Quantum Optics and Photonics Division
Fachverband Quantenoptik und Photonik (Q)

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Overview of Invited Talks and Sessions

(Lecture halls HS V, AP-HS, WP-HS, HS Botanik, HS I, and HS I PI; Poster Tent)

Invited Talks

Q 2.1	Mon	11:00–11:30	AP-HS	**An array of neutral atoms coupled to an optical cavity: A versatile quantum network node** — Raphael Benz, Sebastián Alejandro Morales Ramirez, Micha Kappel, Vincent Beguin, Krishna Relekar, •Stephan Welte
Q 3.1	Mon	11:00–11:30	HS Botanik	**3D photonic model systems for topological effects and quantum-optical analogies** — •Christina Jörg
Q 10.1	Mon	17:00–17:30	AP-HS	**Nuclear quantum memory for hard x-ray photon wave packets** — •Sven Velten, Lars Bocklage, Xiwen Zhang, Kai Schlage, Anjali Panchwanee, Sakshath Sadashivaiah, Ilya Sergeev, Olaf Leupold, Aleksandr I. Chumakov, Olga Kocharovskaya, Ralf Röhlsberger
Q 18.1	Tue	11:00–11:30	HS V	**Strong-field physics and nonlinear optical phenomena in two-dimensional honeycomb materials** — •Anna Galler
Q 20.1	Tue	11:00–11:30	HS Botanik	**Towards quantum logic inspired techniques for high-precision measurements in Penning traps** — •Juan Manuel Cornejo, Jan Schaper, Nikita Poljakov, Julia-Aileen Coenders, Stefan Ulmer, Christian Ospelkaus
Q 32.1	Wed	11:00–11:30	HS Botanik	**Exploring fundamental constants with high-precision spectroscopy of molecular hydrogen ions** — •Soroosh Alighanbari, Magnus R. Schenkel, Stephan Schiller
Q 34.1	Wed	11:00–11:30	HS I PI	**Haken's quantum field theoretical understanding of semiconductors and lasers and its present-day impact** — •Cun-Zheng Ning
Q 34.2	Wed	11:30–12:00	HS I PI	**Bose-Einstein condensation of photons in vertical-cavity surface-emitting lasers** — •Maciej Pieczarka
Q 34.3	Wed	12:00–12:30	HS I PI	**Photons in a dye-filled cavity: quantum-optical system interpolating between Bose-Einstein condensates and laser-like states** — •Milan Radonjić
Q 34.4	Wed	12:30–13:00	HS I PI	**From laser physics to nonlinear dynamics and synergetics** — •Eckehard Schöll
Q 41.1	Wed	14:30–15:00	HS Botanik	**Integration of fiber Fabry-Perot cavities for sensing applications and cavity optomechanics** — •Hannes Pfeifer, Lukas Tenbrake, Carlos Saavedra, Florian Giefer, Jana Blechmann, Johanna Stein, Daniel Stachanow, Dieter Meschede, Karol Krzempek, Randall Goldsmith, Witlef Wieczorek, Stefan Linden, Sebastian Hofferberth
Q 42.1	Wed	14:30–15:00	HS I	**Effective Lindblad master equations for atoms coupled to dissipative bosonic modes** — •Simon Balthasar Jäger
Q 52.1	Thu	11:00–11:30	HS Botanik	**Recent progress towards the development of a ^{229}Th-based nuclear optical clock** — •Lars von der Wense
Q 52.6	Thu	12:30–13:00	HS Botanik	**Making a solid-state nuclear optical clock** — •Kjeld Beeks, Luca Toscani de Col, Ira Morawetz, Rahul Singh, Michael Bartokos, Thomas Riebner, Fabian Schaden, Georgy Kazakov, Tomas Sikorsky, Thomas LaGrange, Fabrizio Carbone, Thorsten Schumm

Q 54.1	Thu	11:00–11:30	HS I PI	**New Opportunities for Sensing via Continuous Measurement** — •Dayou Yang, Susana F. Huelga, Martin B. Plenio
Q 66.1	Fri	11:00–11:30	HS V	**Enhancing pair tunneling in the Hubbard model by Floquet engineering** — •Andrea Bergschneider
Q 67.1	Fri	11:00–11:30	AP-HS	**Towards Quantum Simulation with Qudits** — •Martin Ringbauer
Q 68.1	Fri	11:00–11:30	HS Botanik	**Multi-color excitation of quantum emitters** — •Thomas Bracht

Invited Talks of the joint Symposium Molecular Spectroscopy of Liquid Jets (SYML)

See SYML for the full program of the symposium.

SYML 1.1	Mon	11:00–11:30	HS 1+2	**The challenging road to work function measurements from aqueous solutions** — •Bernd Winter
SYML 1.2	Mon	11:30–12:00	HS 1+2	**Liquid Delivery Systems for Time Resolved X-ray Spectroscopy** — •Zhong Yin
SYML 1.3	Mon	12:00–12:30	HS 1+2	**UV photoelectron spectroscopy of aqueous solutions** — •Helen Fielding, Johanna Rademacher, Kate Robertson, Edoardo Simonetti
SYML 1.4	Mon	12:30–13:00	HS 1+2	**Decoherence and electron transport in liquid water observed with attosecond interferometric spectroscopy** — •Hugo Marroux et al

Invited Talks of the joint Symposium SAMOP Dissertation Prize 2025 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Mon	14:30–15:00	HS 1+2	**A simple method to separate single- from multi-particle dynamics in time-resolved spectroscopy** — •Julian Lüttig
SYAD 1.2	Mon	15:00–15:30	HS 1+2	**Time-resolving quantum dynamics in atoms and molecules with intense x-ray lasers and neural networks** — •Alexander Magunia
SYAD 1.3	Mon	15:30–16:00	HS 1+2	**How rotation shapes the decay of diatomic carbon anions** — •Viviane C. Schmidt
SYAD 1.4	Mon	16:00–16:30	HS 1+2	**Interstellar stardust from stellar explosions recorded in a deep-ocean ferromanganese crust within the last 10 million years** — •Dominik Koll

Invited Talks of the joint Symposium Polaritonic Effects in Molecular System (SYPE)

See SYPE for the full program of the symposium.

SYPE 1.1	Tue	11:00–11:30	HS 1+2	**Ab initio quantum electrodynamics: from microscopic details to thermodynamics** — •Michael Ruggenthaler
SYPE 1.2	Tue	11:30–12:00	HS 1+2	**Ultrafast coherent exciton dynamics mediated by field-matter couplings** — •Antonietta De Sio
SYPE 1.3	Tue	12:00–12:30	HS 1+2	**Open system dynamics for non-radiative transitions in molecules** — •Claudiu Genes
SYPE 1.4	Tue	12:30–13:00	HS 1+2	**Strong light-matter coupling: from self-hybridized polaritons to Casimir self-assembly** — •Timur Shegai

Invited Talks of the joint Symposium Quantum Science and more in Ghana and Germany (SYGG)

See SYGG for the full program of the symposium.

SYGG 1.1	Tue	11:00–11:05	WP-HS	**Welcome Adress** — •Birgit Münch
SYGG 1.2	Tue	11:05–11:20	WP-HS	**Quantum Education in Ghana** — •Dorcas Attuabea Addo
SYGG 1.3	Tue	11:20–11:45	WP-HS	**Mathematical and Computational Physics Research In Ghana: To Cultivate a Knowledge-Based and Sustainable Development Economy** — •Henry Martin, Henry Elorm Quarshie, Mark Paal, Francis Kofi Ampong, Eric Kwabena Kyeh Abavare, Matteo Colangeli, Alessandra Continenza, Jaime Marian

SYGG 1.4	Tue	11:45–12:10	WP-HS	**Forecasting the Economic Health of Ghana Using Quantum-Enhanced Long Short-Term Memory Model** — •Peter Nimbe, Henry Martin, Dorcas Attuabea Addo, Nicodemus Songose Awarayi
SYGG 1.5	Tue	12:10–12:40	WP-HS	**Quantum Technology with Spins** — •Joerg Wrachtrup
SYGG 1.6	Tue	12:40–13:00	WP-HS	**Renewable Energy Technologies for Rural Ghana: The Role of Appropriate Technology for Tailored solutions** — •Michael Kweku Edem Donkor

Invited Talks of the joint Symposium Foundations of Quantum Theory (SYQT)

See SYQT for the full program of the symposium.

SYQT 1.1	Wed	11:00–11:30	HS 1+2	**Against 'local causality'** — •Guido Bacciagaluppi
SYQT 1.2	Wed	11:30–12:00	HS 1+2	**Philosophy of Quantum Thermodynamics** — •Carina Prunkl
SYQT 1.3	Wed	12:00–12:30	HS 1+2	**Can quantum information be the underpinning of quantum physics?** — •Paolo Perinotti
SYQT 1.4	Wed	12:30–13:00	HS 1+2	**Spin-bounded correlations: rotation boxes within and beyond quantum theory** — Albert Aloy, •Thomas Galley, Caroline Jones, Stefan Ludescher, Markus Müller

Invited Talks of the joint Symposium Hidden Variables: Contributions of Women to Quantum Physics (SYWQ)

See SYWQ for the full program of the symposium.

SYWQ 1.1	Thu	11:00–11:30	HS 1+2	**Reshaping the History of Quantum Physics: Paths to Gender Equality** — •Andrea Reichenberger
SYWQ 1.2	Thu	11:30–12:00	HS 1+2	**Lucy Mensing: Forgotten Pioneer of Quantum Mechanics** — •Gernot Münster
SYWQ 1.3	Thu	12:00–12:30	HS 1+2	**Roller-coasting women scientific trajectories: New frontiers to accelerate (quantum) science** — •Marilù Chiofalo
SYWQ 1.4	Thu	12:30–13:00	HS 1+2	**Who decides scientific authority and how?** — •Anna Sanpera

Prize and Invited Talks of the joint Awards Symposium (SYAS)

See SYAS for the full program of the symposium.

SYAS 1.1	Thu	14:30–15:10	HS 1+2	**A journey in mathematical quantum physics** — •Reinhard F. Werner
SYAS 1.2	Thu	15:10–15:50	HS 1+2	**Precision Tests of the Standard Model at Low Energies Using Stored Exotic Ions in Penning Traps** — •Klaus Blaum
SYAS 1.3	Thu	15:50–16:30	HS 1+2	**Controlling light by atoms and atoms by light: from dark-state polaritons to many-body spin physics** — •Michael Fleischhauer
SYAS 1.4	Thu	16:30–16:35	HS 1+2	**Quantum history at your fingertips: Launch of the DPG's Quantum History Wall** — •Arne Schirrmacher

Invited Talks of the joint Symposium Laser-Cooled Molecules (SYLC)

See SYLC for the full program of the symposium.

SYLC 1.1	Fri	11:00–11:30	HS 1+2	**Measuring the electron electric dipole moment with laser-cooled molecules** — •Michael Tarbutt
SYLC 1.2	Fri	11:30–12:00	HS 1+2	**Laser-cooling of molecules in various charge states** — •Robert Berger
SYLC 1.3	Fri	12:00–12:30	HS 1+2	**Progress in quantum gases of polar molecules: Collisions, laser cooling, and trapping techniques** — Mara Meyer zum Alten Borgloh, Jule Heier, Baraa Shammout, Fritz von Gierke, Timo Poll, Julius Niederstucke, Paul Kaebert, Sebastian Anskeit, Jakob Stalmann, Leon Karpa, Mirco Siercke, •Silke Ospelkaus
SYLC 1.4	Fri	12:30–13:00	HS 1+2	**Progress in laser cooling the AlF molecule** — •Sidney Wright

Sessions

Q 1.1–1.6	Mon	11:00–12:30	HS V	**Laser Technology and Applications (joint session Q/K)**
Q 2.1–2.7	Mon	11:00–13:00	AP-HS	**Quantum Networks, Repeaters, and QKD I (joint session Q/QI)**
Q 3.1–3.7	Mon	11:00–13:00	HS Botanik	**Photonics I**
Q 4.1–4.7	Mon	11:00–12:45	HS I	**Rydberg Atoms, Ions, and Molecules (joint session Q/MO)**
Q 5.1–5.8	Mon	11:00–13:00	HS I PI	**Collective Effects and Disordered Systems**
Q 6.1–6.7	Mon	11:00–13:00	HS PC	**Precision Spectroscopy of Atoms and Ions I (joint session A/Q)**
Q 7.1–7.8	Mon	11:00–13:00	HS XV	**Polaritonic Effects in Molecular Systems I (joint session MO/Q)**
Q 8.1–8.6	Mon	11:00–12:45	HS XI ITW	**Laser Systems – Optical Methods (joint session K/Q)**
Q 9.1–9.8	Mon	17:00–19:00	HS V	**Photonics (3D Print) (joint session Q/K)**
Q 10.1–10.7	Mon	17:00–19:00	AP-HS	**Quantum Optics and Nuclear Quantum Optics I**
Q 11.1–11.8	Mon	17:00–19:00	HS Botanik	**QED and Cavity QED**
Q 12.1–12.8	Mon	17:00–19:00	HS I	**Quantum Optomechanics I**
Q 13.1–13.8	Mon	17:00–19:00	HS I PI	**Ultracold Matter (Bosons) I (joint session Q/A)**
Q 14.1–14.6	Mon	17:00–18:45	HS VIII	**Quantum Metrology and Sensing (joint session QI/Q)**
Q 15.1–15.6	Mon	17:00–18:45	HS II	**Atom and Ion Qubits (joint session QI/Q)**
Q 16.1–16.7	Mon	17:00–19:00	KlHS Mathe	**Ultra-cold atoms, ions and BEC I (joint session A/Q)**
Q 17.1–17.7	Mon	17:00–19:00	HS PC	**Precision Spectroscopy of Atoms and Ions II (joint session A/Q)**
Q 18.1–18.6	Tue	11:00–12:45	HS V	**Strong-Field and Ultrafast Phenomena (joint session Q/MO)**
Q 19.1–19.8	Tue	11:00–13:00	AP-HS	**Quantum Networks, Repeaters, and QKD II (joint session Q/QI)**
Q 20.1–20.6	Tue	11:00–12:45	HS Botanik	**Atom & Ion Clocks and Metrology I**
Q 21.1–21.8	Tue	11:00–13:00	HS I	**Quantum Optomechanics II**
Q 22.1–22.8	Tue	11:00–13:00	HS I PI	**Ultracold Matter (Bosons) II (joint session Q/A)**
Q 23.1–23.7	Tue	11:00–13:00	KlHS Mathe	**Ultra-cold Atoms, Ions and BEC II (joint session A/Q)**
Q 24.1–24.6	Tue	14:00–15:30	HS II	**Quantum Computing Implementations (joint session QI/Q)**
Q 25.1–25.65	Tue	14:00–16:00	Tent	**Poster – Cold Atoms and Molecules, Matter Waves (joint session Q/A/MO)**
Q 26.1–26.40	Tue	14:00–16:00	Tent	**Poster – Precision Measurement, Metrology, and Quantum Effects**
Q 27.1–27.34	Tue	14:00–16:00	Tent	**Poster – Ultra-cold Atoms, Ions and BEC (joint session A/Q)**
Q 28.1–28.6	Tue	14:00–16:00	Tent	**Poster – Ultra-cold Plasmas and Rydberg Systems (joint session A/Q)**
Q 29.1–29.6	Tue	14:00–16:00	Tent	**Poster – Polaritonic Effects in Molecular Systems (joint session MO/Q)**
Q 30.1–30.6	Wed	11:00–12:30	HS V	**Quantum Sensing I (joint session Q/QI)**
Q 31.1–31.8	Wed	11:00–13:00	AP-HS	**Quantum Networks, Repeaters, and QKD III (joint session Q/QI)**
Q 32.1–32.7	Wed	11:00–13:00	HS Botanik	**Atom & Ion Clocks and Metrology II**
Q 33.1–33.8	Wed	11:00–13:00	HS I	**Matter Wave Interferometry I**
Q 34.1–34.4	Wed	11:00–13:00	HS I PI	**In Memoriam of Hermann Haken (joint session Q/MO)**
Q 35.1–35.7	Wed	11:00–13:00	HS PC	**Precision Spectroscopy of Atoms and Ions III (joint session A/Q)**
Q 36.1–36.7	Wed	11:00–13:00	KlHS Mathe	**Ultra-cold Atoms, Ions and BEC III (joint session A/Q)**
Q 37.1–37.8	Wed	11:00–13:00	HS XV	**Polaritonic Effects in Molecular Systems II (joint session MO/Q)**
Q 38	Wed	13:15–14:15	AP-HS	**Members' Assembly**
Q 39.1–39.8	Wed	14:30–16:30	HS V	**Photon BEC**
Q 40.1–40.8	Wed	14:30–16:30	AP-HS	**Quantum Optics and Nuclear Quantum Optics II**
Q 41.1–41.7	Wed	14:30–16:30	HS Botanik	**Quantum Technologies (Color Centers and Ion Traps) I (joint session Q/QI)**
Q 42.1–42.6	Wed	14:30–16:15	HS I	**Open Quantum Systems I (joint session Q/QI)**
Q 43.1–43.8	Wed	14:30–16:30	WP-HS	**Ultracold Matter (Bosons) III (joint session Q/A)**
Q 44.1–44.8	Wed	14:30–16:45	HS VIII	**Quantum Networks (joint session QI/Q)**

Q 45.1–45.6	Wed	14:30–16:15	HS IX	**Mechanical, Macroscopic, and Continuous-variable Quantum Systems (joint session QI/Q)**
Q 46.1–46.5	Wed	14:30–15:45	KlHS Mathe	**Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)**
Q 47.1–47.7	Wed	14:30–16:30	HS XVI	**Cold Molecules and Cold Chemistry (joint session MO/Q)**
Q 48.1–48.58	Wed	17:00–19:00	Tent	**Poster – Quantum Optics, Technologies, and Optomechanics**
Q 49.1–49.45	Wed	17:00–19:00	Tent	**Poster – Photonics, Lasers, and Applications**
Q 50.1–50.7	Thu	11:00–12:45	HS V	**Ultracold Matter (Fermions) I (joint session Q/A)**
Q 51.1–51.8	Thu	11:00–13:00	AP-HS	**Quantum Computing and Simulation I (joint session Q/QI)**
Q 52.1–52.6	Thu	11:00–13:00	HS Botanik	**Nuclear Clocks**
Q 53.1–53.8	Thu	11:00–13:00	HS I	**Matter Wave Interferometry II**
Q 54.1–54.6	Thu	11:00–12:45	HS I PI	**Quantum Sensing II (joint session Q/QI)**
Q 55.1–55.6	Thu	11:00–12:45	HS II	**Decoherence and Open Quantum Systems (joint session QI/Q)**
Q 56.1–56.7	Thu	11:00–13:00	KlHS Mathe	**Precision Spectroscopy of Atoms and Ions V (joint session A/Q)**
Q 57.1–57.6	Thu	11:00–12:45	HS PC	**Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)**
Q 58.1–58.8	Thu	14:30–16:30	HS IX	**Quantum Communication II: Implementations (joint session QI/Q)**
Q 59.1–59.8	Thu	14:30–16:30	GrHS Mathe	**Ultra-cold atoms, ions and BEC IV (joint session A/Q)**
Q 60.1–60.7	Thu	14:30–16:30	KlHS Mathe	**Precision Spectroscopy of Atoms and Ions VI (joint session A/Q)**
Q 61.1–61.5	Thu	14:30–15:45	HS PC	**Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)**
Q 62.1–62.45	Thu	17:00–19:00	Tent	**Poster – Quantum Information Technologies (joint session Q/QI)**
Q 63.1–63.69	Thu	17:00–19:00	Tent	**Poster – Quantum Information (joint session QI/Q)**
Q 64.1–64.21	Thu	17:00–19:00	Tent	**Poster – Precision Spectroscopy of Atoms and Ions (joint session A/Q)**
Q 65.1–65.15	Thu	17:00–19:00	Tent	**Poster – Cold Molecules (joint session MO/Q)**
Q 66.1–66.7	Fri	11:00–13:00	HS V	**Ultracold Matter (Fermions) II (joint session Q/A)**
Q 67.1–67.7	Fri	11:00–13:00	AP-HS	**Quantum Computing and Simulation II (joint session Q/QI)**
Q 68.1–68.7	Fri	11:00–13:00	HS Botanik	**Quantum Technologies (Color Centers and Ion Traps) II (joint session Q/QI)**
Q 69.1–69.8	Fri	11:00–13:00	HS I	**Open Quantum Systems II (joint session Q/QI)**
Q 70.1–70.8	Fri	11:00–13:00	HS I PI	**Nanophotonics I**
Q 71.1–71.8	Fri	11:00–13:00	HS II	**Quantum Control II (joint session QI/Q)**
Q 72.1–72.7	Fri	11:00–12:45	GrHS Mathe	**Ultra-cold Atoms, Ions and BEC V (joint session A/Q)**
Q 73.1–73.7	Fri	14:30–16:15	AP-HS	**Quantum Technologies (Detectors and Photon Sources) (joint session Q/QI)**
Q 74.1–74.8	Fri	14:30–16:30	HS Botanik	**Photonics II**
Q 75.1–75.8	Fri	14:30–16:30	HS I	**Quantum Technologies (Solid State Systems) (joint session Q/QI)**
Q 76.1–76.8	Fri	14:30–16:30	WP-HS	**Nanophotonics II**

Members' Assembly of the Quantum Optics and Photonics Division

Wednesday 13:15–14:15 AP-HS

Q 1: Laser Technology and Applications (joint session Q/K)

Time: Monday 11:00–12:30 Location: HS V

Q 1.1 Mon 11:00 HS V

Simulation of Optically Induced Electrical Picosecond Pulses on Coplanar Waveguides Using PySpice — •Sophie-Luise Hachmeister and Heiko Füser — Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

The generation and characterization of optically induced electrical picosecond pulses is vital for the calibration of high-frequency electrical devices. Coplanar waveguides (CPWs) are commonly employed as platform for the generation, propagation and utilization of these pulses. While experimental techniques have been extensively explored, a notable gap persists in accurately simulating the pulse propagation characteristics. This work aims to address this shortcoming by developing a simulation framework utilizing PySpice, an open-source circuit simulation library in Python. The proposed model simulates the generation and propagation of picosecond pulses on CPWs, incorporating optical input parameters, the electrical properties of the CPW, and the characteristics of connected devices. To validate the framework, the simulation results are benchmarked against experimental measurements. Initial findings demonstrate a strong correlation between simulated and observed pulse dynamics, underscoring the model*s capacity to replicate the physical behavior effectively. By bridging the gap between experimental observations and computational simulations, this work offers a powerful tool detailing on high-frequency signal generation and enhances the understanding of optically induced electrical pulses. Future research will expand on these findings by exploring novel experimental setups and adapting the simulation model accordingly.

Q 1.2 Mon 11:15 HS V

Generation of high power cw UV radiation using elliptical focusing enhancement cavities — •Jens Gumm, Denise Schwarz, and Thomas Walther — TU Darmstadt

Long term cw laser operation with high output power in the UV spectral range is of great interest in many scientific and commercial applications.

Generation of cw-UV light is often realized by resonant second harmonic generation employing β-Barium Borate (BBO) as the nonlinear optical medium. A known parasitic effect in BBO is the degradation of the crystal due to two-photon absorption.

We theoretically showed that elliptical focusing can lead to higher conversion compared to the spherical optimum and significantly decreases the peak intensity in the nonlinear crystal. Experimentally, we demonstrated UV powers in excess of 2.4W with a fundamental power of 14W.

Q 1.3 Mon 11:30 HS V

Transportable Pulsed UV Laser System for Bunched Beam Laser Cooling — •Benedikt Langfeld[1,2], Tamina Grunwitz[1], and Thomas Walther[1,2] — [1]TU Darmstadt, Institut für Angewandte Physik — [2]HFHF Campus Darmstadt

Laser cooling of bunched relativistic ion beams has been shown (e.g. at GSI Helmholtzzentrum) to be a powerful technique to generate ion beams with small emittances and narrow longitudinal velocity distributions. For highly relativistic (large γ-factors) and intense heavy-ion beams, laser cooling will be very efficient and cooling times of the order of seconds are expected. For these reasons, laser cooling will be the only available cooling method at the planned heavy-ion synchrotron SIS100 at FAIR.

In this talk, we discuss the principle of bunched beam laser cooling using multiple laser beams. We will give an overview of one of the laser systems that will be used at the SIS100, namely the tunable high repetition rate (1-10 MHz) pulsed UV laser system - with a continuously adjustable pulse duration between 50 and 735 ps and a high average UV power of up to 4 W. Employing a walk-off compensation design with two BBO crystals, the laser frequency can be tuned over a range of 3.4 THz in the UV.

Q 1.4 Mon 11:45 HS V

Integrated Quantum Dot Comb Laser for Three-dimentional Imaging — •Marjan Shojaei, Stephan Amann, and Nathalie Picque — Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany

Holography is a powerful technique for lensless three-dimensional imaging. It is an interferometric imaging technique that allows to measure phase and amplitude simultaneously. In digital holography, the image acquisition is done with a digital camera sensor, and a computer performs the process of image reconstruction. By using a frequency comb, we do not get a single image as would be the case with a continuous-wave laser, but there are multiple images corresponding to the individual comb lines. This allows to reconstruct the phase over a large unambiguous distance with high accuracy. Here, we assess the potential of quantum dot comb lasers for applications in miniaturized three-dimensional imaging systems. Our quantum-dot comb laser spans over 5nm around the central wavelength of 1310nm with a flat-top spectral distribution and a line spacing of 80 GHz. Due to its large line spacing and turn-key operation, quantum dot lasers are promising comb sources for an application in miniaturized three-dimensional imaging systems and could allow to measure the phase profile of macroscopic objects with interferometric precision.

Q 1.5 Mon 12:00 HS V

THz frequency combs for traceable 6G channel characterization — •Adam Kuchnia, David Humphreys, Nora Meyne, and Heiko Füser — Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Traceable characterization of communication systems operating in the 6G frequency range is currently limited by the availability of measurement equipment traced back to primary SI standards. A solution is provided via photoconductive antennas (PCAs) in combination with THz frequency combs, utilized to directly down-convert free-space THz RF signals to baseband. Traceability is ensured by referencing the THz frequency comb to an atomic clock. Within this work, the PCA antenna performance within the 6G frequency range is investigated. CST-Microwave-Studio-based simulations are performed to analyze existing designs and to suggest optimized structures. Channel characterization is realized by measurement of free-space THz RF signals and analyzing amplitude and phase dependency over a wide frequency range. A comparison to the expected antenna behavior is provided. This approach opens new possibilities for THz measurement, including traceable detection of CW and RF-modulated waveforms and channel sounding.

Q 1.6 Mon 12:15 HS V

How to generate XUV frequency combs with only 10 W? — •Muhammad Thariq[1,2], Johannes Weitenberg[1,3], Francesco Canella[4,5], Gianluca Galzerano[5], Theodor W. Hänsch[1,2], Thomas Udem[1,2], and Akira Ozawa[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 Munich, Germany — [3]Fraunhofer-Institut für Lasertechnik ILT, 52074 Aachen, Germany — [4]Dipartimento di Fisica, Politecnico di Milano, 20133 Milan, Italy — [5]Istituto di Fotonica e Nanotecnologie - Consiglio Nazionale delle Richerce, 20133 Milan, Italy

The extreme ultraviolet (XUV) frequency comb (FC) is a vital tool for extending optical frequency metrology into the unexplored wavelength range below 200 nm. However, generating XUV FCs via high harmonic generation (HHG) often demands very high peak intensities. This typically requires an enhancement resonator, where a circulating average power of 10 kW leads to heating and damage issues.

In this work, we propose using a low repetition rate FC to drive single-pass HHG. By reducing the repetition rate by three orders of magnitude with an AOM-based pulse picker while maintaining a high peak power and a frequency comb structure, the average power is decreased proportionally. We have generated high harmonics from a 40 kHz-repetition rate FC with a peak power of 140 MW and pulse width of 35 fs. The results demonstrate the feasibility of generating XUV FCs with average powers below 10 W, making them more accessible to researchers across disciplines.

Q 2: Quantum Networks, Repeaters, and QKD I (joint session Q/QI)

Time: Monday 11:00–13:00 Location: AP-HS

Invited Talk Q 2.1 Mon 11:00 AP-HS

An array of neutral atoms coupled to an optical cavity: A versatile quantum network node — Raphael Benz, Sebastián Alejandro Morales Ramirez, Micha Kappel, Vincent Beguin, Krishna Relekar, and •Stephan Welte — 5. Physikalisches Institut, Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

I will present the plans of a recently established research group in Stuttgart focused on developing multi-qubit quantum network nodes. Our approach leverages an array of tweezer-trapped atomic qubits positioned at the center of a high-finesse optical cavity. All atoms in the array are positioned to ensure strong coupling to the cavity, thus establishing a connection to a photonic quantum channel. I will discuss the prospects of this system as a versatile quantum network node for both quantum computation and communication. Employing the system, a series of experiments is envisioned. I will outline these experiments, including photon-mediated quantum information processing between the intra-cavity atoms, the generation of photonic cluster states, and the generation of optical Gottesman-Kitaev-Preskill qubits. Finally, I will outline the prospects of connecting several atom-cavity systems in a quantum internet architecture.

Q 2.2 Mon 11:30 AP-HS

Quantum network nodes based on neutral atoms in an optical cavity — •Sebastián Alejandro Morales Ramírez, Raphael Benz, Micha Kappel, Vincent Beguin, Krishna Relekar, and Stephan Welte — 5. Physikalisches Institut, Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany.

The practical implementation of a quantum network is an outstanding challenge that is pursued in several different hardware platforms. Single neutral atoms trapped at the centre of an optical cavity are a promising platform, where many of the required capabilities to build a quantum network were demonstrated. The ability to position and individually control an array of atoms with optical tweezers is a key ingredient for the implementation of multi-qubit quantum network nodes. We will outline the plans of our research group to realize such a setup. Employing the system, a series of experiments is envisioned. We will outline these experiments comprising photon-mediated quantum information processing between the intra-cavity atoms, the generation of photonic cluster states, and the generation of optical Gottesman-Kitaev-Preskill qubits.

Q 2.3 Mon 11:45 AP-HS

Heralded Generation of Atom-Photon Entanglement — •Gianvito Chiarella, Tobias Frank, Pau Farrera, and Gerhard Rempe — Max Planck Institute for Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching bei München

Reducing inefficiencies and infidelity errors in quantum information processes is crucial for the successful implementation of advanced quantum communication and computation protocols. In this work, we introduce a novel method to mitigate such errors during the generation of atom-photon entanglement. The approach utilizes cascaded two-photon emission from a single atom coupled to two crossed optical cavities. The polarization state of one photon is entangled with the spin degree of freedom of the atom, while the emission of a second photon serves as a herald, signaling the successful entanglement generation. This heralding process effectively mitigates inefficiencies and infidelities in the entanglement, and we highlight the potential of our source for quantum communication applications over long distances.

Q 2.4 Mon 12:00 AP-HS

Quantum repeater segment with trapped $^{40}Ca^{+}$ ions — •Max Bergerhoff, Pascal Baumgart, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken, Germany

The quantum repeater (QR) segment, as part of a QR link [1], is a fundamental building block for the realization of large-distance quantum networks. By dividing a transmission link into segments and cells it is possible to overcome the exponential loss of direct transmission. Experiments that create atom-atom entanglement with single atoms [2] or single ions in cavities [3] have demonstrated the potential of the atom/ion platform for a QR segment.

We report the implementation of a QR segment with free-space coupled photons from two $^{40}Ca^{+}$ ions in the same Paul trap as memories. Atom-photon entanglement is produced [4] by controlled emission of single photons from the ions via excitation with nanosecond laser pulses and separate single-mode fiber coupling. Atom-atom entanglement is then generated by a photonic Bell-state measurement. A full QR link will combine the QR segment with the already demonstrated QR cell [5]; this will require a new ion trap setup with integrated sub-mm cavity, currently under construction.

[1] P. van Loock et al., Adv. Quantum Technol., 3: 1900141 (2020)
[2] T. van Leent et. al., Nature 607, 69-73 (2022)
[3] V. Krutyanskiy et al., Phys. Rev. Lett. 130, 050803 (2023)
[4] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[5] M. Bergerhoff et al., Phys. Rev. A 110, 032603 (2024)

Q 2.5 Mon 12:15 AP-HS

Hong-Ou-Mandel interference of photons generated with nanosecond laser pulses from two co-trapped $^{40}Ca^{+}$ ions — •Pascal Baumgart, Max Bergerhoff, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Entangling remote quantum memories is an essential step in the realisation of a quantum repeater segment [1]. It requires the ability to create indistinguishable single photons capable of Hong-Ou-Mandel interference on a beam splitter [2]. When generating single photons by exciting a Raman transition in a single atom, back decays and re-excitations on the driven transition lead to an uncertainty in the photon emission time, degrading their temporal indistinguishability [3]. A common approach that limits the number of back decays is excitation via short laser pulses, in the order of the excited-state lifetime. We present a setup to generate few-nanosecond 393-nm laser pulses to excite the $S_{1/2} \rightarrow P_{3/2} \rightarrow D_{5/2}$ Raman transition in single trapped $^{40}Ca^{+}$ ions and create single 854-nm photons. Using two ions in the same trap, we demonstrate Hong-Ou-Mandel interference of the Raman photons. We investigate the dependence of the interference visibility on the pulse length and amplitude, both experimentally and theoretically.

[1] P. van Loock et al., Adv. Quantum Technol., 3: 1900141 (2020)
[2] D. L. Moehring et al., Nature 449, 68-71 (2007)
[3] P. Müller et al., Phys. Rev. A 96, 023861 (2017)

Q 2.6 Mon 12:30 AP-HS

Cavity-enhanced Diamond Color Centers as Quantum Network Nodes — •Yanik Herrmann[1], Julius Fischer[1], Stijn Scheijen[1], Cornelis F. J. Wolfs[1], Julia M. Brevoord[1], Colin Sauerzapf[1], Leonardo G. C. Wienhoven[1], Laurens J. Feije[1], Matteo Pasini[1], Martin Eschen[1,2], Maximilian Ruf[1], Matthew J. Weaver[1], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands — [2]Netherlands Organisation for Applied Scientific Research (TNO), P.O. Box 155, 2600 AD Delft, The Netherlands

In the realization of quantum networks, efficient interfaces between stationary qubits and optical photons are a key requirement. Diamond color centers are on the forefront of solid state qubits due to their long spin coherence and spin register capabilities in combination with spin-state selective optical transitions. To boost the efficiency of the spin-photon interface, open microcavities can be utilized to Purcell-enhance optical transitions of the color centers. We realized a fiber-based microcavity setup at low-temperature with a high passive stability and microwave integration. This setup is used to Purcell-enhance single Tin-Vacancy centers, demonstrating quantum non-linear effects in the coherent coupling regime. Furthermore, we will present our latest results on implementing a cavity-enhanced quantum network node based on Nitrogen-Vacancy centers.

Q 2.7 Mon 12:45 AP-HS

Towards a quantum repeater with trapped Yb+ ions in an optical cavity — •Santhosh Surendra and Michael Köhl — Physikalisches Institut, Universität Bonn, Bonn, Germany

In a quantum network where entangled photons are used as travelling qubits, a critical challenge is in overcoming the absorption loss of optical fibers. One promising approach is to use *quantum repeaters* to 'purify' the state of photons after a certain optical path length by utilizing matter qubits. Such a node is necessary to scale the size of a distributed quantum computer, and quantum communication networks.

We have designed, and are constructing such a repeater node where a sub-millimeter optical cavity can be integrated into a linear Paul trap. Utilization of Purcell effect will allow us efficient extraction, and injection of entangled photons into the fiber-optic network. Furthermore, our system offers independent access to all vibrational modes of ions, enabling us to work directly with the ionic memory qubits. We will share our recent experimental progress, and the challenges we are addressing.

Q 3: Photonics I

Time: Monday 11:00–13:00 Location: HS Botanik

Invited Talk Q 3.1 Mon 11:00 HS Botanik
3D photonic model systems for topological effects and quantum-optical analogies — •Christina Jörg — Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau

I will present our research on topological photonics and beyond using waveguide arrays and photonic crystals fabricated through 3D microprinting. These photonic structures serve as model systems for fundamental studies, providing a versatile platform to emulate electronic phenomena found in condensed matter. By replicating electronic band structures, topological states, and quantum-optical effects, these systems not only deepen our understanding of established physics but also pave the way for discovering phenomena beyond what has been envisioned in electronic systems.

I will provide an overview of our recent work, which includes the use of higher orbital modes for quantum simulations, employing Kerr-nonlinearity to mimic mean-field interaction effects, and exploring higher-dimensional systems through synthetic dimensions.

Q 3.2 Mon 11:30 HS Botanik
Effect of Disorder on Photonic Density of States — •Florin Hemmann[1,2], Ullrich Steiner[1,2], and Matthias Saba[1,2] — [1]Adolphe Merkle Institute, University of Fribourg, Switzerland — [2]NCCR Bio-inspired Materials, University of Fribourg, Switzerland

Structural color arises from visible light interference in the presence of photonic nanostructures in many animals and plants [1]. As the dielectric contrast increases, such structures can form complete photonic band gaps, where light cannot enter the structure from any angle [2]. This phenomenon is well established for periodic systems, so-called photonic crystals. However, the emergence of a reduced photonic density of states due to the interplay of order and disorder in amorphous structures still needs to be fully understood. Here, we investigate how structural correlations at different length scales affect the photonic density of states. To this end, we generate 4-connected 3D continuous random networks with tunable disorder using a Metropolis Monte Carlo algorithm [3-4]. Utilizing a Monte Carlo bond-switch move, this algorithm simulates structural phase transitions from a crystalline to an amorphous diamond network. The effect of these structural phase transitions on the photonic response is analyzed through a finite-difference time-domain method and a planewave eigensolver method.

[1] V. V. Vogler-Neuling et al. (2024), Adv. Funct. Mater. 2024, 34, 2306528.
[2] J. D. Joannopoulos, et al. (2008), Princeton University Press.
[3] F. Wooten et al. (1985), Phys. Rev. Lett. 54, 1392.
[4] G. Barkema and N. Mousseau (1998), Phys. Rev. Lett. 81, 1865.

Q 3.3 Mon 11:45 HS Botanik
Quantum theory of (fractional) topological transport of lattice solitons — •Julius Bohm, Hugo Gerlitz, and Michael Fleischhauer — Fachbereich Physik und Landesforschungszentrum OPTIMAS, RPTU Kaiserslautern-Landau

Thouless pumps are a well known concept for quantized transport in symmetry protected topological systems. A suitable platform to investigate those systems are ultracold atoms in (time-dependent) lattices. While the experiments show good agreement with the theory they are hard to control and costly.

In recent years experimental groups have been able to investigate lattice solitons in waveguides with nonlinear Kerr media [1]. The time dependency needed for Thouless pumping in such systems is simulated via spatial modulation of the waveguides along the propagation axis.

On the theoretical side these solitons have been considered so far from a semiclassical point of view [2]. In our research we extend this to a full quantum mechanical description and therefore are able to test the low-particle limits in which lattice solitons exist. We are able to simulate integer as well as fractional transport of lattice solitons with the help of exact diagonalization and tensor network based approaches. Furthermore the emergence of integer, fractional and localized phases is explained in terms of an effective soliton bandstructure which also allows to determine topological invariants as effective Chern numbers or Wilson loops.

[1]: Jürgensen et. al., Nature 596, 63-67 (2021)
[2]: Mostaan et. al., Nat Commun 13, 5997 (2022)

Q 3.4 Mon 12:00 HS Botanik
Non-Hermitian geometry and topology induce non-trivial wave packet dynamics — •Ismaël Septembre[1,2], Zhaoyang Zhang[3], Pavel Kokhanchik[2], Guillaume Malpuech[2], and Dmitry Solnyshkov[2,4] — [1]University of Siegen, Germany — [2]Institut Pascal, Clermont-Ferrand, France — [3]Xi'an Jiaotong University, China — [4]Institut Universitaire de France, Paris, France

The geometry of quantum states provides a solid framework for explaining complex phenomena that conventional approaches fail to address. Despite its success in Hermitian systems, quantum geometry remains far less understood in non-Hermitian systems.

In this presentation, I want to show new interesting effects that we predicted and observed experimentally recently using Rubidium vapor cells. First, we study a photonic quasicrystal and demonstrate that combined with non-Hermiticity, it leads to the delocalisation of the wave packet [PRL 132, 263801 (2024)]. This is rather counter-intuitive as both effects (quasicrystal and non-Hermiticity) usually lead to localisation. Then, I will show our latest work where a photonic crystal hosting a ring of exceptional points leads to an anomalous non-Hermitian drift, analogous to but different from the anomalous Hall drift of Hermitian systems [arXiv:2410.14428]. To describe this effect, the biorthogonal quantum metric must be used, which proves the utility of this approach.

Our works represent cutting-edge developments in the field of topological photonics in the broad sense and show how non-Hermiticity can lead to new effects with potential applications in beam steering.

Q 3.5 Mon 12:15 HS Botanik
Topological phase transition in non-Hermitian gauge fields — •Bikashkali Midya — Indian Institute of Science Education and Research Berhampur, India

We will describe the point-gap topological phase transitions and skin-effect in non-Hermitian photonic lattice models. These models incorporate site-dependent nonreciprocal hoppings facilitated by a spatially fluctuating complex gauge field that disrupts translational symmetry. We propose a analytical framework that offers a comprehensive method for analytically predicting spectral topological invariance and associated boundary localization phenomena for bond-disordered nonperiodic lattices, based on imaginary gauge-transformed mean-field periodic lattices. Notably, for a lattice with quasiperiodic gauge-field $g = log|\lambda cos 2\pi\alpha n|$ and an irrational previously unknown topological phase transition is unveiled. It is observed that the topological spectral index W assumes values of -N or +N, leading to all N open-boundary eigenstates localizing either at the right or left edge, solely dependent on the strength of the gauge field, where $\lambda < 2$ or $\lambda > 2$. A phase transition is identified at the critical point undergo delocalization. The theory has been shown to be relevant for long-range hopping models $\lambda = 2$, at which all eigenstates undergo delocalization.

Q 3.6 Mon 12:30 HS Botanik
Exciton-Polariton Artificial Gauge Field Topological Pseudospin Hall Effect — •Simon Widmann, Jonas Bellmann, Jo-

hannes Düreth, Siddhartha Dam, Christian G. Mayer, Philipp Gagel, Simon Betzold, Monika Emmerling, Sven Höfling, and Sebastian Klembt — Technische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

We explore the interplay of artificial gauge fields and synthetic dimensions in a chain of coupled elliptical exciton-polariton micropillars, leveraging polariton circular polarization to achieve pseudospin-dependent propagation. The elliptical micropillars, fabricated by etching a GaAs microcavity, exhibit a linear polarization splitting due to their geometry. By carefully engineering the lattice geometry and pillar rotations, we implement an artificial gauge field, inducing complex hopping phases that mimic the effects of a magnetic flux. This design enables pseudospin-dependent propagation: polaritons with opposing circular polarizations travel in opposite directions leading to a Hamiltonian that gives rise to the quantum Hall effect. We introduce an artificial dimension, mapping the effectively 1D chain to a 2D square lattice. Our results highlight the potential of exciton-polaritons as a versatile platform for investigating topological photonics, non-Hermitian physics, and synthetic dimensions in driven-dissipative systems, paving the way for novel approaches to quantum simulation and polaritonic devices.

Q 3.7 Mon 12:45 HS Botanik

Chirped pulses enable robust generation of multiplexed photon states in quantum dots — •Vikas Remesh[1], Moritz Kaiser[1], Gabriela Militani[1], René Schwarz[1], Ria Krämer[2], Stefan Nolte[2], Philip Poole[3], Dan Dalacu[3], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institute for Applied Physics, Friedrich Schiller University Jena, Germany — [3]National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada

To realize a scalable source of frequency-multiplexed single photons, one requires an ensemble of quantum emitters that can be collectively excited with high efficiency. Semiconductor quantum dots hold great potential here. The most efficient scheme is to use chirped laser pulses, due to the robustness against spectral and intensity fluctuations. Here we present a compact, robust, and plug-and-play alternative for chirped pulse excitation of quantum dots, based on chirped fiber Bragg gratings. Using this technique, we demonstrate the collective excitation of vertically stacked, frequency-multiplexed quantum dots in a nanowire, producing high-quality single and entangled photon states. Our experiments set a benchmark towards a simpler yet scalable and resource-efficient approach of producing multiphoton states from quantum dots. APL Photonics 8, 101301 (2023), arxiv.org/abs/2409.13981, Adv Quantum Technol. 2024, 2300352

Q 4: Rydberg Atoms, Ions, and Molecules (joint session Q/MO)

Time: Monday 11:00–12:45 Location: HS I

Q 4.1 Mon 11:00 HS I

Interfacing Rydberg atoms with an GHz electromechanical oscillator — •Julia Gamper, Cedric Wind, Valerie Mauth, Samuel Germer, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Rydberg atoms exhibit strong electric dipole transitions over a large range of the electromagnetic spectrum which make them interesting for hybrid quantum systems bridging vastly different frequency regimes.

In this talk, I will present our approach to interfacing optically controlled Rydberg atoms with an electromechanical oscillator for cooling one of the vibrational modes of the oscillator to its quantum mechanical ground state by exchange of microwave photons with the atoms.

I will discuss the design of this hybrid system and present our progress on the construction. Our system consists of a 3D magneto-optical trap for loading rubidium atoms which are subsequently magnetically transported to the experimental region which is at cryogenic temperatures of 4K and includes a vibration-isolation system that reduces vibrations below 25nm.

As a first step towards our envisioned hybrid system, we plan to trap the rubidium atoms with a superconducting wire trap on a chip with an integrated microwave resonator to drive microwave transitions of the Rydberg atoms close to the cryogenic surface.

Q 4.2 Mon 11:15 HS I

Magic wavelength traps for collective Rydberg excitations — •Daniil Svirskiy[1], Lukas Ahlheit[1], Chris Nill[2], Jan de Haan[1], Nina Stiesdal[1], Wolfgang Alt[1], Igor Lesanovsky[2], and Sebastian Hofferberth[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Theoretical Physics, University of Tübingen, Germany

Storage of optical photons as collective excitation in an ultracold atomic medium is one of the possible candidates for the realization of a quantum memory. However, photon storage times are limited by various decoherence mechanisms, including thermal atomic motion and inhomogeneous differential light shifts between atoms sharing the excitation. The latter can be suppressed by magic trapping, which equalizes the AC Stark shifts for the ground and excited levels of the atom.

In this talk, I present our implementation of a magic trap for ultracold Rydberg atoms. We conduct photon storage and retrieval measurements for two different trapping geometries: a magic lattice and a running wave trap with different trap wavelengths. Our experiments demonstrate that both the longitudinal standing wave and the radial trap shape impact the magic condition. This difference arises from the Rydberg electron wavefunction extending over a significant region of the trap potential and contributing a ponderomotive part to the trap potential. We investigate how this part scales with principle quantum number n and determine the optimal magic lattice wavelength for each Rydberg state.

Q 4.3 Mon 11:30 HS I

Avoided-Crossing Rydberg Facilitation with Phonon Coupling in 1D Lattices — •Daniel Brady and Michael Fleischhauer — RPTU Kaiserslautern, Kaiserslautern, Germany

Rydberg anti-blockade (facilitation) offers one of the most promising mechanisms for realizing robust neutral-atom quantum gates. However, concomitant with the strong dipolar interactions between Rydberg atoms (spins) are mechanical forces coupling Rydberg atoms to high motional states (phonons) in their respective tweezer traps. This has so far kept experimental realizations of quantum gates with facilitation out of reach. Recently, Rydberg excitations have been created by coupling to an avoided-crossing potential in an experimental setting. This approximately harmonic potential alters the nature of the spin-phonon coupling and therefore might offer a method of realizing quantum gates.

For a chain of atoms trapped in tweezer arrays under the facilitation constraint, we numerically simulate the dynamics of the spin-phonon coupling. In particular we investigate how the motional degrees of freedom affect the spreading dynamics of Rydberg excitations.

Q 4.4 Mon 11:45 HS I

Electronically Excited Cold Rydberg Ion Crystals — •Marion Mallweger[1], Natalia Kuk[1], Harry Parke[1], Ivo Straka[1], Robin Thomm[1], Vinay Shankar[1], Weibin Li[3], Igor Lesanovsky[2,3], and Markus Hennrich[1] — [1]Stockholm University, Stockholm, Sweden — [2]Institut für Theoretische Physik, Universität Tübingen, Germany — [3]School of Physics and Astronomy, University of Nottingham, United Kingdom

Trapped Rydberg ions harness two advantages: a well defined confinement through the charge of the ion and strong interactions through its large principle quantum number. In the experiments presented here a trapped strontium ion was excited from the metastable 4D to Rydberg states. While for the ground state of the ion, the polarizability is negligible, for Rydberg ions it increases as $\sim n^7$. Thus, the high polarizability of the Rydberg state with respect to the ground state leads to a change in radial confinement during the Rydberg excitation. For an ion crystal, this change can be enough to cause a structural phase transition from a linear configuration in the lower-lying electronic states to a zigzag configuration in the Rydberg state. We explore and characterize this electronic state dependent structural phase transition. We investigate this effect via spectroscopy scans of the Rydberg resonance with varying radial confinement close to the transition point of the zigzag crystal configuration. By tuning the polarizability, the change in radial trap confinement and therefore the transition point can be tuned. This enables a novel method for studying molecular phenomena with ions in the well-isolated environment of a Paul trap.

Q 4.5 Mon 12:00 HS I

Ultralong-Range Ytterbium Rydberg Molecules — •Tangi Legrand, Florian Pausewang, Xin Wang, Ludwig Müller, Eduardo Uruñuela, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

An ultralong-range Rydberg molecule forms through the interaction between a ground-state atom and the electron of a highly excited Rydberg atom, leading to molecular states characterized by extreme spatial extension, large dipole moments and long lifetimes.

In this work, we present the spectroscopic characterization of such molecules in a dense and ultracold ytterbium (Yb) gas. Using two-photon excitation, we probe the molecular binding energies and map out the vibrational spectra. By applying low-energy quantum scattering techniques to the observed binding energies, we can extract the electron-neutral atom s-wave scattering length. Our data enables precise benchmarking of Yb model wavefunctions derived from multichannel quantum defect theory, offering a robust validation for the accuracy of theoretical descriptions of Rydberg (molecular) states.

We also present our apparatus featuring a two-chamber compact design comprising a dispenser-loaded 2D MOT and a two-color 3D MOT allowing narrow-linewidth cooling. After loading into an optical trap, we reach $T < 10\,\mu$K at atomic densities of $10^{13}\,\mathrm{cm}^{-3}$. By consecutive evaporation we reach $T \approx 200\,$nK. Electrodes around the atomic cloud allow electric field background compensation, field ionization of Rydberg atoms and molecules, and their delivery to a microchannel plate.

Q 4.6 Mon 12:15 HS I

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.

Q 4.7 Mon 12:30 HS I

Control thermalization in one dimensional Floquet driven Rydberg atom chain — •Weibin Li[1], Yunhui He[2], and Jianming Zhao[2] — [1]University of Nottingham, Nottingham, UK — [2]Shanxi University, Taiyuan, China

We study Floquet thermalization of a one dimensional disorder-free Rydberg atom chain. The stroboscopic dynamics of the finite Rydberg atom chain is numerically solved. We show that the Floquet thermalization results from the emergence of an effective multi-body interaction across the atom chain. We characterize the properties of the thermalization using level spacing statistics and entanglement entropy. The dependence of the Floquet thermalization on the driving period and laser detuning is examined. The scaling with the system size and dependence on the initial state are explored. Our results can be readily observed in the current Rydberg atom array experiments.

Q 5: Collective Effects and Disordered Systems

Time: Monday 11:00–13:00 Location: HS I PI

Q 5.1 Mon 11:00 HS I PI

Non-Linear Maser Oscillations at Room Temperature — •Christoph W. Zollitsch[1,2], Christopher W. M. Kay[1,3], and Jonathan D. Breeze[2] — [1]Department of Chemistry, Saarland University, Saarbrücken, Germany — [2]Department of Physics & Astronomy, University College London, London, UK — [3]London Centre for Nanotechnology, University College London, London, UK

The recent realization of a continuous-wave room temperature maser, using NV^- centers in diamond pumped by a 532 nm laser, is a promising platform for novel research and development in areas of signal amplification, timekeeping and sensing. Typically, for such applications a maser oscillator is operated in linear response regime. For masing, the NV^- spin ensemble is pumped into a non-equilibrium state and, for strong enough pump rates, can also be driven into a non-linear regime. Maser oscillation changes dramatically, exhibiting a frequency-comb like spectrum, instead of a single narrow frequency mode. Studying nonlinear behavior in room temperature solid-state masers can lead to new pathways of quantum sensing.

We present an NV^- center maser system and experimentally characterize the transition from linear to non-linear maser oscillation, via frequency and time domain analysis. A feature for non-linear behavior is bifurcation. Here, the inhomogeneous broadened spin distribution experiences bifurcation. The dynamics can be modelled numerically through a quantum master equation with Lindbladian dissipators and is in excellent agreement with experimental data. We discuss individual features of non-linear dynamics and their potential applications.

Q 5.2 Mon 11:15 HS I PI

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)

Q 5.3 Mon 11:30 HS I PI

Exploiting emergent symmetries in disorder-averaged dynamics — •Mirco Erpelding[1], Adrian Braemer[2], and Martin Gärttner[1] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Symmetries are a key tool in understanding quantum systems and, among many other things, allow efficient numerical simulation of dynamics. Disordered systems usually feature reduced sym- metries and additionally require averaging over many realizations, making their numerical study computationally demanding. However, when studying quantities linear in the time evolved state, i.e. expectation values of observables, one can apply the averaging procedure to the time evolution operator resulting in an effective dynamical map, which restores symmetry on the level of super- operators. In this work, we develop schemes for efficiently constructing symmetric sectors of the disorder-averaged dynamical map using short-time and weak-disorder expansions. To benchmark the method, we apply it to an Ising model with random all-to-all interactions in the presence of a transverse field. After disorder averaging, this system becomes effectively permutation invariant, and thus the size of the symmetric subspace scales polynomially in the number of spins allowing for the simulation of very large systems.

