input and the output power and, therefore, experimentally demonstrate the efficiency, which reaches 80% in some regimes [3].

[1] B. Müller et al., Phys. Rev. Applied **11**, 044082 (2019).
[2] E. Goldobin et al., Phys. Rev. E **94**, 032203 (2016).
[3] C. Schmid, et al., arXiv: 2408.01521 (2024).

TT 25.8 Wed 11:30 H32

Investigation of Josephson junctions with Weyl-Kondo semimetals — •Ronja Fischer-Süsslin[1], Roman Hartmann[1], Thành Tran[1], Diana Kirschbaum[2], Xinlin Yan[2], Andrey Prokofiev[2], Angelo Di Bernardo[1,3], Silke Paschen[2], and Elke Scheer[1] — [1]FB Physik, Universität Konstanz, Konstanz, Deutschland — [2]Institut für Festkörperphysik, TU Wien, Wien, Österreich — [3]Dipartimento di Fisica, Università di Salerno, Fisciano, Italy

A superconducting diode, i.e., a device with a polarity dependent supercurrent amplitude, would provide new functionalities for superconducting circuits. The superconducting diode effect (SDE) was observed in 2020 [1] in an artificial superlattice with inversion symmetry breaking and is now investigated in both Josephson junctions and junction-free superconductors. We have fabricated and investigated Josephson junctions composed of Nb electrodes and the Ce-based Weyl-Kondo semimetals $Ce_3Bi_4Pd_3$ [2] and $CeRu_4Sn_6$ [3] as weak links. These topologically nontrivial materials are promising candidates to investigate the SDE due to their noncentrosymmetry and strong spin-orbit coupling, which are also responsible for the purely electric-field-driven nonlinear spontaneous Hall response [2,3].

[1] F. Ando et al., Nature **584**, 373-376 (2020).
[2] S. Dzsaber et al., PNAS **118**, e2013386118 (2021).
[3] D.Kirschbaum et al., arXiv:2404.15924 (2023).

TT 25.9 Wed 11:45 H32

Cooper pair diode in Coulomb blockade Pb islands on graphene — •Stefano Trivini[1,3], Jon Ortuzar[1], Katerina Vaxevani[1], F Sebastian Bergeret[3,4], and Jose Ignacio Pascual[1,2] — [1]CICnanogune, Donostia, Spain — [2]Ikerbasque, Basque Foundation for Science, Bilbao, Spain — [3]Centro de Física de Materiales (CFM),San Sebastián, Spain — [4]Donostia International Physics Center (DIPC), Donostia-San Sebastián, Spain

Non-reciprocity, essential for current rectification in electronics, is challenging to achieve in superconducting devices without external magnetic fields. Current methods rely on non-centrosymmetric materials or magnetochiral effects, limiting their versatility. We investigate small Pb islands on graphene where Coulomb and superconducting correlations coexist. Approaching the STM tip to Josephson regimes, we observe Resonant Cooper Pair Tunneling (RCT) peaks in the current-voltage characteristics. RCT values change with gating. We test this in a current-biased STM junction and find a CP current asymmetric with polarity. This is a realization of non-reciprocal transport of CP, tunable with a gate.

TT 25.10 Wed 12:00 H32

Magnetoelectric phenomena and radial Rashba diode effect in non-centrosymmetric superconductors — •Denis Kochan — Department of Physics, National Cheng Kung University, Tainan, Taiwan — Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia

The superconducting diode effect is a magneto-electric phenomenon where an external magnetic field imparts a non-zero center-of-mass momentum to Cooper pairs, either facilitating or hindering the flow of electric current depending on its direction. One possible mechanism leading to SDE is a lack of inversion symmetry that facilitates spin splitting of the electronic bands by the underlying spin-orbit coupling (SOC). When breaking also the time-reversal by a weak magnetic/exchange field the Cooper pairs condensate displays intriguing magneto-electric and magneto-chiral effects.

This talk will present a theoretical overview and key experimental observations, particularly supercurrent diode effect and Josephson inductance anisotropy in InAs-quantum well-based junctions [1], zero-pi-like transitions and anomalous Josephson effect in non-centrosymmetric systems [2], enhanced vortex pinning and squeezing in Rashba-based superconductors [3]. The new kid on the block is the radial Rashba SOC giving rise to a novel Radial Rashba spin-diode effect [4].

[1] Nat. Nanotech. 17, 39 (2022).
[2] Nat. Nanotech. 18, 1h266 (2023).
[3] Phys. Rev. X 12, 041020 (2022).
[4] Phys. Rev. Lett. 133, 216201 (2024).

TT 25.11 Wed 12:15 H32

The Josephson diode effect with Andreev and Majorana states — •Sayan Mondal[1], Pei-Hao Fu[2], and Jorge Cayao[1] — [1]Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden — [2]Science, Mathematics and Technology, Singapore University of Technology and Design, Singapore 487372, Singapore

We consider a Josephson junction formed by Rashba superconductors and investigate the Josephson diode effect as the system transitions from a trivial to a topological phase under an applied external Zeeman field [1]. The component of the Zeeman field parallel to the spin-orbit axis introduces asymmetry in the Andreev bound states, which in turn leads to an asymmetry in the Josephson current, giving rise to the diode effect. In this study, we analyze the forward and backward currents, which differ due to the presence of the parallel Zeeman field. We discover that the diode's efficiency as a function of the Zeeman field exhibits a rich structure strongly dependent on the Andreev bound states. This dependence reveals clear signatures of the topological phase of transition. Notably, in the topological phase, the diode efficiency develops an oscillatory pattern reflecting Majorana bound states' formation. We have also verified that the functionality of the obtained Josephson diode is robust against finite temperatures, below the superconducting gap. Our findings help us understand the realization of Josephson diodes in topological superconductors and can also be useful for identifying the emergence of Majorana bound states.

[1] S. Mondal, P. -H. Fu, and J. Cayao, In preparation.

TT 26: Correlated Magnetism – Frustrated Systems

Time: Wednesday 9:30–12:45 Location: H33

TT 26.1 Wed 9:30 H33

Temperature-magnetic field phase diagram of the honeycomb Kitaev system $Na_2Co_2TeO_6$ — •Sebastian Erdmann[1], Prashanta Mukharjee[1], Chanhyeon Lee[2], Kwang-Yong Choi[3], and Philipp Gegenwart[1] — [1]Experimental Physics VI, University of Augsburg, Germany — [2]Institute for Materials Research, Tohoku University, Japan — [3]Department of Physics, Sungkyunkwan University, Republic of Korea

Co-based honeycomb magnets have recently attracted considerable interest as promising candidates for the realization of the bond-directional Kitaev exchange [1]. $Na_2Co_2TeO_6$ belongs to this class of materials and displays antiferromagnetic order below 27 K [2]. We investigate a series of phase transitions in $Na_2Co_2TeO_6$ below 4 K, induced by the application of magnetic fields along the a- and a*-axes. The H-T phase diagram is determined by low-temperature measurements of the specific heat and magnetic Grüneisen parameter, supplemented by literature results. We also compare the thermodynamic behavior upon field tuning to similar studies on other Kitaev materials, such as the prototype system α-$RuCl_3$.[3]

[1] H. Liu, G. Khaliullin, Phys. Rev. B 97, 014407 (2018).
[2] E. Lefrançois et al., Phys. Rev. B 94, 214416 (2016).
[3] S. Bachus et al., Phys. Rev. B B 103, 054440 (2021).

TT 26.2 Wed 9:45 H33

Anisotropic magnetetoelastic coupling in $Na_3Co_2SbO_6$ — •Prashanta K. Mukharjee[1], Lichen Wang[2], Anton Jesche[1], Julian Kaiser[1], Matthias Hepting[2], Pascal Puphal[2], Masahiko Isobe[2], Bernhard Keimer[2], Philipp Gegenwart[1], and Alexander A. Tsirlin[3] — [1]Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, 86159 Augsburg, Germany — [2]Max-Planck-Institute for Solid State Research, Heisenbergstraße 1, 70569 Stuttgart, Germany — [3]Felix Bloch Institute for Solid-State Physics, University of Leipzig, 04103 Leipzig, Germany

Research on 3d-based Co^{2+} materials has intensified as they offer the potential to explore novel regimes of honeycomb magnets, including different versions of the extended Kitaev model. In this study, we investigate the thermodynamic properties of the Kitaev candidate $Na_3Co_2SbO_6$ using complementary thermodynamic measurements, including magnetometry, calorimetry, and high-resolution dilatometry. Our results reveal significant in-plane lattice effects both in the zero-field magnetically ordered phase and in the field-induced states, highlighting a robust anisotropic spin-lattice coupling. Notably, we observe a sign change in both thermal expansion and the structural Grüneisen parameter, which points to a quantum critical endpoint. These findings shed new light on the critical behavior and spin-lattice interactions in $Na_3Co_2SbO_6$ contributing to the understanding of its anisotropic magnetic behaviour.

TT 26.3 Wed 10:00 H33

Revisiting magnetic phases of the Kitaev quantum spin liquid $Na_3Co_2SbO_6$ — •Kranthi Kumar Bestha[1,2], Manaswini Sahoo[1,2], Niccolò Francini[3], Robert Kluge[1], Ryan Christopher Morrow[1], Andrey Maljuk[1], Sabine Wurmehl[1], Sven Luther[4], Hannes Kühne[4], Bernd Büchner[1,2], Laura Teresa Corredor Bohorquez[1], Lukas Janssen[1], and Anja U. B. Wolter[1] — [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 — [3]Institute of Theoretical Physics, TU Dresden, 01062 Dresden, Germany — [4]Hochfeld-Magnetlabor Dresden (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

The quest for the elusive Kitaev Quantum Spin Liquid phase (KQSL) in Kitaev candidates has resulted in the discovery of unexpected exotic magnetic phases due to competing Kitaev, Heisenberg and off-diagonal interactions in real materials. Honeycomb cobaltate, $Na_3Co_2SbO_6$ (NCSO) has attracted much interest due to the predictions of its proximity to the KQSL phase. Using magnetic and thermodynamic methods, we mapped out the magnetic phase diagram of high-quality NCSO single crystals for all three main crystallographic directions. We observe a $J_{eff} = \frac{1}{2}$ ground state with antiferromagnetic order ($T_N = 7$ K) and multiple field-induced metamagnetic transitions in three field directions. The observed anisotropy and field-induced transitions are modeled within an extended $JK\Gamma\Gamma'$ model. Our work uncovers new exotic magnetic phases both in-plane and out-of-plane field directions.

TT 26.4 Wed 10:15 H33

Magnetic-field induced phase transition crossover in the triangular lattice antiferromagnet $Ba_3CoSb_2O_9$ — •Sanjay Kumar[1], Rashi Nathawat[1], Arvind Kumar Yogi[2], and Satyapal S. Rathore[3] — [1]Functional Ceramics and Smart Materials Lab, Department of Physics, Manipal University Jaipur, Jaipur - 303007, India. — [2]UGC-DAE Consortium for Scientific Research, Indore - 452001, India. — [3]Department of Physics, Cluster University of Jammu, Jammu - 180001, India.

The effect of magnetic field on the ground state properties of triangular lattice antiferromagnet (TLAF) compound $Ba_3CoSb_2O_9$. The temperature-dependent X-ray diffraction (10 to 300 K) shows no structural changes. The temperature and field-dependent susceptibility indicate that TLAF orders antiferromagnetically below $T_N \sim 3$ K. The susceptibility follows a Curie-Weiss law (above 100 K) with q_{CW} = -133.2 K. The frustration index (f $\sim$ 44) indicates a highly frustrated system. Magnetization curves (dM/dH) at 2 K reveal field-induced spin-flop transitions near H $\sim$ 9 T. Magnetic susceptibility shows a broad peak at T_{max} = 5 K, becoming more pronounced with increasing field. A spin-glass signature appears near $T_g \sim 6.5$ K but vanishes at higher fields. Interestingly, the magnetic ground state in this compound shows a crossover from the various possible spin orders. A significant shoulder-like hump in heat capacity near $T_c \sim 15$ K suggests structural changes, deviating from the typical λ-anomaly. The change in magnetic properties is attributed to the interplay between antisite defects, quantum fluctuations, and geometric frustration in TLAF.

TT 26.5 Wed 10:30 H33

First-principles modeling of Ni-based honeycomb compounds — •Thore Martens and Alexander Tsirlin — Leipzig University, Germany

In recent years, there has been an increasing interest in Kitaev materials for spins higher than 1/2. Using Density functional theory (DFT), anisotropic spin couplings as well as single-ion anisotropy are calculated and compared for several Ni-based honeycomb compounds: $KNiAsO_4$, $BaNi_2(AsO_4)_2$, $BaNi_2(PO_4)_2$ and $Na_3Ni_2BiO_6$. Most of these investigated compounds share a particularly large antiferromagnetic J_3 and a weaker ferromagnetic J_1 as leading couplings giving rise to a zig-zag magnetic structure. The dependence of these couplings on U from LSDA+U as well as full calculations on the tensor elements of J_1 are performed. From this, potential Kitaev interactions are obtained for the four Ni-compounds.

TT 26.6 Wed 10:45 H33

Exploring Geometrical Frustration in Ho_3ScO_6-II: Magnetic Properties and Structural Insights — •Abanoub Hanna[1], Cintli Aguilar Maldonado[1], and Bella Lake[1,2] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Hahn-Meitner Platz 1, D-14109 Berlin, Germany — [2]Institut für Festkörperphysik,Technische Universität Berlin, Berlin, Germany

Geometrical frustration occurs in magnetic compounds when the arrangement of magnetic ions in triangular or tetrahedral lattices leads to competing interactions, resulting in non-classical magnetic states. This study examines the cubic compound Ho_3ScO_6-II, which crystallizes in a bixbyite-type structure with a centrosymmetric cubic space group Ia3* and exhibits no magnetic ordering above 1.8 K, underscoring its geometrically frustrated nature. Unlike its polymorph Ho_3ScO_6-I, which shows long-range magnetic order at 4.4 K, Ho_3ScO_6-II lacks magnetic anisotropy and presents a Curie-Weiss temperature of approximately -20 K and an effective magnetic moment (μ_{eff}) of 9.8 μB, indicating significant antiferromagnetic interactions. Additionally, the study compares Ho_3ScO_6-II with Er_3ScO_6, which is isostructural and exhibits magnetic ordering around 2.1 K that is suppressed under external magnetic fields. This comparison highlights the contrasting behaviours of these compounds, contributing to a deeper understanding of frustrated magnetism within the RE_3ScO_6 system (RE = Ho, Er). The findings provide valuable insights into the unique structural and magnetic properties of Ho_3ScO_6-II and suggest potential applications in spintronic devices and quantum computing.

15 min. break

TT 26.7 Wed 11:15 H33

Continuous Similarity Transformations for the Easy-Axis XXZ Model on the Honeycomb Lattice — •Matthias R. Walther[1], Dag-Björn Hering[2], Vanessa Sulaiman[2], Maximilian Bayer[1], Götz S. Uhrig[2], and Kai P. Schmidt[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany — [2]Condensed Matter Theory, Technische Universität Dortmund, Otto-Hahn-Straße 4, 44221 Dortmund, Germany

Neutron scattering experiments on $YbCl_3$ show that it realizes the antiferromagnetic Heisenberg model on a honeycomb lattice [1]. While key features are captured by linear spin-wave theory (LSWT), a full dispersion cannot be reproduced. We apply continuous similarity transformations (CSTs) [2-4] to the easy-axis antiferromagnetic XXZ-model on the honeycomb lattice. This allows us to derive an effective model which takes the relevant magnon-magnon interactions beyond LSWT into account targeting a quantitative description of the single-particle properties. 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] G. Sala et al., Nat. Comm. 12, 171 (2021).
[2] M.R. Walther et al., Phys. Rev. Res., 013132 (2023).
[3] M. Powalski et al., Rev. Lett. 115, 207202 (2015).
[4] M. Powalski et al., SciPost Phys. 4, 001 (2018).

TT 26.8 Wed 11:30 H33

Magnetic Frustration and Weak Mn Magnetic Ordering in $EuMn_2P_2$ — Sarah Krebber[1], Marvin Kopp[1], Jens Müller[1], Jörg Sichelschmidt[2], Michael Baenitz[2], Kurt Kummer[3], Cornelius Krellner[1], and •Kristin Kliemt[1] — [1]Physikalische Institut, Goethe Universität Frankfurt, Deutschland — [2]Max-Planck-Insitut für Chemische Physik fester Stoffe, 01187 Dresden, Deutschland — [3]European Synchrotron Radiation Facility, 38043 Grenoble, France

$EuMn_2P_2$ is a member of the Eu-based 122-systems with a trigonal $CaAl_2Si_2$ crystal structure. The magnetic properties of the Eu ion in this compound are located in triangular layers of Eu^{2+}. Several quantaties indicated the presence of A-type antiferromagnetic Eu order at $\approx 18\,K$, with magnetic moments oriented in the a-a plane. Nevertheless, no magnetic order of Mn was observed [1,2]. This is intriguing, given that the analogous compounds $EuMn_2As_2$ and $EuMn_2Sb_2$ exhibit phase transitions attributed to Mn magnetic order at elevated temperatures (T_N = 135 K, T_N = 128 K) [3,4].
In this study, we present the results of electron spin resonance (ESR), heat capacity, magnetization, nuclear magnetic resonance (NMR) and electrical resistivity measurements on $EuMn_2P_2$ single crystals, which exhibite a weak magnetic ordering attributed to Mn magnetism.
[1] A. Payne et al., J. Solid State Chem. 163, 2 (2002);
[2] T. Berry et al., J. Am. Chem. Soc. 145, 8 (2023);
[3] V. K. Anand et al., Phys. Rev. B 94, 014431 (2016);
[4] I. Schellenberg et al., ZAAC 636, 85 (2010).

TT 26.9 Wed 11:45 H33

Exploring the Anisotropic Shastry-Sutherland Model by Strain Tuning of $SrCu_2(BO_3)_2$ — •Francisco Lieberich[1,4], Pascal Puphal[2], Ekaterina Pomjakushina[3], and Elena Gati[1,4] — [1]MPI-CPfS, Dresden, Germany — [2]MPI-FKF, Stuttgart, Germany — [3]PSI, Villigen, Switzerland — [4]TUD, Dresden, Germany

The Shastry-Sutherland model is a hallmark of frustrated magnetism and is realized by $SrCu_2(BO_3)_2$, where competing intra-dimer and inter-dimer interactions J and J' stabilize a dimerized ground state. The Shastry-Sutherland model can be generalized to an anisotropic model with two sets of inequivalent couplings J_1, J_2 and J_1', J_2'. This model is predicted to host novel ground states [1] and may address the debate [2] on the nature of the plaquette phase of $SrCu_2(BO_3)_2$. Experimentally, anisotropic strains break the lattice symmetry of $SrCu_2(BO_3)_2$ and may therefore be used to tune the anisotropy in the Shastry-Sutherland model. We use the AC elastocaloric effect, a thermodynamic probe of strain-tuned quantum materials [3], to map out the entropic landscape of $SrCu_2(BO_3)_2$ under large anistropic strains. By comparing the results under [100] and [110] strain, we disentangle the effects of symmetry-breaking and symmetry-conserving strains on $SrCu_2(BO_3)_2$. Our phase diagrams reveal features consistent with hydrostatic-pressure studies [4], alongside new effects that may arise from symmetry breaking.
Supported by the DFG through SFB 1143.
[1] Boos et al., PRB 100, 140413(R) (2019);
[2] Zayed et al., Nat. Phys. 13, 962 (2017);
[3] Ikeda et al., RSI 90, 083902 (2019);
[4] Guo et al., PRL 124, 206602 (2020).

TT 26.10 Wed 12:00 H33

Search for Precursors of Multi-Magnon Bound States in Li_2CuO_2 Single Crystals in Specific Heat Data — •Stefan-Ludwig Drechsler[1], Eli Zoghlin[2], Wolfram Lorenz[1], and Ulrich Roessler[1] — [1]IFW-Dresden, Dresden, Germany — [2]J. Hopkins University, Baltimore, Maryland, USA

We report specific heat c_p-data for high quality single crystals of the edge-sharing chain cuprate Li_2CuO_2 collected in a wide temperature region from 20 to 70 K well above the Ne'el transition $T_N \approx 9.2$ to 9.4 K at ambient magnetic field. The c_p is analyzed within a sensitive c_p/T^3-plot adopting and generalizing an analytical expression [1] by adding precursor multi-magnon bound state (PMMBS) of any order. This way, the problem of missing intensity around 40 K can be resolved. The obtained excitation energies of PMMBS are in accord with recent inelastic neutron scattering data for Li_2CuO_2 [2] regarding single-magnon, two-magnon and three-magnon bound states. The results are discussed within the context of a recenly proposed Bose condensation scenario of MMBS [3] at very low temperature and ambient field.
[1] S. Ebisu *et al.*, J. Phys.Chem.Sol. **59**, 1407 (1998);
[2] E. Zoghlin *et al.*, PRB **108** 064408 (2023);
[3] C.E. Agrapidis, S.-L. Drechsler, S. Nishimoto, arXiv: 2410.00734, Phys. Rev. X (submitted).

TT 26.11 Wed 12:15 H33

Anisotropic Spin Ice on a Breathing Pyrochlore Lattice — •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

Spin ice systems have long captivated researchers due to their exotic magnetic properties and emergent excitations. Recently, breathing pyrochlore compounds have been identified as a platform for studying novel phases, including fracton physics and quantum spin liquids. We explore a spin ice model on a breathing pyrochlore lattice, introducing sublattice-dependent anisotropic interactions that are potentially realizable experimentally, for example, through uniaxial strain. We theoretically uncover a rich phase diagram by varying the strain and show how these anisotropic constraints reduce the ground state degeneracy across the different phases. Our numerical simulations reveal that, at low temperatures, the models undergo a crossover into a constrained spin ice manifold, characterized by an entropy density that falls below the celebrated Pauling entropy of conventional spin ice. Moreover, we observe glassy dynamics in spin correlations when probing the out-of-equilibrium behavior, suggesting slow relaxation and memory effects. This model provides a new perspective on spin ice physics, offering a potentially robust platform for studying fracton phenomena and experimental exploration of constrained magnetism and emergent glassy dynamics.

TT 26.12 Wed 12:30 H33

Efficient Optimization and Conceptual Barriers with Projected Entangled-Pair States — •Erik Weerda[1], Daniel Alcalde[1,2], Konrad Schröder[1], and Matteo Rizzi[1,2] — [1]University of Cologne, Cologne, Germany — [2]Forschungszentrum Jülich

Finite projected entangled-pair states (PEPS) are becoming a widely used tool in the computational study of strongly correlated systems. However, no standard set of computational tools has yet emerged to exploit the power of this approach. In this work we investigate a promising approach to ground state search with PEPS based on sampling methods. Along with presenting strategies for more effi cient optimisation, we also discuss conceptual barriers associated with this approach. A benchmark illustrates the power of these tools in the study of ground states of frustrated magnetic models.

TT 27: Focus Session: Nonlinear Spectroscopy of Collective Excitations in Quantum Magnets (joint session TT/MA)

In recent years, significant progress has been made in understanding strongly correlated quantum magnets, with a particular focus on fractionalized states of matter such as quantum spin liquids. These achievements in understanding have been made possible by remarkable developments in both materials science and experimental techniques. In particular, improvements in both traditional experimental tools (e.g., inelastic neutron scattering, Raman scattering, resonant X-ray scattering, etc.) and the introduction of innovative techniques such as 2D coherent THz spectroscopy and sophisticated noise experiments have advanced studies of quantum matter to qualitatively new levels of insight. This focus session will discuss these recent advancements in nonlinear spectroscopy techniques along with theoretical inroads in describing the nonlinear spectroscopic signatures of complex quantum magnets.

Organizers: Simon Trebst (Universität zu Köln), Johannes Knolle (TU München)

Time: Wednesday 9:30–12:45 Location: H36

Topical Talk TT 27.1 Wed 9:30 H36

Detecting Anyons Using Nonlinear Pump-Probe Spectroscopy — •Max McGinley[1,2], Michele Fava[2], and Sid Parameswaran[2] — [1]Cambridge University, UK — [2]Oxford University, UK

Topologically ordered two-dimensional systems can host excitations that possess statistics that interpolate between bosonic and fermionic—so called anyons. In this talk, I will explain how the presence of such anyonic excitations can be inferred from nonlinear spectroscopic quantities. In particular, we consider pump-probe spectroscopy, where a sample is irradiated by two light pulses with an adjustable time delay between them. The relevant response coefficient exhibits a universal form that originates from the statistical phase acquired when anyons created by the first pulse braid around those created by the second. This behaviour is shown to be qualitatively unchanged by non-universal physics including non-statistical interactions and small finite temperatures. In magnetic systems, the signal of interest can be measured using currently available terahertz-domain probes, highlighting the potential usefulness of nonlinear spectroscopic techniques in the search for quantum spin liquids. I will discuss future prospects for inferring properties of collective excitations using analogous techniques.

Topical Talk TT 27.2 Wed 10:00 H36

Two-Dimensional Nonlinear Dynamic Response of Frustrated Magnets — •Wolfram Brenig — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany

Two-dimensional nonlinear (2DNL) coherent optical spectroscopy is of great interest in order to deconvolute excitation continua in correlated magnets, potentially allowing to analyze individual quasiparticles, including those of fractionalized magnets. We discuss the relevant response functions for the coupling of spin systems to electric fields and analyze the 2DNL dynamical susceptibilities for two scenarios of frustrated magnetism, namely for a quantum spin-liquid (QSL) as well as for a case of incommensurate spiral long-range order (ICO). For the former, we consider the Kitaev magnet, which hosts a quantum spin-liquid, featuring fractionalization in terms of mobile Majorana fermions and static flux-visons. We show that the 2DNL response does not only probe characteristic features of both fractional excitations, but also allows to extract single quasiparticle lifetimes from its multi-particle continua. These properties will be discussed over a wide range of temperatures. For the case of 2DNL response from a magnet with ICO, we chose the J_1-J_3 spin-model on the square lattice. Here, some features of the 2DNL spectra are found to be remarkably similar to those of the QSL case. Going beyond a bare quasiparticle approach, we will also comment on the impact of final-state interactions.

Work done in collaboration with Olesia Krupnitska and profiting from interactions with Roser Valentí, Natalia Perkins, Marius Möller, Anna Keselman, and David Kaib.

Topical Talk TT 27.3 Wed 10:30 H36

Imaging Magnetization Dynamics and Collective Spin Excitations in Compensated Magnets on Ultrafast Timescales — •Benjamin Stadtmüller — Experimentalphysik II, Institute of Physics, Augsburg University, 86159 Augsburg, Germany

Fundamental to the advancement of spintronics and quantum technologies is the ability to encode, manipulate and store information in the spin angular momentum of electrons on ever faster timescales. In this contribution, we therefore discuss the ultrafast magnetic response of compensated magnets, which are interesting candidates for applications due to their robustness against external fields and their fast manipulation speed. We start with the ultrafast magnetization dynamics of conventional antiferromagnets (AFMs), for which the possibility of optical excitation of collective magnon modes on ps timescales has already been demonstrated. For the case of NiO, we show that these timescales can be further reduced by exploiting the strong non-equilibrium excitation with fs laser pulses. These conditions lead to a significant loss of magnetic order and to the excitation of collective magnon modes. We then turn to the ultrafast optical response of the recently discovered class of altermagnets with their d-wave-like spin split band structure. By combining theoretical calculations with ultrafast magneto-optical experiments, we demonstrate the generation of a macroscopic spin polarization in the otherwise fully compensated altermagnet RuO_2, which can additionally be controlled by the excitation geometry [1]. [1] M. Weber and S. Wust et al. arXiv: 2408.05187

15 min. break

Topical Talk TT 27.4 Wed 11:15 H36

Revealing Dynamics of Hidden Sectors with Nonlinear Spectroscopy — •Yoshito Watanabe[1], Simon Trebst[1], and Ciarán Hickey[2,3] — [1]Institute for Theoretical Physics, University of Cologne, 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

Nonlinear spectroscopy, especially in its two-dimensional coherent spectroscopy (2DCS) form, is an emerging and promising tool for studying the dynamics of quantum materials. Unlike traditional linear probes, 2DCS employs a multi-pulse approach that reveals intricate dynamics, including the ability to resolve fractional excitation continua as sharp spinon-echo signals and to study interactions between excitations, phenomena often obscured in traditional measurements.

In this work, we focus on the potential of 2DCS to detect and characterize quadrupolar excitations in quantum magnets. Using exact diagonalization and establishing an effective Hamiltonian that reflects the dynamics of hidden sectors and higher-order excitations, we identify distinct spectroscopic features, including new signatures associated with quadrupolar excitations. These results provide a guide for the experimental detection and characterization of hidden dynamics in quantum materials.

Topical Talk TT 27.5 Wed 11:45 H36

Theory of Nonlinear Spectroscopy of Quantum Magnets — Anubhav Srivastava[1,2], •Stefan Birnkammer[1], GiBaik Sim[3], Michael Knap[1], and Johannes Knolle[1,4] — [1]Technical University of Munich, Garching, Germany — [2]Indian Institute of Science, Bengaluru, India — [3]Hanyang University, Seoul, Korea — [4]Imperial College London, London, United Kingdom

Two-dimensional coherent spectroscopy (2DCS) is an established method for probing molecules and has been proposed in the THz regime as a new tool for probing exotic excitations of quantum magnets but the precise nature of coupling between pump field and spin degrees of freedom has remained unclear. Here, we develop a general response theory of 2DCS and show how magneto-electric as well as polarization couplings contribute to 2DCS in addition to the standardly assumed magnetization. We propose experimental protocols to distill individual coupling contributions, for example from exchange-striction or spin current mechanism. We provide example calculations for the paradigmatic twisted Kitaev chain material $CoNb_2O_6$ and highlight the crucial role of contributions from cross-coupling between polarization and magnetic nonlinear susceptibilities. Our work paves the way for systematic studies of light-matter couplings in quantum magnets and for establishing 2DCS as a versatile tool for probing fractional excitations of exotic magnetic quantum phases.

TT 27.6 Wed 12:15 H36

Quantitative Prediction of the Dynamics of In-Gap States in Correlated Materials as Seen in Pump-Probe PES, XAS and RIXS Experiments: A NiO Case Study — •Sina Shokri and Maurits W. Haverkort — Universität Heidelberg, Institut für Theoretische Physik, Philosophenweg 19, Heidelberg 69120 Germany

Attosecond pump-probe experiments allow one to study and steer quantum materials on their fundamental time-scales. For atoms and small molecules one can theoretically predict the electronic and vibrational dynamics induced by ultra-fast light pulses [1,2]. In solids a theoretical understanding is much harder. The coupling to many continuous degrees of freedom can result into rapid loss of coherence. Quantitative predictions how coherently driven excitations decohere is highly non-trivial. Correlated Mott- Hubbard or charge transfer insulators can show a variety of long lived excitonic excitations within the optical gap. With attosecond pump-probe spectroscopy it is possible to investigate the propagation and decay of such excitations, as recently shown by two-photon photo-emission spectroscopy of NiO. These experiments show photo-induced, long-lived in-gap states with coherent oscillations [3]. In this talk we will show, using non-linear response theory, how to quantitatively predict the dynamics of in-gap states in correlated materials after an optical excitation. We will furthermore show how this dynamics can be probed with different pump-probe experiments including photo-emission spectroscopy, x-ray absorption spectroscopy and resonant inelastic x-ray scattering.

[1] PRL 128, 153001 (2022).
[2] PRA 108, 032816 (2023).
[3] Nat. Commun. 11, 4095 (2020).

TT 27.7 Wed 12:30 H36

Higher-Order Susceptibilities in Extended Kitaev Models Computed Via Krylov-Space Based Methods — •David Kaib, Marius Möller, and Roser Valenti — Institut für theoretische Physik, Goethe-Universität Frankfurt

Recently, it was proposed that techniques measuring higher-order dynamical response, such as two-dimensional coherent spectroscopy (2DCS), could provide more distinguishable signatures in analyzing the excitations of different systems. This is particularly true when linear response reveals only a featureless continuum, which could arise from various different types of excitations, or, for example, static disorder. The numerical evaluation of nonlinear response functions can, however, be computationally very demanding. Here, we propose an efficient Lanczos-based method that computes higher-order susceptibilities directly in the frequency domain. As an application case, we consider extended Kitaev models, that are relevant to α-$RuCl_3$ and related materials. We compare the nonlinear response from our method to the one obtained within linear spin-wave theory, showcasing that nonlinear response measurements can distinguish whether an observed excitation continuum is of conventional two-magnon type or has a different origin.

TT 28: Many-body Quantum Dynamics II (joint session DY/TT)

Time: Wednesday 9:30–13:00 Location: H37

TT 28.1 Wed 9:30 H37

The Sound of Entanglement — •Benjamin Orthner[1], Clemens Wenger[5], Johannes Kofler[2], Richard Küng[2], Enar de Dios Rodríguez[3], Martin Ringbauer[4], Alexander Ploier[2], and Philipp Haslinger[1] — [1]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna, Austria — [2]Johannes Kepler University Linz, Austria — [3]Internationale Forschungszentrum Kulturwissenschaften, Kunstuniversität Linz, Austria — [4]University of Innsbruck, Austria — [5]Universität für Musik und darstellende Kunst Graz, Austria

This contribution presents *The Sound of Entanglement*, a project at the intersection of quantum physics, music, and visual art. At its core lies a Bell experiment setup, where polarization-entangled photon pairs are generated through spontaneous parametric down-conversion in a β-BBO crystal. The experiment acts as a quantum conductor, utilizing the quantum correlations between the photons to coordinate and influence the choices of live musicians in real-time, creating a performance guided by principles beyond classical physics.

This work seeks to make these abstract concepts more accessible and engaging to broader audiences by transforming them into tangible, sensory experiences. By combining live music with a dynamic light show, both controlled by the experiment, this project illustrates how advancements in technology, like those shaping the second quantum revolution, can redefine artistic expression and bridge the gap between science and art.

TT 28.2 Wed 9:45 H37

A Solvable Model for Full Eigenstate Thermalization — •Felix Fritzsch and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The Full Eigenstate Thermalization Hypothesis (Full ETH) aims to characterize thermalization in many-body quantum systems in terms of the dynamics of higher-order spatiotemporal correlation functions, going beyond the current standard ETH paradigm. In this talk, we introduce a solvable random matrix model for many-body quantum dynamics in which the asymptotic dynamics of generalized out-of-time-order correlation functions can be exactly obtained in the thermodynamic limit. The dynamics of this model naturally maps to dynamics on the lattice of non-crossing partitions, combinatorial structures underlying the mathematics of Free Probability and Full ETH. We demonstrate how local observables approach asymptotic freeness at late times and explicitly characterize all relevant time scales. We confirm our analytical results with numerical simulations performed directly in the thermodynamic limit.

TT 28.3 Wed 10:00 H37

Scrutinizing the Mori memory function for transport scenarios — •Scott Daniel Linz, Jiaozi Wang, Robin Steinigeweg, and Jochen Gemmer — Department of Mathematics/Computer Science/Physics, University of Osnabrück, D-49076 Osnabrück, Germany

Diffusion is a phenomenological hydrodynamic transport behavior that holds over a wide range of materials. Within condensed matter physics there is the opinion that as long as the area under the current-current correlation function converges in time, one has a criterion for diffusive behavior of the corresponding spatiotemporal density dynamics. Attempts to derive this statement are notoriously challenging. We will first demonstrate that it is possible to construct correlation functions of some local density, where the area under a current-current correlation function converges, but the system is not diffusive. After this is demonstrated, we shall introduce a method based on the recursion method and the Mori memory formalism, that yields insight into whether or not a process is truly diffusive. The only disadvantage of this strategy is that one would have to know the behavior infinitely many Lanczos coefficients, whereas in practice one can only calculate a finite number of them in most cases. In the cases examined in this talk, however, the convergence or lack thereof becomes apparent to the naked eye with the finite amount of coefficients that were calculated.

TT 28.4 Wed 10:15 H37

Long-time Freeness in the Kicked Top — •Elisa Vallini and Silvia Pappalardi — University of Cologne, Köln, Germany

Recent work highlighted the importance of higher-order correlations in quantum dynamics for a deeper understanding of quantum chaos and thermalization. The full Eigenstate Thermalization Hypothesis, the framework encompassing correlations, can be formalized using the language of Free Probability theory. In this context, chaotic dynamics at long times are proposed to lead to free independence or "freeness" of observables. We investigate these issues in a paradigmatic semiclassical model - the kicked top - which exhibits a transition from integrability to chaos. Despite its simplicity, we identify several non-trivial features. By numerically studying 2n-point out-of-time-order correlators, we show that in the fully chaotic regime, long-time freeness is reached exponentially fast. These considerations lead us to introduce a large deviation theory for freeness that enables us to define and analyze the associated time scale. The numerical results confirm the existence of a hierarchy of different time scales, indicating a multifractal approach to freeness in this model. Our findings provide novel insights into the long-time behavior of chaotic dynamics and may have broader implications for the study of many-body quantum dynamics.

TT 28.5 Wed 10:30 H37

Periodically and aperiodically Thue-Morse driven long-range systems: from dynamical localization to slow dynamics — •VATSANA TIWARI — Indian Institute of Science Education and Research Bhopal, Bhopal, India

In this talk, I will discuss the impact of time-periodic and aperiodic field on power-law random banded matrix (PLRBM) model where variation in the power-law exponent yields a delocalization-to-localization phase transition. We investigate the periodically driven PLRBM model with the help of the static measures such as level spacing ratio and generalized inverse participation ratio and report the drive-induced multifractal to localization transition. The transport study of the periodically driven system demonstrates the transition from diffusive to logarithmically slow relaxation at dynamical localization point. Extending our analysis to the aperiodic Thue-Morse driving, we find that specific driving parameters leads to the *exact dynamical localization* in a disordered-free long-range model regardless of the long-range parameter. In the disordered case, the localized phase exhibits a long prethermal plateau followed by diffusion to an infinite temperature state, while the delocalized phase shows immediate diffusion. Additionally, we compare this with a quasi-periodic model that also undergoes a localization-delocalization transition, noting that, unlike the delocalized side of the disordered long-range model, it features a prolonged plateau followed by diffusion to the infinite temperature state.

TT 28.6 Wed 10:45 H37

Symmetry-Resolved Out-of-Time-Order Correlators with Projected Matrix Product Operators — •Martina Gisti, David Luitz, and Maxime Debertolis — Institute of Physics, University of Bonn, Nußallee 12, 53115 Bonn, Germany

Out-of-Time-Order Correlators (OTOCs) are key measures of quantum many-body chaos and information spreading. We systematically analyse OTOCs as a function of particle number for interacting spinless fermions in one dimension. With the concept of generalized operator charge, we develop a formalism for the time evolution of symmetry-projected matrix product operators, which we use to resolve the scrambling behaviour by particle number sector. Our results reveal a crossover from ballistic to diffusive dynamics at early times and a saturation regime at late times.

TT 28.7 Wed 11:00 H37

Revealing ultrafast phonon mediated inter-valley scattering through transient absorption and high harmonic spectroscopies — •Kevin Lively[1], Shunsuke Sato[2,3], Guillermo Albareda[2,4], Angel Rubio[2], and Aaron Kelly[2] — [1]Deutsches Zentrum für Luft- und Raumfahrt — [2]Max Planck Institute for the Structure and Dynamics of Matter — [3]University of Tsukuba — [4]Ideaded

Processes involving ultrafast laser driven electron-phonon dynamics play a fundamental role in the response of quantum systems in a growing number of situations of interest, as evinced by phenomena such as strongly driven phase transitions and light driven engineering of material properties. To show how these processes can be captured from a computational perspective, we simulate the transient absorption spectra and high-harmonic generation signals associated with valley selective excitation and intraband charge-carrier relaxation in monolayer hexagonal boron nitride. We show that the multitrajectory Ehrenfest dynamics approach, implemented in combination with real-time time-dependent density-functional theory and tight-binding models, offers a simple, accurate, and efficient method to study ultrafast electron-phonon coupled phenomena in solids under diverse pump-probe regimes which can be easily incorporated into the majority of real-time ab initio software packages.

15 min. break

TT 28.8 Wed 11:30 H37

Chiral basis for qubits and decay of spin-helix states — •Frank Göhmann — Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, 42097 Wuppertal, Germany

In a recent cold-atom experiment by the Ketterle group at MIT one-dimensional spin-helix states could be prepared and their time evolution induced by the XXZ Hamiltonian could be observed. The experiment allows to adjust the anisotropy parameter of the latter. For the special case of the XX model we describe the spatio-temporal decay of a transversal spin helix explicitly. The helix pattern stays stable in space, but has a non-trivial time-dependent decay amplitude which is of scaling form and is governed by a universal function that can be represented as a semi-infinite determinant related to the discrete Bessel kernel. This representation is valid for all times, is numerically utterly efficient and allows us to obtain the long-time asymptotics of the function. Our work is a rare example of a quench that has been experimentally realized and for which the full time dependence could be calculated exactly.

V. Popkov, X. Zhang, F. Göhmann and A. Klümper, *Chiral basis for qubits and spin helix decay*, Phys. Rev. Lett. **132** (2024) 220404 (5pp)

TT 28.9 Wed 11:45 H37

Towards the chaotic melting at low energies in large systems — •Mathias Steinhuber[1], Jonas Rigo[2], Juan Diego Urbina[1], Klaus Richter[1], and Markus Schmitt[1,2] — [1]University of Regensburg, Regensburg, Germany — [2]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), Jülich, Germany

Thinking in a classical phase space picture, a many-body ground state should be localized around the minimum of the classical mean-field energy landscape with stable integrable features. But here, we investigate many-body ground states on chaotic features, as the phase space picture is actually fragile if we increase the system size and keep the quantum scale (the effective Plank constant $\hbar_{\mathrm{eff}}$) fixed. With the new degrees of freedom, we disturb the energy landscape in the classical limit more and more such that classical chaos is present even for low energies. We show this phenomenon, called 'chaotic melting' [1,2], is indeed happening in the Bose-Hubbard system with disorder. By using neural quantum states we can push quantum calculations for ground states to large systems and find signatures of chaos at the ground state. An intriguing application for these large systems is that the Bose-Hubbard Hamiltonian with disorder is an effective model for transmon arrays which are a prime candidate for quantum computer hardware. Therefore we also gain access to quantum states describing a possible quantum computer with chaotic features.

[1] S.-D. Börner, et al. Phys. Rev. Research 6, 033128 (2024)
[2] J. Chávez-Carlos, et al. arXiv: 2310.17698 (2024)

TT 28.10 Wed 12:00 H37

Period n-tupling in driven two level systems — •Dhruv Deshmukh and Joachim Ankerhold — Institute for complex quantum systems, Ulm University, Germany

This talk presents the necessary and sufficient conditions for realizing period n-tupling phenomena in periodically driven two-level systems. For the specific case of a two-level system driven linearly by a sinusoidal drive, we numerically identify the drive parameters that enable period n-tupling. Experimental results verifying period doubling in an NV centre driven by a microwave drive, are given. Further, we show that period quadrupling drives yield pulses which are much faster than the standard (Rabi) $\pi/2$ and π pulses built from weak drives. These stronger and faster pulses can be utilized for qubit manipulation, enabling faster gates and more efficient pulse sequences. Moreover, they inspire a new strategy for constructing efficient pulses using a Floquet theory approach to optimal control. Furthermore, the drive parameters could also be set to achieve period-1 (stroboscopic) dynamical freezing. The fragility of such phenomena can be exploited for sensing applications, as illustrated with an example in magnetometry.

TT 28.11 Wed 12:15 H37

Efficient computation of cumulant evolution and full counting statistics: application to infinite temperature quantum

spin chains — •Angelo Valli[1,2], Cătălin Pascu Moca[2,3], Miklós Antal Werner[1,4], Márton Kormos[1,2], Žiga Krajnik[5], and Tomaž Prosen[6] — [1]Budapest University of Technology and Economics, Muegyetem rkp. 3., 1111 Budapest, Hungary — [2]HUN-REN BME Quantum Dynamics and Correlations Research Group — [3]University of Oradea, 410087, Oradea, Romania — [4]HUN-REN Wigner Research Centre for Physics, P.O. Box 49, 1525 Budapest, Hungary — [5]New York University, 726 Broadway, New York, NY 10003, USA — [6]University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia

We propose a numerical method to efficiently compute quantum generating functions (QGF) for a wide class of observables in one-dimensional quantum systems at high temperature. We obtain high-accuracy estimates for the cumulants and reconstruct full counting statistics from the QGF. We demonstrate its potential on spin S=1/2 anisotropic Heisenberg chain, where we can reach time scales hitherto inaccessible to state-of-the-art classical and quantum simulations. Our results are in excellent agreement with a recent Google Quantum AI experiment [2] and challenge the conjecture of the Kardar-Parisi-Zhang universality for isotropic integrable quantum spin chains.

[1] A. Valli et al. arXiv:2409.14442 (2024)
[2] E. Rozenberg et al. Science 384, 48-53 (2024)

TT 28.12 Wed 12:30 H37

Machine learning approach to study the properties of ground and excited states in the 1D Bose-Hubbard model — •Yilun Gao[1], Alberto Rodríguez González[2,3], and Rudolf A. Römer[1] — [1]Department of Physics, University of Warwick, Coventry, CV4 7AL — [2]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain — [3]Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, E-37008 Salamanca, Spain

Many-body quantum interacting systems continue to play a key role in theoretical developments of modern condensed matter physics. Various numerical techniques have been used to explore the features of these many-body systems. Exact diagonalization methods, which most results going beyond ground state properties are based on, can only deal with small system sizes $L \lesssim 15$ because the Hilbert dimensions grow exponentially in L. Recently, deep learning has emerged as a numerical technique that uses strategies of artificial intelligence to predict the physics of such systems. Here we focus on the Bose-Hubbard chain and use HubbardNet [1] to investigate the physics of ground and excited states. We show that the energies and wavefunctions predicted by HubbardNet agree well with the ones calculated by exact diagonalization over a broad range of interaction strengths. We investigate the properties of the eigenstates via their finite-size generalized fractal dimensions. [1] Ziyan Zhu, et al., HubbardNet: Efficient predictions of the Bose-Hubbard model spectrum with deep neural networks, Phys. Rev. Res., **5**, 043084 (2023)

TT 28.13 Wed 12:45 H37

Entanglement Transitions in Quantum Games through Reinforcement Learning — •Giovanni Cemin[1], Marin Bukov[1], and Markus Schmitt[2,3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]University of Regensburg, Regensburg, Germany — [3]Forschungszentrum Jülich, Institute of Quantum Control, Jülich, Germany

In this research, we investigate the dynamics of entanglement in Cliord circuits by employing a reinforcement learning (RL) algorithm in competition with a random agent. The RL agent is designed to strategically place gates that decrease entanglement, while the random agent aims to increase entanglement. This interaction between the two agents results in an entanglement transition, the nature of which is induced by the level of information accessible by the RL agent. By systematically varying the information provided to the RL agent, we analyze its impact on the transition characteristics. Our findings provide new insights into the interplay between entanglement manipulation and information constraints, shedding light on the fundamental mechanisms governing quantum circuit dynamics.

TT 29: 2D Materials: Electronic Structure and Exitations II (joint session O/HL/TT)

Time: Wednesday 10:30–12:45 Location: H11

TT 29.1 Wed 10:30 H11

The Bell-Shaped Component in Diffraction from 2D Materials — •Birk Finke[1], Christian Brand[1], Karim Omambac[1,2], Pascal Dreher[1], Hannah Kohler[1], Frank-J. Meyer zu Heringdorf[1,3,4], and Michael Horn-von Hoegen[1,3] — [1]Universität Duisburg-Essen — [2]Polytechnique Montréal Canada — [3]Center for Nanointegration Duisburg-Essen — [4]Interdisciplinary Center for Analytics on the Nanoscale

In 2D materials, the formation of moiré superlattices with graphene or hBN on crystalline surfaces alters electronic, vibrational, and chemical properties. Here we analysed an unusual broad diffraction background observed in low energy electron diffraction from 2D material systems, which is called the bell-shaped component (BSC). Employing SPA-LEED, LEEM, and μ-LEED we propose the origin to be the inelastic scattering of the low energy electrons at the vertically polarized ZA-phonons of the weakly bound graphene and hBN layers on Ir(111) and SiC(0001). For these systems the ZA-phonon branch exhibits a parabolic dispersion with a finite phonon frequency of a few meV at the Γ point. This results in a high phonon density at low energy, but high momentum causing the strong intensity of the BSC in diffraction. In the framework of kinematic scattering theory, we performed simulations of the inelastic diffuse scattering which quantitively confirm our proposal.

TT 29.2 Wed 10:45 H11

Combining DFT and ML to Explore the Electronic Properties of Nano-porous Graphene — •Bernhard Kretz and Ivor Lončarić — Institut Ruder Bošković, Zagreb, Croatia

Nano-porous graphene (NPG) holds great potential in electronics due to its tunable electronic properties. However, establishing a comprehensive understanding of how structural parameters influence these properties remains a challenge. This work employs density functional theory (DFT) calculations combined with machine learning (ML) to systematically investigate both static and dynamic electronic properties across a set of 460 NPG structures derived from four distinct templates.

Our DFT results reveal correlations between structural features and band gaps within subsets of our NPG structures. Notably, we identify certain NPG configurations exhibiting band gap behavior analogous to armchair graphene nano-ribbons. To predict the dynamic response of our NPG structures, we train two distinct ML networks: one for predicting forces and total energies, and another one for predicting band gaps. Using the former allows us to perform temperature-dependent molecular dynamics simulations for all 460 NPG structures, while the latter enables us to predict band gap evolution under varying operating temperatures, a crucial factor for semiconductor device performance. Our findings identify several NPG structures exhibiting band gaps suitable for semiconductor applications while demonstrating sufficient thermal stability to function effectively at typical operating temperatures.

Invited Talk TT 29.3 Wed 11:00 H11

Polaritons in two-dimensional materials and hybrids probed by electron beams — •Nahid Talebi — Institute for Experimental and Applied Physics, Kiel University, Leibnizstr. 19, 24118 Kiel

Polaritonic quasiparticles in two-dimensional (2D) materials have garnered significant attention in recent years, emerging as a promising platform for studying novel photon- and phonon-mediated correlations between various material excitations. In this work, we employ electron beams to investigate exciton and plasmon polaritons in diverse 2D materials, including transition-metal dichalcogenides, perovskites, hexagonal boron nitride, borophene, and hybrid systems. By comparing cathodoluminescence and photoluminescence spectroscopy, we uncover differences in the selection rules governing the excitation of quasiparticles by coherent light versus electron beams. Furthermore, leveraging a recently developed method that utilizes electron-driven photon sources inside an electron microscope for Ramsey-type spectroscopy, we examine the coherence of cathodoluminescence emitted by exciton polaritons (Nature Physics 19, 869 (2023)) and defects in hexagonal boron nitride (arXiv:2404.09879). These results provide new insights into the temporal coherence of the radiation from 2D materials excited by coherent and incoherent excitations.

TT 29.4 Wed 11:30 H11

Electron-phonon interaction in polar two-dimensional materials — •Gerrit Johannes Mann, Thorsten Deilmann, and Michael Rohlfing — Institute of Solid State Theory, University of Münster, Germany

Electron-phonon interaction is a crucial effect in solid state physics, in particular in two-dimensional materials. We recently developed a generally applicable ab-initio implementation on top of density functional theory that combines finite differences calculations with the perturbative Allen-Heine-Cardona framework in order to calculate the temperature-dependent renormalization of the electronic bandstructure due to electron-phonon interaction using a basis set of localized Gaussian orbitals. Our implementation circumvents the limiting problems of previous implementations and allows to evaluate Debye-Waller contributions beyond the rigid-ion approximation, which are usually neglected [1].

Incorporating effects from macroscopic electric fields into our implementation allows us to extend our calculations to the class of polar materials. In this presentation we discuss our results for two-dimensional transition-metal dichalcogenides, where the renormalization of the electronic bandstructure due to electron-phonon interaction can be as large as several hundreds of meV.

[1] Mann et al., Phys. Rev. B **110**, 075145 (2024)

TT 29.5 Wed 11:45 H11

Structural modulations of unidirectional charge density waves in rare earth tellurides — •Eunseo Kim[1], Sanghun Lee[1], Junho Bang[1], Hyungryul Yang[1], Jongho Park[2], Changyoung Kim[2], Dirk Wulferding[2], Doohee Cho[1], Makoto Hashimito[3], Donghui Lu[3], and Sunghun Kim[4] — [1]Department of Physics, Yonsei University, Seoul 03722, Republic of Korea — [2]Department of Physics and Astronomy, Seoul National University, Seoul 08826, Republic of Korea — [3]Stanford Synchrotron Radiation Lightsource, SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA — [4]Department of Physics, Ajou University, Suwon 16499, Korea

Charge density waves (CDWs) in rare earth tellurides (RTe_3) provide a unique platform for exploring the interplay between lattice deformations and electronic order. Using scanning tunneling microscopy and spectroscopy (STM/S), we investigate unique surface features in two different materials, $GdTe_3$ and $DyTe_3$, that influence the CDW behavior. In $GdTe_3$, twin domain boundaries provide a static platform for observing the spatial "melting" of unidirectional CDWs and the emergence of bidirectional CDWs. Our spatial lock-in analysis demonstrates the attenuation of CDW order parameters and the proliferation of topological defects at these boundaries, correlating with enhanced local density of states near the Fermi level. In $DyTe_3$, nanowrinkles act as topological interfaces, hosting phase-winding CDWs and confining one-dimensional metallic states. These findings emphasize the role of local structural distortions in shaping CDW phenomena, offering insights into manipulating quantum states via lattice engineering.

TT 29.6 Wed 12:00 H11

Ultrafast Charge Separation on the Nanoscale Induced by a Uniform Field — •Jan-Philip Joost and Michael Bonitz — Kiel University, Institute for Theoretical Physics and Astrophysics, 24098 Kiel, Germany

When illuminated by white light, atoms, molecules, and materials absorb only certain characteristic energy contributions based on their absorption properties. Here, we show that this effect can be translated from energy to space: a spatially uniform laser pulse can create strongly localized carrier excitations and spatial charge separation on the sub-nanometer scale within a few femtoseconds, possibly opening new avenues for nanoelectronics. A promising candidate are small graphene heterostructures, which exhibit a pronounced space dependence of the DOS with strongly localized topologically protected states [1]. Direct evidence for this effect is presented by performing extensive NEGF simulations for these systems that take into account strong coupling and dynamical screening [2]. Further, we demonstrate multiple ways to excite targeted areas of the nanostructures, such as a proper choice of the laser energy, polarization, or carrier-envelope phase. Moreover, we find that the observed effects greatly benefit from surface screening, while in free-standing systems the targeted charge excitation is restricted by strongly bound excitons. The findings are expected to be applicable for a broad class of nanoscale monolayer clusters of graphene or TMDCs.

[1] J.-P. Joost et al., Nano Lett. **19**, 9045 (2019)
[2] J.-P. Joost et al., Phys. Rev. B **105**, 165155 (2022)

TT 29.7 Wed 12:15 H11

Two-dimensional breathing Kagome lattice of antimony atoms on a SiC substrate — •Bing Liu[1], Kyungchan Lee[1], Jonas Erhardt[1], Manish Verma[1], Stefan Enyner[1], Cedric Schmitt[1], Philipp Kessler[1], Lukas Gehrig[1], Chris Jozwiak[2], Aaron Bostwick[2], Martin Kamp[1], Eli Rotenberg[2], Jörg Schäfer[1], Simon Moser[1], Giorgio Sangiovanni[1], and Ralph Claessen[1] — [1]Physikalisches Institut, Universität Würzburg, 97074 Würzburg, Germany — [2]Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

The Kagome lattice, characterized by flat electronic bands, which represents a class of candidate materials for charge order, time-reversal symmetry-breaking and exotic superconductivity. In this work, we report the successful synthesis of a breathing Kagome lattice of Sb on SiC surface. Band mapping reveals a significant gap opening at the K point near the Fermi level, driven by different hopping parameters within the breathing Kagome lattice. Scanning tunneling microscopy measurements of this phase confirm a well-ordered 2x2 lattice reconstruction, consistent with the breathing Kagome unit cell. Furthermore, DFT calculations elucidate the role of the Sb p-orbitals. Specifically, near the Fermi level the physics is dominated by px and py orbitals, which are sensitive to hopping and possibly electron correlation, giving rise to an energy gap, and by their splitting reflect the breathing Kagome lattice situation. Our findings demonstrate a pathway for constructing two-dimensional Kagome lattices on semiconductor surfaces, and are encouraging further research into their spin and electronic properties.