Q 5.4 Mon 11:45 HS I PI

Cooperative Quantum Dynamics based on Solid State Quantum Emitters — •Lukas Strauch[1], Stefan Nimmrichter[2], and Mario Agio[1,3] — [1]Laboratory of Nano-Optics, University of Siegen, 57072 Siegen, Germany — [2]TQO, Universität Siegen, Deutschland — [3]National Institute of Optics (INO), National Research Council (CNR), 50125 Florence, Italy

The investigation of the collective radiative dynamics of ring ordered subwavelength spaced point-like dipole emitters and their coupling is crucial for the development of quantum devices, which mimics artificial light harvesting complexes. The coherent and incoherent coupling determines the collective quantum dynamics. Here, we study the effect of decoherence on the cooperative emission dynamics of the complexes, paving a way towards experimental implementation based on solid-state quantum emitters coupled to resonant nanostructures.

Q 5.5 Mon 12:00 HS I PI

Analytical model for the description of the collective nonlinear response of large ensembles of two-level emitters — Max Schemmer, Martin Cordier, Lucas Pache, Philipp Schneeweiss, •Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin

The nonlinear interaction between light and ensembles of quantum emitters is the key ingredient for the generation of non-classical states of light and a central focus of current experimental and theoretical research. Here, we present a model that allows one to theoretically describe and investigate the collective nonlinear optical response of an ensemble of two-level emitters that are weakly coupled to a single-mode waveguide [1]. Our approach generalizes the insight that photon-photon correlations in the light scattered by a single two-level emitter result from two-photon interference to the case of many emitters, where a collective enhancement of the two-photon emission can take place. Using this model, we study different configurations and derive analytical expressions for the second-order correlation function as well as for the squeezing spectrum of the output light. Our results agree with predictions from more computationally expensive models, and show how the collectively enhanced nonlinear response of weakly coupled emitters can be harnessed to generate non-classical states of light using ensembles of thousands of emitters.

[1] M. Schemmer et al., arXiv:2410.21202 (2024)

Q 5.6 Mon 12:15 HS I PI

Dipole-dipole interactions of strongly driven two-level atoms — •Tim Ehret, Vyacheslav Shatokhin, and Andreas Buchleitner — Hermann-Herder-Str. 3, Institute of Physics, Albert-Ludwigs University of Freiburg

We formulate a Floquet-Markov master equation for two spatially separated atoms driven by an intense electromagnetic field and coupled to a common bath. This equation features a modified form of dipolar interactions as compared to the case of weakly driven atoms, giving rise to new shifts in the Floquet quasienergy spectrum of the system. We provide a detailed physical interpretation of the modified dipole-dipole interactions, discuss their manifestations in two-atom resonance fluorescence, and extract the distance-dependence of the dipole force between the atoms.

Q 5.7 Mon 12:30 HS I PI

Examination of the antiferromagnetic superradiant intermediate phase and the effects of geometrical frustration in the Dicke-Ising Model — •Jonas Leibig — 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, and M. Eckstein, "Collective theory for an interacting solid in a single-mode cavity", *arXiv preprint arXiv:2205.05559*, 2022.
[2] A. Langheld, M. Hörmann, and K. P. Schmidt, "Quantum phase diagrams of Dicke-Ising models by a wormhole algorithm", *arXiv preprint arXiv:2409.15082*, 2024.

Q 5.8 Mon 12:45 HS I PI

Disorder-dependent phases of optically deep atomic ensembles — •Kasper J. Kusmierek[1], Max Schemmer[2], Sahand Mahmoodian[3], and Klemens Hammerer[1] — [1]ITP, Leibniz University Hannover, Germany — [2]Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO), Fiorentino, Italy — [3]Centre for Engineered Quantum Systems, University of Sydney, Australian

The interaction of light with an ensemble of two-level systems in a one-dimensional geometry is commonly described by two key models of quantum electrodynamics (QED): the driven-dissipative Dicke model or the Maxwell-Bloch equations. Both exhibit distinct features of phase transitions and separations, depending on optical depth and drive strength. Using a parent spin model derived from bidirectional waveguide QED, we show these models arise as limits corresponding to small and large disorder in atomic positions. We numerically solve the mean-field equations and investigate the phase diagram depending on optical depth, drive strength, and disorder. For the unidirectional model we go beyond mean-field theory by performing a second-order cumulant expansion, complementing analytical mean-field results. Studying atomic inversion and light transmission, we find, in the thermodynamic limit, phase separation occurs with a critical value dependent on the degree of order but not on inhomogeneous broadening effects. Even far from the thermodynamic limit, this critical value marks a special point in the atomic correlation landscape of the unidirectional model. We conclude disordered effective one-dimensional systems can be modeled using unidirectional waveguide approaches.

Q 6: Precision Spectroscopy of Atoms and Ions I (joint session A/Q)

Time: Monday 11:00–13:00 Location: HS PC

Invited Talk Q 6.1 Mon 11:00 HS PC

Towards an optical atomic clock based on Ni^{12+} — •Malte Wehrheim[1], Lukas J. Spiess[1], Shuying Chen[1], Alexander Wilzewski[1], Piet O. Schmidt[1,3], and José R. Crespo Lopez-Urrutia[2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Max-Planck-Instituts für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Highly charged ion (HCI) optical clocks offer reduced susceptibility to systematic shifts due to the high binding energies of the remaining electrons. Our experimental setup allows the co-trapping of individual HCI with Be^+ for sympathetic cooling and quantum logic readout. In the past, this approach allowed us to measure absolute frequencies of optical transitions in HCI with uncertainties in the low 10^{-16} range limited by the ions* short excited-state lifetime of around 10 ms [1].

In this work, we present the progress towards an improved HCI clock based on Ni^{12+}, with expected systematic uncertainties at the low 10^{-18} level and reduced instability due to its long excited-state lifetime of ∼20 seconds, enabling long interrogation times. We report on the initial transition search [2] and the first spectroscopy of the dipole-forbidden clock transition, paving the way for a new generation of high accuracy optical clocks.

[1] S. A. King, L. J. Spiess, et al., Nature 611, 43 (2022)
[2] S. Chen, et al., Phys. Rev. Appl. 22, 054059 (2024)

Q 6.2 Mon 11:30 HS PC

A Cryogenic Permanent Magnet Penning Trap for Sympathetic Laser Cooling at μTEx — •Philipp Justus[1,2], Anton Gramberg[1,2], Stefan Dickopf[1], Annabelle Kaiser[1], Ankush Kaushik[1], Marius Müller[1], Stefan Ulmer[3,4], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik Heidelberg, Germany — [2]Ruprecht-Karls Universität Heidelberg, Germany — [3]Heinrich-Heine Universität Düsseldorf, Germany — [4]RIKEN, Wako, Japan

Penning traps, being versatile tools for various high-precision measurements in atomic and nuclear physics, are used for nuclear magnetic moment measurements at the μTEx experiment in Heidelberg. The experiment aims to measure the $^3He^{2+}$ nuclear magnetic moment with a relative uncertainty on the 10^{-9} level which relies on sympathetic laser cooling with $^9Be^+$ [1-3]. To test and implement sympathetic laser cooling a new experimental setup has been developed. It consists of a five-electrode Penning trap with a permanent magnet system providing a homogeneous magnetic field of $B \sim 240$ mT and cooled to $T \sim 4$ K using a pulse tube cooler. The characterization of Doppler cooling at the $^2S_{1/2} \rightarrow {}^2P_{3/2}$ transition of $^9Be^+$ will employ electronic and photonic detection mechanisms integrated into the system. The entire experiment is designed for quick adjustments and flexible modifications to the setup. In the talk I will present the current status of the design of the experiment.

[1] Mooser et al., J. Phys.: Conf. Ser. 1138 012004 (2018) [2] Schneider et al., Nature 606, 2022 [3] Dickopf et al., Nature 632, 2024

Q 6.3 Mon 11:45 HS PC

Two-Photon Spectroscopy of Xenon — •Felix Waldherr[1], Simon Stellmer[2], Skyler Degenkolb[1], and panEDM Collaboration[3] — [1]Universität Heidelberg, Germany — [2]Rheinische Friedrich-Wilhelms-Universität Bonn, Germany — [3]Institut Laue-Langevin, Grenoble, France

Precision spectroscopy of xenon is relevant for a variety of applications, including searches for the neutron electric dipole moment and magnetometry. However, spectroscopy has been challenging due to the inaccessibility of suitable UV laser systems. We present a spectroscopy setup capable of performing two-photon spectroscopy of xenon, focusing on the $5p^6(^1S_0) \rightarrow 5p^5(^2P_{3/2})6p\ ^2[5/2]_2$ transition at 256 nm. Building on earlier measurements of this transition, the setup incorporates the use of coincidence detection of emitted IR and UV fluorescence photons, which is expected to enhance the signal-to-noise ratio.

Q 6.4 Mon 12:00 HS PC

Spectroscopy of a narrow cooling transition in zinc — •Vedang Sumbre, Lukas Möller, David Röser, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

Zinc has emerged as a strong candidate for a highly precise optical clock, due to its small sensitivity to black body radiation. We perform Doppler-free spectroscopy of the 307.6 nm 1S0 -> 3P1 transition on a thermal vapor of zinc atoms, and measure the isotope shifts of this transition for all the stable isotopes of Zinc.

Q 6.5 Mon 12:15 HS PC

Magneto-optical trapping of Zinc — •Lukas Möller, David Röser, and Simon Stellmer — Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany

Laser-cooling and trapping of neutral atoms is a widely used technique in contemporary atomic physics. It has been demonstrated for many elements of the periodic table and is especially well established for alkaline and alkaline-earth metals. The element zinc, an alkaline-earth-like metal, is a promising candidate for a new optical clock. Work on zinc also motivates the development of new cw-laser sources in the UV range, since its strong cooling transition lies at 213.9 nm. In this talk, I will present the work of our group towards magneto-optical trapping of Zinc, as the first step towards spectroscopy of the clock transition.

Q 6.6 Mon 12:30 HS PC

High-Resolution Dielectronic Recombination of Beryllium-like Gold Ions in the Electron Cooler of the Cryring@ESR Storage Ring — •Mirko Looshorn[1,2], Carsten Brandau[3], Mike Fogle[4], Jan Glorius[3], Elena Hanu[3,5], Volker Hannen[6], Pierre-Michel Hillenbrand[3], Claude Krantz[3], Michael Lestinsky[3], Esther Menz[3,5,7], Reinhold Schuch[8], Uwe Spillmann[3], Ken Ueberholz[6], Shuxing Wang[1,2], and Stefan Schippers[1,2] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Giessen, Germany — [2]Helmholz Forschungsakademie Hessen für FAIR (HFHF), Campus Giessen, 35392 Giessen, Germany — [3]GSI, Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany — [4]Department of Physics, Auburn University, AL 36832, USA — [5]Helmholtz-Institut Jena, 07743 Jena, Germany — [6]Institut für Kernphysik, Universität Münster, 48149 Münster, Germany — [7]Institute for Optics and Quantum Electronics, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany — [8]Department of Physics, Stockholm University, 10691 Stockholm, Sweden

We report on the results of an electron-ion collision experiment with berylliumlike gold ions, which were injected into Cryring@ESR from the full chain of GSI accelerators. Measurements were carried out in the collision-energy range 0-300 eV, where the $2s2p\ (^3P_1)\ nl$ dielectronic recombination (DR) resonances with n=19-21 occur, which are associated with the $2s^2\ ^1S_0 \rightarrow 2s2p\ ^3P_1$ excitation of the Be-like ion core. We will present preliminary comparisons of our experimental DR spectra with corresponding theoretical results.

Q 6.7 Mon 12:45 HS PC

High-precision ground-state hyperfine spectroscopy on a trapped ^{9}Be ion — •Annabelle Kaiser[1], Stefan Dickopf[1], Bastian Sikora[1], Marius Müller[1], Anton Gramberg[1], Ankush Kauschik[1], Philipp Justus[1], Stefan Ulmer[2,3], Zoltan Harman[1], Vladimir Yerokhin[1], Christoph Keitel[1], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Heinrich-Heine Universität Düsseldorf, Germany — [3]RIKEN, Wako, Japan

Measurements of the Zeeman splitting in systems with nuclear magnetic moments can be used to infer the shielded nuclear and the bound electron g-factors, as well as the zero-field hyperfine splitting [1]. We measured the Zeeman splitting of $^9Be^{3+}$ and compare it to measurements on $^9Be^{1+}$ [2] to test the theory of the diamagnetic shielding factor [3] on the parts per billion level. Additionally, we compare our measured zero-field splitting with the value obtained in $^9Be^{1+}$ via the so-called hyperfine specific difference to cancel theoretically intractable nuclear structure contributions. The measurement results as well as future plans will be presented [4].

[1] A. Schneider et al, Nature 606, 878-883 (2022)
[2] D. J. Wineland et al, Phys. Rev. Lett. 50, 628-631 (1983)
[3] K. Pachucki and M. Puchalski, Opt. Commun. 283, 641-643 (2010)
[4] S. Dickopf et al, Nature 632, 757-761 (2024)

Q 7: Polaritonic Effects in Molecular Systems I (joint session MO/Q)

Time: Monday 11:00–13:00 Location: HS XV

Q 7.1 Mon 11:00 HS XV

Changes in excimer properties under collective strong coupling — •Matteo Castagnola, Marcus Takvam Lexander, and Henrik Koch — Department of Chemistry, Norwegian University of Science and Technology, 7491 Trondheim, Norway

The interplay between the local molecular dynamics and the collective polaritonic excitation is a fundamental but challenging aspect of polaritonic chemistry. While light-matter strong coupling has been proven to affect chemical properties, the underlying mechanism is still unclear. We employ a recently developed electronic-structure method for collective strong coupling to study the argon excimer, providing a simple prototype for a more general discussion on excimer properties. The computed potential energy surface exhibits a region where electronic, nuclear, and photonic degrees of freedom are strongly intertwined, and we analyze their coupling. Collective strong coupling produces an abrupt transition in the excited state's vibrational landscape, causing the higher vibrational levels to behave similarly to the ground state vibrations. We thus find that collective strong coupling inhibits the formation of the excimer once the collective coupling exceeds a critical value. We propose this is a general feature of excimers under collective strong coupling, which could be investigated by recording absorption and emission spectra, offering an additional facet of polaritonic chemistry.

Q 7.2 Mon 11:15 HS XV

Quantized embedding approaches for collective strong coupling – and what about Coulomb? — Frieder Lindel[1,2], Dominik Lentrodt[2], Stefan Buhmann[3], and •Christian Schäfer[4] — [1]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [3]Institut für Physik, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany — [4]Department of Physics, Chalmers University of Technology, 41296 Göteborg, Sweden

Collective light-matter interactions have been used to control chemistry and energy transfer, yet accessible approaches that combine ab initio methodology with large many-body quantum optical systems are missing due to the fast increase in computational cost for explicit simulations. We introduce such an accessible ab initio quantum embedding concept for many-body quantum optical systems that allows us to treat the collective coupling of molecular many-body systems effectively in the spirit of macroscopic quantum electrodynamics while keeping the rigor of ab initio quantum chemistry for the molecular structure [1]. We illustrate the underlying assumptions by comparison to the Tavis-Cummings model and highlight the importance of Coulombic interactions between emitter and solvent molecules, as well as their potential interplay in collective strong coupling [2].

[1] J. Chem. Phys. 161, 154111 (2024). [2] J. Phys. Chem. Lett. 2024, 15, 1428-1434.

Q 7.3 Mon 11:30 HS XV

Simulation of polaritons in real cavities through a semiclassical approach — •Carlos Bustamante[1], Franco Bonafé[1], Michael Ruggenthaler[1], Maxim Sukharev[2], Abraham Nitzan[3], and Angel Rubio[1] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Department of Physics, Arizona State University, Tempe, Arizona, USA — [3]Department of Chemistry, University of Pennsylvania, Philadelphia, Pennsylvania, USA

The strong coupling between light and matter reached within optical cavities has opened a new path to modify material properties and chemical reactions. For chemical effects, this strong coupling condition may be achieved when the photonic modes of the cavity resonate with molecular vibrations or electronic transitions, leading to vibrational strong coupling (VSC) and electronic strong coupling (ESC) respectively, creating a hybrid state between light and matter called polaritons. Although this research area is rapidly expanding, the simulation of a realistic experimental setup, capturing all relevant factors, remains a challenge. Our study proposes a semiclassical approach involving the propagation of Maxwell equations on a grid, while incorporating tens to hundreds of molecules using the quantum mechanical simulation software DFTB+. By modelling the mirrors with the Drude permittivity, we can integrate them into the setup to emulate a Fabry-Perot cavity. Our results demonstrate that our setup can accurately represent various experimental observations, including Rabi-splitting and collective effects.

Q 7.4 Mon 11:45 HS XV

Analytic model reveals local molecular polarizability changes induced by collective VSC — •Jacob Horak[1,2], Dominik Sidler[1,2,3], Thomas Schnappinger[4], Michael Ruggenthaler[1,2], and Angel Rubio[1,2,5] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Hamburg, Germany — [3]Paul Scherrer Institut, Villigen, Switzerland — [4]Stockholm University, Stockholm, Sweden — [5]The Flatiron Institute, New York, USA

Despite recent numerical evidence, one of the fundamental theoretical mysteries of polaritonic chemistry is how and if collective strong coupling can induce local changes of the electronic structure to modify chemical properties. Here we present non-perturbative analytic results for a model system consisting of an ensemble of N harmonic molecules under vibrational strong coupling (VSC) that alters our present understanding of this fundamental question. We discover that the electronic molecular polarizabilities are modified even in the case of vanishingly small single-molecule couplings. Consequently, this non-perturbative local polarization mechanism persists even in the large-N limit. In contrast, a perturbative calculation of the polarizabilities leads to a qualitatively erroneous scaling behavior with vanishing effects in the large-N limit. Our fundamental theoretical observations demonstrate that hitherto existing collective-scaling arguments are insufficient for polaritonic chemistry / physics.

Q 7.5 Mon 12:00 HS XV

Polaritonic Molecular Orbitals — •Yassir El Moutaoukal — Norwegian University of Science and Technology, 7491 Trondheim, Norway

A comprehensive understanding of electron-photon correlation is essential for describing the reshaping of molecular orbitals in quantum electrodynamics (QED) environments.

The strong coupling QED Hartree-Fock (SC-QED-HF) theory tackles these aspects by providing consistent molecular orbitals in the strong coupling regime. The previous implementation, however, displays significant convergence issues.

In this talk I present how these limitations can be overcome by capturing the coupling between the electron-photon dressing parameters, enhancing the modeling of large molecular systems coupled to electromagnetic vacuum fluctuations.

The development of more correlated methods and response theory using the SC-QED-HF reference wavefuction are now possible and currently in development, as well as the extension to a multi-mode Hamiltonian and chiral cavities.

Q 7.6 Mon 12:15 HS XV

Higher excitations manifolds in the Tavis-Cummings model for multi-level systems — •Lucas Borges, Thomas Schnappinger, and Markus Kowalewski — Department of Physics, Stockholm University, Stockholm, Sweden

The Tavis-Cummings model describes the interaction of multiple quantum emitters, such as atoms or molecules, with the quantized electromagnetic field modes of an optical cavity, leading to the emergence of polariton states (eigenstates of the coupled system). Most studies focus on the first excitation manifold, which includes states with a single excitation (one photon or one excited atom). The polariton states within this manifold are well separated into bright and dark states.

However, molecular ensembles in a cavity may carry multiple excitations, thus requiring the inclusion of higher excitation manifolds. We present a study of a system of N three-level systems coupled to a single lossy cavity mode, truncating the Hamiltonian to the Nth excitation manifold. The system models a molecular ensemble, where two levels are directly coupled to the cavity, while the third level is weakly coupled to the second energy level. We show that when a fraction of the system's excitations initially reside in these third levels, the cavity mediates its decay to the ground state, revealing a new pathway influenced by the cavity dynamics.

Q 7.7 Mon 12:30 HS XV

Relativistic quantum electrodynamical density functional theory beyond ideal cavities — •Lukas Konecny[1], Mark Kamper Svendsen[2,3], Valeriia Kosheleva[3], Michael Ruggenthaler[3], and Angel Rubio[3] — [1]Hylleraas Centre for Quantum Molecular Sciences, Department of Chemistry, UiT The Arctic University of Norway, Tromsø, Norway — [2]NNF Quantum Computing Programme, Niels Bohr Institute, Copenhagen, Denmark — [3]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, Hamburg, Germany

Quantum electrodynamical density functional theory (QEDFT) is one of the computational methods that combine quantum chemical treatment of matter with quantized description of light. This allows to describe the effect of strong coupling of matter to photonic modes while preserving the accuracy necessary for chemical and spectroscopic applications together with the favourable computational cost associated with density functional theory. Building on recently introduced relativistic QEDFT based on the four-component Dirac–Coulomb Hamiltonian we extend the methodology beyond idealized single-mode Fabry–Pérot cavities to the interaction with a quasi continuum of photonic modes that enables the description of realistic cavities as well as radiative decay via the coupling to vacuum modes while the relativistic approach to electronic structure enables accurate treatment of heavy elements and effects of spin–orbit coupling such as singlet–triplet transitions. Thus we expand the applicability of QEDFT into new domains.

Q 7.8 Mon 12:45 HS XV

Impact of dipole self-energy on cavity-induced nonadiabatic dynamics — Csaba Fábri[1,2], Gábor J. Halász[3], Lorenz S. Cederbaum[4], and •Ágnes Vibók[1] — [1]HUN-REN–ELTE Complex Chemical Systems Research Group, Budapest, Hungary — [2]Department of Theoretical Physics, Debrecen University, Debrecen, Hungary — [3]Institute of Informatics, Debrecen University, Debrecen, Hungary — [4]Theoretische Chemie, Physikalisch-Chemisches Institut, Universität Heidelberg, Heidelberg, Germany

The coupling of matter to the quantized electromagnetic field of a plasmonic or optical cavity can be harnessed to modify and control the chemical and physical properties of molecules. In optical cavities, a term known as the dipole self-energy (DSE) appears in the Hamiltonian to assure gauge invariance.

We study the impact of the DSE on cavity-induced nonadiabatic dynamics in a realistic system. For that purpose, various matrix elements of the DSE are computed as functions of the nuclear coordinates and the dynamics of the system after laser excitation is investigated. The cavity is known to induce conical intersections between polaritons, which gives rise to substantial nonadiabatic effects. The DSE is shown to slightly affect these light-induced conical intersections and, in particular, break their symmetry.

Q 8: Laser Systems – Optical Methods (joint session K/Q)

Time: Monday 11:00–12:45 Location: HS XI ITW

Invited Talk Q 8.1 Mon 11:00 HS XI ITW

Hochleistungs-UKP-Laser für die Fertigung — •Arnold Gillner — Lehrstuhl für Lasertechnik RWTH Aachen Steinbachstrasse 15, 52074 Aachen

Ultrakurzpulslaser mit Pulsdauern von einigen 100 fs bis ps ermöglichen in der industriellen Fertigung neue Bearbeitungsansätze mit bisher unerreichter Genauigkeit. Durch die weitgehende Trennung von Energieabsorption und Materialablation ist der Energieeintrag in den Werkstoff minimal, sofern einige wichtige Randbedingungen berücksichtigt werden. Insbesondere kann es bei hohen Pulswiederholraten zu thermischer Akkumulation kommen und bei hohen Pulsenergien zu Plasmaabschirmung und Beeinflussung des eingehenden Laserstrahls. Als Lösung bieten sich Hochgeschwindigkeits-Scansysteme mit Geschwindigkeiten über 1000 m/s oder Multistrahl-Bearbeitungssysteme mit mehreren 100 Teilstrahlen an, um die eingestrahlte Laserenergie im optimalen Arbeitspunkt zu nutzen. Dieser Arbeitspunkt wird im Wesentlichen von der optischen Eindringtiefe bestimmt, höhere Energiedichten führen mit ballistischen Elektronen zu tieferen Orten der Energiedeposition. Detaillierte Analysen der Wechselwirkung über Pump-and-Probe sowie über hochenergetische Röntgenstrahlung am DESY zeigen dynamische Wechselwirkungsverhältnisse, die es gilt, durch schnelle Strahlformung zu beherrschen. Im Ergebnis steht mit Ultrakurzpuls-Lasern im kW-Bereich ein neues Werkzeug für die Präzisionsfertigung zur Verfügung.

Q 8.2 Mon 11:30 HS XI ITW

Electronically tunable fiber-feedback optical parametric oscillator with intracavity Echelle grating stretcher — •Florent Kadriu, Michael Harteker, Tobias Steinle, and Harald Giessen — University of Stuttgart 4th Physics Institute

Tunable light sources in the near-IR are often limited by tuning speed, stability, and reproducibility due to the physical movement of optics. Fiber-feedback optical parametric oscillators (FF-OPOs) offer broad tuning in the IR with high stability. Thus, ideally static optics are required for ultrafast and reproducible tuning. We present a gain-switched diode-based FF-OPO using an intracavity echelle grating stretcher for temporal-dispersion wavelength tuning. This approach enables four distinct tuning ranges corresponding to four grating orders, achieving a theoretical tuning rate of 500 kHz, a narrow linewidth below 1 nm, and 2 pm wavelength reproducibility. This concept can be transferred to other grating types and spectral ranges and is ideal for applications in infrared narrowband AM/FM spectroscopy.

Q 8.3 Mon 11:45 HS XI ITW

Advancements in large ring laser gyroscopes for geodesy and seismology — •Jannik Zenner[1], Andreas Brotzer[2], Heiner Igel[2], Karl Ulrich Schreiber[3,4], and Simon Stellmer[1] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität, Bonn, Germany — [2]Department of Earth and Environmental Sciences, Ludwig-Maximilians-Universität, Munich, Germany — [3]Research Unit Satellite Geodesy, Technical University of Munich, Munich, Germany — [4]School of Physical Sciences, University of Canterbury, Christchurch, New Zealand

This winter marks the 100 year anniversary of the Michelson-Gale-Pearson experiment, the first interferometric measurement of Earth's rotation. Ring laser gyroscopes have matured considerably and are now able to continuously monitor Earth's rotation rate at a 10^{-8} level. This opens the possibility to detect subtle earth rotation variations driven by diverse geophysical processes across a wide spectrum of frequencies, which have traditionally only been detected by astronomical techniques. We will highlight the technological advancements in ring laser technology and future perspectives.

Q 8.4 Mon 12:00 HS XI ITW

Sub-two-cycle pulses at 1600 nm and in the mid IR from an ultralow-noise fiber-feedback optical parametric oscillator system at 76 MHz — •Johann Thannheimer, Abdullah Alabbadi, Tobias Steinle, and Harald Giessen — University of Stuttgart

We achieve fiber-based self-compression down to sub-two optical cycles (9.5 fs) at 1600 nm with an average power of 620 mW (8.2 nJ) and a 76 MHz repetition rate. A commercial Yb-based pump laser is used to drive a fiber-feedback optical parametric oscillator. The frequency converted pulses are amplified to the Watt scale with an optical parametric amplifier and coupled into a 42-mm-long common single mode fiber. The fiber realizes ultracompact grating-free single stage compression to sub-two optical cycles. An added intra-pulse difference frequency generation stage converts the shot-noise limited few-cycle pulses to tunable ultra-broadband mid-infrared radiation. Beside ultrafast metrology via electro optic sampling, this system is particularly suited for mid-infrared spectroscopy.

Q 8.5 Mon 12:15 HS XI ITW

Laser Ranging for Satellite Gravimetry: GRACE-FO and beyond — •Malte Misfeldt[1,2], Vitali Müller[1,2], Gerhard Heinzel[1,2], Kai Voss[3], and Kolja Nicklaus[3] — [1]MPI für Gravitationsphysik, Hannover — [2]IGP, Leibniz Universität Hannover — [3]SpaceTech Immenstaad GmbH

The Laser Ranging Interferometer (LRI) aboard the GRACE Follow-On (GRACE-FO) mission represents a groundbreaking advancement in satellite geodesy. Designed as an experimental addition to the established microwave ranging system, the LRI employs laser interferometry to measure inter-satellite distance variations with nanometer-scale precision. The enhanced sensitivity enables improved tracking of Earth's gravity field variations, offering refined insights into critical climate change processes such as polar ice mass loss. The LRI's successful deployment and operation have set a new benchmark for the accuracy and resolution of space-based gravity measurements.

This presentation will discuss the key technologies of the LRI. As evolved LRI instruments will be the primary payload in future satellite gravimetry missions, we will highlight lessons learned from several years of successful operation in orbit and their relevance to the design. Finally, we will address the new challenges in transitioning the LRI from a technology demonstrator to a primary payload. These include meeting stricter performance requirements, enhancing robustness for long-term operation, and adding a new sub-unit to measure the laser's wavelength in-orbit to better than 25ppb.

Q 8.6 Mon 12:30 HS XI ITW

The LISA space mission — •Lennart Wissel — Max Planck Institute for Gravitational Physics — Leibniz University Hannover

The LISA observatory is a large ESA-lead mission that will unlock the yet unaccessible millihertz regime of gravitational waves. It will be launched in the mid-2030s and consists of three spacecraft on a heliocentric orbit, each shielding free-falling test masses acting as geodesic reference points. The triangular formation utilises heterodyne interferometers to measure the variations in light travel times between the test masses across 2.5 million km distances to picometer precision.

This talk gives an overview of the mission concept, highlights its technological challenges, its current status, and finishes with an outlook for the exciting timeline ahead.

Q 9: Photonics (3D Print) (joint session Q/K)

Time: Monday 17:00–19:00 Location: HS V

Q 9.1 Mon 17:00 HS V

Lateral Shear Interferometry for Wavefront Measurements of 3D-Printed Micro-Optics — •Yanqiu Zhao, Lunwei Wang, Jan-Niklas Bauer, Leander Siegle, Julian Schwab, Florian Mangold, and Harald Giessen — 4th Physics Institute and Stuttgart Research Center of Photonic Engineering, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

3D-printed micro-optics offer distinct advantages in terms of precision and compact size, enabling them to navigate narrow human tissues, including arteries, to capture clear images of their surroundings. This capability necessitates a meticulous quality control process, not only of the lens shapes, but also of the propagating wavefronts.

Thus, we carry out such measurements on 3D-printed micro-optics to assess their quality comprehensively. Wavefront measurements provide a more holistic evaluation of the micro-optics performance when compared to conventional shape measurements. The micro-optics used in our study are fabricated using a Nanoscribe Quantum X and are printed directly on substrates or on optical fibers, also comparing simple 2-photon printing with 2-photon gray scale lithography.

We demonstrate consistent and precise wavefront measurements using a simple shear plate interferometer setup. Unlike direct wavefront measurements, shear interferograms reveal the spatial wavefront derivative. By analyzing the interferogram fringes, we extract wavefront information that can be fed back into the design process within an iterative loop. This process supports quality improvement for 3D-printed micro-optics.

Q 9.2 Mon 17:15 HS V

Complex light fields produced by 3D-printed computer-generated hologram on fiber — •Zihao Zhang[1], Leander Siegle[1], Pavel Ruchka[1], Daniel Flamm[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]TRUMPF Laser- und Systemtechnik GmbH, Ditzingen, Germany

Non-Gaussian beams are pivotal in numerous scientific and industrial applications, including multi-atom trapping and laser-based material processing. Holographic optical elements can be employed to generate beams with specific intensity distributions. For instance, multiple Gaussian foci can be precisely positioned within three-dimensional space for optical trapping, and the intensity distribution of a Gaussian beam can be modified into various forms for material processing. Despite their utility, many beam-shaping optics are often complex and bulky. Certain applications necessitate solutions that are not only compact and straightforward but also adaptable and capable of rapid adjustments. In this study, we leverage the state-of-the-art technology of two-photon grayscale polymerization (2GL) to create customizable and precise optical elements on a microscale. Here, we present a 3D-printed on-fiber beam shaper, whose design enables the efficient generation of a three-dimensional distribution of 30 foci along a trefoil optical knot using a highly flexible fiber device.

Q 9.3 Mon 17:30 HS V

Millimeter-sized 3D Printed Optics by Two-Photon Grayscale Lithography — •Leander Siegle and Harald Giessen — 4th Physics Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

We demonstrate millimeter-sized optics for focusing and imaging applications fabricated by two-photon grayscale lithography (2GL). Typical sizes of 2GL 3D printed lenses have previously been limited to the sub-millimeter range. Using low-magnification objectives in combination with high photo-initiator density resists, we fabricate aspherical lenses with diameters of 1 to 5 mm. Compared to the typical two-photon polymerization fabrication process, 2GL offers better shape accuracy, while simultaneously increasing throughput. To showcase 2GL fabricated millimeter-sized lenses, we design, 3D print, and optimize high-numerical aperture singlet lenses for focusing and imaging in the visible and near-infrared. We determine the shape accuracy and analyze the optical performance. Furthermore, we investigate a singlet lens for imaging and examine the high-resolution performance with a USAF 1951 resolution test chart. 2GL 3D printed lenses offer toolless rapid prototyping for custom optical solutions in the micron to millimeter range.

Q 9.4 Mon 17:45 HS V

Near-infrared Laser damage in 3D printed microoptics — •Sebastian Klein, Pavel Ruchka, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

In recent years, two-photon-polymerization (2PP) 3D printing has seen a significant rise in importance in the field of microoptics, delivering high precision free-form optics with a low manufacturing cost compared to conventional fused silica microoptics. Applications range from biomedical imaging systems such as endoscopes, to employment in compact high-power fiber-based laser systems and material processing using diffractive optical elements for customized beam shaping. For the latter, high reliability and performance even under high power densities are essential.

In this work, we quantify femtosecond laser-induced damage in the 2PP photoresists IP-S and OrmoComp by microscope imaging cube samples irradiated with different wavelengths and fluences. By incorporating the more sensitive differential interference contrast (DIC) imaging technique, we determine damage thresholds of these photopolymers in the NIR spectral range. Furthermore, we introduce a novel approach for damage detection surpassing the sensitivity of DIC microscopy. With this approach, the damaging effects of telecom C-band radiation after multiple hour exposures are studied, giving a first look at the long-time high-power stability of the polymers.

Q 9.5 Mon 18:00 HS V

3D printed high NA micro-optics for quantum applications — •Pavel Ruchka[1], Sara Jakovljevic[1], Nam Tran[2], Carlos Jimenez[3], Simone Luca Portalupi[2], Michael Jetter[2], Alois Herkommer[3], Stephan Reitzenstein[4], Sven Höfling[5], Caspar Hopfmann[6], Peter Michler[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen and Re-

search Center SCoPE, University of Stuttgart — [3]Institute for Applied Optics and Research Center SCoPE, University of Stuttgart — [4]Institute of Solid State Physics, Technische Universität Berlin — [5]Technische Physik, University of Würzburg — [6]Deutsche Telekom Chair of Communication Networks, TU Dresden

3D-printed micro-optics made with two-photon polymerization have revolutionized fields like imaging, sensing, and illumination. This method allows the creation of complex miniature freeform shapes for mechanical and optical uses with high precision, opening up new possibilities for advanced technology. In this work, we present a novel approach to 3D-printed high numerical aperture (NA) micro-optics on optical fibers, targeting applications such as quantum communication and trapped-atom quantum computing. We fabricate shape-optimized refractive and diffractive lenses with NA values as high as 0.8 and characterize their performance through beam profiling. Additionally, we demonstrate the successful coupling of quantum dots at wavelengths of 780 nm and 1550 nm to corresponding single-mode fibers, enabled by these high-NA 3D-printed micro-optics.

Q 9.6 Mon 18:15 HS V

3D printed micro-sized dark-field condenser by two photon polymerization — •Robert Horvat[1], Leander Siegle[1], Pavel Ruchka[1], Michael Schmid[2], Lukas Weseman[3,4], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Printoptix GmbH, Nobelstraße 15, 70569 Stuttgart, Germany — [3]School of Physics, The University of Melbourne, Victoria 3010, — [4]ARC Centre of Excellence for Transformative Meta-Optical Systems, School of Physics, The University of Melbourne, Victoria 3010, Australia

We demonstrate a miniaturized fully 3D printed dark field condenser for microscopy applications. Dark field microscopy is a simple but effective technique for contrast enhancement that allows imaging of transparent samples, useful in bio-medicine. Usually, microscope setups are bulky and costly. Our approach miniaturizes the system to the micro- and millimeter size, while allowing rapid prototyping and quick adaptation for individual system integration. We realise this by using two photon polymerization to 3D print two photoresists on both sides of a microscope glass slide. We first fabricate an annular ring aperture from a highly absorptive photoresist on one side of the glass slide with diameters between 300 and 2000 micrometers. Next we print a high numerical aperture lens within the same diameter range on the other side of the glass slide. We use the 3D printed dark field condenser to illuminate different samples, such as a USAF 1951 resolution test chart, and compare its performance to the typical bright field illumination.

Q 9.7 Mon 18:30 HS V

Broadband Mode Division Multiplexing of OAM-Modes by a Micro Printed Waveguide Structure — •Julian Schulz[1] and Georg von Freymann[1,2] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, 67663 Kaiserslautern, Germany

To utilize the orthogonal mode space of OAM-modes to increase the amount of information throughput for optical fibers, an efficient and compact device to create, superimpose and to decompose OAM-Modes is needed We present as a proof of principle a waveguide structure, which transformations the eigenmodes from spatially separated single mode waveguides adiabatically into modes of a ring waveguide carrying $|\mathrm{OAM}| \leq 2$. In an adiabatic evolution, the population of the eigenmodes remains constant while the eigenmodes change according to the system. Two mechanisms are utilized to maintain the propagation constants of each individual mode consistently spaced during the propagation thou the structure: Individual waveguides are detuned by changing their radius and an artificial magnetic field is introduced by twisting the structure. The inherent tolerance of an adiabatic evolution allows our device to operate effectively across a wide spectrum of wavelength. Besides that, it can also be used as a demultiplexing structure, if the adiabatic evolution is run backwards. We demonstrate the capabilities of the structure with BPM-simulations and experiments with a polymer waveguide structure fabricated via direct laser writing. [*Advanced Optical Materials* **12**, 2302597, (2024)]

Q 9.8 Mon 18:45 HS V

Fiber-based femtosecond 3D printing — •Anton Hellstern[1], Claudia Imiolczyk[1], Pavel Ruchka[1], Marco Wende[2], Theresa Kühn[3], Moritz Flöss[1], Michael Heymann[3], Andrea Toulouse[2], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart, Germany — [2]Institute of Applied Optics, University of Stuttgart, Germany — [3]Institute of Biomaterials and Biomolecular Systems, University of Stuttgart, Germany

Ultrashort laser pulses are often used in medical applications, for instance for soft-tissue surgeries. However, the progress on using such laser pulses for additive manufacturing of tissue is rather marginal so far. Therefore, we aim to realize an endoscopic fiber-based femtosecond 3D printer to minimally invasively surgically repair organ damage on a micrometer scale. For this, high peakpower femtosecond laser pulses are required, in order to 3D print the desired geometries using two-photon-lithography. By combining a grating compressor, a single-mode fiber, and suitable 3D printed microobjetives directly on the fiber tip, we achieve subpicosecond pulse durations which are able to polymerize both commercial photopolymers as well as bioinks. We report on dose tests, the optimization of printing speed, laser power, pulse compression ratio and pulse duration, as well as slicing and hatching variation. We demonstrate solid cubes as well as connected lines, leading to 3D woodpile structures that represent scaffolds which ultimatively could be colonized by living cells. This direct printing of cell scaffolds by endoscopic 3D printing should allow in the future for example printing of bone tissue inside the body.

Q 10: Quantum Optics and Nuclear Quantum Optics I

Time: Monday 17:00–19:00 Location: AP-HS

Invited Talk Q 10.1 Mon 17:00 AP-HS

Nuclear quantum memory for hard x-ray photon wave packets — •Sven Velten[1,2], Lars Bocklage[1,2], Xiwen Zhang[3], Kai Schlage[1], Anjali Panchwanee[1], Sakshath Sadashivaiah[4,5], Ilya Sergeev[1], Olaf Leupold[1], Aleksandr I. Chumakov[6], Olga Kocharovskaya[3], and Ralf Röhlsberger[1,2,5,4,7] — [1]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging CUI, Hamburg, Germany — [3]Department of Physics and Astronomy and Institute for Quantum Science and Engineering, Texas A&M University, College Station, USA — [4]Helmholtz-Institut Jena, Jena, Germany — [5]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [6]ESRF -The European Synchrotron, Grenoble, France — [7]Friedrich-Schiller Universität Jena, Institut für Optik und Quantenelektronik, Jena, Germany

Quantum optics concepts rarely extend to hard X-ray radiation due to the high field strengths needed for coherent control. However, nuclear transitions, notably the 14.41 keV transition of ^{57}Fe, enabled establishing hard X-ray quantum optics due to their ultranarrow linewidths, their high number densities found in solids, and relatively large resonant cross-sections. Aiming to extend this field to quantum information processing, we demonstrated a nuclear quantum memory. By moving multiple resonant absorbers, a Doppler frequency comb is formed capable of storing X-ray photon wave packets on the single-photon level. Conceptually analogous to atomic frequency combs, it constitutes a robust, highly flexible platform for X-ray quantum memories.

Q 10.2 Mon 17:30 AP-HS

Two-photon excitation spectroscopy of high pressure xenon-noble gas mixtures — •Eric Boltersdorf, Thilo vom Hövel, Frank Vewinger und Martin Weitz — Institut für Angewandte Physik, Bonn, Deutschland

Photons confined in a dye-filled optical microcavity can exhibit Bose-Einstein condensation upon thermalization through repeated absorption and (re-)emission processes on the dye molecules. This has been experimentally demonstrated for photons in the visible spectral regime in 2010. In the present work, an experimental approach is investigated to realize Bose-Einstein condensation of vacuum-ultraviolet (100nm-200nm; VUV) photons via repeated absorption and (re-)emission cycles between the $5p^6$ ground state and the $5p^5 6s$ (J = 1) excited state of xenon-noble gas excimer molecules in dense gaseous ensembles (pressure of up to 100 bar). The optical pumping via two-photon excitation from xenon's $5p^6$ electronic ground-state to higher lying states, e.g. the $5p^5 6p$ and $5p^5 6p'$ states, is investigated. We report on the measurement of excitation spectra with excitations wavelengths ranging from 220 nm to 260 nm. The emission is collected between 145nm and 180nm, which stems from the decay of the $5p^5 6s$ (J = 1) state that was proposedly populated by collisional deactivation from the higher lying excited states. Data will be shown for xenon-helium mixtures as well as for xenon-krypton mixtures, showing strong dependency on pressure and the atomic species.

Q 10.3 Mon 17:45 AP-HS

Quantum optical effects in three-layer thin-film x-ray cavities — •Julien Spitzlay, Fabian Richter, and Adriana Pálffy — Julius-Maximilians-Universität Würzburg

Thin-film cavities with several embedded layers of Mössbauer nuclei are an intriguing platform for the realization of quantum optical effects in the x-ray regime. Many theoretical models have been developed in the past decade to describe the resonant x-ray scattering in these nanostructures, for instance an ab-initio formalism based on the electromagnetic Green's function [1,2].

In this work, we investigate parallels between this numerically efficient description and well-known cavity QED models, which provide a better physical interpretation. Applied to a three-layer x-ray cavity, we are interested in the occurrence of electromagnetically induced transparency (EIT) and Autler-Townes-Splitting (ATS). The aim is to identify parameter regimes where thin-film x-ray cavities can exhibit a behaviour reminiscent to these phenomena and in particular the tuning parameter that controls the transition between EIT and ATS. Our analysis is based on the model of decaying dressed states [3].

[1] D. Lentrodt, K. Heeg, C. H. Keitel, J. Evers, Phys. Rev. Research 2, 023396 (2020)
[2] X. Kong, D. Chang, A. Pálffy, Phys. Rev. A 102, 033710 (2020)
[3] P. Anisimov, O. Kocharovskaya, J. Mod. Opt. 55, 3159 (2008)

Q 10.4 Mon 18:00 AP-HS

ORKA- Cavity enhanced dipole trapping of Rb87 atoms for microgravity — •Marius Prinz, Jan Eric Stiehler, Marian Woltmann, and Sven Herrmann — Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Germany

Using a dipole trap as a source for ultra-cold quantum gases comes at the cost of a high power budget of the trapping lasers. This limits the usability of all-optical trapping/cooling in power limited environments, e.g. space. To overcome this limit, the ORKA project aims to exploit the high intracavity power and crossed beam geometry of a high finesse optical bow-tie cavity. Our goal is to employ such a setup in the Bremen GraviTower to prepare Rb87 BECs as a matter wave source in microgravity. In this talk we will present the design and statud of our drop tower setup as well as first measurements of the basic properties of the cavity. The ORKA project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50 WM 2267.

Q 10.5 Mon 18:15 AP-HS

Cryogenic Feedforward of a Photonic Quantum State — •Niklas Lamberty[1,2], Frederik Thiele[1,2], Thomas Hummel[2], Nina A. Lange[1,2], Lorenzo M. Procopio[1,2], Aishi Barua[1,2], Sebastian Lengeling[3], Viktor Quiring[2], Christof Eigner[2], Christine Silberhorn[3], and Tim J. Bartley[1,2] — [1]Department of Physics, Paderborn University, Warburger Str. 100, Paderborn, 33098, Germany — [2]Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, Paderborn, 33098, Germany — [3]Integrated Quantum Optics Group, Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, Paderborn, 33098, Germany

A wide range of quantum optical protocols require feedforward operations, entailing a partial measurement and subsequent manipulation of a quantum state. Reducing the latency between these two operations reduces the required storage time of the quantum state. By operating the measurement electronics and the modulator in the same cryogenic environment as high efficiency Superconducting Nanowire Single Photon Detectors (SNSPD), we achieve the lowest latency demonstrated so far of (23±3) ns. We use this feedforward operation to manipulate the $g^{(2)}(0)$ of a parametric down conversion source conditional on a photon-number measurement.

Q 10.6 Mon 18:30 AP-HS

Quantum dynamics of nuclear many-body systems driven by an XFEL — •Miriam Gerharz and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Mössbauer nuclei are an extreme platform for quantum optics because of their narrow transitions in the x-ray regime. These narrow transitions feature long lifetimes, but on the other hand also allowed to only study single excitations for decades. This has recently changed with first experiments at X-ray free electron lasers, where now multiple photon excitations and the subsequent dynamics can be studied. This technological progress immediately raises the question whether there are new effects expected depending on the number of resonant photons. In this project we theoretically explore quantum dynamics after multiple photon excitations.

Q 10.7 Mon 18:45 AP-HS

Upper-level spectroscopy of cold trapped ^{174}Yb atoms for their preparation in the metastable $^3P_0$ state — •Ke Li, Gabriel Dick, Saran Shaju, Dmitriy Sholokhov, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken, Germany

We trap and cool ^{174}Yb atoms in a magneto-optical trap (MOT) inside a high-finesse cavity [1] for exploring atom-cavity interaction on the $^1S_0$ – $^3P_0$ clock transition at 578 nm [2]. For populating the metastable $^3P_0$ level, we employ repumping lasers resonantly driving the $^3P_1$ – $^3S_1$ and $^3P_2$ – $^3S_1$ transitions, thereby transferring all atoms to $^3P_0$ via the $^3S_1$ level. We study the time-resolved repumping process to characterize and optimize its efficiency. The detuning-dependent population dynamics include coherent population trapping phenomena.

[1] H. Gothe et al., Phys. Rev. A, 99, 0134 15, 2019.
[2] D. Meiser et al., Phys. Rev. Lett. 102, 163601, 2009.

Q 11: QED and Cavity QED

Time: Monday 17:00–19:00 Location: HS Botanik

Q 11.1 Mon 17:00 HS Botanik

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; Phys. Rev. Lett. 97, 187202 (2006)
[5] L. Lenke, A. Schellenberger, K. P. Schmidt, Phys. Rev. A, 108 (2023)

Q 11.2 Mon 17:15 HS Botanik

Re-entrant phase transition in many-body Cavity QED — •Tom Schmit[1], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

We analyse theoretically self-organization of atoms that couple dispersively to an optical cavity and are subject to a transverse pump, in a configuration experimentally studied[1]. The transverse pump laser is blue-detuned w.r.t. the atomic transition, confining the atoms in the intensity minima of the generated optical lattice. The competition of pump and cavity field leads to self-organization of the atoms in an ordered pattern, giving rise to a re-entrant phase transition, such that by increasing the pump intensity above a critical value, one first observes a transition from disorder to self-organized and then, at larger values, again back to a disordered phase[1]. Our theoretical model, founded on a mean-field ansatz, provides a description of the stationary state's phase diagram in relation to pump intensity and detuning from the cavity frequency, aligning well with experimental observations. We show that stability of the ordered pattern is warranted when the scattered light interferes destructively with the pump at the atomic positions, effectively keeping the atoms in darkness. We discuss the connection between this phenomenon and *inverse melting*, observed in (classical) systems with repulsive and competing long-range interactions.

[1] P. Zupancic, et al., Phys. Rev. Lett. **123**, 233601 (2019).

Q 11.3 Mon 17:30 HS Botanik

Master Equation for Many-Body Cavity Quantum Electrodynamics — •Tom Schmit[1], Simon Jäger[2], Catalin-Mihai Halati[3], Tobias Donner[4], Corinna Kollath[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Physikalisches Institut, University of Bonn, Nußallee 12, 53115 Bonn, Germany — [3]Department of Quantum Matter Physics, University of Geneva, Quai Ernest-Ansermet 24, 1211 Geneva, Switzerland — [4]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zurich, Switzerland

Ensembles of atoms strongly coupled with the electric field of an optical cavity offer a formidable laboratory for studying the out-of-equilibrium dynamics of long-range interacting systems in the quantum regime. In this work, we derive a quantum master equation describing the optomechanical dynamics of the atomic ensemble, by eliminating the cavity degrees of freedom in perturbation theory. The master equation can capture the dynamics over a broad range of mechanical energies, from the thermal gas down to the ultra-cold, quantum degenerate regime. It can further systematically include the effect of external potentials, such as an optical lattice. We reproduce known limits and benchmark the master equation's prediction with exact diagonalization of the full quantum problem. Our model sets the basis for a systematic analysis of the dynamics of the characteristic timescale and correlations of quantum self-organization.

Q 11.4 Mon 17:45 HS Botanik

Three-Body Contributions to the Casimir Polder Force — •Emma Wünsche, Fabian Spallek, and Stefan Yoshi Buhmann — University Kassel, Germany

We study many-body contributions to the Casimir Polder (CP) force. Since for geometries of low symmetry or reduced symmetry no closed expressions for the CP potential are available, we employ a Born series for the Greens tensor and, relating the microscopic polarizability to the macroscopic permittivity, we derive a power series expansion of the CP potential in terms of the polarizabilities of the bodies' constituent atoms. The expansion can be interpreted as the sum of many-body Van-der-Waals contributions: the first term represents two-atom contributions, the second term three-atom interactions, and so on. For comparison, we reformulate existing results of macroscopic approaches for the CP potential and express them as a series in atomic polarizabilities. This allows us to validate the microscopic Van-der-Waals approach. We consider two different dielectric geometries: a small cylinder and an infinite half space, and find very good agreement for the two-atom contributions. While the three-atom contribution to the CP potential of an atom in front of an infinite plate can only be accessed numerically, for the cylinder-case, we find good agreement in the angular dependence of the three-atom contributions to the CP potential for the microscopic and macroscopic approaches.

Q 11.5 Mon 18:00 HS Botanik

Strong Chiral Coupling of a Molecule in a Two-Mode Cavity — •Lara Marie Tomasch, Fabian Spallek, and Stefan Yoshi Buhmann — Institut für Physik, Universität Kassel, Heinrich-Plett Str. 40, 34132 Kassel

We examine the effects of chirality on the interaction of a two-level quantum system with a single mode of the quantised electromagnetic field inside a cavity. We develop a generalised Jaynes-Cummings model and study the modified coupling constants, Rabi oscillations and eigenenergies of the system.

We generalise this system by having two chiral standing modes of opposite handedness present inside the cavity and determine their coupling to the chiral molecule. These two modes are in general detuned and may exhibit distinct coupling strengths as determined by the molecular dipole moments. We further examine the emergence of chiral-induced quantum phenomena and chiral forces acting on the molecule with potential applications in chiral sensing.

Q 11.6 Mon 18:15 HS Botanik

Quantum radiation and its correlations in tuneable dielectrics — •Sascha Lang[1,2,3], Stefan Yoshi Buhmann[1], Ralf Schützhold[2,4,3], and William G. Unruh[5] — [1]University of Kassel, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Universität Duisburg-Essen, Germany — [4]Technische Universität Dresden, Germany — [5]University of British Columbia, Canada

Recent advances in THz nonlinear optics have revealed characteristic imprints of quantum vacuum fluctuations onto the two-point correlations of the electric field [1]. Media with explicitly time dependent properties even allow quantum vacuum fluctuations to be spontaneously promoted to real photon pairs—with distinctive signatures on the field correlations. Existing studies of such *quantum radiation phenomena* in dielectrics typically neglect dissipation and the associated quantum noise close to material resonances.

Based on established results for non-dispersive and lossless media [2], we are going to discuss the potential of correlation measurements for future quantum radiation experiments. Afterwards, we will present a model which includes dispersion and dissipation but still applies to tuneable media. Our formalism builds upon the famous Hopfield model and describes the medium via harmonic oscillators and a scalar environment field that may carry away energy and information [3].

[1] Settembrini, Lindel, Herter, Buhmann & Faist, Nat. Comm. **13**, 3383 (2022)
[2] Lang & Schützhold, Phys. Rev. D **100**, 065003 (2019)
[3] Lang, Schützhold & Unruh, Phys. Rev. D **102**, 125020 (2022)

Q 11.7 Mon 18:30 HS Botanik

Global pseudomode representation of cavity QED — •Lucas Weitzel, Andreas Buchleitner, and Dominik Lentrodt — Albert-Ludwigs Universität Freiburg

We construct an analytical and non-perturbative model for open cavities using discrete leaky modes – the so-called pseudomodes – by "reverse-engineering" the parameters in the model from the exact, position-resolved spectral density within the cavity. Furthermore, the approach generalizes the standard pseudomodes by incorporating an explicit mode expansion for the cavity electric field. The latter feature ultimately allows for a global – that is, at every position within the cavity – description of the dynamics of an emitter and extends the application of pseudomodes to more complex targets such as condensed matter or extended atomic systems and even to very leaky open cavities.

Q 11.8 Mon 18:45 HS Botanik

Quantum friction near chiral media — •Omar Jesus Franca Santiago[1], Stefan Yoshi Buhmann[1], Fabian Spallek[1], Steffen Giesen[2], Robert Berger[2], Kilian Singer[1], and Stefan Aull[1] — [1]Institute of Physics, Uni- versity of Kassel, Germany — [2]University of Marburg

We investigate how the quantum friction experienced by a polarisable charged particle moving with constant velocity parallel to a planar interface is modified when the latter consists of a chiral medium. We use macroscopic quantum electrodynamics to obtain the Casimir–Polder frequency shift and decay rate. These results are a generalization of the respective quantities to matter with parity symmetry breaking. We illustrate our findings by examining the nonretarded and retarded limits for three examples: a perfectly conducting mirror, a perfectly reflecting chiral mirror and an isotropic chiral medium. We also discuss the importance of the symmetries in these examples in the framework of Curie's principle.

[1] Stefan Yoshi Buhmann, David T. Butcher and Stefan Scheel. New Journal of Physics 14, 083034 (2012).
[2] David T. Butcher, Stefan Yoshi Buhmann, Stefan Scheel, New Journal of Physics 14, 113013 (2012).

[3] O. J. Franca, Fabian Spallek, Steffen Giesen, Robert Berger, Kilian Singer, Stefan Aull, and Stefan Yoshi Buhmann. arXiv: 2412.18044 [quant-ph].

Q 12: Quantum Optomechanics I

Time: Monday 17:00–19:00 Location: HS I

Q 12.1 Mon 17:00 HS I

Coupling an optically levitated nanoparticle to an ultrahigh-Q microtoroidal cavity — •Zijie Sheng[1,2], Seyed Khalil Alavi[1,2], Haneul Lee[3], Hansuek Lee[3,4], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, DE — [2]Center for Integrated Quantum Science and Technology (IQST), University of Stuttgart, DE — [3]Department of Physics, Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea — [4]Graduate School of Quantum Science and Technology, KAIST, Republic of Korea

Exploring the dynamics of an optically levitated dielectric nanoparticle and bringing its mechanical motion toward the quantum regime has been widely developed during the last few years. One promising way is to couple its motion to a high-finesse optical cavity. Here, we present a novel platform consisting of a conventional optical tweezer and a toroidal optical microcavity [1]. The optomechanical coupling between the particle and the cavity is established by placing the particle in the near field of the cavity. The significantly reduced mode volume allows us to achieve a 50-fold increase in the single photon optomechanical coupling compared to a conventional Fabry-Pérot cavity with macroscopic mirrors, while having ultralow loss of the cavity can allow us to potentially reach sideband resolved regime. We will present the recent progress of our experiment.

[1] S. Alavi, Z. Sheng, H. Lee, H. Lee, and S. Hong, ACS Photonics 2024 https://doi.org/10.1021/acsphotonics.4c01359

Q 12.2 Mon 17:15 HS I

Inverse numerical design of optically levitated nanoparticles for enhanced stiffness and detection efficiency — •Moosung Lee[1,2] and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology, University of Stuttgart, 70569 Stuttgart, Germany

Levitated optomechanics offers a promising avenue for achieving quantum-limited motional control of massive objects. To enable precision sensing and quantum mechanical tests on larger mass scales, it is essential to scale particle sizes beyond the Rayleigh regime, where the particle diameter is far smaller than the wavelength of optical tweezers. However, the multiple light scattering in larger particles hamper efficient optical trapping and motional detection, limiting quantum-limited applications beyond the nanoparticle scale in levitodynamics. Here, we propose an optimization algorithm based on the adjoint state method to inversely design three-dimensional shapes of optically levitated microparticles suitable for quantum optomechanical experiments. Using this approach, we numerically optimize the structures of silica and silicon particles in a standing-wave optical trap. Preliminary results demonstrate a mass enhancement, while maintaining 3D trap frequencies and detection efficiency comparable to those of Rayleigh nanoparticles. These parameters support the feasibility of achieving 3D quantum-ground-state motional cooling of the shape-optimized microparticles.

Q 12.3 Mon 17:30 HS I

Flexible optical levitation and motion control with 3D printed fiber lenses — •Seyed Khalil Alavi[1,2], Manuel Monterrosas Romero[1,2], Pavel Ruchka[3], Sara Jakovljević[3], Harald Giessen[3], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Stuttgart, DE — [2]Center for Integrated Quantum Science and Technology (IQST), University of Stuttgart, Stuttgart, DE — [3]4. Physikalisches Institut, Research Center SCoPE and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, DE

Optical levitation of single nanoparticles in vacuum provides precise motion control and isolation, offering a versatile tool with applications like force sensing, and exploring macroscopic quantum mechanics. Optical levitation has been achieved using optical tweezers formed by tightly focused beams, typically requiring a high NA optical objective. This approach results in a complex and bulky apparatus with constraints in geometry and size, limiting scalability. We eliminate these constraints and ease experimental requirements by using a compact and portable trapping platform formed by a 3D-printed lens on the facet of an optical fiber, enabling simultaneous trapping and motion detection with high efficiency, a key merit for the quantum-limited control. The orientation and position of our tweezer can be adjusted by moving the fiber while trapping, allowing integration into other elements for constructing hybrid systems. Our platform paves the way for the future generation of portable quantum levitodynamics platforms.

Q 12.4 Mon 17:45 HS I

Prospects of phase-adaptive cooling of levitated magnetic particles in a hollow-core photonic-crystal fibre — •Pardeep Kumar[1], Fidel G. Jimenez[2], Soumya Chakraborty[3,1], Gordon K. L. Wong[1], Nicolas Y. Joly[3,1], and Claudiu Genes[1,3] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, D-91058 Erlangen, Germany — [2]Pontificia Universidad Católica del Perú, Av. Universitaria 1801, San Miguel 15088, Peru — [3]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, D-91058 Erlangen, Germany

We present a viable scheme to mitigate the thermal fluctuations associated with the classical motion of a micro- to nano-sized magnetic particle, optically levitated inside a hollow-core photonic crystal fiber. The proposed technique is based on a phase-adaptive feedback mechanism and requires only the detection of mechanical quadratures to accomplish cooling. Such an operation can be implemented by directly imaging the particle's position and subsequent processing of the acquired information to adjust the trapping laser's phase, which leads to a Stokes type of viscous force. We provide analytical expressions for the achievable final occupancy and cooling rates, considering both the thermal and measurement noises and benchmark our analytical expressions against full numerical stochastic simulations. Our results are consequential for using trapped micro-magnets in sensing, testing the fundamental physics and preparing the quantum states of magnetization.

Q 12.5 Mon 18:00 HS I

Rotational dynamics of Meissner-levitated micromagnets — •Zhiyuan Wei and Benjamin A. Stickler — Institute for Complex Quantum Systems, Ulm University

Levitating microscale magnetic particles above type-II superconductors through the Meissner effect [1,2] reduces heating and photon scattering associated with optical levitation and holds the promise to yield large mechanical quality factors. Here we present the equations of motion for a permanent magnet with arbitrary internal magnetization field interacting with its dynamic image and the flux-pinned fields formed in the superconductor. We show how the magnetic quadrupole moments of the particle can give rise to three-dimensional alignment via normal-modes analysis and numerical Hamiltonian simulations. We discuss implications for future experiments [3] probing the quantum dynamics of Meissner-levitated micromagnets.

[1] J. Gieseler, A. Kabcenell et al., Phys. Rev. Lett. 124, 163604 (2020).

[2] T. Wang, S. Lourette et al., Phys. Rev. Applied 11, 044041 (2019).

[3] P. Fadeev, T. Wang et al., Phys. Rev. D 103, 044056 (2021).

Q 12.6 Mon 18:15 HS I

Towards Matter-Wave Interference Experiments with Levitated Nanoparticles — •Florian Fechtel, Stephan Troyer, Lorenz Hummer, Uroš Delić, and Markus Arndt — University of Vienna, VDS, VCQ, Faculty of Physics, Boltzmanngasse 5, A-1090 Vienna, Austria

When investigating microscopic systems, we usually successfully use quantum mechanics. However, understanding its transition to classical phenomena has remained a significant challenge. Levitated nanoparticles offer a promising platform for observing quantum behavior at mass scales beyond current limits. In our experiment, we trap 150 nm diameter silica nanoparticles, loaded into an infrared tweezer by laser-induced acoustic desorption. We employ coherent scattering cooling in ultra-high vacuum, with a high-finesse (F > 300,000) optical cavity driven by light scattered from the particle. By blue-detuning the cavity mode relative to the optical tweezer, we enhance Anti-Stokes scattering, effectively removing motional energy and cooling the three translational modes to temperatures below 10 mK. Using a fiber laser at 1550 nm, the ultimate cooling limit is constrained by laser phase noise, which acts as a stochastic heating force, as it converts to amplitude noise in the high-finesse cavity. To mitigate this effect, we implement a feedback loop that significantly reduces laser phase noise at frequencies relevant to particle motion. This allows for further cooling and enables precise temperature measurements using sideband thermometry. Looking ahead, we aim to conduct quantum experiments around translational and/or rotational interferometry.

Q 12.7 Mon 18:30 HS I

Loading technique for quantum experiments with levitated dielectric and biological nanoparticles — •Stefan Schrems, Lorentz Hummer, Stephan Troyer, and Markus Arndt — Fakultät für Physik, Universität Wien, Wien, Österreich

Levitated optomechanics has seen a rapid development. A typical experiment requires loading, cooling, detection and ideally also coherent state manipulation. However, in many cases the time scale and success of the experiment is still determined by the time to load a suitable particle. Different techniques have been developed throughout the years: Aerosol based nebulization and electrospray ionization, mechanical piezo loading or laser based methods such as optical desorption, matrix-assisted laser desorption or laser-induced acoustic desorption (LIAD). Our goal is to build a reproducible, on-demand source for loading future quantum experiments with dielectric or biological nanoparticles.To desorb dielectric nanoparticles, we are investigating a new source based on the disintegration of (Poly-)Phtalaldehyde (PPA). It relies on the unique properties of this special polymer to absorb light, depolymerize at a temperature TC = 150°C and sublimate immediately after depolymerisation. We coat a thin PPA layer on a glass slide and nebulize size-selected nanoparticles on top of the polymer layer. A highly focused 266 nm pulsed laser (3 μm waist) of low energy sets individual particles free by disintegrating the PPA layer, avoiding van der Waals forces to the substrate. A visible, off-resonant laser then guides the desorbed nanoparticles into the interaction zone, using the dipole force.

Q 12.8 Mon 18:45 HS I

Dynamics of ellipsoidal superconductors levitated in magnetic quadrupole traps — •Fynn Köller[1], Klaus Hornberger[2], and Benjamin Stickler[1] — [1]Ulm University, Institute for Complex Quantum Systems, Ulm, Germany — [2]University of Duisburg-Essen, Faculty of Physics, Duisburg, Germany

Superconducting bodies can be diamagnetically levitated in magnetic quadrupole traps, where their dynamics is governed by the internal magnetization field induced by the trapping field. We derive an analytical expression for the internal magnetization in ellipsoidal bodies. The induced dipole and quadrupole moments give rise to diamagnetic forces and torques as well as to spin-rotation coupling due to the Einstein-de Haas and Barnett effects, enabling full three-dimensional alignment in the trap center. We investigate how spin-angular momentum of superconductors can be observed through their motion and how the resulting dynamics can be measured, controlled and eventually cooled in upcoming experiments with levitated micron-sized superconductors.

Q 13: Ultracold Matter (Bosons) I (joint session Q/A)

Time: Monday 17:00–19:00 Location: HS I PI

Q 13.1 Mon 17:00 HS I PI

Quantum geometry of bosonic Bogoliubov quasiparticles — •Isaac Tesfaye and André Eckardt — Institut für Theoretische Physik, Technische Universität Berlin Hardenbergstraße 36, 10623 Berlin, Germany

Topological features arising bosonic Bogoliubov-de Gennes (BBdG) systems have mainly been studied by utilizing a generalized symplectic version of the Berry curvature and Chern number. However, the characterization of the geometrical features in BBdG systems is still lacking. Here, we propose a symplectic quantum geometric tensor (SQGT) whose imaginary part leads to the previously studied symplectic Berry curvature, while the real part gives rise to a symplectic quantum metric, providing a natural distance measure in the space of bosonic Bogoliubov modes. We show that all components of the SQGT are measurable by extracting excitation rates in response to periodic modulations of the systems' parameters. Moreover, we connect the symplectic Berry curvature to a generalized symplectic anomalous velocity term for Bogoliubov Bloch wave packets. We test our results for a bosonic Bogoliubov-Haldane model. Our results open new avenues for the quantum geometrical characterization of Bose condensed and parametrically driven photonic quantum systems.

[1] I. Tesfaye and A. Eckardt, arXiv:2406.12981.
[2] R. Shindou et al., Phys. Rev. B **87**, 174427 (2013).
[3] S. Furukawa and M. Ueda, New J. Phys. **17**, 115014 (2015).
[4] V. Peano et al., Nat Commun **7**, 10779 (2016).
[5] G. Engelhardt and T. Brandes, Phys. Rev. A **91**, 053621 (2015).

Q 13.2 Mon 17:15 HS I PI

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 ν=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.

Q 13.3 Mon 17:30 HS I PI

Ghost fixed point dynamics of driven-dissipative BEC — •Moritz Janning[1] and Johann Kroha[1,2] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn — [2]University of St. Andrews, North Haugh

We investigate the driven-dissipative dynamics of an open photon BEC in a single-mode microcavity filled with dye molecules using the Lindblad master-equation approach. While one would expect a dephasing behaviour due to the driven-dissipative nature of the system a stationary condensate has been observed experimentally[1]. In recent theoretical investigations we were able to predict such a long lived stationary condensate which then dephases after a time farly outreaching the experimental observation. Interestingly, the quasi-stationary condensate is strongly influenced by the presence of a ghost fixed point, and its lifetime can be controlled by the driving parameters. This fixed point also enables a crossover to an oscillatory behavior that was experimentally observed as a non-hermitean phase transition[1]. The precise point of the non-hermitian phase transition can subsequently be understood as an exceptional point within the framework of nonlinear dynamics.

[1] F. E. Öztürk et al., Science, 372, 6537, pp. 88-91 (2021)

Q 13.4 Mon 17:45 HS I PI

Matter-wave vortex N00N states by resonant excitation —

•Lars Arne Schäfer and Reinhold Walser — TU Darmstadt, Germany

We study a gas of few interacting bosons in a ring trap that is superimposed with a freely programmable periodic azimuthal potential [1]. This highly controllable quantum system has been proposed as a platform for quantum simulation and sensing [2]. In contrast to angular momentum transfer from Gauss-Laguerre laser beams [3], we describe techniques to use the time-dependent programmable lattice potential. This will induce resonant excitations between angular momentum Fock states in the ring trap. As a specific application, we discuss the creation of the entangled N00N state

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|2_{-p}, 0_p\rangle + |0_{-p}, 2_p\rangle\right),$$

where the two modes are angular momentum eigenstates with $k_{\pm p}$.

[1] M. R. Sturm, M. Schlosser, R. Walser, and G. Birkl, Quantum simulators by design: Many-body physics in reconfigurable arrays of tunnel-coupled traps, Phys. Rev. A **95**, 063625 (2017).

[2] L. Amico et al., Quantum Many Particle Systems in Ring-Shaped Optical Lattices, Phys. Rev. Lett. **95**, 063201 (2005).

[3] G. Nandi, R. Walser, and W. P. Schleich, Vortex creation in a trapped Bose-Einstein condensate by stimulated Raman adiabatic passage, Phys. Rev. A **69**, 063606 (2004).

Q 13.5 Mon 18:00 HS I PI

Temporal Bistability in the Dissipative Dicke-Bose-Hubbard System — Tianyi Wu[1], Fredrik Vermeulen[1], •Sayak Ray[1], and Johann Kroha[1,2] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews, KY16 9SS, United Kingdom

We consider a driven-dissipative system consisting of an atomic Bose-Einstein condensate loaded into a two-dimensional Hubbard lattice and coupled to a single mode of an optical cavity. Due to the interplay between strong, repulsive atomic interaction and the atom-cavity coupling, the system exhibits several phases of atoms and photons including the atomic superfluid (SF) and supersolid (SS). We investigate the dynamical behaviour of the system, where we include dissipation by means of the Lindblad master-equation formalism. Due to the discontinuous nature of the Dicke transition for strong atomic repulsion, we find a extended co-existence region of different phases. Such a co-existence, in the limit of vanishing dissipation, is further investigated from the underlying Ginzburg-Landau free energy landscape. We study the resulting, temporal switching dynamics, particularly between the coexisting SF and SS phases, which eventually become damped due to the dissipation.

Reference: Tianyi Wu, Sayak Ray and Johann Kroha, Annalen der Physik, **536**, 2300505 (2024).

Q 13.6 Mon 18:15 HS I PI

Correlation functions of the anyon-Hubbard model from Bogoliubov theory — •Binhan Tang[1], Axel Pelster[1], and Martin Bonkhoff[2] — [1]Physics Department and Research Center Optimas, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]I. Institut für Theoretische Physik, Universität Hamburg, 22607 Hamburg, Germany

Applying a modified Bogoliubov theory to the bosonic representation of the anyon-Hubbard model faithfully describes its characteristic low-energy properties. These are manifested by an asymmetric dispersion of the Bogoliubov particles, which arises due to the breaking of parity and time reversal symmetry. Furthermore, statistical interactions cause a depletion of both the condensate and the superfluid densities even in the absence of any Hubbard interaction. On the basis of this Bogoliubov theory we determine then characteristic correlation functions as, for instance, density-density correlations, which are experimentally accessible via quantum gas microscopes. In view of recent experimental progress, we re-investigate a quantity previously declared as unobservable, the anyonic quasi-momentum distribution.

Q 13.7 Mon 18:30 HS I PI

Localization/delocalization-phase transition of quantum impurities in 1D Bose gases — •Dennis Breu, Eric Vidal Marcos, Martin Will, and Michael Fleischhauer — University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

We investigate the dynamics of a single finite-mass impurity in a 1D Bose gas in a box potential using Tensor Network simulations. This algorithm makes it possible to theoretically probe Bose polarons in the regime of strong bose-bose interactions for the entire range of the Tonks parameter γ. We observe a transition between a delocalized impurity and an impurity localized at the system boundaries, as a function of Impurity-Bose interaction strength. While this transition can reasonably be predicted by a mean-field ansatz based on coupled Gross-Pitaevski-Schrödinger equations, the mean-field ansatz also suggests the existence of a self-localized polaron solution. We show that the self-localization is an artifact of the underlying decoupling approximation. This shows that even for weak bose-bose interactions, where mean-field approaches are expected to work well, Impurity-Bose correlations are important for representing the true behavior of a system. By comparing energy estimations of the phases, we also calculate the critical Bose-Bose interactions strength of the phase transition.

Q 13.8 Mon 18:45 HS I PI

Driven-dissipative fermionized topological phases of strongly interacting bosons — •Arkajyoti Maity[1], Bimalendu Deb[2], and Jan-Michael Rost[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]Indian Association for the Cultivation of Science, Kolkata

We study the optical response of a one-dimensional array of strongly nonlinear optical microcavities with alternating tunnel transmissivities, mimicking the paradigmatic Su-Schriefer Heeger model. We show that the non-equilibrium steady state of the bosonic system contains clear signatures of fermionization when the intra-cavity Kerr nonlinearity is stronger than both losses and inter-site tunnel coupling. Furthermore, changing the experimentally controllable parameters detuning and driving strength, in a topologically non-trivial phase, one can selectively excite either the bulk or edge modes or both modes, revealing interesting topological properties in a non-equilibrium system.

Q 14: Quantum Metrology and Sensing (joint session QI/Q)

Time: Monday 17:00–18:45 Location: HS VIII

Invited Talk Q 14.1 Mon 17:00 HS VIII

Precision measurement with nanoscale resolution — •Joerg Wrachtrup — University of Stuttgart, Center for Applied Quantum Technologies, 70569 Stuttgart — Max Planck Insitute for Solid State Research, Stuttgart, Germany

Solid state quantum sensors quantitatively measure a variety of parameters on nanometer length scales. In the talk I will show and discuss measurements on correlated electron materials. Recently we were e.g. measuring magnetic order in 2D twisted magnetic monolayers to uncover their Moiré periodicity of magnetization. It turns out that at specific twist angles new magnetic phases beyond the Moiré wavelength emerge which can be interpreted by a gradual modulation of anisotropy parameters. We also probe superconductivity in the 2D limit. We observe fractional vortices in two dimensional 2D NbSe2 superconductors. A close inspection reveals vortex dynamics leading to enhanced dephasing of the quantum spin probe. Our results hint at charge dynamics related to the unconventional band structure of the material.

Q 14.2 Mon 17:30 HS VIII

A comprehensive study of various optically pumped magnetometer schemes — •Marco Decker[1,2], Rafael Rothganger De Paiva[1,3], and René Reimann[1] — [1]Quantum Research Center, Technology Innovation Institute, Abu Dhabi, UAE — [2]Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau — [3]Universidade Federal do ABC, Santo Andre, Sao Paulo, Brazil

Highly precise and accurate magnetic field sensing has real-world applications in non-destructive testing [1], biomedical imaging [2], and positioning and navigation [3]. Optically pumped magnetometers (OPMs) have proven to be a highly suitable choice to meet the requirements of these applications [4]. In this work, we present a comprehensive study of various OPM schemes and evaluate their feasibility for multiple use cases.

Comparing measurement schemes from published works is challenging due to varying gas mixtures, laser setups, and shielding conditions. We systematically evaluate the free induction decay (FID), nonlinear magneto-optical rotation (NMOR), Bell-Bloom, and other setup types, tested with Cs-133 vapor for various buffer gases and coatings. After comparing sensitivity, bandwidth, and dynamic range, we assess the suitability of these schemes for different deployment scenarios.

[1] S. Youssef, Journal of Nondestructive Testing 21, 19390 (2016); [2] P. K. Mandal, Front. Comput. Neurosci. 12 (2018); [3] A. J. Canciani, AFIT, Dissertation, https://scholar.afit.edu/etd/251 (2016); [4] D. Budker and M. Romalis, Nature Physics 3, 227-234 (2007)

Q 14.3 Mon 17:45 HS VIII

Spin Quantum Magnetometry and Gradiometry: Towards clinical applications in unshielded environments — •Magnus Benke, Jixing Zhang, Michael Kübler, Yihua Wang, Anjana Karuvayalil, and Jörg Wrachtrup — 3rd Physics Institute, University of Stuttgart, Stuttgart

Highly sensitive magnetometers are an essential tool for material analysis and medical applications. The Nitrogen Vacancy (NV) centers in diamond provides a promising candidate for a quantum sensor offering high sensitivity together with an exceptional spatial resolution while operating at ambient conditions. Current comparable technology also only has a limited dynamic range which makes it susceptible to background magnetic noise outside of shielded environments. The NV sensor with its broad dynamic range does not suffer from this limitation and can be used to form a gradiometric sensor array of two or more magnetometers to cancel any background fields. This enables unshielded measurements of small magnetic fields orders of magnitude smaller than the surrounding environment.

In this work we present a DC-broadband magnetometer with improved sensitivity reaching a photon shot noise limit of sub-pT/$\sqrt{\text{Hz}}$ using a CW-ODMR (Continuous-Wave Optically Detected Magnetic Resonance) measurement scheme. With two of these highly sensitive magnetometers, we build a gradiometer and achieved a reduction of an artificial background signal by 40 times without decreasing an applied test signal. These advancements open the door to magnetic field-related clinical applications in unshielded environments.

Q 14.4 Mon 18:00 HS VIII

Enhancing NV-center magnetometer sensitivity for quantum sensing using flux concentrators — •Anjana Karuvayalil[1], Jixing Zhang[1], Michael Kübler[1], Stephan Erlhoff[2], Magnus Benke[1], Yi hua Wang[1], Pascal Schmidt[1], Andrej Denisenko[1], Cheuk Cheung[1], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, University of Stuttgart — [2]Max Planck Institute, Stuttgart

Magnetic field sensing is a critical tool in fields such as geophysics, medical science, and magnetic field mapping. Existing magnetic field sensors, including OPMs and SQUIDs, provide high sensitivity but often come with limitations such as complexity or operational constraints. This work highlights the nitrogen-vacancy (NV) center-based magnetometer for its exceptional quantum properties making it more reliable for quantum sensing. The NV-center magnetometer achieved photon shot noise-limited sensitivity in the sub-picotesla range. This sensitivity can be further enhanced by incorporating flux concentrators near the diamond. These flux concentrators, designed and optimized using high permeable materials like MnZn and Permalloy, are capable of amplifying weak magnetic fields and significantly improving the effective sensitivity of the magnetometer. They are precisely machined to integrate seamlessly into the experimental setup. Continuous-Wave Optically Detected Magnetic Resonance (CW ODMR) is employed for measurements, with results showing that the use of flux concentrators leads to a 16-fold enhancement in sensitivity. This approach helps the detection of weak biosignals from muscles, the heart, and the brain.

Q 14.5 Mon 18:15 HS VIII

Activation of metrologically useful genuine multipartite entanglement — •Róbert Trényi[1,2,3,4], Árpád Lukács[1,4,5], Paweł Horodecki[6,7], Ryszard Horodecki[6], Vértesi Tamás[8], and Géza Tóth[1,2,3,4,9] — [1]Dept. of Th. Phys., UPV/EHU, Bilbao, Spain — [2]EHU Quantum Center, UPV/EHU, Bilbao, Spain — [3]DIPC, San Sebastián, Spain — [4]HUN-REN Wigner RCP, Budapest, Hungary — [5]Dept. of Math. Sci., Durh. Univ., UK — [6]Int. Cnt. for Theory of Quant. Tech., UG, Gdansk, Poland — [7]Fac. of Appl. Phys. and Math., Nat. Quant. Inf. Cnt., GUT, Gdansk, Poland — [8]HUN-REN Inst. for Nucl. Research, Debrecen, Hungary — [9]IKERBASQUE, Bilbao, Spain

Quantum states with metrologically useful genuine multipartite entanglement (GME) outperform all states without GME in metrology. States reaching the maximal utility in metrology all belong to this convex set of quantum states. With our proposed scheme, we can identify a broad class of practically important states that possess metrologically useful GME in the case of several copies, even though in the single copy case these states can be non-useful, i.e., not more useful than separable states. Thus, we essentially activate quantum metrologically useful GME. We discuss how our findings are related to error correction. We also analyze the iterative method applied to maximize the metrological usefulness for a given quantum state. In particular, we carry out an optimization of the metrological performance over possible local Hamiltonians with a see-saw method.

Q 14.6 Mon 18:30 HS VIII

Simulators of Quantum Dissipative systems — •Durga Dasari, Jixing Zhang, and Joerg Wrachtrup — 3. Physics Institute, University of Stuttgart, Stuttgart, GERMANY

Multipartite quantum correlations play a central role in our understanding of many-body physics, as they make them classically hard to compute. This difficulty is stimulating great efforts to quantum simulate these systems, i.e. to solve their dynamics using a highly controlled quantum spin system. Quantum simulators based on large spin ensembles can massively increase the Hilbert space, as control and readout happen globally. Equally, with controlled dissipation and decoherence, they can be ideal candidates to simulate open-quantum systems which are computationally more demanding when compared to Hamiltonian systems that are currently simulated. It is now an open question to demonstrate that the control is still sufficient to show a quantum advantage in these large systems, to simulate complex quantum many-body dynamics such that classical methods are systematically outperformed. In this talk we will show how such dissipative Quantum simulators can be realized in central spin systems theoretically, and present some initial experimental studies using the dipolar-coupled NV center ensembles in diamond.

Q 15: Atom and Ion Qubits (joint session QI/Q)

Time: Monday 17:00–18:45 Location: HS II

Invited Talk Q 15.1 Mon 17:00 HS II

Trapped-ion quantum computers based on chip-integrated microwave control — •Christian Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover, Germany — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

We pursue the implementation of quantum gates using chip-integrated microwave conductors rather than the widely used laser beams for scalability, gate fidelity and chip-level integration of functionality. Previous demonstrations of this method have used a single carefully crafted two-qubit gate combined with single-qubit addressing pulses. Here we show for the first time the execution of arbitrary algorithms on a pair of qubits by implementing the cycle benchmarking protocol and thus a universal computation register. To further integrate the control of the qubits at the chip structure, we demonstrate the generation of the microwave control signals qubits using a cryogenic DDS chip that can be directly integrated with the trap chip. Recent advances in the fabrication of scalable trap structures will be presented, in particular the implementation of through-substrate vias (TSVs) and hybrid integration methods. We present two cryogenic quantum computer demonstrator setups that are currently under construction, combining the computation register with storage and preparation/readout registers and interconnected through an X-junction.

This work has been supported by the Ministry of Science and Culture of Lower Saxony through the QVLS-Q1 project, by BMBF through the “MIQRO”, “ATIQ” and “QuMIC” projects and by the EU through Millenion-SGA1.

Q 15.2 Mon 17:30 HS II

Scalable, high-fidelity all-electronic control of trapped-ion qubits — Clemens Löschnauer, Jacopo Mosca Toba, Amy Hughes, Steven King, •Marius Weber, Raghavendra Srinivas, Roland Matt, Rustin Nourshargh, David Allcock, Chris Ballance, Clemens Matthiesen, Maciej Malinowski, and Thomas Harty — Oxford Ionics, Oxford, United Kingdom

The central challenge of quantum computing is implementing high-fidelity quantum gates in a scalable fashion. Our all-electronic qubit control architecture combines laser-free gates with local tuning of electric potentials to enable site-selective single- and two-qubit operations in multi-zone quantum processors. Chip-integrated antennas deliver control fields common to all qubits, while voltages applied to local tuning electrodes adjust the position and motion of ions in each zone, thus enabling local coherent control. We experimentally implement low-noise, site-selective single- and two-qubit control in a microfabricated 7-zone ion trap, demonstrating 99.99916(7)% fidelity for single-qubit gates, and two-qubit Bell state generation with 99.97(1)% fidelity. These results validate the path to directly scaling these techniques to large-scale quantum computers based on electronically controlled trapped-ion qubits.

Q 15.3 Mon 17:45 HS II

Implementation of Quantum Token Protocol with Trapped Ions — •Manika Bhardwaj[1], Jan Thieme[1], Bernd Bauerhenne[1], Moritz Göb[1], Bo Deng[1,2], and Kilian Singer[1] — [1]Experimental Physics I, Institute of Physics, University of Kassel, Heinrich-Plett-Straße 40, 34132 Kassel — [2]Institute of Applied Physics, University of Bonn, Wegelerstraße 8, 53115 Bonn

We present a novel quantum token protocol [1] with trapped ions. This quantum token protocol is based on ensembles exploiting the quantum projection noise. Trapped ions are suitable for implementing a robust quantum token protocol due to their long coherence times and single-shot readout. Specifically, we aim to utilise the $4^2S_{1/2} - 3^2D_{5/2}$ transition of $^{40}Ca^+$ ions for this purpose. The protocol requires preparing the ions in a superposition state, where uniform state preparation across the ensemble is critical for obtaining protocol fidelity. To address potential variations in state preparation due to inhomogeneous control parameters, we will employ tailored composite pulses [2].

[1] K. Singer, C. Popov, and B. Naydenov, Verfahren zum Erstellen eines Quanten-Datentokens (DE 10 2022 107 528 A1) DE-Patent (2023).
[2] G. T. Genov, M. Hain, N. V. Vitanov, and T. Halfmann, PRA 101, 013827 (2020).

Q 15.4 Mon 18:00 HS II

Correction formulas for the Mølmer-Sørensen gate under strong driving — Susanna Kirchhoff[1,2], Frank Wilhelm-Mauch[1,2], and •Felix Motzoi[1,3] — [1]Forschungszentrum Juelich (PGI 8 and 12) — [2]Saarland University — [3]University of Cologne

The Mølmer-Sørensen gate is a widely used entangling gate for ion platforms with inherent robustness to trap heating. The gate performance is limited by coherent errors, arising from the Lamb-Dicke (LD) approximation and sideband errors. Here, we provide explicit analytical formulas for errors up to fourth order in the LD parameter, by using the Magnus expansion to match numerical precision, and overcome significant, orders-of-magnitude underestimation of errors by previous theory methods. We show that fourth order Magnus expansion terms are unavoidable, being in fact leading order in LD, and are therefore critical to include for typical experimental fidelity ranges. We show how these errors can be dramatically reduced compared to previous theory by using analytical renormalization of the drive strength, by calibration of the Lamb-Dicke parameter, and by the use of smooth pulse shaping.

arXiv:2404.17478

Q 15.5 Mon 18:15 HS II

Distributed quantum computing between two trapped-ion processors — Dougal Main, Peter Drmota, •David P. Nadlinger, Ellis M. Ainley, Ayush Agrawal, Bethan C. Nichol, Raghavendra Srinivas, Gabriel Araneda, and David M. Lucas — Dept. of Physics, University of Oxford, Oxford, U.K.

Modular, hybrid quantum systems, where matter qubits are linked via photonic interconnects, hold vast potential across a wide gamut of applications including quantum communication, large-scale computing, and quantum-enhanced metrology. In this talk, I describe an elementary two-node quantum network where $^{88}Sr^+$ acts as the optical interface to generate remote Bell pairs with state-of-the-art performance (fidelities of $\sim 97.0\%$ at rates 100 s^{-1}). By co-trapping $^{43}Ca^+$ ions, which provide a long-lived memory undisturbed by any network activity (remote Bell state coherence times >10 s), we demonstrate the first distributed quantum computation across two optically linked quantum processors using deterministic, repeatable quantum gate teleportation [1]. To illustrate the postselection-free execution of consecutive remote two-qubit gates, we benchmark distributed iSWAP- and SWAP-class circuits along with two-qubit instances of Grover's search algorithm. Finally, we examine how emitter motion impacts atom–photon entanglement generation through phase uncertainty, recoil, and coupling efficiency, proposing an intuitive framework applicable to both conventional optics and waveguide-based systems.

[1] D. Main et al., "Distributed Quantum Computing across an Optical Network Link", Nature (accepted, arXiv:2407.00835)

Q 15.6 Mon 18:30 HS II

Optimizing the circularization of Rydberg atoms — •Matthias Hüls[1,2], Robert Zeier[1], Eloisa Cuestas[1], Felix Motzoi[1,2], and Tommaso Calarco[1,2,3] — [1]Forschungszentrum Jülich GmbH, Quantum Control (PGI-8), Jülich, Germany — [2]University of Cologne, Institute for Theoretical Physics, Köln, Germany — [3]Università di Bologna, Dipartimento di Fisica e Astronomia, Bologna, Italy

Atoms in Circular Rydberg states, with a large principal quantum number n and maximal magnetic quantum number $m = n - 1$, exhibit long state lifetimes and strong, long-range interactions. This renders them a promising platform for quantum simulation and quantum sensing. Yet their preparation is complex and includes a multi-state transfer through a large Rydberg state manifold of dimension n^2 driven by the interaction with radio frequency (RF) pulses. Pulse shapes that achieve the latter with a high fidelity can be designed using optimal control techniques and have enabled a fast and precise circularization of non-interacting atoms in the experiment [1]. With the aim of constructing pulses suitable to circularize arrays of interacting Rydberg atoms, we extend this previous efforts by additional field terms and optimization methods. Further, we study how interactions between atoms affect the performance of current optimized pulses. We therefore build a simulation of the experiment and subsequently use it to optimize RF pulse shapes. [1] Larrouy A, Patsch S, Richaud R, Raimond J-M, Brune M, Koch CP, Gleyzes S. Fast navigation in a large Hilbert space using quantum optimal control. PRX.10:021058 (2020)

Q 16: Ultra-cold atoms, ions and BEC I (joint session A/Q)

Time: Monday 17:00–19:00 Location: KlHS Mathe

Invited Talk Q 16.1 Mon 17:00 KlHS Mathe

QRydDemo - A Rydberg atom quantum computer demonstrator — •Jiachen Zhao[1,2], Christopher Bounds[1,2], Christian Hölzl[1,2], Manuel Morgado[1,2], Govind Unnikrishnan[1,2], Achim Scholz[1,2], Julia Hickl[1,2], Sebastian Weber[3,2], Hans-Peter Büchler[3,2], Simone Montangero[4], Jürgen Stuhler[5], Tilman Pfau[1,2], and Florian Meinert[1,2] — [1]5th Inst. of Physics, University of Stuttgart — [2]IQST — [3]Inst. for Theoretical Physics III, University of Stuttgart — [4]Inst. for Complex Quantum Systems, University of Ulm — [5]TOPTICA Photonics AG

Quantum computing has garnered significant interest for its potential to solve computationally challenging problems. The QRydDemo project focuses on developing a quantum computer based on neutral strontium atoms individually trapped in an optical tweezer array. In our work, we implemented a novel neutral atom qubit, encoded in the magnetically insensitive metastable fine-structure states $^3P_0$ and $^3P_2$ of single Sr atoms. This encoding scheme allows for fast single-qubit gates operating on the 100 ns timescale, which is orders of magnitude faster than the optical clock qubit based on the $^1S_0 \rightarrow {}^3P_0$ transition. To achieve high-fidelity two-qubit gates via single-photon Rydberg transitions, we are investigating a triple magic trap for both the fine-structure qubit states and the Rydberg state. Furthermore, to realize this scalable quantum computer with 500 qubits, we explore an innovative tweezer architecture that enables dynamic reshuffling of qubits during quantum computation, paving the way for efficient and flexible quantum gate operations.

Q 16.2 Mon 17:30 KlHS Mathe

Circular dichroism and quantized Rabi oscillations in a synthetic quantum Hall system — •Franz Richard Huybrechts, Arif Warsi Laskar, and Martin Weitz — Institute of Applied Physics, University of Bonn

Unique physical properties and potential applications in the realm of quantum technology make topological states of matter a highly appealing scientific area. Ultracold atomic gases offer promising platforms to realize such topological states in a well-controlled experimental environment. Exploiting a synthetic dimension encoded in the internal spin degree of freedom of erbium ground state atoms and one real space dimension, we realize a synthetic quantum Hall system and probe its dissipative response to an external circular drive. In general, the dissipative response of topological systems upon circular driving is linked to the quantized Hall conductivity through a Kramers-Kronig relation. Our experiments give evidence for a circular dichroism in the loss rates of the erbium quantum Hall system for the left- and right-handed driving modes respectively. In the bulk region of our synthetic Hall ribbon a distinct Rabi oscillation between the excited and lowest Landau level is observed for only one of the driving modes. As expected, at the edge of the system neither of the drives are seemingly able to excite the system

Q 16.3 Mon 17:45 KlHS Mathe

Polaron spectroscopy of many-body systems — •Ivan Amelio — Université Libre de Bruxelles, Brussels, Belgium

When an impurity is immersed in a many-body background, it is dressed by the excitations of the bath, and forms "a polaron".

As a result, the injection spectrum of the impurity carries the hallmarks of the correlations present in the bath. This physics is relevant for excitons optically injected in a few layer heterostructure, or for cold atomic mixtures.

In this talk, we will first review the basic theoretical framework and recent experimental progress.

Then, we will theoretically analyze a few cases of correlated many-body states: the impurity injection spectra are predicted to display peculiar features, that allow to distinguish whether the bath features BCS pairing, charge density waves, topological phases, the BKT transition, etc.

Q 16.4 Mon 18:00 KlHS Mathe

Atom-ion Feshbach resonances within a spin-mixed atomic bath — •Joachim Siemund[1], Fabian Thielemann[1], Jonathan Grieshaber[1], Kilian Berger[1], Wei Wu[1], Krzysztof Jachymski[2], and Tobias Schätz[1] — [1]Physikalisches Institut, Albert-Ludwigs Universität Freiburg — [2]Faculty of Physics, University of Warsaw

Understanding quantum dynamics at the level of individual particles requires precise control over both, electronic and motional degrees of freedom. Trapped atomic ions have long been valuable in this area, though they are limited in studying collective properties. A novel approach that integrates a single ion with ultracold atoms opens up opportunities to investigate phenomena ranging from single-particle to many-body physics. In our experiment, we immerse a single $^{138}Ba^+$ ion in an ultracold gas of ^6Li atoms to investigate atom-ion Feshbach resonances. We examine how the interactions near a resonance depend on parameters such as the collision energy or the spin admixture of the bath. We compare experimentally observed three-body loss rates to predictions of an adapted two-step quantum recombination model. These results provide valuable insights into the microscopic mechanisms of dimer formation in atom-ion systems.

Q 16.5 Mon 18:15 KlHS Mathe

Engineering quantum droplet formation by cavity-induced long-range interactions — •Leon Mixa[1,2], Milan Radonjić[1,3], Axel Pelster[4], and Michael Thorwart[1,2] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Germany — [3]Institute for Physics Belgrade, University of Belgrade, Serbia — [4]Phyisics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

We investigate a dilute Bose gas with both a short-range contact and an effective long-range interaction between the atoms. The latter is induced by the strong coupling to a cavity light mode and is spatially characterized by a periodic signature and a tunable envelope rooted in the pumping of the cavity. We formulate a Bogoliubov theory which is based on a homogeneous mean-field description and quantum fluctuations around it. We find that the repulsive mean-field contact interaction could be destabilized by quantum fluctuation corrections rooting in the long-range interaction. The competition between both allows for the formation of self-bound quantum droplets. We show analytically how the size and the central density of the cavity-induced quantum droplets depend on the contact interaction strength and on the shape of the spatial envelope of the long-range interaction [arXiv:2409.20072, 2409.18215].

Q 16.6 Mon 18:30 KlHS Mathe

Rapid state preparation for a fermionic quantum simulator — •Andreas von Haaren[1,2], Robin Groth[1,2], Liyang Qiu[1,2], Janet Qesja[1,2], Luca Muscarella[1,2], Titus Franz[1,2], Timon Hilker[3,1], Immanuel Bloch[1,2,4], and Philipp Preiss[1,2] — [1]Max Planck Institute of Quantum Optics, Garching — [2]Munich Center for Quantum Science and Technology — [3]University of Strathclyde, Glasgow — [4]Ludwig Maximilian University of Munich

Reaching low temperatures in dilute atomic clouds is a pivotal step in many atomic physics experiments and reaching quantum degeneracy is often achieved by employing evaporative cooling as the final cooling stage. However, this often gives one of the main contributions to the cycle time. Here, we present progress towards preparing a degenerate Fermi gas of lithium in an optical lattice in short timescales with no or minimal time required for evaporative cooling. We improve our MOT loading rates with a Zeeman slowing beam in our transversal cooling 2D MOT. This approach will help us shorten overall cycle times to less than 2 seconds. Shorter cycle times will allow for much higher data rates in our new quantum gas microscope, which will feature two modes of operation for both analogue quantum simulation and digital fermionic quantum information processing.

Q 16.7 Mon 18:45 KlHS Mathe

Bose and Fermi Polarons in Atom - Ion Hybrid Systems — •Luis Ardila — Dipartimento di Fisica,Università di Trieste, Strada Costiera 11, I-34151 Trieste, Italy

Charged quasiparticles dressed by the low excitations of an electron gas constitute one of the fundamental pillars for understanding quantum many-body effects in some materials. Quantum simulation of quasiparticles arising from atom-ion hybrid systems may shed light on solid-state uncharted regimes. Here, we will discuss ionic polarons created as a result of charged dopants interacting with a Bose-Einstein condensate and a polarized Fermi gas. Here, we show that even in a comparatively simple setup consisting of charged impurities in a weakly interacting bosonic medium and an ideal Fermi gas with tunable atom-ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state in the bosonic case; in contrast, a molecular state appears in the Fermi case. We unravel their vastly different polaronic properties compared to neutral quantum impurities using quantum Monte Carlo simulations. Contrary to the case of neutral impurities, ionic polarons can bind many excitations, forming a nontrivial interplay between few and many-body physics, radically changing the ground-state properties of the polaron.

Q 17: Precision Spectroscopy of Atoms and Ions II (joint session A/Q)

Time: Monday 17:00–19:00 Location: HS PC

Invited Talk Q 17.1 Mon 17:00 HS PC

Precision Measurements to Test Theory at ALPHATRAP

— •Matthew Bohman[1], Fabian Heisse[1], Charlotte König[1], Ivan Kortunov[2], Jonathan Morgner[1], Victor Vogt[2], Klaus Blaum[1], Stephan Schiller[2], and Sven Sturm[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [2]Institute für Experimentalphysik, Univ. Düsseldorf, 40225, Düsseldorf

ALPHATRAP [1] is a Penning-trap apparatus located at MPIK in Heidelberg used to perform high-precision measurements of simple atomic systems. In few-electron highly charged ions, the bound electron g-factor is a highly sensitive probe of new physics and its measurement allows us to test quantum electrodynamics (QED) at extremely high fields with sub-ppb accuracy, which we have recently done with H-like, Li-like, and B-like tin [2]. However, Penning trap g-factor experiments also provide unique opportunities to perform experiments on simple molecular ions such as HD^+ and H_2^+. We have recently developed techniques to track the hyperfine and ro-vibrational state of a single HD^+ ion in the presence of external perturbations, and were able to prepare the ion in the ro-vibrational ground state and measure the hyperfine structure and bound electron g-factor to high precision [3], laying the foundation for upcoming high-precision laser spectroscopy of HD^+ that will allow us to test QED and extract fundamental constants.

[1] Sturm, S. et al. Eur. Phys. J. Spec. Top. 227, 14251491 (2019).
[2] Morgner, J., Tu, B., König, C. et al. Nature 622, 5357 (2023).
[3] C. König, F. Heiße, J. Morgner, *et al.* In preparation.

Q 17.2 Mon 17:30 HS PC

The Cryogenic Ion Trap Experiment for Laser Excitation of $^{229}Th^{3+}$ at LMU

— •Markus Wiesinger, Kevin Scharl, Georg Holthoff, Tamila Teschler, Mahmood I. Hussain, and Peter G. Thirolf — Ludwig-Maximilians-Universität München

The isomeric first excited state in ^{229}Th with an excitation energy of only about 8.356 eV provides a unique opportunity for the development of an optical clock based on a nuclear transition – a nuclear clock. Attractive properties such as insensitivity to environmental conditions and long lifetime promise to enable new applications in fundamental physics, precision metrology, and geodesy.

At LMU work is ongoing towards the realization of a lifetime measurement of the isomeric state, and VUV spectroscopy of the nuclear transition in trapped $^{229}Th^{3+}$ ions. To this end, a cryogenic ion trap has been set up and commissioned. As a prerequisite, nuclear state readout based on optical hyperfine spectroscopy of trapped Th^{3+} ions is currently being prepared.

In this talk we will focus on the experimental setup of the cryogenic ion trap: We will discuss our ion sources and ion loading procedures. We will show sympathetic laser cooling of $^{229}Th^{3+}$ by Doppler-cooled $^{88}Sr^+$ ions and the formation of mixed-species Coulomb crystals. The use of a radioactive ^{233}U source will allow to conduct experiments not only with ^{229}Th in the ground state, but also in the isomeric excited state (populated in 2% of the decays) – enabling a lifetime measurement without preceding laser excitation of the nuclear transition.

We acknowledge support by ERC (856415) and BaCaTec (7-2019-2).

Q 17.3 Mon 17:45 HS PC

Quantum Logic Control of Complex Systems

— •Till Rehmert[1,2], Maximilian J. Zawierucha[1,2], Kai Dietze[1,2], Piet O. Schmidt[1,2], and Fabian Wolf[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Leibniz Universität Hannover

Extending quantum control to increasingly complex systems is crucial for advancing quantum technologies and fundamental physics. Molecules, for instance, offer a rich level structure, permanent dipole moments, and large internal electric fields, making them exceptionally suitable for quantum applications. However, their additional degrees of freedom necessitate sophisticated techniques for cooling, optical pumping, and precise state detection. In trapped ion systems, quantum logic techniques that combine a well-controlled logic ion species with a more complex spectroscopy ion have emerged as powerful tools to overcome these challenges. Using a calcium ion as the logic ion and a co-trapped titanium ion, we have developed schemes for state detection and coherent manipulation of the spectroscopy ion through a far-detuned Raman laser setup. Our results demonstrate the coherent control of different Zeeman manifolds within the a^4F ground state of the titanium ion and include precise measurements of the corresponding Landé g-factors. The universal applicability of the Raman laser approach facilitates the transfer of these methods to other qudit systems, such as molecules, all aiming for high-precision spectroscopy. By enhancing the control in these systems, our work paves the way for novel applications in quantum technology and fundamental physics research by making an entire new class of ions accessible to spectroscopy.

Q 17.4 Mon 18:00 HS PC

Neural-network approach to large atomic structure computations with pCI and other atomic codes

— •Pavlo Bilous[1], Charles Cheung[2], and Marianna Safronova[2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Department of Physics and Astronomy, University of Delaware, Delaware 19716, USA

Atomic structure computations deliver information on atomic properties crucial for applications including atomic frequency standards and analysis of astrophysical spectra. The increasing precision demands lead often to prohibitively large sets of electronic configurations which need to be included in the configuration interaction (CI) framework for accurate modeling of electronic correlations. This necessitates development of efficient configuration selection methods, as well as their integration with existing high-performance atomic codes.

We present a neural-network (NN) approach for efficient selection of electronic configurations integrated with the established pCI atomic codes [1]. The method is applied to otherwise prohibitively large CI computations for the Fe^{16+} and Ni^{12+} energy levels and verified within a few cm^{-1} with an alternative approach of basis upscaling without NN. Our implementation of the NN-supported algorithm allows for integration with other atomic codes providing an efficient and novel tool for a broader atomic physics community.

[1] P. Bilous, C. Cheung, and M. Safronova, Phys. Rev. A 110, 042818 (2024).

Q 17.5 Mon 18:15 HS PC

Hyper-EBIT: The development of a source for very highly charged ions

— •Luca Yannik Geissler, Matthew Bohman, Athulya Kulangara Thottungal George, Fabian Heisse, Charlotte Maria König, Jonathan Morgner, José Ramon Crespo López-Urrutia, Klaus Blaum, and Sven Sturm — Max-Planck-Institut für Kernphysik, 69117 Heidelberg

Quantum electrodynamics (QED) is considered to be the most successful quantum field theory in the Standard Model. Its most precise test is conducted via the comparison of QED calculations with the measurement of the free electron g-factor. However, this test is restricted to low electrical field strengths. Consequently, it is of utmost importance to perform similar tests at high field strengths.

Such tests can be performed using highly charged ions (HCI). Here, only a few or even a single one of the innermost electrons are left, experiencing the strong field originating from the nucleus. The ALPHATRAP experiment is a cryogenic Penning-trap experiment, which is dedicated to perform precision measurements of the HCI's bound-electron magnetic moments.

Recently, we have measured the bound-electron g factor of hydrogen-like tin with ALPHATRAP to sub parts-per-billion precision. Our goal is to further advance such tests towards the heaviest HCIs such as $^{208}Pb^{81+}$. For the production of $^{208}Pb^{81+}$ an electron beam ion trap, Hyper-EBIT, is being constructed at the MPIK with planned beam energies of 300 keV and up to 500 mA beam currents. This contribution presents the recent developments of the Hyper-EBIT.

Q 17.6 Mon 18:30 HS PC

Laser spectroscopy of the hyperfine structure of sympathetically cooled $^{229}Th^{3+}$ ions

— •Gregor Zitzer, Johannes Tiedau, Maksim Okhapkin, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, Braunschweig

The isotope ^{229}Th has a low-lying isomeric state at only about 8.4 eV which enables resonant laser excitation. Future versions of optical clocks are planned to use this special property. For an improved understanding of the nuclear structural changes underlying the low-energy transition, knowledge of the nuclear moments of the ground and isomeric state is required. The hyperfine structure of $^{229}Th^{3+}$ ions in the nuclear ground state are investigated via laser spectroscopy on $^{88}Sr^{+}$ sympathetically cooled ions confined in a linear Paul trap. The relative isotope shift to $^{230}Th^{3+}$ and the hyperfine constants for the magnetic dipole (A) and electric quadrupole (B) for the $5F_{5/2}$ and $6D_{5/2}$ electronic states are determined. The new values reduce the uncertainties of previous measurements.

Q 17.7 Mon 18:45 HS PC

Fiber-Based Phase Noise Cancellation for Links in Networks of Optical Clocks — •Jonas Kankel[1,2], Luis Hellmich[1,2], Steven Worm[1,2], Ullrich Schwanke[2], Lakshmi Kozhiparambil[1,3], Yang Yang[1,3], and Cigdem Issever[1,2] — [1]DESY (Deutsches Elektronen-Synchrotron), Zeuthen, Germany — [2]Platanenallee 6 — [3]Max-Planck-Institut für Kernphysik Heidelberg, Germany

Modern optical atomic clocks, with fractional uncertainties on the order of 10^{-19}, enable the exploration of fundamental physics, such as the temporal variation of fundamental constants and constraints on dark matter models. The fine-structure constant α, predicted to vary in many theories of new physics, can be probed using atomic clocks due to the sensitivity of clock transitions to changes in α.

We aim to build a highly-charged ion (HCI) clock in order to set new limits on variations of α and translate these measurements into bounds on ultra-light scalar dark matter models. Initially, we will compare our HCI clock to a local Sr-lattice clock. In anticipation of comparing clocks not only across one institute but in national or international networks, long-distance transmission of ultra-stable frequency references is required, typically through fiber optic cables. Reference signals are degraded by phase noise from environmental factors like temperature fluctuations and vibrations. We are investigating a fiber-based variant of a Michelson interferometer for active phase noise cancellation in a phase-locked loop scheme.

Q 18: Strong-Field and Ultrafast Phenomena (joint session Q/MO)

Time: Tuesday 11:00–12:45 Location: HS V

Invited Talk Q 18.1 Tue 11:00 HS V

Strong-field physics and nonlinear optical phenomena in two-dimensional honeycomb materials — •Anna Galler — Institute of Theoretical and Computational Physics, TU Graz, Austria

Strong-field physics and extreme nonlinear optical processes in solids have emerged as powerful tools for ultrafast spectroscopy of electron dynamics. Ultrashort intense laser pulses have also been used to control and probe the valley pseudospin in two-dimensional honeycomb materials like transition-metal dichalcogenides. These phenomena are governed by the material-specific electronic structure and the nature of light-matter interaction. In this talk, I will present how ab-initio calculations can provide insights into these processes. Specifically, I will explore the role of the Floquet light-driven electronic structure in nonlinear optical phenomena and demonstrate how valley polarization and photocurrents in monolayer hexagonal boron nitride can be controlled using elliptically polarized, ultrashort laser pulses. Additionally, I will address high-harmonic generation (HHG) in two-dimensional materials, focusing on how interference effects from HHG emissions at distinct k-points in the Brillouin zone explain spectral features like peak splitting in monolayer WS_2. Finally, I will compare these simulation results with experimental observations to highlight the predictive power of our theoretical approach.