TT 29.8 Wed 12:30 H11

Ultrafast lattice dynamics of monolayer ReS_2 — •Victoria C. A. Taylor[1], Yoav W. Windsor[1,2], Samuel Lai[3], Hyein Jung[1,2], Fang Lui[3], and Ralph Ernstorfer[1,2] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, 14195 Berlin, Germany — [2]Technische Universität Berlin, 10623 Berlin, Germany — [3]Stanford University, Stanford, CA 94305, USA

Within the transition metal dichalcogenide (TMDC) material family, TMDCs containing rhenium stand out due to their low crystal symmetry. Instead of the common hexagonal structure, ReS_2 exhibits in-plane 1D chains of rhenium ions due to a Peierls-like distortion. This highly anisotropic crystal structure results in a range of material properties, such as anisotropic effective carrier masses, polarization dependent optical absorption, and extremely weak interlayer coupling.

We present femtosecond electron diffraction (FED) measurements of monolayer ReS_2. FED is a direct probe of photoexcited lattice dynamics, providing quantitative information on coherent and incoherent atomic vibrations on femtosecond timescales. In ReS_2 monolayers we observe a strong and complex lattice response to photoexcitation. In particular, we observe a rapid ($<$1 ps) collective response, indicative of a concerted change in ionic positions within the unit cell. We measure the fluence dependence of this response and investigate the effect of the pronounced polarization dependence of the optical excitation, which results from the material's in-plane anisotropy.

TT 30: Nanomechanical systems (joint session HL/TT)

The session covers the physics of nanomechanical systems.

Time: Wednesday 15:00–15:45 Location: H17

TT 30.1 Wed 15:00 H17

Optimizing an Integrated Photonic Racetrack Resonator for Optomechanical Synchronization — •Agnes Zinth[1] and Menno Poot[1,2,3] — [1]Department of Physics, TUM School of Natural Sciences, Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Institute for Advanced Study, Technical University of Munich, Garching, Germany

In the field of optomechanics, synchronization will be an essential tool in fields like sensing and quantum technologies. Towards this goal, we develop a photonic integrated optomechanical device consisting of a silicon nitride racetrack cavity with partly suspended waveguide that can vibrate freely. A second beam is added to improve the optomechanical coupling. The observed mechanical modes do not match in frequency, so we use a predisplaced beam instead [1]. The remaining frequency distance can be tuned by the laser power. As the light propagates in the predisplaced beam and only past the PhC beam, it shifts further than the photonic crystal one due to thermal effects. To synchronize them with optomechanical backaction, we also need to enhance the optical cavity. Therefore, we modify the transition from supported to suspended parts. Two different approaches lead to the desired improved optical quality. Currently, we are investigating their impact on the mechanics. We believe that, in the next generation of devices, we can synchronize the racetrack and photonic crystal beam.

[1] Geometric tuning of stress in predisplaced silicon nitride resonators. Nano Letters, 22(10), 4013-4019.

TT 30.2 Wed 15:15 H17

Quantum Mechanics in Two-Dimensional Dynamic Spaces — •Benjamin Schwager and Jamal Berakdar — Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany

In the study of systems with reduced dimensions one encounters quantum particles under spatial constraints. Their dynamics have to be modeled based on a configuration space that is a Riemannian manifold, in general, and the resulting quantum wave equations contain correction terms in dependence of its geometric properties. We consider particles which are confined to a flexible thin material shell by studying the Schrödinger equation on moving domains. The model assumes a static observer and couples the deformation dynamics of the material to the quantum dynamics it hosts via additional potential fields. Effects caused by the interplay of geometry and the temporal evolution of the underlying configuration space will be discussed.

TT 30.3 Wed 15:30 H17

Towards cavity optomechanics using 2D materials — •Petricia Sara Peter[1,2], Lukas Schleicher[1,2], Anne Rodriguez[1,2], Leonard Geilen[2,3], Alexander Musta[2,3], Benedict Brouwer[2,3], Alexander Holleitner[2,3], and Eva Weig[1,2] — [1]Chair of Nano and Quantum Sensors, TU Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Walter Schottky Institute, TU Munich, Germany

Two-dimensional (2D) materials, such as hexagonal boron nitride (hBN), are promising candidates for advancing cavity optomechanics due to their low mass, high mechanical strength, and unique optical properties. This work focuses on the fabrication of freely suspended hBN membranes on silicon oxide (SiO_2) and silicon nitride (Si_3N_3) substrates, utilizing a water-assisted wet transfer technique. Compared to the dry transfer method, this approach minimizes inhomogeneous stress and preserves optimal mode shapes, improving mechanical quality factors. A Michelson interferometer is used to measure the mechanical properties of the resulting drumhead resonators, including vibrational resonances, mode shapes, and quality factors. These results provide important insights into the performance and quality of the resonator, laying the groundwork for incorporating 2D materials into cavity optomechanical studies.

TT 31: Topology: Quantum Hall Systems

Time: Wednesday 15:00–16:45 Location: H31

Invited Talk TT 31.1 Wed 15:00 H31

Quantum Skyrmion Hall Effect — •Ashley Cook — MPI-PKS, Dresden, Germany

Motivated by recent discovery of additional topologically non-trivial phases of matter in lattice models beyond established classification schemes, we generalise the framework of the quantum Hall effect (QHE) to that of the quantum skyrmion Hall effect (QSkHE). This involves one key generalisation: considering particles on a two-sphere, which see a U(1) monopole, one can project to the lowest Landau level (LLL). Upon performing such a projection, the position coordinates become proportional to SU(2) generators by quenching of kinetic energy. An almost point-like LLL corresponds to matrix representation size for the SU(2) generators of N by N, with N small. The key generalisation is that such an almost point-like LLL with small orbital degeneracy can still host an intrinsically 2+1 dimensional topologically non-trivial many-body state. Equivalently, in regimes in which spin has previously been treated as a label (small N), spin encodes some finite number of spatial dimensions, in general. This many-body state can play the role, in the QSkHE, that a charged particle plays in the QHE.

TT 31.2 Wed 15:30 H31

Electric Field Induced Second-Order Anomalous Hall Transport in an Unconventional Rashba System — •Ankita Bhattacharya and Annica Black-Schaffer — Uppsala University, Sweden

Nonlinear responses in transport experiments may unveil information and generate new phenomena in materials that are not accessible at linear order due to symmetry constraints. While the linear anomalous Hall response strictly requires the absence of time-reversal symmetry, the second order, thus nonlinear, Hall response needs broken inversion symmetry. Recently, much effort has been made to obtain a second-order Hall voltage in response to a longitudinal ac driving current, both to obtain information about band geometric quantities and for its useful technological applications in rectification and frequency doubling. Typically, additional material engineering is required in noncentrosymmetric systems to obtain second-order responses since it obeys a stringent crystallographic symmetry constraint. To circumvent this, an alternative route is to apply a dc electric field. In our work, we uncover an electric field induced second-order anomalous Hall effect in an inversion-broken system possessing unconventional Rashba bands. We establish that the quantum metric, a geometrical feature of electronic wave functions providing information on non-trivial structure of Bloch bands, is responsible for providing the nonlinear Hall response. We are able to find a highly tunable electric field induced second-order anomalous Hall transport in probably the simplest system in 2D, which should be uncomplicated to verify experimentally due to multiple materials already being proposed.

TT 31.3 Wed 15:45 H31

Topological Thermal Hall Effect in the Geometrically Frustrated Magnet Gd_2PdSi_3 — •Parisa Mokhtari[1,2], Daiki Yamaguchi[1], Rinsuke Yamada[1], Akiko Kikkawa[3], Philipp Gegenwart[2], Yasujiro Taguchi[3], Yoshinori Tokura[1,3], and Max Hirschberger[1,3] — [1]Department of Applied Physics and Quantum-Phase Electronics Center, The University of Tokyo, Bunkyo-ku, Tokyo 113-8656, Japan — [2]Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, 86135 Augsburg, Germany — [3]RIKEN Center for Emergent Matter Science, Wako, Saitama 351-0198, Japan

Geometrical frustrated Skyrmion lattices exemplify nontrivial topological states with non-zero scalar spin chirality and a finite Berry curvature in real space. In 2019, T. Kurumaji *et al.* reported a large topological Hall effect in the skyrmion phase in Gd_2PdSi_3 related to the spin chirality of the ground state [1].

In this talk, I will present the thermal Hall conductivity of the frustrated triangular-lattice magnet Gd_2PdSi_3. By entering the skyrmion lattice ground state, the field-dependent thermal Hall effect sharply increases against the adjacent incommensurate phases, similar to the electric Hall conductivity behaviour. Eventually, I will investigate the relationship of Hall entropy to the charge current and discuss the non-dissipativity of topological quantum transport in the geometrically frustrated magnet Gd_2PdSi_3.

[1] T. Kurumaji *et al.*, Science **365**, 914 (2019).

TT 31.4 Wed 16:00 H31

Orbital Magnetization of Dirac Electrons on Curved Surfaces
— •Maximilian Fürst — Universität Regensburg

Orbital magnetic response of 2D, (almost) free electrons has extensively been studied in the past, starting from the discovery of Landau levels of Schrödinger [1]/(massless) Dirac [2] electrons with a linear/squareroot dispersion in the field strength B. Apart from Landau diamagnetism, this leads to De-Haas-van-Alphen type oscillations of the susceptibility, that are periodic in 1/B [3]. Confining (massless) Dirac electrons on a curved surface predominantly leads to unusual oscillations of the susceptibility with periodicity in B. We discuss three example surfaces (Sphere, Cone, Pseudosphere) in a coaxial magnetic field.

[1] L. Landau, Z. Phys. A 64, 629 (1930).
[2] J. W. McClure, Phys. Rev. 104, 666 (1956).
[3] L. Heße, K. Richter, Phys. Rev. B 90, 205424 (2014).

TT 31.5 Wed 16:15 H31

Probing Fractional Statistics through Aharonov-Bohm Oscillations in Hanbury-Brown-Twiss Geometry
— •Felix Puster, Matthias Thamm, and Bernd Rosenow — Institut für Theoretische Physik, Universität Leipzig, Brüderstraße 16, 04103 Leipzig, Germany

Since the theoretical prediction of anyonic excitations in the fractional quantum Hall effect, experimental evidence for their fractional statistics has been highly sought. In recent years, experiments have determined fractional braiding phases, providing clear evidence for fractional exchange phases. However, the braiding phase fixes the exchange phase of the particles only up to modulo Pi, leaving ambiguity in its exact value. Therefore, experiments capable of determining the exchange phase unambiguously are desired. To this end, we revisit the Hanbury-Brown-Twiss (HBT) geometry in the fractional quantum Hall regime. Our calculations extend previous theoretical work by incorporating an Aharonov-Bohm (AB) phase, finite temperature, and a finite distance between the tunneling points. We compute the current and current-current correlation functions and find that the anyonic exchange phase enters the AB oscillations in both quantities as an additive shift. While this shift is expected for the current-current correlations due to two-particle interference, for the current we interpret it as another example of time domain braiding of anyons – a phenomenon previously reported in geometries with tunneling of anyons across a quantum point contact.

TT 31.6 Wed 16:30 H31

Dipole Representation of Composite Fermions in Graphene's Quantum Hall Systems
— •Sonja Predin — Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia

The even-denominator fractional quantum Hall effect has been observed in graphene's fourth Landau level (N = 3) [1]. Motivated by recent studies [2] on pairing and the nature of the ground state in this system, we extend the dipole representation of composite fermions to adapt it to graphene's quantum Hall systems, focusing on half-filled Landau levels. We derive an effective Hamiltonian incorporating particle-hole symmetry. At the Fermi level, the energetic instability of the dipole state is driven by the interplay between topology and symmetry, pushing the system towards a critical state. While paired states are considered, our findings demonstrate that a boost-invariant state lacking well-defined pairing instabilities is energetically favorable stable state, suggesting the absence of pairing instabilities in this system.

[1] Y.Kim,A.C.Balram,T.Taniguchi,K.Watanabe,J.K.Jain, J.H.Smet, Nat. Phys. 15, 154 (2019).
[2] A.Sharma, S.Pu, A.C.Balram, J.K.Jain, PRL 130, 126201 (2023).
[3] S.Predin, A.Knežević, M.V.Milovanović, PRB 107, 155132 (2023).
[4] S. Predin, arXiv:2408.10375.

TT 32: Superconductivity: Yu-Shiba-Rusinov and Andreev Physics

Time: Wednesday 15:00–16:30 Location: H32

TT 32.1 Wed 15:00 H32

Ab-initio Investigation of YSR States of Fe Adatoms Interacting with Rashba-Split Surface States on $BiAg_2$
— •Ilias Klepetsanis[1,2], Philipp Rüssmann[1,3], and Samir Lounis[1,2] — [1]Forschungszentrum Jülich & JARA, Germany — [2]University of Duisburg-Essen and CENIDE, Germany — [3]University of Würzburg, Germany

One of the most sought after topics in modern condensed matter physics research, has been the creation of topological superconductivity systems that are able to host Majorana states. A plethora of material configurations have been proposed to that end, with emphasis on the interplay between magnetism, SOC and superconductivity. Here, we investigate the behaviour of Fe adatoms deposited on a $BiAg_2$ surface with a superconducting Nb substrate, using the Bogoliubov-de-Gennes full-potential relativistic Korringa-Kohn-Rostoker Green function method [1]. We explore the emergence of Yu-Shiba-Rusinov (YSR) states and their dependence on the adatom deposition site and magnetic moment rotation, as well as the effect of the strong spin-orbit coupling from the substrate. We construct chains of Fe adatoms and study the YSR state behaviour with an increasing chain length and its correlation with the magnetic ground state. Finally we explore the possibility of non-trivial end-states emerging on the Fe chain.

[1] P. Rüßmann, and S. Blügel, Phys. Rev. B 105, 125143 (2022).

TT 32.2 Wed 15:15 H32

Shiba States in Magnet/Superconductor Heterostructures from First Principles
— •Arnold Kole, Andrés Botello-Méndez, and Zeila Zanolli — Utrecht University, Utrecht, The Netherlands

The search for topological superconductors (TSC) with potential applications in quantum computing motivates the study of hybrid systems combining superconductivity, magnetism, and spin-orbit coupling. Previous work has shown the presence of in-gap states in these systems [1]. Of particular interest are Yu-Shiba-Rusinov (YSR) states, that arise due to interactions of magnetic impurities with a superconductor [1]. It has been proposed that these can be used to engineer topological superconductivity [1].

We demonstrate the emergence of topologically trivial in-gap YSR states in $CrCl_3$ islands on superconducting $NbSe_2$ [2]. Using Density Functional Theory (DFT), we show an increase of the Cr 3d density-of-states at the edge and an enhanced exchange interaction between the $CrCl_3$ edge and the $NbSe_2$ substrate [2]. This means that the $CrCl_3$ edge acts as a one-dimensional chain of magnetic impurities interacting with the superconducting $NbSe_2$. This can explain the emergence of the YSR states. Finally, we systematically show that these findings are robust to changes in computational details such as stacking, magnetic configuration and Hubbard U parameters [3].

[1] L. Schneider et al., Nat. Nanotechnol. 17, 384 (2022);
[2] J.P. Cuperus, A.H. Kole et al., submitted (2024);
[3] A.H. Kole et al., manuscript in preparation (2025).

TT 32.3 Wed 15:30 H32

Spin Dynamics in a Josephson Junction Between Two Superconducting Magnetic Impurity States
— Fabian Ziesel[1], Björn Kubala[1,2], Joachim Ankerhold[1], and •Ciprian Padurariu[1] — [1]ICQ and IQST, Ulm University, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

We study the Josephson effect in a junction formed between two superconducting 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]. Our work extends a recent theoretical investigation [2] by considering the mutually coupled dynamics between the impurity spins and the Josephson phase. We suggest that the Josephson effect can be exploited to manipulate the relative magnetic orientation of the impurities due to a Josephson-induced exchange interaction that arises.

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.

[1] H. Huang *et al.*, Phys. Rev. Res. **3**, L032008 (2021);
[2] S. Chakraborty *et al.*, Phys. Rev. B **108**, 094518 (2023).

TT 32.4 Wed 15:45 H32

Yu-Shiba-Rusinov Spectroscopy of Triple Quantum Dot Molecules — •Vladislav Pokorný[1] and Martin Žonda[2] — [1]FZU - Institute of Physics, Czech Academy of Sciences, Na Slovance 2, 182 00 Prague, Czech Republic — [2]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, 121 16 Prague, Czech Republic

We study a system of three quantum dots in triangular geometry with equal distances connected to a common superconducting lead and coupled via interdot Coulomb interaction. We provide complete ground state phase diagrams for the half-filled system in various regimes and study the behavior of the in-gap Yu-Shiba-Rusinov states. We use the superconducting impurity Anderson model to describe the system and solve it using a combination of effective methods based on the superconducting atomic limit and the continuous-time hybridization expansion quantum Monte Carlo. The results can provide deep insight into experiments involving trimers made of magnetic molecules on superconducting substrates.

TT 32.5 Wed 16:00 H32

Experimental Signal of Multiple Andreev Reflexion in Spin Splitted Tunneling Junctions — •David Caldevilla-Asenjo[1], Sara Catalano[2,3], Pietro Cattaneo[4], Fernando Sebastian Bergeret[1], Maxim Ilyn[1], and Celia Rogero[1] — [1]Centro de Fisica de Materiales (CSIC-UPV/EHU),20018 Donostia San Sebastian — [2]Materials Physics Center (MPC), Paseo Manuel de Lardizabal 5,20018 Donostia, Spain. — [3]IKERBASQUE, Basque Foundation for Science, 48009 Bilbao, Basque Country, Spain. — [4]Politecnico di Milano, 20133, Milano, Italy

A ferromagnetic insulator in contact with a superconductor induces an effective exchange field, resulting in a spin splitting of the BCS density of states [1,2]. In this work, we study planar Josephson Junctions where one electrode is in contact with a thin layer of the ferromagnetic insulator europium sulfide. Samples are grown in situ by using the hard-mask technique in UHV. We characterized the junctions through DC transport measurements at a base temperature of 10mK, observing Josephson coupling and Multiple Andreev Reflection according to the transparency of the barrier. We propose a theory model to interpret the junction spectra taking into account the exchange field. Our results provide an experimental and theoretical description of ingap transport processes in superconducting junctions proximitized by a ferromagnetic insulator [3].

[1] R. Meservey and P.M. Tedrow, Phys. Rep. 238, 173 (1994);
[2] A. Hijano et al., Phys. Rev. Res. 3, 021031 (2021);
[3] B. Lu et al., Phys. Rev. B 101, 020502 (2020).

TT 32.6 Wed 16:15 H32

Nonequilibrium Josephson and Andreev Transport in Quantum Dot Junctions — •Jordi Picó-Cortés[1], Gloria Platero[2], Andrea Donarini[1], and Milena Grifoni[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Instituto de Ciencia de Materiales de Madrid (CSIC) 28049 Madrid, Spain

We investigate nonequilibrium transport through superconducting nanojunctions using a Liouville space approach [1]. The formalism allows us to study finite-gap effects, and to account for both quasiparticle and Cooper-pair tunneling. With focus on the weak-tunneling limit, we study the stationary dc and ac current up to second order (cotunneling) in the hybridization energy. For the particular case of a strongly interacting quantum dot sandwiched between two superconductors, we identify the characteristic virtual processes that yield the Andreev and Josephson current and obtain the dependence on the gate and bias voltage for the dc current, the critical current, and the phase-dependent dissipative current. In particular, the critical current is characterized by regions in the stability diagram in which its sign changes from positive to negative, resulting in a multitude of $0-\pi$ transitions. The latter signal the interplay between strong interactions and tunneling at finite bias.

[1] J. Picó-Cortés, G. Platero, A. Donarini, M. Grifoni, Phys. Rev. B 110, 125418 (2024).

TT 33: Correlated Magnetism – Spin Liquids

Time: Wednesday 15:00–18:15 Location: H33

TT 33.1 Wed 15:00 H33

An Atlas of Classical Pyrochlore Spin Liquids — •Daniel Lozano-Gómez[1,2], Owen Benton[3], Michel Gingras[2], and Han Yan[4] — [1]Technische Universität Dresden, Dresden, Germany — [2]University of Waterloo, Waterloo, Canada — [3]Queen Mary University of London, London, United Kingdom — [4]The University of Tokyo, Kashiwa, Japan

The pyrochlore lattice magnet has been one of the most fruitful platforms for the experimental and theoretical search for spin liquids. Besides the canonical case of spin ice, works in recent years have identified a variety of new quantum and classical spin liquids from the generic nearest-neighbor anisotropic spin Hamiltonian on the pyrochlore lattice. Despite the rich variety of SLs realized in this lattice, a general framework for the classification and characterization of these is still lacking. In this work, we develop such a theoretical framework to allocate interaction parameters stabilizing different classical SLs and derive their corresponding effective generalized emerging Gauss's laws at low-temperatures. Combining this with Monte Carlo simulations, we systematically identify all classical SLs for the general nearest-neighbor anisotropic spin Hamiltonian on the pyrochlore lattice. We uncover new SL models with exotic forms of generalized Gauss's law and multipole conservation laws. Our work serves as a treasure map for the theoretical study of classical and quantum spin liquids, as well as for the experimental search and rationalization of exotic pyrochlore lattice magnets.

TT 33.2 Wed 15:15 H33

Higher-Rank Spin Liquids and Spin Nematics from Competing Orders in Pyrochlore Magnets — •Niccolò Francini, Lukas Janssen, and Daniel Lozano-Gómez — Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

Pyrochlore magnets have proven to provide an excellent arena for the realization of a variety of many-body phenomena such as classical and quantum order-by-disorder, as well as spin liquid phases described by emergent gauge field theories. These phenomena arise from the competition between different symmetry-breaking magnetic orders. In this work, we consider a subspace of the most general bilinear nearest-neighbor Hamiltonian on the pyrochlore lattice, parameterized by the local interaction parameter $J_{z\pm}$, where three symmetry-breaking phases converge. We demonstrate that for small values of $|J_{z\pm}|$, a conventional $\mathbf{q} = 0$ ordered phase is selected by a thermal order-by-disorder mechanism. For $|J_{z\pm}|$ above a certain finite threshold, a novel spin-nematic phase is stabilized at low temperatures. Instead of the usual Bragg peaks, the spin-nematic phase features lines of high intensity in the spin structure factor. At intermediate temperatures above the low-temperature orders, a rank-2 U(1) classical spin liquid is realized for all $J_{z\pm} \neq 0$. We fully characterize all phases using classical Monte-Carlo simulations and a self-consistent Gaussian approximation.

TT 33.3 Wed 15:30 H33

Raman Circular Dichroism of Chiral Quantum Spin Liquids — •Eduard Koller[1,2,3], Valentin Leeb[1,3], Natalia Perkins[4], and Johannes Knolle[1,3,5] — [1]Technical University of Munich, Germany — [2]Institute for Advanced Study, TUM, Germany — [3]Munich Center for Quantum Science and Technology, Germany — [4]School of Physics and Astronomy, University of Minnesota, USA — [5]Blackett Laboratory, Imperial College London, United Kingdom

We investigate the Raman circular dichroism (RCD) of chiral Quantum spin liquids as a probe of the topological properties of fractionalised spin excitations. Starting from the Loudon Fleury formalism we show that the scattering Intensity is directly related to the light matter coupling formalism of spinon bands. We reveal that the RCD signal arises as a result of the Berry curvature and Quantum geometry contributions. We show application to different model quantum spin liquids.

TT 33.4 Wed 15:45 H33

Low-Temperature Features of the Quantum Spin Liquid Candidate PCTO Crystal Structure — •Alexander Mistonov[1], Abanoub Hanna[2], Elaheh Sadrollahi[1], Heidi Savey-Bennett[3], Martin von Zimmermann[4], Elizabeth Blackburn[5], Bella Lake[2], and Jochen Geck[1] — [1]Technische Universität Dresden — [2]Helmholtz-Zentrum Berlin — [3]The University of Manchester — [4]Deutsches Elektronen-Synchrotron DESY — [5]Lund University

$PbCuTe_2O_6$ (PCTO) is well known as a promising candidate for quantum spin liquid compounds. Magnetic ordering does not occur down to 0.02 K [1]. Additionally, diffuse continua are observed in magnetic spectra [2]. At the same time, heat capacity and dielectric response demonstrate signatures of an order-disorder ferroelectric (FE) transition at ~ 1 K [3]. According to thermal expansion measurements, this transition is believed to be accompanied by structural changes. We have performed a high-energy single-crystal X-ray diffraction experiment using a dilution refrigerator to investigate it for the first time. We have observed Bragg peaks that are forbidden for the reported high-temperature crystal structure (space group $P4_132$ [4]) and studied their evolution. In the current work, we share our findings from below and above the FE transition.

[1] P. Khuntia et al., Phys. Rev. Lett. 116, 107203 (2016).
[2] S. Chillal et al., Nat. Commun. 11, 2348 (2020).
[3] C. Thurn et. al., npj Quantum Mater. 6, 95 (2021).
[4] A. R. N. Hanna et al., Phys. Rev. Mat. 5, 113401 (2021).

TT 33.5 Wed 16:00 H33

What is carrying the heat in the thermal Hall effect of honeycomb magnets? — •Ralf Claus, Jan Bruin, Yosuke Matsumoto, Pascal Reiss, Akmal Hossain, Lichen Wang, Pascal Puphal, Bernhard Keimer, and Hidenori Takagi — Max-Planck-Institut für Festkörperforschung, D-70569 Stuttgart

The observation of a half-integer quantized thermal Hall effect in the honeycomb magnet α-$RuCl_3$ was interpreted as an experimental hallmark for Kitaev majorana fermions. However, follow-up studies only partly reproduced this result and have offered alternative explanations such as phonons or topological magnons. To narrow down the nature of the heat carrying quasiparticles, we conducted a comparative study of the longitudinal (κ_{xx}) and transversal (κ_{xy}) heat transport on α-$RuCl_3$ and $Na_3Co_2SbO_6$ (NCSO). Both share the same crystal symmetries and have comparable magnetic phase diagrams. However, one key difference is that for applied in-plane magnetic fields $B > 3$ T NCSO is in a fully spin-polarized phase convincingly excluding the presence of any majorana fermions. Remarkably, we observed a finite κ_{xy} in NCSO up to $B \approx 10$ T, which displays striking similarities in shape, angle-dependence, and magnitude to that of α-$RuCl_3$. Furthermore, the field dependences of κ_{xx} and of the thermal Hall angle (κ_{xy}/κ_{xx}) across all α-$RuCl_3$ and NCSO samples suggest a substantial phononic contribution to κ_{xy}. Ultimately, we propose that topological magnons are responsible for generating the Hall temperature gradient which in turn is significantly enhanced by phonon-magnon interaction.

TT 33.6 Wed 16:15 H33

Variational Monte Carlo Simulations of Two-dimensional Quantum Spin Liquids — •Florian Michael and Benedikt Fauseweh — TU Dortmund University, Dortmund, Germany

In this project we use state-of-the-art variational algorithms to train neural quantum states for the quantum spin liquid phase of the J1-J2 Heisenberg model on a square lattice. Specifically, this approach makes use of a hybrid architecture of a restricted Boltzmann machine and pair-product states, capturing both global and local correlations efficiently. To further increase the precision of the wave function representation as well as mitigate finite-size effects, we apply quantum number projections and impose twisted boundary conditions.

The project is implemented within the NetKet framework, leveraging the automatic differentiation and just-in-time compilation of JAX as well as GPU accelerated high-performance clusters. The goal is to further advance the application of neural quantum states in quantum many-body physics and gain new insights on properties of quantum spin liquids that are currently difficult to simulate due to their long-range entanglement and absence of magnetic order.

TT 33.7 Wed 16:30 H33

Quantum simulation of fermionic, non-Abelian lattice gauge theories in (2+1)D — •Gaia De Paciani[1,2], Lukas Homeier[1,2,3], and Fabian Grusdt[1,2] — [1]Department of Physics and Arnold Sommerfeld Center for Theoretical Physics (ASC), Ludwig-Maximilians-Universität, München, Germany — [2]Münich Center for Quantum Science and Technology (MCQST), München, Germany — [3]University of Colorado, Boulder, Colorado

Understanding and simulating non-Abelian quantum spin-liquids and dimer models is an open challenge in the condensed matter and high energy physics landscape. Recent advancements in the field of quantum simulations have significantly expanded its potential for applications, particularly in the context of lattice gauge theories (LGTs). Nevertheless, maintaining gauge invariance throughout a simulation remains a critical challenge, especially for large-scale non-Abelian LGTs. We propose a novel approach to simulate non-Abelian U(N) LGTs with dynamical fermionic matter in (2+1) dimensions, enhancing the reliability of the simulation through the suppression of the occupation of gauge invariant sectors. We present a comprehensive framework to simulate gauge-invariant dynamics and we propose two experimental platforms – utilizing ultracold alkaline-earth-like atoms and Rydberg-dressing – to implement these models, enabling the quantum simulation of large-scale non-Abelian gauge theories in near-term experiments.

15 min. break

Invited Talk TT 33.8 Wed 17:00 H33

Emergent Dynamical Gauge Fields in Generic Kitaev Spin Liquids: From Monolayer to Multilayers — •Aprem Joy and Achim Rosch — Institute for Theoretical Physics, University of Cologne

Emergent gauge fields and fractional excitations are long sought-after in modern condensed matter physics. The Kitaev spin liquid and its potential realization in the so called “Kitaev materials" have been at the frontier of this search. The Kitaev spin liquid realizes an emergent static Z2 gauge field with vison excitations strongly interacting with Majorana fermions, by virtue of its gauge flux. While static in the idealized Kitaev model, single visons and vison pairs become dynamical degrees of freedom in the presence of perturbations. We develop a concise theory of the universal properties of single visons in weakly perturbed Kitaev models. We focus both on single-layer and multilayer systems, motivated by the layered structure of materials. When Kitaev models are stacked on top of each other, weakly coupled by Heisenberg interaction, a rich zoo of mobile gauge excitations emerge whose dynamics is strongly constrained by topology and residual conservation laws, resulting in sub-dimensional mobilities, reminiscent of fractons. Furthermore, we show how vison dynamics in Kitaev materials can lead to novel signatures in relaxation experiments.

[1] A. Joy and A. Rosch, Phys. Rev. X 12, 041004 (2022);
[2] A. Joy and A. Rosch, npj Quantum Mater. 9, 62 (2024).

TT 33.9 Wed 17:30 H33

Pressure-dependent magnetism of the Kitaev candidate Li_2RhO_3 — •Efrain Insuasti Pazmino[1], Bin Shen[2], Ramesh Dhakal[3], Friedrich Freund[2], Philipp Gegenwart[2], Steve M. Winter[3], and Alexander A. Tsirlin[1] — [1]Leipzig University, Germany — [2]University of Augsburg, Germany — [3]Wake Forest University, USA

In the search for a Quantum Spin Liquid (QSL) state in real materials, hydrostatic pressure is employed to move honeycomb Kitaev compounds closer to or farther from a QSL state. The candidates studied so far have exhibited long-range magnetic ordering at lower temperatures. However, the candidate Li_2RhO_3 does not show a magnetic transition at low temperatures but instead exhibits spin freezing. Magnetic couplings obtained through theoretical super-exchange and Exact Diagonalization calculations evolve away from the Kitaev limit as pressure increases. Interestingly, the freezing temperature determined in our magnetization measurements remains constant under increasing pressure and does not correlate with the changes in magnetic couplings. An analysis of simulations and experiments suggests that spin freezing could arise from extrinsic factors such as stacking faults and crystal defects. Furthermore, the J_3 coupling was found to be unusually small in comparison with other Kitaev materials. Our work shows commonalities in the pressure evolution of the Kitaev iridates and rhodates where the decrease in the bond angle suppresses the Kitaev coupling while enhancing the off-diagonal anisotropy.

This work was supported by DFG via TRR360 (492547816).

TT 33.10 Wed 17:45 H33

Frustrated multipolar degrees of freedom: The quadrupolar Kitaev model — •Partha Sarker and Urban Friedrich Peter Seifert — Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, D-50937 Köln

Frustrated multipolar exchange interactions between spin-S local moments ($S > 1/2$) have been suggested to possibly give rise to quantum spin liquid-like ground states featuring an emergent gauge structure and fractionalized excitations. However, only little is known about characteristic features and experimental signatures of such "multipolar spin liquids". To this end, in this work we turn to the "Quadrupolar Kitaev model" of $S = 1$ moments on a honeycomb lattice as a drosophila, for which recent numerical studies have found a deconfined ground state with topological order. As the model, similar to the spin-S generalization of the Kitaev honeycomb model, is not exactly solvable, we use a combination of mean-field theory and exact symmetry analysis to investigate competing ground states, including multipolar liquids, and their (fractionalized) excitations.

TT 33.11 Wed 18:00 H33

Phases of the Anyonic Hubbard Ladder for Fibonacci Anyons — •Nico Kirchner[1], Adam Gammon-Smith[2], and Frank Pollmann[1] — [1]Technical University of Munich, TUM School of Natural Sciences — [2]School of Physics and Astronomy, University of Nottingham

Two-dimensional systems such as quantum spin liquids may exhibit anyonic excitations that feature exchange statistics beyond the bosonic and fermionic cases. A fundamental question regarding such quasiparticles is how the richer exchange statistics influence their mutual interactions and which phases may arise in systems of anyons as a consequence. To study this topic, we consider the particular case of Fibonacci anyons subject to an anyonic Hubbard model with nearest-neighbor repulsion on a two-leg ladder. Focusing on half-filling, for low interaction strengths a metallic phase is found, whereas for strong repulsion, the anyons form a charge-density wave in real space. Within this regime, the effective interactions arising from the exchange statistics give rise to multiple distinct phases that can be distinguished using the scaling of the entanglement entropy and the spectra of matrix product state transfer matrices.

TT 34: Superconductivity: Theory

Time: Wednesday 15:00–18:30 Location: H36

TT 34.1 Wed 15:00 H36

Eliashberg theory and band-off-diagonal superconductivity — •Bernhard Putzer[1,2] and Mathias S. Scheurer[1] — [1]Institute for Theoretical Physics III, University of Stuttgart, 70550 Stuttgart, Germany — [2]Institute for Theoretical Physics, University of Innsbruck, Innsbruck A-6020, Austria

In contrast to the mean field approximation of BCS theory, the Migdal-Eliashberg approach is a more sophisticated framework to describe phonon-mediated superconductivity. Allowing strong coupling between electronic and bosonic fields opens the door to investigate the effects of inter-band processes on the superconducting state in a controllable setting. We derive and solve the Eliashberg equations for a two-band model, inspired by twisted graphene systems, finding an entirely band-off-diagonal superconducting order parameter. By including full momentum and Matsubara fre- quency dependence, we uncover a mixing of even- and odd-frequency states induced by the band splitting. As a result, the superconductor exhibits very unconventional spectral properties for electron-phonon pairing; this includes a region with a nodal spectrum and a region with finite gap, which is, however, much smaller than the order parameter magnitude. Our findings have consequences for recent experiments on the superconducting state in twisted bilayer and trilayer graphene.

TT 34.2 Wed 15:15 H36

From charge fluctuations to pairing instabilities: Nonperturbative enhancement of the electron-phonon coupling driven by electronic correlations — •Emin Moghadas[1], Matthias Reitner[1], Alexander Kowalski[2], Giorgio Sangiovanni[2], Sergio Ciuchi[3,4], and Alessandro Toschi[1] — [1]Institute of Solid State Physics, TU Wien, Vienna, Austria — [2]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Würzburg, Germany — [3]Dipartimento di Scienze Fisiche e Chimiche, Università dell'Aquila, Coppito-L'Aquila, Italy — [4]Istituto dei Sistemi Complessi, CNR, Roma, Italy

We present a thorough investigation of the nonperturbative electronic mechanisms, which could lead to significant enhancements of the electron-phonon coupling in strongly correlated electron systems. Using dynamical mean-field theory (DMFT) for the single band Hubbard model on the square lattice, we analyze corrections to second-order electron-phonon processes arising from electronic fluctuations near the Mott metal-to-insulator transition (MIT). In this regime, the isothermal charge response becomes particularly large at small momenta, indicating tendencies towards phase-separation instabilities and enabling a substantial enhancement of the effective electron-phonon coupling. Eventually, we critically discuss the impact of our findings on observable spectral quantities as well as possible implications for the emergence of pairing instabilities.

TT 34.3 Wed 15:30 H36

Detailed analysis of the superconducting gap with Dynes pair-breaking scattering — •Anastasiya Lebedeva and František Herman — Comenius University in Bratislava

In our work, we study the energy gap behavior within the Dynes superconductor theory. This model generalizes the Bardeen-Cooper-Schrieffer (BCS) approach by including the pair-breaking disorder, introducing the tunneling in-gap states up to a Fermi level. Elaborating on the self-consistent gap equation, we obtain useful results which are also interesting from the experimental point of view. For example, the derived relations may serve to estimate the pair-breaking impurities concentration in the superconductor i.a. using only the energy gap and the critical temperature values of the material. Moreover, we offer the heuristic gap-to-temperature dependence providing up to 5%-precision in the whole temperature range. It is a more convenient tool compared to the cumbersome numerics used by now.

This work has been supported by the Slovak Research and Development Agency under the Contract no. APVV-23-0515, by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478.

TT 34.4 Wed 15:45 H36

Superconducting modes in the presence of Coulomb repulsion — •Joshua Althüser and Götz Uhrig — TU Dortmund, Otto-Hahn-Str. 4, 44227 Dortmund, Deutschland

We numerically study the collective excitations present in BCS-superconductors including screened Coulomb interactions. By varying the screening strength, we analyze its impact on the system. We use a formulation of the effective phonon-mediated interaction between electrons that depends on the energy transfer between particles, rather than being a constant in a small energy shell around the Fermi edge. We compute the system's Green's functions using the iterated equations of motion (iEoM) approach, which ultimately enables a comprehensive analysis of collective excitations. For weak couplings, we identify the well-known amplitude (Higgs) mode at the quasiparticle continuum's lower edge and the phase (Anderson-Bogoliubov) mode at zero energy for a neutral system, which shifts to higher energies as the Coulomb interactions are switched on. As the phononic coupling is increased, the Higgs mode emerges from the continuum, and additional phase and amplitude modes appear, persisting even with active Coulomb interactions.

TT 34.5 Wed 16:00 H36

Obstructed pairs with zero superfluid stiffness — •Tamaghna Hazra and Jörg Schmalian — Karslruhe Institute of Technology

We present a microscopic pairing mechanism in which the kinetic energy of pairs is much lower than the kinetic energy of electrons. This results in interaction-driven localization of charge without extrinsic disorder and is characterized by a vanishing superfluid stiffness. Localized pairs gain more kinetic energy from resonating between sublattices in a bosonic compact localized state, than from delocalizing throughout the material. This is grounded in a microscopic model building on a structural motif shared by many oxide superconductors - strongly interacting localized electrons realize spin degrees of freedom on the vertices and doped charge lives on the edges of the Bravais lattice. In the strong-coupling limit, local unconventional pairs realize the bosonic analogue of flat bands supported on line graphs. We discuss the experimental implications of this pairing mechanism, with concrete falsifiability criteria, and emphasize the broad scope of this recipe in connection to diverse families of strongly correlated materials which share the key ingredients that go into it.

TT 34.6 Wed 16:15 H36

Electronic structure and superconductivity in nickelates and cuprates: Insights from DMFT and DΓA — •Eric Jacob[1], Mario Malcolms de Oliveira[2], Thomas Schäfer[2], Paul Worm[1], Liang Si[3,1], and Karsten Held[1] — [1]Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria — [2]Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany — [3]School of Physics, Northwest University, Xi'an 710127, China

The infinite-layer nickelates and cuprates represent two compelling families of materials for exploring unconventional superconductivity and correlated electronic phenomena. I will discuss recent advances in understanding the electronic structure of infinite-layer nickelates, focusing on insights from dynamical mean-field theory (DMFT) and their comparison with experimental findings ([1]) from angle-resolved photoemission spectroscopy (ARPES). This helps [2] constrain possible scenarios for their electronic states. In particular, there is only one Ni orbital crossing the Fermi surface. Additionally, I will present ongoing investigations into superconductivity in both nickelates and cuprates, based on the dynamical vertex approximation ($D\Gamma A$ [3], [4]).

Funding through the FWF project I5398 is gratefully acknowledged.

[1] W. Sun et al., arXiv:2403.07344 (2024).
[2] L. Si et al., Phys. Rev. Res. 6, 043104 (2024).
[3] G. Rohringer et al., Rev. Mod. Phys. 90, 025003 (2018).
[4] M. Kitatani et al., J. Phys. Mater. 5, 034005 (2022).

TT 34.7 Wed 16:30 H36

Towards an *ab initio* theory of high-temperature superconductors: a study of multilayer cuprates. — •Benjamin Bacq-Labreuil[1,2], Benjamin Lacasse[1], André-Marie Tremblay[1], David Sénéchal[1], and Kristjan Haule[3] — [1]Institut quantique, Université de Sherbrooke, Canada — [2]IPCMS, Université de Strasbourg, France — [3]Center for Materials Theory, Rutgers University, USA

Significant progress towards a theory of high-temperature superconductivity in cuprates has been achieved via the study of effective models. Yet, material-specific predictions for high-temperature superconductors, while essential for constructing a comprehensive theory, remain out of reach. By combining cluster dynamical mean-field theory and density functional theory in a charge-self-consistent manner, here we show that the goal of material-specific predictions for high-temperature superconductors from first principles is within reach. We demonstrate the capabilities of our approach by performing an in-depth study of two representatives ($Ca_{(1+n)}Cu_nO_{2n}Cl_2$ and $HgBa_2Ca_{(n-1)}Cu_nO_{(2n+2)}$) of the still mysterious multilayer cuprates. We shed light on the microscopic origin of many salient features of multilayer cuprates, in particular the n-dependence of their superconducting properties. Our work establishes a framework for comprehensive studies of high-temperature superconducting cuprates, enables detailed comparisons with experiment, and, through its *ab initio* settings, unlocks opportunities for theoretical material design of high-temperature superconductors.

15 min. break

TT 34.8 Wed 17:00 H36

Enhanced entanglement in the pseudogap — •Frederic Bippus[1], Juraj Krsnik[1], Motoharu Kitatani[2,3], Anna Kauch[1], Gergö Roosz[4], and Karsten Held[1] — [1]Institute of Solid State Physics, TU Wien, Vienna, Austria — [2]Department of Material Science, University of Hyogo, Ako, Hyogo, Japan — [3]RIKEN Center for Emergent Matter Sciences (CEMS), Wako, Japan — [4]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary

We show significantly enhanced entanglement in the pseudogap regime of the Hubbard model using the dynamical vertex approximation (DGA) [1], a non-local extension to the dynamical mean-field theory. The pseudogap, a partially gapped electronic state, is observed near the superconducting transition in cuprates and nickelates. Leveraging DGA, we compute the quantum variance-a lower bound to the quantum Fisher information [2] from the spin susceptibility directly on the imaginary Matsubara axis. By circumventing the need for ill-controlled analytical continuation, our approach provides a robust framework for probing entanglement depth. The results show good agreement with experimental data [3]. Additionally, Ornstein-Zernike fits provide analytical insights.

This work is supported by the SFB Q-M&S (FWF project ID F86).

[1] Rohringer et al., Rev. Mod. Phys., 90, 025003 (2018);
[2] Frérot et al., Phys. Rev. B, 94, 075121 (2016);
[3] Chan et al., Nat. Commun., 7, 10819 (2016).

TT 34.9 Wed 17:15 H36

Time evolution of surface state wave packets in nodal noncentrosymmetric superconductors — •Clara Johanna Lapp[1,2], Julia 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

Nodal noncentrosymmetric superconductors can host zero-energy flat bands of Majorana surface states within the projection of the nodal lines onto the surface Brillouin zone. Thus, these systems can have stationary, localized Majorana wave packets on certain surfaces, which may be a promising platfrom for quantum computation. However, for such applications it is important to find ways to manipulate the wave packets in order to move them without destroying their localization or coherence. As the surface states have a nontrivial spin polarization, applying an exchange field, e.g., by introducing a magnetic insulator at the surface, makes the previously flat band slightly dispersive. We aim to use an adiabatic change of the exchange field to move wave packets on the surface. We therefore investigate the time evolution of a maximally localized wave packet under the influence of such an exchange field employing exact diagonalization as well as quasiclassical approximations.

TT 34.10 Wed 17:30 H36

Interplay of superconductivity and altermagnetism: A symmetry perspective — •Kirill Parshukov[1], Niclas Heinsdorf[1,2], Benjamin T. Zhou[2], Marcel Franz[2], and Andreas P. Schnyder[1] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]The University of British Columbia, Vancouver BC, Canada

The interplay between altermagnetism and superconductivity gives rise to several interesting phenomena, including unconventional Josephson effects, diode effects, Cooper pair splitting, and topological superconductivity. In this talk, I investigate how altermagnetic symmetries can lead to new superconducting states with interesting topological properties. Since the superconducting gap functions must transform as irreducible co-representations of the spin-point groups, I first construct all possible superconducting basis functions. Importantly, because the spin-point group symmetries act simultaneously on the spin and the lattice, the spin and spatial parts of the basis functions are coupled in an intricate manner. I illustrate this by considering several examples in two dimensions, including the superconducting states of an altermagnet with four Dirac points [1].

[1] K. Parshukov, R. Wiedmann, A. P. Schnyder, arXiv:2403.09520.

TT 34.11 Wed 17:45 H36

Emergence of a condensate with finite-energy Cooper pairing in hybrid exciton/superconductor systems — •Viktoriia Kornich — University of Würzburg, Würzburg, Germany

I will consider a setup consisting of excitons formed in two valleys, with proximity-induced Cooper pairing, different in the conduction and valence bands. Due to the combination of a Coulomb interaction within excitons and superconducting proximity effects, Cooper pairing between electrons from valence and conduction bands from different valleys is formed. Thus, the gap between these electrons can be much larger than the usual superconducting pairing energies. This Cooper pairing has both even- and odd-frequency contributions. I will show that there is a phase transition into the formation of a robust macroscopic condensate of such Cooper pairs and then will suggest a detection scheme of it via Higgs modes.

TT 34.12 Wed 18:00 H36

Third-harmonic generation currents in pair-density wave superconductor — •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 previously in Refs. [1,2]. The system possesses a unidirectional PDW state with d-wave symmetry in thermodynamic equilibrium ground state without extra need for an additional perturbation such as external Zeeman field or leading charge density wave order. 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 emerging signatures in the third harmonic generation and their origin.

[1] F. Loder et al., Phys. Rev. B 81 (2010).
[2] J. Wårdh and M. Granath., Phys. Rev. B 96 (2017).

TT 34.13 Wed 18:15 H36

Describing superconductivity through interpretable artificial intelligence — •Herzain I. Rivera-Arrieta, Lucas Foppa, and Matthias Scheffler — The NOMAD Laboratory at the Fritz Haber Institute of the Max Planck Society, Berlin, Germany

Superconductivity is governed by an intricate interplay among electronic structure, lattice vibrations, and pressure effects, among many other phenomena [1]. Thus, a (single) physical model might not be enough to describe superconductivity. Interpretable artificial intelligence (AI) can provide valuable insights into the underlying mechanisms driving superconductivity, e.g., in conventional superconductors. Herein, we compile a dataset containing approximately 1,000 materials [2] and a diverse range of compositional, structural, electronic, and phonon-related properties. Then, we employ the symbolic-regression SISSO and subgroup discovery AI approaches [3, 4], to identify the few, key physicochemical parameters correlated with a superconductor's critical temperature. This approach is a step towards identifying the "materials genes" [5] of superconductivity.
[1] X. Gui, B. Lv, and W. Xie, *Chem. Rev.*, **121**, 2966 (2021).
[2] K. Choudhary, and K. Garrity, *Npj. Comut. Mater.*, **8**, 244 (2022).
[3] R. Ouyang, *et al.*, *Phys. Rev. Mat.*, **2**, 083802 (2018).
[4] S. Wrobel, *1st Europ. Symp. on Princ. of Data Min. and Knowl. Discov.*, **19**, 78 (1997).
[5] L. Foppa, *et al.*, *MRS bulletin*, **46**, 1016 (2021).

TT 35: Topology: Poster

Time: Wednesday 15:00–18:00 Location: P3

TT 35.1 Wed 15:00 P3

Conductive surface states in single-crystalline FeSi — •Philip Schröder, Gilles Gödecke, Julius Grefe, Stefan Süllow, and Dirk Menzel — Institut für Physik der Kondensierten Materie, Technische Universität Braunschweig, Mendelssohnstr. 3, 38106 Braunschweig, Germany

The small-gap semiconductor FeSi exhibits an insulating ground state over a wide temperature range [1]. Notably, electric resistivity measurements imply the opening of a metallic transport channel at lowest temperatures, which historically has been attributed to conductivity among impurity levels [2]. However, recent transport studies on high-quality flux-grown FeSi single crystals discuss the conductive behavior in terms of metallic [3] and magnetic [4] surface states. We present (magneto-)resistance measurements on tri-arc Czochralski-grown FeSi single crystals in dependence of the sample thickness. The controlled manipulation of the surface-to-volume ratio by successive grinding of the specimen under investigation allows for separation of the bulk resistivity and the superimposed contribution of the surface channels. An effective two-channel model has been applied to approximate the upper limit of the surface conductivity.
[1] V. Jaccarino et al., Phys. Rev. 160, 476 (1967).
[2] S. Paschen et al., Phys. Rev. B 56, 12916 (1997).
[3] Y. Fang et al., Proc. Natl. Acad. Sci. U.S.A. 115, 8558 (2018).
[4] K. E. Avers et al., Phys. Rev. B 110, 134416 (2024).

TT 35.2 Wed 15:00 P3

Fabrication and characterization of topological insulator-based SET — •Omargeldi Atanov, Junya Feng, and Yoichi Ando — Physics Institute II, University of Cologne, Cologne, Germany

When a topological insulator (TI) Josephson junction is driven through a topological phase transition, the ground-state parity of the system is expected to change, potentially due to the fusion of Majorana bound state (MBS) pairs. Measuring the individual parity of MBS pairs is a critical step in understanding the mechanisms behind these parity changes and for more complex braiding operations. We present the fabrication and characterization of single-electron transistors (SETs) based on bulk-insulating BiSbTeSe2 flakes, which also serve as the material for TI Josephson junctions. This approach simplifies the process flow of the devices and improves fabrication yield. Initial characterization of devices demonstrates well-formed Coulomb diamonds that confirms the robust charge quantization and SET performance. These results pave the way for integrating SETs with TI Josephson junctions and measuring MBS parity in the near future.

TT 35.3 Wed 15:00 P3

Bulk and surface electron scattering in disordered Bi_2Te_3 probed by quasiparticle interference — •Vladislav Nagorkin[1,2], Sebastian Schimmel[1,2], Paul Gebauer[3], Anna Isaeva[1,4,5,6], Danny Baumann[1], Andreas Koitzsch[1], Bernd Büchner[1,3], and Christian Hess[1,2] — [1]IFW Dresden, Germany — [2]Bergische Universität Wuppertal, Germany — [3]TU Dresden, Germany — [4]University of Amsterdam, The Netherlands — [5]TU Dortmund, Germany — [6]Research Center "Future Energy Materials and Systems", UA Ruhr, Germany

We present low temperature scanning tunneling microscopy and spectroscopy studies of the electronic properties of the topological insulator Bi_2Te_3. The high-resolution differential conductance maps were measured in a relatively large energy range and allowed to reveal the quasiparticle interference in this material. We interpret our experimental data by comparing them with the modeled quasiparticle interference patterns with the use of the spin-selective joint density of states approach including the intricate three-dimensional spin texture of this material. Based on that, the topological properties are clearly demonstrated by the linear energy dispersion of the dominant scattering vector and the absence of the backscattering. In addition, non-dispersive scattering modes were detected and interpreted by scattering involving both surface and bulk states. This allowed us to approximate the bulk energy gap range in our samples. Finally, we show that the above-mentioned findings are robust against the external magnetic field of magnitude up to 15 T.

TT 35.4 Wed 15:00 P3

Planar Hall and Anomalous Planar Hall Effects up to Room Temperature in t-$PtBi_2$ — •Ankit Kumar — IFW Dresden

In topological semimetals, Hall measurements provide an important charge transport footprint of the non-trivial geometric properties of the electronic wavefunctions. In Weyl semimetals, the planar Hall effect (PHE) – the appearance of a transverse voltage when coplanar electric and magnetic fields are applied – is a direct consequence of the longitudinal linear magnetoconductance associated with the chiral anomaly of Weyl fermions, and is quantified by the large Berry curvature of Weyl nodes. The anomalous Hall effect is fully determined only by the location in the Brillouin zone and topological charge of the Weyl nodes. Time-reversal invariance prohibits any anomalous Hall signal in the large class of non-magnetic Weyl semimetals thereby leaving the PHE as the only Hall diagnostic tool of Weyl physics, at least in the linear regime. This complicates the identification of non-magnetic topological semimetals by charge transport experiments.

TT 35.5 Wed 15:00 P3

Instabilities driven by electron-electron interactions — •Eva López Rojo, Julia Link, and Carsten Timm — TU Dresen, Germany

We develop a formalism to study the effect of strong electron-electron interactions in a Weyl semimetal. In this poster, we present the findings for the case of two doped Weyl cones with opposite chirality. For this purpose, we employ a path integral formalism to study different instabilities that could take place. Instead of the charge density wave proposed in the literature, the leading instability for strong inter-valley interactions is found to be a spin density wave, which still has the potential to host axion physics.

TT 35.6 Wed 15:00 P3

The Effect of Interface Disorder on the Tunnel Conductance Across Weyl Semimetal Interfaces — •Haoyang Tian[1], Vatsal Dwivedi[2], Adam Yanis Chaou[2], and Maxim Breitkreiz[2] — [1]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77a, 50937 Köln, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany

The chiral anomaly in Weyl semimetals is responsible for various anomalous transport phenomena. In tunnel junctions between Weyl semimetals with staggered Weyl node projections, the chiral anomaly leads to a magnetic-field activated magnetotransport. In this work, we discuss the effect of interface disorder on the magnetotransport across such a tunnel junction employing a semiclassical Boltzmann approach. Our results show that, compared to conventional transport channels, the topological connectivity of interface Fermi arcs ensures that anomalous magnetotransport exhibits stronger robustness against disorder. Additionally, interface disorder enhances magnetic breakdown, a quantum tunneling effect, between the Fermi arcs.

TT 35.7 Wed 15:00 P3

Impact of decoherence on the Kitaev honeycomb model — •Alexander Sattler and Maria Daghofer — Universität Stuttgart, 70550 Stuttgart, Germany

Quantum spin liquids (QSL) are phases of matter with unique properties, including quantum fluctuations, frustration, entanglement, fractionalized excitations, and the absence of long-range order. A rare example of an exactly solvable, strongly interacting two-dimensional model with a QSL ground state is the Kitaev honeycomb model (KHM). This model describes spin-1/2 particles on a honeycomb lattice with direction-dependent Ising-like interactions. The KHM with open boundaries supports edge-localized Majorana zero modes that are robust to certain types of disorder. Quantum systems are inherently coupled to their environment, necessitating the study of the KHM properties in open systems, where environmental interactions, such as decoherence, can influence their features. To study this, we analyze the KHM in a cylindrical geometry while modeling environmental coupling using the Lindblad master equation to simulate decoherence. By examining changes in the dispersion relation, entropy, fidelity, purity and spectral gap over time, we evaluate how environmental interactions affect the properties of the KHM.

TT 35.8 Wed 15:00 P3

Andreev reflection and interferometry of fractional quantum Hall edge states — •Tom Menei, Daniele Di Miceli, and Thomas L. Schmidt — Department of Physics and Materials Science, University of Luxembourg

Recent experimental work has demonstrated that it is possible to couple superconductors (SCs) to quantum Hall (QH) systems, both at integer and fractional filling fractions. Due to the strong required magnetic fields and the presence of disorder and Abrikosov vortices in the SC, the theoretical modeling of such QH/SC interfaces is not trivial, especially in the case of fractional QH states. In our work, we use the Laughlin edge state theory and realistic models of the superconductor to derive the coupling mechanism at QH/SC interfaces. We explore the effects on normal and Andreev reflection and discuss possible experimental implications.