Q 18.2 Tue 11:30 HS V

What does extreme nonlinear optics tell about black holes? — •Lorenzo M. Procopio[1,2], Raul Aguero-Santacruz[3], David Bermudez[3], and Lorenzo Procopio[2] — [1]Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [2]Department of Physics of Complex Systems, Weizmann Institute of Science, Rehovot 761001, Israel — [3]Department of Physics, Cinvestav, A.P. 14-740, 07000 Ciudad de Mexico, Mexico

In 1974, Hawking predicted that black holes should emit radiation. Seven years later, Unruh showed a mathematical analogy of the Hawking effect with sound waves in a fluid flow. Since then, several systems have emerged to demonstrate experimentally Hawking's predictions. Extreme nonlinear optics is a promising platform to study analog event horizons in photonic crystal fibers, where the event horizon is created with near-single-cycle light pulses. We experimentally studied the backreaction of Hawking radiation and present a more complete description of the Hawking process in fiber-optical analogues. For astrophysical black holes, this process would correspond to the mechanism of how Hawking radiation is made at the event horizon, how quanta of gravity produce quanta of radiation. In astrophysics, such a process is elusive and unknown, in extreme nonlinear fiber optics we believe to have observed it.

Q 18.3 Tue 11:45 HS V

Photocurrent control in a light-dressed Floquet topological insulator — •Weizhe Li[1], Daniel Lesko[1], Tobias Weitz[1], Simon Wittigschlager[1], Christian Heide[1,2], Ofer Neufeld[3], and Peter Hommelhoff[1,4] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Stanford PULSE Institute, SLAC National Accelerator Laboratory, Menlo Park, CA, USA — [3]Schulich Faculty of Chemistry, Technion - Israel Institute of Technology, Haifa, Israel — [4]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

Light-dressed materials, based on Floquet engineering, offers unique opportunities to design transient band structures. Most commonly, circularly-polarized dressing light can generate topologically nontrivial nonequilibrium states known as Floquet topological insulators (FTIs) which host a variety of topological phenomena. Floquet engineering with strong optical fields opens routes to optically tunable band structures and devices for petahertz electronics.

Here we demonstrate coherent control of photocurrents in light-dressed graphene. Circularly-polarized laser pulses dress the graphene into an FTI, and phase-locked second harmonic pulses drive electrons in the FTI. We map the resulting dynamics onto two-color phase dependent photocurrents. This approach allows us to measure all-optical anomalous Hall currents and photocurrent circular dichroism. Furthermore, we map out the attosecond Floquet phase by varying the two-color phase. The coherent control of photocurrents in graphene-based FTI connects optics tools to condensed matter physics.

Q 18.4 Tue 12:00 HS V

Strong-field electron dynamics in non-classical light after photoemission from nanometric needle tips — •Jonathan Pölloth[1], Jonas Heimerl[1], Andrei Rasputnyi[2], Stefan Meier[1], Maria Chekhova[1,2], and Peter Hommelhoff[1,2,3] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), 91058 Erlangen — [3]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

In the past, strong-field physics and quantum optics were two seemingly unrelated fields of research. However, in recent years, the development of intense non-classical light sources such as bright squeezed vacuum (BSV) has made it possible to connect these topics and to explore nonlinear interaction processes between intense quantum light and matter. Recent theoretical [1] and experimental [2] studies investigate the influence of the quantum state of light on strong-field processes such as high harmonic generation. For the case of nonlinear electron photoemission from needle tips, it was shown that the electrons inherit the number statistics of the driving light state [3]. Here, we will present the first measurements of strong-field electron energy spectra for photoemission from nanometric needle tips driven by BSV and explain them based on the theoretical frameworks.

[1] A. Gorlach *et al.*, Nat. Phys. **19**, 1689-1696 (2023)
[2] A. Rasputnyi *et al.*, Nat. Phys. (2024)
[3] J. Heimerl *et al.*, Nat. Phys. **20**, 945-950 (2024)

Q 18.5 Tue 12:15 HS V

Ultrafast photoemission from gold tips in the intermediate regime — •Leon Brückner[1], Jonas Heimerl[1], Stefan Meier[1], Philip Dienstbier[1], Constantin Nauk[1,2], and Peter Hommelhoff[1,3] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

— [2]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [3]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

The intermediate regime in photoemission, corresponding to a Keldysh parameter γ around 1-3, lies in between the extreme cases of multiphoton and the quasi-static tunneling emission. This regime shows characteristic features, namely a smooth decrease in the nonlinearity of the emission process as well as the appearance of channel closings. In strong-field experiments at sharp metal needle tips, this picture becomes more complex due to the possible influence of space-charge effects arising from the large number of emitted electrons. We investigate the emitted current from an array of sharp gold tips illuminated with 25 fs laser pulses. Through comparison with time-dependent Schrödinger equation (TDSE) calculations, we identify characteristic intensity-dependent changes in the rate scaling and discuss the influence of space-charge effects.

Q 18.6 Tue 12:30 HS V

Recent advances in splitting and coherent beam recombining of femtosecond beams/pulses using optical vortex lattices — •Lyubomir Stoyanov[1], Yinyu Zhang[2,3], Alexander Dreischuh[1], and Gerhard Paulus[2,3] — [1]Department of Quantum electronics, Faculty of Physics, Sofia University — [2]Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena — [3]Helmholtz Institute Jena

In this work, we will present our recent advances in addressing spectral broadening and temporal compression of high-energy femtosecond pulses by the controllable splitting and coherent beam recombining of such beams/pulses using optical vortex lattices. This controllable and reversible beam reshaping technique known from singular optics is the key feature in this approach. Using fused silica vortex phase plates, etched with square-shaped optical vortex lattices we achieved an experimental realization of controllable beam splitting of intense femtosecond beams/pulses, followed by nonlinear spectral broadening (both in ambient air and fused silica substrate) and a final coherent beam recombination. Moreover, the compression in time of the spectrally broadened pulses down to the Fourier transform limit is demonstrated as well. In our view, the results confirm the feasibility of the proposed idea and provide strong motivation for further optimization and investigation serving as potential alternative to the established methods for coherent beam recombining.

Q 19: Quantum Networks, Repeaters, and QKD II (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: AP-HS

Q 19.1 Tue 11:00 AP-HS

Standalone mobile quantum memory system — •Martin Jutisz[1], Alexander Erl[2,3], Janik Wolters[2,3], Mustafa Gündoğan[1], and Markus Krutzik[1,4] — [1]Humboldt-Universität zu Berlin and IRIS Adlershof, Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany — [3]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany — [4]Ferdinand-Braun-Institut (FBH), Berlin, Germany

Quantum memories (QMs) are central to many applications in quantum information science. As a necessary element of quantum repeaters, these devices should be able to operate in non-laboratory environments, and as such their future deployment in space could advance global quantum communication networks [1]. In this context, warm-vapor QMs are particularly promising due to their low complexity and low size, weight and power.

We will present the implementation and performance analysis of a portable rack-mounted standalone warm vapor quantum memory system [2]. The optical memory is based on hyperfine ground states of Cesium which are connected to an excited state via the D_1 line at 895 nm in a lambda-configuration. The memory is operated with weak coherent pulses containing on average < 1 photons per pulse. The long-term stability of the memory efficiency and storage fidelity is demonstrated over a period of 28 hours together with operation in a non-laboratory environment.

[1] M. Gündoğan et al., npj Quantum Information 7, 128 (2021)
[2] M. Jutisz et al., arXiv:2410.21209 (2024)

Q 19.2 Tue 11:15 AP-HS

On-demand storage of single quantum-dot photons in a warm-vapour quantum memory — •Norman Vincenz Ewald[1,2,3], Benjamin Maass[1,3], Avijit Barua[3], Elizabeth Robertson[1], Kartik Gaur[3], Suk In Park[4], Sven Rodt[3], Jin-Dong Song[4], Stephan Reitzenstein[3], and Janik Wolters[1,3] — [1]DLR, Institute of Optical Sensor Systems, Berlin — [2]PTB, FB 8.2 Biosignals, Berlin — [3]TU Berlin — [4]KIST, Seoul, Republic of Korea

On-demand storage and retrieval of quantum information in coherent light–matter interfaces is key to optical quantum communication. Warm-alkali-vapour memories offer scalable and robust high-bandwidth storage at high repetition rates which makes them a natural fit for interfaces with solid-state single-photon sources. Recently, we deterministically stored and retrieved single photons from an InGaAs quantum dot after a storage time of 17(2) ns [1], an order of magnitude longer than previously reported [2]. Electro-optical laser pulse control allows for variable retrieval times from our ladder-type quantum memory that operates on the Cs D1 line at 895 nm [3]. Employing weak coherent pulses with 0.06(2) photons per pulse, we achieve an internal memory efficiency of $\eta_{\text{int}} = 15(1)\%$, a $1/e$-storage time of $\tau_{\text{s}} \approx 32$ ns, and a high SNR of 830(80). The memory's wide spectral acceptance window of 560(60) MHz enables storage of broadband photons from sources prone to spectral diffusion and frequency drifts.

[1] Manuscript under peer review. [2] S.E. Thomas et al., *Sci. Adv.* **10**, eadi7346 (2024). [3] B. Maaß, N.V. Ewald, A. Barua, S. Reitzenstein, and J. Wolters, *Phys. Rev. Appl.* **22**, 044050 (2024).

Q 19.3 Tue 11:30 AP-HS

All-optical control and readout of individual ^{167}Er nuclear spin qubits — Alexander Ulanowski, •Fabian Salamon, Johannes Früh, Adrian Holzäpfel, and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

Nuclear spins in solids exhibit exceptional coherence times and their coupling to nearby electron spins can enable optical interfacing [1]. In this work, we focus on the nuclear spin of ^{167}Er dopants, which feature an optical transition within the low-loss wavelength window of optical fibers. Using a high-finesse cryogenic Fabry-Perot cavity [2], we achieve all-optical control and readout of individual ^{167}Er dopants in a thin yttrium orthosilicate crystal. In our experiment we demonstrate a single-shot readout fidelity of 92(1)% and a hyperfine coherence time exceeding 0.2 s under dynamical decoupling. This makes our system well-suited for spin-photon entanglement, an important step towards developing long-range, fiber-based quantum networks and quantum repeaters.

[1] M. Zhong, M. Hedges, R. Ahlefeldt et al., Nature 517, 177-180 (2015).
[2] A. Ulanowski, J. Früh, F. Salamon, A. Holzäpfel & A. Reiserer, Adv. Optical Mater., 12, 2302897 (2024).

Q 19.4 Tue 11:45 AP-HS

Single-Shot Readout and Coherent Control of a GeV-^{13}C System for a Multi-Qubit Quantum Repeater Node — •Prithvi Gundlapalli[1], Katharina Senkalla[1], Philipp J. Vetter[1], Nick Grimm[1], Jurek Frey[2,3], Tommaso Calarco[4,5,6], Genko Genov[1], Matthias M. Müller[4], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [2]Peter Grünberg Institute-Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany — [3]Theoretical Physics, Saarland University, D-66123 Saarbrücken, Germany — [4]Peter Grünberg Institute-Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany — [5]Institute for Theoretical Physics, University of Cologne, D-50937 Germany — [6]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Quantum repeater nodes with efficient spin-photon interfaces and long-lived quantum memories are key to enabling practical quantum networks. We present our results on high-fidelity single-shot readout exceeding 90 % on the germanium-vacancy center in diamond and discuss the implementation of a real-time 'blink check' to improve the fidelity. We further present the efficient characterization of a proximal ^{13}C using pulsed optically detected magnetic resonance and correlation spectroscopy and discuss optimization of its coherent control. Leveraging the long coherence times exceeding 20 ms and 2.5 s of the germanium-vacancy and ^{13}C respectively, this work highlights the potential of this system as an efficient multi-qubit quantum repeater node.

Q 19.5 Tue 12:00 AP-HS

Simulation of a heterogeneous quantum network using NetSquid — •Daniel Ventker, Ann-Kathrin Müller, and Florian Elsen — Chair for Laser Technology, RWTH Aachen University

As the relevance of advancing quantum computers continues to grow, so does the need to establish quantum channels between various laboratories to create quantum networks. A quantum internet should be capable of connecting multiple types of qubit platforms, e.g. allowing the use of separate computing and storage nodes or the readout of distinct quantum sensors within the network. The fundamental resource required for such a network is entanglement shared among spatially separated nodes. One way to entangle states over larger distances is through Bell state measurements. In this process, locally entangled photons are emitted from individual nodes to interfere at a central midpoint. This in turn creates entanglement, that transfers over to the respective nodes.

The design of experimental implementations of heterogeneous networks is a complex task. The optimal working point is determined by the characteristics and performance of each individual component. For this reason, a simulation based on the Python package "NetSquid" is developed to combine the theoretical model with the parameters of real components. The goal is to analyze how each of the components influences the overall system and what needs to be considered when designing a new setup. Specifically, this work addresses a heterogeneous connection between an NV-center and a quantum dot, focusing on the system's behavior concerning a quantum frequency converter.

Q 19.6 Tue 12:15 AP-HS

Outlining the design for the receiver module for a scalable free-space quantum network — •Karabee Batta[1,2], Michael Steinberger[1,2], Moritz Birkhold[1,2], Adomas Baliuka[1,2], Harald Weinfurter[1,2,3], and Lukas Knips[1,2,3] — [1]Ludwig Maximilian University (LMU), Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max Planck Institute of Quantum Optics (MPQ), Garching, Germany

QKD leverages principles of quantum mechanics to generate encryption keys that are resistant to eavesdropping. Here, we present the design for a modular receiver unit to establish secure quantum links for polarization-encoded quantum states for ground-based and low-earth orbit satellite systems. The receiver addresses key challenges, such as polarization drift and spatial mode mismatch, which are critical for maintaining high-fidelity quantum links. It does so by employing automated polarization-compensation mechanisms and spatial filtering to avoid dedicated QKD attacks. A key application of this will be communication with the QUBE-II satellite.

Q 19.7 Tue 12:30 AP-HS

Optical single-shot readout of spin qubits in silicon — •Jakob Pforr, Andreas Gritsch, Alexander Ulanowski, Stephan Rinner, Johannes Früh, Florian Burger, Jonas Schmitt, Kilian Sandholzer, Adrian Holzäpfel, and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

Individual erbium emitters are a promising hardware platform for quantum networks as their coherent optical transitions exhibit low loss in optical fibers. Using silicon as a host crystal for erbium allows for scalable fabrication using established processes of the semiconductor industry [1]. To address single dopants, we integrate them into nanophotonic resonators with high $Q \sim 10^5$ and small $V \sim \lambda^3$, thus reducing their lifetime by more than a factor of 60 via the Purcell effect [2]. We then optically initialize the spin, implement high-fidelity optical single-shot readout and realize coherent control of the spin with microwaves [3]. These advances constitute a major step towards quantum information processing with Er:Si. We will further present our measurements of the coherence of photons emitted by individual dopants, which paves the way towards the generation of remote entanglement.

[1] Rinner et. al., Nanophotonics 12(17): 3455-3462, 2023.
[2] Gritsch et. al., Optica 10: 783-789, 2023.
[3] Gritsch et. al., arXiv: 2405.05351, 2024.

Q 19.8 Tue 12:45 AP-HS

Tomography of a Rb-87 Quantum Memory — •Yiru Zhou[1,2], Florian Fertig[1,2], Pooja Malik[1,2], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Neutral atoms with long coherence times are a promising platform for future quantum networks. While recent advances have significantly improved the coherence time of neutral atom quantum memories [1], a deeper understanding of the dynamics of the entangled states remains crucial for further optimization.

In this talk, we present an Rb-87 neutral atom quantum memory that uses magnetically less sensitive atomic qubits, $\{|F=1, m_F=-1>, |F=2, m_F=+1>\}$ or $\{|F=1, m_F=+1>, |F=2, m_F=-1>\}$, as the basis for quantum memory. To investigate the dynamics of quantum states stored in this memory in detail, we perform a series of overcomplete Pauli tomography measurements and reconstruct the density matrices of entangled state. These measurements enable us to analyze the impact of various experimental improvements on the fidelity of the entangled state, providing detailed insights into the evolution of the coherence and dephasing processes.

[1] Y. Zhou et al., PRX Quantum 5, 020307 (2024)

Q 20: Atom & Ion Clocks and Metrology I

Time: Tuesday 11:00–12:45 Location: HS Botanik

Invited Talk Q 20.1 Tue 11:00 HS Botanik

Towards quantum logic inspired techniques for high-precision measurements in Penning traps — •Juan Manuel Cornejo[1], Jan Schaper[1], Nikita Poljakov[1], Julia-Aileen Coenders[1], Stefan Ulmer[2,3], and Christian Ospelkaus[1,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Ulmer Fundamental Symmetries Laboratory, RIKEN, Japan — [3]Heinrich-Heine-Universität Düsseldorf, Germany — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

High-precision experiments in Penning traps have provided the most stringent tests of CPT invariance in the baryonic sector through (anti-)proton q/m ratio and g-factor measurements [1,2]. Within the BASE collaboration [3], we aim to develop quantum logic cooling and detection techniques to enable full motional control over single ions, reducing systematic errors and overall measuring time in (anti-)proton g-factor experiments [4]. In this contribution, we discuss the experimental procedure for implementing these techniques employing a single laser-cooled $^9Be^+$ ion as both a "cooling" and "detection" ion. Furthermore, our recent findings on the manipulation of single $^9Be^+$ ions in our cryogenic multi-Penning trap stack will be presented.

[1] C. Smorra *et. al.*, Nature **550**, 371-374 (2017).
[2] M. J. Borchert *et. al.*, Nature **601**, 53-57 (2022).
[3] C. Smorra *et. al.*, Eur. Phys. J. Special Topics **224**, 3055 (2015).
[4] J. M. Cornejo *et. al.*, New J. Phys. **23**, 073045 (2021).

Q 20.2 Tue 11:30 HS Botanik

Exploring the hyperfine structure of the $D_{5/2}$ state of $^{173}Yb^+$ — •Ikbal Biswas[1], Jialiang Yu[1], Anand Prakash[1], Elena Jordan[1], and Tanja Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

The ytterbium ion (Yb^+) is highly interesting for precision spectroscopy, as it has three clock transitions: two electric quadrupole (E2) and an electric octupole (E3) transition. In addition, it has some unique properties like high sensitivity to the variation of the fine structure constant, high angular momentum of the $F_{7/2}$ state with a lifetime of 1.6 years, which makes Yb^+ an ideal candidate for tests of fundamental physics such as the test of local Lorentz invariance, the search for the new Boson, etc.

In order to improve the stability of clock operation with multiple ions, it is challenging to simultaneously excite the ions in a Coulomb crystal on a transition with the strong AC Stark shift. In that sense, compared to the other isotopes, $^{173}Yb^+$ is an interesting candidate for multi-ion clock operation and tests of fundamental physics due to the predicted hyperfine quenching (and thus a reduced AC Stark shift). Due to its large nuclear spin, precision spectroscopy of this new isotope gives insight of nuclear spin interaction. Both the energy levels and the hyperfine structure of $^{173}Yb^+$ have not yet been explored. In this work, we present the first measurement of the hyperfine structure of the $D_{5/2}$ clock state and the coefficient of the hyperfine interaction by interrogating the E2 transition at 411 nm.

Q 20.3 Tue 11:45 HS Botanik

Clock comparisons with an aluminium ion clock at the 10^{-17} level — •Fabian Dawel[1,2], Derwell Drapier[1], Lennart Pelzer[1], Vincent Barbé[1], Kai Dietze[1,2], Marek Hild[1,2], Johannes Kramer[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

The SI second is defined by a hyperfine transition in caesium. Currently it is discussed to redefine the second using optical frequency standards with lower statistical and systematic uncertainty. One criterion for the redefinition is the agreement of measured frequency ratios from different institutes at a level of $< 5 \times 10^{-18}$, to validate the frequency uncertainty budgets. Here, we present frequency ratio measurements of an aluminium ion clock. For the measurement we use a Ramsey interrogation time of 300 ms, while simultaneous sympathetically cooling via a co-trapped calcium ion. Electromagnetic transparency (EIT) cooling cools all six motional modes close to the motional ground state and keeps the time dilation shift independent from the probe time. Using EIT cooling during interrogation induces a light shift on the clock transition. With calcium as a sensor, we can measure the electric field of the cooling lasers and evaluate the systematic frequency uncertainty of the aluminium ion. We compared our clock against a ^{87}Sr lattice clock and a $^{171}Yb^+$ ion clock and measure the ratios.

Q 20.4 Tue 12:00 HS Botanik

Integrated Photonic AlN-Based High-Bandwidth Phase Modulator for Precision Control in Yb+ Ion Experiments — •Suat Icli[1,2], Rangana Banerjee Chaudhuri[1], Elena Jordan[1], Fatemeh Salahshoori[1], and Tanja E. Mehlstäubler[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [3]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

This work introduces an aluminum nitride (AlN)-based phase modulator designed for precision control in ytterbium ion trapping experiments, which require modulation across a range of wavelengths from UV to IR and frequencies from hundreds of MHz to GHz. Such devices are critical in atomic physics for achieving fine control over laser frequency and phase, directly impacting ion cooling and state preparation. The photonic AlN phase modulator achieves an electrical bandwidth from low frequencies up to 40 GHz, with low S21 (-2 dB) and S11 (-18 dB) ensuring efficient modulation over the bandwidth. At a wavelength of e.g. 411 nm the voltage-length product of 178 V.cm leads to a modulation index of 0.018*U where U is applied voltage. This highlights the suitability of the AlN platform for efficient integrated modulators. The platform offers scalable photonic components for atomic physics, establishing a versatile foundation for next-generation quantum research and technology development.

Q 20.5 Tue 12:15 HS Botanik

Recent advances of PTB's transportable Al^+ ion clock — •Constantin Nauk[1,2], Joost Hinrichs[1,2], Gayatri Sasidharan[1,2], Vanessa Galbierz[1], Benjamin Kraus[1], Sofia Herbers[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks demonstrate exceptional fractional systematic and statistical frequency uncertainties on the order of 10^{-18}, opening the door to novel applications. In particular, transportable clocks enable applications in relativistic geodesy, e.g. height measurements at the cm level or dynamic Earth monitoring, which require highly robust and reliable hardware.

We present a transportable clock setup based on the $^1S_0 \rightarrow {}^3P_0$ transition in $^{27}Al^+$, utilizing a co-trapped $^{40}Ca^+$ ion to enable state detection and cooling through quantum logic spectroscopy and sympathetic cooling. The physics package is fully integrated in commercial 19" racks and comprises an ion trap in an aluminum/titanium composite vacuum system. We detail the optimization of ion loading efficiency, Doppler cooling, and micromotion compensation. Additionally, we show characterization measurements, including trap temperatures, secular motion, and ion swap rates. Finally, we demonstrate coherent manipulation on the $S_{1/2} \rightarrow D_{5/2}$ transition in $^{40}Ca^+$, required for quantum logic spectroscopy.

Q 20.6 Tue 12:30 HS Botanik

Photon recoil spectroscopy enhanced by squeezing and statistical tests. — •Ivan Vybornyi and Klemens Hammerer — Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

In photon recoil spectroscopy, internal transitions of atoms or molecules are identified from the recoil and the resulting motional displacement caused by an applied light field of variable frequency. A notable example of this "needle in a haystack" problem is the search for narrow clock transitions in highly charged ions, as recently discussed in [Phys. Rev. Applied 22, 054059]. A key challenge is to increase the scan speed over a frequency bandwidth by enhancing the sensitivity of displacement detection. In this work, we explore two complementary improvements: the use of squeezed motional states and optimal statistical postprocessing of data within a hypothesis testing framework. We demonstrate that each method independently provides a substantial boost to scan speed, while their combination effectively mitigates state preparation and measurement errors, fully leveraging the quantum enhancement offered by squeezing.

Q 21: Quantum Optomechanics II

Time: Tuesday 11:00–13:00 Location: HS I

Q 21.1 Tue 11:00 HS I

Numerical modelling of particle behaviours in optical tweezers outside paraxial approximation — •Tobias Hanke[1,2], Moosung Lee[1,2], Sara Launer[1,2], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany; — [2]Center for Integrated Quantum Science and Technology, University of Stuttgart, 70569 Stuttgart, Germany;

Optically levitated nanoparticles have gained interest as valuable platforms for various applications in precision sensing and quantum-limited experiments. Accurately predicting the dynamics of an optically trapped nanoparticle is crucial for understanding the system. However, conventional methods of modelling the optical tweezers light rely on paraxial approximations, hindering precise characterization of dynamics. Here, we present a numerical modelling method of an optical tweezer field for predicting the dynamics of an optically trapped nanoparticle. Compared to the conventional paraxial approximation, we experimentally show that our numerical model based on the vectorial angular spectrum method demonstrates better prediction of three-dimensional trapping frequencies of optically trapped silica nanoparticles. Using our model, we also provide the predicted trap parameters relevant for future optomechanical applications, including the scattering power and the recoil heating rate.

Q 21.2 Tue 11:15 HS I

Cavity optomechanics with polymer-based multi-membrane structures — •Lukas Tenbrake[1], Sebastian Hofferberth[1], Stefan Linden[2], and Hannes Pfeifer[3] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Physics, University of Bonn, Germany — [3]Department of Microtechnology and Nanoscience, Chalmers University of Technology, Gothenburg, Sweden

Despite their application in multiple fields, ranging from quantum sensing to fundamental tests of quantum mechanics, conventional state-of-the-art cavity optomechanical experiments have been limited in their scaling towards systems with multiple mechanical resonators. 3D direct laser writing offers a new approach to fabricating multi-membrane structures that can be directly integrated into fiber Fabry-Perot cavities. Here, we experimentally demonstrate direct laser-written stacks of two or more coupled membranes – with normal-mode splittings of up to a MHz – interfaced by fiber cavities. We present finite element simulations for the optimization of the mechanical coupling and investigate the collective optomechanical coupling of multi-membrane stacks (with single-membrane vacuum optomechanical coupling strengths of $\gtrsim 30\,\mathrm{kHz}$). We present our first experimental results and give an outlook on the scalability of the system to an even larger number of coupled mechanical oscillators. Aside from tests of fundamental properties of multimode optomechanical systems, applications for sensing or routing of vibration in acoustic metamaterials and circuits are envisaged.

Q 21.3 Tue 11:30 HS I

Quantum optical binding of nanoscale particles — •Henning Rudolph[1], Uros Delic[2], Klaus Hornberger[1], and Benjamin Stickler[3] — [1]University of Duisburg-Essen, Faculty of Physics, Lotharstraße 1, 47057 Duisburg, Germany — [2]University of Vienna, Faculty of Physics, Boltzmanngasse 5, A-1090 Vienna, Austria — [3]Ulm University, Institute for Complex Quantum Systems, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Recent experiments demonstrate cooling of a levitated nanoparticle to its motional ground state, and realize highly tunable non-reciprocal coupling between levitated nanoparticles invoked by light scattering [1,2]. In light of this, I will present the quantum theory of small dielectric objects interacting via the forces and torques induced by scattered tweezer photons [3,4]. The resulting Markovian quantum master equation describes non-reciprocal coupling consistently with the classical results, and is accompanied by correlated quantum noise. I will show how to tune between reciprocal coupling, non-reciprocal coupling and correlated quantum noise and discuss implications for entanglement generation and unidirectional transport through optical binding.

[1] Rieser et al., Science 377, 987 (2022)
[2] Reisenbauer et al., Nat. Phys. 20, 1629 (2024)
[3] Rudolph et al., Phys. Rev. Lett., in press (2024)
[4] Rudolph et al., Phys. Rev. A, in press, arXiv:2306.11893 (2024)

Q 21.4 Tue 11:45 HS I

Cascaded Optomechanical Sensing — •Marta Maria Marchese[1], Stefan Nimmrichter[1], Daniel Braun[2], and Dennis Rätzel[3,4] — [1]Universität Siegen, Germany — [2]University Tübingen, Germany — [3]ZARM University of Bremen, Germany — [4]Humboldt Universität zu Berlin, Germany

Coherent averaging schemes have been introduced as a method to achieve the Heisenberg limit in parameter estimation. Typically, these schemes involve multiple probes in a product state interacting with a quantum bus, with parameter estimation performed via measurements on the bus. We propose a novel coherent averaging scheme for force sensing using an array of optomechanical detectors. Our setup consists of N optomechanical cavities, unidirectionally coupled via an input laser pulse in the stroboscopic regime. The goal is to detect some weak unknown force that couples with all the mechanical elements within the cavities. Before being read out, the pulse sequentially passes through all the cavities, accumulating phase shifts, which encode information about the force. Potential applications of this approach include the sensing of gravitational fields at the Large Hadron Collider (LHC) and the detection of dark matter signatures.

Q 21.5 Tue 12:00 HS I

Probing spin-rotation coupling with gyroscopically stabilized nanoparticles — •Vanessa Wachter and Benjamin A. Stickler — Institute for Complex Quantum Systems, Ulm University, Germany

Nanoscale objects hosting internal magnetic degrees of freedom can exhibit strong signatures of spin-rotation coupling, rendering them attractive for sensing applications and for future quantum tests. We present a theoretical toolbox to describe the quantum dynamics of a gyroscopically stabilized nanodiamond, electrically suspended in a Paul trap, and show how its rotation can be controlled by microwave driving of a single embedded nitrogen vacancy spin. We study potential applications of the spin-rotational interplay for sensing and gyroscopy.

Q 21.6 Tue 12:15 HS I

Optically Hyperpolarized Materials for Levitated Optomechanics — •Marit O. E. Steiner, Julen S. Pedernales, and Martin B. Plenio — Institute of Theoretical Physics, Ulm University, Germany

Levitated optomechanics is an emerging field that offers unprecedented opportunities. One of the most exciting applications are matter-wave interference experiments with particles of increasing mass.

In my presentation, I will explore the potential of levitating solids embedded with non-permanent, optically controllable electron spins, which can be used to hyperpolarize their nuclear spin ensemble. Pentacene doped naphthalene will serve a leading example. Leveraging photo-excited triplet states in pentacene, this system enables exceptional nuclear spin hyperpolarization in naphthalene, achieving up to 80% polarization rates and ultra-long relaxation times of T1=800 hours. These remarkable properties enable stronger spin-dependent forces.

In that spirit, we explore the applications of naphthalene for tests of fundamental physics such as a multi-spin Stern-Gerlach-type interferometry protocol which, thanks to the homogeneous spin distribution and the absence of a preferential nuclear-spin quantization axis in such materials, avoids many of the limitations associated with materials hosting electronic spin defects, such as diamonds containing NV centers.

[1] M. Steiner, J. S. Pedernales, and M. B. Plenio, Pentacene-Doped Naphthalene for Levitated Optomechanics, arXiv:2405.13869

Q 21.7 Tue 12:30 HS I

Training of neuromorphic systems based on coupled phase oscillators via equilibrium propagation: effects of network architecture — •Qingshan Wang[1], Clara Wanjura[1], and Florian Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstrasse 2, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, 91058 Erlangen, Germany

The increasing scale and resource demands of machine learning applications have driven research into developing more efficient learning machines that align more closely with the fundamental laws of physics. A key question in this field is whether both inference and training can exploit physical dynamics to achieve greater parallelism and acceleration. Equilibrium propagation, a learning mechanism for energy-based models, has shown promising results in physical systems with energy functions more complex than Hopfield-like models.

In this study, we focus on equilibrium propagation training of coupled phase oscillator systems.We investigate the influence of different experimentally feasible network architectures on the training performance. We analyze lattice structures, convolutional networks, and autoencoders, examining the effects of network size and other hyperparameters. Our findings lay the ground work for future experimental implementations of energy-based neuromorphic systems for machine learning, encompassing systems such as coupled laser arrays, CMOS oscillators, Josephson junction arrays, coupled mechanical oscillators, and magnetic systems.

Q 21.8 Tue 12:45 HS I

Towards hybrid cavity optomechanics including an excitonic degree of freedom — •Lukas Schleicher[1,2], Leonard Geilen[1,3], Anne Rodriguez[1,2], Irene Sánchez Arribas[1,2], Benedict Brouwer[1,3], Alexander Musta[1,3], Petricia Peter[1,2], Alexander Holleitner[1,3], and Eva Weig[1,2] — [1]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [2]Chair of Nano and Quantum Sensors, TU Munich, Germany — [3]Walter Schottky Institute, TU Munich, Germany

Freely suspended van-der-Waals materials like hBN or transition metal dichalcogenides (TMDC) like MoS2 are interesting hybrid physical systems which allow for the mutual coupling of mechanical, electronic, as well as optical degrees of freedom. The electromechanical coupling is mediated by strain, and leads to a modification of the electronic band structure upon mechanical deflection, which allows for the coupling exitons.

Here, we present first result on mechanical resonators made of suspended monolayer MoS2 membranes. The mechanical mode shape of these resonators is mapped. Moreover, we map spatially the excitonic shift of the material which is related to mechanical strain. These findings pave the way to a hybrid quantum system, also incorporating additional quantum emitters and a ultra high-finesse fiber optical cavity.

Q 22: Ultracold Matter (Bosons) II (joint session Q/A)

Time: Tuesday 11:00–13:00 Location: HS I PI

Q 22.1 Tue 11:00 HS I PI

Exploring Frustration Effects of Strongly Interacting Bosons via the Hall Response — •Catalin-Mihai Halati and Thierry Giamarchi — Department of Quantum Matter Physics, University of Geneva, Geneva, Switzerland

We investigate the Hall response of interacting bosonic atoms on a triangular ladder in a magnetic field, making inroads in understanding the meaning of the Hall response for many-body quantum phases, by analyzing the effects of frustration effects and phase transitions. We show that the nature of the underlying chiral phases has an important influence on the behavior of the Hall polarization, both in its saturation value and in the short-time dynamics. In particular, we find correlations between the Hall response and the features of the underlying phase diagram stemming from the interplay of interactions and geometric frustration. Thus, one can employ the Hall response as a sensitive probe of the many-body chiral quantum phases present in the system.

Q 22.2 Tue 11:15 HS I PI

Dipolar supersolid in a toroidal trap — •Paul Uerlings[1], Kevin Ng[1], Fiona Hellstern[1], Alexandra Köpf[1], Michael Wischert[1], Tanishi Verma[1], Philipp Stürmer[2], Koushik Mukherjee[2], Jens Hertkorn[4], Stephan Welte[3], Ralf Klemt[1], Stephanie Reimann[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Division of Mathematical Physics and NanoLund, LTH, Lund University — [3]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST and QPhoton,Universität Stuttgart — [4]Department of Physics, MIT

A supersolid is a phase of matter that combines the ordered, periodic density modulation of a solid with the frictionless flow of a superfluid, simultaneously breaking both the global U(1) gauge symmetry and the translational symmetry. This symmetry breaking gives rise to three types of collective excitations: the first and second-sound branch and the amplitude Higgs modes. In harmonic traps the Higgs excitations couples strongly to other modes making it hard to detect experimentally. In this work, we theoretically explore the excitation spectrum of a dipolar quantum gas trapped in a toroidal trap. In contrast to previous studies in a harmonic confinement. Our findings reveal decoupled sound and amplitude modes. In the low-momentum limit we find an isolated and massive Higgs excitation. We show how we can selectively excite individual modes of the supersolid. In order to observe these excitations experimentally, we prepare an ultracold gas of 162Dy atoms in a tunable toroidal trap.

Q 22.3 Tue 11:30 HS I PI

Magnetically ordered flux-supersolids with magnetic atoms in an anti-magic wavelength optical lattice — •Michele Miotto — Technische Universität Berlin — Politecnico di Torino

Supersolidity is one of the most fascinating and investigated states of matter. In this work, we prove that the combination of geometrical frustration and strong long-range interactions can give rise to this many-body phase. In particular, we design an experimental platform where a Raman coupled mixture of bosonic magnetic atoms is trapped in a 1D anti-magic wavelength optical lattice. We model this setup by means of a frustrated extended Bose-Hubbard model and we explore its ground-state properties by means of DMRG simulations. We obtain a rich phase diagram, where we observe well-known insulating phases along with interesting gapless states: a chiral superfluid phase and a supersolid phase. The latter can also be characterized by non-trivial order in the current patterns, which can be related to magnetically ordered states such as ferrimagnets and ferromagnets.

Q 22.4 Tue 11:45 HS I PI

Observation of localization in quasidisordered optical lattices — •David Gröters[1,2], Lee Reeve[1], Zhuoxian Ou[1], Qijun Wu[1], Emmanuel Gottlob[1], Yong-Guang Zheng[1], Bo Song[1], and Ulrich Schneider[1] — [1]Cavendish Laboratory, University of Cambridge, J.J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Quasidisordered materials constitute a unique class of systems that are not periodic yet long-range ordered. They can exhibit localized phases of matter, known as the Bose glass, in which thermalization and transport are inhibited. While the Bose glass has recently been observed, an understanding of how localization prevents transport in quasicrystals in the presence of interactions remains unclear.

In this talk, we present recent results of our optical lattice-based quantum simulator on localization of interacting ^{39}K atoms in 2D. We directly observe a suppression in transport rate by three orders of magnitude in a quasicrystal potential that we compare to numerical exact-diagonalization results. Furthermore, we investigate the quasiperiodic Aubry-André model in which transport characteristics are expected to be strikingly different. Using coherence measurements, we map the disorder vs. interaction strength phase diagram and find signatures of the Bose glass phase. Our results demonstrate robust localization in quasicrystalline lattices in the presence of interactions that renders these systems a valuable platform for future studies of many-body localization.

Q 22.5 Tue 12:00 HS I PI

Designed Potential Edges for Phonon-Based Quantum Simulations — •Jelte Duchene, Nikolas Liebster, Marius Sparn, Elinor Kath, Helmut Strobel, and Markus Oberthaler — Kirchhoff-Institut für Physik, Heidelberg, Deutschland

Experimental quantum simulation has become an important tool for the study of quantum fields out of equilibrium. Often, theoretical models are studied with infinite extension or periodic boundary conditions, which makes comparisons with finite-size experiments challenging. In our quantum field simulator, based on phononic excitations of a two-dimensional Bose-Einstein condensate of potassium-39 atoms, we effectively mimic an infinitely extended system by suppressing coherent reflections of phonons at the edges of the trap while still conserving the atom number. This is achieved using a so-called slanted box (Slox) potential, which is flat in the center and has linearly rising slopes at the edges. Experimentally, this is implemented with a Digital Micromirror Device, enabling us to produce various light potentials. We study wave packet dynamics in 2D experiments and 1D simulations as well as the influence of the Slox parameters on the emergence and stability of spontaneously formed density patterns in an interaction-driven situation. Our observations suggest that spatial noise in the light potential is crucial for the efficient suppression of coherent reflections.

Q 22.6 Tue 12:15 HS I PI

Solidity and Smecticity of a Driven Superfluid — •Nikolas Liebster, Marius Sparn, Elinor Kath, Jelte Duchene, Helmut Strobel, and Markus Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

In recent years, a wealth of studies have surrounded the budding field of supersolids, which are systems that are simultaneously superfluid and crystalline. A consequence of the two spontaneously broken symmetries is an enriched excitation spectrum with distinct Goldstone modes. This generic behavior can be derived hydrodynamically by considering only broken symmetries and conserved quantities. Here, we probe the hydrodynamic excitations of a superfluid with density patterns stabilized by driving the interaction strength. We probe both stripe patterns as well as two-dimensional crystals, observing propagating sound modes in each configuration. Using anisotropic response of the stripe (i.e. smectic), we experimentally determine the relevant hydrodynamic parameters. Additionally, we probe transverse sound modes of a two-dimensional crystal to investigate the symmetry breaking processes of the pattern.

Q 22.7 Tue 12:30 HS I PI

Understanding Phonon Pair Production as 1d Scattering

Problem — •Elinor Kath, Marius Sparn, Nikolas Liebster, Jelte Duchene, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg

Non-adiabatically changing the interatomic interaction strength of a Bose-Einstein Condensate produces pairs of phonons, which interfere with the background condensate and become visible as density fluctuations. The resulting density fluctuation power spectrum depends on the details of the temporal shape of the interaction strength and, because the phonons were produced coherently, will still oscillate when the interaction strength is held constant again. This process of quasiparticle production can be mapped onto a quantum-mechanical scattering problem in 1d, where the time dependence of the interaction strength sets the height and shape of the scattering potential. We demonstrate how to apply this mapping to intuitively understand the shape and time dependence of produced phonon spectra.

Q 22.8 Tue 12:45 HS I PI

Deterministic Generation of Topological Spin Excitations in a Bose-Einstein Condensate — •Yannick Deller, Alexander Schmutz, Raphael Schäfer, Alexander Flamm, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Deutschland

Spinor BEC experiments are an ideal platform for quantum field simulations far from equilibrium with exquisite control over the initial state as well as the readout. The spin-1 system supports a wealth of localized nonlinear excitations, classified by the spatial structure of the spin observables and the atomic densities [1,2,3].
We report on the deterministic generation of topological spin excitations by utilizing a spatially controlled spinor phase imprinting scheme in a quasi one-dimensional ferromagnetic spin-1 BEC. We track their time evolution in all relevant observables by employing a generalized POVM readout scheme [4] and study key properties like propagation speed and lifetime.

1 Lannig et. al., PRL 125, 170401 (2020)
2 Chai et. al., PRL 125, 030402 (2020)
3 Yu and Blakie, PRL 128, 125301 (2022)
4 Kunkel et. al., PRL 123, 063603 (2019)

Q 23: Ultra-cold Atoms, Ions and BEC II (joint session A/Q)

Time: Tuesday 11:00–13:00 Location: KlHS Mathe

Invited Talk Q 23.1 Tue 11:00 KlHS Mathe

Ultracold and ultrafast: Tandem ion imaging and electron spectroscopy for quantum gases — Jette Heyer, Julian Fiedler, Mario Grossmann, Lasse Paulsen, Marlon Hoffmann, Markus Drescher, Klaus Sengstock, Juliette Simonet, and •Philipp Wessels-Staarmann — Center for Optical Quantum Technologies, Universität Hamburg, Hamburg, Germany

Ultrashort laser pulses provide new pathways for probing and manipulating ultracold quantum gases. The strong light field of such a laser pulse can locally ionize few or many atoms in a Bose-Einstein condensate. This allows creating hybrid quantum systems consisting of ultracold atoms and ions. Moreover, an ultrafast excitation of interacting Rydberg atoms below the blockade radius becomes possible within femtoseconds due to the large bandwidth of the laser pulse.

Here we present a new instrument for charged particle analysis of ultracold atoms consisting of a tandem ion microscope and velocity-map-imaging electron spectrometer tailored to resolve the dynamics of these systems. The ion microscope can track the position of ions with a high spatial resolution, while the velocity-map-imaging spectrometer can measure the momentum of the electrons. Moreover, we can detect both properties in coincidence due to a high detection efficiency. A time-resolved extraction and detection on single digit nanosecond timescales allows following the emergence of correlations and many-body phenomena in interacting quantum systems of charged particles.

This work is funded by the Cluster of Excellence "CUI: Advanced Imaging of Matter" of the DFG - EXC 2056 - project ID 390715994.

Q 23.2 Tue 11:30 KlHS Mathe

Quantum bubbles in the Einstein-Elevator facility at Leibniz University Hannover — •Charles Garcion[1], Thimothé Estrampes[1], Gabriel Müller[1], Sukhjovan S. Gill[1], Magdalena Misslisch[1], Éric Charron[2], Christoph Lotz[3], Jean-Baptiste Gérent[4], Nathan Lundblad[4], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, Hannover, 30167, Germany — [2]Institut des Sciences Moléculaires d'Orsay, CNRS, Université Paris-sacay, F-91405, Orsay, France — [3]Institut für Transport- und Automatisierungstechnik c/o Hannover Institute of Technology, Leibniz Universität Hannover, Callinstraße 36, Hannover, 30167, Germany — [4]Department of Physics and Astronomy, Bates College, Lewiston, ME, USA

Quantum bubbles are systems in which atoms are confined to a two-dimensional closed surface. They enable the study of phenomena like vortices, collective modes, and self-interference during expansion. These bubbles are typically created using radiofrequency (RF) dressed potentials and form more naturally in microgravity. However, inhomogeneities in static and RF magnetic fields can alter this advantage.

The Quantumania project adapts the MAIUS-1 payload in the Einstein-Elevator at the Leibniz University Hannover to create quantum bubbles. It will also contribute to efforts in testing and refining techniques for the Cold Atom Laboratory aboard the ISS. A primary goal is optimizing antenna designs and selecting radiofrequency sources to enhance magnetic field homogeneity, ensuring effective trapping in bubble configurations.

Q 23.3 Tue 11:45 KlHS Mathe

Josephson dynamics of a finite temperature BEC in a double well potential — •Kateryna Korshynska[1,2] and Sebastian Ulbricht[1,2] — [1]TU Braunschweig, Institut für Mathematische Physik Mendelssohnstr. 3 38106 Braunschweig — [2]Physikalisch-Technische Bundesanstalt Bundesallee 100 38116 Braunschweig

A many-particle bosonic system placed in a double-well potential is known to exhibit oscillatory dynamics of the particle populations between the wells. Such collective oscillations are well-known as the Josephson effect and have been intensively investigated both theoretically and experimentally. A well-established approach to describe this dynamics at low temperatures is to assume a two-state model, in which the Josephson equations govern population imbalance and phase difference between the wells. This model is formulated under the assumption that the Bose gas forms a fully coherent system, which holds at zero temperature. However, in typical experiment the finite-temperature BEC is not fully coherent, for instance when the thermal equilibrium is established. To describe this we use the density matrix approach and analyze the influence of higher energy levels on the double-well dynamics. We find that this effect is two-fold: while the higher energy levels below the barrier height contribute to the double-well dynamics, the even more excited particles may lead to thermalization and decoherence.

Q 23.4 Tue 12:00 KlHS Mathe

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.

Q 23.5 Tue 12:15 KlHS Mathe

Quantum-gas microscopy of fermionic ^{87}Sr — Carlos Gas[1], Sandra Buob[1], Jonatan Höshele[1], •Antonio Rubio-Abadal[1],

and Leticia Tarruell[1,2] — [1]ICFO - Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain

Ultracold atoms in optical lattices are a popular platform in quantum science for studies in the fields of quantum simulation and quantum metrology. Alkaline-earth atoms like strontium offer many opportunities, such as a large-spin fermions with SU(N) symmetry as well as narrow or ultranarrow transitions.

In particular, ^{87}Sr presents a nuclear spin of I=9/2 (and no electronic spin) allowing the study of the SU(N)-Fermi-Hubbard model and quantum magnetism with N up to 10.

In recent experiments, we have demonstrated single-atom imaging of ^{87}Sr with spin resolution using the narrow linewidth 689 nm transition. Through a combination of Zeeman shifts and spin-resolved optical pumping we aim at a reliable detection of all 10 spin states.

Q 23.6 Tue 12:30 KlHS Mathe

Quantum phases of bosonic mixture with dipolar interaction — •Rukmani Bai and Luis Santos — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstrasse 2, D-30167 Hannover, Germany

Ultracold dipoles in optical lattices, characterized by strong inter-site interactions, open new possibilities for ground-state phases as well as an intriguing dynamics. Recent experiments on dipolar mixtures of magnetic Lanthanide atoms are especially interesting, not only due to the dipolar interaction, but also because these atoms are particularly suitable for realizing component-dependent lattices. Using a combination of DMRG and cluster Gutzwiller methods, we study the ground-state physics that may result when the two components experience mutually intertwined optical lattices, which resemble interacting bilayer geometries.

Q 23.7 Tue 12:45 KlHS Mathe

Chirality-protected state manipulation by tuning one-dimensional statistics — Friethjof Teel[1], •Martin Bonkhoff[2], Peter Schmelcher[1,3], Thore Posske[2,3], and Nathan Harshman[4] — [1]Center for Optical Quantum Technologies, Department of Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg Germany — [2]I. Institute for Theoretical Physics, Universität Hamburg, Notkestraße 9, 22607 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [4]Physics Department, American University, Washington, DC 20016, USA

Chiral symmetry is broken by typical interactions in lattice models, but the statistical interactions embodied in the anyon-Hubbard model are an exception. It is an example of a correlated hopping model in which chiral symmetry protects a degenerate zero-energy subspace. Complementary to the traditional approach of anyon braiding in real space, we adiabatically evolve the statistical parameter in the anyon-Hubbard model and we find non-trivial Berry phases and holonomies in this chiral subspace. States in this subspace possess stationary checkerboard patterns in their N-particle densities which are preserved under adiabatic manipulation. We give an explicit protocol for how these chirally-protected zero energy states can be prepared, observed, validated, and controlled.

Q 24: Quantum Computing Implementations (joint session QI/Q)

Time: Tuesday 14:00–15:30 Location: HS II

Q 24.1 Tue 14:00 HS II

Theory and Experimental Demonstration of Wigner Tomography of Unknown Unitary Quantum Gates — •Amit Devra[1], Leo Van Damme[1], Frederik vom Ende[2], Emanuel Malvetti[1], and Steffen J. Glaser[1] — [1]Technical University of Munich — [2]Freie University Berlin

We investigate the tomography of unknown unitary quantum processes within the framework of a finite-dimensional Wigner-type representation. This representation provides a rich visualization of quantum operators by depicting them as shapes assembled as a linear combination of spherical harmonics. These shapes can be experimentally tomographed using a scanning-based phase-space tomography approach. However, so far, this approach was limited to known target processes and only provided information about the controlled version of the process rather than the process itself. To overcome this limitation, we introduce a general protocol to extend Wigner tomography to unknown unitary processes. This new method enables experimental tomography by combining a set of experiments with classical post-processing algorithms introduced herein to reconstruct the unknown process. We also demonstrate the tomography approach experimentally on IBM quantum devices and present the specific calibration circuits required for quantifying undesired errors in the measurement outcomes of these demonstrations.

Q 24.2 Tue 14:15 HS II

High Energy Quantum Simulation on a Trapped-Ion Quantum Processor — •Christian Melzer[1], Stephan Schuster[2], Diego Alberto Olvera Millán[1], Janine Hilder[1], Ulrich Poschinger[1], Karl Jansen[3], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz — [2]Quantum Optics and Quantum Information Group, Friedrich-Alexander-Universität Erlangen-Nürnberg — [3]Center for Quantum Technology and Applications, DESY Zeuthen

Currently, quantum processors are noisy and only exhibit few qubits. Still, there are executable applications that show potential for future advantages. We investigate the multi-flavor Schwinger model with non-zero chemical potential. This model stems from the field of high energy physics [1] and describes a phase transition in quantum electrodynamics in one space and one time dimension. For classical computing, this fermionic simulation becomes intractable even for small system sizes due to the notorious sign problem. Using our shuttling-based trapped-ion quantum processor [2], we solve instances of this problem by a variational approach (VQE). Thereby, we find the lowest energy eigenstate of the system and determine the phase transition.

[1] Schuster et al., Phys. Rev. D 109, 114508 (2024)
[2] Hilder et al., Phys. Rev. X 12, 011032 (2022)

Q 24.3 Tue 14:30 HS II

Demonstrations of system-bath physics on gate-based quantum computer — Pascal Stadler, Matteo Lodi, Andisheh Khedri, Rolando Reiner, Kirsten Bark, Nicolas Vogt, Michael Marthaler, and •Juha Leppäkangas — HQS Quantum Simulations GmbH, Rintheimer Straße 23, 76131 Karlsruhe, Germany

We develop a quantum algorithm that can be used to perform algorithmic cooling on noisy quantum computers. The approach utilizes inherent qubit noise to simulate the equilibration of an interacting spin system towards its ground state, when coupled to a simulated dissipative auxiliary-spin bath. We test the algorithm on IBM-Q devices and demonstrate the relaxation of system spins to ferromagnetic and antiferromagnetic ordering, controlled by the definition of the system Hamiltonian. The ordering is stable as long as the algorithm is run. We are able to perform cooling and state stabilization for global systems of up to three system spins and four auxiliary spins.

Q 24.4 Tue 14:45 HS II

Variational quantum algorithm based self-consistent calculations for the two-site DMFT model on noisy quantum computing hardware — Jannis Ehrlich, •Daniel F. Urban, and Christian Elsässer — Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany

Dynamical Mean Field Theory (DMFT) is one of the powerful computational approaches to study electron correlation effects in solid-state materials and molecules. Its practical applicability is, however, limited by the quantity of numerical resources required for the solution of the underlying auxiliary Anderson impurity model. Here, the possibility of a one-to-one mapping between electronic orbitals and the state of a qubit register suggests a significant computational advantage for the use of a Quantum Computer (QC) for solving DMFT models. In this work we present a QC approach to solve a two-site DMFT model based on the Variational Quantum Eigensolver (VQE) algorithm. We discuss the challenges arising from stochastic errors and suggest a means to overcome unphysical features in the self-energy. We thereby demonstrate the feasibility to obtain self-consistent results of the two-site DMFT model based on VQE simulations with a finite number of shots. We systematically compare results obtained on simulators with calculations on the IBMQ Ehningen QC hardware.

Q 24.5 Tue 15:00 HS II

Robust Microwave-Driven Quantum Gates in a Cryogenic Surface-Electrode Trap — •Judi Parvizinejad, Sebastian Halama, Giorgio Zarantonello, Celeste Torkzaban, and Christian Ospelkaus — Institute für Quantenoptik, Leibniz University Hannover, Welfengarten 1, 30167 Hannover

A fault-tolerant quantum computer requires a large number of qubits with high gate fidelities, ability to generate entanglement between many qubits, and sufficiently long coherent time. Surface-electrode ion traps [1] have emerged as a promising solution due to their high gate fidelities, long coherence times, and the ability to physically move them around into different zones, which are key requirements for scalable multi-quit operations [1, 4]. Alongside laser-based techniques, microwave-driven gates [2] are promising for advancing fault-tolerant quantum computing. In our cryogenic experiments, 9Be+ ions are confined at a distance of 70 μm above a surface-electrode Paul trap where a strong microwave gradients field generated by an embedded microwave meander is for driving entangling gates [3]. We will present our recent advancements in achieving high-fidelity microwave-driven gate operations, and will share our plan for demonstrating simple quantum error correction algorithms for quantum metrology.

[1] C. Ospelkaus et al., Phys. Rev. Lett. 101, 090502 (2008). [2] C. Ospelkaus et al., Nature 476, 181-184 (2011). [3] M. Carsjens et al., Appl. Phys. B 114, 243 (2014). [4] D. Kielpinski et al., Nature, 417, 709-711 (2002).

Q 24.6 Tue 15:15 HS II

Quantum teleportation of a Bell state via cluster states on IBM Quantum — •Branislav Ilich[1,2] and Nikolay Vitanov[1,2] — [1]Sofia University St. Kliment Ohridski — [2]Center for Quantum Technologies

We report experimental results on the teleportation of a two-qubit entangled Bell state across a six-qubit entangled system on ibm_sherbrooke. The teleportation protocol begins with the generation of a four-qubit cluster state on Bob's subsystem and the preparation of a two-qubit Bell state on Alice's subsystem. The entangled state is then teleported to the last two qubits of Bob's cluster state through a series of controlled-NOT (CNOT) gates.

To maximize the fidelity of the protocol, we implemented targeted optimizations within IBM's transpiler, enabling precise control over gate placement and error mitigation. These modifications were critical in achieving a protocol fidelity of 90%, which represents the upper limit for IBM's quantum hardware.

Our findings demonstrate the feasibility of reliably teleporting entangled states across distributed quantum systems and highlight the importance of hardware-aware optimization strategies in achieving high-fidelity quantum information processing. This work serves as a step forward in scaling entanglement distribution protocols, with implications for quantum communication and distributed quantum computing.

Q 25: Poster – Cold Atoms and Molecules, Matter Waves (joint session Q/A/MO)

Time: Tuesday 14:00–16:00 Location: Tent

Q 25.1 Tue 14:00 Tent

Dephasing of Rydberg excitations in optical traps — •Simon Schroers[1], Lukas Ahhlheit[1], Daniil Svirskiy[1], Nina Stiesdal[1], Jan de Haan[1], Chris Nill[2], Igor Lesanovsky[2], Wolfgang Alt[1], and Sebastian Hofferberth[1] — [1]Institut für Angewandte Physik, Universität Bonn — [2]Institut für Theoretische Physik, Universität Tübingen

Collective Rydberg-excitations of N atoms by a single photon offer a distinct platform for strong light-matter interaction, due to the enhanced coupling by $\sqrt{N}$. This allows for instance the creation of Rydberg superatoms, namely an atom cloud smaller than the Rydberg-blockade-volume acting as an effective two level-system strongly coupled to a few-photon driving field.

On this poster we show recent experimental results of how we implement a so-called magic wavelength trap for ground state and Rydberg atoms. The magic trap equalizes the AC Stark shifts for both states, thereby enhancing the ground-to-Rydberg state coherence time. Using photon-storage measurements we demonstrate that the optimal wavelength for such a trap depends on the trap's geometry, as the almost-free Rydberg electron samples different regions of the trap.

We also show an investigation of Rabi oscillation dephasing between the ground and a collectively excited state of a superatom. Comparing simulations and experimental data we demonstrate that the frequency noise of the excitation lasers plays a significant role in the dephasing and identify the noise regimes that are most crucial for such dephasing.

Q 25.2 Tue 14:00 Tent

Chiral Van der Waals interactions between Rydberg atoms — •Fabian Spallek[1], Stefan Aull[1], Steffen M. Giessen[2], Kilian Singer[1], Robert Berger[2], Akbar Salam[3], and Stefan Yoshi Buhmann[1] — [1]University Kassel, Germany — [2]Phillips-University Marburg, Germany — [3]Wake Forest University, USA

We study the Van der Waals potential between two atoms prepared in chiral superpositions of electronic Rydberg states. By harnessing external electric and magnetic fields, one can induce chiral asymmetry in the Rydberg states, which in turn gives rise to a chiral component in the near-field Van der Waals potential. This chiral component emerges from the interplay of electric and magnetic dipole-dipole interactions and contributes to the overall Van der Waals potential in addition to the conventional electric dispersion interaction. We derive effective potentials by performing various orientational averages and identify specific chiral Rydberg states that significantly enhance chiral the discriminatory component. These states offer a promising platform for realizing strong chiral interactions between Rydberg atoms, potentially enabling novel applications in quantum control and sensing.

Q 25.3 Tue 14:00 Tent

Machine learning optimized time-averaged potentials — •Max Schlösinger[1], Oliver Anton[1], Victoria Henderson[1,3], Elisa Da Ros[1], Mustafa Gündoğan[1], Simon Kanthak[1], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstraße 15, 12489 Berlin, Germany — [2]Ferdinand-Braun-Institut (FBH), Gustav-Kirchhoff-Straße 4, 12489 Berlin — [3]now: RAL Space, Fermi Ave, Harwell, Didcot OX11 0QX, United Kingdom

Time-averaged potentials (TAPs) are a versatile tool for the generation and manipulation of ultracold atom clouds. Using a CCD-based setup to characterize a 2D acousto-optic deflector (2D-AOD) system, we implement and test machine learning routines to optimize 2D geometries, such as harmonic potentials. This approach allows us to compare different methods, evaluate metrics like homogeneity, and improve the predictability of the resulting potentials.

By employing optimization algorithms such as CMA-ES and various Bayesian optimizers, we compare their performance in terms of speed and efficiency. Additionally, we plan to implement an active learning optimizer to minimize the number of required iterations, which is crucial for future integration into a ^{87}Rb Bose-Einstein condensate (BEC) experiment. Ultimately, these advancements will enhance the evaporative cooling routine and improve the performance of a ^{87}Rb BEC-based quantum memory [1].

[1] Phys. Rev. Research **5**, 033003 (2023)

Q 25.4 Tue 14:00 Tent

Rydberg superatoms coupled with super-extended evanescent field nanofiber at the single-photon level — •Ludwig Müller[1], Knut Domke[1], Tangi Legrand[1], Thomas Hoinkes[2], Xin Wang[1], Eduardo Uruñuela[1], Wolfgang Alt[1], and Sebastian Hofferberth[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Department of Physics, Humboldt University of Berlin, Germany

Both Rydberg superatoms driven by free-space photonic modes and single emitters coupled to photonic waveguides have paved the way for strong coherent light-matter coupling at the few-photon level. By combining advantages of both ideas, we aim to achieve homogeneous coupling of multiple Rydberg superatoms coupled to a field confined by a nanofiber. Fibers with diameters of a few hundred nanometers are successfully used to trap and couple arrays of single atoms by their evanescent field. Recent advances allow the fibers to be tapered to even smaller diameters, allowing more than 99 % of the energy to be guided outside the fiber with effective field diameters of $\gtrsim 13\,\lambda$ [1], bringing them up to typical Rydberg blockade radius sizes.

On this poster, we will we will present the current status of planning and building our new Nanofiber experiment such as the vacuum chamber and first tests of the nanofibers. We select Ytterbium due to its advantage of having the two-photon Rydberg excitation transitions close together with 399 nm and 395 nm, which simplifies the fiber design and is expected to have low thermal dephasing effects.

[1] R. Finkelstein *et. al.* Optica **8**, 208-215 (2021)

Q 25.5 Tue 14:00 Tent

Interfacing high overtone bulk acoustic wave resonators and Rydberg atoms in a 4K environment — •Samuel Germer, Valerie Mauth, Cedric Wind, Julia Gamper, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Rydberg atoms possess electric dipole transitions over a large range of the electromagnetic spectrum and are therefore promising candidates for realizing hybrid quantum systems that bridge the microwave and optical regimes. We aim to realize such a hybrid system in which an electromechanical resonator mode can be cooled down to its quantum mechanical ground state via interactions with Rydberg atoms.

On this poster, we discuss the setup build of three parts, the magneto optical trap for Rubidium atoms, an ultra high vacuum chamber hosting the atom chip in a closed-cycle cryostat and a magnetic transport connecting both. The cryostat provides a 4K environment which is a prerequisite for cooling the high overtone bulk acoustic wave resonator (HBAR) close to its ground state and allows the use of superconducting components.

We present machine learning based optimization of the magneto optical trap and magnetic transport. Moreover, a first generation chip, consisting of a superconducting Z-wire trap and a microwave resonator, has been fabricated and characterization measurements are shown. For a second generation atom chip, featuring the HBAR, first simulations are presented which allow, among other things, to estimate the coupling strength between Rydberg atoms and the resonator.

Q 25.6 Tue 14:00 Tent

Cascaded Nonlinearities for Effectively Interacting Bose-Einstein Condensates of Photons — •Niels Wolf, Andreas Redmann, Christian Kurtscheid, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Bonn, Deutschland

Bose-Einstein condensation has been observed in ultracold atomic gases, polaritons, and, more recently, in low-dimensional photon gases. Since the photon-photon interaction is vanishingly small, thermalization of photons, e.g. as dye microcavity photon condensates in the latter systems, is achieved not through particle-particle collisions, but rather via contact with a reservoir, here the dye molecules [1]. Nevertheless, strong photon-photon interactions, such as effective Kerr interactions induced by cascaded second-order nonlinearities, could enable the realization of an interacting photon Bose-Einstein condensate. This could, e.g. open pathways to generating highly entangled photon states by purely thermodynamical methods [2]. We employ a triply resonant optical parametric oscillator setup with independent control over pump and subharmonic wavelength cavities. This configuration enables the generation of cascaded second-order nonlinearities, producing a phase shift potentially stronger than that of direct Kerr interaction. Suitable frequency filtering is crucial to tune the optical parametric oscillator to degeneracy, which is essential for fully characterizing the phase shift and determining the effective Kerr coefficient.

[1] J. Klaers et al., Nature 468, 545 (2010) [2] C. Kurtscheid et al., Science 366, 894 (2019)

Q 25.7 Tue 14:00 Tent

Evalutation of machine learning algorithms for applications in quantum gas experiments — •Oliver Anton[1], Elisa Da Ros[1], Philipp-Immanuel Schneider[3,4], Ivan Sekulic[3,4], Sven Burger[3,4], and Markus Krutzik[1,2] — [1]Institut für Physik and IRIS, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]JCMwave GmbH, Berlin — [4]Zuse Institute Berlin (ZIB), Berlin

The generation of clouds containing cold and ultra-cold atoms is a complex process that requires the optimization of noisy data in multi dimensional parameter spaces. Optimization of such problems can present challenges both in and outside of the lab due to constrains in time, expertise, or access for lengthy manual optimization.
Machine learning offers a solution thanks to its ability to efficiently optimize high dimensional problems without the need for knowledge of the experiment itself. In this poster, we present the results of benchmarking various optimization algorithms and implementations. Their performance is tested in a cold atom experiment, subjected to inherent noise [1]. Current research aims towards the preparation of the cloud for quantum memory applications [2], by engineering the optical density using the tested algorithms.

[1] O. Anton et al., Machine Learning: Science and Technology 5 025022, 2024
[2] E. Da Ros et al., Physical Review Research 5 033003, 2023

Q 25.8 Tue 14:00 Tent

A Dipolar Quantum Gas Microscope in UV Optical Lattices — •Fiona Hellstern, Kevin Ng, Paul Uerlings, Michael Wischert, Alexandra Köpf, Tanishi Verma, Stephan Welte, Ralf Klemt, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

We present progress on our dipolar quantum gas microscope, enabling in situ, single-atom, and single-site resolved detection of Dysprosium atoms in 180 nm spaced UV optical lattices. Using 360 nm light, we can create various lattice geometries to explore strongly correlated quantum phases. Due to the small lattice spacing, nearest-neighbor dipolar interactions can reach 200 Hz at 10 nK, granting us access to phases where long-range dipolar interactions play a dominant role.

UV spectroscopy has been performed to characterize key transitions, including isotope-specific features and a King plot analysis, essential for precise lattice control and future measurements. We present our results on the characterization of our high-NA (0.9) in-vacuum objective, highlighting its ability to achieve 180 nm spatial super-resolution through the implementation of shelving techniques. Finally, we outline our plans to leverage these tools for exploring novel quantum phases, dipolar many-body physics, and emergent phenomena in strongly interacting systems.

Q 25.9 Tue 14:00 Tent

Developing a quantum gas microscope with programmable lattices — Sarah Waddington[1], Isabelle Safa[1], Tom Schubert[1], •Rodrigo Rosa-Medina[1], and Julian Léonard[1,2] — [1]Atominstitut, TU Wien, Vienna, Austria — [2]Institute of Science and Technology Austria (ISTA), Klosterneuburg, Austria

Experiments with ultracold atoms in optical lattices offer a versatile platform for engineering and probing strongly correlated quantum matter. While quantum gas microscopy has significantly advanced the field, enabling unprecedented single-site resolution, current experimental setups are often constrained by rigid lattice configurations and slow cycle times.

Here, we present our ongoing efforts to design and build a next-generation quantum gas microscope for fermionic and bosonic lithium atoms. Our approach relies on atom-by-atom assembly of small lattice systems employing auxiliary optical tweezers combined with all-optical cooling techniques to facilitate sub-second experimental cycles. By leveraging holographic projection techniques, we create tailored optical lattices with dynamically reconfigurable geometries. Our approach opens diverse research avenues, ranging from quantum simulation of fractional quantum Hall states to frustrated phases with unconventional geometries.

Q 25.10 Tue 14:00 Tent

Cooling and trapping of Hg atoms with enhanced UV laser systems — •Rudolf Homm and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

The use of cold Hg atoms in a MOT offers a variety of experimental opportunities. The two stable fermionic isotopes are promising for a new time standard based on an optical lattice clock, using the $^1S_0$ - $^3P_0$ transition at 265.6 nm. All stable isotopes can also form ultracold Hg dimers via photoassociation, combined with vibrational cooling.

Our setup includes two UV laser systems combined with a MOT for Hg atoms and a 2D-MOT for isotope preselection. Each laser system consists of a MOFA configuration, followed by two frequency-doubling stages.

The cooling laser provides a stable frequency and high power, generating over 1 W at 253.7 nm using Doppler-free saturation spectroscopy and an elliptical focus within the BBO crystal. The spectroscopy laser produces over 300 mW at 254.1 nm, mode hop free tunable over 16 GHz with a maximum scan rate of 3 Hz, using a feed-forward setup to stabilize the cavities.

We aim to achieve a high density of Hg atoms in the MOT to improve the signal for dimer spectroscopy. The latest results on trapping of Hg atoms with the improved UV laser systems will be presented.

Q 25.11 Tue 14:00 Tent

Correlation Functions for Interacting Fermi Gases in the BCS Regime — •Nikolai Kaschewski, Sejung Yong, and Axel Pelster — Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany

Recent progress in developing quantum gas microscopes in the continuum [1-3] has opened new possibilities for detecting experimentally correlation functions in the realm of ultracold gases. Motivated by this, we present mean-field calculations of density-density correlation functions for interacting Fermi gases in the BCS regime.

Our results turn out to be strongly influenced not only by the temperature and the interaction strength for a harmonic confinenmnt [4], but also by the effective range of the interaction in the homogeneous case [5]. As the latter has so far remained to be an elusive scattering parameter, its experimental detection via correlation function measurements is promising. This can shed new light on the prediction of two different superfluid phases for interacting Fermi gas [5].

[1] T. Jongh et al., arXiv:2411.08776 (2024).
[2] J. Xiang et al., arXiv:2411.08779 (2024).
[3] R. Yao, et al., arXiv:2411.08780 (2024).
[4] S. Yong et al., arXiv:2311.08853 (2023).
[5] N. Kaschweski, C. A. R. Sá de Melo, and A. Pelster, submitted for publication.

Q 25.12 Tue 14:00 Tent

Studying Dipolar Supersolids in Toroidal Geometries using DMDs — •Tanishi Verma[1], Paul Uerlings[1], Fiona Hellstern[1], Kevin Ng[1], Alexandra Köpf[1], Michael Wischert[1], Stephan Welte[1,2], Ralf Klemt[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Supersolids are characterised by a combination of the crystal structure of solids and the frictionless flow of superfluids, and can be realised experimentally through the self-organisation of long-range interacting trapped BECs into states of matter that resemble crystal like structures. In a recent work, dipolar supersolids in toroidal traps have been studied theoretically. Toroidal traps provide continuous rotational symmetry and periodic boundary conditions, which can be used to study the different amplitude and sound modes which emerge during the superfluid to supersolid phase transition, especially the Higgs amplitude mode, which has yet to be experimentally observed.

We plan to load the BEC produced in our new-generation Dysprosium machine in a toroidal trap made with a Digital Micromirror Device (DMD), and also implement a lightsheet using a 532nm laser for z-direction confinement. This poster presents our progress on the optical setup in order to create toroidal traps to study toroidal dipolar supersolids and their excitation modes.

Q 25.13 Tue 14:00 Tent

High-pressure xenon-noble gas mixtures as a thermalization mediator for VUV photons — •Thilo Falk vom Hövel, Eric Boltersdorf, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

In recent years, microcavity-based Bose-Einstein condensates of photons have become an established experimental platform. In these experiments, photons in the green-to-orange spectral range are confined to high-finesse microcavities filled with a liquid dye solution. Via repeated absorption and emission cycles, the photons adopt a thermal energy distribution, mediated by the thermalization of the dye molecules' rovibronic levels. Conveying these principles into the VUV spectral regime (100 - 200 nm) would allow for the construction of a coherent light source in a regime where the realization of a laser is difficult. For this endeavor, we intend to replace the dye molecules by a dense xenon-noble gas mixture, with xenon as the optically active constituent. For thermalization, we aim to exploit the transitions around a wavelength of 147 nm between the quasimolecular states associated with the (atomic) $5p^6$ and $5p^5 6s$ levels. We report on recent results on the spectroscopic investigation of such mixtures, with sample pressures of up to 100 bar. Centerpiece is a detailed study of absorption and emission spectra, with particular emphasis on the influence of the constituent partial pressures. The fulfillment of the thermodynamic Kennard-Stepanov relation is investigated, which constitutes an essential prerequisite for the suitability of a medium as a thermalization mediator for photons.

Q 25.14 Tue 14:00 Tent

Topological signatures in the dynamical response of periodically driven Su-Schrieffer-Heeger model — Soumya Sasidharan[1], •Souradeep Roy Choudhury[2], Ahmet Levent Subaşı[3], and Naveen Surendran[1] — [1]Indian Institute of Space Science and Technology, Valiamala, Thiruvananthapuram-695547, India — [2]Goethe-Universität, Institut für Theoretische Physik, 60438 Frankfurt am Main, Germany — [3]Department of Physics, Faculty of Science and Letters, Istanbul Technical University, 34469 Maslak, Istanbul, Turkey

We study the dynamics of periodically driven Su-Schrieffer-Heeger model subjected to a range of driving conditions. In the large-amplitude, high-frequency regime, we establish a remarkable correspondence between the bulk dynamical response and the topology of the Floquet phase. At half-filling, we compute the dynamical order parameter Q, which is the time-averaged occupancy of an initially filled band. We show that Q is quantitatively related to a topological invariant. Furthermore, we obtain topologically protected edge states in the nontrivial phases.

Q 25.15 Tue 14:00 Tent

STIRAP for High Fidelity Spin-Flip in Ultracold ^6Li — •Ellen Bräutigam, Carl Heintze, Sandra Brandstetter, Maciej Gałka, and Selim Jochim — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

We report on the implementation of Stimulated Raman Adiabatic Passage (STIRAP) in an ultra-cold few fermion ^6Li system.The atoms are transferred with high fidelity between the hyperfine states $|3\rangle$ and $|4\rangle$ in the ground state manifold. The transition is mediated via resonant coupling to an excited state in the D2 manifold while avoiding its population, ensuring negligible scattering and no atom loss. This method achieves robust and fast state transfer on the order of 1μs, providing a reliable tool for precise quantum state control. Among other things, this allows us in combination with Feshbach resonance to perform a sudden interaction quench.

Q 25.16 Tue 14:00 Tent

Effects of dipolar cutoff shapes on numerical calculation of properties of dipolar condensates — •Denis Mujo[1] and Antun Balaž[1,2] — [1]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Serbian Academy of Sciences and Arts

Here we study the impact of various shapes of dipolar cutoffs on the numerical calculation of ground state properties of dipolar Bose-Einstein condensates (BECs) and quantum droplets. In particular, we examine three distinct setups: the pure dipolar potential, where no cutoff is introduced; the analytically known spherical cutoff; and the cylindrical cutoff, that partially needs to be calculated numerically [1]. To understand how these different cutoff shapes affect the calculated values of physical properties of the ground state, we systematically vary key discretization parameters associated with each configuration. We demonstrate how the calculation precision of the cutoff translates into the precision of numerically obtained values of condensate and droplet properties.

[1] H.-Y. Lu et al., Phys. Rev. A **82**, 023622 (2010).

Q 25.17 Tue 14:00 Tent

Auto-ponderomotive beam manipulation for interaction-free measurements with electrons — •Franz Schmidt-Kaler[1], Nils Bode[1], Fabian Bammes[1], Michael Seidling[1], Robert Zimmermann[1], Justus Walther[1], Lars Radtke[1], and Peter Hommelhoff[1,2] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Department Physik, Ludwig-Maximilians-Universität München

(LMU), 80799 München

Cryo-electron microscopy achieves angstrom resolution for biological samples but requires reconstructing images from hundreds of thousands of identical molecules due to electron beam damage. *Interaction-free* measurements with electrons offer the potential for true single-particle analysis of radiation-sensitive samples. This method, already explored in the optical domain, requires developing electron-optical elements such as beam splitters, resonators, and guides. We present a resonator for 50 eV electrons, a guide for up to 9.5 keV electrons, and determine the first Matthieu stability regime for auto-ponderomotive devices. Our goal is to integrate these components into standard SEMs for broader applicability.

Q 25.18 Tue 14:00 Tent

Quantum gas microscopy of triangular-lattice Mott insulators — •Jan Deppe[2], Liyu Liu[1], Jirayu Mongkolkiattichai[1], Davis Garwood[1], Jin Yang[1], and Peter Schauss[2] — [1]University of Virgina — [2]Institute for Quantum Physics, University of Hamburg

This poster highlights our recent advances in the quantum simulation of electronic systems employing ultracold atoms in geometrically frustrated lattices. Frustrated quantum systems, known for hosting exotic phases like spin liquids, present a formidable challenge to condensed matter theory due to their extensive ground state degeneracy. Our focus centers on a triangular lattice, a paradigmatic example of geometric frustration where the degree of frustration is tunable. The triangular Hubbard model is a paradigm system for the study of kinetic frustration, which shows up in destructive interference between paths of holes, leading to antiferromagnetic polarons in hole-doped regime even at elevated high-temperatures. In our work, we showcase the realization of a Mott insulator of lithium-6 on a symmetric triangular lattice with a lattice spacing of 1003 nm. Spin removal techniques allow us to resolve individual spins and measure nearest neighbor spin-spin correlations across different interaction strengths. We find good agreement with numerical linked cluster expansion calculations and Quantum Monte Carlo simulations. Future endeavors involve the use of spin-resolved imaging through Stern-Gerlach splitting for full density and spin resolution. Additionally, exploration of bound states in strongly repulsive interacting systems is on the horizon.

Q 25.19 Tue 14:00 Tent

Polarization properties of Photon Bose Einstein Condensates — •Sven Enns[1], Julian Schulz[1], Kirankumar Karkihalli Umesh[2], Frank Vewinger[2], and Georg von Freymann[1,3] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern Landau, Germany — [2]Institut für Angewandte Physik, Universität Bonn, Germany — [3]Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany

We experimentally investigate properties of harmonically trapped photon gases in a dye-filled microcavity. Specifically, we analyze the polarization of thermal and condensed light and their dependence on the polarization of the pump beam. Our experimental setup enables the creation of arbitrary polarization states on the Poincaré sphere for the pump beam. Additionally, the measurement basis can be switched from linear to circular polarization allowing for a proper evaluation of the photon gas's polarization by measuring fractions of two orthogonal polarization states simultaneously. In contrast to previous setups, the dye solution is pumped through the cavity mirrors and the pump beam coincides with the optical axis of the resonator so that no spontaneous symmetry breaking is expected. In agreement with previous theoretical work [1], there is a remarkable increase of the polarization strength above the condensation threshold for a linear polarized pump. While the polarization of the condensate aligns with that of the pump beam, a circularly polarized condensate cannot be obtained. Below the condensation threshold, the photon gas stays unpolarized.

[1] R. I. Moodie, P. Kirton, and J. Keeling, Phys. Rev. A 96 (2017).

Q 25.20 Tue 14:00 Tent

Programmable Optical Lattices for Quantum Gas Microscopy — •Tom Schubert[1], Isabelle Safa[1], Sarah Waddington[1], Rodrigo Rosa-Medina[1], and Julian Léonard[1,2] — [1]Atominstitut, Technische Universität Wien, Austria — [2]Institute of Science and Technology Austria (ISTA), Klosterneuburg, Austria

Creating tailored optical potentials on demand is crucial for quantum simulation experiments with ultracold atoms, supporting the exploration of diverse strongly correlated phenomena, such as magnetic frustration or topological order. In this poster, we present the design and projection of tuneable lattice potentials using holographic beam shaping methods, combined with precise corrections of optical aberrations. The corrections and projection of the potentials are achieved employing a Digital Micromirror Device (DMD) and a Spatial Light Modulator (SLM), which facilitate phase and amplitude modulation through the use of programmable diffraction gratings. Through the correction process, we enable phase correction of wavefront aberrations with resolutions on the order of $\lambda/100$. For shaping the corrected beam into the desired optical lattices, we implement different holographic projection methods, including basic Fourier Transform and the Gerchberg-Saxton algorithm, and analyze their performance. Further we implemented a versatile experiment control system (ARTIQ), employing FPGA hardware, facilitating real-time manual control of the SLM-DMD structure. As a result, we are able to implement a variety of optical potentials, ranging from lattices in box-shape potentials to linearly tilted superlattices.

Q 25.21 Tue 14:00 Tent

Stochastic phase noise in momentum-dependent Rabi oscillations — •Samuel Böhringer, Fabian Kienle, and Richard Lopp — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany

The laser-driven two-level system is the most fundamental model in quantum optics. It plays a central role in the description of beam splitters and mirrors in matter-wave interferometry and various other experiments with the ultimate goal to achieve high-precision measurements. A limiting factor to the precision of these measurements is laser phase noise. While there are numerous models for the description of laser phase noise in driven systems, they are lacking the inclusion of the center-of-mass (COM) degrees of freedom. However, the COM-motion is crucial for many application. We provide a theoretical model for phase noise in Rabi oscillations including the COM degrees of freedom. In particular, we derive and solve a set of stochastic differential equations that describe the evolution of momentum-dependent observables during a laser pulse with phase noise.

Q 25.22 Tue 14:00 Tent

Extending the holographic superfluid model — •Martin Zboron[1], Gregor Bals[2,3], Thomas Gasenzer[1,2,3], and Carlo Ewerz[2,3] — [1]Kirchhoff-Institut für Physik, Uni Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Uni Heidelberg, Philosophenweg 16, 69120 Heidelberg — [3]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany

Gauge-gravity duality establishes a connection between strongly correlated quantum systems and higher-dimensional gravitational theories at weak coupling. Utilising an Abelian Higgs model in an asymptotically anti-de Sitter spacetime, one obtains the so-called holographic s-wave superfluid. A rich phenomenology is embodied in this model making dynamics of defects, such as quantised vortices, amenable to precise quantitative analysis. Aside from vortex dynamics in the dissipative superfluid, excitations like Kelvin waves on top of vortex lines can be studied as well as the instability of vortices with high winding numbers. Recent proposals presented possible extensions of the model in order to capture the transition to a holographic model of supersolidity, allowing access to dynamics of vortices as well as their pinning and unpinning within the supersolid state. This also opens a path to understanding the spin-down of pulsars in a supersolid framework.

Q 25.23 Tue 14:00 Tent

Optical dipole trapping of Rubidium in microgravity — •Marian Woltmann, Yann Sperling, Jan Stiehler, Marius Prinz, and Sven Herrmann — Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Germany

The sensitivity of atom interferometric sensors typically scales with the squared interrogation time. Therefore space-borne atom interferometry offers the potential of highly increased senitivities that can be utilized for e.g. gravimetric measurements as well as for tests of fundamental physical principles.

Within the PRIMUS project we develop a compact all-optical matterwave source in a drop tower experiment. The all-optical approach utilizing a $\lambda = 1064\,\mathrm{nm}$ crossed beam optical dipole trap enables the use of Feshbach resonances and offers the advantages of symmetric trapping potentials and magnetic substate insensitive trapping. With our drop tower setup we demonstrated rapid Bose-Einstein condensation of ^{87}Rb with a minimum evaporation time of $t_{\mathrm{evap}} = 1.3\,\mathrm{s}$ to reach a critical phase space density on ground, while now focusing on the efficient preparation in microgravity. The PRIMUS-project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50 WM 2042.

Q 25.24 Tue 14:00 Tent

Long-term stable laser injection locking for quasi-CW applications — Alexandre de Martino, Florian Kiesel, •Kirill Karpov, Jonas Auch, and Christian Gross — Eberhard Karls Universitaet Tuebingen, Tuebingen, Germany

In our work we present a passive stabilization scheme for injection locking of high-power semiconductor laser diodes, that is generally applicable, technically easy to implement, and extremely cost-effective. It is based on the externally synchronized automatic acquisition of the optimal injection state. Central to our simple but powerful scheme is the management of thermalization effects during lock acquisition. By periodical relocking, spectrally pure amplified light is maintained in a quasi-CW manner over long timescales. We characterize the performance of our method for laser diodes amplifying 671nm light and demonstrate the general applicability by confirming the technique to work also for laser diodes at 401nm, 461nm, and 689nm. Our scheme enables the scaled operation of injection locks, even in cascaded setups, for the distributed amplification of single frequency laser light.

Q 25.25 Tue 14:00 Tent

Enhancing Rydberg Atom Cooling and Trapping with a Tunable Light Sheet — Shuanghong Tang, Philip Osterholz, Silpa Baburaj-Sheela, Jule Brosig, •Lukas Fischer, Fabio Bensch, and Christian Gross — Eberhard Karls Universität Tübingen

The utilisation of Rydberg atoms trapped in optical tweezers provides a robust platform for the investigation of strongly interacting and correlated many-body systems. In order to facilitate the tunability of the trapping potential in the vertical direction, we implemented a thin light sheet. The tunability of the vertical confinement increases the trapping frequency, thereby facilitating Raman sideband cooling through the elevation of trap frequencies and the mitigation of gravitational forces, which allows for the implementation of shallower tweezers during the cooling process. A further challenge is the phenomenon of Talbot plane loading, which results in an undesired population of atoms in the planes adjacent to the tweezer array. To address this issue, the light sheet can be employed for loading, thereby ensuring that the atomic reservoir is confined to the primary tweezer plane.

Q 25.26 Tue 14:00 Tent

Pattern formation in dipolar quantum gases — •Andreea-Maria Oros[1], Niklas Rasch[1], Wyatt Kirkby[1,2], Lauriane Chomaz[2], and Thomas Gasenzer[1,3] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227 — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 276 — [3]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16

Ultracold dipolar gases have garnered increasing interest over the past years. The anisotropic and long-range character of the dipolar interaction and the stabilizing nature of the quantum fluctuations give rise to supersolidity, superglasses, and exotic states of matter. Depending on the atom number, scattering length, and trapping geometry, different supersolid morphologies, such as triangular, honeycomb, and labyrinthine, have already been theoretically predicted to be the possible ground states of such a system. Our work expands on these phases by considering the out-of-equilibrium dynamics of a harmonically trapped, three-dimensional dipolar condensate. Following a quench in the scattering length across a phase transition boundary, we investigate the dynamical formation of supersolids, and demonstrate quenches into the triangular, honeycomb, and labyrinth phases. We furthermore investigate systems which have artificially been brought out of equilibrium, such as systems with imprinted vortex ensembles, or where the initial state differs from one that could naturally occur, in order to better aid the search for non-thermal fixed points, as well as far-from-equilibrium and novel phenomena.

Q 25.27 Tue 14:00 Tent

Quantum gas microscopy of Rydberg-dressed extended Bose Hubbard models — •David Gröters[1,2,3], Pascal Weckesser[1,2], Kritsana Srakaew[1,2], David Wei[1,2], Daniel Adler[1,2], Suchita Agrawal[1,2], Immanuel Bloch[1,2,3], and Johannes Zeiher[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany

The competition of different length scales in quantum many-body systems leads to various novel phenomena, including the emergence of correlated dynamics or non-local order. Off-resonant optical coupling to Rydberg states, known as Rydberg dressing, has been proposed as a versatile tool to engineer long-range interactions in lattice-based quantum simulators. So far however, this approach has been limited by collective losses, limiting Rydberg dressing to immobile spin systems.

On this poster, I present our recent findings on realizing an itinerant one-dimensional extended Bose Hubbard model using Rydberg-dressed ^{87}Rb atoms in optical lattices [1]. Here, we reduce the collective losses by two orders of magnitude using stroboscopic dressing. Harnessing our quantum gas microscope, we probe the correlated out-of-equilibrium dynamics of extended-range repulsively-bound pairs at low filling, and kinetically-constrained "hard rods" at half filling. Near equilibrium, we observe density ordering when adiabatically turning on the extended-range interactions.

[1] https://arxiv.org/abs/2405.20128

Q 25.28 Tue 14:00 Tent

Trapping and interfacing laser-cooled strontium atoms using an optical nanofibre — •Luca Göcke, Hector Letellier, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, Germany

We are in the process of building an experimental setup for trapping and optically interfacing laser-cooled strontium atoms using the evanescent field surrounding an optical nanofibre. The nanofibre is produced from a standard step-index optical fibre in a heat-pull process. It features a waist diameter of 200 nm where light is still efficiently guided while a significant part of the light propagates in the form of an evanescent field surrounding the nanofiber. Atoms are trapped in a one-dimensional (1D) optical lattice formed by two fiber-guided light-fields, red- and blue-detuned with respect to the strong transition at a wavelength of 461 nm. The aim is to realize a compensated trap, where the wavelengths of the trapping fields are magic for the 7.4 kHz wide intercombination line at 689 nm. This will allow us to implement advanced schemes for loading single atoms into the 1D optical lattice and to investigate the phenomenon of selective radiance [1], where the atoms themselves act as the waveguide. Here we will present our compact design for trapping strontium atoms from a laser ablated source with a “hot MOT” (operated at 461 nm wavelength), then transfer them to a “cold MOT” (operated at the intercombination line) and to the nanofibre trap.

[1]: A. Asenjo-Garcia et al. PRX 7, 031024 (2017)

Q 25.29 Tue 14:00 Tent

Fractal ground state of mesoscopic ion chains in periodic potentials — Raphael Menu[1], Jorge Yago Malo[2], •Joshua Weissenfels[1], Vladan Vuletic[3], Maria Luisa Chiofalo[2], and Giovanna Morigi[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Università di Pisa, Pisa, Italy — [3]Massachusetts Institute of Technology, Cambridge, USA

Trapped ions in a periodic potential are a paradigm of a frustrated Wigner crystal. The dynamics is captured by a long-range Frenkel-Kontorova model. We show that the classical ground state can be mapped to the one of a long-range Ising spin chain in a magnetic field, whose strength is determined by the mismatch between chain's and substrate lattice's periodicity. The mapping is exact when the substrate potential is a piecewise harmonic potential and holds for any two-body interaction decaying as $1/r^{\alpha}$ with the distance r. The ground state is a devil's staircase of regular, periodic structures as a function of the mismatch and of the interaction exponent α. While the staircase is well defined in the thermodynamic limit for $\alpha > 1$, for Coulomb interactions, $\alpha = 1$, we argue that it disappears and the sliding-to-pinned transition becomes a crossover, with a convergence to the thermodynamic limit scaling logarithmically with the chain's size. Due to this slow convergence, fractal properties can be observed even in chains of hundreds of ions at laser cooling temperatures.

Q 25.30 Tue 14:00 Tent

Lattice phase stabilization for a dipolar quantum gas microscope — •Alexandra Köpf[1], Fiona Hellstern[1], Kevin Ng[1], Paul Uerlings[1], Michael Wischert[1], Tanishi Verma[1], Stephan Welte[2], Ralf Klemt[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology

IQST, Universität Stuttgart — [2]5. Physikalisches Institut, Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Universität Stuttgart

This poster presents the development of a dipolar quantum gas microscope using Dysprosium atoms, focusing on the critical role of optical lattice phase stabilization. Dysprosium atoms will be trapped and imaged in a 360 nm UV lattice, achieving nearest-neighbor dipolar interactions of approximately 200 Hz at 10 nK. Maintaining precise lattice stabilization is also essential to confine the atoms within the narrow depth of focus (approximately 260 nm) of the high-resolution in-vacuum objective (NA = 0.9). To achieve this, we use a 1064 nm infrared lattice for vertical confinement, complemented by an active phase stabilization scheme, stabilizing the lattice relative to the objective position. This setup employs FPGA-based boards to monitor and stabilize the lattice phase through a Michelson interferometer, ensuring robust atom confinement and alignment. This approach enables controlled, long-timescale investigations of dipolar quantum phenomena, offering new insights into strongly interacting quantum systems.

Q 25.31 Tue 14:00 Tent

A comparison of sub-Doppler cooling techniques using a nano-structured atom chip — •Kai-Christian Bruns, Julian Lemburg, Joseph Muchovo, Vivek Chandra, Sam Ondracek, Hendrik Heine, and Ernst M. Rasel — Leibniz Universität Hannover, Institut für Quantenoptik

In the field of cold atomic physics, various sub-Doppler cooling techniques are being used. We investigate two different molasses cooling schemes using an atom chip with a nano-fabricated grating. These chips simplify and miniaturize quantum systems by enabling the trapping of atoms in a MOT with a single incident beam. Additionally, the use of grating atom chips also enhances the scalability and portability of such devices. These techniques holds promise for a wide array of applications, from fundamental research to practical implementations in earth observation.

In this poster, we compare sub-Doppler cooling of ^{87}Rb utilizing bright and gray molasses techniques. We manage to cool the atoms to 13 μK and 5 μK respectively. Additionally, we see an increase in phase-space density by a factor of three, when comparing gray molasses to bright molasses. To understand the benefits that this improvement could bring to experiments employing Bose-Einstein-condensates, we study the transfer into a magnetic trap.

Q 25.32 Tue 14:00 Tent

Double Bragg atom interferometry with Bose-Einstein condensates in microgravity — •Anurag Bhadane[1], Dorthe Leopoldt[2], Priyanka Barik[2], Govindarajan Prakash[3], Julia Pahl[4], Sven Herrmann[3], Andre Wenzlawski[1], Sven Abend[2], Markus Krutzik[4,5], Patrick Windpassinger[1], Ernst Rasel[2], and The Quantus Team[1,2,3,4,6,7] — [1]JGU Mainz — [2]LU Hannover — [3]ZARM, U Bremen — [4]HU Berlin — [5]FBH Berlin — [6]U Ulm — [7]TU Darmstadt

The QUANTUS-2 device is a mobile, robust, high-flux atom interferometer utilizing ^{87}Rb, designed for microgravity environments such as those provided by the Bremen drop tower and Gravitower. The Gravitower enables higher repetition rates for experiments, establishing QUANTUS-2 as a testbed for future space-based missions.

Our experiment employs a magnetic lens via the quadrupole field of an atom chip, achieving extended coherence times and enabling interferometry durations exceeding one second with double Bragg diffraction under microgravity conditions. On this poster, we report recent advancements in atom interferometry at extended timescales, along with the characterization of the system in the Gravitower.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant numbers DLR 50WM1952-1957 and DLR 50 WM 2450A-F

Q 25.33 Tue 14:00 Tent

Mean-field parton construction of Rydberg Quantum Spin Liquid from microscopic properties — •Benno Bock, Simon Ohler, and Michael Fleischhauer — RPTU, Kaiserslautern, Germany

Quantum Spin Liquids (QSL) represent an exotic phase of matter elusive to experiments. One hallmark property is the absence of magnetic spin order even at zero temperature. Despite numerous attempts, the unambiguous experimental confirmation of QSL states remains difficult. In this context, the possibility of realizing QSL physics on Rydberg atom-based quantum simulators has been a promising avenue for investigation [Semeghini et al., Science 374 (2021)].

Recently, the existence of a QSL state has been investigated numerically with Exact Diagonalization (ED) in a system of Rydberg atoms on a honeycomb lattice featuring density-dependent Peierls phases [Ohler et al., PRR 5 (2023)]. Later investigations using projective symmetry group arguments [Tarabunga et al., PRB 108 (2023)] confirmed the state to be a chiral spin liquid by comparing ground-states of ansatz Hamiltonians with ED results. In this work, we take a different approach, deriving explicitly the mean-field parton Hamiltonian starting from the microscopic Rydberg properties. We then determine the mean-field ground-state self-consistently, which yields a more accurate representation of the Rydberg ground-state. It shows large overlap with the ED simulation but is in principle not restricted to small system sizes.

Q 25.34 Tue 14:00 Tent

Aberration correction and trap creation in a dipolar quantum gas microscope — •Michael Wischert[1], Kevin Ng[1], Fiona Hellstern[1], Paul Uerlings[1], Alexandra Köpf[1], Tanishi Verma[1], Stephan Welte[2], Ralf Klemt[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology — [2]5. Physikalisches Institut, Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Universität Stuttgart

This poster focuses on calibrating and correcting optical aberrations as well as holographically projecting optical traps for a dipolar quantum gas microscope. To achieve large nearest-neighbor interactions (200 Hz at 10 nK), a 180 nm spaced near-UV lattice with dysprosium atoms will be used. This setup requires a high NA objective (NA 0.9) where minimizing imaging aberrations is critical for maintaining image fidelity. To mitigate these aberrations, we introduce a spatial light modulator (SLM) after the objective, enabling phase manipulation of the collected light and correction of the distorted wavefront. We test and compare different methods for calibrating and correcting aberrations using the SLM. Additionally, we explore the use of the SLM in creating tailored optical trap potentials by projecting and analyzing various trap geometries in a separate setup. Our work aims at exploring how SLMs can be utilized to improve imaging performance in quantum gas microscopes.

Q 25.35 Tue 14:00 Tent

Quantum turbulence in a dipolar Bose gas at the anomalous non-thermal fixed point — •Niklas Rasch[1] and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg

This work focuses on quantum turbulence in the vicinity of an anomalous non-thermal fixed point (NTFP) characterized by slow, subdiffusive coarsening of a length scale. The NTFP is approached in the temporal evolution of a quasi-2d dipolar Bose gas starting from variously sampled initial vortex configurations. Already in the early dynamics, we observe the build-up of an inverse energy cascade and recover Kolmogorov's $-5/3$ power law in the incompressible energy spectrum. Due to the irreversible conversion of incompressible (vortices) into compressible energy (sound) this is understood in the context of decaying turbulence. By studying higher moments of the velocity circulation, we aim to understand the role that intermittency plays in the approach to a non-thermal fixed point. Further, using the high tunability of the anisotropic and long-range dipolar interaction we can probe its effects on the quantum turbulent behavior.

Q 25.36 Tue 14:00 Tent

Exploring extended Hubbard models in an optical superlattice — •Valentin Jonas, Nick Klemmer, Janek Fleper, Ameneh Sheikhan, Corinna Kollath, Michael Köhl, and Andrea Bergschneider — Physikalisches Institut, Bonn, Germany

Ultracold atoms in optical lattices allow for simulating strongly correlated many-body systems in the Hubbard model. Its quantum phases arising from the interplay of tunneling and on-site interaction have been extensively studied over the last few years experimentally, while systems beyond the simple Hubbard model are much less explored.

Our experimental apparatus uses fermionic potassium atoms in a 3D optical lattice with an in-plane superlattice to realize chains of double wells. By asymmetrically shaking the double wells, we recently realized an effective Floquet system with additional pair tunneling while fully suppressing the dynamics of single particles. By controlling the drive frequency, we could tune the system and enhance pair tunneling up to the size of the superexchange [1].

Currently, we are investigating excited two-particle states in the superlattice such as repulsively bound atom pairs and can demonstrate their deterministic preparation in the double wells. These states are predicted to be connected to pair states featuring unconventional superconductivity.

[1] N. Klemmer et al., PRL (Accepted), 2024

Q 25.37 Tue 14:00 Tent

Reaction-Diffusion Dynamics of Quantum Gases — •Hannah Lehr, Igor Lesanovsky, and Gabriele Perfetto — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We consider the dynamics of quantum gases underlying coherent motion as well as dissipative reactions. For Fermions we discuss e.g., k-body losses $kA \to \emptyset$. In this case the universality lies within the long time decay of the particle density. For Bosons we consider also particle creating processes as branching $A \to A + A$. The competition between the latter and single body decay and coagulation $A + A \to A$ leads to an absorbing state phase transition in the stationary state. Our goal is to understand how quantum effects impact on the universality class of the transition.

We tackle these problems combining a variety of methods ranging from kinetic large-scale equations via the time-dependent generalized Gibbs ensemble method (TGGE), and Keldysh field-theory diagrammatic expansion. Specifically, for the Fermi gas under weak k-body losses we find long-time decay for the density of particles different from mean field. For the Bose gas, we observe a rich stationary phase diagram different from the classical counterpart of the model.

Our findings show that quantum effects impact on large-scale universal behaviour leading to novel universality classes compared to classical physics. These results are experimentally relevant since they directly connect to cold-atomic processes involving dissipative processes such as particle losses and creation.

Q 25.38 Tue 14:00 Tent

Single-Atom Addressing in Optical Lattices Using UV Raman Transitions — •Francesco Testi[1,4], Andreas von Haaren[1,2], Robin Groth[1,2], Luca Muscarella[1,2], Janet Quesja[1,2], Liyang Qiu[1,2], Immanuel Bloch[1,2], Timon Hilker[1,3], Titus Franz[1,2,4], and Philipp Preiss[1,2] — [1]Max Planck Institute of Quantum Optics, Garching — [2]Munich Center for Quantum Science and Technology — [3]University of Strathclyde, Glasgow — [4]Ludwig Maximilian University of Munich

FermiQP is a demonstrator for a lattice-based fermionic quantum processor utilizing ultracold fermions in optical lattices. Operating in analog mode, the system facilitates precision studies of the two-dimensional Fermi-Hubbard model. In its digital mode, it implements a universal gate set on the spin degree of freedom, enabling advanced state engineering and local basis transformations. Combined with a rapid preparation cycle for degenerate Fermi gases, FermiQP opens new pathways for fermionic quantum information processing, with applications in quantum chemistry and strongly correlated materials.

We present a single-atom addressing scheme for coherently manipulating the internal states of individual Lithium-6 atoms within an optical lattice. The scheme employs two-photon Raman transitions at a UV wavelength of 323 nm, optimizing atomic coherence while minimizing cross-talk to neighboring atoms. We provide a comprehensive characterization of the 323 nm laser system and introduce an addressing system based on Acousto-Optic Deflectors capable of delivering up to six independently steerable beams in two dimensions.

Q 25.39 Tue 14:00 Tent

Challenges behind performing atom interferometry in extended free fall — •Priyanka Barik[1], Dorthe Leopoldt[1], Anurag Bhadane[2], Julia Pahl[3], Sven Abend[1], Sven Herrmann[4], André Wenzlawski[2], Patrick Windpassinger[2], Markus Krutzik[3,7], Ernst M. Rasel[1], and QUANTUS Team[1,2,3,4,5,6,7] — [1]LU Hannover — [2]JGU Mainz — [3]HU Berlin — [4]ZARM, U Bremen — [5]U Ulm — [6]TU Darmstadt — [7]FBH Berlin

The QUANTUS-2 apparatus is a high-flux ^{87}Rb BEC machine, based on a magnetic chip-trap, which generates $1{\times}10^5$ atoms at a 1Hz rate. High-precision quantum sensing with atom interferometers requires long interrogation time of several seconds with ultra-low expansion rates of the BECs. Thus, we perform our experiment in the Drop Tower in Bremen with a novel matter-wave lens system for the collimation of the condensate. The QUANTUS-2 setup experiences noticeable tilts and rotations which alter the spatial rotation of the ^{87}Rb atomic cloud and its projection along the imaging axes and the interferometry pulses. These rotations lead to position offsets, which become more pronounced as the TOF is increased, and, hence, are expected to contribute to a loss of contrast of the interferometer. We report on the proposal to mitigate these problems using a retro-reflective mirror mounted on a tip/tilt platform which will pave the way for long interrogation times. This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant numbers DLR 50WM1952-1957 and DLR 50 WM 2450A-F.

Q 25.40 Tue 14:00 Tent

Design and characterization of a compact and transportable strontium MOT — •Darius Hoyer and Simon Stellmer — Physikalisches Institut, Bonn, Deutschland

The broad linewidth of the 461 nm (5s5s) ^{1}S$_0$ $\to$ (5s5p) ^{1}P$_1$ transition of strontium allows for efficient laser cooling and trapping in a magneto-optical trap (MOT). This results in a bright MOT that is visible to the naked eye. Thus the Sr MOT is an ideal toy model for making quantum optics more accessible to a wide audience.
We present the design of a transportable Sr MOT based on permanent magnets for the Zeeman slower and the MOT.

Q 25.41 Tue 14:00 Tent

Rydberg interactions in ultracold Ytterbium — •Florian Pausewang, Tangi Legrand, Xin Wang, Ludwig Müller, Eduardo Uruñuela, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Mapping the strong interactions between Rydberg excitations in ultracold atomic ensembles onto photons opens the door to achieving high optical nonlinearities at the single-photon level. While previous demonstrations of this concept have relied exclusively on alkali atoms, two-valence-electron species like ytterbium offer unique advantages, such as narrow-linewidth laser cooling and, for Yb-174, potentially longer coherence times of polaritons compared to earlier Rubidium-based experiments. In this poster, we present our new ytterbium apparatus including Yb-specific challenges as light-induced atomic repulsion and two-photon ionization processes, and discuss our progress towards photon-photon interactions by Rydberg polaritons. We also report the spectroscopic characterization of ultra long-range Yb Rydberg molecules that arise as bound states in the low energy scattering of a highly excited Rydberg electron and a ground state atom. Our experimental setup featuring a dual-chamber compact design and a two-color MOT allows the creation of dipole trapped atomic ensembles at high density and low temperature, with $5 \cdot 10^6$ atoms and $T < 10\,\mu$K within 2 s. Further evaporative cooling down to condensation is possible. Additionally, a field ionization system with ion detection via a Micro-Channel Plate enables high-precision spectroscopy.

Q 25.42 Tue 14:00 Tent

Toward Magnetically Insensitive ^{39}K BECs — •Wei Liu, Constantin Avvacumov, Alexander Herbst, Ashwin Rajagopalan, Knut Stolzenberg, Daida Thomas, Ernst Rasel und Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The sensitivity of an atom interferometer(AI) is generally limited by the standard quantum limit (SQL). Entangled interferometer schemes generated through atom-atom interactions in a trapped configuration can surpass the SQL, thereby enhancing the sensitivity of the AIs. However, trapped AIs are constrained by phase diffusion stemming from collisions at high atomic density. Feshbach resonances can suppress phase diffusion in trapped AI by tuning scattering length, enabling measurements with high-densities and large atomnumbers. ^{39}K BEC are ideal canidiates for such interfermetry schemes, as they feature broad resonans at low magnetic fields.

To create ^{39}K BEC in $m_F = 0$ suitable for AI at low field, the narrowness of resonance at 59.3G and spin-changing collision pose significant challenges for evaporative cooling. We present several schemes for generating a ^{39}K BEC in $m_F = 0$ through using microwave pulses and co-propagating Raman beam before and after evaporative cooling and discuss their limitations.

Q 25.43 Tue 14:00 Tent

Matter-wave interferometry with large metal clusters in a free-fall setup — •Eric van den Bosch and Klaus Hornberger — University of Duisburg-Essen, Germany

Matter-wave interferometry can be used to probe fundamental quantum properties on increasingly large scales. Using ionising gratings produced by UV lasers mitigates some of the limitations of material gratings, while also allowing for more versatile setups. We study an optical time-domain ionising matter-wave interferometer (OTIMA) setup [1] in a free-fall tower aimed at masses of up to 10^7 amu. We treat the influence of gravity and the Coriolis force in three dimensions and discuss possible experimental schemes to counteract the Coriolis effect.

[1] Nimmrichter, Haslinger, Hornberger, Arndt (2011). Concept of an ionizing time-domain matter-wave interferometer. New Journal of Physics, 13(7)

Q 25.44 Tue 14:00 Tent

Langevin dynamics of a Bose gas coupled to a small heat bath — •Carsten Henkel and Sasha Roewer — Universität Potsdam, Institut für Physik und Astronomie

In an elongated, quasi-one-dimensional trap, a degenerate Bose gas is formed by atoms in the lowest quantum state of the "radial" confinement. Atoms in higher states can provide a heat bath which is, however, not much larger compared to the degenerate gas. We study with the help of Langevin dynamics (stochastic Gross-Pitaevskii equation) the evolution of the complex order parameter, taking into account the exchange of energy and particles with the heat bath. Curiously, as the heat bath gets smaller, its temperature drops, and the Bose gas is more degenerate. At the same time, temperature fluctuations are larger. Thermodynamically relevant quantities like the internal energy are extracted from the simulations. We also explore non-equilibrium situations with an externally imposed temperature difference.

Q 25.45 Tue 14:00 Tent

Symmetry-Preserving Condensation of Photons — Andreas Redmann, •Riccardo Panico, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstrasse 8, 53115 Bonn, Germany

We investigate the statistical behavior of a Bose-Einstein condensate of photons in a dye-filled optical microcavity. This system enables the observation of grand-canonical statistical conditions through the coupling of photons to a reservoir of dye molecules, supporting the coexistence of macroscopic occupation and unusually large fluctuations of the particles number. Building on prior demonstrations of grand-canonical statistics [1,2], we push the boundaries of our system to explore conditions for which the first- and second-order coherence times become comparable. In this regime, the condensate exhibits a discontinuous phase, driven by the relatively high probability of having zero particles in the condensate, with spontaneous emission of photons from the reservoir setting the phase of the condensate each time. Despite this, photons are expected to exhibit macroscopic occupation on average, while at the same time having characteristics of incoherent light sources. From a thermodynamic perspective, this would translate to the formation of a condensate without spontaneous symmetry breaking.

[1] Julian Schmitt, et al., Laser Spectroscopy, pp. 85-96 (2016)
[2] Julian Schmitt, et al., Phys. Rev. Lett. **116**

Q 25.46 Tue 14:00 Tent

Assessing interactions of Rb vapor with mirror coatings for compact cold-atom sources — •Constantin Avvacumov, Alexander Herbst, Wei Liu, Ashwin Rajagopalan, Knut Stolzenberg, Daida Thomas, Ernst Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Atom interferometers are effective tools for fundamental research and geodesy applications, e.g. for gravimetry. Fundamentally, quantum projection noise motivates the development of high-flux cold atom sources. A typical first cooling stage of atom interferometers is a two-dimensional magneto-optical trap (2D-MOT). In recent years, attempts to improve on 2D-MOTs' SWaP (size, weight, and power) budget raised questions regarding the compatibility of high-quality optical coatings exposed to alkali vapor, e.g., rubidium or potassium.

In this poster, we present systematic analysis of the interaction of Rb vapor with highly reflective coating materials (gold, silver, aluminium, dielectric coatings) and compare samples with and without protective coating. In our mirror testing setup, we observe mirror reflectivity degradation as a function of time and Rb partial pressure in a long-term perspective. Six mirror samples are exposed to alcali vapor at partial pressures up to and about saturation level (about $5 * 10^{-7}$ mbar at room temperature). The results show significant reduction in mirror lifespan at Rb pressures above saturation level, which varies, however, for different samples. Analysis of the reactivity of alkali vapor with various materials at different pressures has an application in design of future compact quantum optical experiments.