TT 35.9 Wed 15:00 P3

Variational Trial States for Fractional Chern Insulators — •Giacomo Amadore — LMU, Munich, Germany

Early on, Laughlin's wave functions and other variational trial states provided deep physical insights into the nature of fractional quantum Hall (FQH) systems. One particularly fruitful approach in motivating such trial states is based on the composite fermion description of the FQH problem in the continuum. In contrast, variational states describing fractional Chern insulators in lattice systems remained scarce. While existing methods can construct lattice analogs of familiar FQH states, these states are not generally expected to be the ground state of simple discretized FQH Hamiltonians, but instead a parent Hamiltonian is only constructed a posteriori. To address this limitation, we propose a conceptually different approach motivated by the possibility to study FQH physics in optical lattice experiments realizing the Hofstadter-Bose-Hubbard model. We derive trial states for the ground state of this specific Hamiltonian by turning hard-core bosons into composite fermions through the attachment of a single flux quantum and deriving an effective Hamiltonian for the composite fermions coupled to a dynamical gauge field. To benchmark our findings, we compare the variational energies of different ansätze to (quasi-)exact numerical results. We anticipate that our preliminary results provide a promising starting point for further variational studies and investigations of lattice analogs of FQH systems.

TT 36: Nanotubes, BEC, Cryocoolers: Poster

Time: Wednesday 15:00–18:00 Location: P3

TT 36.1 Wed 15:00 P3

Quantum Dot Spectroscopy in Suspended 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 of Regensburg, 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 quantum dot transport measurements of suspended nanotubes as well as insights into fabrication challenges regarding this approach.

[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 36.2 Wed 15:00 P3

MoS_2 Nanotubes as 1D Superconductors? — •Konstantin D. Schneider[1], Robin T. K. Schock[1], Stefan Obloh[1], Matthias Kronseder[1], Matjaz Malok[2], Maja Remskar[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 two dimensional nature, planar MoS_2 is at the center of manifold research efforts. Previous work has shown that MoS_2 exhibits superconducting properties in single and multi layer flakes when increasing its charge density by heavily doping the MoS_2 surface using a liquid-ion gate [1-3].

Clean and defect-free MoS_2 nanotubes, as grown via chemical transport reaction [4,5], should provide an even better test bed for the interplay of a tubular geometry and Ising superconductivity. In addition, with ionic doping mostly affecting the outermost shell of a multi-wall nanotube, the material system lends itself intrinsically for core-shell semiconductor/superconductor hybrid structures at strong spin-orbin interaction. Here, we present our ongoing work towards this objective [6,7].

[1] T. Ye *et al.*, Science 338, 1193 (2012).
[2] Costanzo *et al.*, Nat. Nano. 11, 339 (2016).
[3] C. Shen *et al.*, Nature 593, 211.
[4] M. Remskar *et al.*, Appl. Phys. Lett. 69, 351 (1996).
[5] M. Remskar *et al.*, Isr. J. Chemistry 62, e202100100 (2022).
[6] T. K. Schock *et al.*, Advanced Materials 35(13) (2023).
[7] Reinhardt *et al.*, pssRRL 13, 1900251 (2019).

TT 36.3 Wed 15:00 P3

Simulations to enhance the conductivity of graphene-based macromaterials — •Florian Fuchs[1,2,3], Fabian Teichert[1,2,3], and Jörg Schuster[1,2,3] — [1]Fraunhofer Institute for Electronic Nanosystems (ENAS), Chemnitz, Germany — [2]Center for Microtechnologies,Chemnitz University of Technology, Chemnitz, Germany — [3]Center for Materials, Architecture and Integration of Nanomembranes (MAIN), TU Chemnitz, Germany

Our aim is to enhance the conductivity of graphene-based macromaterials. These materials consist of many graphene flakes, which are arranged layerwise. A twofold strategy is pursued to improve the material: 1) optimizing the flake properties and the size of the macromaterial, and 2) intercalating molecules in-between the graphene layers.

A network model enables us to estimate the conductivity of the macromaterial for large model systems consisting of thousands of flakes. Particular emphasis will be given in our contribution on the variation of the layer numbers, which is of relevance for printed graphene paths.

To study the impact of intercalants, we perform density functional theory calculations. We concentrate on different fluorides and chlorides, where we vary the cation type and the anion number. The charge carrier density after intercalation is studied and related to more fundamental physical properties such as orbital overlaps and charge transfer.

TT 36.4 Wed 15:00 P3

Quantum Solvation of Flexible Molecules at Low Temperatures from Path Integral Simulations — •Katharina Leitmann[1], Harald Forbert[1,2], and Dominik Marx[1] — [1]Lehrstuhl für Theoretische Chemie, Ruhr-Universität Bochum, 44780 Bochum, Germany — [2]Center for Solvation Science ZEMOS, Ruhr-Universität Bochum, 44780 Bochum, Germany

Protonated methane (CH_5^+) is a fluxional molecule whose sensitivity to its environment makes it an excellent probe for studying molecular interactions at low temperatures. We investigated CH_5^+ microsolvation in *para*-hydrogen clusters $(pH_2)_n$ subject to bosonic exchange at 1 K using a hybrid simulation approach that combines Path Integral Molecular Dynamics (PIMD) for CH_5^+ and bosonic Path Integral Monte Carlo (PIMC) to establish Bose-Einstein statistics of the $(pH_2)_n$ quantum solvation environment.

Our simulations, based on highly accurate High-dimensional Neural Network Potentials parametrised using coupled cluster theory (CCSD(T)), demonstrate stable solvation of CH_5^+ at least up to $n = 12$ pH_2 molecules, which we found to build the first solvation shell. We revealed, that the structure of CH_5^+ is not significantly perturbed by the solvation with pH_2. But we revealed significant fluctuations in the large amplitude motion of CH_5^+ associated to the phenomenon of partial hydrogen scrambling as a function of cluster size n. Further, we investigated the superfluid properties of pH_2 clusters. Analysing the superfluid fraction and bosonic permutation patterns, indicates the manifestation of superfluidity.

TT 36.5 Wed 15:00 P3

Generating a photonic Bose-Einstein condensate in a waveguide — •Lukas Schamriss[1,2,3], Louis Garbe[1,2,3], and Peter Rabl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

We aim to propose a superconducting device designed to generate a photonic Bose-Einstein condensate (BEC). The core component is a coupler that induces a pure three-wave mixing interaction linking a waveguide which hosts the condensate to a LC-mode for dissipating energy from the waveguide. This interaction induces an incoherent photon-number conserving thermalization process in the waveguide. Generally, this system is a minimal example for generating a thermalization mechanism for microwave photons which is a key ingredient for the preparation of finite-temperature equilibrium states on superconducting hardware for analog quantum simulations.

TT 36.6 Wed 15:00 P3

Loop current states and their stability in small fractal lattices of Bose-Einstein condensates — •Georg Koch and Anna Posazhennikova — Institut für Physik, Universität Greifswald, 17487 Greifswald , Germany

We consider a model of interacting Bose-Einstein condensates on small Sierpinski gaskets. We study eigenstates which are characterised by cyclic supercurrents per each triangular plaquette ("loop" states). For noninteracting systems we find at least three classes of loop eigenmodes: standard; chaotic and periodic. Standard modes are those inherited from the basic three-site ring of condensates with phase differences locked to $2\pi/3$. Standard modes become unstable in the interacting system but only when the interaction exceeds a certain critical value u_c. Chaotic modes are characterised by very different circular currents per plaquette, so that the usual symmetry of loop currents is broken. Circular supercurrents associated with chaotic modes become chaotic for any finite interaction, signalling the loss of coherence between the condensates. Periodic modes are described by alternating populations and two different phase differences. The modes are self-similar and are present in all generations of Sierpinski gasket. When the interaction is included, the circular current of such a mode becomes periodic in time with the amplitude growing linearly with the interaction. Above a critical interaction the amplitude saturates signalling a transition to a macroscopic self-trapping state originally known from a usual Bose Josephson junction. We perform a systematic analysis of this rich physics.

TT 36.7 Wed 15:00 P3

Sub-50 mK Adiabatic Demagnetization Refrigeration with Frustrated Yb-Oxide Magnets in the PPMS — •Anna Klinger, Jorginho Villar Guerrero, Marvin Klinger, Tim Treu, Anton Jesche, and Philipp Gegenwart — Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg

Accessing temperatures in the millikelvin (mK) regime is a prerequisite for quantum-matter research and quantum technologies. Adiabatic demagnetization refrigeration (ADR) is a simple and sustainable alternative to ^{3}He/^{4}He dilution refrigeration. We have shown recently, that geometrically frustrated Yb-oxides feature important advantages compared to the traditionally utilized hydrated paramagnetic salts for mK-ADR [1,2]. We report the development of Yb-oxide-based customized ADR cooling platforms for the use in the Quantum Design Physical Property Measurement System (PPMS) ®. Temperatures below 50 mK and hold times of several hours are demonstrated. Our ADR insert offers multiple experimental capabilities, including electrical transport, stress/strain and heat capacity measurements.

[1] Y. Tokiwa et al., Commun. Mater. 2 (2021) 42.
[2] T. Treu et al., J. Phys. Condens. Matter 37, 013001 (2025).

TT 36.8 Wed 15:00 P3

Experimental and Numerical Investigations of the Temperature and Mass Flow Behaviour in the Cold Heat Exchanger of a Single Stage GM-type Puls Tube Cooler — •Elias Eisenschmidt[1,3], Jack-Andre Schmidt[2,3], Bernd Schmidt[2,3], Hardy Weisweiler[1,3], 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

GM-type PTCs play an important role in cooling sensitive electronics. Especially due to the recent developments in quantum computing, low vibration regenerative cooling is needed more than ever. [1]

The refrigeration power is usually calculated using a sinusoidal approximation of the mass flow, temperature and pressure of the working fluid inside a pulse tube cooler. However, several measurements have been carried out to gain insight into the actual time-dependent gas properties. It has been shown that the temperature and pressure curve differ significantly from a sinusoidal assumption. [2]

The goal of this work is to measure the time dependent mass flow and temperature behaviour of the helium gas in the cold end of the cooler, using a RTD and a CTA probe.

[1] Y. Zhai et al., IEEE Trans. Appl. Supercond. 34, May 2024
[2] P. P. Steijaert, Thermodynamical aspects of pulse-tube refrigerators, Technische Universiteit Eindhoven, 1999

TT 36.9 Wed 15:00 P3

Optimisation of Rotary Valve Size and Timing for High Mass-flow GM-Type Pulse Tube Cryocoolers — •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, such as IR astronomy, SNSPDs or surface science[1]. Here we focus on Gifford-McMahon (GM) type pulse tube cryocoolers (PTC), which offer low maintenance and long measurement periods[2]. A crucial component of a GM type PTC is the rotary valve. Losses in the rotary valve are a sizable fraction of overall losses in a GM type PTC [3,4]. This poster will focus on the effects of valve size and timing for a two stage high input power system(11 kW). Both valve size and timing show a strong effect on cooling performance of the first cooling stage. An increase of up to 90

[1] R. Güsten et al., Nature 568 (2019) 357.
[2] R. Radebaugh, J. Phys.: Condens. Matter 21 (2009) 164219.
[3] D. Liu et al., Cryogenics 81 (2017) 100.
[4] L.M. Qiu et al., Cryogenics 42 (2002) 327.

TT 37: Correlated Electrons: Poster

Time: Wednesday 15:00–18:00 Location: P4

TT 37.1 Wed 15:00 P4

Unveiling the Origin of Magnetic Anisotropy in $CeSb_2$ — •Jan T. Weber[1,2], Kristin Kliemt[1], Sergey L. Bud'ko[2,3], Paul C. Canfield[2,3], and Cornelius Krellner[1] — [1]Physikalisches Institut, Goethe-Universität Frankfurt, Max-von-Laue Straße 1, 60438 Frankfurt am Main, Germany — [2]Ames National Laboratory, U.S. DOE, Ames, Iowa 50011, USA — [3]Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA

$CeSb_2$ is a well-established Kondo-lattice system, crystallizing in the orthorhombic $SmSb_2$ structure (space group 64) [1] and forming plate-like crystals. Extensive past studies have revealed a rich magnetic phase diagram for fields within the plane and a strong suppression of magnetization out of plane [2-5]. However, the in-plane magnetization anisotropy remains poorly understood. Nearly identical lattice parameters present challenges in aligning the crystals within the plane, and unexpected magnetization curves - seemingly inconsistent with symmetry arguments - pose additional questions.

In this contribution, we present rotational magnetization measurements together with magnetic measurements as a function of field, temperature and orientation, providing new insights into the in-plane anisotropy addressing these open questions.

[1] R. Wang et. al., Inorg. Chem. 6, 1685 (1967).
[2] S. L. Bud'ko et. al., Phys. Rev. B 57, 13624 (1998).
[3] Y. Zhang et al., Chin. Phys. B 26, 067102 (2017).
[4] B. Liu et al., J. Phys.: Condens. Matter 32, 405605 (2020).
[5] C. Trainer et al., Phys. Rev. B 104, 205134 (2021).

TT 37.2 Wed 15:00 P4

Single Crystal Growth and Characterisation of $EuMn_2Si_2$ and $EuMn_2Ge_2$ — •Janina Strahl, 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 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 $EuMn_2Ge_2$ with reported ferromagnetic Eu ordering below 13 K [2]. 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 Mn spin-reorientation transitions in polycrystalline $EuMn_2Si_2$ samples at low temperatures were observed. In this contribution, we present the single crystal growth and magnetic properties of both compounds. We found antiferromagnetic ordering of the Eu ions in single crystalline $EuMn_2Ge_2$ below 8.5 K and evidence that previously reported Mn reorientation transitions are absent in pure $EuMn_2Si_2$ single crystals.

[1] M. Hofmann et al., Phys. Rev. B 69, 174432 (2004)
[2] I. Nowik et al., Phys. Rev. B 55, 3033 (1997)

TT 37.3 Wed 15:00 P4

Single Crystal Growth and Characterization of a New Yb-based Heavy Fermion Compound — •Fabian Fiedler[1], Florian Stoll[1], Kristin Kliemt[1], Manuel Brando[2], and Cornelius Krellner[1] — [1]Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt am Main, Germany — [2]MPI CPfS, 01187 Dresden, Germany

A system near a quantum-critical point usually shows anomalous thermodynamic and transport properties at low temperatures [1,2].
Presently there are only rare cases of such systems with a ferromagnetic ground state together with pronounced Kondo interactions. Especially Yb-based intermetallic compounds with their possible unstable 4f-shell are of interest due to their low magnetic ordering temperatures.

We found a candidate system for Yb-based ferromagnetic quantum criticality with a large and diverging Sommerfeld coefficient below 10

K. We used substitution in order to manipulate the ground state. Here we report on the single crystal growth as well as the structural and physical characterization of these systems.

[1] Steppke et al., Science 331, 933 (2013);
[2] Shen et al., Nature 579, 51 (2020).

TT 37.4 Wed 15:00 P4

Negative Pressure Studies on $CeRh_2As_2$ with La Substitution — •Sushma Lakshmi Ravi Sankar[1,2], Arushi Yadav[1], Manual Brando[1], Joachim Wosnitza[2], and Seunghyun Khim[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Technische Universität Dresden, 01069 Dresden Germany

$CeRh_2As_2$ is a Kondo-lattice system with novel phase diagrams involving a superconducting and an unknown ordered state appearing below T_c and T_0, respectively. Recent observations of a suppression of T_c and T_0 under external pressure [1] motivated an investigation of a negative pressure study, which can be achieved by a La substitution with Ce. We have succeeded in growing single crystals of ($Ce_{1-x}La_xRh_2As_2$) up to x ∼ 0.1. We found a negative pressure effect as the La substitution leads to an increase in the a- and c- lattice parameters (unit cell volume increase by ∼ 0.15% with x = 0.1) while maintaining the $CaBe_2Ge_2$-type crystal structure. Resistivity measurements showed that both T_c and T_0 decrease with the La substitution to be almost suppressed at x ∼ 0.08, while the resistivity maximum is slightly shifted to a lower temperature. At the same time, the residual resistivity ratio decreases from 2.24 at x = 0 to 1.46 at x = 0.1, indicating additional disorder introduced by the La substitution. This suggests that both the negative pressure effect and the increased disorder should be considered in understanding the evolution of T_c and T_0 with the La substitution.

[1] M. Pfeiffer et al., Phys. Rev. Lett. 133, 126506 (2024).

TT 37.5 Wed 15:00 P4

Terahertz Time-domain Spectroscopy on the Topological Kondo Insulator SmB_6 — •Zekai Chen, Debankit Priyadarshi, Erik de Vos, and Manfred Fiebig — Department of Materials, ETH Zurich, Zurich, Switzerland

We present a terahertz time-domain spectroscopy (THz-TDS) measurement on the topological Kondo insulator samarium hexaboride (SmB_6). These results are aimed at providing insight into the coexistence of a topologically conductive surface state and the opening of a bandgap below the Kondo temperature. Previous work on Kondo insulators has shown that the Kondo quasiparticles disintegrate near a quantum critical point (QCP) in response to THz radiation, leading to a delayed echo-pulse-like response in the time domain [1]. In contrast to these materials, SmB_6 exhibits an additional in-gap state that could be related to its topological surface conductivity. In the presented experiment, this in-gap state is resonantly probed with THz radiation. Our measurement concentrates on studying the emergence of the in-gap state through correlated electron interaction.

[1] Nat. Phys. 14, 1103 (2018).

TT 37.6 Wed 15:00 P4

Cyclotron Resonance on SmB_6 Probed by Superconducting Coplanar Microwave Resonators — •Anastasia Bauernfeind and Marc Scheffler — 1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

Samarium hexaboride (SmB_6) is a homogeneously mixed-valent, narrow-gap semiconductor typically classified as a topological Kondo insulator. Its resistivity increases sharply as the temperature decreases, showing activated behavior that saturates below approximately 5 K. Experimental evidence suggests that topological surface states dominate low-temperature transport. Two notable studies on quantum oscillations in SmB_6 have sparked intense debate about their origin: one observes behavior consistent with a two-dimensional (2D) Fermi surface attributed to surface states, while the other reports a three-dimensional (3D) bulk Fermi surface, despite the insulating nature of the bulk at low temperatures. In our research, we perform cyclotron resonance experiments on SmB_6 using superconducting coplanar waveguides, a powerful method for investigating the Fermi surface of various materials. By tracing the evolution of the cyclotron frequency (up to 20 GHz) as a function of magnetic field, we can determine the type of charge carriers, the effective mass, and the properties of the associated electronic bands. Combined with temperature-dependent measurements (down to 20 mK) and power-dependent studies, this approach provides valuable insights into the electronic structure of the strongly correlated material SmB_6.

TT 37.7 Wed 15:00 P4

Bonding in UO_2^{2+} Dumbbell Structures: The Influence of a Non-Orthogonal Atomic Basis Set and the U 5f, 6d, 7s, and 6p Orbitals — •Henrik Hahn, Michelangelo Tagliavini, Kevin Ackermann, Sarah L. Goerlitz, Johann Collard, Ruth Kaiser, and Maurits W. Haverkort — Institute for Theoretical Physics (ITP), Heidelberg University, Philosophenweg 19, 69120, Heidelberg, Germany

Actinide compounds exhibit a wide range of complex properties, making their theoretical description a significant challenge. This complexity arises primarily from the open 5f shell, which introduces strong electronic correlations, as well as the close proximity of multiple subshells with different angular momentum (l) values due to the large principal quantum numbers (n) of actinides. In this study, we investigate the U-O bond in UO_2^{2+}, a well-known coordination structure of U^{2+} ($5f^0$). Notably, the stronger σ bond derived from the 5f z^3 orbital lies higher in energy than the weaker π bonds formed by the 5f xz^2 and yz^2 orbitals - an unusual ordering. Through a detailed analysis of the underlying LDA Hamiltonian in a non-orthogonal basis, we provide an explanation for this behavior. Our findings demonstrate that fully understanding the bonding and properties of actinides requires a many-orbital model that transcends the conventional assumption that the low-energy physics is governed solely by the 5f shell. This broader perspective is essential for capturing the intricate electronic structure and bonding characteristics of these materials.

TT 37.8 Wed 15:00 P4

Quantum-Spin Impurities Coupled to a Chern Insulator: Topological Remnants — •David Alan Krüger[1] and Michael Potthoff[1,2] — [1]University of Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

Treating quantum-spin impurities as classical vectors is a frequently used approximation to study the impact of local magnetic impurities on the formation of subgap bound states in insulators. Recently, the classical-spin approximation has been exploited for a "local" topological characterization of the ground-state bundle over the manifold of impurity-spin configurations, as opposed to the bundle over the Brillouin zone. This has been achieved by computing spin-Chern numbers $C^{(S)}$ as the corresponding topological invariants.

Here, we numerically solve a system with a single or two quantum spin-$\frac{1}{2}$ locally exchange coupled to a Chern insulator given by the QWZ model. Via Lanczos tridiagonalization, the system is mapped onto a gapped Kondo-impurity model. Local ground-state properties and local single-particle as well as magnetic excitations spectra are obtained by means of an adaptive natural-orbital configuration-interaction technique.

We study the interplay of possible remnants of the classical-spin topology, the intrinsic QWZ topology, and the finite-size Kondo effect. To this end we trace subgap excitations as a function of the local exchange-coupling strength and the mass parameter.

TT 37.9 Wed 15:00 P4

Chiral Kondo Lattice Analyzed via Variational Cluster Approach — •Benjamin Heinrich and Maria Daghofer — Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Germany

Moiré systems composed of van der Waals heterostructures provide an experimentally accessible platform to realize a wide range of strongly correlated electron phenomena. Using transition metal dichalcogenide materials, such as an AB-stacked $MoTe_2/WSe_2$ bilayer, gives rise to an effective multi-orbital Hubbard model on the honeycomb lattice, which can be tuned via doping and the introduction of charge transfer energy through external voltages. Including strong Ising spin-orbit coupling leads to chiral Kondo exchange between localized and itinerant electrons in different layers near half-filling.[1]

To gain a better understanding of experimentally observed phenomena, including magnetic ordering, numerical modeling is performed using the variational cluster approach. This methodology, closely related to cluster dynamical mean-field theory, has been proven effective for studying analogous systems exhibiting Kondo lattice behavior.

[1] Guerci et al., Sci. Adv. 9, eade7701 (2023).

TT 37.10 Wed 15:00 P4

Influence of Band Mixing on FCI and CDW — •Marco Schönleber and Maria Daghofer — Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany

Fractional quantum hall physics with vanishing magnetic fields has become an increasingly important research topic in recent years due to new findings in the field of moiré materials. Experimental signatures of these phases are often observed in combination with signatures of charge ordered or other symmetry broken phases. This indicates that band mixing might play an elementary role in the complete description of this phase of matter. For this purpose, an extended Hubbard model on a triangular lattice with $\nu = 1/3$ and $\nu = 2/3$ is considered. This allows the formation of bands of non-trivial topology as well as the formation of commensurate charge density waves. The analysis is carried out by exact diagonalisation. By varying the band gap, it can be shown that the stability of the charge order depends on this, whereby the degree of filling plays a decisive role.

TT 37.11 Wed 15:00 P4

Quantum Monte Carlo simulations of generalized Dicke-Ising models — •Anja Langheld, Max Hörmann, and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

Recently, we introduced a wormhole algorithm for the paradigmatic Dicke-Ising model to gain quantitative insights on effects of light-matter interactions on correlated quantum matter [1]. This method enabled us to determine the quantum phase diagram for ferro- and antiferromagnetic interactions on the chain and square lattice alongside the criticality of its second order quantum phase transitions. The continuous superradiant phase transitions are in the same universality class as the Dicke model, leading to a well-known peculiar finite-size scaling which can be understood in terms of scaling above the upper critical dimension.

Going one step further we now introduce new ingredients to the matter Hamiltonian like geometric frustration, long-range interactions and disorder to study the interplay between a variety of correlated matter phenomena and light-matter interactions.

[1] A. Langheld et al., arXiv:2409.15082

TT 37.12 Wed 15:00 P4

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, Stuttgart 70569, Germany — [2]Department of Physics, Technical University of Munich, Garching 85749, 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 chromodynamics1-4. 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 angle5-6. Motivated by this, we explore the quantum phase transition of a 2D Dirac material which spontaneously develops a gap that breaks an Ising symmetry7. We model it via an effective Gross-Neveu-Yukawa theory and employ the functional renormalization group method to map out the phase diagram. We analyze the quantum critical behavior at the transition and investigate the effect of a chemical potential which introduces a finite charge density.

TT 37.13 Wed 15:00 P4

NMR in Pulsed Magnetic Fields - Recent Developments — •Hannes Kühne[1] and Yoshihiko Ihara[2] — [1]HLD-HZDR, Dresden — [2]Department of Physics, Hokkaido University

NMR measurements in the highest pulsed magnetic fields have been developed at dedicated large-scale research facilities for some time and are becoming increasingly available for user experiments. On the poster, I will give an overview of the current developments, possibilities and peculiarities of NMR experiments in pulsed magnetic fields. In particular, the implementation of NMR experiments with dynamically controlled flat-top field pulses has recently been reported, enabling the measurement of broadband NMR spectra and relaxation times up to the ms range [1]. Furthermore, through several examples on low-dimensional spin systems, I will present opportunities to work on scientific questions that can be uniquely addressed using this technique [2].

[1] Y. Ihara et al., Rev. Sci. Instrum. 92, 114709 (2021).
[2] H. Kühne and Y. Ihara, Contemp. Phys. 65, 40 (2024).

TT 37.14 Wed 15:00 P4

Magnetic Anisotropy and Low-Energy Spin Dynamics in van der Waals Magnets $M_2P_2S_6$ Probed by Electron Spin Resonance — Joyal J. Abraham[1,2], Yurii Senyk[1,2], Yuliia Shemerliuk[1], Sebastian Selter[1,2], Saicharan Aswartham[1], Bernd Büchner[1,2,3], Vladislav Kataev[1], and •Alexey Alfonsov[1,3] — [1]Leibniz IFW Dresden, 01069 Dresden, Germany — [2]TU Dresden, 01062 Dresden, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, 01062 Dresden, Germany

In the past recent years magnetic van der Waals (vdW) materials have become increasingly attractive for the fundamental investigations since they provide immense possibility to study intrinsic magnetism in a low-dimensional limit. The weak vdW forces hold together the atomic monolayers in vdW crystals, which results in a poor interlayer coupling, and therefore renders these materials intrinsically two dimensional. That makes them particularly attractive for probing the low-dimensional physics while investigating bulk crystals. On the other hand, a remarkable success in exfoliation of this class of materials due to the lack of significant interlayer chemical bonds unlocks vast potential for applications in the fields of advanced electronics, opto-electronics, and spintronics. In this work we present the results of the electron spin resonance investigation of such magnetic vdW materials $M_2P_2S_6$ (M = Mn, Ni, Cu, Cr) performed in the broad range of temperatures, magnetic fields and excitation frequencies, and discuss their low-energy spin dynamics as well as magnetic anisotropy responsible for the stabilization of the magnetic order.

TT 37.15 Wed 15:00 P4

Magnetic Properties of a Trillium Lattice Compound $Li_2NiGe_3O_8$ — •Annarose Jose Palliyan[1,2], Nazmul Islam[2], Ralf Feyerherm[2], and Bella Lake[2,1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany

Frustrated magnets are interesting materials that exhibit exotic properties due to the competing localized spins [1]. Certain lattices are intrinsically predisposed to show frustration due to the arrangement of their magnetic ions and one such lattice is the trillium lattice [2]. The trillium lattice is composed of a three-dimensional chiral network of corner sharing equilateral triangles. $Li_2NiGe_3O_8$ is a trillium lattice candidate where each Ni^{2+} ion is shared between three equilateral triangles. Polycrystalline samples of $Li_2NiGe_3O_8$ were synthesized by solid - state reaction method. The magnetic properties of this complex spinel oxide were studied by magnetization, susceptibility and heat capacity measurements down to He-3 temperatures. Our studies shows the presence of weak antiferromagnetic interactions in this material with no long-range order. A three-level schottky anomaly was observed in this material because of the splitting of the S = 1 triplet state.

[1] J. M. Bulled et al., Phys. Rev. Lett. 128, 177201 (2022);
[2] N. Tristan et al., Phys. Rev. B 72, 174404 (2005).

TT 37.16 Wed 15:00 P4

Geometric Magnetic Frustration in $Mn_3Al_2Si_3O_{12}$ — •Marwa Abouelela[1,2], Nazmul Isalam[2], Ralf Feyerherm[2], and Bella Lake[1,2] — [1]Institut für Festkörperphysik, Technische Universität, Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany

Geometric magnetic frustration in triangular lattices has garnered significant interest in recent research [1]. $Mn_3Al_2Si_3O_{12}$ exhibits geometrical frustration, where Mn^{2+} ($3d^5$) ions form a hyperkagomé structure [2]. In this study, the spessartine was synthesized at high temperatures, and its magnetic susceptibilities and heat capacities were investigated at low temperatures. Temperature-dependent magnetic susceptibility measurements revealed an antiferromagnetic ordering of the Mn^{2+} ions below T_N=6.5K, with a Curie-Weiss temperature of -26.7K. The high ratio of Curie-Weiss temperature to Néel temperature suggests strong frustration in the system.

[1] A. P. Ramirez, Annu. Rev. Mater. Sci. 24, 453 (1994);
[2] G. C. Lau et al., Phys. Rev. B 80, 214414 (2009).

TT 37.17 Wed 15:00 P4

Static and Dynamic Properties of Quantum Magnets: Results from Numerical Linked Cluster Expansion — •Alexander Schwenke and Wolfram Brenig — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany

We consider static and dynamic properties of two-dimensional frustrated quantum antiferromagnets utilizing the numerical linked cluster expansion (NLCE). In particular, we are interested in spin-$^1/_2$ models showing quantum phase transitions versus internal parameters, e.g., the J_1-J_2 model on the square lattice or the triangular lattice XXZ model in external magnetic fields.

For the NLCE, we employ a single-site representation focussing on three topics: First, we present results for thermodynamic quantities, namely the internal energy and the specific heat at finite temperature. Second, we study the ground-state energy per site as a function of competing exchange coupling constants focussing on its second derivative. Finally, we investigate the dynamics of the system following a quantum quench.

TT 37.18 Wed 15:00 P4

Magnetism in i-Tb-Cd Quasicrystals — •Andreas Kreyssig[1,2], P. Das[2], G. S. Tucker[2], A. Podlesnyak[3], Feng Ye[3], Masaaki Matsuda[3], T. Kong[2], S. L. Bud'ko[2], P. C. Canfield[2], R Flint[2], P. P. Orth[2,4], T. Yamada[5], and A. I. Goldman[2] — [1]Experimental Physics IV, Ruhr University Bochum, Bochum, Germany — [2]Ames Laboratory, U.S. DOE, and Department of Physics and Astronomy, Iowa State University, Ames, USA — [3]Neutron Scattering Division, Oak Ridge National Laboratory, USA — [4]Department of Physics, Harvard University, Cambridge, USA — [5]Department of Applied Physics, Tokyo University of Science, Tokyo, Japan

i-Tb-Cd orders as icoshedral quasicrystal with the magnetic Tb^{3+} ions arranged in Tsai-type clusters. We studied the magnetic correlations and excitations by elastic and inelastic neutron scattering on single-grain isotopically enriched samples. The measurements of the crystalline electric field excitations demonstrated that the Tb^{3+} moments are directed along the local fivefold axes of the Tsai-type clusters. We calculated the magnetic diffuse scattering for the low-energy configurations using an Ising-type model for the moment arrangements on a single Tb^{3+} icosahedron. By comparison with our diffuse neutron scattering signals, we identified the most likely moment configuration in a single cluster. We further studied the role of intercluster interactions for magnetic frustration and the magnetic scattering.

This work was supported by the U. S. DOE, BES, DMSE, Contract DE-AC02-07CH11358, and resources at HFIR and SNS, U. S. DOE.

[1] P. Das, A. Kreyssig et al., Phys. Rev. **B** 108, 134421 (2023).

TT 37.19 Wed 15:00 P4

Chiral spin liquid in external magnetic field: Phase diagram of the decorated-honeycomb Kitaev model — •Sabastian Granberg Cauchi and Matthias Vojta — TU Dresden, Germany

Studies of Kitaev models on different lattices have shown signatures of topological phase transitions as a function of external magnetic field direction and magnitude. These transitions are often accompanied by a change in the statistics of the low-energy anyonic excitations. In particular, the antiferromagnetic Kitaev system yields a field-induced spin liquid, of arguably gapless U(1) or Abelian character. The existence of field-induced spin liquids on different lattices has consequently been intensely investigated. Here, we determine the phase diagram of the decorated-honeycomb Kitaev model for different inter- and intra-triangle coupling ratios and magnetic fields using a mean-field theory derived from Kitaev's Majorana parton decomposition.

TT 37.20 Wed 15:00 P4

Low-energy description of the SU(3) Hubbard model on the triangular lattice — •Linus Hein — Ludwig-Maximilians-Universität München

It has been a longstanding goal to better understand strongly correlated fermionic systems. Extensive studies have been conducted on these systems, particularly on the square lattice Hubbard model. To find out which of the results are artefacts of this fine-tuned model, it is sensible to analyze slightly modified models with for instance enlarged symmetry. We consider an SU(3) antiferromagnet on a tripartite triangular lattice near one third filling. Previous works explored a non-linear sigma model and its emerging Goldstone modes. Building on these results, we derive a linear spin-wave description of the low-energy excitations. Furthermore, we consider the hole-doped system and derive an effective Hamiltonian to describe the emergent magnetic polarons. Thereby, we broaden our understanding of strongly correlated fermionic systems, in a setting that can be experimentally explored using e.g. ultracold atom experiments.

TT 37.21 Wed 15:00 P4

Temperature Dependent Infrared Spectroscopy on the Frustrated Spin-Ladder System $BiCu_2PO_6$ — •Johanna Strauss[1], Renjith Mathew Roy[1], Maxim Wenzel[1], Haidong Zhou[2], Martin Dressel[1], and Komalavalli Thirunavukkuarasu[3] — [1]1. Physikalisches Institute, University of Stuttgart, Germany — [2]Department of Physics, University of Tennessee Knoxville, Knoxville, USA — [3]3. Department of Physics, Florida A and M University, Tallahassee, USA

Spin systems with frustrated geometries are of significant interest due to their potential to exhibit quantum spin liquid behaviour. This study focuses on $BiCu_2PO_6$ which exhibits no magnetic ordering down to 0.1 K. Various experimental studies on this zig-zag spin-ladder compound reveal that the magnetism in this material arise from complex exchange coupling mechanisms that are not completely understood yet. However, it is clear that the magneto-structural correlations play a major role. Here, we present our attempt to employ infrared spectroscopy to determine the optical conductivity and phonons along planes parallel and perpendicular to the spin-ladders at temperatures ranging from 300 K to 10 K and look for signatures on the nature of spin-phonon coupling.

TT 37.22 Wed 15:00 P4

Magnetic Phase Diagrams of the Frustrated Langbeinite Material $Tl_2Mn_2(SO_4)_3$ — •Manuel Tönnissen[1], Alexander Bäder[1], Ladislav Bohatý[2], Petra Becker-Bohatý[2], Oliver Breunig[1], and Thomas Lorenz[1] — [1]II. Physikalisches Institut, Universität zu Köln — [2]Institut für Kristallographie, Universität zu Köln

Antiferromagnetic Heisenberg spins on the so-called trillium lattice form a highly frustrated 3-dimensional spin system [1]. This theoretical model can be realizied in cubic, low-symmetry space group $P2_13$ materials. One family of materials that partially crystallizes in this space group are langbeinites. Recent studies report that the langbeinite $K_2Ni_2(SO_4)_3$ with S=1 Ni^{2+} ions show close proximity to a field-driven quantum spin-liquid behavior, although there is magnetic order in zero field [2] [3]. Here we focus on the different magnetic phases of the related langbeinite $Tl_2Mn_2(SO_4)_3$ with S=5/2 Mn^{2+} ions. By conducting specific-heat, magnetocaloric-effect, and magnetization measurements, we derive B-T phase diagrams for different orientations of the magnetic field. Our data reveal the presence of at least 3 magnetic phases below a temperature of about 1.5 K for the magnetic field along the [1 1 1] direction and even 4 magnetic phases for fields applied along the [1 1 0] or [0 0 1] directions.

This work is supported through CRC1238 (projects A02 and B01).

[1] J. Hopkinson, Phys. Rev. B, **74**, 224441 (2006);
[2] M. G. Gonzalez et al., Nat. Commun. **15**, 7191 (2024);
[3] I. Živković et al., Phys Rev. Lett. **127**, 157204 (2021).

TT 37.23 Wed 15:00 P4

Magnetic Order in the Low-Dimensional Quantum Magnet $Cu_2(OH)_3Br$ — •S. Luther[1], Z. Wang[2], A. Reinold[2], Z. Zhao[3], J. Wosnitza[1,4], and H. Kühne[1] — [1]Hochfeld-Magnetlabor Dresden, HZDR — [2]Fakultät Physik, TU Dortmund — [3]Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences — [4]Institut für Festkörper- und Materialphysik, TU Dresden

Low-dimensional quantum magnets, such as the quasi-two-dimensional spin system $Cu_2(OH)_3Br$, can host exotic phenomena and ground states. We will present results of high-field magnetization and nuclear magnetic resonance (NMR) spectroscopy that probe the microscopic details of the magnetic structure at finite magnetic fields. In $Cu_2(OH)_3Br$, the Cu^{2+} ions in the distorted crystal structure form alternating ferromagnetic and antiferromagnetic spin-1/2 chains with finite interchain coupling, leading to a Néel temperature of 9.3 K at zero field. Here, we investigate the phase diagram for $H||b$, where a splitting of the NMR spectral lines below T_N and elevated fields reveals a commensurate long-range antiferromagnetic order. Maxima in the temperature-dependent spin-lattice relaxation rate $1/T_1$ at different magnetic fields indicate the transition temperature to the ordered phase. An anomaly in the high-field magnetization at low temperatures and around 16 T suggests the suppression of the magnetically ordered phase.

TT 37.24 Wed 15:00 P4

ESR Investigations of $AgCrSe_2$, $AgCrS_2$ and Cr_3Se_4 — •Jörg Sichelschmidt, Pierre Chailloleau, Michael Baenitz, Seo-Jin Kim, Helge Rosner, Vicky Hasse, and Marcus Schmidt — Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

We investigated the Electron Spin Resonance (ESR) of Cr in the layered triangular lattice systems $AgCrSe_2$, $AgCrS_2$ and the structurally related Cr_3Se_4. These materials display a variety of interesting physical properties such as unconventional magnetic ordering [1], a spin-polarized surface state [2], an unconventional anomalous Hall effect [3] in $AgCrSe_2$ or multiferroic behavior in $AgCrS_2$, or directional Kondo transport [4]. At low temperatures, all these materials show a divergent ESR spin relaxation, which is typical for low-dimensional spin systems and indicates an increasing importance of Cr^{3+} spin correlations. This also leads to the formation of internal fields, as evidenced by the marked decrease in the resonance field. The relatively narrow Cr^{3+} ESR spectra allow to determine an ESR intensity which reflects the static susceptibility probed locally at the site of the Cr spins.

[1] M. Baenitz *et al.*, Phys. Rev. B **104**, 134410 (2021);
[2] G.-R. Siemann *et al.*, npj Quantum Mater. **8**, 61 (2023);
[3] S.-J. Kim *et al.*, Adv. Sci. **11**, 2307306 (2024);
[4] J. Guimaraes *et al.*, Commun. Phys. **7**, 176 (2024).

TT 37.25 Wed 15:00 P4

Electronic Structures of $AgCrS_2$, $AgCrSe_2$, and Cr_3Se_4 — •Seo-Jin Kim, Jörg Sichelschmidt, Michael Baenitz, Marcus Schmidt, and Helge Rosner — Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

We study the electronic structures of triangular lattice systems $AgCrS_2$, $AgCrSe_2$, and the related compound Cr_3Se_4 using density functional theory (DFT). Although $AgCrSe_2$ and $AgCrS_2$ are isostrucural, they exhibit different physical properties. $AgCrSe_2$ is a self-doped p-type semiconductor characterized by spin-polarized surface states[1], the cycloidal magnetic ordering[2], and the unconventional anomalous Hall effect[3] and directional Kondo transport[4]. In contrast, $AgCrS_2$ is an insulator that undergoes symmetry lowering to a monoclinic phase and exhibits a collinear double-stripe antiferromagnetic ground state below $T_N = 42$ K. This study aims to present a comprehensive analysis of the electronic structures of these compounds. Additionally, we extend our investigation to the structurally related compound Cr_3Se_4.

[1] M. Baenitz et al., Phys. Rev. B 104, 134410 (2021);
[2] G.-R. Siemann et al., npj Quantum Mater. 8, 61 (2023);
[3] S.-J. Kim et al., Adv. Sci. 11, 2307306 (2024);
[4] J. Guimaraes et al., Commun. Phys. 7, 176 (2024).

TT 37.26 Wed 15:00 P4

Synthesis and Physical Properties of 2D van der Waals Magnets $Fe_{1-x}TM_xPX_3$ (TM: Transition Metals) — •Masoumeh Rahimkhani, Saicharan Aswartham, Andreas Kreyssig, and Anna Böhmer — Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum, Germany

Transition-metal phosphochalcogenides ($TMPX_3$) belong to the family of layered van-der-Waals materials in which TM is a transition-metal and X is a chalcogenide. These materials exhibit various electric, optical, and magnetic properties. $FePSe_3$ belongs to this family of $TMPX_3$ with interesting magnetic and electronic properties. Here, we describe the preparation of $FePSe_3$ and its substitution series with different transition metals through solid-state synthesis and CVT. The samples are characterized by X-ray diffraction and scanning electron microscope for structural and phase analysis. Further on, the magnetic and electronic properties will be investigated.

TT 37.27 Wed 15:00 P4

Single-Crystal Study of Kagome Magnets CrRhAs and CrNiAs — •Franziska Breitner, Bin Shen, Anton Jesche, and Philipp Gegenwart — Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, 86159 Augsburg, Germany

CrRhAs and CrNiAs are metals with distorted kagome lattice of magnetic Cr atoms [1]. While CrRhAs is an antiferromagnet with a reported Néel temperature of 165 K for polycristalline samples, CrNiAs is ferromagnetic with T_C=170 K. More recently, interesting properties such as anomalous Hall effect were predicted for CrRhAs [2].

We report the first growth of CrRhAs and CrNiAs single crystals utilizing the flux method and present their specific heat, magnetic susceptibility and electrical transport. Magnetoresistance and Hall effect for CrRhAs indicate no anomalous behaviors. For CrNiAs we also investigate the influences of hydrostatic pressure as well as partial substitution of As with P on the ferromagnetic transition.

Supported by DFG-TRR 360*492547816 and the Alexander von Humboldt Foundation.

[1] S. Ohta et al., J. Mag. Mag. Mater. 90, 171 (1990).
[2] Y. N. Huang et al., npj Quantum Mater. 8, 32 (2023).

TT 37.28 Wed 15:00 P4

Inelastic Scattering in Anisotropic Heisenberg Models on Square and Honeycomb Lattice Via Continuous Similarity Transformations — •Vanessa Sulaiman[1], Dag-Björn Hering[1], Matthias R. Walther[2], Kai P. Schmidt[2], and Götz S. Uhrig[1] — [1]Condensed Matter Theory, Technische Universität Dortmund, Otto-Hahn-Straße 4, 44221 Dortmund, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany

We apply a continuous similarity transformation (CST) [1,2] with a magnon-conserving generator to the antiferromagnetic anisotropic XXZ model. For the square lattice, the resulting effective Hamiltonian has already been analyzed [3]. We extend the approach by applying the CST to observables as well. Using the continuous fraction representation, we calculate spectral densities for these observables on the square and honeycomb lattice. These are then compared to experimental data from RIXS measurements [4], for example with single-layered $Ca_2CuO_2Cl_2$.

[1] M. Powalski et al., Phys. Rev. Lett. **115**, 207202 (2015);
[2] M. Powalski et al., SciPost Phys. **4**, 001 (2018);
[3] M. R. Walther et al., Phys. Rev. Res. **5**, 013132 (2023);
[4] K.-J. Zhou et al., J. Synchrotron Rad. **29**, 563 (2022).

TT 37.29 Wed 15:00 P4

Stochastic Simulation of Spin Transport — •Franz Pöschl[1,4], Xin Zhang[1,2,3], Aristo Kevin Ardyaneira P[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 — [4]Ludwig-Maximilians Universität München, Fakultät für Physik, Geschwister-Scholl-Platz 1, 80539 München

Simulating out of equilibrium steady states of large systems is a hard task. It is therefore necessary to develop novel approaches permitting to simulate the dynamics of those systems efficiently. In our work, we use the Discrete Truncated Wigner Approximation which is a semiclassical approach mapping hamiltonians and dissipative processes into a classical phase space. This mapping allows to compute stochastic trajectories and to evaluate the evolution of the system. In this poster I will present this method and show how it can be employed to study the out-of-equilibrium phases of the XXZ spin model and to derive its transport properties.

TT 37.30 Wed 15:00 P4

Anisotropic Magnetoresistance and Hall Effect of $Sr_4Ru_3O_{10}$ — •Simone Seipel[1], Lara Pätzold[1], Zahra Ghazinezhad[1], Augustus 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 with a layered orthorhombic crystal structure. It is a ferromagnetic metal with $T \simeq 105$ K and shows an additional metamagnetic transition below 50 K, of which a deeper understanding is still missing. Here, we present a single-crystal study of the anisotropic magnetization and electrical transport properties. For in-plane electric currents ($j||ab$) and $B||c$, we present normal and anomalous Hall effect data. The latter shows a non-monotonic temperature dependence and a characteristic sign change at low temperature which similarly occurs in the magnetoresistance $\rho_{xx}(B||c)$. Such a behavior is known from the sister compound $SrRuO_3$ and associated with Weyl points in the band structure [1]. In addition, we studied the out-of-plane resistivity that is highly anisotropic ($\rho_c >> \rho_{ab}$) due to the layered crystal structure and strongly changes at the metamagnetic transition. Based on magnetoresistance data $\rho_c(B||ab)$ we derive the magnetic-field induced metamagnetic transition at low temperatures and discuss the angular dependence of the transition fields and the magnetoresistance for in-plane magnetic fields.

Funded by the DFG via CRC 1238 Projects A02, B01 and B04

[1] K. Takiguchi et al., Nat. Commun. **11**, 4969 (2020).

TT 37.31 Wed 15:00 P4

Thermal Transport in Swedenborgite $CaBaCo_4O_7$ — •Reza Firouzmandi[1], Matthias Gillig[1], Yasujiro Taguchi[2], Yoshinori Tokura[2], Yusuke Tokunaga[2], Vilmos Kocsis[1], and Bernd Büchner[1] — [1]IFW-Dresden, Dresden, Germany — [2]RIKEN-CEMS, Wako, Japan

The interplay between electronic, magnetic, and lattice degrees of freedom in multiferroic materials gives rise to novel transport phenomena, including the thermal Hall effect (THE), thermal analog of the Hall effect, where heat flow is deflected under an external magnetic field. Here, we investigate the thermal transport properties of the multiferroic Swedenborgite $CaBaCo_4O_7$, a compound featuring alternating Kagome and triangular layers of edge-sharing CoO_4 tetrahedra in a mixed valence state. The longitudinal thermal conductivity exhibits anomalies associated with magnetic ordering, while the transverse thermal conductivity (κ_{xy}) reveals an anomalous thermal Hall effect that vanishes at low temperatures, resembling the magnon thermal Hall effect. These results provide insight into the role of spin-lattice coupling in the thermal transport of frustrated magnetic systems.

TT 37.32 Wed 15:00 P4

Strain dependance of the antiferromagnetic transition of $Ca_{1-x}Sr_xCo_2As_2$ with a substitution induced structural collapse — •Michael Paul, Maik Golombiewski, Teslin R. Thomas, N.S. Sangeetha, Andreas Kreyssig, and Anna E. Böhmer — Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum, Germany

The tetragonal structure of $SrCo_2As_2$ undergoes a gradual collapse with the substitution of Sr by Ca atoms. This collapse is accompanied by the emergence of antiferromagnetic order with a transition temperature T_N of up to 55 K [1]. It has been shown that T_N can be tuned with biaxial strain that is created by cooling a thin $Ca_{1-x}Sr_xCo_2As_2$ sample that is glued to a quartz substrate [2].

A more controlled application of uniaxial force to the sample can be achieved with the use of the cryogenic stress cell Razorbill FC100. The modification of the antiferromagnetic transition of $Ca_{1-x}Sr_xCo_2As_2$ is investigated by applying uniaxial stress to the sample with this device.

We acknowledge the support by the Deutsche Forschungsgemeinschaft (DFG) under CRC/TRR 288 (Project A02).

[1] N. S. Sangeetha et al., Phys. Rev. Lett. 119, 257203 (2017);
[2] T. R. Thomas et al., in preparation

TT 37.33 Wed 15:00 P4

Single crystal synthesis of $FeSb_2$ and investigation of its electronic transport properties — •Maximilian van de Loo, Maik Golombiewski, Andreas Kreyssig, and Anna E. Böhmer — Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum, Germany

$FeSb_2$ is a diamagnetic narrow band gap semiconductor with interesting electronic transport properties [1]. Huge thermoelectric power factor and a paramagnetic crossover have been reported at low temperatures [1, 2] and attempts to influence and understand these properties by doping have been made [3]. A metal-semiconductor crossover along the b axis can be observed under certain growth conditions. We have synthesized single crystals of $FeSb_2$ via self-flux growth and successfully realized substitutions $(Fe_{1-x}TM_x)Sb_2$ with different transition metals (TM). The samples were characterized with electron microscopy, energy-dispersive x-ray spectroscopy, powder x-ray diffraction and Laue diffraction measurements, as well as electrical resistivity measurement. The appearance of the metal-semiconductor crossover has been investigated by varying the growth conditions.

We acknowledge support by the Deutsche Forschungsgemeinschaft (DFG) under CRC/TRR 288 (Project A02).

[1] C. Petrovic, J. W. Kim, S. L. Bud'ko, A. I. Goldman, P. C. Canfield, W. Choe, and G. J. Miller, Phys. Rev. B 67, (2003).
[2] C. Homes, Q. Du, C. Petrovic, W. H. Brito, S. Choi, and G. Kotliar, Sci. Rep. 8, (2018).
[3] Y. Cao, S. Yuan, M. Liu, B. Kang, B. Lu, J. Zhang, and S. Cao, J. Cryst. Growth 363, (2013).

TT 37.34 Wed 15:00 P4

Feshbach resonance in a strongly repulsive ladder of mixed dimensionality: a possible scenario for bilayer nickelate superconductors — •Hannah Lange[1,2,3], Lukas Homeier[1,3], Eugene Demler[4], Fabian Grusdt[1,3], and Annabelle Bohrdt[3,5] — [1]LMU Munich — [2]Max-Planck-Institute for Quantum Optics, Garching — [3]Munich Center for QST, Munich — [4]ETH Zurich — [5]University of Regensburg

Since the discovery of superconductivity in cuprate materials, the minimal ingredients for high-Tc superconductivity have been an outstanding puzzle. Motivated by the recently discovered nickelate bilayer superconductor LNO under pressure, we study a minimal bilayer model, in which, as in LNO, inter- and intralayer magnetic interactions but no interlayer hopping are present: a mixed-dimensional (mixD) t-J model. The single and coupled mixD ladders we study feature a crossover from tightly bound pairs of holes (closed channel) at small repulsion, to more spatially extended, correlated pairs of individual holes (open channel) at large repulsion. We derive an effective model for the latter, in which the attraction is mediated by the closed channel, in analogy to atomic Feshbach resonances. Using density matrix renormalization group (DMRG) simulations we reveal a dome of large binding energies at around 30% doping, accompanied by a change of the Fermi surface volume. Our work provides a microscopic theory of pairing in the doped mixD system with dominant repulsion and our predictions can be tested in state-of-the-art quantum simulators.

TT 37.35 Wed 15:00 P4

Fluctuation Spectroscopy on $La_2NiO_{4+\delta}$ RRAM devices — •Demian Ranftl[1], Yingxin Li[2], Tristan Stadler[1], Eszter Piros[2], Aleksandra Koroleva[3], Lambert Alff[2], Mónica Burriel[3], and Jens Müller[1] — [1]Institute of Physics, Goethe University, Frankfurt am Main, Germany — [2]Institute of Materials Science, TU Darmstadt, Darmstadt, Germany — [3]Laboratory in Materials Science and Physical Engineering, Université Grenoble Alpes, Grenoble, France

Memristive devices, whose resistance is programmable and retainable, are considered to be most promising for the next generation of nonvolatile memory. Low-frequency current noise spectroscopy is a noninvasive investigative tool for probing the effect of defects on resistive switching [1, 2]. Annealing $La_2NiO_{4+\delta}$ films under inert (Ar) or oxidising (O_2) atmospheres results in devices with filamentary and interfacial-type resistive switching respectively [3]. In this work we explore the effect of the switching mechanism, readout voltage and area dependency on the noise characteristics of LNO-based RRAM.

[1] E. Piros, M. Lonsky *et al.* Phys. Rev. Appl. **14** (2020)
[2] T. Thyzel, M. Kopp *et al.* Meas. Sci. Technol. **36** (2025)
[3] A. Koroleva *et al.* Adv. Electron. Mater. 2400096 (2024)

TT 37.36 Wed 15:00 P4

Resistance Fluctuation (Noise) Spectroscopy in EuS and $LiCu_3O_3$ — •Philipp Swoboda[1], Demian Ranftl[1], Nazia Kaya[1], Katharina Zoch[1], Kristin Kliemt[1], Simon Moser[2], Cornelius Krellner[1], and Jens Müller[1] — [1]Institute of Physics, Goethe-University Frankfurt, Frankfurt (Main), Germany — [2]Institute of Physics, University Würzburg, Würzburg, Germany

Noise spectroscopy gives insights into the low-frequency dynamics of charge carriers in condensed-matter systems, which is energy-resolved information that can't be obtained from mean values alone. Here the interest lies in $1/f^{\alpha}$-noise, which can be described as a superposition of independent two-level processes. For instance it has been used to identify energy scales of thermally-activated switching processes like fluctuating polar nanoregions (PNR) in the past [1, 2]. In general the processes observed by resistance fluctuation are sensitive to slow dynamics. Examples are the slowing down of charge carriers in the vicinity of a metal insulator transition and the freezing of PNR at the onset of glassy dynamics. This work aims to use noise spectroscopy as a function of temperature and magnetic field in order to investigate how magnetic polarons influence the colossal magnetoresistance in the ferromagnetic semiconductor EuS, as well as to investigate the exotic electron glass phase in $LiCu_3O_3$.

[1] npj Spintronics 2, 24 (2024).
[2] Meas. Sci. Technol. 36 (2025) 015501.

TT 37.37 Wed 15:00 P4

Single spin-flip dynamics in the Ising model — •Luca Cervellera and Björn Sothmann — Faculty of Physics and CENIDE, University Duisburg- Essen, 47057 Duisburg

The surface of Si(001) consists of buckled Si dimers with alternating orientation in the ground state. At around 190 K, the system undergoes an order-disorder phase transition which can be described in terms of an antiferromagnetic 2D Ising model with anisotropic couplings [1]. Here, we aim at understanding the switching dynamics of a single Ising spin by means of Monte Carlo simulations of the temperature-dependent dynamics using different algorithms which allow us to analyze the waiting-time distribution and full counting statistics of spin flips.

[1] C. Brand et al., Phys. Rev. Lett. 130, 126203 (2023).

TT 37.38 Wed 15:00 P4

Quantum Monte-Carlo study of the bond- and site-diluted transverse-field Ising model — •Calvin Krämer, Max Hörmann, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik V, Staudtstraße 7, Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We study the transverse-field Ising model on a square lattice with bond- and site-dilution at $T = 0$ by quantum Monte Carlo simulations. By tuning the transverse field h and the dilution p, the phase diagram of both models is explored. Finite-size scaling of the order parameter and averaged Binder ratios is employed to determine the positions of critical points and the critical exponents β and ν along the critical lines and at the multi-critical point. Dynamical properties in the vicinity of the quantum critical point are analyzed through the local susceptibility. We complement these findings by stochastic analytical continuation [1] of imaginary-time Green's functions, providing momentum-resolved insights into the behavior of excitations. [1] Anders W. Sandvik, Phys. Rev. B 57, 10287

TT 37.39 Wed 15:00 P4

Typical medium theory for disordered electronic systems on simple lattices with Cauchy distribution of on-site potentials — Andreas Ostlin[1], Hanna Terletska[2], Dylan Jones[1], and •Liviu Chioncel[1,3] — [1]Institute of Physics, University of Augsburg, Augsburg, Germany — [2]Middle Tennessee State University, Murfreesboro, Tennessee, USA — [3]ACIT, University of Augsburg, Augsburg, Germany

Effective medium approaches using single-site averaging procedures of various kinds contributed substantially in understanding the density of states of electronically disordered systems in models and materials. The nature and the conditions for appearance of single-particle (Anderson) localization seems to be qualitatively understood, yet discussions concerning special applied methods and quantitative results for the critical conditions are still ongoing. Here we present results using the typical medium theory for the one-particle and two-particle Green's function (conductivities) for the special case of Cauchy-distribution.

TT 37.40 Wed 15:00 P4

Excitations and Their Decay: Calculating the Non-Lorentzian Line Shape of Excited States at the Ti $L_{2,3}$ edge in $SrTiO_3$ — •Sarah L. Görlitz[1], Sina Shokri[1], Widad Louafi[2], Martin Brass[1,3], Marc Merstorf[1], Jonas Hoecht[1], Michelangelo Tagliavini[1], Kevin Ackermann[1], and Maurits W. Haverkort[1] — [1]Institut for Theoretical Physics, Heidelberg University, 69120 Heidelberg — [2]Laboratory of Theoretical Physics, Faculty of Exact Sciences, University of Bejaia, 06000 Bejaia, Algeria — [3]Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria

Understanding electron dynamics in real materials following photon excitations is a challenging task. Ultrafast pump-probe and multi-color experiments require precise control, while strong electron correlations in excited states complicate the theoretical description. Accurate calculations must reproduce absorption line shapes for single-photon absorption, often non-Lorentzian due to multi-channel decay processes.

In this work, we calculate the line shape of Ti 2p $\rightarrow$ 3d core excitations in $SrTiO_3$. While crystal-field models predict seven delta-function peaks, the real spectrum reveals distinct line widths and non-Lorentzian line shapes. Incorporating Auger-Meitner decay, fluorescence decay, and coupling to the valence-conduction bath continuum, we establish a framework to explain these broadenings. This approach is critical for predicting higher-order response functions, essential for modeling resonant inelastic X-ray scattering (RIXS) and ultrafast spectroscopies, providing insights into the interplay of decay processes and electron dynamics.

TT 37.41 Wed 15:00 P4

Role of interlayer coupling and anisotropy in 1T-TaS_2 studied by ellipsometry — •Achyut Tiwari[1], Renjith M. Roy[1], Christian Prange[1], Yuan Yan[2], Bruno Gompf[1], and Martin Dressel[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]School of Physics, Nankai University, Tianjin, 300071 China

The layered transition metal dichalcogenide 1T-TaS_2 has attracted considerable attention due to its rich electronic phase diagram, characterized by multiple charge density wave (CDW) phases. With decreasing temperature, the material transitions from a metallic incommensurate phase to a metallic nearly commensurate phase and finally to an insulating commensurate phase featuring the star-of-David lattice distortion. The metal-insulator transition (MIT) is a first-order phase transition that exhibits hysteresis during cooling and heating, with an additional intermediate phase in the 215 K-280 K range upon heating. Here, temperature-dependent ellipsometry revealed pronounced anisotropy between in-plane and out-of-plane responses, attributable to significant interlayer interactions. The temperature-dependent out-of-plane dielectric constant exhibited marked changes across the MIT, highlighting the role of interlayer coupling. Furthermore, the effective medium approximation confirmed the existence of the intermediate phase during heating, providing a microscopic description. These findings underscore the importance of interlayer coupling in layered materials and elucidate on the previously unexplored intermediate phase of 1T-TaS_2.

TT 37.42 Wed 15:00 P4

The Interplay Between Diagonal and Off-Diagonal Electron-Phonon Coupling in two-dimensional systems — •jadson lucas portela e silva[1,2], gabriel rein[2], sebastião a. s. júnior[1], willdauany c. f. da silva[1], fakher f. assaad[2], and natanael c. costa[1] — [1]instituto de física universidade federal do rio de janeiro, rio de janeiro, brasil — [2]institut für theoretische physik und astrophysik, universität würzburg, würzburg, germany

The interplay between diagonal and off-diagonal electron-phonon coupling in two-dimensional systems is explored using the Holstein-Su-Schrieffer-Heeger (HSSH) model through non-perturbative Monte Carlo simulations on a square lattice at half-filling. Electron-phonon coupling is crucial in determining exotic phases like charge-density waves (CDW), valence bond solids (VBS), and superconductivity. The HSSH model uniquely combines features of the Holstein and SSH models, where the former modulates the on-site potential energy, and the latter modifies the electron's kinetic energy through lattice displacements. The study constructs phase diagrams by analyzing charge-charge, bond-bond, and pairing correlation functions. Key findings include a competition between CDW and VBS phases, similar to one-dimensional systems. However, unlike the 1D case, no metallic phase is observed between these states, likely due to perfect nesting and van Hove singularities in the density of states, which destabilize the Fermi liquid state. Further exploration beyond half-filling shows that melting of CDW and VBS phases leads to superconductivity.

TT 37.43 Wed 15:00 P4

Picosecond periodic oscillation modulated by Higgs amplitude mode in a superconductor-metal hybrid metasurface — •Siyu Duan[1,2], Jingbo Wu[1], Caihong Zhang[1], Kebin Fan[1], Biaobing Jin[1], and Zhe Wang[2] — [1]School of Electronic Science and Engineering, Nanjing University, Nanjing, China — [2]Department of Physics, TU Dortmund University, Dortmund, Germany

We report on a time-resolved terahertz spectroscopic study of a superconductor-metal hybrid metasurface that is fabricated by introducing superconducting microbridges into metallic resonators. By exploiting the nonlinear response of the superconducting NbN microbridges to a multicycle narrowband terahertz excitation pulse, we observe a picosecond periodic oscillation of terahertz transmission spectra. This oscillation contains components of the fundamental frequency of the narrowband excitation pulse and its second harmonic, which we ascribe tentatively to an excited Higgs mode oscillation. Furthermore, we can modulate the amplitude and duration of periodic oscillations by changing the field strength of the terahertz excitation pulse and the sample temperature.

TT 37.44 Wed 15:00 P4

Density Functional Theory-based Multiplet Ligand Field Theory Calculations of Ultrafast Pump-Probe Electron Dynamics in Correlated Materials — •Ruth Kaiser, Sina Shokri, and Maurits W. Haverkort — Heidelberg University, Institute for Theoretical Physics, Philosophenweg 19, 69120 Heidelberg, Germany

Ultrafast pump-probe spectroscopy allows one to study and steer quantum materials on their fundamental time-scales. In correlated molecules and solids a theoretical understanding is challenging and quantitative predictions how coherently driven excitations decohere is highly non-trivial. We have developed a recipe for quantitatively predicting pump-probe spectra, starting with a Hamiltonian on a basis of local Wannier orbitals derived from density-functional calculations, describing the charge-transfer in the system and, on top of that, we include the full local Coulomb repulsion [1]. Using non-linear response theory, we then calculate the time-resolved spectra, such as photo-emission spectroscopy, x-ray absorption spectroscopy and resonant inelastic x-ray scattering, which captures the pump-probe dynamics. Our routine can be used for different types of correlated materials, such as Mott-Hubbard and Charge-Transfer insulators as well as molecules [2, 3]. Furthermore, we show examples where we implemented our method for real materials like NiO and SF_6 and compare our results with experiments.

[1] PRB 85, 165113 (2012);
[2] PRL 128, 153001 (2022);
[3] PRA 108, 032816 (2023).

TT 37.45 Wed 15:00 P4

Understanding Resonant Inelastic X-ray Spectroscopy Using Dynamical Mean-Field Theory and Model Hamiltonians — •Lukas Hellmann, Aleksandrs Zacinskis, Sina Shokri, Michelangelo Tagliavini, Kevin Ackermann, and Maurits W. Haverkort — Universität Heidelberg, Institut für Theoretische Physik, Philosophenweg 19, Heidelberg 69120 Germany

Using model Hamiltonians with local Coulomb interactions, we demonstrate how resonant inelastic X-ray scattering spectra (RIXS) can be interpreted within the framework of the dynamical mean-field approximation. Our approach incorporates both valence correlations and core-valence Coulomb repulsion, enabling a detailed examination of spectral features across the metal-insulator transition. The calculated RIXS spectra reveal two distinct types of excitations: (1) locally excited excitons exhibiting a resonant enhancement at constant energy loss, and (2) a fluorescence regime characterized by resonant intensity enhancement at constant emitted energy. We analyze the transition in intensity between these two excitation regimes and discuss its implications for understanding electronic dynamics. All calculations are performed directly on the real frequency axis using the software package Quanty (www.quanty.org). This methodology not only provides accurate predictions for RIXS spectra but also offers a versatile framework for studying the dynamics of other correlated systems.

TT 37.46 Wed 15:00 P4

Material Specific Real Frequency LDA+DMFT Calculations of Transition Metals — •Johann Collard, Michelangelo Tagliavini, Kevin Ackermann, Sina Shokri, Aleksanders Zacinskis, Lukas Hellmann, and Maurits W. Haverkort — Institute for Theoretical Physics, Heidelberg University, Philosophenweg 19, 69120, Heidelberg, Germany

3d transition metals exhibit a wide range of intriguing properties. At the same time their accurate theoretical description is challenging task due to the presence of correlated electrons in their open d-shells. Abinitio approaches, such as LDA+DMFT (Local Density Approximation + Dynamical Mean-Field Theory), have proven successful in capturing many material-specific properties and electron correlation effects. Most existing DMFT algorithms rely on Quantum Monte Carlo simulations, which operate on imaginary frequencies. While effective for static property calculations, these methods require analytical continuation to compute spectral functions, a process that is ill-posed and thus computationally challenging. In this work, we demonstrate how real-frequency DMFT, as implemented in Quanty, can directly compute spectral functions within the LDA+DMFT framework for real materials. This approach avoids the complications of analytical continuation, providing a more straightforward and reliable means of exploring the spectral properties of 3d transition metals.

TT 37.47 Wed 15:00 P4

An Accessible Implementation and Detailed Test of Real-Frequency Dynamical Mean-Field Theory — •Aleksandrs Zacinskis, Sina Shokri, Kevin Ackermann, Michelangelo Tagliavini, and Maurits W. Haverkort — Heidelberg University, Institute for Theoretical Physics, Philosophenweg 19, 69120 Heidelberg, Germany

Dynamical Mean-Field Theory (DMFT) has become a powerful tool for studying materials with correlated electrons. However, most DMFT solvers operate on imaginary Matsubara frequencies, making the extraction of accurate spectral functions challenging due to the need for analytical continuation.

Here, we perform DMFT calculations using a real-frequency solver implemented in Quanty [1]. This implementation utilizes a one-particle basis of natural impurity orbitals [2] to investigate several correlated model systems with local interactions. We systematically examine critical metal-insulator transition interaction strengths and the chemical potential as a function of filling, comparing different bath discretization schemes and numerical cut-offs to manage Hilbert space size.

Our results demonstrate robust and satisfactory convergence at moderate computational costs, validating the reliability of this approach. All calculations were performed using the open-source quantum many-body code *Quanty* (www.quanty.org), emphasizing its accessibility for broader applications in correlated electron systems.

[1] Phys. Rev. B 85, 165113 (2012);
[2] Phys. Rev. B 90, 085102 (2014).

TT 37.48 Wed 15:00 P4

Engineering Correlated Electrons in Adatom Lattices on Semiconductors — •Tim Kullick[1], Niklas Enderlein[1], Henri Menke[1,2], Giorgio Sangiovanni[3], and Philipp Hansmann[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Max Planck Institute for Solid State Research, Stuttgart — [3]Julius-Maximilian-Universität of Würzburg

Adatom lattices on (111) surfaces of zinc-blende structured semiconductors have proven to be versatile, experimentally realizable platforms for hosting flat bands with strong electronic correlations near the Fermi energy. A recent study [1] revealed transition metals on 3C-SiC(111) surfaces to be intriguing adatom systems, showcasing the diverse nature of strongly correlated systems. Together with earlier theoretical and experimental studies on adatom lattices on the Si(111) surfaces, this recent work underlines the great potential of this material family. In the present project we explore other promising material candidates on SiC and other substrates that might realize (one-, two-, and three-band) Hubbard models at different fillings and a potential impact of spin-orbit coupling. Combined with estimates of the quasiparticle interaction via cRPA, we point out new material directions in this increasingly vivid field.

[1] H.Menke, N.Enderlein *et al.*, arXiv:2410.17165.

TT 37.49 Wed 15:00 P4

Calculating Moments for Many-Electrons Systems — •Elaheh Adibi and Erik Koch — Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

We present a combinatorial approach to calculate the M^{th} moment of an N-electron system, defined as $\langle E^M \rangle = \mathrm{Tr}\, H^M$. Working in the basis of Slater determinants $|\boldsymbol{\alpha}\rangle = \prod c^\dagger_{\alpha_i}|0\rangle$, matrix elements $\langle \boldsymbol{\alpha}|H^M|\boldsymbol{\alpha}\rangle$ may only be non-zero for terms where the orbital indices of the creation operators in H^M are permutations of the orbital indices of the annihilators. The trace for a given permutation can then be evaluated combinatorially, without having to deal with the many-body Hilbert space explicitly. Since all permutations related by cyclic rotations give the same contribution, we classify them into groups and evaluate the trace only for a single group member. For the special case of all orbitals in the permutation being different, the calculation simplifies further, as in this irreducible case all permutations written in terms of cycles with a given number of descents give the same contribution to the moment. Relating the groups of permutations for the irreducible and the reducible terms allows us to efficiently evaluate the moments.

TT 37.50 Wed 15:00 P4

Exact t^1_{2g} Superexchange Hamiltonians for Complex Orbital Ordering — •Amit Chauhan, Xue-Jing Zhang, and Eva Pavarini — Peter Grünberg Institute, Forschungszentrum Jülich, 52425 Jülich, Germany

We derive exact superexchange interactions for t^1_{2g} systems with spin-orbit coupling. To this end we extend the formalism developed in [1], which we have successfully used in [2,3] to study the origin of orbital ordering. As first application we consider the case of cubic and tetragonal lattices and study the stability of complex orbital ordering in the presence of spin-orbit interaction and crystal-field splitting.

[1] X.-J.Zhang, E.Koch, E.Pavarini, Phys.Rev. B **105**, 115104 (2022);
[2] X.-J.Zhang, E.Koch, E.Pavarini, Phys.Rev. B **102**, 035113 (2020);
[3] X.-J.Zhang, E. Koch, E.Pavarini, Phys.Rev. B **106**, 115110 (2022).

TT 37.51 Wed 15:00 P4

Scaling and convergence behaviour of linked-cluster expansions — •Harald Leiser, Max Hörmann, and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We derive effective block-diagonal Hamiltonians $H_{\text{eff}} = T^\dagger H T$ using the projective-cluster additive transformation (PCAT) [1]. Numerical linked-cluster expansions (NLCEs) are employed to study the (anti)ferromagnetic transverse-field Ising model (TFIM) on diverse lattice geometries such as chains and various ladders. By calculating energy gaps, we compare the scaling behavior with other methods such as deepCUT [2]. A key challenge arises from the presence of avoided-level crossings (ALCs) [3] which complicates convergence. To probe this issue, we analyze ALCs in the simplified setting of the XXZ model on a chain. A key property of PCAT is the cluster additivity of both H_{eff} and the generator $S = \log(T)$. This allows transforming larger systems via a cluster expansion in S. Using S from clusters up to size N, we compute $\exp(-S)H\exp(S)$ in the thermodynamic limit and compare it with standard NLCE and CUT methods [4]. Notably, S for local clusters generates higher-order terms, mitigating some scaling challenges in traditional cluster expansions.

[1] M. Hörmann et al., SciPost Phys. 15 (2023) 097.
[2] H. Krull et al., Phys. Rev. B 86.
[3] K. Coester et al., EPL, 110(2):20006.
[4] C. Knetter et al., EPJ B 13:209.

TT 37.52 Wed 15:00 P4

Computing Excited States in Quantum Many-Body Clusters with Neural Network Support — •Max Kroesbergen[1], Louis Thirion[1], Gianluca Levi[3], Pavlo Bilous[2], Paul Fadler[1], Yorick Schmerwitz[3,4], Elvar Ö. Jónsson[3], Hannes Jónsson[3], and Philipp Hansmann[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Max Planck Institute for the Science of Light, Erlangen — [3]University of Iceland, Reykjavik — [4]Max Planck Institute for Coal Research, Mühlheim

In this study, we used SOLAX [1], our newly developed Python library for configuration interaction (CI) calculations of fermionic quantum systems, to compute the energies of ground and excited states for various quantum clusters. SOLAX can leverage the power of a neural network (NN) classifier to perform selective CI which mitigates the exponential growth of the many-body Hilbert space. Our benchmarks indicate a significant boost in computational efficiency while maintaining high accuracy. We validate our method for the (discrete) Single Impurity Anderson Model [2] as well as molecular systems, such as N_2 and H_2 [3]. For the latter, we study the dissociation curves of ground- and excited states and their dependence on the underlying single-particle basis, including Hartree-Fock orbitals optimized for excited states. Additionally, SOLAX enables us to simulate spectral functions defined by a transition operator, providing deeper insights into the excitation dynamics of these systems.

[1] L. Thirion, P. Hansmann, P. Bilous, arXiv:2408.16915v1.
[2] P. Bilous *et al.*, arXiv:2406.00151.
[3] Y. L. A. Schmerwitz *et al.*, arXiv:2406.08154.

TT 37.53 Wed 15:00 P4

Using the Anderson Impurity Model to Look for Particles Beyond the Standard Model — •Vera Butz and Maurits W. Haverkort — Universität Heidelberg, Institut für theoretische Physik, Philosophenweg 19, 69120 Heidelberg

High-precision comparisons between experimental measurements and numerical simulations [1] not only test the accuracy of computational methods but also offer deeper insights into fundamental physics. In this work, we investigate the interaction of charged ions with multiple electrons and continuum states, presenting a generalized Anderson impurity model. The continuum states considered include photons, free electrons, or as-yet-unobserved particles, such as axions. These interactions can be described through the self-energy or hybridization function [2]. The real part of the self-energy induces energy shifts in atomic multiplets, such as the Lamb shift, while the imaginary part results in finite lifetimes for excited states, leading to phenomena like fluorescence or Auger-Meitner decay. When applied to highly charged heavy ions, whether in laboratory settings or astrophysical environments such as the Sun, these enhanced electron-photon (or other particle) interactions provide a platform to probe the Standard Model. Additionally, they may reveal evidence of new physics, including the potential detection of axions, a leading dark matter candidate that could also address the strong CP problem.

[1] Nat. Phys. 20, 921 (2024).
[2] arXiv:2307.13812v1.

TT 37.54 Wed 15:00 P4

Properties of the Density Matrix for Metavalent Materials — •Niklas Penner[1,2], Lucia Reining[1], Matteo Gatti[1], and Matthias Wuttig[2] — [1]ETSF, LSI, CNRS, CEA/DRF/IRAMIS, Ecole Polytechnique, Institut Polytechnique de Paris, France — [2]I. Institute of Physics (IA), RWTH Aachen University, Germany

In the experimental investigation of phase change materials and their unique properties, peculiarities in the bonding character were determined. A corresponding classification of these metavalent materials has so far been carried out on the basis of shared and transferred electrons. The corresponding values were determined using density functional theory (DFT) calculations. Density functional theory has become one of the most universal methods in condensed matter physics and material science to determine and investigate properties of materials. The longer-term goal of the present work is to investigate to which extent the spatial extension of the density matrix is characteristic for metavalent materials, and whether numerical calculations based on the Kohn-Sham formulation of density functional theory can capture this aspect.

TT 37.55 Wed 15:00 P4

Traces of powers of many-body Hamiltonians — •Marcus Kollar — Theoretische Physik III, University of Augsburg

The high-temperature expansion of the partition function for a many-body system of fermions or bosons involves Fock space traces of powers of the Hamiltonian. Here we use algebraic means to evaluate such moments for a fixed number of non-interacting particles with arbitrary discrete spectrum and express them as polynomials of power sums of the single-particle energies. In the fermionic case our expressions agree with those obtained by combinatorial considerations [1]. We discuss possible applications and generalizations of our results.

[1] E. Adibi and E. Koch, Verhandl. DPG, Berlin TT 80.44 (2024).

TT 37.56 Wed 15:00 P4

Ising model on a sphere — •Grigorios Makris[1], Fabian Hassler[2], Stefan Wessel[1], and Ion Cosma Fulga[3,4] — [1]Institute for Theoretical Solid State Physics, RWTH Aachen University, Germany — [2]Institute for Quantum Information, RWTH Aachen University, Germany — [3]Institute for Theoretical Solid State Physics, IFW Dresden, Germany — [4]Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany

The study of the Ising models is of primary interest in the theory of phase transitions. The models have been extensively studied in flat space and analytical solutions exist in two dimensions. Their scaling behavior is known to substantial precision and confirms the theory of finite-size scaling.

Here, we study Ising models on the surface of a sphere. As it is generally not possible to place a regular lattice on a sphere, for arbitrary number of points, we implement the Fibonacci lattice. The lattice is tested to have a reasonably uniform distribution of points. In order to establish the expected $SO(3)$ symmetry, we first solve the free-particle problem as a tight-binding model and then utilize the hopping coefficients as interaction terms on the Ising model. This is shown to yield better, approximate, $SO(3)$ degeneracies on the low energy levels of the transverse-field Ising model. Having set up the Hamiltonian, we further investigate the critical point of the expected phase transition.

TT 37.57 Wed 15:00 P4

Two site entanglement in the two dimensional Hubbard model — Anna Kauch[1], •Gergo Roosz[2], Frederic Bippus[1], Daniel Wieser[1], Fakher Assaad[3,4], and Karsten Held[1] — [1]Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria — [2]HUN-REN Wigner RCP, Budapest — [3]Universitat Wurzburg, 97074 Wurzburg, Germany — [4]Wurzburg-Dresden Cluster of Excellence ct.qmat, Am Hubland, 97074 Wurzburg, Germany

We calculate the reduced density matrix of two sites in the two-dimensional Hubbard model using the D Gamma A method. We calculate the density matrix by calculating the expectation value of a complete set of hermitian operators in the subspace of the two sites. We can express these eigenvalues with the one- and two-particle Greens functions, and the imaginary time derivatives of these functions. The derivatives are calculated in Matsubara representation. To test convergence we compare our results for the second Renyi entropy with quantum Monte Carlo data. To investigate the entanglement and correlations of the Hubbard model we calculate the mutual information and the entanglement negativity between the two sites.

TT 37.58 Wed 15:00 P4

Thouless time in a spin-$1/2$ XX ladder — •Kadir Çeven[1], Lukas Peinemann[1], Rohit Patil[2], Marcos Rigol[2], and Fabian Heidrich-Meisner[1] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, Göttingen, Germany — [2]Department of Physics, Pennsylvania State University, University Park, USA

The eigenstate thermalization hypothesis (ETH) offers a powerful framework for understanding many properties of thermalization dynamics in non-equilibrium quantum many-body systems. Here, determining the time scales associated with thermalization is a key focus in the research of nonequilibrium dynamics of such systems. In this study, we investigate a spin-1/2 XX ladder, an experimentally realizable model exhibiting diffusive dynamics, to explore the connections among ETH, transport properties, and measures purely based on its energy spectrum. Specifically, we analyze the spectral form factor and the smooth spectral function, each of which provides a characteristic relaxation time scale potentially linked to the Thouless time–the longest relaxation time defined in terms of the diffusion constant. Using various numerical methods, we compare the time scales obtained from these different measures to identify potential discrepancies and similarities.

We acknowledge funding from the Deutsche Forschungsgemeinschaft (German Research Foundation) within the Research Unit FOR5522 (Project No. 499180199).

TT 37.59 Wed 15:00 P4

Nonequilibrium Phenomena in Strongly Correlated Systems under Structured Fields — •Sajad Mirmohammadi and Jamal Berakdar — Martin-Luther-Universität Halle-Wittenberg Karl-Freiherr-von-Fritsch-Str. 3 06120 Halle/Saale

Strongly correlated systems provide a rich platform for exploring quantum phenomena and understanding nonequilibrium many-body dynamics. A central challenge lies in unraveling the interplay of various interactions that govern the emergence of exotic quantum states. Here, we investigate how phase- and polarization-structured electromagnetic fields interact with strongly correlated materials modeled by the extended Peierls Hubbard Hamiltonian. Using exact diagonalization with the Lanczos algorithm, we demonstrate how structured fields imprint their characteristics onto excitation dynamics, including charge and spin density waves.

TT 37.60 Wed 15:00 P4

Application of the TraSPI Method to Aharonov-Bohm Interferometry with Interacting Quantum Dots — •Alexander Hahn, Jürgen König, and Alfred Hucht — Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany

Utilizing the *Transfer-matrix Summation of Path Integrals* (TraSPI) approach, we extend the method's application to the study of quantum transport in an Aharonov-Bohm interferometer housing two parallel quantum dots. Here the usage of TraSPI allows the calculation of the current influenced by the enclosed magnetic flux, in presence of Coulomb interaction. The numerical accuracy and efficiency of the TraSPI method allow for a detailed exploration of the interplay between quantum coherence and dot interactions.

TT 37.61 Wed 15:00 P4

Metastability in Correlated Electron Systems — •Lara Bremer[1], Martin Eckstein[1], Hugo Strand[2], and Tim Wehling[1] — [1]I. Institute of Theoretical Physics, University of Hamburg, Notkestraße 9-11, 22607 Hamburg, Germany — [2]School of Science and Technology, Örebro University, SE-701 82 Örebro, Sweden

The objective of this study is to describe metastable states in correlated electron systems, with a particular focus on numerically accessing unstable solutions within coexistence regions of first-order phase transitions. Our work is based on the well-established phenomenon observed in the Mott transition of the single-orbital Hubbard model, where a coexistence region between a metallic phase and an insulating phase, accompanied by a third unstable solution, has been demonstrated within the framework of Dynamical Mean Field Theory. A Phase Space Extension algorithm is employed to effectively identify and analyse these solutions. By accessing this unstable solution, the double occupancy on this branch can be calculated, thus enabling the Landau free energy to be calculated via a thermodynamic route, as opposed to fitting a Landau free energy functional.

TT 37.62 Wed 15:00 P4

Simulating nonequilibrium systems in the steady-state: GW+EDMFT — •Fabian Künzel — University of Hamburg, 20355 Hamburg, Germany

The Keldysh formalism for nonequilibrium Green's functions provides a versatile theoretical framework for analyzing the dynamics and structure of correlated many-body systems. To address the intrinsic cubic scaling of computational time in the Kadanoff-Baym equations (KBE) for nonequilibrium Green's functions, a truncation of the underlying memory kernel can be incorporated into the time-stepping algorithm of the NESSi simulation package. This reduces the computational cost to linear scaling with respect to the maximum simulation time. For systems where long-time dynamics extend beyond the capabilities of state-of-the-art methods, the KBE can be formulated within the Keldysh steady-state formalism. The resulting equations are then solved using a Fourier transform, enabling the description of systems with exponentially separated timescales. We aim to introduce new methods that extend the reach of the existing NESSi package and present a steady-state study of a Mott insulator, incorporating nonlocal correlations through a steady-state GW+EDMFT formalism.

TT 38: Superconducting Electronics: SQUIDs, Qubits, Circuit QED I

Time: Wednesday 16:45–18:30 Location: H32

TT 38.1 Wed 16:45 H32

Microwave characterization of planar Josephson junction arrays — •Alexander Kirchner[1], Johanna Berger[1], Simon Feyrer[1], Narges Momeni[1], Matthias Kronseder[1], Michael Prager[1], Dieter Schuh[1], Dominique Bougeard[1], Nicola Paradiso[1], Christoph Strunk[1], and Leandro Tosi[2,1] — [1]Institut für Experimentelle und Angewandte Physik, University of Regensburg, 93040 Regensburg, Germany — [2]Centro Atómico Bariloche and Insitituto Balseiro, CNEA, CONICET, San Charlos de Bariloche, Río Negro 8400, Argentina

We present microwave characterization measurements of Josephson junction arrays (JJAs) based on a proximitized Al-InAs quantum well heterostructure. JJAs can be used to achieve high inductances, suitable for the implementation of quantum circuits. They also provide an excellent test-bed for studying the microscopic excitations of hybrid superconductor-semiconductor devices associated to the presence of Andreev states. By probing the low-energy plasmon modes of these devices, we have been able to derive the Josephson inductance and to demonstrate its tunability in out-of-plane magnetic field, following the Fraunhofer diffraction pattern of planar Josephson junctions. Furthermore, the temperature dependence of the inductance provides information about the induced superconducting gap in the two-dimensional electron gas.

TT 38.2 Wed 17:00 H32

Niobium-trilayer based Dimer Josephson Junction Array Amplifiers — •Bhoomika R Bhat, Asen L Georgiev, Fabian Kaap, Victor Gaydamachenko, Christoph Kissling, Judith Felgner, Mark Bieler, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Qubit readout and other quantum technologies using microwave signals at low powers of a few fW benefit from amplification with the least possible added noise. Josephson parametric amplifiers are a well-established class of devices meeting this condition. We design a Dimer Josephson Junction Array Amplifier (DJJAA) [1], which has several pairs of modes, so-called dimers, in the 4 GHz to 12 GHz range. In principle, each of these dimers can be used to achieve non-degenerate amplification using the four-wave mixing regime. Our devices, consisting of arrays with 600-1200 dc-SQUIDs, are fabricated in Nb/Al-AlOx/Nb trilayer technology. We present finite element simulations of our design as well as the fabrication process and the first experimental results of our devices.

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

TT 38.3 Wed 17:15 H32

Towards a traveling-wave parametric amplifier with two-octave bandwidth — •Christoph Kissling, Victor Gaydamachenko, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Traveling-Wave Parametric Amplifiers (TWPAs) are among the leading technologies for amplifying weak microwave signals. They provide a gain of 15-20 dB over a bandwidth of more than 1 GHz while keeping the added noise close to the quantum limit. Although TWPAs are widely used in quantum computing, certain applications in fields like radio astronomy require amplifiers with broader bandwidth, ranging from e.g. 4 to 12 GHz. In this work, we present a TWPA consisting of ca. 2400 rf-SQUIDs, which operates in the three-wave mixing regime and achieves a 3-dB bandwidth of 3.6 to 8.3 GHz. Our device provides a gain of 20 dB and has a saturation power of around -90 dBm. By incorporating this TWPA as the first amplifier in our readout chain, we attain a total system noise of 2-3 photons across the entire bandwidth. Finally, we discuss strategies to extend the bandwidth to two octaves and improve the flatness of the gain profile.

TT 38.4 Wed 17:30 H32

Mitigating phase velocity mismatch in flux-pumped Josephson traveling wave parametric amplifiers — •Daniil Bazulin[1,2], Lars Aaron Anhalt[1,2], Kevin Kiener[1,2], Matthias Grammer[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Matthias Althammer[1,2], Stephan Geprägs[1,2], Stefan Filipp[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Josephson traveling wave parametric amplifiers (JTWPAs) play a key role in enabling fast readout of multiple qubits in scalable superconducting quantum processors. These amplifiers utilize wave-mixing processes in extended nonlinear media, to achieve broadband amplification with noise performance close to the standard quantum limit. Flux-pumped JTWPAs, employing the SNAIL-based nonlinear media, are particularly interesting due to their potential to eliminate the problem of pump depletion and mitigate upconversion losses. However, these devices exhibit a phase velocity mismatch between pump and signal modes, which suppresses a maximum achievable amplification gain. This issue can be addressed by using materials with high dielectric constant or kinetic inductance, like $SrTiO_3$ and NbTiN, respectively. Here, we present our progress in millikelvin characterization of these materials and their prospects in the flux-pumped JTWPAs.

TT 38.5 Wed 17:45 H32

Towards superconducting quantum-accurate arbitrary waveform generators for microwave frequencies — •Michael Haas, Abdulrahman Widaa, Oliver Kieler, Shekhar Priyadarshi, Marco Kraus, Ralf Behr, Johannes Kohlmann, and Mark Bieler — Physikalisch Technische Bundesanstalt, Braunschweig, Germany

The Josephson Arbitrary Waveform Synthesizer (JAWS) consists of an array of Josephson Junctions being driven by electrical pulses to produce quantum-accurate output signals with high spectral purity and low noise [1]. It has been subject of research for many years and is well established at output frequencies in the kHz and low MHz range. However, the extension to GHz frequencies, which could prove to be very important for quantum applications and metrology, has just recently started [2, 3]. This effort requires completely new circuit designs. Moreover, at high frequencies part of the input signal is fed through to the output signal and it is essential to accurately determine and minimize this so-called feedthrough error. We will present the status of the GHz-JAWS development at PTB, including new approaches to circuit design and feedthrough reduction.

[1] O. Kieler, Encyclopedia of Condensed Matter Physics, 2e 1 Oxford: Elsevier (2024). DOI: 10.1016/B978-0-323-90800-9.00001-9
[2] C. Donnelly et al., IEEE Trans. Appl. Supercond. 30 (2020). DOI: 10.1109/TASC.2019.2932342
[3] A. Babenko et al., IEEE Trans. Appl. Supercond. 32 (2022). DOI: 10.1109/TASC.2022.3201188

TT 38.6 Wed 18:00 H32

Characterization of stacked Josephson junction arrays for the Josephson Arbitrary Waveform Synthesizer with integrated on-chip power dividers — •Omar M. Aladdin[1], Oliver Kieler[1], Abdulrahman Widaa[1], Hannes Preissler[1], Erasmus Wolf[2], Marco Schubert[2], Johannes Kohlmann[1], and Mark Bieler[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Supracon AG, An der Lehmgrube 11, 07751 Jena, Germany

The Josephson Arbitrary Waveform Synthesizer (JAWS) is based on pulse-driven Josephson junction (JJ) arrays and provides precisely controlled, spectrally pure quantum-based AC voltages with low noise and no drift. Being widely used at National Metrology Institutes, increasing the output voltage of JAWS might significantly expand its application range. In this contribution, we describe our current efforts towards reaching JAWS output voltage of 1 V RMS. We are improving the existing on-chip RF power dividers enabling up to 8 parallel JJ arrays to operate simultaneously per chip with sufficient operation margins. Additionally, we are increasing the number of active junctions by means of fabricating of up to 5-stacked SNS-type JJ with Nb_xSi_{1-x} as barrier material. The target is to integrate about 50 000 to 60 000 JJ per chip. The circuit layout with integrated on-chip power dividers, the fabrication technology and first measurement results will be presented at the conference.

TT 38.7 Wed 18:15 H32

High-temperature superconducting Josephson junctions for optical neuromorphic computing — •Elena Vinnemeier[1], Sebastian Schaper[1], Malik Ayachi[2], Vincent Humbert[2], Javier Villegas[2], and Ursula Wurstbauer[1] — [1]Institute of Physics, University of Münster, Münster, Germany — [2]Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, Palaiseau, France

Josephson Junctions (JJ) offer a promising platform for neuromorphic computing, owing to their inherent ability to emulate key neuronal behaviours such as spiking and bursting. When coupled with high-temperature superconductors and reconfigurable interconnects, these junctions present a viable alternative to traditional CMOS-based approaches, providing a low-power solution that is both faster and more efficient. The integration of high-temperature superconductors into the JJs enhances energy efficiency while exploiting their sensitivity to external stimuli. The currently missing integrated memory element is addressed by replacing passive interconnections with active links, which can be tuned by external stimuli. Our goal is to achieve optical modulation of the critical current I_C through light irradiation. To explore this capability, we characterize semiconducting materials from the transition metal dichalcogenide (TMDCs) family in combination with superconducting JJs using Raman spectroscopy and photoluminescence (PL), contrasting their properties as a function of environmental conditions.

This project was supported by the EIC pathfinder grant No. 101130224 'JOSEPHINE'.

TT 39: Twisted Materials / Systems (joint session TT/HL)

Time: Wednesday 17:00–18:30 Location: H31

TT 39.1 Wed 17:00 H31

Formation, persistence and ordering of local moments in magic angle twisted bilayer graphene — •Lorenzo Crippa[1,2], Gautam Rai[1], Dumitru Călugăru[3,13], Haoyu Hu[4], Luca de' Medici[5], Antoine Georges[6,7,8,9], Bogdan Andrei Bernevig[3,4,10], Roser Valentí[11], Giorgio Sangiovanni[2], and Tim Wehling[1,12] — [1]University of Hamburg — [2]University of Würzburg — [3]Princeton University — [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 University Frankfurt — [12]Hamburg CUI — [13]University of Oxford

The physics of magic angle twisted bilayer graphene (MATBLG) is remarkably diverse across a wide range of dopings and temperatures.

By means of a Dynamical Mean-Field Theory (DMFT) approach, we study the effect of electronic correlations in MATBLG, with particular focus on the physics of local spin and valley isospin moments. We analyze their magnitude and screening across a broad temperature range, discuss the limits of very low and infinite temperature, and obtain two different scales for their formation (around 100 K) and ordering (around 10 K).

We discuss their implications in terms of transport properties of the system (e.g. resistivity) and of spectral features (resonance peaks) and contextualize our findings with recent experimental results.

TT 39.2 Wed 17:15 H31

Nematic versus Kekulé phases in twisted bilayer graphene under hydrostatic pressure — Miguel Sánchez Sánchez[1], Israel Díaz[1], José González[2], and •Tobias Stauber[1] — [1]Instituto de Ciencia de Materiales de Madrid, CSIC — [2]Instituto de Ciencia de Materiales, CSIC

We address the precise determination of the phase diagram of magic angle twisted bilayer graphene under hydrostatic pressure within a self-consistent Hartree-Fock method in real space, including all the remote bands of the system. We further present a novel algorithm that maps the full real-space density matrix to a 4x4 density matrix based on a SU(4) symmetry of sublattice and valley degrees of freedom. We find a quantum critical point between a nematic and a Kekulé phase, and show also that our microscopic approach displays a strong particle-hole asymmetry in the weak coupling regime. We arrive then at the prediction that the superconductivity should be Ising-like in the hole-doped nematic regime, with spin-valley locking, and spin-triplet in the electron-doped regime [1].

[1] M. Sánchez Sánchez, I. Díaz, J. González, T. Stauber, Phys. Rev. Lett. (in press), arXiv:2403.03140.

TT 39.3 Wed 17:30 H31

Quantum diffusion in sheared bilayer graphene — •Taher Rhouma[1], Florie Mesple[2], Vincent Renard[3], and Guy Trambly de Laissardière[1] — [1]LPTM, CY Cergy Paris Univ., CNRS, Cergy-Pontoise, France. — [2]Dept. Physics, Univ. of Washington, USA — [3]CEA, Univ. Grenoble Alpes, IRIG, PHELIQS, Grenoble, France

The identification of correlated insulators and superconductivity in magic-angle twisted bilayer graphene (MATBG) has sparked significant interest in its electronic properties [1]. When examining the MATBG moiré patterns along the line with alternating regions of AA, AB, and BA, we observe striking similarities to those found in a 1D moiré of a sheared bilayer graphene, where one layer is laterally displaced. That may lead to a localization of the electronic states [2]. In this study, we investigate numerically the electronic and quantum transport properties in sheared bilayer graphene, focusing on how the degree of shear influences these characteristics.

[1] Y. Cao, et al., Nature **556**, 43 (2018); Nature **556**, 80 (2018).
[2] J. Gonzalez, Phys. Rev. B **94**, 165401 (2016).

TT 39.4 Wed 17:45 H31

Ab-initio fRG study on tWSe$_2$ — •Hannes Braun — Max Planck Institut für Festkörperforschung — Technische Universität München

The recent experimental reports on superconductivity in twisted WSe$_2$ have served to justify the already considerable interest in twisted TMD systems. From a theoretical standpoint, there have been numerous attempts to describe these systems. To study the phase diagram and analyse the governing physics, we employ the functional renormalisation group method. This approach allows us to gain an unbiased understanding of the interplay between fluctuations leading to symmetry-broken phases. To develop a model capable of describing the material, we integrate *ab-initio* results as initial conditions. In this talk, we present method developments for a more efficient momentum integration and results on the interplay between magnet and pairing instabilities.

TT 39.5 Wed 18:00 H31

Mott transitions and doping asymmetry in twisted bilayer WSe$_2$ — •Siheon Ryee[1], Lennart Klebl[2,1], Valentin Crépel[3], Ammon Fischer[4], Lede Xian[5,6], Angel Rubio[6,3], Dante Kennes[4,6], Andrew Millis[3,7], Antoine Georges[8,3], Roser Valentí[9], and Tim Wehling[1] — [1]University of Hamburg, Hamburg, Germany — [2]University of Würzburg, Würzburg, Germany — [3]Flatiron Institute, New York, USA — [4]RWTH Aachen University, Aachen, Germany — [5]Tsientang Institute for Advanced Study, Zhejiang, China — [6]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [7]Columbia University, New York, USA — [8]Collège de France, Paris, France — [9]Goethe Universität Frankfurt, Frankfurt am Main, Germany

The recent discovery of superconductivity in twisted bilayer WSe$_2$ (tWSe$_2$) at two distinct twist angles (3.65 deg and 5 deg) along with previous reports of metal-insulator transitions, spin density wave states, and fractional Chern insulators raises deep questions in correlated electron physics. We present results of a dynamical mean-field theory-based investigation of a model that faithfully captures the band structure and topology of twisted transition metal dichalcogenides as functions of twist angle and displacement field. We find good agreement with several key aspects of the experimental data. Focusing further on the twist angle of 3.65 deg, we discuss the nature of the electric-field-induced metal-insulator transition, the experimentally observed coherence temperature, and the origin of the observed doping asymmetry in resistivity.

TT 39.6 Wed 18:15 H31

Twisted bilayer MoS$_2$ under electric fields: A system with tunable symmetry — •Aitor Garcia-Ruiz[1,2] and Ming-Hao Liu[1] — [1]National Cheng Kung University, Tainan, Taiwan — [2]National Graphene Institute, University of Manchester, Manchester, United Kingdom

Gate voltages take full advantage of two-dimensional systems, making it possible to explore novel states of matter by controlling their electron concentration or applying perpendicular electric fields. Here, we study the electronic properties of small-angle twisted bilayer MoS$_2$ under a strong electric field. We show that the transport across one of its constituent layers can be effectively regarded as a two-dimensional electron gas under a nanoscale potential. We find that the band structure of such system reconstructs following two fundamentally different symmetries depending on the orientation of the external electric field, namely, hexagonal or honeycomb. By studying this system under magnetic fields, we demonstrate that this duality not only translates into two different transport responses, but also results in having two different Hofstadter's spectra. Our work opens up a new route for the creation of controllable artificial superlattices in van der Waals heterostructures.

TT 40: Spin Transport and Orbitronics, Spin-Hall Effects II (joint session MA/TT)

Time: Wednesday 17:30–19:00 Location: H19

TT 40.1 Wed 17:30 H19

Orbital torques and orbital pumping in two-dimensional rare-earth dichalcogenides — •Mahmoud Zeer[1,2,3], Dongwook Go[3], Mathias Kläui[3,4], Wulf Wulfhekel[5], Stefan Blügel[1], and Yuriy Yuriy Mokrousov[1,3] — [1]Peter Gr *unberg Institute, Forschungszentrum J *ulich, 52425 J *ulich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, German — [3]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany — [4]Centre for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, 7491 Trondheim, Norway — [5]5Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

The design of spin-orbit torque (SOT) properties in two-dimensional (2D) materials represents a key challenge in modern spintronics. We now explore ferromagnetic Janus H-phase monolayers of 4f-Eu rare-earth dichalcogenides EuSP, EuSSe, and EuSCl using first-principles calculations. Our findings reveal that these compounds exhibit substantial SOT, primarily driven by the colossal current-induced orbital response of Eu f-electrons. Additionally, the resulting orbital torques can generate strong in-plane currents of orbital angular momentum with non-trivial orbital polarization directions. These results establish f-based 2D materials as a highly promising platform for in-plane orbital pumping and SOT applications, positioning f-based 2D materials as a promising platform for next-generation orbitronic and spintronic technologies with 2D materials.

TT 40.2 Wed 17:45 H19

Orbital Topology of Chiral Crystals for Orbitronics — •Ying-Jiun Chen[1], Kenta Hagiwara[1,2], Dongwook Go[3], Xin Liang Tan[1,2], Sergii Grytsiuk[1], Kui-Hon Ou Yang[4], Guo-Jiun Shu[5], Jing Chien[4], Yi-Hsin Shen[4], Xiang-Lin Huang[5], Iulia Cojocariu[1], Vitaliy Feyer[1,2], Minn-Tsong Lin[4,6], Stefan Blügel[1], Claus Michael Schneider[1,2], Yuriy Mokrousov[1,3], and Christian Tusche[1,2] — [1]Forschungszentrum Jülich — [2]University of Duisburg-Essen — [3]Johannes Gutenberg University Mainz — [4]National Taiwan University, Taiwan — [5]National Taipei University of Technology, Taiwan — [6]Academia Sinica, Taiwan

Chirality is ubiquitous in nature and manifests in a wide range of phenomena including chemical reactions, biological processes, and quantum transport of electrons. In quantum materials, the chirality of fermions, given by the relative directions between the electron spin and momentum, is connected to the band topology of electronic states. Here, we show that in structurally chiral materials like CoSi, the orbital angular momentum (OAM) serves as the main driver of a nontrivial band topology in this new class of unconventional topological semimetals, even when spin-orbit coupling is negligible. A nontrivial orbital-momentum locking of multifold chiral fermions in the bulk leads to a pronounced OAM texture of the helicoid Fermi arcs at the surface. Our findings highlight the pivotal role of the orbital degree of freedom for the chirality and topology of electron states, in general, and pave the way towards the application of topological chiral semimetals in orbitronic devices.

TT 40.3 Wed 18:00 H19

Vectorial flow of the Berry curvature and its relation to the transport and band structure — •Jaroslav Hamrle[1,2], Ondřej Stejskal[1], Milan Vrána[2,1], and Martin Veis[2] — [1]Czech Technical University, Prague, Czechia — [2]Charles University, Prague, Czechia

Berry curvature expresses the curvature of the reciprocal space, in a similar manner as magnetic field express curvature of the real space, resulting in a curved transport of electrons in solids. Therefore, Berry curvature is a base of various lossless transport phenomena such as anomalous Hall effect, anomalous Nerst effect, orbital magnetization or electric polarization. Here, in model materials bcc Fe and Fe_3Ga, we demonstrate details of the vectorial flow of the Berry curvature (monopole source, 1-dimensional flow, 2-dimensional flow), and its relations to the band structure, orbital magnetization as well as anomalous Hall and Nerst effects.

[1] O. Stejskal, M. Veis, J. Hamrle, Sci Rep **12**, 97 (2022) [doi: 10.1038/s41598-021-04076-z]

[2] O. Stejskal, M. Veis, J. Hamrle, Phys. Rev. Materials **7**, 084403 (2023) [doi:10.1103/PhysRevMaterials.7.084403]

TT 40.4 Wed 18:15 H19

Finite-temperature transport properties of magnetic/non-magnetic alloys: trends in the longitudinal and in the transverse charge and spin currents — •Alberto Marmodoro[1], Yang Wang[2], Yuqing Lin[3], and Ilja Turek[4] — [1]Institute of Physics (FZU), Czech Academy of Sciences, Prague, Czech Republic — [2]Pittsburgh Supercomputer Center (PSC), Carnegie Mellon University, Pittsburgh, USA — [3]Mellon College of Science, Carnegie Mellon University, Pittsburgh, USA — [4]Institute of Physics of Materials, Czech Academy of Sciences, Brno, Czech Republic

Alloys composed of magnetic and non-magnetic metals exhibit non-trivial transport trends as a function of composition and temperature. The stoichiometry controls not only the Curie point, but also the slope of resistivity vs. temperature. Beside affecting longitudinal currents, this has further implications also for transverse charge and spin currents, i.e. on anomalous Hall effects [1]. We report first-principles results based on density functional theory (DFT), relativistic linear response and Green function methods based on the multiple scattering Korringa-Kohn-Rostoker (KKR) or linear muffin tin orbitals (LMTO) frameworks.

[1] "Large anomalous Hall angle in the Fe(60),Al(40) alloy induced by substitutional atomic disorder" by J.Kudrnovsky et al. PRB 101, 054437 (2020); "Exploiting Spin Fluctuations for Enhanced Pure Spin Current" by P.Wu et al. PRL 128, 227203 (2022); "Critical enhancement of the spin Hall effect by spin fluctuations" by S.Okamoto et al. Quantum Materials 29, 9 (2024).

TT 40.5 Wed 18:30 H19

Impact of the substrate on angular momentum transport between separated ferromagnets — •Fiona Sosa Barth[1,2], Matthias Grammer[1,2], Richard Schlitz[3], Tobias Wimmer[1,2], Janine Gückelhorn[1,2], Luis Flacke[1,2], Sebastian T.B. Goennenwein[3], Rudolf Gross[1,2,4], Hans Huebl[1,2,4], Akashdeep Kamra[5], and Matthias Althammer[1,2] — [1]Walther-Meißner-Institut, BAdW, Garching, Germany — [2]School of Natural Sciences, TUM, Garching, Germany — [3]Department of Physics, University of Konstanz, Konstanz, Germany — [4]Munich Center for Quantum Science and Technology, München, Germany — [5]RPTU Kaiserslautern-Landau, Kaiserslautern, Germany

Spintronics relies on the transfer of angular momentum between electrons and solid state excitations such as magnons and phonons. In our recent work, we demonstrate angular momentum transfer between two ferromagnetic strips on diamagnetic substrates [1] by converting a DC current at one of the electrodes to a non-equilibrium magnon accumulation. Due to dipolar and potentially phononic coupling, angular momentum is transferred to the magnonic system of the second FM electrode and measured by the inverse processes. In this work, we investigate the substrate influence on the angular momentum transport by comparing our results for SiOx and SiN layers on Si substrates. As a next step, we investigate substrate-supported strips versus freestanding strings to separate phononic contributions from dipolar coupling.
[1] R. Schlitz et al., Phys. Rev. Lett. 132, 256701 (2024)

TT 40.6 Wed 18:45 H19

Orbital Edelstein contribution to the spin-charge conversion in Germanium Telluride — •Sergio Leiva-Montecinos[1], Libor Vojáek[2], Jing Li[2], Mairbeck Chshiev[2], Ingrid Mertig[1], and Annika Johansson[3] — [1]Martin Luther University Halle-Wittenberg, Halle (Saale), Germany — [2]Université. Grenoble Alpes, CEA, CNRS, SPINTEC, Grenoble, France — [3]Max Planck Institute of Microstructure Physics, Halle (Saale), Germany

The Edelstein effect (EE) is a promising mechanism for generating spin and orbital polarization from charge currents in systems without inversion symmetry. In ferroelectric materials, such as Germanium Telluride (GeTe), the combination of bulk Rashba splitting and voltage-controlled ferroelectric polarization provides a pathway for reversible spin-charge interconversion [1, 2].

In this work, we investigate current-induced spin and orbital magnetization in bulk GeTe using Wannier-based tight-binding models derived from DFT calculations and semiclassical Boltzmann theory.

Employing the modern theory of orbital magnetization (MTOM), we demonstrate that the orbital Edelstein effect (OEE) entirely dominates its spin counterpart (SEE). This difference is visualized through the spin and orbital textures at the Fermi surfaces, where the orbital moment surpasses the spin moment by one order of magnitude. Moreover, the OEE remains largely unaffected when we suppress the spin-orbit coupling, highlighting its distinct physical origin compared to the SEE.

[1] D. Di Sante *et al.*, Adv. Mater. **25**, 509 (2012).
[2] C. Rinaldi *et al.*, Nano Lett. **18**, 2751 (2018).

TT 41: Quantum-Critical Phenomena (joint session TT/DY)

Time: Thursday 9:30–12:45 Location: H31

TT 41.1 Thu 9:30 H31

Missing Spectral Weight in a Paramagnetic Heavy-Fermion System — •Debankit Priyadarshi[1], Jingwen Li[1], Chia-Jung Yang[1], Ulli Pohl[2], Oliver Stockert[3], Hilbert von Löhneyesen[4], Shovon Pal[5], Manfred Fiebig[1], and Johann Kroha[2,6] — [1]ETH Zurich, Switzerland. — [2]University of Bonn, Germany — [3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [4]Karlsruhe Institute of Technology, Germany — [5]NISER, HBNI, Jatni, India. — [6]University of St. Andrews, UK

Time-resolved terahertz spectroscopy (THz-TDS) has proven to be a powerful method to study the correlation dynamics in many-body systems, particularly heavy-fermions [1]. The competition between the Kondo screening effect and the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction in these materials drives a quantum phase transition (QPT) between a magnetically ordered and a liquid-like ground state of heavy Kondo quasiparticles. These quasiparticles disintegrate near a quantum critical point (QCP). Using THz-TDS, we report a suppression in the quasiparticle spectral weight in $CeCu_{6-x}Au_x$ on the antiferromagnetic side of the QPT at temperatures much higher than the Neel temperature, which has a different origin from the suppression at QCP [2]. We study the paramagnetic phase of $CeCu_{6-x}Au_x$ with $x = 0.2$, 0.3, and 0.5 samples, and show that the suppression results from a quantum frustration effect induced by the temperature-independent RKKY interaction, which may influence material properties at QCP.

[1] C. Wetli *et al.*, Nat. Phys. 14, 1103 (2018);
[2] J.Li *et al.*, arXiv:2408.07345 (2024).

TT 41.2 Thu 9:45 H31

Terahertz Crystal Electric Field Transitions in a Kondo-Lattice Antiferromagnet — •Payel Shee[1], Chia-Jung Yang[2], Shishir Kumar Pandey[3], Ashis Kumar Nandy[1], Ruta Kulkarni[4], Arumugam Thamizhavel[4], Manfred Fiebig[2], and Shovon Pal[1] — [1]NISER, HBNI, Jatni, India. — [2]ETH Zurich, Switzerland. — [3]Artificial Intelligence for Science Institute, Beijing, China. — [4]Tata Institute of Fundamental Research, Mumbai, India.

The interplay between the Kondo effect and Ruderman-Kittel-Kasuya-Yosida (RKKY) leads to the emergence of many intriguing phenomena in strongly correlated systems. Metallic materials doped with magnetic impurities are ideal for such studies. These impurities interact with the crystal electric field (CEF) produced by neighboring ions, lifting the degeneracy of their energy levels and creating CEF states. Given that CEF excitations occur in the millielectronvolt (meV) range, the terahertz (THz) frequency range is particularly suited for these investigations. Using time-domain THz reflection spectroscopy, we show the first direct evidence of two low-energy CEF transitions at 0.6 THz (2.5 meV) and 2.1 THz (8.7 meV) in $CeAg_2Ge_2$, a prototype Kondo-lattice antiferromagnet. In addition, we also observe that the lower CEF transition peak undergoes a blue-shift once the sample enters into the antiferromagnetic phase. The temporal spectral weights obtained directly from the THz time traces corroborate the corresponding CEF energy scales of the compound [2].

[1] S. Pal *et al.*, Phys. Rev. Lett. 122, 096401 (2019);
[2] P. Shee *et al.*, Phys. Rev. B 109, 075133 (2024).

TT 41.3 Thu 10:00 H31

Tuning a ferromagnetic quantum phase transition by interface engineering in artificial heterostructures — Robin Heumann[1], Robert Gruhl[1], Ludwig Scheuchenpflug[1], Leonard Schüler[2], Vasily Moshnyaga[2], and •Philipp Gegenwart[1] — [1]Lehrstuhl für Experimentalphysik VI, Universität Augsburg — [2]Erstes Physikalisches Institut, Georg-August-Universität-Göttingen

The substitution series $Sr_{1-x}Ca_xRuO_3$ between the itinerant ferromagnet $SrRuO_3$ (SRO) and the non-Fermi liquid paramagnetic metal $CaRuO_3$ (CRO) constitutes a broadly smeared quantum phase transition (QPT) between $x = 0.7$ and 1. To avoid the impact of structural disorder we explore the possibility of tuning ferromagnetism by confining SRO to thin layers placed in between those of CRO. Ordered epitaxial $[SRO_n/CRO_m]_K$ superlattices, with n ranging from 8 down to the monolayer limit, keeping $m/n = 2$ and 3 with $K = 32/n$, were grown on $SrTiO_3$ (100) substrates, characterized and investigated by electrical transport and Hall effect measurements. We observe stable ferromagnetism from SRO layers for $n \geq 3$ and fragile low-temperature ferromagnetism due to the SRO/CRO interfaces. The latter survives down to the monolayer limit $n = 1$, explaining the difficulty to cross a ferromagnetic QPT in $Sr_{1-x}Ca_xRuO_3$. We also find that the effective interface density $K/(n + m)$ is a new suitable control parameter and construct the T_C vs $K/(n + m)$ phase diagram.