Q 25.47 Tue 14:00 Tent

Local Chern number for noninteracting fermions in the Haldane model with external confinement — •Daniel Samoylov and Walter Hofstetter — Goethe Universität, Institut für Theoretische Physik, 60438 Frankfurt, Germany

We numerically study the formation of topological domains in the Haldane model on a honeycomb lattice in the presence of an external trapping potential. To map out topological domains in real space we calculate the local Chern number of the system as a function of position. The local Chern number was introduced by Bianco and Resta [1] as a topological marker of the Chern number. In order to test our implementation, we calculate the local Chern number of the Haldane model without external potential and confirm the results in [1]. By adding an external potential to the system, we find different topological domains which are indicated by a spatial variation of the local Chern number across the honeycomb lattice. We investigate the formation of topologically non-trivial domains, both as a function of the Fermi energy and for different shapes of the trapping potential. Related results were obtained for the Hofstadter model in [2].

[1] R. Bianco and R. Resta, Phys. Rev. B 84, 24 (2011)
[2] U. Gebert, B. Irsigler, and W. Hofstetter, Phys. Rev. A 101, 6 (2020)

Q 25.48 Tue 14:00 Tent

Laser-induced lattice potentials for optical quantum gases inside microcavities — •Purbita Kole[1], Nikolas Longen[1], Daniel Ehrmanntraut[1], Peter Schnorrenberg[1], Kevin Peters[1], and Julian Schmitt[1,2] — [1]Universität Bonn, IAP, Wegelerstr. 8, 53115 Bonn — [2]Universität Heidelberg, KIP, Im Neuenheimer Feld 227, 69120 Heidelberg

Lattice potentials provide a fundamental ingredient for the description and study of the behaviour of particles in crystal-like structures, most notably in condensed matter systems. The realisation of photon Bose-Einstein condensates in arrays of coupled dye-filled microcavities opens a new platform for such physics owing to the high degree of tunability of the potentials in 1D and 2D. Here, we present laser-induced reversible and irreversible mirror structuring techniques for the generation of periodic lattice potentials for photon Bose-Einstein condensates with variable site-resolved control of the potential energy. As the dispersion relation for the two-dimensional photon gas inside an optical dye-filled microcavity depends on the cavity length, static potentials are introduced by modulating the mirror surface with a laser writing method. Harnessing the thermo-optic effect in the dye solution, we then modify the optical path length in a reversible way by projecting structured light onto an absorbing Si-layer in the backside of one of the cavity mirrors. The two-fold tuning of lattice potentials opens the possibility to study a variety of novel Hermitian and non-Hermitian effects with quantum gases of light.

Q 25.49 Tue 14:00 Tent

Fast 24-bit analog-to-digital converter for high-precision experiment control — •Jonas Drotleff, Philipp Lunt, Johannes Reiter, Paul Hill, Maciej Gałka, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Cold atom experiments rely on precision measurements and stable experimental parameters to prepare and control quantum states with high fidelity. High-dynamic range analog-to-digital converters (ADCs) minimize the information loss caused by the digitalization and play a major role in modern experiment control systems. We present a novel measurement device that provides a large dynamic range (19 noise-free bits) at sampling rates of up to 2 million samples per second. At lower sampling rates, the converter yields up to 24 noise-free bits, allowing for enhanced flexibility in the type and bandwidth of input signals. With its small and portable design, the device allows for digitalization close to the signal's origin, thereby eliminating long signal paths and subsequent noise pickup. This ADC is the first step towards more precise control of experimental parameters, with potential applications in the range from ultra-precise stabilization of optical trap depths to magnetic offset field control at unprecedented levels.

Q 25.50 Tue 14:00 Tent

Towards trapping of single atoms in a micro-fabricated optical tweezer — •Marian Rockenhäuser[1], Lukas Blessing[2], and Tim Langen[1] — [1]TU Wien, Atominstitut, Cold Molecules and Quantum Technologies — [2]Universität Stuttgart, 5. Physikalisches Institut

The trapping of single ultracold atoms is a crucial technique for applications in quantum computation, communication, and sensing. However, one of the main disadvantages of most experiments is their considerable large size and complexity. Here we present our progress towards the miniaturization of a classic single atom experiment. This is achieved by the use of a sophisticated compact laser system and the integration of a 3D-printed optical tweezer with a rubidium magneto-optical trap. The tweezer is created using micrometer-scale lenses fabricated directly onto the tip of a standard optical fiber. These unique properties enable the efficient trapping of single atoms and the collection of their fluorescence using the same fiber. Its unique properties will make it possible to both trap single atoms and the subsequent collection of their fluorescence with high efficacy. Based on this, a single-photon source can be realized which will have extensive applications in the field of quantum information processing.

Q 25.51 Tue 14:00 Tent

Quantum simulation and computation using fermions in an optical superlattice — •Marnix Barendregt[1], Thomas Chalopin[1,2], Petar Bojović[1], Si Wang[1], Johannes Obermeyer[1], Dominik Bourgund[1], Titus Franz[1], Immanuel Bloch[1], and Timon Hilker[1,3] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Université Paris-Saclay, Institut d*Optique Graduate School, CNRS, Laboratoire Charles Fabry, Palaiseau 91127, France — [3]Department of Physics, University of Strathclyde, Glasgow, G4 0NG, UK

Strongly-correlated materials show rich phase diagrams at low temperatures and finite dopings. The Fermi-Hubbard model and its variations are believed to describe many of these phases, including cuprate high-Tc superconductivity and the pseudogap phase. We have implemented a single-site and spin resolved quantum gas microscope with an optical superlattice. Control over the doping and temperature has allowed us to explore large regions of the Fermi-Hubbard phase diagram and find indications of the pseudogap phase by measuring spin and dopant-spin correlations up to fifth order. Additionally, atoms in the superlattice can be isolated into an array of double wells, which we dynamically control to implement two-qubit collisional gates with excellent fidelity. This paves the way for fermionic quantum computation.

Q 25.52 Tue 14:00 Tent

Experimental Study of the Solidity and Smecticity of a Driven Superfluid — •Nikolas Liebster, Marius Sparn, Elinor Kath, Jelte Duchene, Helmut Strobel, and Markus Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Bosonic quantum gases have been shown to result in spontaneously arising, self-stabilized periodic density modulations when the two-particle interaction strength is driven in time. Here we experimentally demonstrate that such states share key properties to a seemingly different physical system, namely supersolids, not only in their superfluidity and periodic density structure but also in their excitations. This correspondence is made possible through the effective theory of hydrodynamics of supersolids, which is constructed using assumptions of spontaneously broken symmetries and conserved quantities. We experimentally investigate both stripe patterns as well as two-dimensional crystals, using novel techniques to instigate sound modes in each configuration.

Q 25.53 Tue 14:00 Tent

Realization and characterization of a tunable 2D optical accordion for ultracold atoms — •Krishnan Sundararajan, Alexander Guthmann, Felix Lang, Louisa Marie Kienesberger, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

Optical lattices, formed by the interference of coherent laser beams, are powerful tools for manipulating quantum gases. A versatile implementation, the optical "accordion," enables tuneable lattice spacing by adjusting the angle between beams. We aim to develop such a setup using a beam splitter made of custom Dove prisms bonded with UV-curing epoxy, combined with a large aspherical lens. The prism pair splits a single beam into two parallel rays, whose separation depends on the incoming beam properties. Focusing these rays creates an interference pattern forming the lattice potential. We will present the design, assembly, and ex-situ characterization of this optical accordion and its extension to a 2D configuration for accessing lower-dimensional systems with ultracold lithium-6 atoms.

Q 25.54 Tue 14:00 Tent

Two-dimensional grating magneto-optical trap — •Joseph Muchovo, Julian Lemburg, Sam Ondracek, Kai-Christian Bruns, Vivek Chandra, Hendrik Heine, and Ernst M. Rasel — Leibniz Universität Hannover, Institut für Quantenoptik

Ultracold atoms provide exciting opportunities for advancing matter-wave interferometry and enabling more precise tests of fundamental physics in a variety of experimental and applied settings. To achieve larger atom numbers and higher repetition rates, two-dimensional (2D) magneto-optical traps (MOTs) can be employed as separate source chambers. These offer distinct advantages in the pre-cooling and faster, more efficient loading of atoms into three-dimensional grating MOTs, a key step for many precision measurements. To realise field applications of quantum sensors utilising cold atoms, there is need for simpler, more efficient and more compact sources.

In this poster, we will present the design and implementation of a 2D grating MOT requiring only a single input cooling beam in combination with pusher-retarder beams, thereby simplifying the setup. This innovative approach will result in a robust, highly compact, and efficient source of ultracold atoms that can be used in field and space applications.

Q 25.55 Tue 14:00 Tent

Developing a hybrid tweezer array of Rydberg atoms and polar molecules — •Kai Voges, Daniel Hoare, Joe Vagge, Qinshu Lyu, Jonas Rodewald, Ben Sauer, and Michael Tarbutt — Centre for Cold Matter, Imperial College London, UK

Hybrid tweezer arrays of atoms and molecules are an innovative tool for new applications in quantum science and technology. The combination of Rydberg atoms with their large electric dipole moment and polar molecules with their rich level structure and long state coherence times makes this approach a promising platform for quantum simulation [1] and computing [2,3].

In this poster, we present our recent results on the realization of such a hybrid tweezer array based on ultracold Rb atoms and directly laser-coolable CaF molecules. We discuss the advantages and challenges of using two different ultracold particle types and present our preparation strategies for the atoms and molecules. In addition, we show our results in single atom trapping, imaging and tweezer trap characterisation and present our progress for highly efficient tweezer loading.

Our approach will make it possible to construct arbitrary patterns of atoms and molecules. Through the dynamic rearrangement of tweezers and the long-range interactions mediated by Rydberg atoms, this hybrid platform will be a compelling candidate for scalable quantum computing.

[1] J. Dobrzyniecki et al., PRA 108, 052618 (2023)
[2] C. Zhang et al., PRX Quantum 3, 030340 (2022)
[3] K. Wang et al., PRX Quantum 3, 030339 (2022)

Q 25.56 Tue 14:00 Tent

Observation of an integer quantum Hall state of six fermions — •Johannes Reiter, Paul Hill, Philipp Lunt, Jonas Drotleff, Maciej Galka, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Deutschland

Integer and fractional quantum Hall states underpin the understanding of topological phases of matter featuring exotic macroscopic properties such as the quantization of the transverse resistivity and emergence of robust edge currents.

Expanding upon our deterministic preparation of a spinful two-particle Laughlin state [arXiv:2402.14814], we present the recent observation of an integer quantum Hall state of six rapidly rotating fermions confined in a tight optical tweezer. Momentum-space imaging of the many body density reveals the hallmark uniform flattening of the particle density distribution and provides access to the microscopic correlations. This measurement demonstrates the scalability of our atom-by-atom assembly technique of quantum hall states and opens new avenues for probing the microscopic dynamics of topological phase transitions.

Q 25.57 Tue 14:00 Tent

Exploring the superfluid phase diagram for imbalanced Fermi gases in 2D — •René Henke, Cesar R. Cabrera, Moritz von Usslar, Artak Mkrtchyan, and Henning Moritz — Institut für Quantenphysik, Universität Hamburg

In Fermionic superfluids, condensation occurs through the pairing of fermions with opposite momenta and spin. This process is disturbed by introducing a spin imbalance, which leads to a mismatch between the respective Fermi surfaces. The result is a complex phase diagram including different phases, such as phase separation between a balanced superfluid and free fermions, as well as more exotic phases like the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state, where the pairs carry non-zero momentum. As of now, the phase diagram of imbalanced Fermi gases in two dimensions remains largely unexplored.

In this poster, we present our results on spin-imbalanced homogeneous Fermi gases in two dimensions. Using lattice modulation spectroscopy, we excite a collective mode associated to the superfluid order parameter of the system. Our results show how this collective mode vanishes at a critical polarization and interaction strength, providing a step towards understanding exotic pairing in low dimensions.

Q 25.58 Tue 14:00 Tent

Towards a Potassium-39 quantum gas microscope — Scott Hubele, •Yixiao Wang, Martin Schlederer, Alexandra Mozdzen, Guillaume Salomon, and Henning Moritz — Institute for Quantum Physics, University of Hamburg, Germany

The rapid development of quantum simulation has enabled us to study many-body physics with cold atom experiments in a controlled way, avoiding the computational complexity of solving the problems with classical computers. The introduction of quantum gas microscopes further allows to study the system with single-site resolution in real space.

In our experiment, we prepare ultracold Potassium-39 in a 1064nm optical lattice in a bowtie configuration, which can be well described by the Bose-Hubbard model, and confine the atoms in quasi-2D geometry with a pancake-shaped trap and a vertical repulsive lattice. To achieve single-site resolution, we employ Raman sideband imaging at near-zero magnetic field to cool the atoms while simultaneously collecting fluorescence photons with a high-NA objective.

Here, we present the progress towards building a Potassium-39 quantum gas microscope and introduce the experimental techniques for preparing ultracold atoms in the optical lattices and imaging them with high resolution using Raman sideband imaging.

Q 25.59 Tue 14:00 Tent

An experimental study of the heating of laser-cooled atoms in a nanofiber-based two-color trap — •Antoine Glicenstein, Riccardo Pennetta, Daniel Lechner, Jürgen Volz, Philipp Schneeweiss, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

The lifetime of atoms in nanofiber-based optical traps is significantly smaller than in comparable free-space traps. This experimental observation has been made for different types of trapped atoms such as Cesium or Rubidium, and the mechanical motion of the nanofiber has been proposed to be the major factor behind the excess heating [1]. By analyzing the polarization fluctuations of light transmitted through the nanofiber, we observe the nanofiber's fundamental torsional mode [2], which exhibits a Q-factor of up to 10^7 and a resonance frequency close to the trapping frequencies. In order to study its potential influence on the atoms' lifetime, a piezo actuator is integrated into the nanofiber holder. While we successfully implemented feedback cooling to suppress the torsional motion and actively drove the torsional mode, neither approach resulted in a significant modification of the lifetime, indicating that the torsional mode is irrelevant for the heating rate of trapped atoms. Our research now shifts to investigating flexural modes, which are theoretically predicted to contribute most strongly to the heating [1] but are experimentally more challenging to address.

[1] Hümmer et al., PRX 9, 041034 (2019) [2] Tebbenjohanns et al., PRA 108, L031101 (2023)

Q 25.60 Tue 14:00 Tent

Possible configurations of the Heidelberg Quantum Architecture — •Daniel Dux, Tobias Hammel, Maximilian Kaiser, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Heidelberg, Germany

We present the current status of our new modular Lithium-6 platform. Besides a high degree of adaptability, this platform aims for a very fast cycle rate. We show first results from some of the already implemented modules, such as dipole traps, optical tweezers, an optical accordion to provide a 2D confinement, RF coils that enable fast spin flips, a free space imaging setup that allows simultaneous spin selective readout and a self optimization routine to set experiment parameters. Given these modules, we will discuss possible configurations that will be achievable within the Heidelberg Quantum Architecture and find applications in quantum technologies.

Q 25.61 Tue 14:00 Tent

Deterministic Generation of Localized Spin Excitations in a Spin-1 BEC — Yannick Deller, •Alexander Schmutz, Raphael Schäfer, Alexander Flamm, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Deutschland

We present the experimental techniques to reliably generate localized spin excitations in a quasi one-dimensional ferromagnetic spin-1 BEC. We utilize a steerable laser at the tuneout-wavelength for ^{87}Rb in order to locally induce an effective magnetic offset field which can be controlled on the μm scale. Localized transitions between hyperfine states are implemented by amplitude modulation of the laser beam at the transition frequency [1].

To characterize the resulting spin excitations, we track their time evolution in all relevant observables by employing a generalized POVM readout scheme [2].

We investigate their properties such as lifetime and propagation speed in different parameter regimes and compare with numerical simulations and analytical models to investigate for a topological classification of the excitations.

1 Lannig et. al., PRL 125, 170401 (2020)
2 Kunkel et. al., PRL 123, 063603 (2019)

Q 25.62 Tue 14:00 Tent

Heidelberg Quantum Architecture - Fast and modular quantum simulation — •Finn Lubenau, Maximilian Kaiser, Daniel Dux, Tobias Hammel, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany

We are presenting our Heidelberg Quantum Architecture, a quantum gas platform that combines individual modules to implement a large variety of functionalities, that can be quickly updated and exchanged.

Currently, the core modules consist of a cold atom source that allows for very fast cycle time, dipole traps and optical tweezers, high fidelity single atom and spin resolved imaging, confinement to a 2D plane using an optical accordion. Here we will present progress on implementing a spatial light modulator (SLM) module to create tunable light fields in a precise and reproducible way, including the ability to correct for optical aberrations.

Q 25.63 Tue 14:00 Tent

ORKA - Towards a Cavity Enhanced All Optical Rb87 BEC Source for Atom Interferometry in Microgravity — •Jan Eric Stiehler, Marius Prinz, Marian Woltmann, and Sven Herrmann — Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Germany

Evaporative cooling in optical traps is a common method to prepare ultra-cold atoms and generate Bose-Einstein-condensates (BEC). This usually comes at the price of an increased power budget for the trapping lasers. For setups that require energy efficiency, e.g. in space, magnetic chip traps are thus often preferred. However, these also come with their own limitations and lack some of the benefits of all-optical trapping and cooling. As an alternative, we are investigating the use of a resonantly enhanced 1064nm optical dipole trap for Rb87 to mitigate the power needs for all optical evaporative cooling. We are working on employing a bow-tie cavity for evaporative cooling down to a BEC to then be used as a matterwave source for interferometry in free-fall experiments at the Gravitower Bremen facility. Here we present our design and current progress of the experiment as well as first tests of the resonator. The ORKA project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50 WM 2267.

Q 25.64 Tue 14:00 Tent

Ground Support for the BECCAL Laser System for Cold

Atom Experiments onboard the ISS — •Hamish Beck[1], Hrudya Thaivalappil Sunilkumar[1], Marc Kitzmann[1], Matthias Schoch[1], Christoph Weise[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Jakob Pohl[1], Achim Peters[1], and the BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hanover — [5]DLR-SI, Hanover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR-SC, Braunschweig

The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is designed for operation onboard the International Space Station (ISS). This multi-user facility will enable experiments with K and Rb ultra-cold atoms and BECs in mircogravity. Fundamental physics will be explored at longer time- and lower energy-scales compared to those achieved on earth.

The BECCAL laser system is comprised of micro-integrated diode lasers, miniaturized free-space optics on Zerodur boards, and a system of fibres to bring light to the physics package. The design is subject to strict size, weight, and power (SWaP) constraints, and the operation of the system is supported by extensive ground-based systems.

The ground-based systems built for validation and testing will be presented alongside the design of the flight model.

This work is supported by the DLR with funds provided by the BMWK under grant number 50WP2102.

Q 25.65 Tue 14:00 Tent

Kármán vortex streets in a dissipative superfluid — •Georg Trautmann[1], Gregor Bals[2,3], Thomas Gasenzer[1,2,3], Carlo Ewerz[2,3], and Davide Proment[3,4,5] — [1]Kirchhoff-Institut für Physik, Uni Heidelberg — [2]Institut für Theoretische Physik, Uni Heidelberg — [3]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung — [4]School of Engineering, Mathematics and Physics, University of East Anglia, Norwich Research Park — [5]Centre for Photonics and Quantum Science, University of East Anglia

Moving an obstacle potential in a two-dimensional Bose-Einstein condensate can lead, depending on the potential's size and velocity, to different phases of vortex shedding. Of particular interest is the formation of a long-lived alternating series of vortex pairs with the same winding number, similar to the Bérnard-von Kármán vortex street known from classical fluid dynamics. Furthermore, simulating the vortex dynamics in a dissipative framework allows one to compare observations to a holographic superfluid where the strongly correlated quantum system is modeled through a higher-dimensional, weakly coupled gravitational theory. Recent literature has already shown successfully that the trajectories of simple vortex configurations simulated by dissipative Gross-Pitaevskii equations can be matched to the holographic analog. On the experimental side, the strongly dissipative quantum fluid can also describe liquid helium close to the lambda-transition qualitatively. Additionally, strong dissipation gives rise to further phases of vortex shedding that are not present in the non-dissipative condensate.

Q 26: Poster – Precision Measurement, Metrology, and Quantum Effects

Time: Tuesday 14:00–16:00 Location: Tent

Q 26.1 Tue 14:00 Tent

Real-Space Dynamical Mean-Field Theory Analysis of the Disordered Bose-Hubbard Model — •Bastian Schindler, Renan da Silva Souza, and Walter Hofstetter — Goethe-Universität, Institut für Theoretische Physik, 60438 Frankfurt am Main, Germany

We numerically investigate the two-dimensional Bose-Hubbard model with local onsite disorder, where the competition between disorder and short-range interactions leads to the emergence of a Bose Glass (BG) phase between the Mott Insulator (MI) and superfluid (SF) phases [1]. In order to solve the inhomogeneous system we employ real-space bosonic dynamical mean-field theory [2] and include the stochastic nature of the system via an ensemble average over disorder realizations. To distinguish the MI from the BG phase we compare the Edwards-Anderson order parameter and the compressibility with the energy gap condition [3]. To find the insulator to SF transition we apply a percolation analysis to the condensate order parameter. In accordance with the theorem of inclusions [3] we always find an intermediate BG phase between the SF and MI. Analyzing the spectral function in the strong coupling regime reveals evidence for analytically predicted damped localized modes in the dispersion relation [4].

[1] M. P. A. Fisher et al., Physical Review B 40, 546 (1989)
[2] M. Snoek and W. Hofstetter, Quantum Gases (2013) https://doi.org/10.1142/9781848168121_0023
[3] V. Gurarie et al., Phys. Rev. B 80, 214519 (2009)
[4] R. S. Souza et al., New J. Phys. 25, 063015 (2013)

Q 26.2 Tue 14:00 Tent

Adiabatic Control of Photon Transport in Ring Geometries — •Milena Djatchkova[1], Igor Lesanovsky[1,2], and Beatriz Olmos Sanchez[1,2] — [1]Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Dense atomic ensembles couple collectively to the electromagnetic field. This gives rise to interesting effects, like the well-known super- and subradiant emission of light from the ensemble and exchange long-ranged interactions. Previous studies have demonstrated that, in a ring of atoms, a single photon can be trapped for times that largely exceed the lifetime of an isolated excitation by harnessing the presence of a subradiant manifold of states and the angular dependence of the induced dipole-dipole interactions (e.g. [1]). Here, we show that the photon can furthermore be transported in a dispersionless way across the ring by adiabatically altering the orientation of the atomic transition dipole moments (via, e.g., the direction of an external magnetic field). Moreover, we go beyond the single-photon case and model the dynamics of two rings, each containing a single photon. Our results reveal that, as the distance between the rings decreases, the photons can be brought to interact with each other, leaving as a trace a phase imprinting on the photonic wave functions. [1] M.Cech, I.Lesanovsky, and B.Olmos, Dispersionless subradiant photon storage in one-dimensional emitter chains, Phys. Rev. A108,L051702 (2023).

Q 26.3 Tue 14:00 Tent

Quantum non-demolition measurements in Ramsey interferometry — •Maja Scharnagl and Klemens Hammerer — Institute for theoretical physics, Leibniz University Hanover, Germany

We investigate quantum non-demolition (QND) measurements and their application in Ramsey protocols. In doing so, we optimize the axes of signal imprint and measurement and compare the optimized sensitivity to the classical and quantum Fisher information. Moreover, we discuss the performance of the optimized Ramsey protocols in the clock simulator.

Q 26.4 Tue 14:00 Tent

Quantum dynamics of trapped atom interferometers in optical lattices — •Patrik Mönkeberg[1], Florian Fitzek[1,2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Insitut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Bloch oscillations of atoms in optical lattices offer a powerful technique to significantly enhance the sensitivity of atom interferometers by orders of magnitude. To fully exploit the potential of this method, an accurate theoretical description of losses and phases beyond current treatments is essential. In this work, we expand the theoretical framework introduced by [Fitzek et al., arXiv:2306.09399] to three dimensions. We introduce multiple approaches to treat the transversal motion of atoms trapped in an accelerated optical lattice and investigate the influence of transversal effects on the interferometer. We compare our model to state-of-the-art atom interferometers, mainly [Panda et al., arXiv:2210.07289].

Q 26.5 Tue 14:00 Tent

A high accuracy multi-ion clock with instability below $\times 10^{-16}/\sqrt{\tau}$ — •Ingrid Maria Richter[1], Shobhit Saheb Dey[1], Hartmut Nimrod Hausser[1], Jonas Keller[1], and Tanja E Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

Single-ion optical clocks represent some of the most accurate experiments and are applicable in research on high-precision spectroscopy, metrology and geodesy[1]. Although these systems have the potential to reach inaccuracies below 10^{-18}[2], their statistical uncertainty is fundamentally limited by quantum projection noise (QPN) and they require averaging times on the order of weeks to resolve frequencies at this limit.

This motivates our approach to develop a multi-ion system based on $^{115}In^+$ ions within Coulomb crystals sympathetically cooled by $^{172}Yb^+$ ions. Next to presenting a systematic frequency uncertainty of 2.5×10^{-18}[2] for single-ion operation, we show the scaling of clock instability with number of ions by a factor of $1/\sqrt{N_{\rm ion}}$ below $1 \times 10^{-15}/\sqrt{\tau}$. Furthermore, we discuss plans for deploying a second cooling stage to reach the quantum-mechanical ground-state in order to reduce the thermal time dilation shift to below 2×10^{-19}.

[1] T. E. Mehlstäubler et al., *Rep. Prog. Phys.* **81**, 064401 (2018)
[2] S. M. Brewer et al., *Phys. Rev. Lett.* **123**, 033201 (2019)
[3] H. N. Hausser et al., arXiv:2402.16807 (2024)

Q 26.6 Tue 14:00 Tent

High accuracy multi-ion clock operation — •Shobhit S. Dey[1], Ingrid M. Richter[1], H. Nimrod Hausser[1], Jonas Keller[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

Optical clocks based on multiple trapped ions have the potential for maintaining the remarkably low systematic uncertainties obtained in present single-ion systems [1], while reducing statistical uncertainties [2]. We operate a clock based on mixed-species Coulomb crystals, with $^{115}In^+$ clock ions sympathetically cooled by $^{172}Yb^+$ ions. In operation with a single In^+ ion, at a systematic uncertainty of 2.5×10^{-18}, we have performed frequency comparisons – including the most accurate to date – with other optical clocks [3]. With an increased clock ion number N, the instability follows the expected $1/\sqrt{N}$ scaling.

In this contribution, we provide experimental details for the automated operation of mixed-species clocks. To obtain reproducible sympathetic cooling conditions, our system autonomously applies a sorting sequence, ensuring favorable positions of the cooling ions within the crystal. We also derive an instability limit for decay-based state preparation of multiple clock ions [4], which we have surpassed by addition of a quench laser.

[1] S. M. Brewer et al., *Phys. Rev. Lett.* **123**, 033201 (2019)
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019)
[3] H. N. Hausser et al., arXiv:2402.16807 (2024)
[4] J. Keller et al., *J. Phys.: Conf. Ser.* **2889**, 012050 (2024)

Q 26.7 Tue 14:00 Tent

Theoretical Description of The Sequential Bragg Large Momentum Transfer — •Ashkan Alibabaei[1,2], Patrik Mönkeberg[2], Florian Fitzek[1,2], Naceur Gaaloul[1], and Klemens Hammerer[2] — [1]Leibniz University Hannover, Institut of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany — [2]Leibniz University Hannover, Institute für Theoretical physics, Hannover, Germany

We present a comprehensive mathematical framework for the sequential Bragg technique as a method for large momentum transfer (LMT) atom interferometry, utilizing the Floquet formalism, and draw comparisons with the Bloch oscillation LMT approach. In this analysis, we identify a novel loss formalism arising from complex-valued eigenenergies, which we interpret as losses to the continuum. This framework establishes critical design criteria for optimizing the efficiency and accuracy of LMT techniques. To illustrate the practical implications of our findings, we apply them to a recent state-of-the-art experiment[Rodzinka, T., Dionis, E., Calmels, L. et al.].

Q 26.8 Tue 14:00 Tent

Towards x-ray quantum optics using periodically structured cavities — •Robert Horn and Jörg Evers — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

Due to their narrow linewidth, Mössbauer nuclei, such as ^{57}Fe, have become an important platform for studying the nature of photons in the hard x-ray regime. These nuclei not only serve as potential nuclear clocks but also emerge as promising candidates for x-ray quantum dynamics. A typical environment for studying quantum optical effects in the linear x-ray regime is that of a thin-film cavity with embedded Mössbauer nuclei probed at grazing incidence. A recently developed ab initio approach using the electromagnetic Green's tensor provides a robust theoretical and numerically efficient framework for describing this setup.

In this project, we propose a modified setup that breaks the cavity's translational symmetry along the wave propagation direction by introducing a grating on the topmost layer. The aim is to investigate the emergence of additional scattering channels and to study photon correlations at varying incident angles.

Q 26.9 Tue 14:00 Tent

Shot-noise limited detection system for the INTENTAS project — •Viviane Wienzek[1] and The INTENTAS Team[1,2,3,4,5,6,7] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Leibniz Universität Hannover, Institut für Transport- und Automatisierungstechnik, 30823 Garbsen, Germany — [3]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89081 Ulm, Germany — [4]Ferdinand-Braun-Institut (FBH), 12489 Berlin, Germany — [5]Technische Universität Darmstadt, Fachbereich Physik, Institut für Angewandte Physik, 64289 Darmstadt, Germany — [6]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik (DLR-SI), 30167 Hannover, Germany — [7]Humboldt Universität zu Berlin, Berlin, 12489, Germany

The INTENTAS project aims to demonstrate sensitivity gains using squeezed Bose-Einstein condensates in microgravity. Set to operate in the Einstein-Elevator in Hannover, it will deploy rubidium (Rb) atoms to show that measurements below the Standard Quantum Limit (SQL) can be achieved under challenging conditions.

Detecting at or below the SQL imposes strict requirements on the detection system, particularly in terms of quantum efficiency and the reduction and rejection of stray light. This contribution will outline the design of the detection system for the INTENTAS project, presenting initial characterizations and results.

Q 26.10 Tue 14:00 Tent

Towards a transportable Al^+ optical clock — •Joost Hinrichs[1,2], Constantin Nauk[1,2], Gayatri Sasidharan[1,2], Vanessa Galbierz[1], Sofia Herbers[1], Benjamin Kraus[1], and Piet O. Schmidt[1,2] — [1]Physikalisch Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz University Hannover, 30167 Hannover, Germany

Optical atomic clocks are precise measurement tools, which achieve fractional frequency uncertainties on the order of 10^{-18} and below. We are setting up a transportable Al^+ clock to use this high accuracy for height measurements in relativistic geodesy and side-by-side clock comparisons, as a step to a future redefinition of the SI-Second.
Our fully rack integrated clock setup is based on the $^1S_0 \to ^3P_0$ transition in $^{27}Al^+$. A co-trapped $^{40}Ca^+$ ion allows state detection and cooling through quantum logic spectroscopy and sympathetic cooling. We present our progress on loading and Doppler cooling Ca^+, first spectroscopy measurements of the Ca^+ $^2S_{1/2} \to ^2D_{5/2}$ logic transition, and the characterization of our segmented trap. In addition, the clock hardware integrated in 19" racks is presented. It includes the laser systems, a physics package with a room temperature vacuum setup and a multilayer chip trap.

Q 26.11 Tue 14:00 Tent

Laser stabilization for a compact inertial navigation system — •Philipp Barbey, Mouine Abidi, Xingrun Chen, Ashwin Rajagopalan, Ann Sabu, Polina Shelingovskaia, Matthias Gersemann, Dennis Schlippert, Ernst M. Rasel, and Sven Abend — Leibniz Universität Hannover - Institut für Quantenoptik, Hannover, Germany

The use of cold and ultracold atoms in light-pulse atom interferometry provides highly accurate measurements of inertial forces, with an emphasis on long-term stability. Especially inertial measurement systems for navigation are driving the development of advanced technologies. To deploy these sensors in practical field applications, significant progress is needed in creating compact and scalable technologies.

We present a new laser stabilization system for our atom interferometer, utilizing digital electronics based on the ARTIQ/Sinara experiment control framework. This system allows stabilization of our laser to a rubidium spectroscopy, while a frequency offset lock enables driving different transitions necessary for cooling and trapping atoms. This digital approach makes parameter adjustments easier, and the use of off-the-shelf components simplifies installation.

We acknowledge financial support by the DFG EXC2123 QuantumFrontiers - 390837967 and by the DLR with funds provided by BMWK under Grant No. DLR 50NA2106 (QGyro+).

Q 26.12 Tue 14:00 Tent

Multi-axis quantum gyroscope with multi loop atomic Sagnac interferometry — •Ann Sabu, Polina Shelingovskaia, Mouine Abidi, Philipp Barbey, Ashwin Rajagopalan, Xingrun Chen, Matthias Gersemann, Dennis Schlippert, Ernst M. Rasel, and Sven Abend — Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover

Twin-lattice atom interferometry enables precise and highly sensitive rotation measurements through large-area Sagnac interferometry. Our goal is to develop a compact and transportable gyroscope capable of multi-axis inertial sensing. In the future, this gyroscope shall reach unprecedented Sagnac areas on the order of 100 cm^2 by employing multi-loop interferometry[1].

The multi-loop interferometer with extended free fall time will employ large momentum transfer utilizing Bose-Einstein condensates (BECs) of ^{87}Rb atoms. The system design, including the laser system for cooling and manipulation of the atomic ensemble is presented.

We acknowledge financial support by the DFG EXC2123 QuantumFrontiers - 390837967 and by the DLR with funds provided by BMWK under Grant No. DLR 50NA2106 (QGyro+).

[1]Schubert, C., Abend, S., Gersemann, M. et al. Multi-loop atomic Sagnac interferometry. Sci Rep 11, 16121 (2021). https://doi.org/10.1038/s41598-021-95334-7

Q 26.13 Tue 14:00 Tent

Realizing of multi-axis interial quantum sensor — •Xingrun Chen, Mouine Abidi, Philipp Barbey, Ashwin Rajagopalan, Ann Sabu, Matthias Gersemann, Ernst Rasel, and Sven Abend — Leibniz Universität Hannover, Institut für Quantenoptik,Germany

Atom interferometers utilizing Bose-Einstein condensates (BECs) as input state, produced by atom chips, have proven to exhibit exceptional capabilities in measuring rotations or accelerations, opening up the prospect of developing new quantum sensors to increase the sensitivity of inertial measurements. Integrating the three-axis quantum sensors with classical Inertial Measurement Units (IMUs), the emergence of hybrid quantum navigation presents a promising solution to mitigate drifts inherent in classical devices, irrespective of their limited band width and dynamic range. Collaborative efforts involve the exploration, of novel algorithms for the hybrid quantum sensor design, as well as the characterization of sensor dynamics and noise processes.

The quantum sensor initiative incorporates a specially designed fiber laser source operating at 1560nm, jointly with a commercial compact vacuum system. Furthermore, innovative optical configurations are em ployed to enhance the sensitivity of the quantum sensor. Ultimately, the finalized device is deployed on a gyro-stabilized platform.

Our current effort focuses on overcoming the main challenge of transitioning a sophisticated laboratory-based apparatus into a robust and compact unit for use in dynamic environments, such as reconstructing three-dimensional trajectories of GNSS.

Q 26.14 Tue 14:00 Tent

Absolute light-shift compensated twin-lattice atom interferometry — •Mikhail Cheredinov[1], Matthias Gersemann[1], Ekim T. Hanimeli[2], Simon Kanthak[3], Sven Abend[1], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU zu Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Twin-lattice atom interferometry is a method for forming symmetric interferometers with matter waves of large relative momentum spitting by using two counter-propagating optical lattices. This method utilizes double Bragg diffraction in combination with Bloch oscillations. It has the potential to enable highly sensitive inertial measurements. Until now, a limiting factor for this type of large momentum transfer has been the loss of contrast in the interferometer. Differential absolute light shifts arise due to diffraction effects of our Gaussian beam at apertures and other imperfections. By using a Flat-Top beam profile, such diffraction effects can be suppressed. Adding an oppositely detuned light field helps to cancel out remaining absolute light shifts. This contribution presents the recent results of this realization of a twin-lattice atom interferometer.

We acknowledge financial support by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and by DLR under grant no. DLR 50WM2450A (QUANTUS-VI).

Q 26.15 Tue 14:00 Tent

Sensing tilt in an optics lab — •Stefan Gessler, Jannik Zenner, and Simon Stellmer — Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität, Bonn, Germany

Precision measurements are often influenced by external parameters that need to be monitored by environmental sensors. One such disturbing factor can be the local tilt, induced by movement of the building and ground water dynamics. We report on the characterization and operation of a tiltmeter operating at resolution and stability in the nanorad regime.

Q 26.16 Tue 14:00 Tent

General Relativistic Center-of-Mass Coordinates for Composite Quantum Particles — •Gregor Janson and Richard Lopp — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany

Recently, quantum clock interferometry has been proposed for tests of the Einstein equivalence principle. While most atom interferometric models include relativistic effects in an *ad hoc* manner, this work begins with the multi-particle nature of quantum-delocalizable atoms in curved spacetime and extends the special-relativistic concepts of center-of-mass (COM) and relative coordinates, which were previously studied for Minkowski spacetime only, to describe light-matter dynamics in curved spacetime. Specifically, for a local Schwarzschild observer at the Earth's surface using Fermi-Walker coordinates, we identify gravitational correction terms for the Poincaré symmetry generators. These corrections allow us to derive general relativistic COM and relative coordinates. Using these coordinates, we derive the Hamiltonian for a fully first-quantized two-particle atom interacting with an electromagnetic field in curved spacetime which naturally incorporates both special and general relativistic effects.

Q 26.17 Tue 14:00 Tent

Dimensional Reduction in Quantum Optics — •Jannik Ströhle and Richard Lopp — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany

One-dimensional quantum optical models usually rest on the intuition of large-scale separation or frozen dynamics associated with the different spatial dimensions, for example when studying quasi one-dimensional atomic dynamics, potentially resulting in the violation of (3+1)-dimensional Maxwell's theory.Our work provides a rigorous foundation for this approximation by means of the light-matter interaction. We show how the quantized electromagnetic field can be decomposed*exactly*into an infinite number of subfields living on a lower-dimensional subspace and containing the entirety of the spectrum when studying axially symmetric setups, such as with an optical fiber, a laser beam, or a waveguide. The dimensional reduction approximation then corresponds to a truncation in the number of such subfields that in turn, when considering the interaction with for instance an atom, corresponds to a modification to the atomic spatial profile. We explore under what conditions the standard approach is justified and when corrections are necessary in order to account for the dynamics due to the neglected spatial dimensions. In particular we examine what role vacuum fluctuations and structured laser modes play in the validity of the approximation.

Q 26.18 Tue 14:00 Tent

High-dimensional maximally entangled photon pairs in parametric down-conversion — •Richard Bernecker[1,2], Baghdasar Baghdasaryan[3], and Stephan Fritzsche[1,2] — [1]Institute for Theoretical Physics, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Helmholtz Institute Jena, Fröbelstieg 3, 07743 Jena, Germany — [3]Institute of Applied Physics, Friedrich Schiller University Jena, Albert-Einstein-Str. 6, 07745 Jena, Germany

Photon pairs generated through spontaneous parametric down-conversion constitute a well-established approach for creating entangled bipartite systems. Laguerre-Gaussian modes, which carry orbital angular momentum (OAM), are commonly used to engineer high-dimensional entangled quantum states within the spatial domain. For Hilbert spaces with dimension $d>2$, maximally entangled states (MESs) enhance the capacity and security of quantum communication protocols and increase the efficiency of quantum-computational tasks. However, directly generating MESs within well-defined high-dimensional subspaces of the infinite OAM basis remains challenging. In this work, we formalize how the spatial distribution of the pump beam and phase-matching conditions within the nonlinear crystal can be utilized to generate MESs without additional spatial filtering of OAM modes in a given subspace. We demonstrate our method with maximally entangled qutrits ($d = 3$) and ququints ($d = 5$).

Q 26.19 Tue 14:00 Tent

Software framework for decoherence-free control design in surface ion traps — •Eric Benjamin Kopp — Universität Innsbruck

We present details of the Generalized Control of Noiseless Subspaces (GCNS) framework, a MATLAB- and Java-based software library for computing decoherence-free control strategies for a broad class of open quantum model representations (e.g., Lindbladians, channel matrices, Kraus operators). The framework efficiently solves four constituent problems: *i)* identifying candidate subsystem codes in quantum noiseless subspaces (including decoherence-free subspaces), *ii)* determining model controllability subject to the requirement for zero information loss, *iii)* programmatically selecting control channels/resources from large candidate sets, and *iv)* generating control input signals for realizing arbitrary unitary gates acting on 1-6 logical qudits. The presentation includes results from the framework applied to a segmented surface ion trap model currently under development at the Universität Innsbruck.

Q 26.20 Tue 14:00 Tent

Setup for Laser Excitation of the ^{229}Th Nucleus in a Cryogenic Environment — •Florian Zacherl[1], Keerthan Subramanian[1], Nutan Kumari Sah[1], Srinivasa Pradeep Arasada[1], Valerii Andriushkov[2,3], Jonas Stricker[1,2], Yumiao Wang[1,4], Ke Zhang[1], Christoph E. Düllmann[1,2,3], Dmitry Budker[1,2,3,5], Thorsten Schumm[6], Ferdinand Schmidt-Kaler[1], and Lars von der Wense[1] — [1]Johannes Gutenberg University Mainz, Germany — [2]Helmholtz Institute Mainz, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [4]Fudan University, Shanghai, China — [5]University of California, Berkeley, USA — [6]Vienna University of Technology, Austria

The low isomeric energy level of only 8.4 eV in ^{229}Th places the transition wavelength in the vacuum-ultraviolet (VUV) and therefore provides the unique opportunity to excite it with optical lasers. The described setup aims to excite the nucleus of Th^{4+} ions in a $Th : CaF_2$ crystal with a continuous wave (CW) laser around 148 nm. The crystal is placed and excited in a cryogenic environment to reduce vibrations caused by phonons as well as to probe for variations in decay time at very low temperatures. Entering the cryogenic regime will also provide the possibility of better investigation of temperature dependent transition frequency shifts. The main part of the detection system of the radiative decay including a photomultiplier tube (PMT) is decoupled from the cryogenic area and placed in a separate chamber.

This work is supported by the BMBF Quantum Futur II Grant Project 'NuQuant' (FKZ 13N16295A).

Q 26.21 Tue 14:00 Tent

Modeling LMT Atom Interferometers Using Adiabatic Perturbation Theory — •Eric P. Glasbrenner, Richard Lopp, and Wolfgang P. Schleich — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany

Atom interferometers have become essential tools for high-precision sensing, with applications in gravimetry, rotation sensing and quantum clock interferometry. Initially developed to test fundamental principles of relativity and quantum mechanics, they are now advancing toward practical and commercial use, requiring compact, miniaturized setups. To enhance sensitivity, large-momentum transfer methods, such as double Bragg diffraction, sequential pulses, or Bloch oscillations (BO), are employed. However, accurately modeling the non-adiabatic effects influencing these methods remains challenging. We propose a semi-analytical approach based on adiabatic perturbation theory (APT), supported by numerical simulations, to describe light-pulse beam splitters and mirrors. This approach enables a unified treatment of Bragg diffraction and Bloch oscillations and allows for the analysis of a wide range of interferometer types. Using APT, we model imprinted phases, including non-adiabatic effects such as e.g. Landau-Zener tunneling, and identify the limits where APT fails for BO-based atom interferometers. APT versatility in modeling different interferometer types is further demonstrated and validated through detailed numerical simulations.

Q 26.22 Tue 14:00 Tent

A single-atom array strongly coupled to an optical cavity for quantum simulation — •Marcel Kern, Thomas Picot, Clément Raphin, Jakob Reichel, and Romain Long — Laboratoire Kastler-Brossel, Paris, France

Coupling certain materials to an optical cavity in the strong coupling regime can drastically change their chemical properties - a field of research known as polaritonic chemistry [1]. The underlying microscopic mechanisms are subject to intense research, where disorder and infinite long-range interactions are key in proposed theoretical models. One potential experimental implementation involves individually controllable, single, neutral atoms strongly coupled to an optical cavity, enabling an infinite and tunable interaction range, as well as frequency disorder via local light shifts.

In our group, high-finesse Fiber Fabry-Perot Cavities allow the operation in the strong coupling regime for a single emitter (Cooperativity ~ 100). Single ^{87}Rb atoms are trapped in an array of optical tweezers, providing individual detectability and control over their coupling parameters. The states of the atoms can be either detected one by one via cavity transmission or at once via background-free fluorescence spectroscopy. With this platform, the transport properties in long-range interacting spin chains can be explored, relevant for polaritonic chemistry, and generally for studying quantum entanglement propagation.

[1] T. W. Ebbesen, et al. - Chemical Reviews *2023* 123(21)

Q 26.23 Tue 14:00 Tent

Entanglement and coherence in the resonance fluorescence of a two-level quantum emitter — •Gabriele Maron, Xinxin Hu, Luke Masters, Arno Rauschenbeutel, and Jürgen Volz — Department of Physics, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin

The resonance fluorescence of a single two-level emitter is a fundamental phenomenon in quantum optics and is a key resource for photonic quantum technologies. It is well-known that the scattered field consists of a stream of photons that shows antibunched statistics. However, as we recently experimentally showed [1], this behaviour can be viewed as a quantum interference effect between two distinct two-photon components of the scattered light, commonly referred to as coherent and incoherent, which interfere perfectly destructively. Furthermore, it turns out that the incoherently scattered component consists of energy-time entangled photon pairs. Here, the properties of these two-photon components are the subject of further investigation. In particular, we study their interference behaviour in order to analyse the coherence and indistinguishability of photons emitted at different times. Our results demonstrate a high degree of coherence between the emitted photon pairs, which opens up new pathways for the realization of sources of entangled photon pairs based on resonance fluorescence from a single two-level emitter.

[1] Masters et al, Nat. Photon. 17, 972-976 (2023)

Q 26.24 Tue 14:00 Tent

Towards a Chip-Scale Quantum Gravimeter — •Julian Lemburg[1], Joseph Muchovo[1], Kai-Christian Bruns[1], Vivek Chandra[1], Sam Ondracek[1], Hendrik Heine[1], Waldemar Herr[2], Christian Schubert[2], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik (SI)

In the field of gravimetry, atom interferometry offers the perspective of a highly powerful tool for measuring gravity, with an expected residual uncertainty on the order of nm/s^2. To enable in-field or space-borne experiments, the development of compact, lightweight devices with low power consumption is crucial. We address these challenges by using atom chips for a rapid production of Bose-Einstein condensates, which enable high contrast, the implementation of large momentum transfer processes, and control of systematic effects in atom interferometry. To date, atom chips have either been equipped with a grating to simplify the optical setup for the magneto-optical trap (requiring only a single input beam) or with a mirror designed for atom interferometry. In our approach, we aim to integrate both functionalities.

In this poster, we present our concept and initial results of the optical characterization using test chips that combine the features of a grating and a mirror. These chips pave the way for performing both laser cooling and atom interferometry using a single optical beam.

Q 26.25 Tue 14:00 Tent

Towards a two-photon E1-M1 clock transition excitation in ^{174}Yb — •Mario Montero[1], Ali Lezeik[2], Dominik Koester[2], Klaus Zipfel[2], Ernst M. Rasel[2], Christian Schubert[1], and Dennis Schlippert[2] — [1]Institut für Satellitengeodäsie und Inertialsensorik, Deutsches Zentrum für Luft und Raumfahrt, Hannover, Deutschland — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Deutschland

Atom interferometry experiments measuring gravitational redshift require access to long-lived internal states, such as the $^1S_0 \rightarrow\ ^3P_0$ optical transition in group II atoms. An E1-M1 two-photon excitation directly access the clock state from the ground state by coupling to a far detuned intermediate state through a pair of electric and magnetic dipole allowed transitions [1]. This avoids state mixing, enhancing the excited state's lifetime. Moreover, using counter-propagating photons with degenerate frequencies eliminates first-order Doppler effects.

We report the progress of our experimental setup to drive the clock transition. We prepare an ultra-cold atomic ensemble of ^{174}Yb through a dual-stage magneto-optical trap sequence, followed by evaporative cooling in a crossed optical dipole trap [2]. To excite the transition, we utilize a high-power (10 W), narrow-linewidth 1156 nm laser system referenced to a high-finesse cavity and a frequency comb.

We discuss further applications of the two-photon Doppler-free excitation as a beam splitting method for quantum clock interferometry experiments.

[1]PRA **90**, 012523 (2014). [2]J.Phys.B **54**, 035301 (2021).

Q 26.26 Tue 14:00 Tent

Cooling and diffraction of atoms with a multi-purpose laser system — •Ekim Taylan Hanimeli[1], Simon Kanthak[2], Matthias Gersemann[3], Mikhail Cheredinov[3], Sven Herrmann[1], Claus Lämmerzahl[1], Sven Abend[3], Ernst M. Rasel[3], and the QUANTUS team[1,2,3,4,5,6] — [1]ZARM, Universität Bremen — [2]Institut für Physik, HU Berlin — [3]Institut für Quantenoptik, LU Hannover — [4]Universität Ulm — [5]Technische Universität Darmstadt — [6]Johannes Gutenberg-Universität Mainz

As part of the QUANTUS project, we are working to advance matter-wave interferometry techniques. One of the avenues we investigate is the application of Bragg and Raman diffractions in a single experimental sequence, allowing independent manipulation of the internal and external states of atoms, enabling techniques such as blow-away pulses or the use of clock states.

This contribution presents results obtained with a compact fiber laser system that enables these diffraction techniques, and provides optical cooling and detection. We have achieved stable and efficient double Bragg and double Raman beamsplitters, as well as blow away sequences. We were also able to utilize the capability for Raman pulses for gray molasses cooling.

The project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant number DLR 50 WM 2450C (QUANTUS-VI).

Q 26.27 Tue 14:00 Tent

Utilizing Bose-Einstein condensates for atom interferometry in the transportable Quantum Gravimeter QG-1 — •Smit Kanawade[1], Pablo Nuñez von Voigt[1], Nina Heine[1], Waldemar Herr[2], Jürgen Müller[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik, Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

Atom interferometers have demonstrated unprecedented sensitivity and stability for sensing inertial quantities in complex lab-based environments. The Quantum Gravimeter (QG-1) aims to transfer this ability to a transportable device for performing long-term geodetic measurements of the acceleration due to gravity with sub-nm/s^2 uncertainty. The reduced SWaP (size, weight, and power) of the sensor is realized using atom chip technology for efficient source preparation of delta-kick collimated ^{87}Rb Bose-Einstein condensate. Using a lensed cloud with a low expansion rate allows spatially resolving absorption imaging compared to cold atom sensors, which have to rely on fluorescence imaging for detection. The atom chip provides precise control over the release of the probe cloud, and together with the spatial information of the condensate's center of mass motion from absorption imaging, it can help minimize the residual horizontal velocity. This provides a better understanding and control of the systematic effects, such as Coriolis bias and characterization of wavefront aberrations.

Q 26.28 Tue 14:00 Tent

Transportable highly stable laser system for an Al$^+$/Ca$^+$ quantum logic clock — •Gayatri R. Sasidharan[1], Benjamin Kraus[1], Sofia Herbers[1], Fabian Dawel[1,2], Constantin Nauk[1,2], Joost Hinrichs[1,2], Vanessa Galbierz[1], Pascal Engelhardt[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunchweig, Germany — [2]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical clocks offers fractional frequency uncertainties down to 10^{-18}, making them suitable candidates for applications ranging from dark matter research, redefinition of the SI second to geodesy. With these applications in mind, we develop a transportable clock based on Al$^+$. The cooling and detection transitions of the clock ion species ^{27}Al$^+$ are not directly accessible and therefore a co-trapped Ca$^+$ ion is used for sympathetic cooling and state readout through quantum logic spectroscopy. We present our extensive infrastructure of highly stable laser systems build to address clock and logic transitions precisely on ^{27}Al$^+$ and ^{40}Ca$^+$ respectively [1],[2]. This involves locking laser to stable cavities maintained at 10^{-9} mbar pressure levels, stability comparison setups using frequency comb and optical path length stabilization units. We also report on finesse and photo thermal measurements of our dual wavelength coated logic cavity.

[1] B. Kraus, PhD thesis, Leibniz Universität Hannover (2024).
[2] Fabian Dawel, et al., Opt. Express 32, 7276-7288 (2024).

Q 26.29 Tue 14:00 Tent

Scalable Multi-Loop Cold Atom Rotation Sensor — •Sandra Rühmann, Holger Ahlers, Christian Deppner, Waldemar Herr, and Christian Schubert — Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Hannover

Matter-wave interferometry with cold atoms offers a competitive tool for absolute measurements of acceleration and rotation. The sensitivity of atom-interferometric gyroscopes depends on the area enclosed by the interferometer. In this contribution, we present a concept for a rotation sensor, utilizing a multi-loop interferometer geometry to achieve a scalable area while maintaining a compact setup. It enables rotation measurements of a single axis on ground and can be extended to measure rotations along all three spatial axes in microgravity, for potential applications in space missions, Earth observation, and navigation systems.

Q 26.30 Tue 14:00 Tent

Commissioning of the Very Long Baseline Atom Interferometry facility — •Guillermo Alejandro Pèrez Lobato, Vishu Gupta, Kai C. Grensemann, Klaus Zipfel, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The Very Long Baseline Atom Interferometry (VLBAI) facility in Hannover opens the possibility of testing questions in fundamental physics e.g. macroscopic delocalization of wavefunctions and constraining fundamental decoherence mechanisms. The 10 m baseline enables free fall times of up to $2T = 2.4$ s and therefore large sensitivity scale factors $k_{eff}T^2$. The use of this equipment imposes a series of technical demands that need to be achieved such as obtaining an ultracold sample of atoms with the number of atoms in the order of one million, with sub-nanokelvin temperatures.

This contribution focuses on the progress towards achieving highly delocalized matter waves, including the manipulation of rubidium atoms utilizing purely optical potentials for matter wave lensing. We discuss the performance requirements of the atom source in the various parameters of interest such as number of atoms, temperatures required, and others that are imposed by the manipulation and control methods used for the measurement process. The methods utilized include the use of lensing and dipole trap launches with painted optical dipole traps, and the coherent manipulation of atomic wave functions by Bragg beam splitting processes.

Q 26.31 Tue 14:00 Tent

Absolute Aero Quanten-Gravimetrie (AeroQGrav) — •Patrick Rössler, Knut Stolzenberg, Ernst Rasel, and Dennis Schlippert — Leibniz Universität Hannover - Institut für Quantenoptik

To map the Earth's gravitational field on a large scale, satellites are used for this purpose. This comes with the down-side of a spatial resolution of several km. To improve the spatial resolution, we utilize an airplane as a platform for combining inertial and positional sensors at lower altitudes. Within a measuring duration of 5 s we are aiming for a spatial resolution of 0.3 to 0.5 km, by the implementation of a cold atom quantum gravimeter with the sensitivity of 1 μm/s^2 and correlate it with GNSS antennas, a terrestrial laser scanner and a laser velocity meter. The work shown here gives an overview of all the necessary electronics to merge the aforementioned sensors and the read-out scheme to operate the quantum gravimeter using sensor fusion in the noisy environment of an airplane.

Q 26.32 Tue 14:00 Tent

Numerical simulations and differential wavefront analysis for a Ramsey-Bordé interferometry based optical clock — •Levi Wihan[1], Oliver Fartmann[1], Amir Mahdian[1], Vladimir Schkolnik[1], Ingmari Tietje[1], and Markus Krutzik[1,2] — [1]Humboldt-Universität, Inst. f. Physik, Newtonstr. 15, 12489 Berlin — [2]Ferdinand-Braun-Institut (FBH), Gustav-Kirchhoff-Straße 4, 12489 Berlin

We develop a compact optical atomic clock based on Ramsey-Bordé interferometry (RBI) with a thermal strontium beam. This atomic beam clock leverages the narrow $^1S_0 \rightarrow ^3P_1$ intercombination line at 689 nm, offering enhanced stability compared to vapour cell clocks and greater simplicity than cold atom clocks, making it well-suited for field applications and clock networks. Given RBI's sensitivity to the wavefront of the interrogating laser, we investigated the impact of wavefront aberrations by adapting a numerical RBI model to include Gaussian beam effects, traditionally neglected in plane-wave approximations. The model guided the optimization of key beam parameters such as waist size and position. To mitigate wavefront aberrations in the portable setup, which is in development, wavefront analysis of the used optical elements is necessary. Therefore, we developed a workflow using a Shack-Hartmann wavefront sensor which is independent of the beam's position on the detector. Using differential wavefront analysis we identify sources of aberrations, which helps to ensure consistent beam quality throughout the interferometer.

Q 26.33 Tue 14:00 Tent

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

Q 26.34 Tue 14:00 Tent

Strongly coupled Yb atoms in a high-finesse cavity: lasing and spectral dynamics — •Saran Shaju[1], Dmitriy Sholokhov[1], Ke Li[1], Simon B. Jäger[2], and Jürgen Eschner[1] — [1]Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken, Germany — [2]Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We report on the investigation of optical gain and lasing emission from an ensemble of a few thousand Yb atoms which are magneto-optically trapped using the $^1S_0$ – $^1P_1$ transition at 399 nm, inside a 5 cm-long high-finesse cavity. By optically pumping the atoms on the $^1S_0$ – $^3P_1$ intercombination transition at 556 nm, continuous-wave lasing on the same transition is observed [1]. We have analyzed this two-photon lasing process using heterodyne detection techniques and formulated an empirical modeled based on Bloch equations [2]. Employing magneto-optical trapping solely on the intercombination line results in a colder, denser atomic ensemble, facilitating the collective strong coupling regime in cavity QED. In this setting, we observe additional light scattering from the side-pumped atoms, outside the lasing regime. We investigate experimentally and theoretically these atom number-dependent dynamics that emerge from the strong nonlinear interactions.

[1] H. Gothe et al., Phys. Rev. A 99, 013415 (2019).
[2] D. Sholokhov et al., arXiv:2404.16765 (2024).

Q 26.35 Tue 14:00 Tent

An open-fiber cavity system for quantum dot spectroscopy — •Moritz Meinecke, Peter Gschwandtner, Sven Höfling, and Tobias Huber-Loyola — Technische Physik, Physikalisches Institut Würzburg, 97074 Würzburg, Germany

Single-photon sources are an essential resource for quantum communication and quantum computing. Semiconductor quantum dots have been proven to be a great platform for delivering single photons on demand. Embedding quantum dots in so-called open cavities, improves the device performance due to a higher extraction efficiency of the single-photons stream. Overall efficiencies of > 70 % have been shown in such type of cavities.

Laser ablation techniques made it possible to imprint a curved mirror into the tip of a fiber, enabling to design fiber-based Fabry-Pérot cavities. The advantage of fiber-based cavities is the support of smaller mode volumes compared to conventional Fabry-Pérot cavities based on bulk optical mirrors. A small mode volume allows easier exploitation of the Purcell effect to increase the source brightness. Here, we present our design of a single photon source based on InAs quantum dots embedded in a fiber-based Fabry-Pérot cavity.

Q 26.36 Tue 14:00 Tent

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

Q 26.37 Tue 14:00 Tent

Setup of a laser system for Th ions cooling and spectroscopy in a Paul Trap — •Yumiao Wang[1,2], Valerii Andriushkov[3,4], Keerthan Subramanian[1], Ke Zhang[1], Florian Zacherl[1], Nutan Kumari Sah[1], Jonas Stricker[1,3], Srinivasa Pradeep Arasada[1], Christoph E. Düllmann[1,3,4], Dmitry Budker[1,3,4,5], Ferdinand Schmidt-Kaler[1], and Lars von der Wense[1] — [1]University of Mainz, Germany — [2]Fudan University, China — [3]Helmholtz Institute Mainz, Germany — [4]GSI Helmholtz Centre for Heavy Ion Research, Germany — [5]University of California, USA

The ^{229m}Th isomeric state, with its low excitation energy, offers the potential for highly precise nuclear optical clocks, aiding in dark matter detection and measuring physical constants. Recent experiments have shown direct excitation and de-excitation of the ^{229m}Th nuclear transition in Th-doped crystals using VUV lasers and frequency combs, though excitation in a Paul trap has not yet been achieved. We aim to excite the nuclear transition in $^{229}Th^{3+}$ ions, sympathetically cooled with Ca+ in a Paul trap, and detect it via a double-resonance scheme, where nuclear spin changes affect electronic levels through hyperfine interaction. Progress towards setting up the Paul trap and laser systems to probe the Th^{3+} electronic shell, along with future precision measurement possibilities for the octupole moment of the ground and isomeric states, will be presented.

This work is supported by the DFG Project 'TACTICa' (grant no. 495729045) and the BMBF Quantum Futur II Grant Project 'NuQuant' (FKZ 13N16295A).

Q 26.38 Tue 14:00 Tent

Stabilization of a tunable coherence laser system for scattered light suppression — •Lennart Manthey, Daniel Voigt, and Oliver Gerberding — Institut für Experimentalphysik, Universität Hamburg, 22761 Hamburg, Germany

Scattered light limits the sensitivity of laser interferometric ground based gravitational wave detectors. To suppress this noise, we test tunable coherence which uses pseudo-random-noise (PRN) phase modulations. We showed suppression levels of 40dB for 170kHz scatter frequency in Michelson interferometers are possible. To achieve better results at lower measurement frequencies of 3Hz to 10kHz a stabilization of the laser amplitude and frequency is needed. The amplitude stabilization uses a photodiode connected in a control loop to actuate the diode voltage of the laser. The frequency stabilization uses an ultra-stable cavity to lock the frequency on its length. We present the status of our noise level of the amplitude and frequency and its effects on the scattered light suppression.

Q 26.39 Tue 14:00 Tent

Developing compact displacement sensors using Deep Frequency Modulation Interferometry (DFMI) — •Lea Carlotta Hügel, Leander Weickhardt, and Oliver Gerberding — Institut für Experimentalphysik, Universität Hamburg, 22761 Hamburg, Germany

Gravitational-wave detectors are currently, especially at low frequencies, limited by the noise of displacement sensors. Therefore, building high-precision displacement sensors is crucial for improving future gravitational wave detectors.

The displacement sensing technique, presented here, is called Deep Frequency Modulation Interferometry (DFMI). DFMI is a laser interferometry technique in which the frequency of the laser is rapidly modulated by a sine wave. DFMI is practical for more precise sensors because low-frequency signals are projected to higher frequencies, where they are not affected by higher readout noise in their original frequency region. To improve future implementations, identifying and evaluating the performance limits of DFMI, is the first step. An effect that can spoil the overall readout performance of DFM is the excitation of higher harmonics in the laser frequency modulation. This can e.g. be caused by non-linearities in the frequency actuation. DFMI is also limited by readout noise. By combining resonant enhancement and DFMI the overall sensitivity can be improved to a few $\mathrm{fm}/\sqrt{\mathrm{Hz}}$.

By looking at the latest status of our experiments, addressing these two problems, an interesting inside to the field of high precision displacement sensors can be gained.

Q 26.40 Tue 14:00 Tent

Study of Adsorption Kinetics with the Zero Range Process — •Mark Paal[1], Henry Martin[1], and Matteo Colangeli[2] — [1]Kwame Nkrumah University of Science and Technology — [2]University of L'Aquila

The Zero Range Process (ZRP) stands as a pivotal model in nonequilibrium statistical mechanics, offering profound insights into the macroscopic behaviour of systems driven away from equilibrium. This process, exemplifying driven diffusive systems on a lattice, unveils intricate phenomena including phase separation, transitions, and long-range correlations. In this study, we explore adsorption and desorption kinetics in confined geometries hoping it can provide insights into the behaviour of interacting particles. A discrete hopping model, such as the zero-range process, can be used to investigate these kinetics even on a one-dimensional lattice.

Q 27: Poster – Ultra-cold Atoms, Ions and BEC (joint session A/Q)

Time: Tuesday 14:00–16:00 Location: Tent

Q 27.1 Tue 14:00 Tent

Symmetry breaking and non-ergodicity in a driven-dissipative ensemble of multilevel atoms in a cavity — •Enrique Hernandez[1], Elmer Surez[1], Igor Lesanovsky[2], Beatriz Olmos[2], and Philippe Courteille[3] — [1]Center for Quantum Science and Physikalisches Institut, Eberhard-Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Auf der Morgenstelle 14 — [3]Instituto de Física de São Carlos, Centro de Pesquisa em Óptica é Fotônica, Universidade de São Paulo, Av. Trab. São Carlense 400, São Carlos, 13566-590 São Paulo, Brazil

Dissipative light-matter systems can display emergent collective behavior. Here, we report a $\mathbb{Z}_2$-symmetrybreaking phase transition in a system of multilevel ^{87}Rb atoms strongly coupled to a weakly driven two-mode optical cavity. In the symmetry-broken phase, nonergodic dynamics manifests in the emergence of multiple stationary states with disjoint basins of attraction. This feature enables the amplification of a small atomic population imbalance into a characteristic macroscopic cavity transmission signal. Our experiment does not only showcase strongly dissipative atom-cavity systems as platforms for probing nontrivial collective many-body phenomena, but also highlights their potential for hosting technological applications in the context of sensing, density classification, and pattern retrieval dynamics within associative memories.

Q 27.2 Tue 14:00 Tent

Advanced Interferometer Techniques for Measuring Near-Resonant Light Shifts and Superresolving Trapped-Ion Dynamics — •Frederike Doerr, Florian Hasse, Ulrich Warring, and Tobias Schaetz — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

This work introduces two innovations in Ramsey interferometry with trapped ions, advancing precision in quantum metrology. First, we implement a Mach-Zehnder-inspired technique to detect near-resonant AC Zeeman shifts, enabling precise measurement of weak fields and enhanced ion-state manipulation. Second, we enhance temporal resolution via improvements in an acousto-optic modulator (AOM) setup, enabling the tracking of rapid ion dynamics and real-time phase encoding at sub-wavelength scales [1]. This is particularly beneficial for experiments requiring squeezed states and exact phase control. These advancements enhance Ramsey interferometry's capability to probe complex quantum systems, with broad applications in quantum simulation, sensing, and control technologies.

[1] Florian Hasse et al., Phys. Rev. A 109, 053105 (2024)

Q 27.3 Tue 14:00 Tent

Strongly Correlated Fermions with Cavity-mediated Long-range Interactions — •Renan da Silva Souza, Youjiang Xu, and Walter Hofstetter — Goethe- Universität, Institut für Theoretische Physik, 60438 Frankfurt am Main, Germany

Motivated by the recent experimental realization of the superradiant self-organization phase transition in ultracold Fermi gases [1], we investigate a gas of spin-1/2 fermions in a transversely pumped cavity with a static 2D optical lattice. In the dispersive regime, the system is well described by an extended Hubbard model with cavity-mediated long-range interactions. Using real-space dynamical mean-field theory (DMFT) [2], we study the paramagnetic Mott transition at half-filling. In addition to the expected metallic and Mott insulating phases, characterized respectively by a finite or vanishing quasiparticle residue at the Fermi level, we find a density wave ordered phase marked by an imbalance in the site occupations. By varying short- and long-range interaction strengths, we map the phase boundaries and establish a connection between our findings and the relationship between perfect Fermi surface nesting in the non-interacting Hamiltonian and the critical long-range interaction strength required for density wave instability.

[1] V. Helson et al. Nature 618, 716-720 (2023)
[2] M. Snoek et al. NJP 10, 093008 (2008)

Q 27.4 Tue 14:00 Tent

Stabilizing and controlling linear spin quantum systems based on trapped ions — •Andreas Weber, Florian Hasse, Frederike Doerr, Ulrich Warring, and Tobias Schaetz — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

The stability and control of quantum systems are fundamental to quantum simulation, as they enable accurate and reproducible modeling of complex quantum phenomena. This work focuses on the stability and control of both the electronic and motional degree of freedom of single trapped magnesium ions. The ions are stored in a linear Paul trap and laser cooled to Microkelvin temperatures. The hyperfine splitting of the electronic ground state allows to span and control a dedicated two-level spin system that can be addressed by microwave fields and initialized by optical pumping techniques. Further control is realized by coupling the motional states of the ion in the trapping potential with the spin states by so-called sideband transitions, allowing to cool the system even further close to absolute ground state of motion. Stabilized electronics make the fields in the vicinity of the trap stable enough to maintain the two-level systems phase information and suppress coupling with the environment. As part of my project, this is implemented using home-built feedback circuits. We expect coherence on millisecond timescales and preparation fidelities above 99%. Stability measurements based on Ramsey spectroscopy not only serve to benchmark our electronics but also show the high precision and sensitivity in detecting systematic changes of physical quantities.

Q 27.5 Tue 14:00 Tent

Dark energy search using atom interferometry in the Einstein-Elevator — •Magdalena Misslisch[1], Sukhjovan Singh Gill[1], Charles Garcion[1], Alexander Heidt[2], Ioannis Papadakis[3], Vladimir Schkolnik[3], Sheng-wey Chiow[4], Nan Yu[4], Christoph Lotz[2], and Ernst Maria Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut für Transport- und Automatisierungstechnik, Leibniz Universität Hannover, Germany — [3]Institut für Physik, Humboldt Universität zu Berlin, Germany — [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

Dark energy is estimated to represent around 70 % of the universe energy budget, yet its nature remains unknown. A possible solution for this problem is the proposed scalar chameleon field whose effects are hidden from usual high density probe particles due to a screening effect. The project DESIRE (Dark energy search by atom interferometry in the Einstein-Elevator) aims to detect chameleon dark energy by atom interferometry in microgravity. In this experiment multi-loop interferometry with Rb-87 Bose-Einstein condensates will be performed to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity. Atoms traverse a periodic test mass designed in cooperation with the JPL while accumulating the signal within a multi-loop interferometer over several seconds. To reach these long interaction times the experiment will be performed in the Einstein-Elevator, an active drop tower in Hanover that allows up to 4 s in microgravity.

Q 27.6 Tue 14:00 Tent

Quantum bubbles in the Einstein-Elevator facility at Leibniz University Hannover — •Charles Garcion[1], Thimothé Estrampes[1], Gabriel Müller[1], Sukhjovan S. Gill[1], Magdalena Misslisch[1], Éric Charron[2], Christoph Lotz[3], Jean-Baptiste Gérent[4], Nathan Lundblad[4], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, Hannover, 30167, Germany. — [2]Institut des Sciences Moléculaires d'Orsay, CNRS, Université Paris-sacay, F-91405, Orsay, France — [3]Institut für Transport- und Automatisierungstechnik c/o Hannover Institute of Technology, Leibniz Universität Hannover, Callinstraße 36, Hannover, 30167, Germany — [4]Department of Physics and Astronomy, Bates College, Lewiston, ME, USA

Quantum bubbles are systems in which atoms are confined to a two-dimensional closed surface. They enable the study of phenomena like vortices, collective modes, and self-interference during expansion. These bubbles are typically created using radiofrequency (RF) dressed potentials and form more naturally in microgravity. However, inhomogeneities in static and RF magnetic fields can alter this advantage.

The Quantumania project adapts the MAIUS-1 payload in the Einstein-Elevator at the Leibniz University Hannover to create quantum bubbles. It will also contribute to efforts in testing and refining techniques for the Cold Atom Laboratory aboard the ISS. A primary goal is optimizing antenna designs and selecting radiofrequency sources to enhance magnetic field homogeneity, ensuring effective trapping in bubble configurations.

Q 27.7 Tue 14:00 Tent

QRydDemo - Architecture for Dynamic Tweezer Arrays — •Julia Hickl[1,2], Christopher Bounds[1,2], Manuel Morgado[1,2], Govind Unnikrishnan[1,2], Achim Scholz[1,2], Jiachen Zhao[1,2], Sebastian Weber[3,2], Hans-Peter Büchler[3,2], Simone Montangero[4], Jürgen Stuhler[5], Tilman Pfau[1,2], and Florian Meinert[1,2] — [1]5th Inst. of Physics, University of Stuttgart — [2]IQST — [3]Inst. for Theoretical Physics III, University of Stuttgart — [4]Inst. for Complex Quantum Systems, University of Ulm — [5]TOPTICA Photonics AG

Within the QRydDemo project, aiming to realize a Rydberg atom quantum computer using strontium, we develop fully dynamic optical tweezer platforms. For our primary array we employ an all electro-optical setup containing 20 Acousto-Optic Deflectors (AODs), where each AOD can be driven by up to 100 tones and row spacing is achieved using a three-staged step mirror. This allows us to generate 2D arrays with an unprecedented dynamical connectivity reminiscent of an abacus. Through shuffling operations on a timescale of the qubit coherence time, atoms can be rearranged into various geometries. This allows for fast sorting as well as rearrangement during the algorithm, enabling error correction by physical movement using a dedicated feedback-loop. To extend the qubit architecture, we aim to realize a fully bichromatic array enabling processing and storage in a dual-qubit setting, where the second array will be generated using a phase-only spatial light modulator with fast frame rates.

Q 27.8 Tue 14:00 Tent

Towards Local Single- and Two-Qubit Control in a Neutral Atom Quantum Computer — •Achim Scholz[1,2], Christopher Bounds[1,2], Christian Hölzl[1,2], Manuel Morgado[1,2], Govind Unnikrishnan[1,2], Jiachen Zhao[1,2], Julia Hickl[1,2], Sebastian Weber[3,2], Hans-Peter Büchler[3,2], Simone Montangero[4], Jürgen Stuhler[5], Tilman Pfau[1,2], and Florian Meinert[1,2] — [1]5th Inst. of Physics, University of Stuttgart — [2]IQST — [3]Inst. for Theoretical Physics III, University of Stuttgart — [4]Inst. for Complex Quantum Systems, University of Ulm — [5]TOPTICA Photonics AG

The QRydDemo project aims to realize a Rydberg atom quantum computer based on the novel fine-structure qubit in strontium. This qubit offers fast single-qubit gates via strong two-photon Raman transitions and, by exploiting a single-photon Rydberg transition, two-qubit gates on the same timescale. Our experimental platform combines a dynamic tweezer architecture with fast optical addressing units, allowing for local control on the full array. To demonstrate coherent control of the novel fine-structure qubit, we show Rabi oscillations for single atoms paving the way for high-fidelity single-qubit gates. Using Ramsey spectroscopy we extract the qubit coherence time and investigate magic trapping conditions for the qubit by tuning the tensor polarizability via an external magnetic field. Towards the realization of high-fidelity two-qubit gate operations we investigate Rydberg state spectroscopy and Rabi oscillations, for which we initialize the fine-structure qubit using a three-photon Raman transfer.

Q 27.9 Tue 14:00 Tent

Excitation spectrum of a double supersolid in a trapped dipolar Bose mixture — Daniel Scheiermann[1], •Albert Gallemi[2], and Luis Santos[3] — [1]Leibniz Universität Hannover — [2]Leibniz Universität Hannover — [3]Leibniz Universität Hannover

Dipolar Bose-Einstein condensates constitute an excellent platform for the study of supersolidity, characterized by the coexistence of density modulation and superfluidity. The realization of dipolar mixtures opens intriguing new scenarios, most remarkably the possibility of observing a double supersolid, composed by two coexisting interacting miscible supersolids with different superfluidity. We analyze the rich excitation spectrum of a miscible trapped dipolar Bose mixture, showing that it provides key insights about the double supersolid regime. This regime may be in particular probed experimentally by monitoring the apperance of doublets of superfluid compressional modes, linked to the different superfluid character of each component. Moreover, the two-fluid character results in a non-trivial nature of the roton excitations, as well as of the Higgs and low-lying Goldstone modes.

Q 27.10 Tue 14:00 Tent

Bayesian Thermometry with Single-Atom Quantum Probes for Ultracold Gases — •Julian Fess, Sabrina Burgardt, Silvia Hiebel, and Artur Widera — Department of Physics, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Quantum probes are atomic sized devices mapping information of their environment to quantum mechanical states. By improving measurements and at the same time minimizing perturbation of the environment, they form a central asset for quantum technologies. We experimentally realize spin-based quantum thermometers by immersing individual Cs atoms into an ultracold Rb bath. Controlling inelastic spin-exchange processes between the probe and bath allows us to map motional and thermal information onto quantum-spin states. We find that the information gain per inelastic collision can be maximized by harnessing the nonequilibrium spin dynamics. The parameters that need to be tuned to achieve maximum information gain depend on the temperature being estimated, making this system well-suited for Bayesian estimation strategies. In this work, we compare three protocols: unoptimized, a priori optimized, and adaptively optimized. These protocols are evaluated based on their convergence speed and the magnitude of the estimation error. Among them, the adaptive protocol performs best, as it dynamically adjusts the parameters to optimize the information gained from each measurement. This approach highlights the potential of leveraging nonequilibrium dynamics to optimize measurement strategies, paving the way for more efficient and precise quantum thermometry.

Q 27.11 Tue 14:00 Tent

Transport of single atoms through an ultracold bath in an accelerated optical lattice — •Silvia Hiebel, Julian Fess, Sabrina Burgardt, and Artur Widera — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern-Landau, Erwin Schrödinger Str. 46, 67663 Kaiserslautern, Germany

Diffusion, a fundamental transport phenomenon, plays a significant role across nearly all physical systems. While extensively studied in classical contexts, transport phenomena in ultracold gases of neutral atoms remain relatively underexplored. At the same time, diffusion under external forces provides critical insights into transport phenomena in complex systems. Quantum gases, with their high degree of controllability and observable dynamics, offer a unique platform to investigate these processes.

Here, we present a system for observing the one-dimensional transport dynamics of single atoms in tilted optical lattices. Our optical system enables precise control of lattice parameters such as depth, velocity, and acceleration, facilitating the application of tunable external forces. Additionally, the system includes a thermal bath of ultracold rubidium atoms, which provides a controlled environment for introducing friction and interactions with open systems.

Q 27.12 Tue 14:00 Tent

Characterization of a coincidence detection unit for ultracold quantum gases combining electron velocity-map-imaging and ion microscopy — Julian Fiedler, Jette Heyer, Mario Grossmann, •Lasse Paulsen, Marlon Hoffmann, Klaus Sengstock, Markus Drescher, Philipp Wessels-Staarmann, and Juliette Simonet — Center for Optical Quantum Technologies, Universität Hamburg, Hamburg, Germany

Femtosecond laser pulses enable instantaneous ionization or excitation of ultracold quantum gases, facilitating studies of strongly interacting many-body systems like ultracold microplasma and dense Rydberg gases. To gain a detailed understanding of the dynamics of these systems, a high temporal, spatial, energetic and angular resolution of the ionization products is required.

We report on the construction of a novel detection unit consisting of an electron velocity-map-imaging spectrometer and an ion microscope. This setup enables simultaneous measurements of ion spatial distributions at a simulated resolution of 100 nm and electron momentum distributions with a simulated energy resolution $< 10\,\%$ over six orders of magnitude. We characterize the coincidence unit via photoionization studies of a pulsed krypton gas jet using femtosecond laser pulses. The integration of this new coincidence detection unit in an ultracold quantum gas experiment will grant access to correlations as well as the time-resolved dynamics.

This work is funded by the Cluster of Excellence "CUI: Advanced Imaging of Matter" of the DFG - EXC 2056 - project ID 390715994.

Q 27.13 Tue 14:00 Tent

A strontium quantum-gas microscope for Bose and Fermi Hubbard systems — Carlos Gas[1], Sandra Buob[1], Jonatan Höshele[1], •Antonio Rubio-Abadal[1], and Leticia Tarruell[1,2] — [1]ICFO - Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain

The combination of quantum-gas microscopy with alkaline-earth atoms offers many exciting prospects for quantum simulation of Hubbard models.

In this contribution, we present the latest results on quantum-gas microscopy from the Strontium Lab at ICFO. In a first set of experiments, we worked with the bosonic isotope ^{84}Sr. We routinely prepared Bose-Einstein condensates of ^{84}Sr, load them in a square optical lattice and realized the Bose-Hubbard model. In recent experiments, we have extended our microscope setup to work with fermionic ^{87}Sr. This opens the door to studies of exotic quantum magnetism with $N > 2$, which could be characterized through site-resolved spin-sensitive detection.

Q 27.14 Tue 14:00 Tent

Quantum Manipulation of Optically Trapped Ions — •Wei Wu, Igor Zhuravlev, Rick Bevers, and Tobias Schaetz — University of Freiburg, Institut of Physics, Hermann-Herder-Strasse 3, Freiburg 79104, Germany

Ions confined in Paul traps provide an exceptional platform for the realization of few-particle systems with high-fidelity control over electronic and motional degrees of freedom, as well as individual addressability. However, extending such precise control to two- or higher-dimensional systems poses significant challenges, primarily due to the presence of driven motion inherent to rf trapping, which introduces decoherence and motional heating. In contrast, optical trapping techniques offer a driven-motion free environment while preserving the long-range Coulomb interactions that are intrinsic property of ion-based systems.

In this work, we demonstrate coherent control of the electronic states of optically trapped Barium ions on the quadrupole transition (6S1/2 -> 5D5/2) using a narrow-linewidth 1762 nm laser system. This system also enables precise spectroscopic resolution of the ions' motional states, facilitating advanced quantum state manipulations. Furthermore, we are studying electronic state dependent confinement of the optically trapped ions and aiming at coherent electronic superposition state and their prospects to allow for investigating superpositions of related electronic structural phase transition from linear ion-chains to 2D zig-zag structures.

Q 27.15 Tue 14:00 Tent

2D matter wave array for gyroscopy — •Daida Thomas, Knut Stolzenberg, Sebastian Bode, Alexander Herbst, Wei Liu, Ernst M Rasel, Naceur Gaaloul, and Dennis Schlippert — Institut für Quantenoptik, Leibniz universität hannover, Welfengarten 1, 30167 Hannover

Interferometers based on matter-waves offer significant advantages in inertial sensing due to their exceptional long-term stability and sensitivity. Using 2D matter-wave arrays as input, simultaneous Mach-Zehnder like interferometers capable of measuring rotations and accelerations has recently been demonstrated. We describe a modification of this scheme by applying initial velocities to the columns of the array, thereby enabling the matter waves to span a Sagnac area. This allows for differential readout of the sagnac phase of the parallelized interferometers, showing a linear dependency on the rotation rate. The conjugate interferometers also provide robustness to environmental noise by suppressing common-mode noise, including vibrations and external perturbations. This system could achieve sensitivity in the order of 10^{-5} rad/s making it a good canditate for precise inertial measurements, highlighting its potential for applications in navigation, geophysics, and fundamental physics tests.

Q 27.16 Tue 14:00 Tent

An Atomtronic Toolbox for Josephson Physics — •Florian Binoth[1], Erik Bernhart[1], Marvin Röhrle[1], Leon Scherne[1], Monika Mayer[1], Vijay Pal Singh[2], Ludwig Mathey[3,4], Luigi Amico[2,5,6], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Kaiserslautern, Germany — [2]Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE — [3]Zentrum für Optische Quantentechnologien and Institut für Quantenphysik, Universität Hamburg, Hamburg, Germany — [4]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [5]Dipartimento di Fisica e Astronomia, Università di Catania, Catania, Italy — [6]INFN-Sezione di Catania, Catania, Italy

We present an atomtronic toolbox to investigate Bose-Einstein condensates in spatially and temporally modulated optical potential landscapes. Our platform enables the arbitrary creation of such potentials with acousto-optical deflectors and a digital micromirror device. We additionally work on implementing a novel sub-wavelength dark state barrier using a pair of resonant Raman beams with differing transverse modes. The potentials are projected onto the atoms with an objective inside the vacuum chamber. Combining DC and AC drive, we have observed the occurrence of Shapiro steps in superconducting Josephson junctions. These are plateaus in the current-voltage characteristic, which form today's voltage standard. We show that these steps exhibit universal features and that they are directly connected to phonon emission and soliton nucleation.

Q 27.17 Tue 14:00 Tent

A UV laser setup for neutral atom based quantum computation. — •Tobias Pätkau[1], Jonas Gutsche[1], Jens Nettersheim[1], Suthep Pomjaksilp[1], Jonas Witzenrath[1], Niclas Luick[2], Dieter Jaksch[2], Henning Moritz[2], Thomas Niederprüm[1], Herwig Ott[1], Peter Schmelcher[2], Klaus Sengstock[2], and Artur Widera[1] — [1]RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]University of Hamburg, 22761 Hamburg, Germany

The emergence of commercially viable quantum processing holds the potential to significantly enhance our ability to address complex optimization problems. As a promising platform, neutral atom based quantum computing offers efficient solutions for problems ranging from supply chain optimization to logistical transportation.

Within the Rymax One project, a neutral atom quantum computer is built up that consists of neutral Ytterbium atoms trapped in arrays of optical tweezers, where interactions between the qubits are mediated via Rydberg blockade mechanisms. To excite Rydberg states, we demonstrate a laser setup to generate frequency and amplitude controlled pulses of UV light with an AOM in a prism-based double pass configuration. Combining two UV lasers at 301 nm and 308 nm using a reflective grating, we couple both lasers simultaneously in a UV optical fiber. This allows us to simultaneously address Ytterbium Rydberg states from two different intermediate states. To estimate the effect on the qubit fidelity, we measure the phase noise of the laser in reference to a frequency comb and feed that data into a master equation simulation of the maximum independent set Hamiltonian.

Q 27.18 Tue 14:00 Tent

Rymax one: A neutral atom quantum processor to solve optimization problems — •Silvia Ferrante[1], Jonas Witzenrath[2], Benjamin Abeln[1], Tobias Ebert[1], Kapil Goswami[1], Jonas Gutsche[2], Hauke Biss[1], Hendrik Koser[1], Rick Mukherjee[1], Jens Nettersheim[2], Martin Schlederer[1], Suthep Pomjaksilp[2], José Vargas[1], Niclas Luick[1], Thomas Niederprüm[2], Dieter Jaksch[1], Henning Moritz[1], Herwig Ott[2], Peter Schmelcher[1], Klaus Sengstock[1], and Artur Widera[2] — [1]University of Hamburg, 22761 Hamburg, Germany — [2]RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

From the optimisation of supply chains to efficient vehicle routing - computationally hard problems are deeply embedded into modern society. Finding solutions to these problems via classical means still requires substantial computational effort. Quantum processors, on the contrary, promise a significant advantage in solving them. To explore the potential of quantum computing for real-world applications, we set up Rymax One, a quantum processor designed to solve hard optimisation problems. We trap ultracold neutral Ytterbium atoms in arbitrary arrays of optical tweezers, ideally suited to solve optimisation problems and perform quantum operations in a hardware-efficient manner. The level structure of Yb provides the possibility of attaining qubits with long coherence times as well as Rydberg-mediated interactions and high-fidelity gate operations. These features allow us to realise a scalable platform for quantum processing to test the performance of novel quantum algorithms tailored to tackle real-world problems.

Q 27.19 Tue 14:00 Tent

Long-lived and trapped Circular Rydberg states of alkaline-earth atoms at room temperature — •Einius Pultinevicius, Aaron Götzelmann, Armin Humic, Moritz Berngruber, Christian Hölzl, and Florian Meinert — 5. Physikalisches Institut, Universität Stuttgart

Highly excited Rydberg atoms have become prominent in the field of quantum simulation and computation. While these excitations result in favourable long-range dipolar interactions for the implementation of many-body spin models, usual excitations at low orbital momentum, however, come with fundamental restrictions such as lifetime limited coherence times and challenging trapping requirements.

To overcome these caveats, we are working towards a quantum simulator based on circular Rydberg states (CRS) of neutral ^{88}Sr atoms. At maximum orbital momentum, these states feature only a handful of decay channels which can be suppressed using a resonator made from indium tin oxide (ITO) coated glass plates. This allows the enhancement of the black-body radiation limited lifetime to the millisecond range without use of cryogenics. We explore this effect in our field control structure, and to this end probe CRS at principle quantum numbers up to 90 via coherent microwave-control. Measurements at such timescales further require trapping, which is enabled by the second valence electron of strontium for Gaussian tweezers. The low overlap of the ionic core with the circular wavefunction further allows autoionization-free excitations, which is demonstrated by probing state-dependent interactions with the Rydberg electron.

Q 27.20 Tue 14:00 Tent

Atom-ion Feshbach resonances within a spin-mixed atomic bath — •Jonathan Grieshaber[1], Joachim Siemund[1], Fabian Thielemann[1], Kilian Berger[1], Wei Wu[1], Krzysztof Jachymski[2], and Tobias Schätz[1] — [1]Physikalisches Institut, Albert-Ludwigs Universität Freiburg — [2]Faculty of Physics, University of Warsaw

Exploring particle interactions lies at the core of physics and chemistry. Feshbach resonances allow us to control atomic binding processes at the quantum level. In our hybrid atom-ion setup, we manipulate the interaction between a cloud of ultracold ^{6}Li in an optical dipole trap and a $^{138}Ba^+$ ion in a linear Paul trap. We measure and analyze the effects of mixing Lithium spin states on the interaction and pseudo-molecular formation between atom and ion. Our findings offer valuable insights into the predictive capability of an adapted theoretical two-step quantum recombination model for molecular formation already partially established for Feshbach resonances in neutral atoms.

Q 27.21 Tue 14:00 Tent

ATOMIQ: A block based, highly flexible and user friendly extension for ARTIQ — •Christian Hölzl[1], Suthep Pomjaksilp[2], Thomas Niederprüm[2], and Florian Meinert[1] — [1]5th Institute of Physics, Universität Stuttgart, Germany — [2]Department of Physics and research center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

The demand for fast and reliable experiment control hardware and software has increased dramatically with recent advances in quantum technology. For the fast cycle times required in atom computing and simulation, highly flexible yet nanosecond-precise systems are needed. By providing fully open source software and hardware the ARTIQ/Sinara ecosystem has propelled itself to a leading solution for ion and neutral atom based quantum experiments. However, the out-of-the-box software functionality is heavily limited and requires major time commitment from the end user. Our ATOMIQ extension aims to mitigate this problem by adding a user-friendly abstraction layer. By using a block-based experiment structure, we achieve a drastic reduction of boilerplate without compromising the speed of ARTIQ. Combining simple primitives through multiple inheritance patterns to graspable lab devices like lasers ensures easy extensibility. ATOMIQ further aims to tightly implement data management and non-real-time devices, such as environmental sensors, which are becoming increasingly important in the ever-growing complexity of quantum devices. By providing this flexible interface to lab infrastructure it is also easy to implement ATOMIQ in an already existing system.

Q 27.22 Tue 14:00 Tent

Stroboscopic Measurement Techniques to Observe Cyclic Dynamics Showcased in a Trapped-Ion Quantum Simulator — •Florian Hasse, Frederike Doerr, Andreas Weber, Deviprasath Palani, Apurba Das, Tobias Spanke, Ulrich Warring, and Tobias Schaetz — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

The study of dynamical processes in trapped-ion systems provides insights into the fundamentals of quantum mechanics. Such studies uniquely combine theory, experiment, and technological innovation, enabling a deeper understanding of the dynamics of physical systems.

Introducing an approach, creating and maintaining the coherence of four oscillators: a global microwave reference field, a polarization-gradient traveling-wave pattern of light, and a single trapped ion's spin and motional states. Utilized to stroboscopically trace dynamical variations in position and momentum observables of a coherently displaced state with noise floors of 1.8(2) nm and 8(2) zμNs, respectively [1].

This stroboscopic measurement technique offers the observation of motional states with minimal disturbance. Additionally, this method could benefit the generation of multi-particle entangled states, facilitating the transfer of spatial entanglement in multimode squeezed states into the robust electronic degrees of freedom of multiple ions. By improving the switching times of our acousto-optic modulator setup, we aim to expand the applicability of these techniques and explore analogs of early-universe physics.

[1] F. Hasse et al., Phys. Rev. A 109, 053105 (2024)

Q 27.23 Tue 14:00 Tent

Modeling thermodynamic and dynamic properties of Bose-Einstein condensate bubbles in microgravity — •Brendan Rhyno[1,2], Timothé Estrampes[1,3], Gabriel Müller[1], Charles Garcion[1], Eric Charron[3], Jean-Baptiste Gerent[4], Nathan Lundblad[4], Smitha Vishveshwara[2], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover — [2]University of Illinois at Urbana-Champaign — [3]Université Paris-Saclay — [4]Bates College

The study of Bose-Einstein condensate (BEC) bubbles has received increasing attention in recent years. We discuss our efforts to model the properties of such systems in view of the current Cold Atom Lab experiments and the prospects of realizing BEC bubbles in the microgravity environment of the Einstein-Elevator at the Leibniz University of Hanover. Using an isotropic 'bubble trap' potential, we explore both the thermodynamic and dynamic inflation of dilute Bose-condensed bubbles. In the thermodynamic treatment, adiabatic inflation from an initial filled spherical BEC into a large thin spherical shell leads to condensate depletion. In the dynamic treatment, we study the non-equilibrium expansion and contraction of the system in the vicinity of the BEC phase transition. We conclude by discussing how our work can inform the ongoing experimental efforts.

Q 27.24 Tue 14:00 Tent

Exploring atom-ion Feshbach resonances below the *s*-wave limit — •Kilian Berger[1], Joachim Siemund[1], Fabian Thielemann[1], Jonathan Grieshaber[1], Daniel von Schönfeld[1], Wei Wu[1], Pascal Weckesser[2], Krzysztof Jachymski[3], Thomas Walker[4], and Tobias Schätz[1] — [1]Faculty of Physics, University of Freiburg — [2]Max Planck Institute of Quantum Optics, Garching — [3]Faculty of Physics, University of Warsaw — [4]Blackett Larboratory, Imperial College London

Understanding quantum dynamics at the level of individual particles requires precise control over both, electronic and motional degrees of freedom. Trapped atomic ions have long been valuable in this area, though they are limited in studying collective properties. A novel approach that integrates a single ion with ultracold atoms opens up opportunities to investigate phenomena ranging from single-particle to many-body physics. In our experiment, we immerse a single $^{138}Ba^{+}$ ion in an ultracold gas of ^{6}Li atoms to investigate atom-ion Feshbach resonances. We examine how the Feshbach resonances depend on the collision energy. By controlling the ion's kinetic energy and the temperature of the atomic bath, we observe a variation in inelastic losses at higher collision energies near resonance. These findings offer key experimental insights into the energy dependence of partial-wave interactions in atom-ion systems.

Q 27.25 Tue 14:00 Tent

A High-Resolution Ion Microscope to Spatially Observe Ion-Rydberg Interactions — •Jennifer Krauter, Viraatt Anasuri, Óscar Andrey Herrera-Sancho, Moritz Berngruber, Florian Meinert, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Here, we present the findings of our recent studies on ion-Rydberg atom interactions conducted in the ultracold quantum regime using a high-resolution ion microscope. This experimental apparatus offers temporal and spatial imaging of charged particles with a resolution of up to 200 nm. Systems combining ions and Rydberg atoms offer various interesting phenomena for research. Already simple ion-Rydberg atom pair states allow for the observation of collisional dynamics on steep attractive potential energy curves featuring multiple avoided crossings with adjacent states. Those can lead to a drastic speed-up of the collision process. Avoided crossings can also give rise to bound molecular states by forming potential wells. These bound states between an ion and a Rydberg atom feature huge bond lengths of several micrometers, enabling the direct observation of vibrational dynamics. Further, this binding mechanism is not limited to diatomic molecules but can be extended to polyatomic molecules, for which we expect interactions that are even more complex. In particular, for a bound state between two Rydberg atoms and one ion, we predict a rich interaction potential that comprises the interaction between induced dipoles, ion-Rydberg atom interactions, and the Rydberg blockade effect.

Q 27.26 Tue 14:00 Tent

Microwave-Optical Four-Photon Lattice for Ultracold Rubidium Atoms — •Stefanie Moll, Patrick Haas, and Martin Weitz — Institut für Angewandte Physik, Bonn, Germany

Optical lattices have become an important tool in fields ranging from the simulation of solid state physics theory effects to quantum information. In earlier work of our group, the versatility of this system has allowed for the simulation of quantum Rabi physics with cold atoms.

We here report on the development of a scheme to realize state selective lattices for alkali atoms despite the usage of extremely far detuned trapping light fields. The method is used on a combination of optical and microwave transitions. We present a proof of principle experiment demonstrating the introduced double resonant lattice. Prospects of the described scheme include fault-tolerant quantum computation in optical lattices and the generation of highly entangled cluster states for measurement-based quantum computation.

Q 27.27 Tue 14:00 Tent

Improved Power Efficiency in Wide-Range Frequency Tuning with a Combined Single-/Double-Pass AOM System — •Luca Leon Granert, Silvia Hiebel, Sabrina Burgardt, Julian Fess, and Artur Widera — Department of Physics, RPTU Kaiserslautern-Landau, Kaiserslautern, Germany

In experiments with ultracold quantum gases, precise control of not only the position of laser beams for cooling and trapping but also their frequency and intensity is crucial. Acousto-optical modulators (AOMs) are widely used to achieve this level of control, as they enable fine-tuning of a laser's frequency and power. Applications like compressed magneto-optical traps require large frequency detuning ranges to minimize photon scattering rates, thereby ensuring efficient loading into an optical dipole trap. AOM systems are typically configured in a double-pass configuration to achieve these extended detuning ranges and ensure intensity control. While such configurations are effective, they reach the limit of their angular tolerance when operated over broad detuning ranges within the same experimental run, leading to a significant decrease in efficiency, which can drop to below 1% at the extremes of the operating range.

We present an experimental setup, consisting of a single-pass and a double-pass AOM, built in series. Our system provides substantially higher efficiency at large detunings compared to typical double-pass configurations, while also extending the achievable effective detuning range. With this, power loss due to excessive detuning is minimized, ensuring that less light power is lost at large detunings.

Q 27.28 Tue 14:00 Tent

Ultracold strontium quantum simulator for studying open quantum systems — •Jan Geiger[1,2], Felix Spriestersbach[1,2], Valentin Klüsener[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

We simulate an open quantum system using a quantum simulator based on ultracold strontium atoms with state-dependent trapping. This system is implemented by coupling trapped metastable atoms to a structured reservoir, represented by mobile ground-state atoms in a shallow optical lattice. The coupling can be tuned using high-resolution spectroscopy, allowing us to directly address different momenta within the band structure. We show control of the system by characterizing it in one and two dimensions by performing momentum-resolved measurements. Additionally, we can directly study the system in real space using single-atom resolved microscopy. These results open a new perspective for studying open quantum systems in one and two dimensions.

Q 27.29 Tue 14:00 Tent

Interplay of topology and disorder in driven honeycomb lattices — Alexander Hesse[1,2,3], Johannes Arceri[1,2,3], •Moritz Hornung[1,2,3], Christoph Braun[1,2,3], and Monika Aidelsburger[1,2,3] — [1]Ludwig-Maximilians-Universitä Fakultät für Physik, München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

One of the most fascinating properties of topological phases of matter is their robustness to disorder [1]. While various methods have been developed to probe the geometric properties of Bloch bands with ultracold atoms [2], most fail in the presence of disorder due to their reliance on translational invariance. Here, we demonstrate that topological edge modes can be employed to detect a disorder-induced phase transition between distinct topological phases in a Floquet-engineered 2D optical honeycomb lattice.

[1] J. Zheng, et al., Floquet top. phase transitions, Phys. Rev. B (2024)
[2] N. R. Cooper, J. Dalibard, and I. B. Spielman, Topological bands, Rev. Mod. Phys. (2019)

Q 27.30 Tue 14:00 Tent

Quantum phase slips and transport in one-dimensional supersolids — •Alicia Biselli, Chris Bühler, and Hans Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, DE-70550 Stuttgart, Germany

Quantum fluctuations in one dimension prevent the appearance of long-range order for a continuous symmetry even at zero temperature. Furthermore, the nucleation of quantum phase slips can have significant influence on the phase diagram and transport properties. Here, we study the influence of quantum phase slips on the phase diagram of a one-dimensional supersolid as they can be realized with dysprosium atoms. We demonstrate the appearance of a novel quantum phase transition from the supersolid to the superfluid phase and study in detail its influence on transport properties.

Q 27.31 Tue 14:00 Tent

Development of a spin and density-resolved Strontium quantum gas microscope — Thies Plassmann[1,2], Meny Menashes[1], •Leon Schäfer[1], and Guillaume Salomon[1,2] — [1]Institute for Quantum Physics, Hamburg University, Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Center for Ultrafast Imaging, Hamburg University, Luruper Chaussee 149, 22761 Hamburg

Neutral atom quantum simulators with single particle and spin resolution offer fascinating opportunities for experiments. Microscopy of the SU(2) Fermi-Hubbard model is shedding new lights on strongly correlated fermions. Quantum gas microscopy of SU(N) fermions, with N up to 10 for strontium, requires however the development of novel experimental techniques in order to detect both the spin and density on each individual sites of optical lattices. We report here on our current efforts towards spin and density resolved imaging of strontium atoms which we plan to use to study the intriguing phase diagram of the SU(N) Fermi-Hubbard model.

Q 27.32 Tue 14:00 Tent

The Digital Micromirror Device for the creation of arbitrary optical potentials in ultracold quantum gas experiments — •Louisa Marie Kienesberger, Alexander Guthmann, Felix Lang, Krishnan Sundararajan, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

The Digital Micromirror Device (DMD) enables the creation of arbitrary optical potentials by dynamically controlling an array of micromirrors, which direct light to form desired intensity patterns. This provides a powerful tool for the precise manipulation of ultracold quantum gases. A modular design of a DMD setup is presented for a seamingless integration into the already existing experimental apparatus in our research group. Additionally, custom software was developed to control the DMD, including an active feedback loop for the stabilization of the optical potential. This system facilitates the study of diverse quantum phenomena, such as homogeneous systems using box potentials, superfluid dynamics in ring geometries, and Anderson localization in disordered potentials.

Q 27.33 Tue 14:00 Tent

Progress toward a Lithium-based quantum gas microscope — Ruijia Li and •Timon Hilker — University of Strathclyde, Glasgow, UK

We will present our plans and progress towards a new quantum gas microscope with lithium atoms. Our goal is to gain full control over the motion of the atoms in an optical lattice using local digital gates by employing an optical superlattice and local addressing. This bottom-up approach to quantum simulations has the potential to upgrade an optical lattice to a flexible programmable quantum hardware with fermionic exchange statistics.

We aim to achieve fast cycle times and robust preparation of deeply degenerate gases using a single-chamber design with a high-power optical lattice which can be directly loaded from the MOT.

Q 27.34 Tue 14:00 Tent

Towards the observation of collective radiance phenomena in a 1D-array of waveguide-coupled atoms — •Hector Letellier, Lucas Pache, Martin Cordier, Max Schemmer, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, Germany

Recently, it has been shown theoretically that the infidelity of photon storage and retrieval in quantum memories scales exponentially better with the number of emitters if one harnesses the collective response of closely spaced atoms ordered in an array [1]. The improved scaling relies on the effect of selective radiance, i.e., destructive interference suppressing the scattering into undesired modes. This occurs when the period of an array of emitters is smaller than half of the atomic resonant wavelength ($d < \lambda/2$). In order to realize this situation, we trap and optically interface laser-cooled cesium atoms using a two-color nanofiber-based dipole trap [2]. It is composed of a blue-detuned partial standing wave and two red-detuned running waves light fields which counter-propagate in the fiber. The resulting trapping potential consists of two 1D-arrays of trapping sites located on opposite sides of the nanofiber, where the axial period is $d = 0.35\lambda$. We characterize the trap by measuring the trap frequencies, the total number of stored atoms, the fraction of sites filled with a single atom in the collisional blockade regime, and the lifetime of the atoms.

[1] A. Asenjo-Garcia et al. PRX 7, 031024 (2017)
[2] L. Pache et al. arXiv:2407.02278 (2024)

Q 28: Poster – Ultra-cold Plasmas and Rydberg Systems (joint session A/Q)

Time: Tuesday 14:00–16:00 Location: Tent

Q 28.1 Tue 14:00 Tent

Study of Rydberg states in ultra cold ytterbium — •Alexander Miethke, Nele Koch, and Axel Görlitz — Institut für Experimentalphysik, Heinrich-Heine-Universität, Düsseldorf, Deutschland

In recent years Rydberg atoms with their special features, like dipole-dipole interaction or van-der-Waals blockade, have become more and more important for quantum optics. Particularly ultra cold Rydberg atoms are of great interest for the investigation of long range interaction.

A special feature of ytterbium is that due to its two valance electrons atoms in Rydberg states can be easily manipulated and imaged using optical fields. A first step towards studies of ultra cold ytterbium is to gain precise knowledge on the Rydberg states.

Here we present the study of the Rydberg states of ultra cold ytterbium. Using a Micro-Channel-Plate to detect the Rydberg atoms it is possible to measure lifetimes and hyperfine structures of several states (n=35-90). In addition we could measure the energy and polarizability of s, p and d states in the region of high principal quantum numbers n (n=70-90). Using a second stage trap we are able to cool the atoms down to several *K to reduce their distances and investigate interactions.

Q 28.2 Tue 14:00 Tent

Avalanche events and universality crossover on a dynamical network in a driven, dissipative Rydberg gas — •Simon Ohler, Daniel Brady, and Michael Fleischhauer — RPTU Kaiserslautern-Landau, Germany

In an off-resonantly laser-driven gas of Rydberg atoms, it is known that there exists an absorbing-state phase transition. In the spreading phase the gas is saturated with Rydberg excitations, whereas in the absorbing phase Rydberg excitations stay isolated. At the critical point separating the two, which is the attractor of the dynamics via the self-organized criticality (SOC) mechanism, one can observe scale-free avalanche events where a single Rydberg seed excitations leads to a cascade effect. We numerically investigate the response of a critical gas of atoms under such a minimal perturbation and observe a scale-free avalanche-response irrespective of the thermal motion of the gas. Determining the exponents of power-law avalanche distributions we confirm that the universality class of the associated absorbing-state phase transition changes as a function of temperature. Additionally, we consider the emerging network structure that determines the dynamics and quantify the degree to which this excitation graph is dynamical.

Q 28.3 Tue 14:00 Tent

Continuous observation of non-equilibrium phase transitions in facilitated Rydberg avalanches — •Patrick Mischke, Fabian Isler, Jana Bender, Thomas Niederprüm, and Herwig Ott — Department of Physics and research center OPTIMAS, RPTU Kaiserslautern-Landau

We investigate the facilitation dynamics in a Rydberg system and the phase transition resulting from the interplay between driving strength and excitation decay.

In an off-resonantly driven cloud of atoms, the strong dipole-dipole interactions between two Rydberg states compensates the laser detuning for a specific interatomic distance. For high enough driving strength, this results in a spreading of correlated excitations. We investigate the non-equilibrium steady state phase transition between this active phase and the absorbing phase in which the spread of excitations is suppressed.

Non-destructive phase-contrast imaging is employed to continuously monitor the ground state density of our sample. Time resolved ion detection enables the characterization of excitation avalanches around the critical point of the phase transition. We use this information to extract the relevant universal exponents.

Q 28.4 Tue 14:00 Tent

High precision spectroscopy of trilobite Rydberg molecular series — •Markus Exner[1], Richard Blättner[1], Rohan Srikumar[2], Matt Eiles[3], Peter Schmelcher[2], and Herwig Ott[1] — [1]RPTU, Kaiserslautern — [2]Zentrum für Optische Quantentechnologie, Hamburg — [3]Max Planck Institute for the Physics of Complex Systems, Dresden

Trilobite Rydberg molecules consist of a highly excited Rydberg atom and a perturber atom in the electronic ground state. The underlying binding mechanism is based on the scattering interaction between the Rydberg electron and the perturber. These molecules exhibit extreme properties: their dipole moments are in the kilo-Debye range, and their molecular lifetimes may exceed the lifetimes of the close by atomic Rydberg states. We use three-photon photoassociation and a reaction microscope to perform momentum-resolved spectroscopy on trilobite ^{87}Rb Rydberg molecules for principal quantum numbers n=22,24,25,26,27. The large binding energies and the high spectroscopic resolution of 10^{-4} allow us to benchmark theoretical models. Previous models relied on exact diagonalization, which suffered from basis-dependent convergence problems. Using a recent basis-independent theoretical method based on Green*s functions, which accounts for all relevant spin interactions, we fit the measured spectra. This enables a new estimate of the involved low-energy scattering lengths. However, with the precision of our experiment, we encounter conceptual issues, suggesting that the fundamental modeling of the molecular Hamiltonian has reached the limits of its predictive power.

Q 28.5 Tue 14:00 Tent

Experimental setup for the generation of atomic Rydberg states with chiral signatures — •Miles DeWitt[1], Stefan Aull[1], Steffen Giesen[2], Moritz Göb[1], Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Experimental Physics 1, Institute of Physics, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Berger Group, Institute of Chemistry, University of Marburg, Hans-Meerwein-Str. 4, 35043 Marburg, Germany — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, Tzarigradsko Chaussee 72, 1784 Sofia, Bulgaria

We present an experimental setup for the preparation and detection of Rydberg states with chiral properties [1] using a novel excitation scheme. We have achieved the loading of Rubidium atoms from a MOT to a crossed dipole trap, to carry out subsequent two-photon excitation into Rydberg states. The dipole trap has been characterized in terms of atom number and temperature using absorption imaging. Subsequently, a superposition of circular states can be generated to realize Rydberg wave functions with chiral signatures. The design of a field ionization setup for state selective detection is presented.