TT 41.4 Thu 10:15 H31

Interplay of nematic fluctuations and transverse phonons near a nematic quantum critical point — •Morten H. Christensen[1], Michael Schütt[2], Avraham Klein[3], and Rafael M. Fernandes[4] — [1]Niels Bohr Institute, University of Copenhagen — [2]University of Minnesota — [3]Ariel University — [4]University of Illinois Urbana-Champaign

In an electronic fluid absent an atomic lattice, an electronic nematic transition can be described as a consequence of a Pomeranchuk instability of the Fermi surface with an associated critical nematic mode. As a coupling to an atomic lattice is introduced, the nematic transition is accompanied by a structural distortion of the lattice. Here, we study the fluctuation spectra near such a coupled nematic-structural transition driven primarily by the electronic nematic fluctuations. This requires coupling the nematic fluctuations to transverse phonons which implies that the transition is no longer accompanied by a critical nematic mode, but rather by the vanishing of the transverse phonon velocity along a certain direction. To understand how, e.g., superconductivity is affected by this, knowledge of the dynamic behaviour of the hybrid nematic/phonon soft excitation is crucial. The purpose of this presentation is to elucidate the properties of this mode. We find that the low-energy fluctuations are generally overdamped except near the soft lattice directions where they become underdamped. How the transition from overdamped to underdamped takes place depends on the proximity to the nematic quantum critical point.

TT 41.5 Thu 10:30 H31

Chiral Heisenberg Gross-Neveu-Yukawa criticality: Honeycomb vs. SLAC fermions — •Thomas C. Lang[1] and Andreas M. Läuchli[2,3] — [1]Institute for Theoretical Physics, University of Innsbruck, Austria — [2]Laboratory for Theoretical and Computational Physics, Paul Scherrer Institute, Switzerland — [3]Institute of Physics, École Polytechnique Féedérale de Lausanne, Switzerland

We perform large scale quantum Monte Carlo simulations of the Hubbard model at half filling with a single Dirac cone close to the critical point, which separates a Dirac semi-metal from an antiferromagnetically ordered phase where SU(2) spin rotational symmetry is spontaneously broken. We discuss the implementation of a single Dirac cone in the SLAC formulation for eight Dirac components and the influence of dynamically induced long-range super-exchange interactions. The finite size behavior of dimensionless ratios and the finite size scaling properties of the Hubbard model with a single Dirac cone are shown to be superior compared to the honeycomb lattice. We extract the critical exponents believed to belong to the chiral Heisenberg Gross-Neveu-Yukawa universality class which coincide for the two lattice types once honeycomb lattices of sufficient linear dimension are considered.

TT 41.6 Thu 10:45 H31

Fractionalized multicriticality in Kitaev spin-orbital liquids — •Max Fornoville[1,2] and Lukas Janssen[3] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

Two-dimensional spin-orbital magnets with Kitaev-like exchange frustration realize spin-orbital liquid ground states that are characterized by the appearance of gapless Majorana fermions and a static $\mathbb{Z}_2$ gauge field. It has been shown that the introduction of an antiferromagnetic Heisenberg interaction between nearest-neighbor spin degrees of freedom facilitates a transition towards a partially ordered spin-orbital liquid state with a spontaneously broken spin-rotation symmetry. The associated quantum critical point belongs to the fractionalized fermionic Gross-Neveu-SO(3)* universality class and only partially gaps out the fermionic spectrum. Here, we consider an enlarged theory space, introducing an anisotropic XXZ interaction in the spin sector. The explicit breakdown of spin-rotation symmetry allows for two types of antiferromagnetic order, depending on the nature of the anisotropy. By means of Majorana mean-field theory and ε-expansion to leading order, we uncover the phase diagram of the model and characterize its multicritical behavior. Additionally, we present evidence for the appearance of a symmetry-enhanced first-order transition between the two ordered phases.

15 min. break

TT 41.7 Thu 11:15 H31

One-loop perturbative structure of a (2+1)D bosonized non-Fermi liquid — •Parasar R. Thulasiram[1,2], Chris Hooley[3], and Roderich Moessner[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [3]Centre for Fluid and Complex Systems, Coventry University, Coventry, United Kingdom

Non-Fermi liquids are a class of metals with no quasiparticle excitations often arising from the interaction of slow collective modes, such as an emergent critical boson, with a Fermi surface. Minimal models of this type are called Hertz-Millis-Moriya models and historically suffer from uncontrolled approximations in perturbation theory and patchy treatments of the Fermi surface, preventing the study of global-Fermi surface physics. Delacrétaz et al. (2022) recast Fermi liquid theory in any dimension via a bosonic field that parametrizes macroscopic particle-hole excitations about the whole Fermi surface. This bosonized field theory is suggested to reduce the order in perturbation theory necessary to calculate important quantities and is considerate of whole Fermi surface fluctuations, potentially providing the first robust results of a Hertz-Millis-Moriya theory when coupled to a critical boson. We present initial results of the one-loop critical boson self-energy in 2+1D for calculating the dynamical critical exponent and discuss the benefits and challenges of this theory.

TT 41.8 Thu 11:30 H31

Exotic quantum criticality in Luttinger semimetals — •David Moser and Lukas Janssen — TU 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, fixed-point annihilation scenarios, and large-N aspects. 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 41.9 Thu 11:45 H31

Examination of the antiferromagnetic superradiant intermediate phase and the effects of geometrical frustration in the Dicke-Ising model — •Jonas Leibig, Anja Langheld, Andreas Schellenberger, and Kai Phillip Schmidt — Chair for Theoretical Physics V, FAU Erlangen-Nürnberg, Germany

We map the Dicke-Ising model to a self-consistent matter Hamiltonian in the thermodynamic limit [1, 2] and solve it using a variety of methods, including exact diagonalization, perturbative and numerical linked-cluster expansions, and density matrix renormalization group. In one dimension, we explore the intermediate phase in the antiferromagnetic model and the multi-critical point in the ferromagnetic model, comparing our results with complementary quantum Monte Carlo simulations [2]. Additionally, we investigate the antiferromagnetic model on the frustrated geometry of the sawtooth chain. We employ high-order series expansions in the strong coupling limit, where the mapping to the self-consistent matter Hamiltonian is definitively valid. Independently, we analyze in greater detail whether the mapping also holds in the specific regime emerging from the frustrated Ising limit induced by an infinitesimal light-matter perturbation.

[1] K. Lenk, J. Li, P. Werner, M. Eckstein, arXiv:2205.05559;
[2] A. Langheld, M. Hörmann, K. P. Schmidt, arXiv:2409.15082.

TT 41.10 Thu 12:00 H31

Critical behavior of the 1d superconductor in the FLEX approximation — •Šimon Kos[1], Sunil D'Souza[1], Jan Gebel[1], Ján Minár[1], and Václav Janiš[2] — [1]University of West Bohemia, Univerzitní 8, CZ-301 00 Plzeň, Czech Republic — [2]Institute of Physics, The Czech Academy of Sciences, Na Slovance 2, CZ-18200 Praha 8, Czech Republic

The dynamical quantum fluctuations below the lower critical dimension push the superconducting critical point to zero temperature. We study the quantum critical behavior of the 1d superconductor with one-particle self-consistency provided by the FLEX approximation within the canonical Baym-Kadanoff scheme. We use the non-interacting singlet electron-electron bubble in the two-particle vertex of the Schwinger-Dyson equation, allowing for a qualitatively correct and tractable treatment of the low-energy critical behavior compatible with the Mermin-Wagner theorem. We use a polar approximation to transform the convolutive Schwinger-Dyson equation into an algebraic one that can be solved semi-analytically. We confirm the position of the critical point and assess the low-temperature behavior of the Hubbard model with attractive interaction.

TT 41.11 Thu 12:15 H31

Tunable criticality and pseudo-criticality in a quantum dissipative spin system — •Manuel Weber — Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

The study of competing orders in two-dimensional quantum magnets was strongly motivated by the prediction of non-Landau quantum phase transitions, but often we found symmetry-enhanced first-order transitions or pseudocriticality with a logarithmic drift of critical exponents. Here we present results for a (0+1) dimensional spin-boson model where all of these phenomena occur due to a fixed-point annihilation within the critical manifold. Our recently-developed wormhole quantum Monte Carlo method for retarded interactions allows us to study the critical properties of this model with unprecedented precision. We find a tunable transition between two ordered phases that can be continuous or first-order, and even becomes weakly first-order in an extended regime close to the fixed-point collision. We provide direct numerical evidence for pseudo-critical scaling on both sides of the collision manifesting in an extremely slow drift of critical exponents. We also find scaling behavior at the symmetry-enhanced first-order transition as described by a discontinuity fixed point. Our study motivates future work in higher-dimensional quantum dissipative spin systems.

TT 41.12 Thu 12:30 H31

Universality of the quantum Heisenberg model with sub-volume long-range couplings — •Daniel Resch and Thomas C. Lang — Institute for Theoretical Physics, University of Innsbruck, Austria

We investigate the critical properties of effective spin models which emerge from low energy band structures, or momentum space patches of strongly interacting fermions. As representative worst case scenario we present quantum Monte Carlo simulations of phase transitions in the major-axis coupled, long-range quantum Heisenberg model in two spatial dimensions at finite and zero temperature. We quantify the effects of sub-volume anisotropic long range spin-coupling with power-law form $1/r^{\alpha}$ on the critical exponents of the transitions where SU(2) spin symmetry is spontaneously broken for at low, finite temperatures in accordance with the Mermin Wagner Hohenberg theorem. Performing finite-size scaling analyses for different α we determine the extent of the regimes where the (quantum) phase transitions are represented by Gaussian fixed point, short-range Wilson-Fisher, or continuously varying long-range non-Gaussian critical exponents.

TT 42: Superconductivity: Tunneling and Josephson Junctions

Time: Thursday 9:30–13:15 Location: H32

TT 42.1 Thu 9:30 H32

Extraction of the Density of States and the Gap Function on a Temperature Smearing Scale from the Tunneling Conductance Data — •Lucia Gelenekyová and František Herman — Comenius University in Bratislava

The aim of our work is to extract the density of states (DOS) and the gap function from the tunneling conductance data at higher temperatures. It is known that if the temperature approaches zero, the DOS function is proportional to the tunneling conductance, and therefore, it can be easily extracted. However, with increasing temperature, the temperature smearing causes that this approximation can no longer be used. Thus, we have developed an algorithm that was designed to extract the details of the DOS function and the gap function on a typical temperature scale, which can be used approximately up to 1/2 of T_c. Moreover, knowledge of the DOS in its normal state plays an important role. Hence, we present the results of the testing data sets and also the outcome from experimentally measured tunneling conductance data of the NbN superconductor.

This work has been supported by the Slovak Research and Development Agency under the Contract no. APVV-23-0515, by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478.

TT 42.2 Thu 9:45 H32

Superconductivity of α-Gallium Probed on the Atomic Scale by Normal and Josephson Tunneling — Corinna Fohn[1], David Wander[1], Danilo Nikolic[2,3], Stéphanie Garaudée[1], Hervé Courtois[1], Wolfgang Belzig[3], Claude Chapelier[4], Vincent Renard[4], and •Clemens B. Winkelmann[1,4] — [1]Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, F-38000 Grenoble, France — [2]Institut für Physik, Universität Greifswald, Felix-Hausdorff-Strasse 6, D-17489 Greifswald, Germany — [3]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [4]Université Grenoble Alpes, CEA, Grenoble INP, IRIG/DEPHY/PHELIQS, F-38000 Grenoble, France

We investigate superconducting gallium in its α phase using scanning tunneling microscopy and spectroscopy at temperatures down to about 100 mK. High-resolution tunneling spectroscopies using both superconducting and normal tips show that superconducting α-Ga is accurately described by Bardeen-Cooper-Schrieffer theory, with a gap $\Delta_{\rm Ga} = 163$ μeV on the $\alpha-$Ga(112) facet, with highly homogeneous spectra over the surface, including atomic defects and step edges. Using a superconducting Pb tip, we furthermore study the low-bias conductance features of the Josephson junction formed between tip and sample. The features are accurately described by dynamical Coulomb blockade theory, highlighting $\alpha-$Ga as a possible platform for surface science studies of mesoscopic superconductivity.

TT 42.3 Thu 10:00 H32

Current Phase Relation of HgTe Nanowire Josephson Junctions in an Axial Magnetic Field — •Niklas Hüttner[1], Wolfgang Himmler[1], Ralf Fischer[1], Dmitriy Kozlov[1], Michael Barth[2], Jacob Fuchs[2], Andreas Costa[2], Klaus Richter[2], Leandro Tosi[1], Nicola Paradiso[1], Dieter Weiss[1], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg — [2]Institute for Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany

Proximitized semiconductor nanowires are expected to show Anomalous Josephson effect by spin-orbit interaction and Zeeman effect in a magnetic field parallel to the wire direction [1]. The φ_0 shift is accompanied by a direction dependent critical current (Superconducting diode effect).[1] We directly probe the current phase relation (CPR) of HgTe nanowires proximitized by niobium leads via an asymmetric SQUID measurement. The topological surface states additionally pick up an Aharanov Bohm phase for $B_{\parallel}$ in wire direction [2]. We observe an highly tunable φ_0 shift, a 0-π transition, and a superconducting diode effect from the corresponding CPRs. Additionally a strong modulation of both the critical current and the content of higher harmonics is observed for magnetic flux between 0 and $1.5\Phi_0$.

[1] T. Yokoyama et al., Phys. Rev. B 89, 195407 (2014).
[2] W. Himmler et al., Phys. Rev. Res. 5, 043021 (2023).

TT 42.4 Thu 10:15 H32

Theory of Josephson Scanning Tunneling Microscopy with s-Wave Tip on a Cuprate Surface — •Peayush Kumar Choubey[1] and Peter Hirschfeld[2] — [1]Indian Institute of Technology Roorkee, Roorkee 247667, Uttarakhand, India — [2]University of Florida, Gainesville, Florida 32611, USA

The Josephson scanning tunneling microscopy (JSTM) is a direct local probe of superconducting gap order parameter (SCOP). JSTM studies have been largely limited to the cases where superconducting sample and superconducting tip, both, have the same gap symmetry- either s-wave or d-wave. It has been generally assumed that in an s-to-d SJTS study of cuprates the critical current would vanish everywhere owing to the orthogonality of tip and sample SCOPs. We show here that this is not the case. Using first-principles Wannier functions for $Bi_2Sr_2CaCu_2O_8$, we develop a scheme to compute Josephson critical current (I_c) measured by a JSTM setup employing an s-wave tip with sub-angstrom resolution. We show that I_c remains finite everywhere in the unit cell except along Cu-Cu directions, changes sign under four-fold rotation, and attains largest magnitude above O sites, which can be regarded as a hallmark of the d-wave gap symmetry. Further, we find that I_c is suppressed near a strong scatterer like Zn and modulations in I_c around an impurity occur at wavevectors distinct from quasi-particle interference (QPI). Our work provides a theoretical foundation for probing unconventional superconductivity using JSTM set-up with s-wave tip.

TT 42.5 Thu 10:30 H32

Optimal Parametric Control of Transport Across a Josephson Junction — •Hannah Victoria Kleine-Pollmann, Guido Homann, and Ludwig Mathey — Zentrum für Optische Quantentechnologien and Institut für Quantenphysik, *Universität Hamburg, 22761 Hamburg, Germany

We present optimal control strategies for the DC transport across a Josephson junction. Specifically, we consider a junction in which the Josephson coupling is driven parametrically, with either a bichromatic or a trichromatic driving protocol, and optimize the prefactor of the $1/\omega$ divergence of the imaginary part of the conductivity. We demonstrate that for an optimal bichromatic protocol an enhancement of 70 can be reached, and for an optimal trichromatic protocol an enhancement of 135. This is motivated by pump-probe experiments that have demonstrated light-enhanced superconductivity along the c-axis of underdoped YBCO, where the junction serves as a minimal model for the c-axis coupling of superconducting layers. Therefore, the significant enhancement of superconductivity that we show for multi-frequency protocols demonstrates that the advancement of pump-probe technology towards these strategies is highly desirable.

TT 42.6 Thu 10:45 H32

Gate-Controlled Superconductivity: Mechanisms, Parameters and Technological Potential — Leon Ruf, Jennifer Koch, Elke Scheer, and •Angelo Di Bernardo — University of Konstanz, Universitätsstraße 10, 78464 Konstanz

Over the past few years, several research groups have demonstrated the reversible control of the superconducting current flowing through a nanoscale-size constriction under the application of a gate voltage (V_G) - currently known as gate-controlled supercurrent (GCS) [1].

The numerous differences between fabrication protocols, device parameters and measurement setups adopted by these groups, however, have made it difficult to find universal features of the GCS effect.

In this talk, I will discuss the results of systematic studies carried by our group [2-4] that have allowed us to identify parameters that are key for the GCS observation and to achieve high reproducibility in the functioning of GCS devices [4]. In addition, I will review the progress that we have made towards the optimization of performance parameters that are important for the future development of technological applications based on the GCS.

[1] L. Ruf et al., Appl. Phys. Rev. **11**, 041314 (2024).
[2] L. Ruf et al., APL Mater. **11**, 091113 (2023).
[3] J. Koch et al., Nano Res. **17**, 6575 (2024).
[4] L. Ruf et al., ACS Nano **18**, 20600 (2024).

TT 42.7 Thu 11:00 H32

Gate-Controlled Supercurrents in Three-Terminal Devices Made on Industrial Grade SiO_2 and Al_2O_3 — •Leon Ruf, Jennifer Koch, Elke Scheer, and Angelo Di Bernardo — University of Konstanz, Universitätsstraße 10, 78457 Konstanz

Gate-controlled supercurrent (GCS) is a growing, highly debated field of research. It was found that in gated three-terminal devices made of Ti and Al the supercurrent could be modulated by the application of a gate voltage [1]. The authors attribute their observation to a direct electric field effect, which would pave the way for future CMOS compatible transistors. Contrary, other works reported about a leakage related effect: high-energy quasiparticle emission through vacuum [2], phonon-induced heating of the electronic system [3], out-of-equilibrium state induced by phonons and/or high energy electrons without sizeable heating [4]. Here we are studying the GCS in Nb and NbRe Dayem bridges on industrial grade SiO_2 and Al_2O_3. Our results reveal a strong correlation between the substrate material and the GCS parameters, such as suppression voltage and stability. Herby, SiO_2 and Al_2O_3 show major differences. Further, our results suggest that for both SiO_2 and Al_2O_3 the leakage current is mediated via defects giving rise to trap-assisted tunneling. We discuss our results in the light of the above-mentioned mechanism [1-4].

[1] De Simoni et al., Nat. Nanotechnol. **13**, 802 (2018);
[2] Alegria et al., Nat. Nanotechnol. **16**, 404 (2021);
[3] Ritter et al., Nat. Electron. **5**, 71 (2022);
[4] Basset et al., Phys. Rev. Rese. **3**, 043169 (2021).

15 min. break

TT 42.8 Thu 11:30 H32

Transport Measurements on Arrays of Four-Terminal Nb-Pt-Nb Josephson Junctions — •Justus Teller[1,2], Christian Schäfer[1,2], Benjamin Bennemann[1], Matvey Lyatti[1,2], Kristof Moors[1,2], Detlev Grützmacher[1,2], Roman-Pascal Riwar[1], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI-9, PGI-10, PGI-2), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany

Arrays of interconnected two-terminal Josephson junctions have been investigated since the 1980's. Usually, the array is realized as a square lattice with four two-terminal Josephson junctions connected in a square unit cell. Recently, Graziano et al. [1] showed that a multi-terminal Josephson junction can be described as a network of interconnected two-terminal Josephson junctions. Based on that concept, we present an array made of 30×30 four-terminal Nb-Pt-Nb Josephson junctions. The in-situ fabrication of large networks of Josephson junctions, using molecular beam epitaxy, is described. For this process, a periodically patterned shadow mask of Si_3N_4 has been developed. The physical concept of a multi-terminal Josephson junction array is introduced. Its theoretical explanation is based on a lattice of interconnected two-terminal Josephson junctions, each described as a resistively-capacitively-shunted junction. Critical current and resistance of the array show oscillations connected to its unit cell.

[1] G. V. Graziano et al., Phys. Rev. B 101, 054510 (2020).

TT 42.9 Thu 11:45 H32

Superconducting Atomic Contacts under Microwave Irradiation, Photon-Assisted Tunneling and Fractional Shapiro Steps — •Oliver Irtenkauf[1], Patrick Raif[1,2], Carlos Cuevas[1,3], and Elke Scheer[1] — [1]University of Konstanz, Germany — [2]University of Basel, Switzerland — [3]Universidad Autónoma de Madrid, Spain

We form an atomic contact from a mechanically controlled aluminum break junction and irradiate it with microwaves in its superconducting state [1]. In the dI/dV spectra, we observe the well-known structures caused by photon-assisted tunneling, which, in the case of tunnel contacts, are fully explained by the Tien-Gordon (TG) model [2]. However, for higher-order transport processes, the model requires extensions, as shown in simulations based on the TG model [3,4]. Shapiro steps, i.e., replicas of the supercurrent, reveal deviations from the theoretical predictions described in references [5,6]. Fractional Shapiro steps, which we observe in atomic contacts with high-transmission channels at high frequencies, differ from traditional Shapiro steps and represent a new phenomenon.

[1] P. Raif, Master Thesis, *Uni. Konstanz* (2024);
[2] P. K. Tien & J. P. Gordon, *PR* **129**, 647 (1963);
[3] P. E. Gregers-Hansen et al., *PRL* **31**, 524 (1973);
[4] J.C. Cuevas et al., *PRL* **88**, 157001 (2002);
[5] G. Falci, V. Bubanja & G. Schön, *Z. Phys.* **85**, 451 (1991);
[6] P. Kot et al., *PRB* **101**, 134507 (2020).

TT 42.10 Thu 12:00 H32

High-Frequency Irradiation of Single-Atom Josephson Junctions — •Martina Trahms[1,2], Bharti Mahendru[2], Clemens B. Winkelmann[1], and Katharina J. Franke[2] — [1]University Grenoble Alpes, LATEQS, 38042 Grenoble, France — [2]Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany

Understanding superconducting junctions on the atomic scale yields significant insights for the prospect of using superconducting circuits in future technological applications. Here, we investigate the influence of single magnetic adatoms (Mn) on the phase dynamics of current-biased Pb-Pb Josephson junctions in a scanning tunneling microscope (STM) in the presence of high-frequency (HF) irradiation that is applied via an antenna close to the junction. We observe Shapiro steps that indicate coherent absorption of the irradiation while at the same time phase diffusion is enhanced due to incoherent absorption. In the presence of a magnetic adatom, phase diffusion is more prominently enhanced compared to the pristine junction which indicates that the quantum spin of the magnetic impurity influences the coherence of the tunneling processes in the junction.

TT 42.11 Thu 12:15 H32

Amplification Schemes for Single Microwave Photons — •Lukas Danner[1,2], Hanna Zeller[2], Ciprian Padurariu[2], Joachim Ankerhold[2], and Björn Kubala[1,2] — [1]Institute for Quantum Technologies, German Aerospace Center (DLR), Ulm (Germany) — [2]Institute for Complex Quantum Systems and IQST, University of Ulm, Ulm (Germany)

The detection of single microwave photons plays a crucial role in a wide range of envisioned technological applications of quantum microwaves. However, this is challenging because of the large thermal background and the low energy of a single photon. Here, we investigate schemes to amplify single itinerant mircowave photons using Josephson photonics devices [1, 2]. These devices consist of a dc-voltage biased Josephson junction, connected in series with two microwave cavities. By tuning the dc voltage, various resonances can easily be accessed, such that e.g. a Cooper pair tunneling through the junction enables a coherent transfer between one excitation in the first cavity and n excitations in the second cavity. We show that a single photon pulse absorbed by the device effectively triggers the emission of multiple photons from the second cavity that can subsequently be detected. To study such processes theoretically, we use a recently developed formalism [3] to describe arbitrary traveling photon pulses interacting with a quantum system in a cascaded manner.

[1] Leppäkangas et al., Phys. Rev. A 97, 013855 (2018)
[2] Albert et al., Phys. Rev. X, 14, 011011 (2024)
[3] Kiilerich and Mølmer, Phys. Rev. Lett. 123, 123604 (2019)

TT 42.12 Thu 12:30 H32

Tunneling in Altermagnet/Superconductor/Altermagnet Junctions — •Marcel Polák[1], František Herman[1], Andreas Costa[2], and Jaroslav Fabian[2] — [1]Comenius University Bratislava, Slovakia — [2]University of Regensburg, Germany

Their unprecedented spectral characteristics—particularly their large local magnetic exchange splittings in momentum space without rising an overall net spin polarization—make altermagnets promising candidates for engineering strongly spin-polarized currents in superconducting heterostructures.

In this talk, we will focus on lateral altermagnet/superconductor/altermagnet junctions in the ballistic limit to theoretically explore the ramifications of their d-wave-like spin-split Fermi surfaces on superconducting transport. We will demonstrate that the subgap interplay of Andreev and quasiparticle tunnelings, and thereby the experimentally accessible tunneling conductance, is tunable through the absolute and relative orientations of the altermagnets' Fermi surfaces, recovering the two important limiting cases in which the altermagnets behave either rather like normal metals or ferromagnets. Finally, we will also investigate geometrical conductance oscillations at supergap voltages in the presence of resonant scattering and compare our results against the ferromagnetic junction counterpart.

This work has been supported by Contract no. APVV-23-0515, by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478 and by DFG Grants 314695032 (SFB 1277) and 454646522.

TT 42.13 Thu 12:45 H32

Chiral Interference Pattern in Tunneling Junctions and SQUIDs Made of Time-Reversal Invariant Weyl Superconductors — •Anastasiia Chyzhykova[1,2], Vira Shyta[1], Jeroen van den Brink[1], and Flavio Nogueira[1] — [1]Leibniz Institute for Solid State and Materials Research, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Technische Universität Dresden

In recent years a number of experiments have reported superconductivity in various Weyl semimetals. The low-energy electromagnetic response of Weyl semimetals is governed by the axion term in the action arising due to the chiral anomaly. A recent publication [1] demonstrated that the time-reversal invariant Weyl superconductors (SCs) exhibit a chiral Meissner state. In our work we explore the influence of the chiral Meissner state on the tunnel junctions and squids made of time-reversal invariant Weyl SCs. We derive a modified Fraunhofer interference pattern in such a junction and demonstrate how the presence of the axion term affects Josephson energy in asymmetric squids and Berry phase in charge qubits. The effect of the chiral Meissner state manifests as a temperature-dependent deficit flux, which provides a new tuning parameter compared to ordinary squids.

[1] V.Shyta, J.van den Brink, F.S.Nogueira, Phys.Rev.Res. 6, 013240 (2024).

TT 42.14 Thu 13:00 H32

Superconductor-Altermagnet Proximity Effect with Nonmagnetic Impurities — •Christian Wiedemann[1], Danilo Nikolić[2], Matthias Eschrig[2], and Wolfgang Belzig[1] — [1]Universität Konstanz, Konstanz, Germany — [2]Universität Greifswald, Greifswald, Germany

Altermagnetism is a novel magnetic phase with zero net magnetization and momentum-dependent (e.g. d-wave) spin-split Fermi surface which has been recently discovered [1]. Similarly to ferromagnets [2,3], when brought to the proximity of a superconductor (S) an altermagnet (AM) modifies the spectral properties of the former [4,5]. However, most works in the field of superconducting spintronics involving altermagnets have assumed the absence of impurities that are, however, typically unavoidable in experiments. In this talk, we address this question explicitly presenting a systematic analysis of the inverse proximity effect in an S/AM bilayer in the presence of nonmagnetic impurities. Utilizing the quasiclassical Green's function theory, we investigate the effect of impurities on observables, e.g., the self-consistently calculated order parameter and the density of states. We observe interesting phenomena such as the gapless superconductivity and an impurity-enhanced critical temperature.

[1] L. Šmejkal *et al.*, Phys. Rev. X **12**, 040501 (2022).
[2] A. I. Buzidn, Rev. Mod. Phys. **77**, 935 (2005).
[3] M. Eschrig, Rep. Prog. Phys. **78**, 104501 (2015).
[4] S. Chourasia *et al.*, arXiv:2403.10456.
[5] M. Wei *et al.*, Phys. Rev. B **109**, L201404 (2024).

TT 43: Correlated Electrons: Other Theoretical Topics

Time: Thursday 9:30–13:00 Location: H33

TT 43.1 Thu 9:30 H33

Fragility of local moments for singular hybridizations — •Max Fischer[1,2], Arianna Poli[3], Lorenzo Crippa[1,2], Sergio Ciuchi[3,4], Matthias Vojta[2,5], Alessandro Toschi[6], and Giorgio Sangiovanni[1,2] — [1]Universität Würzburg, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat — [3]Università dell'Aquila, Italy — [4]CNR, Italy — [5]TU Dresden, Germany — [6]TU Wien, Austria

Some transition-metal phtalocyanines on an Ag(001) surface show hybridizations for xz/yz-orbitals with sharp peaks superimposed on a rather constant z^2 contribution. These sharp peaks in the hybridization correspond to an Anderson impurity model with one impurity site hybridized with one bath site. Investigating only a constant hybridization this typically shows rich physics arising from the Kondo effect yielding local moments and screening of them at low temperatures. Expanding the constant hybridization by a peak at the Fermi level, the formation of the local moment is shifted to lower temperatures with increasing weight of the peak. With such a toy model we analyze the vanishing of the local moment at large weights of the peak. Here, we find the evolution from screening of the local moment to the formation of a singlet ground state for the two site AIM.

TT 43.2 Thu 9:45 H33

Inducing strong electronic correlation by charged impurities in weakly interacting two-dimensional electron system — Junho Bang[1], Byeongin Lee[1], João Augusto Sobral[2], Sayan Banerjee[2], Mathias Scheurer[2], •Jianfeng Ge[3], and Doohee Cho[1] — [1]Department of Physics, Yonsei University, Seoul 03722, Korea — [2]Institute for Theoretical Physics III, University of Stuttgart, 70550 Stuttgart, Germany — [3]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

When translational invariance is broken, e.g. in the presence of impurities, an ordered state can emerge where the electronic charge density modulates spatially. While conventional charge modulations are explained by weak-impurity scattering of Landau quasiparticles, strong correlations may drive the electrons to depart from the Fermi liquid behavior. Using scanning tunneling microscopy and spectroscopy, we switch the ionization state of individual surface impurities and discover a local phase transition induced by the impurity potential. A nanoscale charge-ordered phase, which breaks the symmetry of the underneath hosting lattice, spontaneously emerges from the otherwise uniform two-dimensional electron system. Further, the charge modulations appear with an anisotropy distinct from that of the Fermi surface, excluding any Fermi-surface-related interpretations for the ordered phase. While the exact origin of the solid-like electronic phase remains a mystery, our work demonstrates a microscopic approach for creating and manipulating strongly correlated electrons in two-dimensional systems even with weak intrinsic interactions.

TT 43.3 Thu 10:00 H33

Anomalous quantum oscillations from boson-mediated interband scattering — •Léo Mangeolle[1,2] and Johannes Knolle[1,2,3] — [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]Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom

Quantum oscillations (QO) in metals refer to the periodic variation of thermodynamic and transport properties as a function of inverse applied magnetic field. QO frequencies are normally associated with semi-classical trajectories of Fermi surface orbits but recent experiments challenge the canonical description. We develop a theory of composite frequency quantum oscillations (CFQO) in two-dimensional Fermi liquids with several Fermi surfaces and interband scattering mediated by a dynamical boson, e.g. phonons or spin fluctuations. Specifically, we show that CFQO arise from oscillations in the fermionic self-energy with anomalous frequency splitting and distinct strongly non-Lifshitz-Kosevich temperature dependencies. Our theory goes beyond the framework of semi-classical Fermi surface trajectories highlighting the role of many-body effects. We provide experimental predictions and discuss the effect of non-equilibrium boson occupation in driven systems.

TT 43.4 Thu 10:15 H33

Disentangling real space fluctuations: The diagnostics of metal-insulator transitions beyond single-particle spectral functions — •Michael Meixner[1], Marcel Krämer[1,2], Nils Wentzell[3], Pietro Bonetti[1,4], Sabine Andergassen[2], Alessandro Toschi[2], and Thomas Schäfer[1] — [1]Max-Planck-Insitut für Festkörperforschung, Stuttgart, Germany — [2]TU Wien, Vienna, Austria — [3]CCQ at Flatiron Institut, New York NY, USA — [4]Harvard University, Cabridge MA, USA

The destruction of metallicity due to the mutual Coulomb interaction of quasiparticles gives rise to fascinating phenomena of solid state physics such as the Mott metal-insulator transition and the pseudogap. A key observable characterizing their occurrences is the single-particle spectral function, determined by the fermionic self-energy. In this paper we investigate in detail how real space fluctuations constitute a self-energy that drives the Mott-Hubbard metal-insulator transition.

To this aim we first introduce a real space fluctuation diagnostics approach to the Hedin equation, which connects the fermion-boson coupling vertex λ to the self-energy Σ. Second, by using cellular dynamical mean-field theory calculations for λ we identify the leading physical processes responsible for the destruction of metallicity across the transition. Eventually, to pave the way for relating our findings to the pseudogap phenomenology, we discuss the influence of real space fluctuations on the momentum-dependence of correlations.

TT 43.5 Thu 10:30 H33

Numerical indications for two-channel physics in the lightly doped t-J model — •Pit Bermes[1,2], Lukas Homeier[1,2], Sebastian Paeckel[1,2], Annabelle Bohrdt[2,3], and Fabian Grusdt[1,2] — [1]Department of Physics, Arnold Sommerfeld Center of Theoretical Physics, University of Munich, Theresienstrasse 37, 80333 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstrasse 4, 80799 München, Germany — [3]University of Regensburg, Universitätsstr. 31, Regensburg D-93053, Germany

The infamous cuprate superconductors at low doping are effectively described by hole doped antiferromagnets. Due to strong correlations however, standard techniques fail to describe these materials and full understanding of the microscopic mechanism remains elusive. Here we analyze numerical simulations of the lightly doped t-J model in two dimensions and present indications for two effective scattering channels in the simulated pair spectrum. We employ a previously proposed effective model whose degrees of freedom are given by magnetic polarons and bipolarons and show that it qualitatively reproduces the two branches in the pair spectrum. In addition, we propose a scheme to experimentally measure these signatures. The understanding of the effective quasiparticles presents an important step to unravel the elusive phases of high Tc superconductors.

TT 43.6 Thu 10:45 H33

Interplay of local and non-local electronic correlations in the Hubbard model — •Maria Chatzieleftheriou[1], Silke Biermann[2], and Evgeny Stepanov[2] — [1]Goethe University Frankfurt, Germany — [2]Ecole Polytechnique, IP Paris, France

Strongly correlated electronic systems exhibit intriguing properties and highly complex phase diagrams, including metal-to-insulator transitions, magnetic/charge orderings and the field's holy grail: high temperature superconductivity. Their theoretical description is very challenging and various many-body methods have been developed to this direction. I will present results using state-of-the-art numerical techniques that allow for an accurate description of both strong local electronic correlations and spatial fluctuations. I will discuss the application of this approach on the study of the Hubbard model, relevant for a series of materials, where we have analyzed the interplay of Mott physics and magnetic fluctuations at half-filling. We have identified the Slater and Heisenberg regimes in the phase diagram, which are separated by a crossover region of competing spatial and local electronic correlations. This bridging of the two limits (the spin-fluctuation dominated Slater regime at weak coupling and the Mott insulator at strong-coupling) had been a key missing ingredient to our understanding of metal-insulator transitions in real materials. Lastly, I will present recently obtained results on the evolution of the system's magnetic and charge susceptibility as a function of doping.

TT 43.7 Thu 11:00 H33

Fracton and topological order in the XY checkerboard toric code — Max Vieweg and •Kai Phillip Schmidt — Frichdrich-Alexander Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany

Topological and fraction phases are of great importance in current research due to their fascinating physical properties like entangled ground states, exotic excitations with non-trivial particle statistics or restricted mobility as well as potential applications in quantum technologies. The 2D toric code is the most paradigmatic, simplest, and exactly solvable model displaying topological order, which has been proposed as quantum memory and is relevant for quantum error correction. Consequently, the toric code plays an important role in several domains of research covering condensed matter physics, quantum optics, and quantum information.

However, the toric code has so far not been linked to the field of fracton physics. Here we introduce the XY checkerboard toric code (XYTC) connecting for the first time topological and fracton order in two dimensions within the same model. The XYTC represents a generalization of the conventional toric code with two types of star operators and two anisotropic star sublattices forming a checkerboard lattice. The quantum phase diagram is deduced exactly by a duality transformation displaying topological and type-I fracton phases.

15 min. break

TT 43.8 Thu 11:30 H33

Deconfinement Phase Transitions in a nematic two dimensional XY model with Long-range couplings — •Luis Walther[1], Josef Willsher[1,2], and Johannes Knolle[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstraße 4, 80799 Munchen, Germany — [3]Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom

The Modified XY model is an illustrative example of the interplay between ferromagnetic and nematic couplings, hosting both vortex and half-vortex excitations. The model gives rise to an exotic second order phase transition driven by the deconfinement of vortices into half-vortices. This transition is in the universality class of the Ising model, displaying features of the 'Deconfined Criticality' scenario. We analyse the effect of long-range algebraically decaying couplings $\sim r^{-2-\sigma}$ on the model. Long-range couplings enrichen the phase diagram and influence the deconfinement phase transition. We find that the transition persists for long-range couplings decaying fast enough so that $\sigma > 2-\eta$ holds, where η is the the correlation function exponent of the short-range XY model. Our results are based on Landau Peierls type arguments as well as Renormalisation Group flow techniques. Long-range couplings appear in many experimental setups including 2D Rydberg simulators. Therefore we hope our work contributes to enable the experimental observation of the deconfinement phase transition present in the model.

TT 43.9 Thu 11:45 H33

Mapping out Localization Phases in Bond-Disordered XXZ Models — Adrian Braemer[1], •Javad Vahedi[2], and Martin Gärttner[2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Historically, the phenomenon of many-body localization (MBL) has been studied in spin systems subject to random, local magnetic fields. At strong disorder, the system is found to be localized, with the local integrals of motion (LIOMs) consisting of single spins. However, this is not the only type of MBL: in bond-disordered Heisenberg models, the LIOMs have been shown to involve pairs of spins.

In this talk, we show that the bond-disordered XXZ model also exhibits a single-spin localized phase at strong anisotropy and map out the transitions between these three phases. To this end, we generalize the notion of occupation distance introduced by Hopjan et al. [1] to different observables, enabling us to characterize all three phases.

[1] Phys. Rev. B 104, 235112 (2021).

TT 43.10 Thu 12:00 H33

Melting of Devil's Staircases in the Long-Range Dicke-Ising Model — •Jan Alexander Koziol and Kai Phillip Schmidt — Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstraße 7, 91058 Erlangen, Germany

We present ground-state phase diagrams of the antiferromagnetic long-range Ising model under a linear coupling to a single bosonic mode on the square and triangular lattice. In the limit of zero coupling the ground state magnetization forms a Devil's staircase structure of magnetization plateaux as a function of an applied longitudinal field in Ising direction. The linear coupling to a single bosonic mode melts this structure to a so-called superradiant phase with a finite photon density in the ground state. The long-range interactions lead to a plethora of intermediate phases that break the translational symmetry of the lattice, as well as having a finite photon density. To study the ground-state phase diagram we apply an adaption of the unit-cell-based mean-field calculations [1,2], which capture all possible magnetic unit cells up to a chosen extent. Further, we exploit a mapping of the non-superradiant phases to the Dicke model in order to calculate upper bounds for phase transitions towards superradiant phases [3]. In the case of second-order phase transitions, these bounds agree with the boundaries determined by the mean-field calculations.

[1] J. A. Koziol et al., SciPost Phys. 14, 136 (2023);
[2] J. A. Koziol et al., SciPost Phys. 17, 111 (2024);
[3] A. Schellenberger et al., SciPost Phys. Core 7, 038 (2024).

TT 43.11 Thu 12:15 H33

Anyonic phase transitions in the 1D extended Hubbard model with fractional statistics — •Sebastian Eggert[1], Martin Bonkhoff[2], Kevin Jägering[1], Shi-Jie Hu[3], Axel Pelster[1], and Imke Schneider[1] — [1]University of Kaiserslautern-Landau — [2]Theoretische Physik, Univ. Hamburg — [3]Beijing Computational Science Research Center

Recent advances in quantum technology allow the realization of "lattice anyons", which have enjoyed large interest as particles which interpolate between bosonic and fermionic behavior. We now study the interplay of such fractional statistics with strong correlations in the one-dimensional extended Anyon Hubbard model at unit filling by developing a tailored bosonization theory and employing large-scale numerical simulations. The resulting quantum phase diagram shows several distinct phases, which show an interesting transition through a multicritical point. As the anyonic exchange phase is tuned from bosons to fermions, an intermediate coupling phase changes from Haldane insulator to a dimerized phase. Detailed results on the universality classes of the phase transitions are presented.

TT 43.12 Thu 12:30 H33

Nonlinear effects on the transport of fractional charges in quantum wires — •Imke Schneider[1], Flavia Braga Ramos[1], Rodrigo Gonçalves Pereira[2], and Sebastian Eggert[1] — [1]Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Kaiserslautern, Germany — [2]International Institute of Physics and Departamento de Física Teórica e Ex- perimental, Universidade Federal do Rio Grande do Norte, Natal, Brazil

We investigate the transport properties of one-dimensional systems beyond linear response, focusing on the fractionalization of propagating charges. Starting from a right-moving unit charge, we predict its evolution into at least three distinct stable parts: a fractionally charged particle with freeparticle dynamics, a left-moving signal, and a right-moving low-energy excitation, which can carry positive or negative charge depending on the interaction strength and energy regime. Our findings provide deep insights into the universal correlated nature of these emergent particles and pave the way for out-of-equilibrium transport measurements, offering a direct method to extract the interaction parameters governing correlations in the system.

TT 43.13 Thu 12:45 H33

To Infinity and Back - $1/N$ Graph Expansion of Light-Matter Systems — •Andreas Schellenberger and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Erlangen, Deutschland

We present a method for performing a full graph expansion for light-matter systems, utilizing the linked-cluster theorem. This enables us to explore $1/N$ corrections to the thermodynamic limit $N \to \infty$, giving us access to the mesoscopic regime. This region is yet largely unexplored, as it is challenging to tackle with established solid-state methods. However, it hosts intriguing features, such as entanglement between light and matter that vanishes in the thermodynamic limit [1-3]. We calculate physical quantities of interest for paradigmatic light-matter systems like generalized Dicke models by accompanying the graph expansion by both exact diagonalization (NLCE [4]) and perturbation theory (pcst++ [5]), benchmarking our approach against other techniques.

[1] J.Vidal, S.Dusuel, EPL 74, 817 (2006).
[2] K.Lenk, J.Li, P.Werner, M.Eckstein, arXiv:2205.05559 (2022).
[3] A.Kudos,D.Novokreschenov,I.Iorsh,I.Tokatly,arXiv:2304.00805(2023).
[4] M.Rigol, T.Bryant, R.R.P.Singh, PRL 97, 187202 (2006).
[5] L.Lenke, A.Schellenberger, K.P.Schmidt, PRA, 108 (2023).

TT 44: Focus Session: Ising Superconductivity in Monolayer Transition Metal Dichalcogenides (joint session TT/HL/MA)

Superconducting monolayer transition metal dichalcogenides (TMDs) like $NbSe_2$, TaS_2, and gated WSe_2 or MoS_2, have attracted lot of interest in recent years. On the one hand Ising spin-orbit coupling pins the electron's spin out of plane, and hence is responsible for critical in-plane magnetic fields by far exceeding the Pauli limit. On the other hand, while the underlying pairing mechanism is still under debate, recent experiments provide strong evidence for its unconventional, multiband, nature. The Focus Session will feature experimental and theoretical advances on the superconductivity in monolayer TMDs, with focus on universal features, a possible Luttinger-Kohn mechanism, a nodal or even chiral nature of the gap functions, and their phase diagram.

Organizers: Milena Grifoni (Universität Regensburg), Julian Siegl (Universität Regensburg)

Time: Thursday 9:30–12:45 Location: H36

Topical Talk TT 44.1 Thu 9:30 H36

Evidence of Unconventional Superconductivity in Monolayer and Bulk van der Waals Material TaS_2 — •Somesh Chandra Ganguli[1], Viliam Vano[1,2], Yuxiao Ding[1], Maryam Khosravian[1], Jose Lado[1], and Peter Liljeroth[1] — [1]Department of Applied Physics, Aalto University FI-00076 Aalto, Finland — [2]Joseph Henry Laboratories and Department of Physics, Princeton University, Princeton, NJ, USA

Unconventional superconductors are at the forefront of modern quantum materials' research. Even though unconventional superconductivity has been discovered in a large number of bulk systems, intrinsic unconventional superconductivity in the monolayer limit has remained elusive.

In our work, we demonstrate the evidence of nodal f-wave superconductivity in monolayer 1H-TaS_2. We also observe the emergence of many-body excitations potentially associated to its unconventional pairing mechanism. Furthermore, the nodal f-wave superconducting state in the pristine monolayer 1H-TaS_2 is driven to a conventional gapped s-wave state by the inclusion of non-magnetic disorder. I will also briefly describe our recent results on bulk layered superconductor 6R-TaS_2 where alternating metallic and Mott insulating layers gives rise to unconventional superconductivity.

Our results demonstrate the emergence of unconventional superconductivity in van der Waals (vdW) materials and therefore opens possibilities to create designer unconventional superconductivity in vdW heterostructures.

Topical Talk TT 44.2 Thu 10:00 H36

Signatures of Unconventional Superconductivity in Transition Metal Dichalcogenides — •Miguel Ugeda — Donostia International Physics Center, San Sebastián, Spain

Lowering the dimensionality of a material is an effective strategy to boost electronic correlations that fail to be captured by conventional pictures. In this arena, two-dimensional (2D) materials provide an ideal platform for the exploration of quantum collective phenomena arising from such strong interactions due to their simple synthesis and modelling. In this talk, I will review the rich physics that emerges in the family of transition metal dichalcogenide (TMD) metals in the superconducting state in the 2D limit. While many of these TMD metals exhibit superconductivity in both the bulk form down to the monolayer, the latter limit stores exciting surprises beyond the BCS frameworks that have been revealed in the last years. I will focus on our $NbSe_2$, the most representative TMD superconductor, where I will describe our recent STM/STS experiments. Lastly, I will briefly describe our current efforts to induce unconventional superconductivity in more complex TMD heterostructures.

Topical Talk TT 44.3 Thu 10:30 H36

Friedel Oscillations and Chiral Superconductivity in Monolayer NbSe$_2$ — •Magdalena Marganska[1,2], Julian Siegl[1], Anton Bleibaum[1], Marcin Kurpas[3], Wen Wan[4], John Schliemann[1], Miguel M. Ugeda[4,5], and Milena Grifoni[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93 053 Regensburg — [2]Institute for Theoretical Physics, Wrocław University of Science and Technology, Wyb. Wyspiańskiego 27, 50-370 Wrocław, Poland — [3]Institute of Physics, University of Silesia in Katowice, 41-500 Chorzów, Poland — [4]Donostia International Physics Center, Paseo Manuel de Lardizábal 4, 20018 San Sebastián, Spain — [5]Ikerbasque, Basque Foundation for Science, Bilbao 48013, Spain

In 1965 Kohn and Luttinger proposed a mechanism for superconductivity, based on the electronic Coulomb interaction alone. The screening effects, which cause Friedel oscillations of charge density around impurities, modulate also the interaction between moving electrons. If it has attractive regions, superconductivity can arise by exploiting them. This mechanism, negligible in 3D metals, can become much stronger in 2D electronic systems. In a monolayer of NbSe$_2$ the screening is further suppressed, due to the multi-orbital nature of the electronic band at the Fermi level. We show how this, and the presence of K/K' Fermi surfaces, leads to superconducting pairing. The dominant gap solution at $T = 0$ has the chiral p+ip symmetry. It evolves with increasing temperature, turning from fully chiral at T=0 to a nematic solution with p-like symmetry close to the critical temperature. Our results are also consistent with our tunneling spectroscopy measurements in NbSe$_2$.

15 min. break

Topical Talk TT 44.4 Thu 11:15 H36

Unconventional Pairing in Ising Superconductors — •Andreas Kreisel[1], Subhojit Roy[2,3,4], Brian M. Andersen[1], and Shantanu Mukherjee[2,3,4] — [1]Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark — [2]Department of Physics, Indian Institute of Technology Madras, Chennai, 600036, India — [3]Center for Atomistic Modelling and Materials Design, IIT Madras, Chennai 600036, India — [4]Quantum Centers in Diamond and Emergent Materials (QCenDiem)-Group, IIT Madras, Chennai, 600036 India

Ising spin orbit coupling arises in materials with non-centrosymmetric crystal structure in conjunction of an in-plane mirror symmetry and is realized in some two dimension transition metal dichalcogenides. Example materials are monolayer NbSe$_2$, MoS$_2$, TaS$_2$, and PbTe$_2$, where signatures of unconventional superconductivity are found in contrast to their three dimensional bulk counterparts. In this talk, I present a microscopic formalism to calculate the superconducting instability from a momentum-dependent spin- and charge-fluctuation-mediated pairing interaction in presence of spin orbit coupling that induces a spin splitting. This pairing is then applied to the electronic structure of transition metal dichalcogenides. We provide a quantitative measure of the mixing between the even- and odd-parity superconducting states which varies with Coulomb interaction. The pairing scenario from spin fluctuations together with the mixing of the odd-parity superconducting state gives rise to an enhancement of the critical magnetic field.

Topical Talk TT 44.5 Thu 11:45 H36

High-Field Study of Ising Superconductivity in TMDs — •Oleksandr Zheliuk[1,2], Xiaoli Peng[3], Andrew Ammerlaan[1,2], Puhua Wan[3], Yulia Kreminska[3], Steffen Wiedmann[1,2], Uli Zeitler[1,2], and Jianting Ye[3] — [1]High Field Magnet Laboratory (HFML-EMFL), Radboud University, Toernooiveld 7, Nijmegen 6525 ED, The Netherlands — [2]Radboud University, Institute for Molecules and Materials, Nijmegen 6525 AJ, The Netherlands — [3]Zernike Institute for Advanced Materials, University of Groningen, 9747 AG Groningen, The Netherlands

Semiconducting transition metal dichalcogenides are known for their strong spin-orbit coupling, the possibility of hosting a variety of quantum phases such as two-dimensional superconductivity with upper critical fields that by far bypasses the Pauli limit, Josephson coupled states, and high mobility electron gasses accessed in electric double-layer transistor (EDLT) configuration. Despite its well-established electronic structure, the dome-shaped superconducting phase diagram where the critical temperature T_c can be modulated by carrier concentration is yet to be understood. This talk will sharpen the understanding of the electronic structure of the electron-doped MoS_2, covering recent insights into superconductivity in MoS_2 probed via the multivalley transport phenomena accessed in high magnetic field.

TT 44.6 Thu 12:15 H36

Unconventional Pairing in Ising Superconductors: Application to Monolayer NbSe$_2$ — •Subhojit Roy[1], Andreas Kreisel[2], Brian Andersen[3], and Shantanu Mukherjee[4] — [1]Indian Instititute of Technology Madras, Chennai, 600036, India — [2]Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark — [3]Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark — [4]Indian Instititute of Technology Madras, Chennai, 600036, India

The presence of a non-centrosymmetric crystal structure and in-plane mirror symmetry allows an Ising spin-orbit coupling to form in some two-dimensional materials, where a nontrivial nature of the superconducting state is currently being explored. In this study(1), we develop a microscopic formalism for Ising superconductors that captures the superconducting instability arising from a momentum-dependent spin- and charge-fluctuation-mediated pairing interaction. We apply our pairing model to the electronic structure of monolayer NbSe$_2$, where first-principles calculations reveal the presence of strong paramagnetic fluctuations. Our calculations provide a quantitative measure of the mixing between the even- and odd-parity superconducting states and its variation with Coulomb interaction. Further, numerical analysis in the presence of an external Zeeman field reveals the role of Ising spin-orbit coupling and mixing of odd-parity superconducting state in influencing the low-temperature enhancement of the critical magnetic field.

[1] S. Roy et al., 2D Mater. 12 015004 (2025).

TT 44.7 Thu 12:30 H36

Emergence of Unconventional Superconductivity and Doped Mott Physics in 6R-TaS$_2$ — •Yuxiao Ding[1], Amritroop Achari[2], Jonas Bekaert[3], Jose Lado[1], Rahul R. Nair[2], Peter Liljeroth[1], and Somesh C. Ganguli[1] — [1]Aalto University, Finland — [2]University of Manchester, UK — [3]University of Antwerp, Belgium

Discovery of Unconventional superconductivity in van der Waals (vdW) materials have brought about a paradigm shift in modern condensed matter research for their tunability and potential application in quantum computing. Among these, most prevalent are 4Hb-TaS$_2$ and 6R-TaS$_2$. They comprise of alternating Mott insulating and metallic layers and give rise to exotic quantum states such as topological superconductivity, anomalous Hall effect potentially associated with hidden magnetism etc. We have studied, using low temperature STM/STS, the newly discovered vdW superconductor 6R-TaS$_2$. For the 1T phase, a doped Mott phase was observed with potential charge order occurring due to hybridisation between 1T and underlying 1H layer. We also observe Kondo sites in the half-filled regime, which unlike 4Hb-TaS$_2$, were more robust under the application of tip-induced electric field. This indicates significantly different interlayer interactions in these two systems. We also observe evidence of unconventional superconductivity in the 1H phase, indicated by the presence of V-shaped superconducting gap and many-body excitations. Our results pave a new direction in understanding the role of interplay between magnetism and superconductivity in layered unconventional superconductors.

TT 45: 2D Materials: Electronic Structure and Exitations III (joint session O/HL/TT)

Time: Thursday 10:30–12:30 Location: H11

TT 45.1 Thu 10:30 H11

Charge ordered phases in the hole-doped triangular Mott insulator 4*Hb*-TaS$_2$ — •Byeongin Lee[1], Junho Bang[1], Hyungryul Yang[1], Sunghun Kim[2], Dirk Wulferding[3], and Doohee Cho[1] — [1]Department of Physics, Yonsei University, Seoul 03722, Republic of Korea — [2]Department of Physics, Ajou University, Suwon 16499, Republic of Korea — [3]Center for Correlated Electron Systems, Institute for Basic Science, Seoul 08826, Republic of Korea

4*Hb*-TaS$_2$ has a unique layered structure, featuring a heterojunction between a 2D triangular Mott insulator and a charge density wave metal. Since a frustrated spin state in the correlated insulating layer is susceptible to charge ordering with carrier doping, it is required to investigate the charge distribution driven by interlayer charge transfer to understand its various phases. In this study, we utilize scanning tunneling microscopy and spectroscopy (STM/S) to examine the charge-ordered phases of 1*T*-TaS$_2$ layers within 4*Hb*-TaS$_2$, explicitly focusing on the non-half-filled regime. Our STS findings reveal an energy gap that exhibits an out-of-phase relation of the charge density. We attribute the emergence of the charge-ordered insulating phase in a doped triangular Mott insulator to the interplay between on-site and nonlocal Coulomb repulsion.

TT 45.2 Thu 10:45 H11

Superlattice engineering in graphene and 1T-NbSe$_2$ 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 has become a major branch of condensed matter research, not at least due to the variety of exotic states observed twisted in van der Waals heterostructures. We here present a new method to periodically modulate graphene by stacking it on 1T/2H-NbSe$_2$. By tuning the twist angle, we realized two near-commensurate superlattices: $\sqrt{3}\times\sqrt{3}$ and 2×2 aligned with the charge density wave (CDW) of 1T-NbSe$_2$. Using scanning tunnelling microscopy, we visualized local stacking configurations for these two superlattices. We applied a newly developed symmetry analysis method to track rotational symmetry breaking as a function of bias. In the 2×2 superlattice, C_3 rotational symmetry was preserved. However, in the $\sqrt{3}\times\sqrt{3}$, a strong strip phase occurs. This symmetry breaking is explained by our tight-binding model. Our findings highlight a mechanism for superlattice-induced symmetry breaking that hints towards exotic states of matter.

TT 45.3 Thu 11:00 H11

Influence of Edge Termination on the Electronic Structure of Single Layer MoS$_2$ on Graphene/Ir(111) — •Alice Bremerich[1], Marco Thaler[2], Thais Chagas[1], Borna Pielic[1], Laerte Patera[2], and Carsten Busse[1] — [1]Universität Siegen, Deutschland — [2]Universität Innsbruck, Österreich

MoS$_2$ is the prototypical semiconducting single-layer transition-metal dichalcogenide (TMDC). It exhibits a metallic edge state that induces partial charge accumulation at its edges, resulting in band bending effects. This 1D state acts as a barrier to electron transport across the edge and contributes significantly to quantum confinement effects in TMDC islands. In this study, we tune the edge state and the associated band bending by altering the edge termination of MoS$_2$/gr/Ir(111) and investigate the resulting changes in the electronic structure by Scanning Tunneling Microscopy and Spectroscopy (STM and STS) at 8 K.

Quasi-freestanding MoS$_2$ is grown on gr/Ir(111) by Molecular Beam Epitaxy (MBE). We prepare hexagonal islands that exhibit two geometrically different edge types (Mo- and S-type). We vary the chemical potential of sulfur and thereby modify the chemical environment of the boundaries. The partial charge at the perimeter depends on edge type as well as edge chemistry. In consequence, also the upward bending of both valence and conduction band shows distinct variations.

TT 45.4 Thu 11:15 H11

magnetic-field-induced dimensionality transition of charge density waves in strained 2H-NbSe2 — •Ryo Ichikawa[1], Yukiko Takahashi[2], Eiichi Inami[3], and Toyo Kazu Yamada[1,4] — [1]Department of Material Science, Chiba University — [2]National Institute for Material Science, Tsukuba — [3]School of system Engineering, Kochi University of Technology — [4]Molecular Chirality Research center, Chiba University

Layered transition metal dichalcogenides (TMDs) exhibit various correlated phases, including charge density waves (CDW), superconductivity, and magnetic orders. Bulk 2H-NbSe2 (2H niobium diselenide) is one of the most extensively studied TMDs, showing a triangular (3Q) incommensurate CDW with a 3a period in real space (3 * 3, TCDW ~ 33 K). Electric and magnetic fields have been used to manipulate spatial or time inversion symmetry, while the CDW in 2H-NbSe2 remains robust even under large magnetic fields on the order of tens of Tesla. However, magnetic-field-sensitive CDWs have been reported in few-layer NbSe2, where a weak magnetic field of approximately 30 mT can switch the electronic phase within the thin film, resulting in a supercurrent diode effect. This study investigates the strained 2H-NbSe2 exhibiting the 2*2 CDW phase. We utilize low-temperature (4.3 K) scanning tunneling microscopy and spectroscopy (STM/STS) in ultrahigh vacuum (UHV). STS maps reveal the coherence of the 2*2 CDW patterns. However, applying an out-of-plane magnetic field induces a dramatic transformation akin to that observed in 1T-NbSe2, shifting the metallic 2D CDW pattern to a 1D CDW pattern.

TT 45.5 Thu 11:30 H11

Ultrafast phonons dynamics of monolayer transition metal dichalcogenides — •yiming pan and fabio caruso — Kiel University, Germany

Valley degrees of freedom in transition-metal dichalcogenides influence thoroughly electron-phonon coupling and its nonequilibrium dynamics. Here we present a time-resolved ab-initio study of the ultrafast dynamics of chiral phonons following carrier excitation with circularly-polarized light. By investigating the valley depolarization dynamics of monolayer MoS$_2$ and WS$_2$, we find that a population imbalance of carriers distributed at K and K′ can lead to valley polarized phonons persisting beyond 10 ps, and characterized by a distinctive chirality [1]. Additionally, we find that strain can be exploited as a tool to control the phonon emission and the relaxation channels of hot carriers [2]. Finally, we briefly discuss available opportunities for experimental detection of these phenomena

[1] Y. Pan and F. Caruso, Nano Lett. 23, 7463 (2023)
[2] Y. Pan and F. Caruso, npj 2D Mater. Appl. 8, 42 (2024)

TT 45.6 Thu 11:45 H11

Probing Excitonic Properties and Structural Effects in WS$_2$-Graphene Heterostructures Using EELS and DFT-BSE Modeling — •Max Bergmann, Jürgen Belz, Oliver Massmeyer, Robin Günkel, Badrosadat Ojaghi Dogahe, Andreas Beyer, Stefan Wippermann, and Kerstin Volz — Department of Physics, Philipps-Universität Marburg, Germany

This study investigates the excitonic properties of WS$_2$ epitaxially grown on graphene by metal-organic chemical vapor deposition. We focus on understanding the effects of structural changes, such as variations in the number of WS$_2$ layers. Using monochromatic electron energy loss spectroscopy (EELS) in a scanning transmission electron microscope (STEM), we observe in the monolayer region of WS$_2$ an excitonic spectrum with excitonic peaks at 2.0 eV and 2.4 eV, as well as additional spectral features at higher energies. Measurements in the bilayer region show a small redshift of these features due to the additional layer. Complementary density functional theory and Bethe-Salpeter calculations show that this redshift in the K-valley excitons is due to both a change in quantum confinement and a change in the WS$_2$ lattice constant, with the latter being the dominant effect. Using STEM, this lattice distortion can be attributed to the heteroepitaxial alignment of the lower WS$_2$ layer to the graphene substrate, while the upper layer is relaxed. This study provides valuable insights into the relationship between atomic structure and optical properties in complex material systems, providing essential knowledge for the design and optimization of 2D heterostructures for advanced device applications.

TT 45.7 Thu 12:00 H11

Optical excitations in 2H-MoS_2 bilayers under pressure — •Jan-Hauke Graalmann[1], Paul Steeger[2], Rudolf Bratschitsch[2], and Michael Rohlfing[1] — [1]University of Münster, Institute of Solid State Theory, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]University of Münster, Institute of Physics and Center for Nanotechnology, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Theoretical and experimental investigations have shown several changes in the optical spectrum of the 2H-MoS_2 bilayer under pressure [1].

By using density functional theory (DFT) and many-body perturbation theory in combination with linear elasticity, our computational investigations show an effective shift of the A exciton under pressure. It is strongly connected to the behavior of the direct band gap at the K point, which shifts in energy under pressure. The direction of this shift depends on the stress condition. While a hydrostatic pressure leads to a blueshift, a suppression of the in-plane contraction, as it appears in diamond anvil cell-experiments due to the interaction between the sample and the substrate, shows a redshift.

Moreover, we observe a similar behavior for the interlayer exciton, whereas the shift rate is smaller than that of the A exciton, which results in a decreasing A-IL splitting for an increasing pressure.

[1] P. Steeger, J. Graalmann et al., Nano Lett., 23, (2023)

TT 45.8 Thu 12:15 H11

Visualizing and controlling charge states of metal nanoislands on a two dimensional semiconductor — •Junho Bang[1], Byeongin Lee[1], Jian-Feng Ge[2], and Doohee Cho[1] — [1]Department of Physics, Yonsei University, Seoul, Korea — [2]Department of Topological Quantum Chemistry, Max Planck Institute for Chemical Physics of Solids, München ,Germany

Nanoscale objects show unique electronic behaviors when weakly coupled to electrodes. Coulomb blockade (CB) can occur in such systems, where the repulsive Coulomb interaction between electrons prevents additional electrons from entering the quantum dots, hindering their flow. Single electron tunneling occurs by these correlated electron transports, leading to the discrete charge states of objects in double barrier tunneling junctions. Despite enormous progress, challenges remain in precisely controlling the interplay between objects' charge states and tunneling dynamics under varying conditions. Here, we visualize the charge states and their spatial variation on the random array of the indium islands on two-dimensional semiconductor black phosphorus using scanning tunneling microscopy and spectroscopy. Our spatially resolved tunneling spectra reveal that the junction capacitance varies across the islands. Furthermore, we find that the CB features are visible outside the islands, which is attributed to the remote gating of the islands. Our work advances the manipulation of electron transport at the nanoscale, which will be helpful in the application of nanoscale object-based single-electron devices.

TT 46: Transport Properties (joint session HL/TT)

Time: Thursday 15:00–17:15 Location: H13

TT 46.1 Thu 15:00 H13

Quasi-Ballistic Transport in Phase-Pure GaAs/InAs Core/Shell Nanowires — •Farah Basarić[1,2], Vladan Brajović[1,2], Gerrit Behner[1,2], Kristof Moors[1], William Schaarman[1], Raghavendra Juluri[3], Ana M. Sanchez[3], Hans Lüth[1,2], Detlev Grützmacher[1,2], Alexander Pawlis[1,2], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany — [3]Department of Physics, University of Warwick, Coventry CV4 7AL, UK

Core/shell GaAs/InAs nanowires represent tubular conductors due to their insulating core and confined conducting states in the InAs shell. We investigate nanowires with a crystalline phase purity of the InAs shell, where reduced scattering in electronic transport is expected. Low-temperature gate-dependent transport measurements give us insight into different contributions to the oscillatory behavior in the magnetoconductance, as well as the possibility to probe non-local transport phenomena due to large phase coherence length. With temperature-dependent measurements, we resolved the quasi-ballistic transport regime, and estimate the phase coherence length. Both measurements indicate superior transport properties of phase-pure GaAs/InAs nanowires in contrast to previous reports on non-phase pure nanowires. Our findings are an important optimization step for further development of nanowire-based hybrid devices.

TT 46.2 Thu 15:15 H13

Influence of defects and shape of thin InAs nanowires on their thermal conductivity, assessed via machine-learning potentials — •Sandro Wieser[1], YuJie Cen[1], Georg K. H. Madsen[1], and Jesús Carrete[2] — [1]Institute of Materials Chemistry, TU Wien, Wien, Austria — [2]Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, Zaragoza, Spain

Nanowires (NWs) grown from the zincblende (ZB) phase of InAs in the (111) direction commonly contain twin boundary defects consisting of narrow wurtzite (WZ) (001) phase regions between ZB sections. To investigate the impact of these and other defects on heat transport, we employ Green-Kubo equilibrium molecular dynamics simulations utilizing cepstral analysis to efficiently process the noise, and an accurate MACE model trained via active learning strategies to achieve transferability for a wide range of surface conditions.

We show that these twin boundaries reduce the thermal conductivity with respect to that of defect-free WZ-phase (001) NWs by a factor of more than two and that surface conditions lead to lower thermal conductivity values for defect-free ultrathin InAs ZB NWs. Analysis of the shape of twinning NWs reveals that structures mimicking experimentally measured surface configurations can enhance heat transport compared to strictly hexagonal NWs. Additional insights are gained from an analysis of line-group symmetries and vibrational properties for various NW shapes. Furthermore, experimentally motivated symmetric and symmetry-breaking surface defects are studied to reveal more and less influential defect sites.

TT 46.3 Thu 15:30 H13

Ab-initio heat transport in defect-laden quasi-1D systems from a symmetry-adapted perspective — •Yujie Cen[1], Sandro Wieser[1], Georg Kent Hellerup Madsen[1], and Jesús Carrete Montaña[2] — [1]Institute of Materials Chemistry, TU Wien, A-1060 Wien, Austria — [2]Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, Zaragoza, Spain

Due to their aspect ratio and wide range of thermal conductivities, nanotubes hold significant promise as heat-management nanocomponents. However, one major limitation preventing their widespread use is the typically high thermal resistance that arises from defects or contact with other materials. An intriguing question is the role that structural symmetry plays in thermal transport through those defect-laden sections. However, the ab-initio study of lattice thermal transport is hindered by factors such as the large number of atoms involved and the artifacts introduced by formalism designed for 3D systems.

We employ an Allegro-based machine learning potential to calculate the force constants and phonons of single and multi-layer MoS_2-WS_2 nanotube with near-DFT accuracy and efficient scaling. Subsequently, we combine representation theory with the mode-resolved Green's function method to calculate detailed phonon transmission profiles across defects, and connect the transmission probability of each mode to structural symmetry. while more drastic symmetry breakdowns might be expected to increase scattering and thermal resistance, our results show they actually reduce it by the suppression of selection rules and opening more phonon transmission channels.

TT 46.4 Thu 15:45 H13

Analysis of the electrical transport properties of MBE grown cubic Galliumnitride (c-GaN) sample structures — •Hannes Hergert[1,2], Mario F. Zscherp[1,2], Silas A. Jentsch[1,2], Jörg Schörmann[1,2], Sangam Chatterjee[1,2], Peter J. Klar[1,2], and Matthias T. Elm[1,2,3] — [1]Center for Materials Research, Heinrich-

Buff-Ring 16, 35392 Giessen — [2]Institute of Experimental Physics I, Heinrich-Buff-Ring 16, 35392 Giessen — [3]Institute of Physical Chemistry, Heinrich-Buff-Ring 17, 35392 Giessen

Due to its lack of internal polarization fields cubic gallium nitride (c-GaN) is a promising semiconductor system for 'more-than-Moore' applications such as high-power electronics or optoelectronic devices. The analysis of its electrical transport properties is challenging since the molecular beam epitaxy (MBE) growth of high-quality c-GaN thin films requires a complex substrate architecture in order to accommodate the lattice mismatch between c-GaN and the 3C-SiC template. However, a reliable characterization of the electrical transport properties of c-GaN is crucial for the design of advanced functional devices. Here we analyze the electrical transport properties of the whole sample structure (MBE grown c-GaN/c-AlN thin films onto a 3C-SiC/Si template) with different c-GaN thicknessses using electrochemical impedance spectroscopy (EIS) as well as angle- and temperature-dependent magnetoresistance (MR) measurements. MR measurements reveal the existence of a highly conductive channel while EIS measurements allow the determination of the position of the channel between the c-AlN thin film and the 3C-SiC layer.

15 min. break

TT 46.5 Thu 16:15 H13

Fabrication and Characterisation of Short-channel Junctionless Nanowire Transistors — •Alessandro Puddu — Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

The downscaling limitations of conventional planar transistors require the investigation of alternative device configurations. Because of their excellent electrostatic control and intrinsic scalability, junctionless nanowire transistors (JNTs) present a feasible solution and are highly desirable for next-generation electronics. The key factor that characterizes the JNTs is the absence of pn-junctions. This provides several benefits, such as an easier fabrication process since the devices do not require abrupt doping profiles within the nanowire channel, which is now uniformly doped.

This work focuses on the fabrication and characterisation of short-channel Si JNTs. A top-down approach based on e-beam lithography (EBL) and inductively coupled plasma reactive ion etching (ICP-RIE) was used to fabricate the Si nanowires. The device characterisation showed improved performances due to the channel length shrinking.

TT 46.6 Thu 16:30 H13

***Ab initio* investigation of drag effect in germanium** — •Dwaipayan Paul and Nakib Protik — Humboldt-Universität zu Berlin, Zum Großen Windkanal 2, 12489 Berlin, Germany

In a system of interacting electrons and phonons, the transport of one induces transport in the other. This phenomenon is known as the electron-phonon drag effect [1]. Now, an important milestone in the history of drag physics is the first recorded measurement of this phenomenon in germanium [2]. Here we present the results of our *ab initio* computations of the thermoelectric transport coefficients of germanium for various temperatures and charge carrier concentrations using the `elphbolt` code [3]. We investigate how the various scattering channels in the system enable this material to exhibit strong drag phenomena.

[1] Gurevich, Yu G., and O. L. Mashkevich. "The electron-phonon drag and transport phenomena in semiconductors." Physics Reports 181.6 (1989): 327-394.

[2] Frederikse, H. P. R. "Thermoelectric power of germanium below room temperature." Physical Review 92.2 (1953): 248.

[3] Protik, Nakib H., et al. "The elphbolt ab initio solver for the coupled electron-phonon Boltzmann transport equations." npj Computational Materials 8.1 (2022): 28.

TT 46.7 Thu 16:45 H13

Anomalous Knudsen effect signaling long-lived modes in 2D electron gases — •Grigorii Starkov and Björn Trauzettel — Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany

Careful analysis of electron collisions in two spatial dimensions leads to the conclusion, that the odd harmonics of the electron distribution function decay much slower in comparison to the even ones at finite temperatures. Focusing on a channel geometry with boundary scattering, we show, that such behaviour of the odd decay rates leads to a characteristic behaviour of the resistance that we dub anomalous Knudsen effect: increasing temperature leads to decreasing resistance, that quickly slows down and turns into growth. The further increase of temperature exhibits the usual Gurzhi peak in the resistance related to the crossover from ballistic to hydrodynamic transport. The simultaneous observation of the Gurzhi peak preceded by an anomalous Knudsen dip can serve as a concrete signature of the long-lived modes in the 2D electron transport at low temperatures.

TT 46.8 Thu 17:00 H13

Quantum confinement and stoichiometry fluctuations in nm-thin SiGe layers — •Daniel Dick[1,2,3,4], Florian Fuchs[1,2,3], Sibylle Gemming[2,4], and Jörg Schuster[1,2,3] — [1]Center for Micro- and Nanotechnology, TU Chemnitz, Germany — [2]Center for Materials, Architecture and Integration of Nanomembranes, TU Chemnitz, Germany — [3]Fraunhofer Institute for Electronic Nanosystems (ENAS), Chemnitz, Germany — [4]Institute of Physics, TU Chemnitz, Germany

We simulate biaxially strained SiGe layers of varying thickness in the range of a few nanometers, as found in the base layer of heterojunction bipolar transistors (HBTs). At this length scale, local fluctuations in atomic concentrations can strongly influence the electronic properties of the device, especially the distribution of dopants like e.g. boron. Even at high doping concentrations, only a single atom is present at a 1 nm^2 cross section of the layer on average.

Employing a new parameterization of silicon and germanium in the framework of extended Hückel theory (EHT), we calculate the local band gap for different permutations of the atomic structure. Various distributions of boron atoms are simulated. We study the impact of locally increased and decreased concentrations on the band gap. By varying layer thickness, we evaluate the effects of quantum confinement and how it impacts transport properties of the thin layer in contrast to bulk material.

TT 47: Fluctuations, Noise and Other Transport Topics (joint session TT/DY)

Time: Thursday 15:00–18:30 Location: H31

TT 47.1 Thu 15:00 H31

Noise and reliability characterization of ferroelectric field-effect transistors under cryogenic conditions — •Yannick Raffel[1], Shouzhuo Yang[1], Oliver Ostien[1], Maik Simon[1], Thomas Kämpfe[1], Konrad Seidel[1], Maximilian Lederer[1], and Johannes Heitmann[2] — [1]Fraunhofer Institute IPMS-CNT, Dresden, Germany — [2]TU Bergakademie Freiberg, Freiberg, Germany

This study explores the impact of defects in the ferroelectric (FE) hafnium oxide (HfO_2) layer on the low-frequency noise (LFN) characteristics of HfO_2-based ferroelectric field-effect transistors (FeFETs), which show great potential as memory devices for quantum computing applications under cryogenic conditions. The investigation focuses on device degradation and material-dependent changes under various temperature conditions, including cryogenic temperatures as low as 2 K. A clear link between device reliability and flicker noise was identified. Initially, the endurance of the devices was evaluated across a range of temperatures, including cryogenic conditions. Subsequently, their data retention behavior was characterized, revealing a notably prolonged electron detrapping time at 2 K. In addition, flicker noise trends were analyzed and discussed, shedding light on key factors influencing device optimization and reliability.

TT 47.2 Thu 15:15 H31

Charge dissipation in Josephson systems and its impact on phase diffusion — •Johannes Hauff, Joachim Ankerhold, and Dominik Maile — Institut für komplexe Quantensysteme, Universität Ulm

We theoretically investigate the dynamics of the Josephson phase for different quantum circuits in the presence of dissipative couplings. Thereby, we study the environmental assisted quantum tunneling of the superconducting phase in a current-biased Josephson junction and 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, which is strongly dependent on the shape of the potential. This effect appears already in the low Ohmic regime and also occurs in the presence of phase dissipation that favors localization [1]. Inserting realistic circuit parameters, we address the question of its experimental observability, the impact of temperature and discuss suitable parameter spaces for the observation of the enhanced rate. Furthermore, we show how the interplay of thermal and quantum fluctuations in such nonlinear systems can lead to an interesting stochastic cooling process. In this context, we also discuss the relevance of dissipative couplings for quantum annealing procedures.

[1] D. Maile et al., Phys. Rev. B 106, 045408 (2022)

TT 47.3 Thu 15:30 H31

Thermodynamic and energetic constraints on out-of-equilibrium tunneling rates — Ludovico Tesser[1], •Matteo Acciai[2,1], Christian Spånslätt[3,1], Inès Safi[4], and Janine Splettstoesser[1] — [1]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Göteborg, Sweden — [2]Scuola Internazionale Superiore di Studi Avanzati, Trieste, Italy — [3]Department of Engineering and Physics, Karlstad University, Karlstad, Sweden — [4]Laboratoire de Physique des Solides, CNRS-Université Paris-Sud and Paris-Saclay, Orsay, France

We consider a bipartite quantum system, where the two parts are kept at different temperatures and are connected by a tunnel coupling. In this setup, we show that the out-of-equilibrium tunneling rates between the two subsystems (depending on the applied temperature bias) are bounded by two constraints. The derived bounds are related to the dissipated heat and the absorbed energy neede to establish and deplete the temperature bias, thus providing a thermodynamic and energetic constraint on the tunneling rates.

Except for the restriction to the tunneling regime, our results are valid for arbitrary Hamiltonians of the two subsystems, that can include generic many-body interactions. The derived bounds thus apply to a large class of systems, such as molecular junctions and coupled cavities, and can be tested by measuring the out-of-equilibrium tunneling current and its fluctuations.

Based on: arXiv:2409.00981

TT 47.4 Thu 15:45 H31

Colored noise Langevin equation for photon counting — •Steven Kim and Fabian Hassler — Institute for Quantum Information, RWTH Aachen, Germany

For open quantum systems, obtaining the photon counting statistics of the emitted radiation is central to obtain insights into phenomena such as entanglement and correlations, in particular super- and anti-bunching. Typically, these systems are described by a Lindblad master equation, which allows the counting statistics to be derived from normal-ordered number operators. However, the Lindblad equation relies on the rotating wave approximation (RWA), which assumes that the dissipation rate is much smaller than the characteristic photon frequency. While this requirement is always fulfilled at optical frequencies, microwave cavities can have broader linewidths, making the RWA inaccurate. Alternatively, such systems can be effectively described by an equivalent Langevin equation with correlated (colored) noise, which bypasses the need for the RWA. In this work, we derive the photon counting statistics directly from the Langevin equation, providing a broader framework for understanding photon emission in open quantum systems.

TT 47.5 Thu 16:00 H31

Quantum stochastic resonance in a periodically-driven quantum dot — •Johann Zöllner[1], Hendrik Mannel[1], Eric Kleinherbers[2], Marcel Zöllner[1], Nico Schwarz[1], Fabio Rimek[1], Andreas Wieck[3], Arne Ludwig[3], Axel Lorke[1], Martin Geller[1], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen — [2]Department of Physics and Astronomy, University of California, Los Angeles — [3]Faculty of Physics and Astronomy, Ruhr University Bochum

The combination of periodic driving and fluctuations in a system with an inherent noise source leads to stochastic resonance, where the synchronization of the system dynamics with the external drive leads to an enhanced signal-to-noise ratio. This phenomenon has been found in many different noisy systems in palaeoclimatology, biology, medicine and physics. The classical stochastic resonance with thermal noise has recently been experimentally extended to the quantum regime, where the fundamental randomness of individual quantum events is the noise source [1]. Here we demonstrate quantum stochastic resonance in the single-electron tunneling dynamics of a periodically driven single self-assembled quantum dot, tunnel-coupled to an electron reservoir [2]. We extend the statistical evaluation to factorial cumulants to gain a deeper understanding of the transition between stochastic and deterministic transport through the quantum dot.

[1] T. Wagner et al., Nat. Phys. 15, 330 (2019).
[2] A. Kurzmann et. al., Phys. Rev. Lett. 122, 247403 (2019).

TT 47.6 Thu 16:15 H31

Curvature-assisted high harmonic generation in strongly-driven superconductors — •Björn Niedzielski and Jamal Berakdar — Institut für Physik, Martin-Luther Universität Halle-Wittenberg, Halle/Saale 06099, Germany

Superconductors (SCs) under strong driving fields show inherently nonlinear dynamics, offering potential for nonlinear optics and high harmonic generation. However, the weak coupling of SCs to homogeneous transverse fields limits their efficiency. Here, we show that introducing curvature to mesoscopic type-II SC structures enables enhanced coupling to strong THz fields. Applied transport currents further allow for controlled emission of even and odd-order harmonic light modes.

The enhanced coupling of SCs and light arises from geometric and finite-size effects steering supercurrents while preserving the coherence of the SC state. Using the time-dependent Ginzburg-Landau framework, we simulate the dynamics of the superconducting order parameter in nanostructures with large coherence lengths under near-gap driving frequencies. Our simulations reveal the time-dependent supercurrents and their contributions to dipole radiation and high harmonic generation.

Our results highlight the role of the SC geometry and finite-size effects for amplifying nonlinear optical responses, offering a new method to use SCs for nonlinear THz optics.

15 min. break

TT 47.7 Thu 16:45 H31

Quantum oscillations in magneto-thermoelectrical conductivities of 2DEG: The Keldysh field-theoretical approach — •Kitinan Pongsangangan — Mahidol University, Bangkok, Thailand

The purpose of this work is to formulate a kinetic theory describing transport properties of interacting electrons in a uniform magnetic field of arbitrary magnitude. Exposing an electronic system to a constant magnetic field quenches its energy bands into a series of discrete energy levels, known as Landau levels. Following Keldysh formalism, we derive the quantum kinetic equation with the Landau-level basis. The Landau-level states, exact solutions of the Schroedinger equation in a constant background magnetic field, are natural and suitable basis to use, especially, for the investigation of strong-magnetic-field phenomena. In the weak-field limit, the lowest order approximation of the quantum kinetic equation reduces to a Boltzmann equation into which the magnetic field enters as the Lorentz force. As an application of our quantum transport equation, we calculate magneto-thermoelectric coefficients of a disordered two-dimensional electron gas (2DEG) in the quantum hall regime interacting with acoustic phonons.

TT 47.8 Thu 17:00 H31

Typical medium theory for disordered electronic systems on simple lattices with Cauchy distribution of on-site potentials — Andreas Ostlin[1], Hanna Terletska[2], Dylan Jones[1], and •Liviu Chioncel[1,3] — [1]Institute of Physics, University of Augsburg, Augsburg, Germany — [2]Middle Tennessee State University, Murfreesboro, Tennessee, USA — [3]ACIT, University of Augsburg, Augsburg, Germany

Effective medium approaches using single-site averaging procedures of various kinds contributed substantially in understanding the density of states of electronically disordered systems in models and materials. The nature and the conditions for appearance of single-particle (Anderson) localization seems to be qualitatively understood, yet discussions concerning special applied methods and quantitative results for the critical conditions are still ongoing. Here we present results using the typical medium theory for the one-particle and two-particle Green's function (conductivities) for the special case of Cauchy-distribution.

TT 47.9 Thu 17:15 H31

Dynamical current as tool to distinghuish degenerate spin states in open-shell graphene nanoribbons — •Nico Leumer, Thomas Frederiksen, and Geza Giedke — Donostia International Physics Center

The recent advances of surface synthesis unlocked the potential of open-shell physics in graphene nanoribbons (GNRs) which ever since have gained significant attention. Normally chemically unstable, these structures feature unpaired, localized p_z-electrons pinned at zero energy, giving rise to the unique phenomenon of π-magnetism. Intrinsically low spin-orbit/hyperfine interactions suppress spin relaxation, making GNRs ideal for tunable spin physics and spintronics applications. Although scanning probe techniques provide the necessary access to electron's spins and their interactions, state preparation, manipulation and detection remains an open challenge. Our ambition addresses the latter.

At half-filling certain GNRs host quasi degenerate spin singlets/triplets states with a vanishing energy gap for long ribbons. Without significantly increasing the gap, e.g., via magnetic fields, conventional current-based measurements hardly distinguish these spin textures. However, and even for absent gap, we demonstrate that in our setup $I(t)$ discriminates between the responsible states by exploiting the states's distinct spatial profiles. To probe the spatial information, we apply a constant bias between two STM tips. The scheme is suitable for single shot measurements and a quantum master equation (Hubbard model) accounts for the time evolution (GNR).

TT 47.10 Thu 17:30 H31

Josephson force in a vibrating carbon nanotube Josephson 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 single carbon nanotube suspended between superconducting electrodes acts simultaneously as nanomechanical resonator and as Josephson junction. Its energy-dependent density of states and thus displacement-dependent Josephson energy couple electronics and mechanics. Measurements on such a system display complex behaviour of the vibrational resonance with respect to junction biasing; strikingly, the resonance frequency decreases in a distinct parameter region where the bias is similar in size to the junction switching current.

We numerically solve the coupled differential equation system of the driven (via an ac gate voltage and an ac bias) system for realistic device parameters, using highly parallelized Julia code, and characterize the evolving steady state. Specific attention is given to the effect of the Josephson junction behaviour on the mechanical resonance frequency and the vibration amplitude. In the numerical results, we observe a clear impact of superconductivity on the mechanical response, with a rather counterintuitive dependence on externally tunable parameters.

TT 47.11 Thu 17:45 H31

Tunable nonlinear Duffing response of a driven carbon nanotube nanomechanical resonator — •Akong Loh, Furkan Özyigit, Fabian Stadler, Katrin Burkert, Niklas Hüttner, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

Extremely lightweight and with very high quality factors, Carbon nanotube nanomechanical resonators have been used as ultrasensitive force, mass, and charge sensors [1-5]. When suspended on source and drain leads and gated, a CNT nanomechanical resonator can also be operated as a quantum dot. The motion of the nanotube is strongly coupled to single electron tunneling, dominating the nonlinear response [1-5]. Control of the strong nonlinear dynamics of a CNT will be useful for engineering mechanical qubits with information stored in the vibrations and mechanical Schrödinger's cat states [3]. Here, we analyze the nonlinear vibrational response of a driven CNT quantum dot, at ∼10mK in a dilution refrigerator and with opaque tunnel barriers to minimize dissipation. We demonstrate how the nonlinearity parameters of the coupled system can be controlled via Coulomb blockade and the associated gate voltage, leading to a rich interplay of frequency, damping, and Duffing behavior.

[1] A. K. Hüttel *et al.*, Nano Lett. 9, 2547 (2009).
[2] G. A. Steele *et al.*, Science 325, 1103 (2009).
[3] C. Samanta *et al*, Nat. Phys. 19, 1340 (2023).
[4] S. Blien *et al.*, Nat. Commun. 11, 1636 (2020).
[5] N. Hüttner *et al.*, Phys. Rev. Appl. 20, 064019 (2023).

TT 47.12 Thu 18:00 H31

Vibrational instabilities in molecular nanojunctions: A mixed quantum-classical analysis — •Martin Mäck, Samuel Rudge, Riley Preston, and Michael Thoss — Institute of Physics, University of Freiburg

Understanding the current-induced vibrational dynamics in molecular nanojunctions is critical for gaining insight into the stability of such systems. While it is well known that Joule at higher bias voltages plays an important role for the stability of the nanojunction, a different mechanism caused by current-induced nonconservative forces has been reported to cause vibrational instabilities already at much lower voltages [1].

In this contribution, we apply a mixed quantum-classical approach based on electronic friction and Langevin dynamics [2,3] to a model system for which vibrational instabilities have previously been reported. Such a mixed quantum-classical description has the benefit of giving valuable insight into the electronic forces acting on the molecular vibrations. We analyze the possible occurrence of vibrational instabilities and compare our results to previous approaches, which were limited to small amplitude motion of the vibrational degrees of freedom [1].

[1] J.-T.Lü, M.Brandbyge, P.Hedegård, Nano Lett. **10**, 1657 (2010).
[2] S.L.Rudge, C.Kaspar, R.L.Grether, S.Wolf, G.Stock, M.Thoss, J.Chem. Phys.**160**, 184106 (2024).
[3] R.J.Preston, D.S.Kosov, J.Chem.Phys.**158**, 224106 (2023).

TT 47.13 Thu 18:15 H31

Vortex shedding in superfluid He-4 and in a Bose-Einstein condensate — •Wilfried Schoepe — Fakultät für Physik, Universität Regensburg, D-93040 Regensburg, Germany

Our experiments on vortex shedding from a microsphere oscillating in superfluid He-4 at mK temperatures is compared with experiments on vortex shedding from a laser beam moving in a Bose-Einstein condensate as observed by other authors. In either case a linear dependence of the shedding frequency fv=a(v-vc) is observed a above some critical velocity vc for the onset of turbulence and the coefficient a is proportional to the oscillation frequency f above some characteristic value and assumes a finite value for steady state motion f=0. An analytical relation between the superfluid Reynolds number and the superfluid Strouhal number is presented.

TT 48: Topology: Majorana Physics

Time: Thursday 15:00–16:30 Location: H32

Invited Talk TT 48.1 Thu 15:00 H32

Optical Conductivity as a Probe for Chiral Majorana Edge Modes — •Lina Johnsen Kamra[1,2,3], Bo Lu[4], Jacob Linder[1], Yukio Tanaka[5], and Naoto Nagaosa[6] — [1]Norwegian University of Science and Technology, Trondheim, Norway — [2]Universidad Autónoma de Madrid, Madrid, Spain — [3]Massachusetts Institute of Technology, Cambridge, USA — [4]Tianjin University, Tianjin, China — [5]Nagoya University, Nagoya, Japan — [6]RIKEN, Saitama, Japan

Recent years have seen considerable progress towards realizing non-abelian particles for topological quantum devices. A prominent example is the chiral Majorana mode at the edge of topological superconductors. It introduces the possibility of using wave packets propagating at high speed as an alternative to the braiding of zero-dimensional Majorana bound states. However, a weak spot in detecting them lies in reliably capturing quantitative measures such as a quantized conductivity. Recent advances in microwave microscopy [1] have opened a promising new avenue for observing distinct qualitative signatures in their optical conductivity [2,3]. These emerge due to the unique dispersion of the Majorana edge mode that allows photons to break up Cooper pairs into propagating Majorana fermions [2]. As a guide to future experiments, we have shown how the local optical conductivity presents distinct and tunable qualitative features that depend on the symmetry of the superconductivity [3].

[1] K. Lee et al., Sci. Adv. 6, eabd1919 (2020);
[2] J. J. He et al., Phys. Rev. Lett. 126, 237002 (2021);
[3] L. J. Kamra et al., Proc. Natl. Acad. Sci. 121, e2404009121 (2024).

TT 48.2 Thu 15:30 H32

Interedge backscattering in time-reversal symmetric quantum spin Hall Josephson junctions — •Cajetan Heinz[1], Patrik Recher[1,2], and Fernando Dominguez[1,3] — [1]Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, D-38106 Braunschweig, Germany — [3]University of Würzburg, D-97074 Würzburg, Germany

Using standard tight-binding methods, we investigate a novel backscattering mechanism taking place on quantum spin Hall N'SNSN' Josephson junctions in the presence of time-reversal symmetry. This extended geometry allows for the interplay between two types of Andreev bound states (ABS): the usual phase-dependent ABS localized at the edges of the central SNS junction *and* phase-independent ABS localized at the edges of the N'S regions. Crucially, the latter arise at discrete energies E_n and mediate a backscattering process between opposite edges on the SNS junction, yielding gap openings when both types of ABS are at resonance. In this scenario, a 4π-periodic ABS decouples from the rest of the spectrum, and thus, it can be probed preventing the emission to the quasicontinuum. Interestingly, this backscattering mechanism introduces a new length scale, determining the ratio between 4π- and 2π-periodic supercurrent contributions and distorts the superconducting quantum interference (SQI) pattern. Finally, to prove the participation of these ABS, we propose to use a magnetic flux to tune E_n to zero, resulting in the selective lifting of the fractional Josephson effect.

TT 48.3 Thu 15:45 H32

Geometric measure of entanglement in systems with poor man's Majorana modes — •Vimalesh Vimal and Jorge Cayao — Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

The physical realization of minimal Kitaev chains has recently opened an alternative avenue for engineering Majorana physics with interesting applications in quantum computing. Central to these applications is the utilization of the Majorana-like quasiparticles in these systems, known as poor man's Majorana modes, for realizing qubits and highly entangled states. In this work we consider a minimal Kitaev chain hosting poor man's Majorana modes and investigate the generation of maximally entangled quantum states by using an entirely geometric approach [1]. In particular, for pure states, the geometric measure of entanglement is quantified by its distance from the nearest separable state and provides an advantageous approach for quantifying entanglement in multipartite mixed states, in contrast to conventional bipartite measures. We characterize regimes with maximally entangled states, which surprisingly emerge with and without poor man's Majorana modes. We also discuss the generation and control of maximally entangled states by the Josephson effect in a Josephson junction based on minimal Kitaev chains. Our work thus demonstrates the potential of minimal Kitaev chains for applications in quantum information.

[1] V. K. Vimal and J. Cayao, Manuscript in preparation.

TT 48.4 Thu 16:00 H32

Emerging Majorana bound states in superconducting Haldane nanoribbons — •Simone Traverso[1], Niccolò Traverso Ziani[1], Maura Sassetti[1], and Fernando Dominguez[2] — [1]Physics Department, University of Genoa and CNR-SPIN, 16146 Genoa, Italy — [2]Faculty of Physics and Astrophysics and Würzburg-Dresden Cluster of Excellence ct.qmat, University of Würzburg, 97074 Würzburg, Germany

In the rapidly evolving field of quantum technologies, topological superconductors are promising platforms for topologically protected quantum computation. In this context, manipulating Majorana bound states (MBSs) would be a significant breakthrough.

We introduce a novel approach to designing MBSs, based on the geometric confinement of 2D nodal topological superconductors. We illustrate this mechanism in a superconducting extension of the Haldane model. In 2D, the model displays a nodal topological superconducting phase with chiral Majorana modes. However, by confining one of the dimensions the bulk bands gap out faster than the edge states, allowing for their hybridization and potentially resulting in Majorana zero modes. We assess their emergence by computing the topogical invariant for the quasi-1D setup and inspecting the energy spectrum of open flakes. Their topological nature is confirmed by the zero bias conductance in a normal-superconducting junction, precisely quantized to $2\frac{e^2}{h}$ in presence of an MBS. Our findings indicate quantum confinement as a crucial ingredient for developing quasi-1D topological superconducting phases starting from 2D nodal topological superconductors.

TT 48.5 Thu 16:15 H32

Absence of gapless Majorana edge modes in few-leg bosonic flux ladders — •Felix A. Palm[1,2], Cécile Repellin[3], Nathan Goldman[2,4], and Fabian Grusdt[1] — [1]LMU Munich & MCQST, Munich, Germany — [2]Université Libre de Bruxelles, Brussels, Belgium — [3]Université Grenoble-Alpes, Grenoble, France — [4]Laboratoire Kastler Brossel, Collège de France, Paris, France

Non-Abelian phases of matter, such as certain fractional quantum Hall states, are a promising framework to realize exotic Majorana fermions. Quantum simulators provide unprecedented controllability and versatility to investigate such states, and developing experimentally feasible schemes to realize and identify them is of immediate relevance. Motivated by recent experiments, we consider bosons on coupled chains, subjected to a magnetic flux and experiencing Hubbard repulsion. At magnetic filling factor $\nu = 1$, similar systems on cylinders have been found to host the non-Abelian Moore-Read Pfaffian state in the bulk.

Here, we address the question whether more realistic few-leg ladders can host this exotic state and its chiral Majorana edge states. We perform extensive DMRG simulations and determine the central charge of the ground state. While we do not find any evidence of gapless Majorana edge modes in systems of up to six legs, exact diagonalization of small systems reveals evidence for the Pfaffian state in the entanglement structure. By systematically varying the number of legs and monitoring the appearance and disappearance of this signal, our work highlights the importance of finite-size effects for the realization of exotic states in experimentally realistic systems.

TT 49: Graphene and 2D Materials (joint session TT/HL)

Time: Thursday 15:00–18:30 Location: H33

TT 49.1 Thu 15:00 H33

Magnetotransport of the Radial Rashba Spin-Orbit Coupling in Proximitized Graphene — •Wun-Hao Kang[1,2], Ming-Hao Liu[1,2], and Denis Kochan[2,3] — [1]Department of Physics, National Cheng Kung University, Tainan 70101, Taiwan — [2]Center for Quantum Frontiers of Research and Technology (QFort), National Cheng Kung University, Tainan 70101, Taiwan — [3]Institute of Physics, Slovak Academy of Sciences, 84511 Bratislava, Slovakia

Graphene-based van der Waals heterostructures take advantage of tailoring spin-orbit coupling (SOC) in the graphene layer by the proximity effect. The proximity effect can be effectively modeled by the tight-binding Hamiltonian involving novel SOC terms[1] and allows for an admixture of the tangential and radial spin-textures[2]. Taking such effective models we perform realistic large-scale magnetotransport calculations–transverse magnetic focusing–and show that there are unique qualitative and quantitative features allowing for an unbiased experimental disentanglement of the conventional Rashba SOC from its novel radial counterpart, called here the radial Rashba SOC. Along with that, we propose a scheme for a direct estimation of the Rashba angle by exploring the magneto response symmetries when swapping an in-plane magnetic field[3].

[1] M. Gmitra et al., Phys. Rev. B 93, 155104 (2016).
[2] K. Zollner et al., Phys. Rev. B 108, 235166 (2023).
[3] W.-H. Kang et al., Phys. Rev. Lett. 133, 216201 (2024).

TT 49.2 Thu 15:15 H33

Nonequilibrium Spin Transport in Graphene Proximitized by WSe_2 — •Ming-Hao Liu — Department of Physics, National Cheng Kung University, Tainan 70101, Taiwan

Spin-orbit coupling (SOC) in graphene is known to be negligibly weak, on the order of 0.1 meV, due to its composed atom, carbon, a light element of atomic number only 6. A decade ago, it was found that the SOC in graphene can be significantly enhanced simply by attaching it to a transition metal dichalcogenide of strong SOC, known as the spin-orbit proximity effect. Our recent theoretical work in collaboration with a transport experiment on graphene proximitized by WSe_2 reported a supporting number for the SOC as strong as 12.6 meV [1]. Inspired by this finding, here I present numerical results on nonequilibrium spin Hall accumulation in graphene/WSe_2 heterostructures based on the Landauer-Keldysh formalism [2]. Combined with the recently discussed radial Rashba SOC [3], nonequilibrium spin precession will be shown, paving an alternative way to realize the Datta-Das spin transistor.

[1] Q.Rao *et al.*, Nat. Commun. **14**, 6124 (2023);
[2] B.K.Nikolic *et al.*, Phys. Rev. Lett. **95**, 046601 (2005);
[3] W.-H.Kang,M.Barth,A.Costa,A.Garcia-Ruiz,A.Mrenca-Kolasinska, M.-H.Liu, D.Kochan, Phys. Rev. Lett. **133**, 216201 (2024).

TT 49.3 Thu 15:30 H33

Resistively Detected Electron Spin Resonance and g Factor in Few-Layer Exfoliated MoS_2 Devices — •Chithra H. Sharma[1,2], Appanna Parvangada[2], Lars Tiemann[2], Kai Rossnagel[1,3], Jens Martin[4], and Robert H. Blick[2,5] — [1]Christian-Albrechts-Universität zu Kiel, 24098 Kiel, Germany — [2]Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Germany — [4]Leibniz Institut für Kristallzüchtung, 12489 Berlin, Germany — [5]University of Wisconsin-Madison, University Ave. 1550, Madison, 53706, Wisconsin, USA

MoS_2 has recently emerged as a promising material for enabling quantum devices and spintronic applications. In this context, the demonstration of resistively detected electron spin resonance (RD-ESR) and the determination and improved physical understanding of the g factor are of great importance. However, its application and RD-ESR studies have been limited so far by Schotttky or high-resistance contacts to MoS_2. Here, we exploit naturally n-doped few-layer MoS_2 devices with ohmic tin (Sn) contacts that allow the electrical study of spin phenomena. Resonant excitation of electron spins and resistive detection is a possible path to exploit the spin effects in MoS_2 devices. Using RD-ESR, we determine the g factor of few-layer MoS_2 to be $\approx$1.92 and observe that the g factor value is independent of the charge carrier density within the limits of our measurements.

TT 49.4 Thu 15:45 H33

Unifying Recent Experiments on Spin-Valley Locking in TMDC Quantum Dots — Aakash Shandilya[1], Sundeep Kapila[2], Radha Krishnan[3], Bent Weber[3], and •Bhaskaran Muralidharan[2] — [1]Department of Physics, IIT Bombay, Powai, Mumbai-400076, India — [2]Department of Electrical Engineering, IIT Bombay, Powai, Mumbai-400076, India — [3]Division of Physics and Applied Physics, School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore 637371, Singapore

The spin-valley qubit promises significantly enhanced spin-valley lifetimes due to strong coupling of the electrons* spin to their momentum (valley) degrees of freedom. Very recently, few experiments on TMDC quantum dots have, for the first time, shared evidence for spin-valley locking at the few-electron limit. Employing quantum transport theory, we numerically simulate the ground- and excited-state transport spectroscopy signatures of these experiments under diverse conditions through a unified theoretical framework, and reveal the operating conditions, based on intrinsic properties, for spin- valley locking. We thus provide a method to experimentally deduce the degree of spin-valley locking based on the SOC strength, inter-valley mixing, and the spin and valley g-factors. Our theoretical analysis provides an important milestone towards the next challenge of experimentally confirming valley-relaxation times using single-shot projective measurements.

[1] A.Shandilya, S.Kapila, R.Krishna, B.Weber B.Muralidharan, ArXiv:2410.21814 (2024).

TT 49.5 Thu 16:00 H33

Estimation of Relaxation Parameters of Spin-Valley Qubits Via Readout Simulations — •Sundeep Kapila, Aparajita Modak, and Bhaskaran Muralidharan — Department of Electrical Engineering, IIT Bombay, Powai, Mumbai-400076, India

Two dimensional (2D)-material quantum dot systems, can host multiple qubit possibilities, namely, spin, valley and the spin-valley qubits. The spin-valley qubit, often referred to as the Kramers qubit, is of special interest due to the possibility of long relaxation and coherence times. Experimentally, such long relaxation times (T_1) have been demonstrated in the bilayer graphene (BLG) platform via Elzerman single-shot readout techniques [1-3]. However, there is a lack of comprehensive synergy in explaining the experimental trends in the relaxation times of different types of qubit possibilities, especially at low magnetic fields [1-3]. Here, we present a detailed master equation-based simulation approach to mimic the Elzerman readout schemes to understand the experimental data presented and to characterize the relaxation processes. Our approach allows us to directly extract from the experimental data, the relaxation rates for individual decay processes. We then extend our analysis to unify various experimental data observed across varying conditions in the BLG platform [1-3]. Our analysis backed up by dedicated machine learning algorithms also enables the extension of the model to qubit systems in the transition metal dichalcogenide platform.

[1] Ennslin et al., Arxiv, Mar 2024
[2] Stampfer et al., Arxiv, Feb 2024
[3] Stampfer et al., Nat. Commun. (2022)

TT 49.6 Thu 16:15 H33

Quantum transport in graphene-based Chern mosaics — •Patrick Wittig[1], Fernando Dominguez[1,2], and Patrik Recher[1,3] — [1]Institute of Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Faculty of Physics and Astrophysics and Würzburg-Dresden Cluster of Excellence ct.qmat, University of Würzburg, 97074 Würzburg, Germany — [3]Laboratory of Emerging Nanometrology, 38106 Braunschweig, Germany

Chern mosaics [1] are systems composed of domains with different Chern numbers within the bulk of the material. Here, the difference in the Chern number between neighboring domains leads to the emergence of chiral boundary modes that propagate along their interface. In our research, we construct a phenomenological scattering network theory based on the symmetries of the system to model the propagation of these chiral modes in triangular and kagome lattice structures, which can arise in graphene-based systems with characteristic valley-chiral edge modes. In particular, we investigate effects such as energy-dependent scattering [2] and spin-orbit coupling [3] within these

networks to analyze the spectrum and transport properties.
[1] S. Grover et al., Nat. Phys. **18**, 885 (2022).
[2] P. Wittig et al., Phys. Rev. B **108**, 085431 (2023).
[3] P. Wittig et al., Phys. Rev. B **109**, 245429 (2024).

TT 49.7 Thu 16:30 H33

Effects of relaxation in deformed graphene structures — Jan Verlage[1], Thomas Stegmann[2], and •Nikodem Szpak[1] — [1]Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany — [2]Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, Cuernavaca, Mexico

It is known that locally deformed graphene creates strong pseudomagnetic fields (of over 100 T) giving rise to Landau levels and being crucial elements of various valleytronic devices. However, taking into account the atomic relaxation of such structures may lead to reduction and regularization of the strain. Here, we revise these effects in various previously studied setups, including membranes and bumps. Our numerical simulations indicate that the atomic relaxation induces a reduction of the pseudomagnetic field by a factor of $5 \div 10$. It may have several consequences for applications.

15 min. break

TT 49.8 Thu 17:00 H33

Landau level mixing in moderately disordered graphene junctions — •Yu-Ting Hsiao and Ming-Hao Liu — Department of Physics,National Cheng Kung University,Tainan 70101,Taiwan

Landau levels are quantized eigenenergy levels in two-dimensional (2D) systems in the presence of an applied perpendicular magnetic field. They are the basic origin of the (integer) quantum Hall effect (QHE). To observe the QHE, i.e., electrical conductance quantized into a sequence of an integer multiple of the universal conductance quantum $\nu * \frac{e^2}{h}$, the sample quality and the strength of the magnetic field typically play the most decisive roles. The cleaner the sample, the weaker the magnetic field required to form the Landau levels. Collaborating with the experiment group led by Prof. Wei Yang from the Institute of Physics(CAS), China, who observed phase shifts of quantized conductance plateaus in ultraclean two-terminal, single-gated graphene devices. From our quantum transport simulations with a systematic tuning of different parameters that could influence the conductance behavior of the graphene device, we found that the experimentally observed phase shift shall arise from the mixing of Landau levels across two neighboring regions with slightly different doping concentrations. Interestingly, we found that the Landau level mixing occurs only when the graphene sample is moderately disordered. In the purely ballistic regime or under strong disorder, the Landau levels mixing fails to form. Our finding reveals a counter-intuitive role played by disorder, possibly also required in other fundamental transport phenomena, such as the Shubnikov-de Haas oscillation.

TT 49.9 Thu 17:15 H33

Dirac meets flat bands: Topological Mottness swap over through hybridization control — Siheon Ryee[1], •Niklas Witt[2,1,3], Lennart Klebl[2,1], Jennifer Cano[4,5], Giorgio Sangiovanni[2], and Tim Wehling[1,3] — [1]Universität Hamburg — [2]JMU Würzburg — [3]Hamburg Centre for Ultrafast Imaging — [4]Stony Brook University — [5]CCQ

Graphene-based multilayer systems provide a versatile platform to explore the interplay between correlation physics and topology. These systems' unique electronic properties arise from their low-energy bands, characterized by significant Berry curvature originating from graphene's Dirac bands, which is believed to play a crucial role in stabilizing emergent correlated states such as superconducting order and various pseudomagnetic states. In this work, we investigate single-site functionalized graphene, where the Dirac bands hybridize with a correlated flat band of localized orbitals. Our findings based on dynamical mean-field theory (DMFT) calculations reveal a hybridization-driven transition between two symmetry-distinct Mott insulators with a protected metallic state emerging in between. Density functional theory (DFT) calculations suggest that the topological transition observed in our model system is achievable in real materials, specifically through the proximity coupling of epitaxial graphene on SiC with group IV intercalants. Unlike phenomena in other correlated graphene-based platforms, such as twisted bilayer graphene and rhombohedral graphene multilayers, the topology-enforced Mottness swap over occurs at a much higher energy scale of electron-volts.

TT 49.10 Thu 17:30 H33

Magnetism in monolayer graphene near 1/4 doping — •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 flat-band 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 [2], but unlike other lattices [3] its magnetic properties beyond half filling are mostly unexplored, except at 1/4 doping [4]. Here, we present our analysis of graphene magnetism using a combination of the Hubbard model and Hartree-Fock mean-field theory. We work at density values around 1/4 doping (average number of electron per site N_e=0.75) as it puts the system right into one of the Van Hove singularities found in graphene's density of states, giving rise to interesting magnetic properties. We present an interaction-density phase diagram and its associated magnetic orders, described by their band structure and spin structure factor.
[1] Y. Cao et al., Nature 556, 43 (2018); Nature 556, 80 (2018).
[2] M. Raczkowski et al., Phys. Rev. B 101, 125103 (2020), and Refs. therein.
[3] R. Scholle et al., Phys. Rev. B 108, 035139 (2023).
[4] S. Jiang, A. Mesaros, Y. Ran, Phys. Rev. X 4, 031040 (2014).

TT 49.11 Thu 17:45 H33

Electronic transport and anti-super-Klein tunneling in few-layer black phosphorus — •Jorge Alfonso Lizarraga Brito[1], Yonatan Bentancur Ocampo[2], and Thomas Stegmann[1] — [1]Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, Cuernavaca, México — [2]Instituto de Física, Universidad Nacional Autónoma de México, Ciudad de México, México

The electronic transport of few-layer black phosphorus is analyzed theoretically. This work was performed using recent experimental results obtained by μ-ARPES, where tight-binding parameters up to the 4th nearest neighbors within and between the layers were estimated. It is confirmed that the anisotropic band structure of few-layer black phosphorus leads to highly anisotropic transport properties. Most prominently, it is found that the electrons can pass through a potential barrier aligned in a certain crystallographic direction, while for potential barriers rotated by 90 degrees, the transport is completely blocked (anti-super-Klein tunneling). Finally, the study was extended to the case where the top layer of the system is oxidized, showing that the electronic transport is significantly reduced in the oxidized layers, whereas it can be largely unaffected in the central layers.

TT 49.12 Thu 18:00 H33

Pressure-induced structural phase transitions in the van der Waals multiferroic $CuCrP_2S_6$ — •Swarnamayee Mishra[1] and Jochen Geck[1,2] — [1]Institute for Solid State and Materials Physics, TU Dresden, D-01062 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, D-01062 Dresden, Germany

Two-dimensional (2D) crystals with strong in-plane covalent bonds and weak van der Waals (vdW) interlayer interactions have garnered significant attention following the discovery of graphene and its remarkable properties. $CuCrP_2S_6$ (CCPS) is a promising 2D material exhibiting antiferromagnetic behavior due to the collective ordering of Cr^{3+} spins and antiferroelectric properties driven by Cu+ ion ordering. As a type-I multiferroic, CCPS is particularly notable for its coexistence of antiferroelectricity and antiferromagnetism, coupled with strong polarization-magnetization interactions. These ferroic properties arise from spin-orbit coupling associated with crystal symmetry breaking. Despite its potential, a detailed pressure-dependent crystallographic study of CCPS remains unexplored. In this work, we address this gap using high-pressure single-crystal X-ray diffraction (XRD) to investigate the interplay between structural changes and the material's ferroic behaviors. Our study reveals a phase transition from the low-pressure monoclinic Pc phase to the high-pressure monoclinic C2/c phase at low temperatures, providing new insights into the structure-property relationships of this promising 2D vdW material.

TT 49.13 Thu 18:15 H33

^{31}P NMR studies of quasi-two-dimensional (2D) magnetic correlations in $ACrP_2S_6$ (A = Cu, Ag) — •Saramgi Sivan[1,2], Kizhake Malayil Ranjith[1], Lukas Prager[1,2], Saicha-

RAN 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-01062

The $AA'P_2S_6$ (A, A' = transition metal ions) family of quasi-2D van der Waals materials has proven to be a model system for low-dimensional magnetism. Here we present detailed ^{31}P NMR measurements on the single crystals of $ACrP_2S_6$. The high-temperature single narrow NMR line shows a splitting at about 160 K for $CuCrP_2S_6$, which is attributed to the antiferroelectric (AFE) transition, while a pake-doublet NMR spectrum is observed for $AgCrP_2S_6$ at room temperature, but no AFE transition at lower temperatures. In $CuCrP_2S_6$, 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 $CuCrP_2S_6$ measured at 2.5 T shows a sharp peak due to the critical fluctuations. The T_N is suppressed towards lower temperatures when measured at higher magnetic fields. The $(T_1T)^{-1}(T)$ measured at 7 T shows a broad maximum at about 60 K and a critical enhancement at T_N. On the other hand, $AgCrP_2S_6$ exhibits in-plane AFM order at 20 K, as evidenced by the clear splitting of the NMR spectra, the divergence of $T_1^{-1}(T)$ at T_N, and a broad maximum in the NMR Knight shift. In contrast to $CuCrP_2S_6$, the $(T_1T)^{-1}(T)$ shows only a critical enhancement around T_N without a broad anomaly.

TT 50: Superconducting Electronics: SQUIDs, Qubits, Circuit QED II

Time: Thursday 15:00–18:30 Location: H36

TT 50.1 Thu 15:00 H36

Development of ultrasensitive dc SQUIDs with sub-micrometric circuit elements — •MAURO ESATTORE[1], MICHAEL PAULSEN[2], JÖRN BEYER[2], OLIVER KIELER[1], MARK BIELER[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

The dc SQUID is one of the most established applications of superconductor technology. Their sensitivity to magnetic flux allows for numerous applications, such as low-temperature thermometry or current sensing for electrical metrology. In this contribution, we present superconducting "fine-pitch" input coils with sub-micrometric parameters to be integrated into existing Nb/Al-AlO$_x$/Nb-based SQUID sensor designs. The aim is to reduce inductive losses of the signal-to-SQUID coupling, without compromising the overall device layout. In a SQUID current sensor, to maximize the inductive coupling constant k between the signal input coil and the SQUID loop means to achieve a low coupled energy sensitivity $\epsilon_c = (1/k^2)\times\epsilon$ - where ϵ is the SQUID-intrinsic energy sensitivity. Fine-pitch input coils will increase k, as well as extend the range of input coil inductances for our existing devices. The energy sensitivity $\epsilon \propto \sqrt{C}$: reduced Josephson junction (JJ) sizes will lower the capacitance C and improve ϵ_c. Thus, we are refining our JJ definition process to obtain JJs with sub-micrometric lateral size. The contribution will provide details on the fabrication process and design aspect of the sensors, as well as characterization results.

TT 50.2 Thu 15:15 H36

Superconducting Pb stripline resonators: Role of coupling and applications in spectroscopy — ELIES BEN ACHOUR, CENK BEYDEDA, GABRIELE UNTEREINER, MARTIN DRESSEL, and •MARC SCHEFFLER — 1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

Planar superconducting microwave resonators play an important role for various research directions in solid state physics and quantum technologies. Here we investigate superconducting lead (Pb) stripline resonators, which we probe at various harmonics between 0.7 GHz and 6 GHz and at temperatures between 1.5 K and 7 K.

We discuss on general grounds how the loaded quality factor Q_L of a planar microwave resonator made of a conventional superconductor should depend on temperature and frequency. We consider contributions due to dissipation by thermal quasiparticles Q_{QP}, due to residual dissipation Q_{Res}, and due to coupling Q_C. We focus on the role of coupling, and we compare resonators with different coupling capacitance. For the Pb resonators, we find a strongly frequency- and temperature-dependent Q_L, which we can describe by a lumped element model. For certain resonators at the lowest studied temperatures we observe a maximum in the frequency-dependent Q_L when Q_{Res} and Q_C match, and here the measured Q_L can exceed 2×10^5.

We also present the application of such Pb stripline resonators for microwave spectroscopy at temperatures down to the mK range.

TT 50.3 Thu 15:30 H36

Hybrid Microwave Resonators Integrated with van der Waals Superconductors — •YEJIN LEE[1], HAOLIN JIN[1,2], GIUSEPPE SERPICO[1,3], TOMMASO CONFALONE[2,4], BERIT GOODGE[1], EDOUARD LESNE[1], KORNELIUS NIELSCH[2,4], NICOLA POCCIA[3,4], and URI VOOL[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Technische Universität Dresden, Germany — [3]University of Naples Federico II, Italy — [4]Leibniz Institute for Solid State and Materials Science Dresden, Germany

Superconducting microwave resonators are highly coherent devices that are extensively used in quantum circuits. Their robustness and sensitivity also make them excellent probes for exploring novel materials, which are coupled to them in a hybrid system. Particularly good candidates are van der Waals materials, whose microscopic size makes them incompatible with conventional bulk measurement methods. However, such hybrid platforms require the development of a new process to maintain the high quality of the circuit. We present a technique to integrate a microwave resonator with a superconducting thin van der Waals flake with a crystalline-preserved interface. We investigate their microwave response as a function of temperature under various microwave powers and magnetic field. The hybrid resonator exhibits a significant modification in its resonant mode with the presence of the flake while maintaining a high-quality factor. Hybrid superconducting circuits integrated with vdW crystals offer an extensive potential in probing materials' unique properties and for developing high-quality devices for quantum technology.

TT 50.4 Thu 15:45 H36

Two-level system involved nonlinear response in van der Waals hybrid microwave resonators — •HAOLIN JIN[1,3], GIUSEPPE SERPICO[1,2], YEJIN LEE[1], BERIT GOODGE[1], EDOUARD LESNE[1], NICOLA POCCIA[2,3], and URI VOOL[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]University of Naples Federico II, Italy — [3]Leibniz Institute for Solid State and Materials Science Dresden, Germany

Two-level system (TLS) bath is considered as the main loss channel in coplanar superconducting microwave resonators and is often associated with an upshift in resonance frequency as the temperature increases. The individual TLS can be saturated at the high input power, improving the quality factor of the resonator. However, the resonance frequency upshift remains unaffected by driving power because all TLS at different energy can contribute to the frequency shift, whereas only those close to the resonance frequency can be saturated. Here, we observed a positive nonlinearity in a van der Waals superconductor integrated hybrid resonator device. The hybrid device exhibited a significant upshift in resonance frequency with increasing temperature, indicating strong coupling to a TLS bath. It maintained a high-quality factor despite this coupling. These findings suggest that the resonance mode in the hybrid device is coupled to an off-resonant TLS bath and the hybrid system provides a new source of lossless nonlinearity unrelated to the Josephson effect. This work opens a path towards high quality hybrid superconducting circuits with vdW materials and highlights the development of new devices for quantum technology.

TT 50.5 Thu 16:00 H36

Dielectric waveguide setup tested with a superconducting millimeter-wave Fabry-Pérot interferometer at milli-Kelvin temperatures — •JAKOB LENSCHEN[1], HANNES ROTZINGER[1,2], and ALEXEY V. USTINOV[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie — [2]Institut für Quantenmaterialien und Technologie (IQMT), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany

Superconducting quantum circuits operating at mm-wave frequencies of around 100 GHz may offer many interesting new possibilities. The order of magnitude higher photon energy compared to current implementations and the wider bandwidth would not only improve the resilience to thermal fluctuations, but could also speed up qubit manipulation. Millimeter-wave measurements at ultra-low temperatures are largely unexplored due to several technical difficulties, such as a difficult signal path isolation and thermalization. We have developed a cryogenic setup consisting of dielectric waveguides and a superconducting Fabry-Pérot cavity located at the dilution cryostat base temperature. We show that the quality of the mm-wave signal guided to and from a temperature of 10 mK is sufficient to measure resonator cavity quality factors of over one million at 110 GHz in the few photon limit.

TT 50.6 Thu 16:15 H36

Resonant escape in Josephson tunnel junctions under millimeter-wave irradiation — •Jonas N. Kämmerer[1], Sergei Masis[1], Karo Hambardzumyan[1], Philipp Lenhard[1], Urs Strobel[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

Operating superconducting quantum circuits at mm-wave frequencies around 100 GHz promises several advantages. For example, it may allow for much higher operating temperatures above 1 K and faster qubit manipulation. We study the microwave-driven dynamics of a superconducting phase qubit made of Nb/AlO$_x$/Nb junction. In particular, we have measured the switching current distributions at radiation frequencies above 100 GHz and observed clear double-peak structures. The data indicate a resonant escape of the phase as well as an irradiation-induced suppression of the potential barrier. This behavior is well described by the strong-driving model of the resonant escape[1]. While being measured in the quasi-classical regime of thermally activated escape, our results point towards a feasibility of operating phase qubits at mm-wave frequencies.

[1] M.V.Fistul,A.Wallraff,A.V.Ustinov, Phys.Rev.B**68**, 060504 (2003).

15 min. break

TT 50.7 Thu 16:45 H36

Heat transport in the quantum Rabi model: Universality and ultrastrong coupling effects — 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

Heat transport in a qubit-oscillator junction weakly coupled to heat baths displays a rich variety of effects depending on the junction parameters. Signatures of the transition to the regime of ultrastrong qubit-oscillator coupling appear in the thermal conductance, current, and rectification. For example, upon increasing the coupling, the conductance as a function of a bias applied to the qubit undergoes a transition from a resonant to a broadened, zero-bias peak behavior. At low temperatures, coherent heat transfer via virtual processes yields a universal power-law behavior in the linear conductance as a function of the temperature. In addition, the low-temperature conductance is modulated by a prefactor which unravels the multilevel nature of the junction: A coherent suppression arises in the presence of quasi-degeneracies in the spectrum. At higher temperatures, sequential processes dominate heat transfer and a scaling regime is found when quantities are scaled with a coupling-dependent Kondo-like temperature.

[1] L.Magazzù, E.Paladino, M.Grifoni, Phys.Rev.B110, 085419 (2024);
[2] L.Magazzù, E.Paladino, M.Grifoni, arXiv:2403.06909 (2024).

TT 50.8 Thu 17:00 H36

Gauging away the ground-state photon content of the quantum Rabi model — •Arka Dutta, Daniel Braak, and Marcus Kollar — Theoretische Physik III, University of Augsburg

The quantum Rabi model (QRM) features the simplest type of coupling between a single cavity light mode and an atomic electron. It is integrable if the electronic degree of freedom is truncated to just two states [1]. The derivation of the effective Hamiltonian leads to different forms depending on the chosen gauge [2]. In the dipole gauge, the ground state of the QRM exhibits non-zero photon number in contrast to its weak coupling approximation, the Jaynes-Cummings model. We compute the exact photon content for all eigenstates in an arbitrary gauge and obtain a gauge for which the ground state contains no photons. Thus only this gauge fits the intuitive understanding that the cavity should be empty in the lowest energy state even for strong light-matter interaction.

[1] D. Braak, Phys. Rev. Lett. **107**, 100401 (2011).
[2] O. Di Stefano et al., Nat. Phys. **15**, 803 (2019).

TT 50.9 Thu 17:15 H36

Dispersive and dissipative interactions in niobium-based photon-pressure circuits — •Zisu Emily Guo, Mohamad el Kazouini, Janis Peter, Kevin Uhl, Dieter Koelle, Reinhold Kleiner, and Daniel Bothner — Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, Universität Tübingen

Photon-pressure (PP) circuits consist of one superconducting microwave resonator in the GHz range and one low-frequency (LF) circuit in the MHz range and are the cQED analog of cavity optomechanics. The LC circuits in a PP device are coupled to each other via a superconducting quantum interference device (SQUID), emulating an optomechanical interaction and offering access to sensing and control of MHz photons with potential applications in axion dark matter detection and quantum information technologies. Here, we report the realization of niobium- and nanoconstriction-based photon-pressure circuits operated in the thermal regime. In contrast to previous implementations, we observe in our experiments both dispersive and dissipative PP coupling - meaning that not only frequency but also linewidth modulations contribute significantly to the overall interaction. We investigate dynamical backaction effects with these dissipative contributions as well as sideband-cooling of the LF mode, measured through photon-pressure-induced transparency and output noise thermometry, respectively. Additionally, our circuit design with on-chip flux-bias line allows the parametric modulation of the LF mode resonance frequency, which may be used for LF squeezing and (phase-sensitive) amplification of the PP coupling rate.

TT 50.10 Thu 17:30 H36

Exact and Dispersive Models for Superconducting Networks — •Adrian Parra-Rodriguez — Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — Institute of Fundamental Physics IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain — Institut Quantique and Département de Physique, Université de Sherbrooke, Sherbrooke, Quebec J1K 2R1, Canada

In this presentation, I will address the construction of exact quantum mechanical models for quasi-lumped electrical networks [1,2], comprising (nonlinear) capacitors, inductors, nonreciprocal elements (circulators), and transmission lines (TLs). Traditional quantization methods, such as node-flux or loop-charge approaches, often lead to singularities and unphysical predictions, stemming from incorrect identification of the TLs' infinite-dimensional Hilbert space. Using a geometrical description [1] and the Faddeev-Jackiw method, we resolve these issues via a mixed charge-flux first-order quantization. I will also introduce a systematic method to construct effective dispersive Lindblad master equations for weakly anharmonic superconducting circuits coupled by generic linear nonreciprocal systems, deriving coupling parameters and decay rates from the coupler's immittance parameters [3]. Extending the work of Solgun et al. (2019) on reciprocal couplers, this approach includes nonreciprocal elements, stray coupling, and collective dissipative effects from external environments, while avoiding potential singularities.

[1] A. Parra-Rodriguez et al., Quantum 8, 1466 (2024);
[2] A. Parra-Rodriguezet al., arxiv:2401.09120;
[3] Labarca et al., Phys. Rev. App. 22, 034038 (2024).

TT 50.11 Thu 17:45 H36

Nonlinear High-Kinetic-Inductance Microstrips for Integrated Non-Reciprocal Devices — •Niklas Gaiser[1], Ciprian Padurariu[1], Björn Kubala[1,2], Nadav Katz[3], and Joachim Ankerhold[1] — [1]ICQ and IQST, University of Ulm, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [3]The Racah Institute of Physics, The Hebrew University of Jerusalem, Israel

Superconducting microwave circuits offer a rich platform for many quantum information devices and quantum-technological applications. Recently, nonlinear properties of circuit elements have become of increasing interest as they allow new functionalities, such as frequency mixing or self-interaction of waves. Microstrip waveguides with high-kinetic-inductance, as experimentally realized in [1], possess strong nonlinear features. Moreover, they yield a greatly reduced phase velocity which addresses the challenge of long wavelengths in the microwave regime and enable highly compact and integrated on-chip solutions.

Here, we present a theoretical proposal for a devices that utilizes a nonlinear high-kinetic-inductance to achieve a non-reciprocal effect. Diode-like behaviour is proven with markedly dissimilar transmission spectra for signals propagating through the device in different directions. We discuss the nonlinearities' power dependence as well as the special boundary conditions posed by the nonlinear propagation problem.

[1] S. Goldstein, G. Pardo, N. Kirsh, N. Gaiser, C. Padurariu, B. Kubala, J. Ankerhold, N. Katz, New J. Phys. 24, 023022 (2022).

TT 50.12 Thu 18:00 H36

Observation and Modelling of Self-Sustained Oscillations in Non-Linear Cavity-Optomechanics — •Korbinian Rubenbauer[1,2], Shivangi Dhiman[4], Thomas Luschmann[1,2], Achim Marx[1,2], Rudolf Gross[1,2,3], Anja Metelmann[4,5], 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 Technology, Munich, Germany — [4]Institute for Theory of Condensed Matter and Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, Karlsruhe, Germany — [5]Institut de Science et d'Ingénierie Supramoléculaires, University of Strasbourg and CNRS

Quantum sensing uses quantum elements or quantum principles to detect an external stimulus. In this context, cavity-electromechanics focuses on mechanical sensor elements dispersively coupled to a microwave resonator. This setting typically uses linear mechanical elements and linear microwave cavities. Here, we discuss the case of a non-linear or Kerr microwave resonator as a readout circuit. Our device integrates a mechanically compliant nanostring into a superconducting quantum interference device (SQUID), which is part of a flux-tunable superconducting resonator. This enables large tunable single-photon optomechanical coupling. We present an experimental and theoretical study investigating the impact of the Kerr nonlinearity on the device performance, particularly in the context of mechanical instabilities. We find excellent quantitative agreement.

TT 50.13 Thu 18:15 H36

Engineering Cooper Pair Bunching Using an Anharmonic Environment — •Surangana Sengupta[1], Björn Kubala[1,2], Joachim Ankerhold[1], and Ciprian Padurariu[1] — [1]ICQ and IQST,Ulm University,Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

The electromagnetic environment of superconducting circuits provides exciting opportunities to engineer the tunneling of Cooper pairs. The simplest example is a dc biased Josephson junction in series with a microwave cavity. There has been extensive work showing that when the dc bias is chosen to be resonant with a well-defined cavity mode, the transport of Cooper pairs has the same statistics in the long time limit as that of the photon emission from the cavity mode [1].

In my talk, I extend this study to the case when the cavity mode is anharmonic. I investigate the case when the voltage bias is detuned from the transition between Fock states 0 and 1. Due to the anharmonicity however, this voltage can be resonant with half the transition between Fock states 0 and 2. Therefore, the process of coherent two-Cooper pair tunneling accompanied by two-photon creation is favored compared to single Cooper pair tunneling and single photon creation. This results in bunched Cooper pair tunneling, with Fano factor approaching $F = 2$, and in a squeezed cavity state. I will compare this effect to a similar and competing inelastic co-tunneling process arising from second-order rotating wave approximation.

[1] M. Hofheinz *et al.*, Phys. Rev. Lett. **106**, 217005 (2011).

TT 51: Topological Superconductors

Time: Thursday 16:45–18:15 Location: H32

TT 51.1 Thu 16:45 H32

Disentangling the Individual Junctions in Multi-Terminal Devices — •Josua Thieme[1,2], Nisha Shahi[1], Abdur Rehman Jalil[1], Benedikt Frohn[1], Detlev Grützmacher[1,2], and Peter Schüffelgen[1] — [1]Forschungszentrum Jülich, Germany — [2]RWTH Aachen, Germany

One avenue towards building a topological qubit, is by creating and manipulating Majorana zero modes in a hybrid device made from s-wave superconductors and 3D topological insulators (TIs). Such hybrid multi-terminal devices possess an increased number of interfaces and the coupling between all electrodes needs to be assured. We present low-temperature measurements of a TI-based three-terminal Josephson device fabricated by a combination of selective-are growth of $(BiSb)_2Te_3$ and shadow evaporation of Nb. This approach allows for the in-situ fabrication of Josephson devices with an exceptional interface quality, which is important for obtaining a strong proximity effect. In our measurements, we find quartet resonances, formed by two entangled Cooper pairs. Additionally, we present a method on how to disentangle the contributions of individual junctions in a multi-terminal device.

TT 51.2 Thu 17:00 H32

Non-Hermitian Topology in Multi-Terminal Superconducting Junctions — •Valentin Wilhelm, David Christian Ohnmacht, Hannes Weisbrich, and Wolfgang Belzig — Universität Konstanz, Konstanz, Germany

Recent experimental advancements in dissipation control have yielded significant insights into nonhermitian Hamiltonians for open quantum systems. Of particular interest are the topological characteristics exhibited by these non-hermitian systems, that arise from exceptional points–distinct degeneracies unique to such systems. In this study, we focus on Andreev bound states in multiterminal Josephson junctions with non-hermiticity induced by normal metal or ferromagnetic leads [1]. By investigating several systems of different synthetic dimensions and symmetries, we predict fragile and stable non-hermitian topological phases in these engineered superconducting systems.

[1] D.C. Ohnmacht, V. Wilhelm, H. Weisbrich, W. Belzig, arXiv:2408.01289 (2024).

TT 51.3 Thu 17:15 H32

Localized Edge States in Antiferromagnet-Superconductor Hybrid Structures — •Ignacio Sardinero[1,2], Yuriko Baba[1,2], Rubén Seoane-Souto[3], and Pablo Burset[1,2,4] — [1]Department of Theoretical Condensed Matter Physics, Universidad Autónoma de Madrid, 28049 Madrid, Spain — [2]Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, 28049 Madrid, Spain — [3]Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC), Sor Juana Inés de la Cruz, 3, 28049 Madrid, Spain — [4]Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain

Topological superconductors (TSCs) are promising building blocks for robust and reliable quantum information processing [1]. Most approaches to implement TSCs focus on materials with intrinsic spin-orbit coupling (SOC). However, a recent alternative strategy relies on synthetically engineering spin orbit using spatially varying magnetic fields [2]. Such proximitized structures need to be carefully designed so that the magnetic and superconducting orders coexist, avoiding stray fields detrimental for superconductivity. Here, we circumvent this challenge by investigating the role of antiferromagnetic (AF) textures in proximity to 2-dimensional superconducting surfaces. Our results reveal that the interplay between AF order and the SC coherence length impacts the density of states at the Fermi level. We show that lattice symmetry plays a crucial role for emerging topological phases, with higher-order phases arising when interlayer SOC is considered.

[1] S. Das Sarma et al., npj Quantum Inf. 1, 15001 (2015);
[2] I. Sardinero, R. Seoane-Souto, P. Burset, PRB 110, L060505 (2024).

TT 51.4 Thu 17:30 H32

Proximity-Induced Superconductivity into Thin Films of Magnetic Topological Insulators — •Daniele Di Miceli[1,2], Eduárd Zsurka[1,3], and Thomas Schmidt[1] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg — [2]Department of Physics, University of the Balearic Islands, E-07122 Palma, Spain — [3]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, D-52425 Jülich, Germany

Inducing superconducting (SC) correlations into magnetic topological insulators (MTIs) is becoming a promising route toward topological superconductivity and the realization of topologically protected Majorana bound states. However, a detailed understanding of the proximity effect in such MTI-SC heterostructures is still missing.

To address this question, we have developed a theory for the SC pairing induced by a conventional BCS superconductor on top of a 3D MTI thin film. By performing a perturbation series expansion in the electron tunneling between the SC and the MTI, we computed the corrections to the normal and anomalous Green's functions in the MTI in terms of the unperturbed propagators in the two isolated materials. Since the latter can be obtained exactly as a solution to the Gor'kov equations, this makes it possible to evaluate the Green's functions in the full MTI-SC heterostructures.

Our results provide a detailed description of the induced pairing, in particular showing the existence of p-wave correlations in the MTI.

TT 51.5 Thu 17:45 H32

Topological Classification of Chiral Symmetric One Dimensional Interfaces — •Harry MullineauxSanders and Bernd Braunecker — University of St. Andrews, St. Andrews, United Kingdom

Low dimensional topological phases can be engineered by placing a scattering interface into a higher dimensional bulk where the in-gap bands of quasi low dimensional interface modes can be tuned to a topologically non-trivial phase. However the classification of such modes cannot be done through low-dimensional conventional methods due to the dimensional mismatch and local nature of the topological bands. We demonstrate that there exists a simple and efficient classification method through the local Green's function at the interface, that sidesteps numerically heavy real space computations. We show that the Green's function maintains the protecting symmetries of the Hamiltonian and produces the correct phase diagram, together with a formula disentangling the contributions to the topological invariant from the substrate and the interface. For illustration we apply our method to a model of a spiral magnetic interface in an s-wave superconductor. Furthermore we compare with an alternative classification scheme derived from the spatially reduced ground state projector and show that it can produce an erroneous topological classification due to gap closures driven by the strong entanglement between the internal and spatial degrees of freedom which are naturally contained in the local Green's function. [arXiv:2407.01223]

TT 51.6 Thu 18:00 H32

Role of Spin-Orbit Coupling on Topological Superconductivity from First Principles — •András Lászlóffy[1], Bendegúz Nyári[2], Levente Rózsa[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

Recent developments on magnetic structures on superconductors paved the way to explore topological phases in real materials [1,2]. This was achieved by solving the Kohn-Sham-Dirac Bogoliubov-de Gennes equations within the Korringa-Kohn-Rostoker multiple scattering theory. By investigating 1D magnetic chains on superconductors we demonstrate that the spin-orbit coupling plays a key role in the formation of a topological phase, however, it is challenging to scale it up, because SOC is implicitly included in the Dirac equation. To circumvent this, we calculate the superconducting order parameter and the Shiba band structure of magnetic chains on a Ta overlayer on Nb. Ta has a very similar crystal structure and lattice constant to Nb. It is also a superconductor with a much smaller gap size and a considerably larger SOC. With varying the Ta layer thickness SOC can be tuned in a way which is in principle reproducible in experiments. We show that a few layers of Ta has tiny effects on the energy of the Yu-Shiba-Rusinov states of single adatoms, however, varying the SOC can tune the chains into a topologically non-trivial domain.

[1] Nyári et. al., PRB 108, 134512 (2023);
[2] Lászlóffy et. al., PRB 108, 134513 (2023).

TT 52: Nickelates and Other Complex Oxides

Time: Friday 9:30–11:15 Location: H31

TT 52.1 Fri 9:30 H31

High-temperature superconductivity and polymorph structures in $La_3Ni_2O_7$ — •Matthias Hepting[1], Pascal Puphal[1], Pascal Reiss[1], Niklas Enderlein[2], Yu-Mi Wu[1], Vignesh Sundaramurthy[1], Peter A. van Aken[1], Hidenori Takagi[1], Bernhard Keimer[1], Y. Eren Suyolcu[1], Björn Wehinger[3], and Philipp Hansmann[2] — [1]Max-Planck-Institute for Solid State Research, Stuttgart, Germany — [2]University of Erlangen-Nürnberg, Erlangen, Germany — [3]ESRF, Grenoble, France

The recent discovery of high-temperature superconductivity in $La_3Ni_2O_7$ under high pressure has drawn considerable interest [1]. Using high-resolution synchrotron x-ray diffraction and scanning transmission electron microscopy, we observed that $La_3Ni_2O_7$ single crystals which show signs of filamentary superconductivity exhibit a crystal structure composed of alternating monolayer (ML) and trilayer (TL) units [2]. This lattice architecture diverges significantly from the previously assumed bilayer configuration [1]. In addition, we employed density functional theory to examine the distinct contributions of the ML and TL structural units to the electronic structure of the $La_3Ni_2O_7$ polymorph. In combination with recent angle resolved photoemission spectroscopy experiments [3], our findings set the stage for future investigations into unique properties of the ML-TL polymorph and the possibility of bulk high-temperature superconductivity.

[1] H. Sun et al., Nature 621, 493 (2023);
[2] P. Puphal et al., Phys. Rev. Lett 133, 146002 (2024);
[3] S. Abadi et al., arXiv:2402.07143

TT 52.2 Fri 9:45 H31

Theory of potential impurity scattering in pressurized superconducting $La_3Ni_2O_7$ — •Steffen Bötzel[1], Frank Lechermann[1], Takasada Shibauchi[2], and Ilya Eremin[1] — [1]Theoretische Physik III, Fakultät für Physik und Astronomie, Ruhr-Universität Bochum — [2]Department of Advanced Materials Science, The University of Tokyo, Kashiwa, Chiba 277-8561, Japan

We study the effect of the point-like non-magnetic impurities on the superconducting state of La-327 and show that the interlayer $s_\pm$-wave and d-wave symmetries show a very different behavior as a function of impurity concentration, which can be studied experimentally by irradiating the La-327 samples by electrons prior applying the pressure. While $d-$wave superconducting state will be conventionally suppressed, the $s_\pm$-wave state shows more subtle behavior, depending on the asymmetry between bonding and antibonding subspaces. For the electronic structure, predicted to realize in La-327, the $s_\pm-$wave state will be robust against complete suppression and the transition temperature, T_c demonstrates a transition from convex to concave behavior, indicating a crossover from $s_\pm$-wave to s_{++}-wave symmetry as a function of impurity concentration. We further analyze the sensitivity of the obtained results with respect to the potential electronic structure modification.

TT 52.3 Fri 10:00 H31

Surface effects in infinite layer nickelates — •Leonard M. Verhoff[1], Liang Si[1,2], and Karsten Held[1] — [1]Institute of Solid State Physics, TU Wien, Vienna, Austria — [2]School of Physics, Northwest University, Xi'an, China

Nickelates have emerged as a compelling platform for studying high-temperature superconductivity, drawing comparisons to cuprates. Infinite layer rare-earth (R) nickelates, $RNiO_2$, consist of an alternating stacking of NiO_2 layers and rare-earth spacing layers along the crystallographic z-axis. While their bulk structure has been extensively studied computationally, the samples that exhibit superconductivity in experiments are thin nickelate films. They are synthesized through a chemical reduction process that removes apical oxygen from perovskite $RNiO_3$, often grown on substrates such as $SrTiO_3$ (001).

We explore emerging surface effects by studying the formation of various surfaces within the framework of DFT. While perfect stoichiometry favors a NiO_2-terminated surface, the presence of excess apical oxygen in the surface region – possibly a remnant of the chemical reduction process – might favor an RO-terminated surface. The atomic structures of the studied surfaces strongly influence the local electronic structure in the surface region. These surface effects indicate the absence of an electron pocket around the Γ point – even for $NdNiO_2$ surfaces, in contrast to DFT and *dynamical mean field theory* bulk

calculations.
We acknowledge support through a joint German and Austrian Science Funds (DFG and FWF) project; IWF project ID I5398.

TT 52.4 Fri 10:15 H31

Uniaxial pressure dependencies of the metal-to-metal transition in $P2_1/a$ and $Bmab$ $La_4Ni_3O_{10}$ single crystals — •Lukas Gries, Jan Arneth, Ning Yuan, Ahmed Elghandour, and Rüdiger Klingeler — Kirchhoff Institut for Physics, Heidelberg, Germany

The $n = 3$ Ruddlesden-Popper nickelate $La_4Ni_3O_{10}$ exhibits an intriguing metal-to-metal transition (MMT) accompanied by the evolution of intertwined charge and spin order [1]. We report report high-resolution capacitance dilatometry and magnetisation data on phase-pure single crystals of $P2_1/a$ and $Bmab$ $La_4Ni_3O_{10}$ grown by the high-pressure floating-zone method [2]. Our data show pronounced magnetoelastic coupling at the MMT for both phases. The extracted uniaxial pressure dependencies are negative for the *ab* plane and positive along the *c* axis. The uniaxial pressure dependencies are quantified and the relevant energy scales are investigated via Grüneisen scaling and Ehrenfest analysis.

[1] J. Zhang et al., Nat. Commun. 11, 6003 (2020)
[2] N. Yuan, et al., J Cryst. Growth 627, 127511 (2024)

TT 52.5 Fri 10:30 H31

A versatile microscope for simultaneous optical and thermodynamic investigation of $Ca_3Ru_2O_7$ — •Simli Mishra[1], Elena Gati[1], Fei Sun[1], Hilary Noad[1], Dmitry Sokolov[1], Andrew Mackenzie[1,2], and Veronika Sunko[1,3] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]School of Physics and Astronomy, University of St. Andrews, St. Andrews, UK — [3]Department of Physics, University of California, Berkeley, California, USA

Ruddlesden-Popper-type ruthenates are well-known for hosting intriguing phenomena, including unconventional superconductivity, metal-insulator transitions, spin-orbit coupling, and strange metal behavior. Among these, the bilayer ruthenate $Ca_3Ru_2O_7$ is a polar metal that exhibits strong electronic correlations. It undergoes an antiferromagnetic transition at 56 K and a first-order structural phase transition at 48 K at ambient pressure.

In our experiments, we utilize a versatile, optics-based microscope with high spatial resolution, to investigate quantum materials. The setup has been integrated with a uniaxial pressure cell that enables pressure to be used as both a tuning parameter and a thermodynamic probe. Using this technique, we simultaneously measure the optical reflectivity and the elastocaloric effect to understand the behavior of $Ca_3Ru_2O_7$ as a function of temperature and uniaxial pressure.

TT 52.6 Fri 10:45 H31

Designed cleaving planes in ruthenium dioxide for ARPES experiments — •Marieke Visscher[1,2], Lea Richter[1], Sebastian Buchberger[2], Bruno Saika[2], Andy Mackenzie[1,2], and Phil King[2] — [1]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Straße 40, 01187 Dresden, Germany — [2]Scottish Universities Physics Alliance, School of Physics and Astronomy, University of St Andrews, St Andrews, KY16 9SS, UK

Ruthenium dioxide has a complex band structure, underpinning a variety of phenomena including superconductivity under strain and a Dirac nodal line network. It has also been proposed as a candidate altermagnet, and although recent studies suggest it lacks the requisite magnetic order, it has been shown to host unusual spin-polarised states in its band structure. These phenomena motivate the need for more detailed studies into its electronic structure. Angle-resolved photoemission spectroscopy (ARPES) would be an ideal probe for this, but the three-dimensional structure of ruthenium dioxide makes it difficult to prepare atomically clean and flat surfaces with conventional methods. We have therefore investigated a fabrication method based on Focused Ion Beam (FIB) structuring to stimulate sample cleavage along desired crystallographic planes. With this method, we were able to obtain high quality surfaces, on which we performed ARPES measurements. With this new capability to tailor the sample cleavage, we significantly improve the quality of ARPES data from this compound, opening new perspectives for studying its low-energy electronic structure.

TT 52.7 Fri 11:00 H31

Localized Ti-4s molecular orbitals and correlated 3d states in the bad metal TiO_x — •Daisuke Takegami[1,2], Anna Melendez-Sans[2], Takashi Miyoshino[1], Ryo Nakamura[1], Miguel Ferreira-Carvalho[3,2], Georg Poelchen[2], Chun-Fu Chang[2], Masato Yoshimura[4], Ku-Ding Tsuei[4], Haruka Matsumoto[5], Asuka Yanagida[5], Takuro Katsufuji[5], Liu Hao Tjeng[2], and Takashi Mizokawa[1] — [1]Department of Applied Physics, Waseda University, Japan — [2]Max Planck Institute for Chemical Physics of Solids, Germany — [3]Institute of Physics II, University of Cologne, Germany — [4]National Synchrotron Radiation Research Center, Taiwan — [5]Department of Physics, Waseda University, Japan

We have investigated the electronic structure of the rocksalt TiO_x system using polarizationdependent hard x-ray photoelectron spectroscopy. The spectra showed a vanishingly small intensity at the Fermi level, classifying TiO_x as a bad metal. With the main spectral features attributed to the Ti^{2+} 3d2 configuration, we were able to detect spectroscopically also the co-existence of both Ti and O vacancies. The presence of Ti^{3+} states were identified. It was a surprise not to find signs for Ti1+ entities. Instead a sharp occupied state of Ti 4s origin was unveiled in the valence band, which gave evidence that localized Ti-4s-based molecular orbitals are formed around the O vacancies. Our findings suggest that a defect free and stoichiometric TiO would have been a strongly correlated a Mott-Hubbard insulator, and that the 4s is an important degree of freedom for low-valent 3d materials.

TT 53: Topology: Other Topics

Time: Friday 9:30–12:45 Location: H32

TT 53.1 Fri 9:30 H32

Quantum Geometric Tensor and Inertial Effects — •Maike Fahrensohn and Richard Matthias Geilhufe — Condensed Matter and Materials Theory Division, Department of Physics, Chalmers University of Technology, 41258 Göteborg, Sweden

The quantum geometric tensor (or Fubini-Study metric), defined on a parametrized quantum state manifold, encodes the full geometric structure of quantum space. The real part of the quantum geometric tensor, known as the quantum metric tensor, is a positive semidefinite Riemannian metric that measures the geometric distance between quantum states. This tensor has recently been shown to play a crucial role in the description of physical phenomena such as quantum transport, quantum noise, and optical conductivity. The antisymmetric part of the quantum geometric tensor, proportional to the Berry curvature, has been extensively studied and is central to the classification of topological insulators through their first Chern number.

While inertial effects have been well explored in classical mechanics, their role in quantum systems remains less understood. We build a connection between the quantum geometric tensor and inertial effects to bridge the geometric and topological properties of quantum systems to their physical response. This relationship may offer new insights into transport phenomena, stability, and collective dynamics in quantum systems.

TT 53.2 Fri 9:45 H32

Theory of Quantum Geometry in Unconventional Magnets — •Johannes Mitscherling, Jan Priessnitz, and Libor Smejkal — Max Plank Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany

Metals with altermagnetic spin-polarisation [1] and non-collinear spin textures [2] are emerging platforms exhibiting rich fundamental physics and spintronics applications. Remarkably, this class of materials intrinsically yields a complex interplay of at least two orbital degrees of freedom besides spin. It was recently noticed that such multiband Hamiltonians host previously overlooked geometric invariants beyond the quantum metric and Berry curvature, especially when more than two bands are involved, making altermagnetic and non-collinear magnetic systems promising candidates for novel quantum geometric responses [3]. In this talk, I will introduce a quantum geometric perspective adequate for multiband systems with both spin and orbital degrees of freedom, which helps us to determine and quantify the properties of the nontrivial Bloch states. With this systematic geometric characterization, I will elaborate on a pathway to identify the most promising observables, model parameter regimes, and tuning parameters, simplifying the search for experimental realizations.

[1] L. Smejkal, J. Sinova, T. Jungwirth, PRX 12, 031042 (2022).
[2] A. Birk Hellenes, T. Jungwirth, R. Jaeschke-Ubiergo, A. Chakraborty, J. Sinova, L. Smejkal, arXiv:2309.01607v3.
[3] A. Avdoshkin, J. Mitscherling, J. E. Moore, arXiv:2409.16358.

TT 53.3 Fri 10:00 H32

Topological Order in the Spectral Riemann Surfaces of Non-Hermitian Systems — •Anton Montag[1,2], Alexander Felski[1], and Flore Kiki Kunst[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

We show topologically ordered states in the complex-valued spectra of non-Hermitian systems. These arise when the distinctive exceptional points in the energy Riemann surfaces of such models are annihilated after threading them across the boundary of the Brillouin zone. This process results in a non-trivially closed branch cut that can be identified with a Fermi arc. Building on an analogy to Kitaev's toric code, these cut lines form non-contractible loops, which parallel the defect lines of the toric-code ground states. Their presence or absence establishes topological order for fully non-degenerate non-Hermitian systems. Excitations above these ground-state analogs are characterized by the occurrence of additional exceptional points. We illustrate the characteristics of the topologically protected states in a non-Hermitian two-band model and provide an outlook toward experimental realizations in metasurfaces and single-photon interferometry.

TT 53.4 Fri 10:15 H32

Exceptional Points of Any Order in a Generalized Hatano-Nelson Model — •Julius T. Gohsrich[1,2], Jacob Fauman[1,2], and Flore K. Kunst[1,2] — [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

Exceptional points (EPs) are truly non-Hermitian (NH) degeneracies where matrices become defective. The order of such an EP is given by the number of coalescing eigenvectors. On the one hand, most work focuses on studying Nth-order EPs in ($N \leq 4$)-dimensional NH Bloch Hamiltonians. On the other hand, some works have remarked on the existence of EPs of orders scaling with systems size in models exhibiting the NH skin effect.

In this talk, I introduce a new type of EP and provide a recipe on how to realize EPs of arbitrary order not scaling with system size. Therefore, I introduce a generalized version of the paradigmatic Hatano-Nelson model with longer-range hoppings. The EPs existing in this system show remarkable physical features: Their associated eigenstates have support on a subset of sites and exhibit the NH skin effect, which can be tuned to localize on the opposite end of the chain compared to all remaining states. Furthermore, the EPs are robust against generic perturbations in the hopping strengths as well as against a specific form of on-site disorder.

TT 53.5 Fri 10:30 H32

Topological Properties of the Non-Reciprocal α-Diamond Chain — Carolina Martinez-Strasser[1] and •Dario Bercioux[1,2] — [1]Donostia International Physics Center (DIPC), 20018 Donostia-San Sebastián, Spain — [2]Ikerbasque, Basque Foundation for Science, Plaza Euskadi 5 48009 Bilbao, Spain

This work explores the topological properties of a generalized non-Hermitian quasi-1D lattice, dubbed as the non-reciprocal α-diamond chain. The diamond chain is a tripartite lattice featuring three sites per unit cell, characterized by a flat band at zero energy associated with compact localized states, and topological edges edge states in the Hermitian and non-Hermitian regimes [1,2]. Building upon our previous investigations [2], we extend the analysis to a more general framework by introducing an α-parameter, quantifying the non-reciprocal hopping strength in the lower part of the diamond chain. Our generalization reveals a spectrum of non-Hermitian phenomena, including exceptional points of order 3 (EP3s) under specific parameter tuning. These EP3s, where three eigenvalues and their eigenvectors coalesce, offer valuable insights into the behavior of three-band non-Hermitian systems. The α-diamond chain thus serves as an effective 1D platform for exploring such phenomena, particularly in the presence of sublattice symmetries [3].

[1] Bercioux *et al.*, Ann. Phys. **529**, 1600262 (2017).
[2] Martinez-Strasser *et al.*, Adv.Quantum.Technol.**7**,2300225(2023).
[3] Montag and Kunst, Phys. Rev. Res. **6**, 023205 (2024).

TT 53.6 Fri 10:45 H32

Topological characterization of carbon nanotubes — •Udo Schwingenschlögl, Xiaoning Zang, and Nirpendra Singh — King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia

Orbital angular momentum plays a central role in quantum mechanics, from the microscopic interaction between light and matter to the macroscopic behavior of superconductors and superfluids. We show that the topology of carbon nanotubes can be characterized by winding numbers related to the orbital angular momentum. The tight-binding Hamiltonian of any carbon nanotube with C_N symmetry can be represented by N tight-binding Hamiltonians of decoupled molecular chains, for which a pseudospin formulation, characterized by specific paths in a two-dimensional auxiliary space, is developed. The quantum phases are given by the N winding numbers of these paths. The paths rotate in the auxiliary space when a magnetic field of varying strength is applied along the carbon nanotube, which gives rise to quantum phase transitions.

15 min. break

TT 53.7 Fri 11:15 H32

Non-Hermitian Quantum Fractals and Inner Non-Hermitian Skin Effects — Changan Li[1], Junsong Sun[2], Huaming Guo[2], and •Björn Trauzettel[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany — [2]School of Physics, Beihang University, Beijing, 100191, China

The first quantum fractal discovered in physics is the Hofstadter butterfly. It stems from large external magnetic fields. We discover instead a class of non-Hermitian quantum fractals (NHQFs) emerging in coupled Hatano-Nelson models on a tree lattice in the absence of any fields. Based on analytic solutions, we are able to rigorously identify the self-similar recursive structures in the energy spectrum and wave functions. We prove that the complex spectrum of NHQFs bears a resemblance to the Mandelbrot set in fractal theory. We further investigate the non-Hermitian Su-Schrieffer-Heeger (SSH) model on Bethe lattice, revealing a novel localization phenomenon coined inner non-Hermitian skin effect. Our findings open another avenue for investigating quantum fractals in non-Hermitian systems.

TT 53.8 Fri 11:30 H32

Non-Hermitian Dynamics Close to Exceptional Points — •Aisel Shiralieva, Grigorii Starkov, and Björn Trauzettel — University of Würzburg, Würzburg, Germany

Exceptional points (EPs), which are degeneracies occurring in both open classical and quantum systems, play a crucial role across numerous areas of physics. This work examines the behavior of dissipative systems with N levels, with a particular emphasis on non-Hermitian qubits and qutrits. These systems are of interest due to recent experimental studies involving a driven non-Hermitian superconducting qubit embedded within a three-level structure, where the ground state serves as an "effective bath". Although significant progress have been made in understanding EPs, the precise connection between their occurrences in non-Hermitian Hamiltonians and in the Lindblad formalism remains unclear, especially if quantum jumps are treated as perturbations. Our results reveal how EPs in these two frameworks relate to each other and illustrate how perturbations can either lift the degeneracy or eliminate the EPs entirely in the Lindblad formalism.

TT 53.9 Fri 11:45 H32

Polarization-Induced Topology in Quantum Emitter Chains — •Jonathan Sturm and Adriana Pálffy — Julius-Maximilians-Universität Würzburg

Synthetic quantum matter has become a field of strongly growing interest over the past decade due to its versatility, adaptibility, and applicability in areas like quantum simulation and others. One particulary suited platform for engineered quantum systems are arrays of quantum emitters, which can be optically excited and couple by the exchange of virtual photons [1].

We theoretically study a quantum emitter implementation of the Su-Schrieffer-Heeger model. Different from earlier studies [2], we show that for certain chain geometries the topological invariant depends on the polarization of the chain, allowing us to alter the topology without altering the lattice. Moreover, we demonstrate how this mechanism can be used for a topological pumping protocol enabling controlled transport of photons through the chain.

[1] M. Reitz *et al.*, PRX Quantum **3**, 010201 (2022).
[2] B. X. Wang and C. Y. Zhao, Phys. Rev. A **98**, 023808 (2018).

TT 53.10 Fri 12:00 H32

Topological Signatures and Induced Triplet Pairing in Proximitized Quantum Hall - Superconductor Heterostructures — •Yuriko Baba, Rafael Sánchez, Alfredo Levy Yeyati, and Pablo Burset — Department of Theoretical Condensed Matter Physics, Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, 28049 Madrid, Spain

In a quantum Hall (QH) state, the proximity to a superconductor (SC) leads to the formation of hybridized electron-hole states called chiral Andreev edge states (CAES). Although the strong magnetic fields required for the QH effect are detrimental to superconductivity, recent experiments have achieved QH-SC hybrid junctions based on InAs 2DEGs [1], graphene [2], and magnetic topological insulators [3]. In this work, we theoretically study the formation of CAES in QH-SC hybrid junctions on a 2DEG. Using numerical simulations in Kwant [4], we study the formation of spin-polarized triplet Cooper pairs induced by Rashba spin-orbit coupling and Zeeman splitting [5], which may be important in 2DEG devices. We also consider the effect of the geometry of nanodevices in planar junctions [6] and in a narrow-finger configuration. In these geometries, the coupling of CAES can induce a topological band inversion and trivial localized states, both of which show particular signatures in non-local electron transport.

[1] Hatefipour et al, Nano Lett. 22, 6173 (2022);
[2] Zhao et al., Nat. Phys. 16, 862 (2020);
[3] Uday et al., Nat. Phys. 20, 1589 (2024);
[4] Groth et al., NJP. 16, 063065 (2014);
[5] Arrachea et al., arXiv:2310.13729;
[6] David at al. PRB 107, 125416 (2023).

TT 53.11 Fri 12:15 H32

Optical Hopfion quantizes inverse Faraday effect — •Emma L. Minarelli and Matthias R. Geilhufe — Chalmers University of Technology, Department of Physics, 412 96 Göteborg, Sweden

Control and manipulation of quantum materials is of paramount significance, both for fundamental characterization and for quantum technologies. Among others, light-matter interaction has recently gained traction because both optical counterpart of solid-state phenomena and emergent effects can be investigated.

We extend this paradigm to 3D topological optical quasiparticle i.e. optical Hopfion (oHop) - a knotted structure presenting robust topological protection, resolution on ultrafast time-scales, localization on nanometer-scale - as novel source to probe and regulate properties and phases of matter.

We show a first instance of OHop-matter coupling: an oHop travelling through a non-magnetic material induces a net effective magnetization, that is now promoted to be topologically quantized in virtue of the linking number (Hopf index) classifying the oHop source. By relating the induced magnetization to the Hopf index, we identify the quantum inverse Faraday effect. This quantized optical response is obtained without constraints on the material but only by introducing topological light. We conclude with a demonstration for a specific material and we give predictions about its promising application in optical protocols for communication and storage of information.

TT 53.12 Fri 12:30 H32

Network Model for Magnetic Higher-Order Topological Phases — Hui Liu[1,2], Ali G. Moghaddam[3,4,5], •Daniel Varjas[1,2,6,7], and Ion Cosma Fulga[1] — [1]IFW Dresden, Dresden, Germany — [2]Stockholm University, Stockholm, Sweden — [3]Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran — [4]Research Center for Basic Sciences and Modern Technologies (RBST), Zanjan, Iran — [5]Tampere University, Tampere, Finland — [6]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [7]Budapest University of Technology and Economics, Budapest, Hungary

We propose a network-model realization of magnetic higher-order topological phases (HOTPs) in the presence of the combined space-time symmetry $C_4\mathcal{T}$ – the product of a fourfold rotation and time-reversal symmetry. We show that the system possesses two types of HOTPs. The first type, analogous to Floquet topology, generates a total of 8 corner modes at 0 or π eigenphase, while the second type, hidden behind a weak topological phase, yields a unique phase with 8 corner modes at $\pm\pi/2$ eigenphase (after gapping out the counterpropagating edge states), arising from the product of particle-hole and phase-rotation symmetry. By using a bulk $\mathbb{Z}_4$ topological index (Q), we found both HOTPs have $Q = 2$, whereas $Q = 0$ for the trivial and the conventional weak topological phase. Together with a $\mathbb{Z}_2$ topological index associated with the reflection matrix, we are able to fully distinguish all phases. Our work suggests that such phases may find their experimental realization in coupled-ring-resonator networks.

TT 54: Correlated Electrons: Charge Order

Time: Friday 9:30–12:45 Location: H33

TT 54.1 Fri 9:30 H33

Broad-Band Noise at the Different CDW Transitions in $BaNi_2As_2$ — •Julian Beu[1], Marvin Kopp[1], Markus König[2], Amir Haghighirad[3], Matthieu Le Tacon[3], Jure Demsar[4], and Jens Müller[1] — [1]Institute of Physics, Goethe-University Frankfurt, Frankfurt (Main), Germany — [2]MPI CPfS, Dresden, Germany — [3]KIT, Karlsruhe, Germany — [4]Institute of Physics, JGU, Mainz

Ever since collective modes like charge (CDW) and spin density waves (SDW) have been routinely found near to or in direct competition with unconventional superconductivity in many interesting compounds, including high-T_c cuprates and iron-pnictides, the influence of these states on the superconducting phase is of interest. In this work we focus on $BaNi_2As_2$ (BNA), a structurally close analogue of the 122-type iron-based superconductors. In contrast to the iron-pnictides, no magnetic ordering was observed in BNA, and two different CDW phases, one incommensurate (I-CDW) and the other commensurate (C-CDW), replace a SDW phase. We investigate the charge carriers in samples of $BaNi_2(As_{1-3.5\%}P_{3.5\%})_2$ by analyzing the resistance and broad-band noise properties. The samples are structured by a FIB process with a meander current path in order to increase the absolute resistance by two orders of magnitude, making fluctuation spectroscopy possible. Our measurements reveal significant differences in the behavior of the electronic fluctuations at the two CDW formations, that show interesting connections to recent findings regarding the properties of the I-CDW in BNA [1] and our noise measurements performed on the conventional CDW system $K_{0.3}MoO_3$. [1] Phys. Rev. Lett. 129, 247602.

TT 54.2 Fri 9:45 H33

Visualizing p-Orbital Texture in the Charge Density Wave State of CeSbTe — Xinglu Que[1], Qingyu He[1], Lihui Zhou[1], Shiming Lei[2], Leslie Schoop[3], •Dennis Huang[1], and Hidenori Takagi[1,4,5] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Hong Kong University of Science and Technology, China — [3]Princeton University, USA — [4]University of Stuttgart, Germany — [5]University of Tokyo, Japan

The collective reorganization of electrons into a charge density wave (CDW) inside a crystal has long served as a textbook example of an ordered phase in condensed matter physics. Two-dimensional square lattices with p electrons are well-suited to the realization of CDW, due to the anisotropy of the p orbitals and the resulting one dimensionality of the electronic structure. In spite of a long history of study of CDW in square-lattice systems, few reports have recognized the existence and significance of a hidden orbital degree of freedom. The degeneracy of p_x and p_y electrons inherent to a square lattice may give rise to nontrivial orbital patterns in real space that endow the CDW with additional broken symmetries or unusual order parameters. Using scanning tunneling microscopy, we visualize signatures of p-orbital texture in the CDW state of the topological semimetal candidate CeSbTe, which contains Sb square lattices with $5p$ electrons. We image atomic-sized, anisotropic lobes of charge density with periodically modulating anisotropy, that ultimately can be mapped onto a microscopic pattern of p_x and p_y bond density waves.

TT 54.3 Fri 10:00 H33

Charge Density Wave and Phonon Softening in $EuAl_4$ — •Aleksandr Sukhanov[1], Steven Gebel[1], Artem Korshunov[2], and Marein Rahn[1] — [1]Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, 86159 Augsburg, Germany — [2]Donostia International Physics Center (DIPC), Paseo Manuel de Lardizabal, 20018 San Sebastian, Spain

$EuAl_4$ is a rare earth intermetallic in which competing itinerant and/or indirect exchange mechanisms give rise to a complex magnetic phase diagram, including a centrosymmetric skyrmion lattice. These phenomena arise not in the tetragonal parent structure but in the presence of a charge density wave (CDW), which lowers the crystal symmetry and renormalizes the electronic structure. Microscopic knowledge of the corresponding atomic modulations and their driving mechanism is a prerequisite for a deeper understanding of the resulting equilibrium of electronic correlations and how it might be manipulated.

In my talk, I present inelastic x-ray scattering results, which can clarify the origin of the CDW in $EuAl_4$.

TT 54.4 Fri 10:15 H33

Charge Density Wave Quantum Critical Point under Pressure in $2H$-$TaSe_2$ — •Yuliia Tymoshenko[1], Amir-Abbas Haghighirad[1], Rolf Heid[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]2European Synchrotron Radiation Facility, 71 avenue des Martyrs, CS 40220, Grenoble 38043, France

Suppression of the ordered state is one of the ways to increase the superconducting (SC) transition temperatures. Materials characterized by charge density waves (CDW) and SC are promising candidates for such studies, since both states can be associated with electron-phonon coupling. Transition metal dichalcogenides (TMD) are prominent examples of such coexisting phases, however, not all such materials show the expected behavior or possess additional mechanisms that complicate an unambiguous interpretation. Here, we report high-pressure X-ray diffraction (XRD) and inelastic X-ray scattering (IXS) measurements of a prototypical transition metal dichalcogenide $2H$-$TaSe_2$ and determine the evolution of the CDW state and its lattice dynamics. We found that the quantum critical point (QCP) of the charge density wave is in close proximity to the reported maximum superconducting transition temperature $T_{\rm sc} = 8.2$ K. Ab-initio calculations confirm that $2H$-$TaSe_2$ is a typical example of enhanced superconductivity with suppressed order and can serve as a textbook example for studying superconductivity near the quantum critical point of the CDW.

TT 54.5 Fri 10:30 H33

Tunable Charge Density Wave Orders in 2H-TaS_2 — •Mihir Date[1,2], Joost Aretz[3], Enrico da Como[4], Marcin Mucha-Kruczynski[4], Malte Roesner[3], Stuart S P Parkin[1], Niels B M Schroeter[1], and Matthew D Watson[2] — [1]Max Planck Institute of Microstructure Physics, Halle, Germany — [2]Diamond Light Source Ltd., Didcot, UK — [3]Radboud University, Nijmegen, The Netherlands — [4]University of Bath, Bath, UK

The charge density wave (CDW) transition is an electronic instability driven by strong electron-phonon coupling, where the parent electronic band is renormalized, and shows a spectral gap. Angle-resolved photoemission spectroscopy (ARPES) has been extremely successful in identifying these spectral features, most prominently in layered van der Waals materials like 2H-$NbSe_2$ and $TaSe_2$. Surprisingly, however, until now there has not been any high-quality data reported on the 2H-TaS_2, presumably due to materials challenges. Making use of spatially resolved ARPES, we were able to overcome these challenges and measure high-quality bandstructures revealing the 3x3 commensurate charge density waves (CCDW) ground state in 2H-TaS_2. We further find variation of the stoichiometry between samples prepared by different routes, and incredibly, at a different band filling we find evidence of a new CDW order that is commensurate, but not the 3x3 reconstruction as observed in previous experiments. Our results are compared with tight-binding and ab-initio modelling which show that TaS_2 is prone to multiple instabilities that can be tuned by the band filling, with an important role played by a van Hove singularity.

TT 54.6 Fri 10:45 H33

Resistance of Vapor-Grown $NbSe_2$ Single Crystals under Strain — •Maik Golombiewski, Tianyi Xu, Simon Knudsen, Michael Paul, Sven Graus, Teslin R. Thomas, Andreas Kreyssig, and Anna E. Böhmer — Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum, Germany

$NbSe_2$ shows a charge density wave (CDW) transition upon cooling below $T_{\rm CDW} = 32$ K and becomes superconducting at $T_{\rm c} = 7.2$ K. Large $NbSe_2$ single crystals were grown via chemical vapor transport with iodine as transport agent. Growth conditions, such as temperature gradient, were optimized resulting in an increase in RRR. Samples were shown to have a 1:2 stoichiometry via energy-dispersive x-ray spectroscopy and the 2H-structure was confirmed by powder x-ray diffraction measurements. Temperature-dependent resistance was measured while simultaneously straining the samples using cryogenic strain and force cells. This so-called elastoresistance exhibits a minimum around $T_{\rm CDW}$. Using the force cell, large strains were applied and investigated.

We acknowledge support by the Mercator Research Center Ruhr (MERCUR), under project number Ko-2021-0027.

TT 54.7 Fri 11:00 H33

Fingerprints of a Charge Ice State in the Doped Mott Insulator Nb_3Cl_8 — •Evgeny Stepanov — CNRS, Ecole Polytechnique

Monolayer Nb_3Cl_8 is a textbook example of a Mott insulator [1,2]. However, little is known about its characteristics, particularly in doped regimes where the strong local correlations responsible for the Mott state are competing with significant spatial collective electronic fluctuations.

Our many-body calculations suggest that monolayer Nb_3Cl_8 undergoes phase separation (PS) upon doping, driven by the emergence of a charge ice state [3]. In close proximity to the PS, the charge susceptibility dramatically increases and displays a distinctive bow-tie pattern in momentum space, resembling the form of magnetic susceptibility observed in spin ice states. At the same time, the effective exchange interaction between charge densities undergoes a striking transformation, acquiring a power-law dependence in real space. This dependence is reminiscent of hydrogen bonding interactions in water and serves as a hallmark of spin ice states when applied to spin degrees of freedom. These findings allow us to associate the observed PS with a charge ice state, characterized by a remarkable power-law dependence of correlations between electronic densities in real space.

While spin ice states were first experimentally realized in 1997 by Harris et al. [4], an analogue for charge degrees of freedom has remained elusive until now. Our work not only provides a theoretical description of the charge ice state but also offers compelling evidence that this novel phase can be realized in a real material.

[1] Nano Lett. 22, 4596 (2022);
[2] PRX 13, 041049 (2023);
[3] arXiv:2405.19114;
[4] PRL 79, 2554 (1997).

15 min. break

TT 54.8 Fri 11:30 H33

Non-Thermal Cavity Control of Order in Electronic Systems — •Md Mursalin Islam[1], Michele Pini[2,1], Rafael Flores-Calderón[1], and Francesco Piazza[2,1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]University of Augsburg, Augsburg, Germany

Cavity quantum materials have emerged as a platform to study non-thermal many-body physics with applications to the control of collective electron behavior. In an electronic system coupled to cavity photons, the superconducting gap has been predicted previously to be enhanced, due to a 'Eliashberg effect' taking place due to electromagnetic fluctuations as instead of a coherent laser source [1,2]. We extend this idea for the case of charge-density-wave order and systematically derive a generalized gap equation for the non-thermal situation using field theoretical methods. This allows us to compare the modified gap equations for superconductors and charge density waves: we find that while the two equations are exactly equivalent in thermal equilibrium, they assume different forms in non-thermal settings. Our formalism also allows us to systematically investigate the role of disorder in the non-thermal enhancement of the gap in both the cases.

[1] G. M. Eliashberg, JETP Lett. 11, 114 (1970);
[2] J. B. Curtis et. al., PRL 122, 167002 (2019).

TT 54.9 Fri 11:45 H33

Disorder in Photoexcited Charge Density Wave Systems: Insights from Stochastic Resonance in Impurity Models. — •Francesco Valiera and Martin Eckstein — Department of Physics, University of Hamburg, D-22607 Hamburg, Germany

Photoexcitation in charge density wave (CDW) systems can potentially lead to inhomogeneously disordered phases [1], where ions are displaced locally but do not achieve global ordering. In these phases, each ion moves within a local double-well potential and settles in one of the two equilibrium positions with equal probability. Similar behaviours have also been observed experimentally in VO_2 through scattering experiments [2]. A fundamental question in understanding these disordered states is identifying their signatures beyond X-ray scattering. In order to explore this, we have developed a model of a single ion embedded in a metallic host and use the semiclassical stochastic approach [3] to compute its linear response to an external probe. At low frequencies, the system exhibits a peak in the response amplitude as a function of temperature, which we attribute to stochastic resonance. The latter is typical of bistable systems that experience both periodic driving and noise and it can provide insights into the features of the local double-well potentials and the fluctuations to which the ions are subject.

[1] A. Picano et al., Phys. Rev. B 107, 245112 (2023);
[2] S. Wall et al., Science 362, 572 (2018);
[3] A. Picano et al., Phys. Rev. B 108, 035115 (2023).

TT 54.10 Fri 12:00 H33

Kinetic Magnetism and Stripe Order in the Antiferromagnetic Bosonic t-J Model — •Timothy J. Harris[1,2], Ulrich Schollwöck[1,2], Annabelle Bohrdt[1,2,3], and Fabian Grusdt[1,2] — [1]Ludwig Maximilian University of Munich, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]University of Regensburg, Regensburg, Germany

Understanding the microscopic mechanisms governing the physics of doped quantum magnets is a central challenge in strongly correlated many-body physics. In this talk, I will present results that disentangle the role of particle statistics from the intrinsic physics of strong correlations in the antiferromagnetic (AFM) bosonic t-J model. Using large-scale density matrix renormalization group (DMRG) calculations, we map out the T=0 phase diagram on the 2D square lattice [1]. At low doping, we find evidence of partially-filled stripe structures, reminiscent of those observed in high-T_c cuprates. As doping increases, a transition occurs to a partially-polarized ferromagnetic (FM) phase, driven by formation of Nagaoka polarons as mobile holes bind to localized FM regions. At high doping or large t/J, these polarons overlap, and the system evolves into a full-polarized ferromagnet. Our findings shed new light on the role of particle statistics in strongly correlated quantum matter, revealing connections to stripe formation and the physics of kinetic ferromagnetism. I will also discuss experimental realizations of this model using state-of-the-art quantum simulators, paving the way for future studies of doped bosonic quantum magnets.

[1] T.J. Harris et al., arXiv:2410.00904 (2024).

TT 54.11 Fri 12:15 H33

SU(2) Gauge Theory for Fluctuating Stripes in the Pseudogap Regime — •Mark Henrik Müller-Groeling, Pietro Maria Bonetti, Paulo Forni, and Walter Metzner — Max Planck Institute for Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart, Germany

We investigate the role of charge order in a pseudogap described by an SU(2) gauge theory of fluctuating magnetic order.

The theory is based on a fractionalization of electrons into a fermionic chargon pseudospinor and a bosonic spinon, which leads to an emergent SU(2) pseudospin symmetry. In the mean-field solution of the 2D Hubbard model, which we use to describe the electrons in the copper-oxygen planes, Néel, spiral, or stripe order were observed below a density dependent transition temperature T^* [1].

Fluctuations of the spin orientation are described by a non-linear sigma model obtained from a gradient expansion of the spinon action. The spin stiffnesses are computed from a random phase approximation for the chargon susceptibility. The spinon fluctuations prevent magnetic long-range order of the electrons at any finite temperature. The phase with magnetic chargon order exhibits the most salient features characterizing the pseudogap regime in high-T_c cuprates: a strong reduction of charge carrier density, a spin gap, and Fermi arcs [2], and we set out to observe the effects of charge order in this context.

[1] R. Scholle, P. M. Bonetti, D. Vilardi, W. Metzner, PRB **108** 035139 (2023);
[2] P. M. Bonetti, W. Metzner, PRB **106**, 205152 (2022).

TT 54.12 Fri 12:30 H33

Combined Cluster and Diagrammatic Method for Symmetry Broken Phases in Correlated Electron Systems — •Félix Fossati and Evgeny Stepanov — Ecole Polytechnique

In this work, we investigate dynamical symmetry breaking in correlated electron systems. To achieve this, we refine a theoretical approach called D-TRILEX [1-3], which constructs a diagrammatic expansion based on an interacting reference system, using a cluster problem as a reference. Traditional cluster methods account for short-range correlation effects within the cluster exactly but neglect correlations beyond the cluster size. Our approach addresses this limitation by self-consistently combining the non-perturbative treatment of short-range correlations with a diagrammatic description of long-range collective electronic fluctuations. We demonstrate the effectiveness of this method by applying it to the one-dimensional Hubbard model. Our results show that the cluster extension of D-TRILEX accurately captures the transitions to the charge density wave (CDW) and bond-ordered wave (BOW) phases, which are associated with local and non-local order parameters, respectively, across various regimes of electronic interactions. This implementation provides new insights into the role of non-local interactions in dynamical symmetry breaking, establishing D-TRILEX as a promising tool for investigating complex phases in strongly correlated systems.

[1] E. A. Stepanov et al., Phys. Rev. B 100, 205115 (2019);
[2] V. Harkov et al., Phys. Rev. B 103, 245123 (2021);
[3] M. Vandelli et al., SciPost Phys. 13, 036. (2022).

TT 55: Superconducting Electronics: SQUIDs, Qubits, Circuit QED III

Time: Friday 9:30–13:00 Location: H36

TT 55.1 Fri 9:30 H36

Superconducting devices based on the NbTiN Josephson junctions — •Vasilii Sevriuk[1], Azat Gubaydullin[1], Aki Ruhtinas[2], Michael Perelshtein[1], Alexey Mironov[1], Pertti Hakonen[3], Ilari Maasilta[2], and Valerii Vinokur[1] — [1]Terra Quantum AG, Kornhausstrasse 25, 9000 St. Gallen, Switzerland — [2]Nanoscience Center, Department of Physics, University of Jyväskylä, FI-40014 Jyväskylä, Finland — [3]QTF Centre of Excellence, Department of Applied Physics, Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland

Quantum devices based on superconducting circuits are a promising technology that could have a significant impact on many aspects of human life. However, the production of high-coherence circuits remains one of the key challenges. Recent results on the fabrication of NbTiN Josephson junctions using a focused helium ion beam [1] suggest that this method is well-suited for a wide range of applications in superconducting electronics, due to the excellent mechanical, electrical, and microwave properties of NbTiN. Here we present our results on the characterization of the superconducting circuits based on this technology.

[1] A. Ruhtinas, I. Maasilta, arXiv:2303.17348v2.

TT 55.2 Fri 9:45 H36

Argon milling strategies for Tantalum Transmon qubits — •Philipp Lenhard[1], Mathieu Fechant[1], Ritika Dhundhwal[1], Thomas Reisinger[1], and Ioan M. Pop[1,2,3] — [1]IQMT, Karlsruhe Institute of Technology — [2]PHI, Karlsruhe Institute of Technology — [3]1. Physikalisches Institut, University of Stuttgart

Tantalum has emerged as a promising material for enhancing the coherence time of superconducting qubits [1,2]. This study focuses on the fabrication of qubits, emphasizing the necessity of establishing a coherent contact between Ta-based structures and Al/AlO$_x$/Al Josephson junctions. The removal of native oxide layers via Argon milling is critical to this process. We present various approaches to achieve optimal contact through Argon milling, along with a discussion of the associated challenges and potential solutions.

[1] Place et al., Nat. Commun. 12:1779 (2021).
[2] Ganjam et al., Nat. Commun. 15:3687 (2024).

TT 55.3 Fri 10:00 H36

Simultaneous locking and operation of gradiometric fluxonium qubits — •Denis Bénâtre[1], Mathieu Féchant[1], Nicolas Gosling[1], Nicolas Zapata[1], Patrick Paluch[1], Martin Spiecker[1], and Ioan Pop[1,2,3] — [1]IQMT, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany — [2]PHI, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]PI1, Stuttgart University, 70569 Stuttgart, Germany

Gradiometric fluxoniums, introduced by Gusenkova et al. (Appl. Phys. Lett. 120, 2022), have the ability to be flux-locked at the sweet spot of operation by trapping a persistent current in their most external loop. We demonstrate the reliability of the procedure by simultaneously locking several fluxoniums sitting in the same waveguide and show that the locking in stable in time. We engineer devices with varying asymmetries and exhibit samples with close-to-zero asymmetry, allowing them to be used with little additional flux-biasing. Such devices could thus help reduce cross-talk between flux lines addressing flux qubits.

TT 55.4 Fri 10:15 H36

Low cross-talk modular flip-chip architecture for coupled superconducting qubits — •Sören Ihssen[1], Simon Geisert[1], Gabriel Jauma[2,3], Patrick Winkel[1,4,5], Martin Spiecker[1], and Ioan M. Pop[1,6,7] — [1]IQMT, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute of Fundamental Physics IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain — [3]Applied Physics Department, Salamanca University, Salamanca 37008, Spain — [4]Departments of Applied Physics and Physics, Yale University, New Haven, CT 06520, USA — [5]Yale Quantum Institute, Yale University, New Haven, CT 06520, USA — [6]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [7]Physics Institute 1, Stuttgart University, 70569 Stuttgart, Germany

We introduce a novel flip-chip architecture designed for an array of coupled superconducting qubits, where each circuit component is housed within its own microwave enclosure. Unlike traditional flip-chip designs, our approach features electrically floating qubit chips, enabling a straightforward and fully modular assembly of capacitively coupled components, including qubits, control systems, and coupling structures. This design minimizes crosstalk among components. We validate our concept using a chain of three nearest-neighbor coupled generalized flux qubits, with the central qubit functioning as a frequency-tunable coupler. Through this coupler, we achieve a transverse coupling on/off ratio of approximately 50, zz-crosstalk below 1.4 kHz between resonant qubits, and over 70 dB of isolation between the qubit enclosures.

TT 55.5 Fri 10:30 H36

Optically mediated control for superconducting qubits — •Kevin Kiener[1,2], Gleb Krylov[1,2], Florian Wallner[1,2], Max Werninghaus[1,2], Nadeem Akhlaq[2,3], Frederik Pfeiffer[1,2], Johannes Schirk[1,2], and Stefan Filipp[1,2] — [1]Walther-Meißner-Instiut, Bayerische Akademie der Wissenschaften — [2]Technical University of Munich, TUM School of Natural Sciences, Department of Physics — [3]Walter Schottky Institut

In superconducting quantum computers, scaling control and readout wiring infrastructure presents significant challenges. Optical fibers offer a promising alternative to microwave cables by providing lower passive heat load, reduced footprint per channel, reduced crosstalk and the potential for multiplexing control channels. Here, we explore the conversion of microwave- to optical signals via amplitude modulation and the subsequent reconversion to microwave signals at millikelvin (mK) temperatures. Two fiber coupling strategies are experimentally evaluated in a cryogenic environment, focusing on their practicality for qubit control. We theoretically investigate methods to reduce the power dissipation of the photodiode at mK temperatures, focusing on two approaches: utilizing an impedance converter and employing high-impedance transmission lines. We investigate the validity of the signal generation for different frequencies and identify suitable frequency ranges to control different qubit architectures and coupling elements.

We acknowledge financial support from GeQCoS, MUNIQC-SC, MCQST, OpenSuperQPlus100, the Munich Quantum Valley and the Deutsche Forschungsgemeinschaft.

TT 55.6 Fri 10:45 H36

Spectroscopic characterization of noise and decoherence mechanisms in superconducting qubits — •Julian Englhardt[1,2], Emily Wright[1,2], Niklas Glaser[1,2], Leon Koch[1,2], Ivan Tsitsilin[1,2], Christian Schneider[1,2], Max Werninghaus[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Department of Physics — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften

Dynamical decoupling sequences during free evolution time have proven effective in suppressing the impact of environmental noise in superconducting qubits, thereby increasing coherence times towards the theoretical 2T1 limit. While primarily used for error suppression during quantum computation, these sequences can also serve as a diagnostic tool for noise characterization by revealing the qubit's response across specific frequency ranges. Beyond standard dynamical decoupling sequences, here we employ additional methods such as time resolved single-shot Ramsey measurements to probe low-frequency noise sources and the signature noise spectra of specific decoherence events. Specifically, we investigate charge parity jumps in superconducting Transmon qubits induced by quasiparticle tunneling across the Josephson junction. We believe that the combined toolkit for noise spectroscopy can contribute to the understanding of decoherence mechanisms in superconducting qubits.

We acknowledge financial support from GeQCoS, MUNIQC-SC, MCQST, OpenSuperQPlus100, the Munich Quantum Valley and the Deutsche Forschungsgemeinschaft.

TT 55.7 Fri 11:00 H36

Suppressing chaos with mixed superconducting qubit devices — •Ben Blain[1,2], Giampiero Marchegiani[1], Luigi Amico[1,3,4], and Gianluigi Catelani[5,1] — [1]Quantum Research Center, Technology Innovation Institute, Abu Dhabi 9639, UAE — [2]School of Physics and Astronomy, University of Kent, Canterbury CT2 7NH, United

Kingdom — [3]Dipartimento di Fisica e Astronomia, Via S. Sofia 64, 95123 Catania, Italy — [4]INFN-Sezione di Catania, Via S. Sofia 64, 95127 Catania, Italy — [5]JARA Institute for Quantum Information (PGI-11),Forschungszentrum Jülich, 52425 Jülich, Germany

In quantum information processing, a tension between two different tasks occurs: while qubits' states can be preserved by isolating them, quantum gates can be realized only through qubit-qubit interactions. In arrays of qubits, weak coupling leads to states being spatially localized and strong coupling to delocalized states. Here, we study the average energy level spacing and the relative entropy of the distribution of the level spacings to analyze the crossover between localized and delocalized (chaotic) regimes in linear arrays of superconducting qubits. We consider both transmons as well as capacitively shunted flux qubits, which enables us to tune the qubit anharmonicity. Arrays with uniform anharmonicity display remarkably similar dependencies of level statistics on the coupling strength. In systems with alternating anharmonicity, the localized regime is found to be more resilient to the increase in qubit-qubit coupling strength in comparison to arrays with a single qubit type. This result supports designing devices that incorporate different qubit types to achieve higher performances.

15 min. break

TT 55.8 Fri 11:30 H36

Higher Josephson harmonics in superconducting qubits — •Abbas H. Hirkani[1,2], Giampiero Marchegiani[1], Luigi Amico[1,3,4], and Gianluigi Catelani[1,5] — [1]QRC, TII, Abu Dhabi, UAE — [2]SISSA, Trieste, Italy — [3]Dipartimento di Fisica e Astronomia, Catania, Italy — [4]INFN-Catania, Catania, Italy — [5]Forschungszentrum Jülich, Jülich, Germany

Measurements of higher-level spectra of transmon cannot be explained using the standard $I = I_0 \sin\phi$ current-phase relation, and a more accurate description of the Josephson element, with non-negligible contributions from higher harmonics, is needed [1]. Stray inductances can also lead to similar corrections to the spectrum; here we investigate the Fraunhofer effect in transmons comprising thin-film $Al/AlO_x/Al$ junctions under parallel magnetic field [2] as a tool to discriminate between contributions from inductances and from intrinsic higher harmonics of the junctions. The magnetic field modulates each harmonic on a different field scale; this results in a field dependence of the qubit spectrum measurably different from the one due to a stray inductance alone. We also examine how the presence of a few percent higher harmonic contributions affects various qubit designs, and comment on the implications for accurate targeting of qubit parameters.

[1] D. Willsch et al., Nat. Phys. 20, 815 (2024);
[2] J. Krause et al., Phys. Rev. App. 22, 044063 (2024).

TT 55.9 Fri 11:45 H36

Impact of infrared photons on superconducting qubits — •Markus Griedel[1,2], Jonathan Huschle[2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Institut for Quanten Materials and Technologies (IQMT), Karlsruhe Institut for Technology (KIT), Karlsruhe, Germany — [2]hysikalisches Institut (PHI), Karlsruhe Institut for Technology (KIT), Karlsruhe, Germany

Low-noise superconducting quantum circuits are manipulated by microwave photons with energies below the superconducting energy gap. However, the impact of photons with much higher energies may break Cooper pairs and result in an increase in the noise level. Stray infrared (IR) radiation, e.g. transmitted through the dielectrics of coaxial cables, must be blocked by a low-pass filter to avoid this additional noise. The coherence of superconducting qubits is particularly sensitive to this influence and can be used as a detector. In the qBriqs project, we focus on studying the impact of far-infrared photons and present the results of a detailed experimental study. We propose materials to suppress the IR radiation, e.g. with an in-line filter, while maintaining good microwave properties.

TT 55.10 Fri 12:00 H36

Investigation of parasitic two-level systems in merged-element Transmon qubits — •Etienne Daum[1], Benedikt Berlitz[1], Alexey V. Ustinov[1,2], and Jürgen Lisenfeld[1] — [1]PHI, Karlsruher Institut für Technologie, 76131 Karlsruhe, Deutschland — [2]IQMT, Karlsruher Institut für Technologie, 76131 Karlsruhe, Deutschland

In conventional transmon qubits, decoherence is dominated by large numbers of parasitic two-level systems (TLS) residing at the edges of its large area coplanar shunt capacitor. Avoiding these defects by improvements in design, fabrication and materials proved to be a significant challenge that so far led to limited progress. The merged-element transmon qubit, a recently proposed paradigm shift in transmon design, attempts to address these issues by engineering the Josephson junction to act as its own parallel shunt capacitor. Incorporating an additional aluminium deposition and oxidation into the *in-situ* bandaged Niemeyer-Dolan technique, we were able to fabricate flux-tunable mergemon qubits in the low transmon regime ($E_J/E_C \approx 34$). A mean T_1 relaxation time of about $20\mu s$ ($Q \approx 5.4 \times 10^5$) has been observed over a six hour time period. TLS spectroscopy under applied strain and electric fields revealed that the majority of coherence limiting TLS ($\sim 60\%$) still reside on the interfaces of exposed qubit electrodes, despite their drastically reduced surface area. This indicates that material and fabrication improvements, in combination with optimized electrode geometries, are still necessary before the advantages of the "mergemon" approach can be exploited.

TT 55.11 Fri 12:15 H36

Demonstration of a Solid-State Random Defect Maser — •Christian Ständer, Jan Blickberndt, Andreas Fleischmann, Andreas Reiser, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University

The low temperature properties of amorphous solids are governed by atomic tunneling 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 experimental investigations of atomic tunnelling systems.
We designed and microfabricated a superconducting LC-resonator to study the dielectric rf-response of an amorphous sample in the presence of a slowly varying electric bias field and two symetrically detuned pump tones. A novel method of applying this electrical bias field was introduced to the resonators. By shifting the energy splitting of the inverted TLS with the external bias, to match the resonators frequency we found a paramterspace of negative dielectric loss, hence gain. In this way we demonstrate that a media containing random TLS could be transformed from an inertially lossy system to a system that features no significant dielectric loss, up to a point of coherent gain.

TT 55.12 Fri 12:30 H36

Two-qubit entangling quantum gates in a 2D ring resonator architecture — •Anirban Bhattacharjee[1,2], Panya Jain[1], Jay Deshmukh[1], Srijita Das[1], Madhavi Chand[1], Meghan Patankar[1], and Rajamani Vijayaraghavan[1] — [1]Tata Institute of Fundamental Research, Mumbai, India — [2]Walther Meissner Institute, Garching b Muenchen, Germany

A novel ring resonator [1] design allows interqubit connectivity beyond nearest neighbours, which has always been a topological constraint in present state-of-art quantum architectures. In this work, we demonstrate connectivity between three fixed-frequency transmon qubits coupled to a ring resonator in a planar 2D architecture. We have also demonstrated two-qubit entangling gates between two fixed-frequency qubits in this geometry. Our results show the ability to demonstrate quantum entanglement using the ring resonator and opens up the possibility of exploring various gate implementations in this architecture.

[1] Phys. Rev. Appl. 16, 024018 (2021).

TT 55.13 Fri 12:45 H36

Study of the quarton-quarton qubits interaction — •Hossam Tohamy[1], Alex Kreuzer[1], Andras Di Giovanni[1], Thilo Krumrey[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruhe Institute of Technology (KIT) — [2]Institute for Quantum Materials and Technologies (IQMT), Karlsruhe Institute of Technology (KIT)

Tunable qubits are a useful resource in superconducting quantum processors to enable high-performance quantum gates. While much of the recent focus has been on the exploration of transmon multiqubit architectures, the quarton qubit [1] offers a three- to five-times higher and, in addition, positive anharmonicity. In this work, we experimentally study the interaction between two quarton qubits. We have performed spectroscopy and time-domain measurements on these qubits system, and compared the experimental results with theoretical model.

[1] F. Yan et al., arXiv:2006.04130 (2020).

TT 56: Quantum Dynamics, Decoherence, and Quantum Information (joint session DY/TT)

Time: Friday 9:30–11:15 Location: H37

TT 56.1 Fri 9:30 H37

Entanglement phase transitions in unitary circuit games with free fermions — •Raúl Morral-Yepes[1,2], Marc Langer[1,2], Adam Smith[3,4], Barbara Kraus[1,2], and Frank Pollmann[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences — [2]Munich Center for Quantum Science and Technology (MCQST) — [3]School of Physics and Astronomy, University of Nottingham — [4]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems

In the recently introduced framework of unitary circuit games, two competing parties an entangler and a disentangler can induce an entanglement phase transition, distinct from measurement-induced transitions. In this work, we study such games within the context of matchgate dynamics, which correspond to free fermion systems. First, we investigate the entanglement properties of fermionic Gaussian states (FGS) and explore different methods for their disentangling. We propose a representation of FGS using a minimal matchgate circuit in a standard form, and introduce algorithms for updating this representation as unitary operations are applied. Within this framework, we define a natural disentangling procedure that reduces the number of gates in the circuit, thereby decreasing the system's entanglement. We then analyze the unitary game using this gate disentangler, observing a phase transition between a volume-law and area-law entanglement phase. The nature of this transition differs depending on whether we examine Rényi-0 or other entanglement entropies.

TT 56.2 Fri 9:45 H37

Measurement Induced Entanglement Transitions in Random Qudit Clifford Circuits — •Aamod Vinayak Atre, Raúl Morral Yepes, and Frank Pollmann — Department of Physics, Technical University of Munich

Random quantum circuits with local projective measurements uncover the universal dynamical properties of generic chaotic quantum many-body systems, as their unitary evolution is independent of the microscopic features of Hamiltonians. Entanglement measures characterize these universal dynamics into volume-law and area-law regimes, which exhibit bipartite entropy scaling proportional to the system volume and system boundary respectively. This continuous entanglement scaling transition, driven by the rate of measurement, has been extensively studied in spin-1/2 (qubit) systems of various spatial geometries. In this talk, we discuss the characterization the entanglement transitions in 1D random quantum circuits of spins (qudits) with arbitrary local Hilbert-space dimension d. This work employs the generalized stabilizer formalism, taking advantage of the Clifford group which forms a unitary 2-design on the space of unitaries. We find the nature of the entanglement transition, from volume-law to area-law regimes, to be preserved for $d > 2$. The critical measurement density increases, converging to $1/2$ in the limit $d \to \infty$. Lastly, we describe the stabilizer dynamics in the limit $d \to \infty$, by a dynamical classical model.

TT 56.3 Fri 10:00 H37

Entanglement phases, localization and ergodicity of monitored free fermions in 2D — •Karim Chahine and Michael Buchhold — Institut für Theoretische Physik, Universität zu Köln, D-50937 Cologne, Germany

Monitored quantum systems, characterized by the interplay between unitary evolution and mid-circuit measurements, have recently emerged as a novel expression of quantum dynamics. Despite their inherently out-of-equilibrium nature, these systems can host robust quantum phases and display measurement-induced phase transitions (MIPT) in the entanglement entropy. Remarkably, they are also unique in providing a link between quantum dynamics in D dimensions and quantum statistical mechanics in $D+1$ dimensions. In this talk, I will present our recent work on a new arena with a rich phenomenology: continuously monitored, $U(1)$-symmetric free fermions in 2D. I will address the emerging MIPT and its similarities and differences with Anderson-type localization transitions. Some emphasis will be put on the low-measurement regime, where intriguing features in the entanglement structure and ergodic properties emerge, revealing a richer phenomenology than previously anticipated.

TT 56.4 Fri 10:15 H37

Spectral Properties and Magic generation of T-doped Random Clifford Circuits — •Dominik Szombathy — Budapest University of Technology and Economics

We investigate the spectral properties and magic generation of T-doped random Clifford circuits. There is a direct relation between the structure of Pauli string orbits and the eigenvalue spectrum of a Clifford circuit. Operatively, we sample the closed trajectories with brick-wall circuits and determine the distribution of the eigenvalues $\lambda = e^{i\Theta}$. The autocorrelation function of the phases of the eigenvalues displays peculiar properties: extreme degeneracies as well as some level-repulsion, and features reminiscent of a fractal pattern.

To investigate the stability of orbits and head towards universal quantum computation, we introduce $\pi/4$ phase shift gates (T-gates). We find that even a single T-gate completely changes the properties of the circuit. By increasing the number of T-gates (N_T), the correlation function rapidly approaches that of the random unitary circuits. Nevertheless, some statistically significant fraction of non-trivial orbits persists at low T-gate densities (N_T/N).

We observe a similar phenomenology in the magic generation as a function of T-gate density. In particular, we find universal scaling of the maximum and mean magic as a function of N_T/N . We also highlight the structure of magic generated by these circuits. Injecting a few T-gates the distribution is discrete but becomes continuous as N_T increases. At large densities N_T/N , most of the weight is found in a sharp peak well below the theoretical maximum.

TT 56.5 Fri 10:30 H37

Magic transition in measurement-only circuits — •Poetri Sonya Tarabunga[1,2] and Emanuele Tirrito[3,4] — [1]Technical University of Munich, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany — [3]The Abdus Salam International Centre for Theoretical Physics (ICTP), 34151 Trieste, Italy — [4]Dipartimento di Fisica "E. Pancini", Università di Napoli "Federico II", 80126 Napoli, Italy

Magic quantifies the distance of a quantum state to the set of stabilizer states, and it serves as a necessary resource for potential quantum advantage over classical computing. In this work, we study magic in a measurement-only quantum circuit with competing types of Clifford and non-Clifford measurements, where magic is injected through the non-Clifford measurements. This circuit can be mapped to a classical model that can be simulated efficiently, and the magic can be characterized using any magic measure that is additive for tensor product of single-qubit states. Leveraging this observation, we study the magic transition in this circuit in both one- and two-dimensional lattices using large-scale numerical simulations. Our results demonstrate the presence of a magic transition between two different phases with extensive magic scaling, separated by a critical point in which the mutual magic exhibits scaling behavior analogous to entanglement. We further show that these two distinct phases can be distinguished by the topological magic. In a different regime, with a vanishing rate of non-Clifford measurements, we find that the magic saturates in both phases.

TT 56.6 Fri 10:45 H37

Developing a Framework for Predicting Useful Quantum Advantage in the Calculation of Molecular NMR Spectra — •Keith Fratus, Andisheh Khedri, Juha Leppäkangas, Michael Marthaler, and Jan Reiner — HQS Quantum Simulations GmbH, Karlsruhe, Germany

Demonstrating useful quantum advantage remains a primary goal of quantum computing efforts in the NISQ era. Key to such efforts is the ability to estimate the accuracy and performance of competing classical approximation methods when exact comparisons are not available. In this talk we report on our efforts to develop and understand the behaviour of various classical approximation methods which aim to solve a specific class of chemical simulation problems. In particular, we develop classical simulation methods designed to predict molecular NMR spectra, with the aim of being able to quantify the accuracy and computational requirements of performing these simulations, even for parameter regimes which we do not directly simulate. Using such methods, we work towards a framework for predicting in which parameter regimes, system sizes, and target accuracies one can expect the failure of classical methods for this class of systems, thus allowing for the possibility of quantum advantage.

TT 56.7 Fri 11:00 H37

Linear differential equation approach to the Loschmidt amplitude — •Michael Vogl — King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

The Loschmidt amplitude is a popular quantity that allows making predictions about the stability of quantum states under time evolution. We present an approach that allows us to find a linear differential equation that can be used to compute the Loschmidt amplitude. This approach, while in essence perturbative, has the advantage that it converges at finite order. We demonstrate that the approach for generically chosen matrix Hamiltonians often offers advantages over Taylor and cumulant expansions even when we truncate at finite order. Even in low dimensional systems such as two band Hamiltonians (multi-Weyl semimetals and AB bilayer graphene) it can be used to obtain general formulas for the Loschmidt amplitude after a quench. Results readily generalize to find transmission amplitudes and specific contributions of the partition function, too. Our method can also be applied to many body spin and fermionic Hamiltonians. Here, while the approach still offers advantages, more care has to be taken than in a generic case. We also provide an estimate for a breakdown time of the approximation.

TT 57: Topology and Symmetry-protected Materials (joint session O/TT)

Time: Friday 10:30–12:15 Location: H25

TT 57.1 Fri 10:30 H25

Topological material in the III–V family: heteroepitaxial InBi on InAs — •L. Nicolaï[1], J. Minár[1], M.C. Richter[2,3], O. Heckmann[2,3], J.-M. Mariot[4], U. Djukic[2], J. Adell[5], M. Leandersson[5], J. Sadowski[6], J. Braun[7], H. Ebert[7], J.D. Denlinger[8], I. Vobornik[9], J. Fujii[9], P. Šutta[1], G.R. Bell[10], M. Gmitra[11,12], and K. Hricovini[2,3] — [1]Univiversity of West Bohemia — [2]CY Cergy-Paris Université — [3]Université Paris-Saclay — [4]Sorbonne Université — [5]Lund University — [6]Polish Academy of Sciences — [7]LMU München — [8]ALS — [9]Istituto Officina dei Materiali, CNR — [10]University of Warwick — [11]Pavol Jozef Šafárik University in Košice — [12]Slovak Academy of Sciences

InBi(001) is formed epitaxially on InAs(111)-A by depositing Bi on to an In-rich surface. ARPES measurements reveal topological electronic surface states, close to the $\overline{\mathrm{M}}$ high symmetry point. InBi surprisingly shows coexistence of Bi and In surface terminations. For the Bi termination, the study gives a consistent physical picture of the topological surface electronic structure of InBi(001) terminated by a Bi bilayer rather than a surface formed by splitting to a Bi monolayer termination. Theoretical calculations based on relativistic DFT and the one-step model of photoemission clarify the relationship between the InBi(001) surface termination and the topological surface states, supporting a predominant role of the Bi bilayer termination. Furthermore, a tight-binding model based on this Bi bilayer termination with only Bi–Bi hopping terms gives a deeper insight into the spin texture[1]. [1] Nicolaï *et al.* Phys. Rev. Research 6.4 (2024): 043116.

TT 57.2 Fri 10:45 H25

Hidden spin-texture in an inversion-symmetric Dirac crystal — Kenta Hagiwara[1,2], Peter C. Schmitz[1], Philipp Rüssmann[1], Xin Liang Tan[1,2], Ying-Jiun Chen[3], Kui-Hon Ou Yang[4], Raman Sankar[5], Chien Jing[4], Yi-Hsin Shen[4], Mahmoud Zeer[1], Dongwook Go[6], Iulia Cojocariu[1], Daniel Baranowski[1], Vitaliy Feyer[1], Minn-Tsong Lin[1,6], Stefan Blügel[1], Claus M. Schneider[1,2], Yuriy Mokrousov[1,5], and •Christian Tusche[1,2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, — [2]Faculty of Physics, University of Duisburg-Essen — [3]Ernst Ruska-Centre, Forschungszentrum Jülich — [4]Department of Physics, National Taiwan University, Taipei, Taiwan — [5]Academia Sinica, Taipei, Taiwan — [6]Johannes-Gutenberg University Mainz

A hidden spin polarization refers to a local spin polarization caused by apparent symmetry breaking and offers new perspectives for spintronics applications. Transition metal dichalcogenides can host various topological phases depending on the symmetry of their crystal structure. Here, by means of spin-resolving momentum microscopy, we reveal the spin texture of both topologically and symmetrically distinct surface and bulk Dirac cones in the inversion symmetric Dirac semimetal $NiTe_2$. We discovered a “hidden” spin polarization the bulk Dirac cone, localized at the different Te layers of the inversion symmetric bulk unit cell, such that the overlap of the two states results in a topologically trivial Dirac cone enforced by the global crystal symmetry. This work establishes a link between topology, spin-texture, and symmetry, enabling control by external perturbations.

TT 57.3 Fri 11:00 H25

Edge spectroscopy of the quantum spin Hall insulator indenene — •Jonas Erhardt[1,2], Mattia Ianetti[3], Gianni Profeta[3], Domenico Di Sante[4], Giorgio Sangiovanni[2,5], Simon Moser[1,2], and Ralph Claessen[1,2] — [1]Physikalisches Institut, Universität Würzburg — [2]Würzburg-Dresden Cluster of Excellence ct.qmat — [3]Department of Physical and Chemical Sciences, University of L'Aquila — [4]Department of Physics and Astronomy, University of Bologna — [5]Institut für Theoretische Physik und Astrophysik, Universität Würzburg

The non-trivial topology of the quantum spin Hall insulator indenene was recently demonstrated through bulk probes that reveal its topological band ordering [1,2]. According to the bulk-boundary correspondence, this ensures the existence of robust metallic states confined to the edge of this triangular indium monolayer. In this study, we employ scanning tunneling spectroscopy to investigate all three edge types of indenene for this correspondence. Our results demonstrate metallic edge density of states with suppressed backscattering near the bulk band gap, providing strong evidence for the existence of topologically protected edge states in indenene.

[1] M. Bauernfeind, J. Erhardt, and P. Eck *et al.*, Nat. Commun. **12**, 5396 (2021)
[2] J. Erhardt *et al.*, Phys. Rev. Lett. **132**, 196401 (2024)

TT 57.4 Fri 11:15 H25

Bismuthene at the Graphene/SiC Interface: A Protected Quantum Spin Hall Insulator — •Niclas Tilgner[1], Susanne Wolff[1], Serguei Soubatch[2], Andres D. P. Unigarro[1], Sibylle Gemming[1], F. Stefan Tautz[2], Christian Kumpf[2], Thomas Seyller[1], Fabian Göhler[1], and Philip Schädlich[1] — [1]Institute of Physics, Chemnitz University of Technology, Germany — [2]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany

Quantum spin Hall insulators (QSHIs) hold the potential to revolutionize next-generation technologies. Kane and Mele identified 2D honeycomb structures of heavy atoms with strong spin-orbit coupling as promising candidates for these materials. To realize this potential, however, the QSHI must be shielded from environmental influences. Previous research has demonstrated the intercalation of 2D Bi layers beneath graphene on SiC, resulting in the formation of two distinct phases. Among those, the β-phase exhibits a $(\sqrt{3} \times \sqrt{3})R30°$ periodicity relative to the substrate. We identify the Bi adsorption site using x-ray standing wave imaging, a method which deterimes the element specific, 3D atomic distribution with respect to the bulk unit cell. After subsequent hydrogen intercalation, the Bi position changes significantly from hollow to top site adsorption. Further measurements with angle-resolved photoelectron spectroscopy reveal the band structure of the QSHI bismuthene with a pronounced Rashba splitting and slight p-type doping. We propose that the initial β-phase has to be considered as an electronically inactive layer of bismuthene, whose electronic structure can be established by subsequent hydrogen intercalation.

TT 57.5 Fri 11:30 H25

Probing the Electronic Structure at the Boundary of Topological Insulators in the Bi2Se3 Family by Combined STM and AFM — •Christoph S. Setescak[1], Irene Aguilera[2], Adrian Weindl[1], Matthias Kronseder[1], Andrea Donarini[1], and Franz J. Giessibl[1] — [1]University of Regensburg, Regensburg, Germany — [2]University of Amsterdam and European Theoretical Spectroscopy Facility (ETSF), Amsterdam, The Netherlands

We develop a numerical scheme for the calculation of tunneling current

I and differential conductance dI/dV of metal and CO terminated STM tips on the topological insulators Bi2Se3, Bi2Te2Se and Bi2Te3 and find excellent agreement with experiment. The calculation is an application of Chen's derivative rule, whereby the Bloch functions are obtained from Wannier interpolated tightbinding Hamiltonians and maximally localized Wannier functions from first-principle DFT+GW calculations. We observe signatures of the topological boundary modes, their hybridization with bulk bands, Van Hove singularities of the bulk bands and characterize the orbital character of these electronic modes using the high spatial resolution of STM and AFM. Bare DFT calculations are insufficient to explain the experimental data, which are instead accurately reproduced by many-body corrected GW calculations.

TT 57.6 Fri 11:45 H25

Revealing higher-order topological bulk-boundary correspondence in Bi crystals with spin-helical hinge state loop and proximity superconductivity — •Dongming Zhao[1], Yang Zhong[1], Tian Yuan[1], Haitao Wang[1], Tianxing Jiang[1], Yang Qi[1], Hongjun Xiang[1,2,3], Xingao Gong[1,2,3], Donglai Feng[2,3,4], and Tong Zhang[1,2,3,4] — [1]Fudan University, Shanghai, China — [2]Collaborative Innovation Center for Advanced Microstructures, Nanjing, China — [3]Shanghai Research Center for Quantum Sciences, Shanghai, China — [4]Hefei National Laboratory, Hefei, China

Topological materials are typically characterized by gapless boundary states, known as bulk-boundary correspondence. Recently, this concept has been generalized in higher-order topological insulators (HOTIs). E.g., a 2nd-order 3D TI hosts 1D topological hinge states winding around the crystal. A complete verification of HOTI will require probing all crystal boundaries. Here we studied a promising candidate of 2nd-order TI, Bi, in the form of mesoscopic crystals grown on superconducting V3Si. Using low-temperature STM, we directly observed dispersive 1D states on various hinges. Upon introducing magnetic scatterers, new scattering channels emerged selectively on certain hinges, revealing their spin-helical nature. Combining first-principle calculation and global symmetry analysis, we find these hinge states topological and formed a closed loop encircling the crystal. This provides direct evidence on the HOTI in Bi. Moreover, proximity superconductivity is observed in the topological hinge states serving as a promising platform for realizing topological superconductivity.

TT 57.7 Fri 12:00 H25

Simultaneous Atomic-Scale Imaging and Electronic Characterization of Wet-Chemically Prepared Bi_2Se_3 Nanoplatelets — •Auke Vlasblom, Victor Wesselingh, Jara Vliem, Daniel Vanmaekelbergh, and Ingmar Swart — Utrecht University, Utrecht, The Netherlands

Colloidal semiconductor nanoparticles are of great interest for various optoelectronic applications, such as integration in displays, solar cells and electronics. For applications, the surface of nanoparticles is of critical importance. However, until now, no technique exists to simultaneously investigate the atomic structure (e.g. the presence of defects) and the electronic properties of a nanoparticle, foremost limited by the presence of ligands that prevent direct access to the surface with a local probe. Here, we present a new and widely applicable procedure that allows investigation of the surface of a nanoparticle with a local probe. Using this method, nanoparticles are transferred to an atomically clean substrate under ultra-high vacuum conditions. We demonstrate the procedure for topological two-dimensional Bi_2Se_3 nanoplatelets deposited on Au(111). We reveal the atomic and electronic structure of the surface of colloidally synthesised Bi_2Se_3 nanoplatelets with scanning tunneling microscopy and spectroscopy measurements. In this talk, I will highlight the various types of defects that occur at the (sub-)surface of Bi_2Se_3 nanoplatelets and I will show their influence on the electronic structure.

TT 58: f-Electron Systems and Heavy Fermions

Time: Friday 11:30–13:00 Location: H31

TT 58.1 Fri 11:30 H31

The in-plane magnetic anisotropy of the coupled antiferromagnetic and charge-multipolar orders in $CeRh_2As_2$ — •Konstantin Semeniuk[1], Seunghyun Khim[1], and Elena Hassinger[1,2] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Dresden University of Technology, Institute for Solid State and Materials Physics, Dresden, Germany

The heavy-fermion superconductor $CeRh_2As_2$ displays multiple intriguing electronic orders (1,2). Besides two superconducting phases, the material also hosts a state called Phase I at temperatures below $T_0 = 0.5$ K. Phase I exhibits magnetism (3), but the response of T_0 to a magnetic field H along the ab plane of the tetragonal lattice is incompatible with conventional magnetic orders. In particular, while $T_0(H)$ is rather stable in Phase I, at a critical field H_{cr} the material transitions into Phase II, in which T_0 rapidly increases with field.

We conducted a detailed investigation of the H-T phase diagram of $CeRh_2As_2$ for various in-plane field orientations. The behaviour of $T_0(H)$ is remarkably different for $H||[100]$ and $H||[110]$, with, respectively, suppression and enhancement of T_0 in Phase I, as well as strong anisotropy of H_{cr}. In line with recent theoretical work (4), we regard Phase I as a unique case of coupled antiferromagnetic and charge-multipolar orders, and use our results to constrain the model.

[1] S. Khim et al., Science **373**, 1012 (2021).
[2] D. Hafner et al., Phys. Rev. X **12**, 011023 (2022).
[3] S. Khim et al., arXiv:2406.16575.
[4] B. Schmidt & P. Thalmeier, Phys. Rev. B **110**, 075154 (2024).

TT 58.2 Fri 11:45 H31

Complex magnetic order from multiple Ce–sites in $CeRhSn_2$. — Petr Opletal[1], Jan Fikáček[1], Arumugam Thamizhavel[2], Zakir Hossain[3], Róbert Tarasenko[4], Vladimír Tkáč[4], and •Jeroen Custers[1] — [1]Charles University, MMF DCMP, Prague, Czech Republic — [2]DCMP & MS, Tata Institute of Fundamental Research, Mumbai, India — [3]Dept. of Physics, Indian Institute of Technology, Kanpur, India — [4]Institute of Physics, Faculty of Science, P.J. Šafárik University, Košice, Slovak Republic

Previous reports on polycrystalline $CeRhSn_2$ reveal different magnetic ground states being ferromagnetic (T_C = 4 K) or antiferromagnetic (T_N = 3.5 K). To elucidate we have grown a single crystal and conducted measurements of the magnetization (M), specific heat (C_p/T), and electrical resistivity (ρ). The compound crystallizes in the orthorhombic lattice structure with space group $Cmcm$ characterized by the cell parameters $a = 4.5905(10)$Å, $b = 16.9758(5)$Å and $c = 9.5924(3)$Å. Moreover, it exhibits two crystallographic inequivalent Ce–sites with a zigzag chain of Ce–atoms running along the c–axis. Our measurements reveal an AFM phase transition at $T_{M1} = 3.6$ K manifesting by a strong decrease of the orthorhombic c–axis magnetization, while only a tiny cusp is notable along the other directions, a sharp discontinuity in C_p/T and a kink in ρ and a subsequent ferrimagnet–like (FIM) ordering at $T_{M2} = 1.7$ K visible by a λ-shape of peak in C_p/T and a sudden drop in the resistivity. We map out a B–T phase diagram for field $B \parallel b$–axis and follow the evolution of the transitions under hydrostatic pressure up to 3 GPa.

TT 58.3 Fri 12:00 H31

Anderson impurity model calculations for line shape analyses of core to valence RIXS spectra of Ce Kondo materials — •Michelangelo Tagliavini[1], Federico Mazza[2], Xinlin Yan[2], Andrey Prokofiev[2], Kurt Kummer[3], Maurits W. Haverkort[1], and Silke Paschen[2] — [1]*Institute for Theoretical Physics (ITP), Heidelberg University*, Philosophenweg 19, 69120, Heidelberg, Germany — [2]*Institute of Solid State Physics, Vienna University of Technology*, Wiedner Hauptstr. 8-10/138 A 1040 Vienna, Austria — [3]*European Synchrotron Radiation Facility*, 71 Avenue des Martyrs, CS40220, F-38043 Grenoble Cedex 9, France

In rare-earth-containing heavy-fermion compounds, the interaction of continuum electrons with 4f local moments can give rise to a Kondo screened ground state. Crystal-field excited states can be probed using Resonant Inelastic X-ray Scattering (RIXS). Interaction between localized 4f states and continuum electrons transforms the crystal-field excitations into resonances with hybridization-dependent asymmetric line shapes. In this study, we present results for two heavy-fermion compounds: $CeBa_7Au_6Si_{40}$ and $CeRu_4Sn_6$, which exhibit low (≈1 K) and high (≈ 200 K) Kondo temperatures, respectively. Using density-functional-theory-based Anderson impurity model calculations implemented in Quanty (www.Quanty.org), we link the f-f transition line shapes to the hybridization function in these materials. Our findings reveal a direct relationship between the hybridization function, the Kondo temperature, and the crystal fields, offering new insights into the underlying physics of these complex systems.

TT 58.4 Fri 12:15 H31

Emergent in-plane anisotropic elastoresistance in $YbRh_2Si_2$ — •Soumendra Nath Panja, Jacques Gounelle-Pontanel, Anton Jesche, and Philipp Gegenwart — Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, 86159 Augsburg, Germany

We have shown recently that the Kondo interaction in the tetragonal heavy-fermion metal $YbRh_2Si_2$ can be efficiently tuned by tensile and compressive uniaxial strain along the [100] axis [1]. Here, we present a detailed investigation of the temperature dependent elastoresistance $d\rho/d\epsilon_i$ of $YbRh_2Si_2$, for both i=[100] and [110] directions. Remarkably, elastoresistance develops a pronounced in-plane strain anisotropy at low temperatures that is analyzed with respect to the influence of uniaxial strain on the crystal electric field splitting and Kondo interaction. Furthermore, we investigate the combined impact of magnetic field and strain on the low-temperature elastoresistance behavior in $YbRh_2Si_2$.

[1] S.N. Panja, A. Jesche, N. Tang, P. Gegenwart, Phys. Rev. B **109**, 205152 (2024).

TT 58.5 Fri 12:30 H31

Anisotropic antiferromagnetic order in $EuPd_3Si_2$ — •Michelle Ocker[1], Nour Marayatta[2], Michael Merz[2], Kristin Kliemt[1], and Cornelius Krellner[1] — [1]Physikalisches Institut, Goethe Universität Frankfurt, 60438 Frankfurt/Main, Germany — [2]Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany

The magnetic order of a rare earth compounds is determined by the RKKY exchange interaction. In case of Eu compounds small changes in the growth method or the initial composition can potentially lead to small composition changes which than modify the physical properties [1]. For example, the compound $EuPd_3Si_2$, which crystallises in the orthorhombic space group Imma, shows a ferromagnetic transition at T_{C1} = 78 K and a spin reorientation at T_{C2} = 5 K according to Ref. [2]. Whereas our $EuPd_3Si_2$ samples show an antiferromagnetic transition at T_{N1} = 61 K and a possible reorientation at T_{N2} = 40 K. With field aligned along the three main symmetrie directions, our samples show different degrees of anisotropy, as has been observed for related compounds [3]. In this presentation, we report about the crystal growth and our evaluation of the physical properties, from which we constructed a magnetic phase diagram.

[1] K.Kliemt et al. Cryst. Growth Des. 22, 5399 (2022).
[2] S.Sharma et al. Phys. Rev. Mater. 7, 023402 (2023).
[3] K.Shigetoh et al. Phys. Rev. B 76, 184429 (2007).

TT 58.6 Fri 12:45 H31

Coherent valence dynamics in UAl_3 — •Vinicius Estevo Silva Frehse[1], Hlynur Gretarsson[2], Eric Bauer[3], Atsushi Hariki[4], Filip Ronning[3], and Marein Rahn[1] — [1]Center for Electronic Correlations and Magnetism, Augsburg, Germany — [2]P01 High Resolution Dynamics Beamline, Hamburg, Germany — [3]Institute for Materials Science, Los Alamos, USA — [4]Department of Physics and Electronics, Osaka, Japan

The interaction between itinerant and localized electrons, as proposed by the Kondo model, enables the formation of heavy fermions, and unconventional superconductivity. In f-electron intermetallics with a large Kondo temperature, the emergence of lattice-coherent valence dynamics can be resolved by resonant inelastic x-ray scattering (RIXS). In the simple cubic, strongly valence fluctuating compound UAl_3, a coherent Fermi surface of Kondo quasiparticles emerges around $T_{coh} \sim 200$ K. We study the excitations of these quasiparticles using the newly available RIXS instrumentation for the tender x-ray range. The spectra indeed reveal dispersive trends of the $5f$ interband excitations at low temperatures, reminiscent of the isostructural $4f$ compound $CePd_3$[1]. [1] M.C.Rahn, *et al.*, Nat. Comm. **13**, 6129 (2022).

TT 59: Quantum Chaos (joint session DY/TT)

Time: Friday 11:30–13:00 Location: H37

TT 59.1 Fri 11:30 H37

Semiclassical foundation of universality in many-body quantum circuits — •Maximilian Kieler[1], Felix Fritzsch[2], and Arnd Bäcker[1] — [1]TU Dresden, Institut für Theoretische Physik, Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany

For single particle systems the fundamental equivalence of quantum chaotic systems and random matrix theory is well-understood by means of semiclassical periodic orbit theory. We propose an extension to spatially local many-body systems by incorporating the concept of symmetry-breaking. Using this we show that random matrix behavior arises generically in quantum chaotic many-body systems in the form of a symmetry breaking of local time-translation symmetries. This general framework is applied to quantum circuits where an explicit correspondence to the random matrix result for the spectral form factor can be shown.

TT 59.2 Fri 11:45 H37

Distribution of resonance poles of chaotic scattering systems — •Jan Robert Schmidt, Florian Lorenz, and Roland Ketzmerick — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

The distribution of resonance poles of chaotic scattering systems is investigated in the semiclassical limit at unprecedented small wavelengths. For the paradigmatic three-disk scattering system, we study the spectral gap towards the real axis, the fractal Weyl law, which counts the number of resonance poles, and the distribution of decay rates. These properties are compared to previous analytical results, e.g. from random matrix theory. In contrast to this system with full escape, systems with partial escape have significantly different properties. For the example of a dielectric cavity, we show that results from random matrix theory cannot explain the distribution of decay rates.

TT 59.3 Fri 12:00 H37

Solved after 60 years: Exact Derivation of the Ericson Transition in Quantum Chaotic Scattering — •Simon Köhnes and Thomas Guhr — University of Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany

Scattering experiments are the prime source of information on the quantum world. Scattering theory nowadays has numerous applications in various branches of physics and beyond, even including classical wave phenomena. We analyze chaotic scattering systems in the framework of Random Matrix Theory. The distribution of the scattering matrix elements is the key quantity. A strong sign of chaos in complex quantum systems is the Ericson regime of strongly overlapping resonances in which the cross sections exhibit random behavior. We apply the Supersymmetry Method. For the three Wigner-Dyson symmetry classes, we analytically calculate the transition to the Ericson regime, facilitating direct comparison with experimental results. In the course of doing so, we also gather new information on features of the underlying supersymmetric non-linear sigma model.

TT 59.4 Fri 12:15 H37

Chaotic Quantum Scattering: Exact Solutions for Systems with Spin — •Nils Gluth and Thomas Guhr — Universität Duisburg-Essen, Duisburg, Germany

Scattering experiments facilitate access to quantum systems. Scattering theory is needed to fully describe the involved experimental situations. Over the years, it became a powerful tool with applications to a large variety of different systems, such as for example compound nuclei, atoms, molecules, quantum graphs or even microwave networks and cavities. These systems are typically complex or in a broad sense chaotic, calling for statistical approaches, in particular Random Matrix Theory. Considerably extending our previous work, we calculate the distribution of scattering matrix elements and cross sections using Supersymmetry. We focus on the symplectic symmetry class which had not yet been solved, because a theoretical understanding is needed in view of recent experiments. We provide a comparison of our results with experimental data.

TT 59.5 Fri 12:30 H37

Phase-space representations and exceptional points of coupled polarized modes in cylindrical cavities — •Tom Rodemund[1], Shilong Li[2], Síle Nic Chormaic[3], and Martina Hentschel[1] — [1]Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany — [2]College of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, China — [3]Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan

% Optical microcavities are often assumed to be two-dimensional (2D). This allows a convenient phase-space representation in 2D, where Poincaré surface of section for particle dynamics and the Husimi function for their wave counterpart are prominent methods. Here we extend the concept of Husimi functions for open systems [1] to three-dimensional (3D) optical microcavities of arbitrary shape. In particular we study deformed cylindrical cavities and illustrate their mode dynamics in terms of generalized Husimi functions.

The coupling between the two different polarizations (TE and TM) is a new feature in realistic 3D optical cavities that is not present in 2D. We find the interaction of polarized modes to be governed by a network of exceptional points that reflects the openness, or non-Hermiticity, of the system. The mode coupling is analyzed using the extended Husimi formalism that we find to be a comprehensive and useful way to represent the mode structure of 3D microcavities [2].

[1] Hentschel et al., Europhys. Lett. 62 636 (2003)

[2] Rodemund et al., to be submitted.

TT 59.6 Fri 12:45 H37

The classical Maldacena-Shenker-Standford bound — •Gerrit Caspari, Fabian Haneder, Juan-Diego Urbina, and Klaus Richter — University of Regensburg, Regensburg, Deutschland

The Maldacena-Shenker-Stanford (MSS) bound [1] is a condition on a system's quantum Lyapunov exponent, defined as half the growth rate of the regularised out-of-time-ordered correlator (OTOC), which states that said exponent is bounded by the system's temperature, with, e.g., black holes as characteristic systems saturating the bound.

From the perspective of classical chaos, this is surprising, since the classical Lyapunov exponent seems not to be bounded. We study chaotic quantum systems in a hyperbolic geometry with and without cusps and magnetic fields [2][3] via Selberg's Trace Formula (STF). Through this we derive bounds on the classical Lyapunov exponent from analyticity conditions in the trace formula and relate them to the MSS bound.

We report our progress in studying these bounds using the STF, which entails an investigation of the analyticity condition needed to prove the STF for the partition function of our systems and its relation to possible phase transitions.

[1] Maldacena, J., Shenker, S.H. & Stanford, J. High Energ. Phys. 2016, 106 (2016).

[2] Aurich, R., & Steiner, F. (1992)., Proceedings: Mathematical and Physical Sciences, 437(1901), 693-714

[3] Avron, J.E., Klein, M. & Pnueli, A., Phys. Rev. Lett. 69 (1992)