[1] S. Y. Buhmann et al., Quantum sensing protocol for motionally chiral Rydberg atoms, New J. Phys., **23**, 8, 8 (2021).

Q 28.6 Tue 14:00 Tent

Construction of a versatile platform for Rydberg atom experiments — •Aaron Thielmann, Sven Schmidt, Suthep Pomjaksilp, Thomas Niederprüm, and Herwig Ott — Department of Physics and research center OPTIMAS, RPTU Kaiserslautern-Landau

In recent years, atomic arrays emerged as a ground-breaking platform in quantum physics. These setups feature single-atom control and offer large flexibility to study quantum information processing and many-body physics in different geometric configurations.

We present a new experimental setup utilizing a stainless steel chamber and in-vacuum electrodes, allowing to produce arrays of single atoms or small samples, while having as much control over sorrounding parameters as possible. We use holographically generated tweezer traps from an SLM at a wavelength of 1064nm, which are projected together with additional addressing beams through a high resolution objective into the vacuum chamber. This opens the possibility to site-selectively excite and deexcite the atoms, thus enabling the investigation of transport with controlled dissipation in arbitrarily arranged arrays of Rubidium atoms. Additional features include electric and magnetic field control in combination with an ion detector as well as the ability for global application of microwave and optical fields.

Q 29: Poster – Polaritonic Effects in Molecular Systems (joint session MO/Q)

Time: Tuesday 14:00–16:00 Location: Tent

Q 29.1 Tue 14:00 Tent

Modifying the electronic properties of the topological systems with cavity — •Saber Rostamzadeh, Remi Avriller, Clement Dutreix, and Fabio Pistolesi — Laboratoire Ondes et Matiere d Aquitaine, Universite de Bordeaux, France

Topological systems exhibit fascinating electronic applications due to their distinctive edge and zero-mode states. A central question is how these states interact with various environments, such as intense light. Similarly, hybrid quantum systems containing a few electrons, such as quantum dots, serve as valuable models for engineering topological electronic states. These systems have also garnered significant interest in cavity quantum electrodynamics (cavity QED) for their potential to achieve ultrastrong light-matter interactions. Their simplified architectures offer significant enhancements and optimizations in electron-photon coupling. In this study, we investigate modifications in electronic transport within single and double quantum dot arrays placed inside a cavity.

Q 29.2 Tue 14:00 Tent

Vibrational dynamics of individual oscillators under Vibrational Strong Coupling — •Helena Poulose[1], Mathis Noell[2], Yannik Pfeifer[1], Till Stensitzki[1], Carsten Henkel[2], Wouter Koopman[2], and Henrike Müller-Werkmeister[1] — [1]Institut für Chemie, Universität Potsdam, Germany — [2]Institut für Physik und Astronomie, Universität Potsdam, Germany

The novel field of polariton chemistry opens up a way to tune material properties and steer chemical reactions by manipulating quantum light-matter interactions. Fabry-Perot cavities can be constructed to confine electromagnetic field, allowing the light mode to strongly couple with vibrational transitions of molecules, generating quasi light-matter states, characterised by vacuum rabi splitting. However the underlying mechanism behind how it effects the reaction dynamics is not completely understood. Combining Ultrafast nonlinear spectroscopy with Strong coupling could provide insights to how the energy distribution changes when these delocalized hybrid states are formed. Experiments of vibrational dynamics can possibly provide valuable insights into the fundamental mechanisms of polaritons and how polaritons might modulate Chemistry. Here we report on our a) cavity design and characterisation, b) static polariton spectra supported by theory and c) first attempts in performing nonlinear IR and 2DIR spectra of organic compounds, like Benzaldehyde(C=O), under VSC in cavities. We aim to investigate vibrational lifetimes and energy transfer processes and examining how these depend on cavity and molecular properties.

Q 29.3 Tue 14:00 Tent

Coherent state switching using vibrational polaritons in an asymmetric double-well potential — •Loïse Attal[1], Florent Calvo[2], Cyril Falvo[1,2], and Pascal Parneix[2] — [1]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, 91405 Orsay, France — [2]Université Grenoble Alpes, CNRS, LIPhy, 38000 Grenoble, France

The quantum dynamics of vibrational polaritonic states arising from the interaction of a bistable molecule with the quantized mode of a Fabry-Perot microcavity is investigated using {a generic} asymmetric double-well potential as a simplified one-dimensional model of a reactive molecule. After discussing the role of the light-matter coupling strength in the emergence of avoided crossings between polaritonic states, we investigate the possibility of using these crossings to trigger a dynamical switching of these states from one potential well to the other. Two schemes are proposed to achieve this coherent state switching, either by preparing the molecule in an appropriate vibrational excited state before inserting it into the cavity, or by applying a short laser pulse inside the cavity to obtain a coherent superposition of polaritonic states. The respective influences of the dipole amplitude and potential asymmetry on the coherent switching process are also discussed.

Q 29.4 Tue 14:00 Tent

Chemical reaction rate of molecules in a cavity — •Yannic Joshua Banthien[1], Abraham Nitzan[2], and Michael Thorwart[1] — [1]I. Institut für Theoretische Physik, Universita*t Hamburg, Notkestraße 9, 22607 Hamburg, Germany — [2]Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA

We determine the reaction dynamics of N identical molecular systems, each represented by a particle in a double-well potential and each coupled to the same broadened mode of an optical cavity. Every reaction system is restricted to its lowest four energy eigenstates of the double well, forming a doublet-doublet system. A Markovian approximated master equation is set up following the Feynman-Vernon approach. It is constructed for the purpose of strong system-bath interaction. We solve for the time evolution of the quantum many-body system and extract the inter- and intra-well relaxation rates, leading to the chemical reaction rate. We study the impact of the common cavity mode on the reaction rate, determine the condition under which a Rabi splitting is found, and reveal emerging cooperative effects in the transfer rate.

Q 29.5 Tue 14:00 Tent

Modifying Photoacids under Vibrational Strong Coupling — •Swathi Swaminathan[1], Julia Berger[2], Gregor Jung[2], and Thomas Ebbesen[1] — [1]University of Strasbourg, Strasbourg, France — [2]Saarland University, Saarbrücken, Germany

Vibrational strong coupling (VSC) between molecular transitions and cavity modes can significantly alter molecular properties and intermolecular interactions in the ground state. Here we explore the properties of photoacids,[1] which exhibit acidity in the excited state, and provide an ideal platform to explore the effects of VSC on their photophysics. Photoacids typically exhibit characteristic fluorescence properties associated with the proton transfer from the solute to the solvent. Under cooperative VSC, we observe that this behavior is modified. This study shows that VSC can also affect excited-state properties, opening new avenues for understanding and controlling light-induced processes in molecular systems under strong coupling conditions.

[1] B. Finkler et al., Photochem. Photobiol. Sci. 2016, 15, 1544.

Q 29.6 Tue 14:00 Tent

Vibrational strong coupling: a detailed analysis of the cavity tilt angle — •Mathis Noell[1], Helena Poulose[2], Yannik Pfeifer[2], Till Stensitzki[2], Wouter Koopman[1], Henrike Müller-Werkmeister[2], and Carsten Henkel[1] — [1]Universität Potsdam, Institut für Physik und Astronomie — [2]Universität Potsdam, Institut für Chemie

Plasmonic chemistry is an emerging field that seeks to uncover new pathways for chemical reactions. One intriguing phenomenon in this domain is the strong coupling between a plasmonic cavity field and molecular excitations, resulting in the formation of hybrid polariton states. These hybrid states can modify potential energy surfaces and potentially tune material properties to benefit from enhanced reaction rates. To deepen our understanding of polariton dynamics, we investigate an analogous system where molecular vibrational resonances hybridize with an IR Fabry-Pérot cavity field mode. In this work, we present a detailed analysis of vibrational cavity strong coupling under angular variation, including the shift in polariton energy as the cavity is tilted. Additionally, we explore the polariton composition (Hopfield coefficients) and predict transmission, reflection, and absorption spectra. Our goal is to compare these theoretical results with pump-probe experiments, thereby contributing to a more comprehensive understanding of strong coupling dynamics.

Q 30: Quantum Sensing I (joint session Q/QI)

Time: Wednesday 11:00–12:30 Location: HS V

Q 30.1 Wed 11:00 HS V

Coherent Control in Quartz-Enhanced Photoacoustics: Fingerprinting a Trace Gas at ppm-Level within Seconds — •Simon Angstenberger, Moritz Floess, Luca Schmid, Pavel Ruchka, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Stuttgart Research Center of Photonic Engineering, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Quartz-enhanced photoacoustic spectroscopy (QEPAS) has become a versatile tool for detection of trace gases at extremely low concentrations, leveraging the high quality (Q)-factor of quartz tuning forks. However, this high Q-factor imposes an intrinsic spectral resolution limit for fast wavelength sweeping with tunable laser sources due to the long ringing time of the tuning fork. Here, we introduce a technique to coherently control the tuning fork by phase-shifting the modulation sequences of the driving laser [1]. Particularly, we send additional laser pulses into the photoacoustic cell with a timing that corresponds to a π phase shift with respect to the tuning fork oscillation, effectively stopping its oscillatory motion. This enables acquisition of a complete methane spectrum spanning 3050-3450 nm in just three seconds, preserving the spectral shape. Our measured data is in good agreement with the theoretically expected spectra from the HITRAN database when convolved with the laser linewidth of $< 2\,\mathrm{cm}^{-1}$. This will leverage the use of QEPAS with fast-sweeping OPOs in real-world gas sensing applications beyond laboratory environments with extremely fast acquisition speed enabled by our novel coherent control scheme.

[1] S. Angstenberger, M. Floess, L. Schmid, *et al.*, Optica, accepted.

Q 30.2 Wed 11:15 HS V

Photonic Integrated Circuit Platforms for Scalable Quantum Sensors — •Fatemeh Salahshoori[1], Suat Icli[1,2], Carl-Frederik Grimpe[1], Guochun Du[1], Rangana Banerjee Chaudhuri[1], Elena Jordan[1], Klaus Boller[3], Alexander Bachmann[5], Sonia M. Garcia-Blanco[4], and Tanja E. Mehlstäubler[1,2,6] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [3]Laser Physics and Nonlinear Optics Group, MESA+ Institute of Nanotechnology, University of Twente, Enschede, The Netherlands — [4]Integrated Optical Systems, MESA+ Institute of Nanotechnology, University of Twente, Enschede, The Netherlands — [5]TOPTICA Photonics, Gräfelfing, Germany — [6]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

As part of the EU project "QU-PIC," we aim to develop scalable photonic integrated circuit (PIC) modules designed to meet the stringent requirements of quantum sensor applications. These modules will feature multiwavelength tunable lasers ranging from UV to the near-IR, specialized light conditioning systems, and photonic-integrated ion trap chips, all engineered for the realization of an ion trap-based quantum sensor demonstrator. This talk will give an overview of the individual components and detail on ring resonator couplers for PIC-based lasers and grating outcouplers based on an Al_2O_3 platform, using benchmarking protocols for 3D beam tomography of the PIC-based ion-trap system.

Q 30.3 Wed 11:30 HS V

Vector Magnetometry Using Shallow NV Centers with Waveguide-Assisted Dipole Excitation and Readout — •Sajedeh Shahbazi[1], Giulio Coccia[2], Argyro N. Giakoumaki[2], Johannes Lang[1], Vibhav Bharadwaj[1], Fedor Jelezko[1], Shane M. Eaton[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Institute for Photonics and Nanotechnologies (IFN) - CNR, Piazza Leonardo da Vinci, 32, Milano 20133, Italy

On-chip magnetic field sensing with NV centers in diamond requires scalable integration of 3D waveguides into diamond substrates. Here, we develop a sensing array device with an ensemble of shallow implanted NV centers integrated with arrays of laser-written waveguides for excitation and readout of NV signals. Our approach enables an easy-to-operate on-chip magnetometer with a pixel size proportional to the Gaussian mode area of each waveguide. The performed continuous wave optically detected magnetic resonance on each waveguide gives an average dc-sensitivity value of $195 \pm 3\mathrm{nT}/\sqrt{\mathrm{Hz}}$. We apply a magnetic field to separate the four NV crystallographic orientations of the magnetic resonance and then utilize a DC current through a straight wire antenna close to the waveguide to prove the sensor capabilities of our device. We reconstruct the complete vector magnetic field in the NV crystal frame using three different NV crystallographic orientations. The waveguide mode's polarization allows B-filed projection into the lab frame[1]. Ref.1: Shahbazi et al.(2024), arXiv:2407.18711

Q 30.4 Wed 11:45 HS V

Limits of absolute vector magnetometry with NV centers in diamond — •Dennis Lönard, Isabel Cardoso Barbosa, Stefan Johansson, Jonas Gutsche, and Artur Widera — Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

The nitrogen-vacancy (NV) center in diamond has established itself as a promising quantum sensing platform. Most notably, vector magnetometry can be performed by observing the Zeeman splitting of the NV's spin resonance frequencies. Relative magnetometry has been shown to reach magnetic-field sensitivities down to fT/rt(Hz), and the current literature contains many examples of how to improve these sensitivities. However, the accuracy of absolute magnetometry is limited by factors other than sensitivity, and formulas for computing the magnetic-field vector are often only approximated.

In this talk, we discuss exact, analytical, and fast-to-compute formulas for calculating the magnetic-field vector from measured resonance frequencies and vice versa. We do not use any approximations and find solutions that are exact within the measurement accuracy, valid for all ranges of magnetometry and all types of NV diamonds, and are much faster to compute than comparable numerical techniques. Finally, we discuss often-used approximations for these calculations and assess their validity and accuracy for different magnetic-field regimes. We developed an open-source Python package that includes all the shown formulas.

Q 30.5 Wed 12:00 HS V

Ultra-stable miniaturized optical systems for compactatom-based quantum sensors — •Conrad Zimmermann, Marc Christ, Sascha Neinert, and Markus Krutzik — Ferdinand-Braun-Institut (FBH), Berlin, Germany

The transition of atom-based quantum sensors from laboratory experiments towards compact field-usable devices demands for specialized miniaturization and integration technologies. On that path we develop and qualify a versatile technology toolbox enabeling robust and ultra-stable miniaturized optical systems to trap, probe and manipulate atomic ensembles. We set up a micro-integrated optical dipole trap system with a system volume of about 25 ml. It creates two high-power laser beams which precisely overlap in their focal points ($\omega_0 = 32\,\mu$m) at an angle of 45°. After two years of operation with up to 2.5 W of optical power and no signs of degradation, we share measurements demonstrating the mechanical stability and the capabilities and potentials of used technologies [1].
In addition, we utilize additive manufacturing of ceramics [2] and metals to realize functionalized components such as micro-optical benches, mounts and vacuum systems. We also report on our efforts regarding ultra-high vacuum (UHV) compatibility of components and bonds using our dedicated outgassing qualification system.

[1] M. Christ et al. *Opt. Express* 32, 40806-40819 (2024)
[2] M. Christ et al. *Adv. Quantum Technol.*, 2400076 (2024)

Q 30.6 Wed 12:15 HS V

A Miniaturized Fiber-Based Magnetic Field Sensor Based on Nitrogen-Vacancy Centers — •Stefan Johansson, Dennis Lönard, Isabel Cardoso Barbosa, Jonas Gutsche, and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Sensing based on quantum effects is believed to be one of the technologies of the near future. Among other quantum magnetic field sensors, such as optically pumped magnetometers and superconducting interference devices, the nitrogen-vacancy (NV) center in diamond is a prime candidate for measuring magnetic fields. It provides a solid crystalline platform operating under ambient conditions without extensive cooling or encapsulation. This chemically and physically robust diamond platform allows measurements in direct contact with a sample, making it highly sensitive to an emitted field, e.g., from muscle signals or magnetic surfaces. While many fiber-based sensors have been published, only a few are portable or provide the capability to measure vectorial magnetic fields using optically detected magnetic resonance measurements. Here, we present our flexible, portable, yet robust fiber-based sensor. The design allows the use of lithographic processes such as direct laser writing of elementary silver and polymer structures on the optical fiber tip. The silver structure allows excitations using microwaves, while the polymer waveguide structure guides excitation and fluorescence light and is used to fixate a 15 μm-sized diamond to the tip of the optical fiber. We verify the capabilities of our sensor in vectorial measurements of a magnetic coil system.

Q 31: Quantum Networks, Repeaters, and QKD III (joint session Q/QI)

Time: Wednesday 11:00–13:00 Location: AP-HS

Q 31.1 Wed 11:00 AP-HS

Diamond Membrane with strained SiV color centers coupled to a fabry perot microcavity — •Florian Feuchtmayr[1], Robert Berghaus[1], Selene Sachero[1], Gregor Bayer[1], Julia Heupel[2], Tobias Herzig[3], Jan Meijer[3], Cyril Popov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik Universitat Ulm — [2]Institute of Nanostructure Technologies and Analytics, Center for Interdisciplinary Nanostructure Science and Technology, University of Kassel — [3]Division of Applied Quantum Systems, Felix Bloch Institute for Solid State Physics, University Leipzig

Group IV color centers in diamond, such as silicon vacancy (SiV), are promising for quantum optics because of their optical transitions, spin access, and good coherence properties. SiV centers typically require millikelvin temperatures, but increasing the ground state splitting improves coherence, allowing operation at higher temperatures. Here, we demonstrate the integration of a single-crystal diamond membrane into a high-finesse microcavity (F = 3000), achieving significant lifetime shortening with a Purcell factor of 2.2 in a liquid helium atmosphere. Absorption and strain spectroscopy confirm enhanced ground-state splitting, paving the way for a spin-photon interface.

Q 31.2 Wed 11:15 AP-HS

Indistinguishability of quantum-dot molecule based single photon sources — •Steffen Wilksen[1], Alexander Steinhoff[2], and Christopher Gies[1] — [1]Institut für Physik, Fakultät V, Carl von Ossietzky Universität Oldenburg — [2]Institut für theoretische Physik, Universität Bremen

Quantum-dot molecules (QDMs) consist of two self-assembled semiconductor quantum dots on top of each other separated by a thin tunnelling barrier, allowing charge carriers to tunnel between dots and form delocalized states. Due to their high tunability and rich level scheme, they provide a promising entanglement-generation platform for use in quantum communication and measurement-based quantum computing.

A key property of the emitted individual photons is their indistinguishability. Due to interaction with the environment during the emission process, the photons lose their coherence and ability to interfere with one another. These influences are of particular relevance in semiconductor systems, and to minimize their effects, one aims to reduce external noise while decreasing the emission time using optical cavities.

We investigate the indistinguishability of single photons emitted from a QDM solving both the independent boson model and the Jaynes-Cummings model using both analytic and numerical approaches. We extend the independent-boson model to account for a more realistic behaviour of phonons while keeping it exactly solvable. When a cavity is included, we use exact diagonalization to calculate the attainable indistinguishability.

Q 31.3 Wed 11:30 AP-HS

Large-Range Tuning and Stabilization of the Optical Transition of Diamond Tin-Vacancy Centers by In-Situ Strain Control — •Julia M. Brevoord[1], Leonardo G. C. Wienhoven[1], Nina Codreanu[1], Tetsuro Ishiguro[1,2], Elvis van Leeuwen[1], Mariagrazia Iuliano[1], Lorenzo DeSantis[1], Christopher Waas[1], Hans K.C. Beukers[1], Tim Turan[1], Carlos Errando-Herranz[1,3], Kenichi Kawaguchi[2], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands — [2]Quantum Laboratory, Fujitsu Limited, 10-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0197, Japan — [3]Department of Quantum and Computer Engineering, Delft University of Technology, Delft 2628 CJ, Netherlands

Quantum technologies, such as quantum networking based on photonic links rely on entanglement generation via indistinguishable photons from the qubits. The tin-vacancy (SnV) center in diamond has emerged as a promising platform, offering good optical and spin properties. However, variations in local strain and electronic environments have posed significant challenges to photon indistinguishability, limiting scalability. In this work, we achieve large-range optical frequency tuning and active stabilization of SnV centers using microelectromechanical strain control integrated into photonic waveguide devices. These results represent a critical step forward in overcoming scalability challenges and enabling the development of robust, large-scale quantum networks.

Q 31.4 Wed 11:45 AP-HS

Feasibility of Long-Distance Multi-Photon Interference in Satellite-Based Quantum Networks — •Baghdasar Baghdasaryan[1], Karen Lozano Méndez[2], Meritxell Cabrejo Ponce[2], Stephan Fritzsche[3,4], and Fabian Steinlechner[1,2] — [1]Institut für Angewandte Physik, Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena, Germany — [3]Theoretisch-Physikalisches Institut, Jena, Germany — [4]Helmholtz-Institut, Jena, Germany

Interference of multi-photon states involves the interaction of two photons on a beam splitter, where the photons must be indistinguishable across all degrees of freedom. Temporal indistinguishability occurs when the photons can not be distinguished based on their arrival times. This can be achieved with time-synchronized pulsed photon sources by controlling photon generation times. However, time synchronization is challenging in satellite-based communication systems due to satellite motion. A promising alternative is the use of photon sources with continuous emission. Temporally indistinguishable photons can be post-selected by carefully measuring the respective arrival times. While post-selection eliminates the need for active time synchronization, the finite resolution of detectors limits the precision of time-resolved detection. Here, we examine the impact of limited detector resolution on the efficiency of multi-photon interference with a focus on entanglement swapping. We estimate the maximum achievable entangled photon pair rate by optimizing the performance of the source and analyzing potential losses in a Earth-satellite link.

Q 31.5 Wed 12:00 AP-HS

Towards compensation of component imperfections in polarization-based BB84 QKD transmitters — •Silas Eul[1,2,3], Joost Vermeer[1,3], Domenico Paone[2], Ömer Bayraktar[1,3], Julian Struck[2], and Christoph Marquardt[1,3] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen, Germany — [2]Tesat-Spacecom GmbH & Co. KG, Gerberstr. 49, 71522 Backnang, Germany — [3]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany

Quantum key distribution systems typically rely on components that are highly polarization-dependent, such as polarization splitters and waveplates, as well as components that are intended to keep the polarization intact, such as fibers or non-polarizing beam splitters. In a real case scenario, there are no perfect components and the polarization errors generally increase when using smaller components, for example when transitioning from free space to fiber-based to photonic integrated circuit-based setups. In this work the influence of these components is discussed and possibilities to compensate, minimize or bypass these problems are highlighted. Here we focus on transmitters for polarization-based BB84 for free space and satellite applications.

Q 31.6 Wed 12:15 AP-HS

Detection of Intercept-Resend Blinding Attacks for Quantum Key Distribution with Waveguide-Integrated Superconducting Nanowire Single-Photon Detectors — •Connor A. Graham-Scott[1,3,4], Roland Jaha[2,3,4], Konstantin Zaitsev[5], Polina Acheva[5], Robin Terhaar[2,3,4], Wolfram Pernice[2,3,4], Vadim Makarov[5], and Carsten Schuck[1,3,4] — [1]Department of Quantum Technologies, University of Münster, Germany — [2]Kirchhoff-Institute for Physics, University of Heidelberg, Germany — [3]Center for Nanotechnology, Münster, Germany — [4]Center for Soft Nanoscience, Münster, Germany — [5]Quantum Hacking and Certification Lab, Vigo Quantum Communication Center, Spain

Quantum key distribution (QKD) offers secure communication via quantum mechanics but is vulnerable to eavesdroppers exploiting single-photon detectors with high-intensity optical pulses to blind and control them. Superconducting nanowire single-photon detectors (SNSPDs) can be attacked by manipulating the decaying-edge of the signal around a comparator trigger voltage, enabling quantum key replication.

We demonstrate that waveguide-integrated SNSPDs counteract such attacks by inducing a permanent resistive latching state above single-photon optical intensities without compromising performance. Testing devices with kinetic inductance from 625nH to 41nH revealed that lower-inductance devices (41nH) latched under multi-photon pulses, exposing eavesdropping attempts. This establishes waveguide-integrated SNSPDs as a secure solution for eavesdropping in QKD.

Q 31.7 Wed 12:30 AP-HS

QKD with Single Photons from Semiconductor Quantum Dots — •Joscha Hanel[1], Jingzhong Yang[1], Jipeng Wang[1], Vincent Rehlinger[1], Zenghui Jiang[1], Frederik Benthin[1], Tom Fandrich[1], Jialiang Wang[1], Fabian Klingmann[2], Raphael Joos[3], Stephanie Bauer[3], Sascha Kolatschek[3], Ali Hreibi[4], Eddy Rugeramigabo[1], Michael Jetter[3], Simone Portalupi[3], Michael Zopf[1,5], Peter Michler[3], Stefan Kück[4], and Fei Ding[1,5] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover — [2]Fraunhofer-Institut für Photonische Mikrosysteme, Dresden — [3]Institut für Halbleiteroptik und Funktionelle Grenzflächen, IQST and SCoPE, University of Stuttgart — [4]Physikalisch-Technische Bundesanstalt, Braunschweig — [5]Laboratorium für Nano-und Quantenengineering, Leibniz Universität Hannover

We present a BB84 QKD system based on single photons from a quantum dot (QD) source embedded into a circular bragg grating (CBG). The QD emits directly into the telecom C-band with high brightness and a low $g^{(2)}(0)$ of 0.7%. The encoding scheme features a phase modulator in a Sagnac configuration to inscribe four polarization states at a high modulation speed of 76MHz and with a low quantum bit error rate (QBER) on the order of 1%. We demonstrate the QKD capabilities of the system over increasing transmission distances in fiber, utilizing live polarization drift compensation and software-based synchronization, and show that it is fit for use on an intercity scale.

[1] Yang, J. et al., https://doi.org/10.1038/s41377-024-01488-0
[2] Nawrath et al., https://doi.org/10.1002/qute.202300111

Q 31.8 Wed 12:45 AP-HS

Photonic-integrated components for satellite-based QKD aboard the launched mission QUBE — •Ömer Bayraktar[1,2], Jonas Pudelko[1,2], Joost Vermeer[1,2], and Christoph Marquardt[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Max Planck Insitute for the Science

of Light, Erlangen, Germany

Satellite-based quantum key distribution (SatQKD) presents a promising advancement in secure communications. CubeSats, in particular, offer a cost-effective means for conducting QKD over long distances; however, they necessitate the creation of highly integrated optical systems. Within the framework of the QUBE mission, we have developed an integrated sender for modulated weak coherent states and an integrated quantum random number generator. Following the successful launch of the QUBE satellite in August 2024, we report on the progress achieved and the challenges encountered in one of only a few missions testing components for SatQKD in space.

Q 32: Atom & Ion Clocks and Metrology II

Time: Wednesday 11:00–13:00 Location: HS Botanik

Invited Talk Q 32.1 Wed 11:00 HS Botanik

Exploring fundamental constants with high-precision spectroscopy of molecular hydrogen ions — •Soroosh Alighanbari, Magnus R. Schenkel, and Stephan Schiller — Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

Molecular hydrogen ions (MHIs) have great potential for refining our understanding of fundamental physics, e.g. novel tests of CPT invariance and determination of fundamental constants (FCs). Among the MHI isotopologues, HD^+ has been intensely studied, providing precise data on transitions frequencies, in agreement with ab initio predictions [1]. Homonuclear H_2^+ presents challenges for laser spectroscopy due to the absence of electric-dipole transitions. We succeeded in the measurement of an electric-quadrupole transition in H_2^+, overcoming historical limitations [2]. We have also performed a Doppler-free spectroscopy of H_2^+ and have measured a first-overtone transition. We have determined the spin-averaged transition frequency, enabling the derivation of a value of m_p/m_e. The value is consistent with the recent CODATA2022 value [3] and the uncertainty is comparable. This work marks a significant step toward refining FCs and presents progress towards a test of CPT invariance through comparison of a single transition in H_2^+ and anti-H_2^+. Precision spectroscopy of a set of transitions in all MHI isotopologues enables the determination of FCs, including nuclear radii, with improved uncertainties. [1] S. Schiller, Cont. Phys. 63, 247 (2022). [2] M.R. Schenkel, et al. Nat. Phys. 20, 383 (2023). [3] S. Alighanbari, et al. Under review in Nature (2024).

Q 32.2 Wed 11:30 HS Botanik

Ramsey-Bordé atom interferometry with a thermal strontium beam for a compact optical clock — •Oliver Fartmann[1], Marc Christ[2], Amir Mahdian[1], Vladimir Schkolnik[1], Ingmari C. Tietje[1], Levi Wihan[1], and Markus Krutzik[1,2] — [1]Humboldt-Universität, Inst. f. Physik, Newtonstr. 15, 12489 Berlin — [2]Ferdinand-Braun-Institut (FBH), Gustav-Kirchhoff-Straße 4, 12489 Berlin

Compact optical atomic clocks have become increasingly important in field applications and clock networks. Systems based on Ramsey-Bordé interferometry (RBI) with a thermal atomic beam offer higher stability than optical vapour cell clocks while being less complex than cold atom clocks.

Here, we demonstrate RBI with strontium atoms, utilizing the narrow $^1S_0 \rightarrow {}^3P_1$ intercombination line at 689 nm, yielding a 60 kHz broad spectral feature [1].

The obtained Ramsey fringes for varying laser power are analyzed and compared with a numerical model. The atomic state is detected via fluorescence either on the $^1S_0 \rightarrow {}^1P_1$ transition at 461 nm or on the $^3P_1 \rightarrow {}^3P_0$ transition at 483 nm, limited by atomic shotnoise.

We present the experimental setup, our clock stability measurements and our progress towards more compact systems for mobile and space applications.

[1] Fartmann et al. "Ramsey-Borde Atom Interferometry with a Thermal Strontium Beam for a Compact Optical Clock." arXiv preprint arXiv:2409.05581 (2024).

Q 32.3 Wed 11:45 HS Botanik

High precision test of the equivalence of active, passive, and gravitating mass — •Claus Lämmerzahl and Eva Hackmann — ZARM, University of Bremen, Germany

The kilogram is one of the basic physical units. It has been given by the Paris prototype consisting of platinum and Iridium. Recently, within the new SI (Systeme International) the kilogram has been defined through the setting of the Planck constant.

While the Plack constant is unique, the operational definition of mass has a variety of aspects which need not be equivalent: We can define an *inertial* mass appearing on the "right" hand side of Newton's third axiom through, e.g, scattering processes, we have a *passive gravitational* mass which is the weight of a body in an external gravitational field, and we have the active gravitational or *gravitating* mass which creates a gravitational field. These three definitions are independent and in principle may lead to completely different quantities. However, high precision tests prove that these three masses are equivalent to very high precision.

Here we report on the basics notions, describe theoretical and metrological aspects as well as experimental implications of a hypothetical non-equivalence of these masses, and highlight the recent experimental progress on testing the equivalence of these masses achieved with Lunar Laser Ranging and with the MICROSCPE space mission, and outline future planned tests.

Q 32.4 Wed 12:00 HS Botanik

Towards Miniaturized Spaceborne Rubidium Two-Photon Frequency References — •Daniel Emanuel Kohl[1,2], Julien Kluge[1,2], Moritz Eisebitt[1,2], Janice Wollenberg[1], Klaus Döringshoff[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik - Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut (FBH)

We present the development of a miniaturized rubidium two-photon frequency reference using the $5S_{1/2} \rightarrow 5D_{5/2}$ transition at 778.1 nm, in the context of the CRONOS project. The goal of the project is to demonstrate an optical clock on a micro-satellite in low earth orbit. Recent development of miniaturized two-photon references based on atomic vapor spectroscopy allow for the realization of compact clocks for application in next generation global navigation satellite systems.

We report on beat-note measurements between two laboratory-based references showing a fractional frequency instability below $1.7 \cdot 10^{-13}/\sqrt{\tau}$, reaching $6 \cdot 10^{-15}$ for an averaging time τ of 1000 s. We further present a prototype of a compact spectroscopy module achieving instabilities in the regime of $10^{-13}/\sqrt{\tau}$. The design comprises a volume below 0.5 l, mass below 1 kg and power consumption below 10 W. We show preliminary results of a frequency reference utilizing MEMS rubidium vapor cells, as a step towards chip-scale devices.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971, 50WM2164.

Q 32.5 Wed 12:15 HS Botanik

Ultracold mercury as a probe for physics beyond the standard model — •Sascha Heider, Thorsten Groh, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nußallee 12, 53115 Bonn, Germany

Mercury, being one of the heaviest laser-coolable elements, is an ideal platform for beyond standard model physics like baryon asymmetry searches and isotope shift spectroscopy by exploring its relativistic nucleus and the large number of naturally occurring isotopes, all of which we laser cool in our lab.

We report on recent improvements and upgrades to the machine for transferring magneto-optically trapped mercury atoms to a high power optical dipole trap as a step towards degenerate quantum gases of mercury and measurements of the atomic electric dipole moment.

Q 32.6 Wed 12:30 HS Botanik

Entanglement dynamics of photon pairs and quantum memories in the gravitational field of the earth — Roy Barzel[1], Mustafa Gündoğan[2], Markus Krutzik[2], •Dennis Rätzel[1], and Claus Lämmerzahl[1] — [1]ZARM, University of Bremen, Am Fallturm 2, 28359 Bremen, Germany — [2]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany

We investigate the effect of entanglement dynamics due to gravity, the basis of a mechanism of universal decoherence, for photonic states and quantum memories in Mach-Zehnder and Hong-Ou-Mandel interferometry setups in the gravitational field of the earth. We show that chances are good to witness the effect with near-future technology in Hong-Ou-Mandel interferometry. This would represent an experimental test of theoretical modeling combining a multi-particle effect predicted by the quantum theory of light and an effect predicted by general relativity. Our article represents the first analysis of relativistic gravitational effects on space-based quantum memories which are expected to be an important ingredient for global quantum communication networks.

Q 32.7 Wed 12:45 HS Botanik

Scenario Building of a Quantum Space Gravimetry Mission for Earth Observation — •Gina Kleinsteinberg, Christian Struckmann, and Naceur Gaaloul — Leibniz University Hannover, Institute of Quantum Optics, Welfengarten 1, 30167 Hannover

Space-borne quantum sensors, being drift- and calibration-free, are in the future promising to outperform classical accelerometers currently used for space gravimetry. In the presence of climate change, quantum space gravimetry holds the potential to enable deeper insights into the changes in Earth's static and time-variable gravitational field, driven by the redistribution of large water masses.

To derive the precise requirements on the satellite platform and the experimental setup for a mission embarking a space-borne quantum sensor, extensive simulations are required. In this contribution, we present a simulation tool capable of building and analysing scenarios for quantum pathfinder gravimetry missions. This includes simulations of the atom interferometer itself as well as detailed analyses of systematic effects arising from environmental influences. To this end, multi-objective optimisation is used to explore options for balancing the multitude of mission parameters, while simultaneously optimising the sensor performance. The tool is developed in close cooperation with the geodesy community, leveraging the capabilities of classical satellite simulations and enabling the generation of realistic, synthetic atom interferometer phase signals. This work is supported by DLR funds from the BMWK (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 33: Matter Wave Interferometry I

Time: Wednesday 11:00–13:00 Location: HS I

Q 33.1 Wed 11:00 HS I

Atom interferometry based quantum inertial navigation sensor — •Mouine Abidi, Philipp Barbey, Xingrun Chen, Ann Sabu, Matthias Gersemann, Dennis Schlippert, Ernst. M. Rasel, and Sven Abend — Leibniz Universität Hannover - Institut für Quantenoptik, Hannover, Germany

Current GNSS-based navigation systems and MEMS sensors provide convenient capabilities but are constrained by GNSS signal unavailability, vulnerability to jamming, and the long-term drift of MEMS sensors. In contrast, atom interferometry-based inertial sensors offer exceptional sensitivity and drift-free performance, making them ideal for applications in navigation, geodesy, and fundamental physics.

In this talk, the latest advancements from the QGyro project will be presented, focusing on the development of a quantum accelerometer that integrates state-of-the-art technologies, including a fiber-based laser system, flat-top beam shaping, ARTIQ electronics, and compact vacuum technology.

We also demonstrate the integration of this compact and robust quantum accelerometer onto a gimbal platform, facilitating its hybridization with classical MEMS sensors and quantum inertial navigation devices, such as accelerometers and gyroscopes. This hybrid system provides continuous, stable, and highly sensitive measurements of accelerations and rotations.

This work is supported by the Federal Ministry of Economics and Climate Protection (BMWK) due to the enactment of the German Bundestag under Grant No. DLR 50NA2106 (QGyro+).

Q 33.2 Wed 11:15 HS I

Space-deployed differential atom interferometers for magnetometry — •Matthias Meister[1], Naceur Gaaloul[2], Nicholas P. Bigelow[3], and the CUAS team[1,2,3,4] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Leibniz University Hannover, Institute of Quantum Optics, QUESTLeibniz Research School, Hanover, Germany — [3]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA — [4]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQST, Ulm University, Ulm, Germany

Matter-wave interferometers deployed in space are excellent tools for high precision measurements, relativistic geodesy, or Earth observation. In particular, differential interferometric setups feature common-mode noise suppression and enable reliable measurements in presence of ambient platform noise. Here we report on orbital magnetometry campaigns performed with differential Mach-Zehnder and differential butterfly interferometers on NASA's Cold Atom Lab aboard the International Space Station. By comparing measurements with atoms in magnetically sensitive and insensitive states, we have measured tiny magnetic-field force gradients and set bounds on force curvatures. Our results pave the way towards precision quantum sensing missions in space.

This work is supported by NASA/JPL through RSA No. 1616833 and the DLR Space Administration with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers 50WM2245-A/B.

Q 33.3 Wed 11:30 HS I

Simulation of 3D inhomogeneous Raman excitation rates under arbitrary rotations — •Ali Mouttaki[1,2], Christian Struckmann[1], Cyrille des Cognets[2], Vincent Jarlaud[2,3], Jan-Niclas Kirsten-Siemss[1], Vincent Ménoret[3], Baptiste Battelier[2], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Institute of Quantum Optics, Germany — [2]Laboratoire Photonique, Numérique et Nanosciencces (LP2N), Univ. Bordeaux, CNRS, Institut d'Optique d'Aquitaine, France — [3]Exail, Institut d'Optique d'Aquitaine, France

Atom interferometers offer several advantages over classical sensors for inertial measurements due to their high sensitivity, great precision and long-term stability. Building on these strengths, the joint laboratory iXAtom - established by LP2N and Exail - aims to develop the next generation of inertial sensors based on cold atoms for geophysics and navigation [Science Advances, vol. 8, no. 45, 2022]. However, onboard applications still face persistent challenges such as low excitation rates and contrast loss caused by rotation and vibrations.

In this work, we present a simulator of 3D inhomogeneous Raman excitation rates of thermal atomic clouds operating under arbitrary orientations and rotation rates of the laser beam. The numerical simulations are validated through comparisons with experimental data. Moreover, we highlight how this simulator allows to better quantify and understand the impact of rotation on atom interferometers.

Q 33.4 Wed 11:45 HS I

Transverse recoil of diffraction wavelets within a matter-wave beam splitter — •Abhay Mishra[1], Adam Abdalla[2], Oleksandr Marchukov[3], and Reinhold Walser[4] — [1]Technical university Darmstadt, Darmstadt, Germany — [2]Technical university Darmstadt, Darmstadt, Germany — [3]Technical university Darmstadt, Darmstadt, Germany — [4]Technical university Darmstadt, Darmstadt, Germany

Atomic Bragg beam-splitters are integral devices for matter-wave interferometers. Interferometric measurements can be used for geodesy, inertial sensing or fundamental physics in space [1]. To achieve the ultimate measurement precision, one has to understand and rectify all sources of aberrations [2], eventually. In this contribution, we consider the transversal recoil of an axially decentered Bose-Einstein condensate in counter-propagating Gaussian beams. Due to the non-separability of the optical dipole potential, one obtains an entanglement between the longitudinal and transversal motion [3]. We study position displacement and momentum transfers using a (3+1D) numerical simulation of the Gross-Pitaevskii equation. These findings are explained by a dynamical model for the coupled motion of the center-of-mass coordinates of the diffraction wavelets, as well as their Schrödinger-amplitudes.

[1] D. Becker, et al., Nature 562, 391 (2018). [2] A. Neumann, et al., Phys. Rev. A 103, 043306 (2021). [3] S. Blatt, et al., Rabi Spectroscopy and Excitation Inhomogeneity in a One-Dimensional Optical Lattice Clock, Phys. Rev. A 80, 052703 (2009).

Q 33.5 Wed 12:00 HS I

Atom diffraction through free-standing graphene — •Carina Kanitz[1], Jakob Bühler[1], Vladimir Zobac[2], Joseph James Robinson[1], Toma Susi[2], Maxime Debiossac[1], and Christian Brand[1] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Wilhelm-Runge-Strasse 10, 89081 Ulm, Germany — [2]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria

Diffraction of particles through materials allows studying their properties in great detail as shown, for instance, in transmission electron microscopy. So far, coherent transmission through materials has only been demonstrated for electrons and neutrons, but not for atoms. This leads to the fundamental question whether this is possible [1]. Here, we report the first results on atomic diffraction through crystalline materials [2]. To achieve this feat, we used H and He atoms with an energy between 400 and 1600 eV normal to the surface. We observe highly-detailed patterns featuring diffraction up to the eighth diffraction order. Our findings are interesting both from a fundamental and applied point of view. They show that atoms can pass through a pristine material and retain their coherence. In this future, this might pave the path for new approaches to study 2D materials in transmission.

[1] Brand et al., New J. Phys. 21, 033004 (2019)
[2] Kanitz et al., in preparation

Q 33.6 Wed 12:15 HS I

Entangled center-of-mass dynamics of diffraction wavelets in a matter-wave beam splitter — •Adam Abdalla[1], Abhay Mishra[2], Oleksandr Marchukov[3], and Reinhold Walser[4] — [1]Institute of Applied Physics, TU Darmstat, Darmstadt, Germany — [2]Institute of Applied Physics, TU Darmstadt, Darmstadt, Germany — [3]Institute of Applied Physics, TU Darmstadt, Darmstadt, Germany — [4]Institute of Applied Physics, TU Darmstadt, Darmstadt, Germany

The resonant momentum exchange between matter-waves and photons from counter-propagating laser beams leads to Bragg diffraction.It is the building block of atom-interferometry used for quantum metrology and inertial sensing [1]. Usually, it is described by a Schrödinger-equation for the matter-wave amplitudes in a static plane-wave basis. However, in typical experiments with Bose-Einstein condensates, one has a superposition of several wavelets $\psi(\boldsymbol{r},t) = \sum_l c^l(t) u(\boldsymbol{r}, \boldsymbol{R}^{(l)}(t), \boldsymbol{K}^{(l)}(t))$ that extend in the longitudinal x-direction over many optical wavelength $\sigma_x \gg \lambda_L$ and are much smaller than the Gaussian laser waist $w_0 \gg \sigma_{y,z}$ in the transversal direction [2]. In this contribution, we analyze the dynamical center-of-mass evolution of the coupled diffraction wavelets $(c^l(t), \boldsymbol{R}^{(l)}(t), \boldsymbol{K}^{(l)}(t))$ in the non-separable Bragg interference potential [3]. The results are supported by (3+1)D simulations of the Gross-Pitaevskii equation and experiments of QUANTUS Collaboration (DLR, grant number 50WM2450E). [1] S. Abend, et al., AVS Quantum Sci. 6, 024701 (2024) [2] A. Neumann, et al., Phys. Rev. A 103, 043306 (2021) [3] S. Blatt, et al., Phys. Rev. A 80, 052703 (2009)

Q 33.7 Wed 12:30 HS I

Parallelized atom interferometers for inertial sensing — •Knut Stolzenberg, Christian Struckmann, Daida Thomas, Ashwin Rajagopalan, Alexander Herbst, Ernst M. Rasel, Naceur Gaaloul, and Dennis Schlippert — Leibniz University Hannover, Institute of Quantum Optics, Welfengarten 1, 30167 Hannover

Atom interferometers have become a viable tool for inertial sensing and fundamental research, showing excellent long-term stability and sensitivity. However, they are commonly bound to a single sensitive axis, enabling multi-axis inertial sensing only via post-correction with external classical sensors, or correlation with other simultaneous atom interferometers.
We show our results on measuring the Euler- and centrifugal acceleration, as well as transversal acting linear acceleration induced by gravity, utilizing a 3×3 array arrangement of Bose-Einstein condensates. The array has a spatial extent of 1.6 mm^2 and serves as input for Mach-Zehnder type atom interferometers, driven by double-Bragg diffraction. We call this method Parallelized Interferometers for XLerometry (PIXL) and discuss its prospects as a future quantum inertial measurement unit and in 3D-reconstruction of electro-magnetic fields.

Q 33.8 Wed 12:45 HS I

Seismic noise suppression for Very Long Baseline Atom Interferometry — •Kai C. Grensemann, Vishu Gupta, Guillermo A. Perez Lobato, Klaus Zipfel, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The Hannover Very Long Baseline Atom Interferometer (VLBAI) facility offers exciting capabilities for absolute gravimetry beyond state-of-the-art precision with applications in geodesy and test of fundamental physics. Its 10 m baseline enables free fall times of up to $2T = 2.4\,\mathrm{s}$ and therefore large sensitivity scale factors $k_{\mathrm{eff}}T^2$. The currently limiting technical noise source for atom interferometers is vibration of the inertial reference mirror. To attenuate seismic vibrations coupling to the mirror, the VLBAI facility is equipped with a unique six degrees of freedom in-vacuum seismic attenuation system (SAS).

Here we present a characterization of the passive seismic isolation performance, as well as our progress towards the six degrees of freedom active stabilization. We utilize three low-noise triaxial seismometers as inertial sensors and six voice-coils for force feedback driven by a digital real-time control system. Furthermore, a central out-of-loop low-noise seismometer can be used to post-correct the interferometer measurements. We estimate that the SAS in combination with ideal post-correction will allow instabilities of below $10^{-9}\,\frac{\mathrm{m}}{\mathrm{s}^2}$ at 1 s, close to the shot-noise limit of $\approx 2 \cdot 10^{-10}\,\frac{\mathrm{m}}{\mathrm{s}^2}$ for 10^6 atoms.

Q 34: In Memoriam of Hermann Haken (joint session Q/MO)

Physicist Hermann Haken, who died on August 14, 2024 at the age of 97, made groundbreaking contributions to solid-state physics and quantum optics. As a pioneer of laser theory, he recognized early on the ubiquity of non-equilibrium phase transitions. This led to the foundation of the self-organization theory of synergetics, which has been applied to countless systems of both inanimate and living nature. The Symposium honours his life work and outlines exemplarily how his scientific achievements live on in current quantum optics research.

Time: Wednesday 11:00–13:00 Location: HS I PI

Invited Talk Q 34.1 Wed 11:00 HS I PI

Haken's quantum field theoretical understanding of semiconductors and lasers and its present-day impact — •Cun-Zheng Ning — Shenzhen Technology University, China

Prof. Haken was among the earliest few who applied the then-new quantum field theory (QFT) to understand physical processes in semiconductors in the 1950s and lasers in the 1960s. The first decade of his scientific career was devoted to the QFT treatment of non-metallic solids. His long-lasting impacts are reflected by popular terms such as the Haken Potential for excitons and Feynman-Haken Path Integral for calculating the ground-state energy of polarons. The second decade of his career started at Stuttgart. It was devoted to the newly invented laser whose fundamental understanding, as he quickly realized, required extending the known QFT to include noise and dissipation. In the process, he established the full quantum theory for open systems and laid the foundation for Synergetics. His laser theory not only explained or predicted many phenomena in lasers but also provided a general framework for the understanding of problems whenever light-matter interaction is involved. While his first two decades focused on the QFT treatment of semiconductors or light field respectively,

a proper description of semiconductor optics requires the QFT treatment of both semiconductors and optical field self-consistently. This task turns out to be as challenging as it is rewarding when Coulomb interaction is included and remains an active field of research today, continued by generations of his students. This talk will cover aspects of Prof Haken's early contributions and some recent progress.

Invited Talk Q 34.2 Wed 11:30 HS I PI
Bose-Einstein condensation of photons in vertical-cavity surface-emitting lasers — •Maciej Pieczarka — Wrocław University of Science and Technology, Wrocław, Poland

Professor Haken pioneered the development of the quantum theory of lasers and discovered that lasing action can be viewed as a nonequilibrium second-order phase transition. This visionary and broader view inspired many to find a link between lasing and the Bose-Einstein condensation (BEC) of photons. It appears that the worlds of lasers and BEC are deeply intertwined, as BEC was found in dye-filled microcavities [1] and, more recently, in semiconductor lasers [2].

I will present our demonstration of photon BEC phase transition in a real-world device - a Vertical-Cavity Surface-Emitting Laser (VCSEL) [2]. Besides distinctive differences from the complete thermal equilibrium, we show that photons in a VCSEL follow the equation of state for an ideal bosonic gas. We argue that photon BEC can be a much more common phenomenon in laser physics than previously anticipated.

[1] J. Klaers et al., Nature **468**, 545 (2010).
[2] M. Pieczarka et al., Nature Photonics **18**, 1090 (2024).

Invited Talk Q 34.3 Wed 12:00 HS I PI
Photons in a dye-filled cavity: quantum-optical system interpolating between Bose-Einstein condensates and laser-like states — •Milan Radonjić — Universität Hamburg, Germany — University of Belgrade, Serbia

It is well known that photons in a dye-filled cavity exhibit a Bose-Einstein condensate (BEC) of light [1]. We generalize the microscopic non-equilibrium Kirton-Keeling model [2] of such a system by carefully considering the interplay of coherent and dissipative dynamics within the Lindblad master equation framework pioneered by Hermann Haken in his theory of lasers [3]. The resulting equations of motion of both photonic and matter degrees of freedom are then used to study the steady-state properties of the system. We demonstrate that this system can interpolate between photon BEC and laser-like states, depending on whether the dissipative or coherent influence of the environment is dominant [4]. In the former case, we show that the cavity modes of different energies are essentially uncorrelated. In the laser-like regime, some cavity mode acquires macroscopic occupation, while the populations of other cavity levels strongly deviate from the Bose-Einstein distribution. Additionally, the steady state contains a rather high degree of correlations between the different cavity modes.

[1] J. Klaers et al., Nature **468**, 545 (2010).
[2] P. Kirton and J. Keeling, Phys. Rev. Lett. **111**, 100404 (2013).
[1] H. Haken, Laser Theory, Springer (1970, 1984).
[4] M. Radonjić et al., New J. Phys. **20**, 055014 (2018).

Invited Talk Q 34.4 Wed 12:30 HS I PI
From laser physics to nonlinear dynamics and synergetics — •Eckehard Schöll — TU Berlin, Germany

Hermann Haken was a pioneer of laser physics and developed the first full quantum theory of the laser [1]. He interpreted the laser transition as a nonequilibrium phase transition [2], and found that this is a special case of a much wider class of open systems driven far from thermodynamic equilibrium. Based upon this observation he founded the field of synergetics which deals with systems composed of many subsystems like atoms, molecules, photons, cells, etc., and shows that cooperation of the subsystems leads to spatial, temporal, or functional structures by self-organization [3]. He demonstrated that the semiclassical laser equations are mathematically equivalent to the Lorenz equation derived from fluid dynamics [4], exhibiting higher instabilities and chaos, like many other nonlinear dynamical systems in physics, chemistry, biology, medicine, and even economics, sociology and psychology. This has given rise to a plethora of new phenomena in nonequilibrium system widely studied during the past five decades. Coherence resonance is just one example which was first discovered by Haken [5], and later studied in various systems ranging from lasers to the brain.

[1] H. Haken, Laser Theory, Springer (1970, 1984).
[2] R. Graham and H. Haken, Z. Phys. **237**, 31 (1970).
[3] H. Haken, Synergetics, An Introduction, Springer (1977).
[4] H. Haken, Phys. Lett. **53A**, 77 (1975).
[5] G. Hu et al., Phys. Rev. Lett. **71**, 807 (1993).

Q 35: Precision Spectroscopy of Atoms and Ions III (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: HS PC

Invited Talk Q 35.1 Wed 11:00 HS PC
A planar rotor in an ion crystal — •Monika Leibscher[1], Ferdinand Schmidt-Kaler[2], and Christiane P. Koch[1] — [1]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Germany — [2]QUANTUM, Institut für Physik, Universität Mainz, Germany

Charged molecules and nanoparticles are a promising platform for quantum sensing, quantum information or for tests of fundamental physics. Their rotational structure is amenable to sideband quantum logic spectroscopy if it can be coupled to the collective vibrations of a mixed crystal, composed of atomic ions and one molecular ion, or one charged nanoparticle. We model the dipole coupling by a planar rotor in the center of a linear ion Coulomb crystal. Calculating the dipole interaction for particles with mass ranging from diatomic molecular ions to that of charged silicon nanoclusters we identify its strength. We identify ranges, where the resulting energy splitting is sufficiently large to be detected by state-of-the-art sideband laser spectroscopy.

Q 35.2 Wed 11:30 HS PC
Upper-level spectroscopy of cold trapped 174Yb atoms for their preparation in the metastable $^3P_0$ state — •Ke Li, Gabriel Dick, Saran Shaju, and Jürgen Eschner — Universität des Saarlandes, Saarbrücken,Germany

We trap and cool 174 Yb atoms in a magneto-optical trap (MOT) inside a high-finesse cavity for exploring atom-cavity interaction on the $^1S_0$ - $^3P_0$ clock transition at 578 nm[1,2]. For populating the metastable $^3P_0$ level, we employ repumping lasers resonantly driving the $^3P_1$ - $^3S_1$ and $^3P_2$- $^3S_1$ transitions, thereby transferring all atoms from $^3P_1$, $^3P_2$ states to $^3P_0$ state via $^3S_1$.In order to characterize how effective the repumping process is, the time-resolved measurements including repumping rate, population dynamics are studied, which also facilitating detailed investigations of the clock transition.

[1]D. Meiser, Jun Ye, D. R. Carlson, and M. J. Holland Phys. Rev. Lett. 102, 163601, 2009
[2]H. Gothe, D. Sholokhov, A. Breunig, M. Steinel, and J. Eschner. Phys. Rev. A, 99, 0134 15, 2019.

Q 35.3 Wed 11:45 HS PC
Shelving spectroscopy of narrow UV transitions in dysprosium — •Kevin Ng[1], Paul Uerlings[1], Fiona Hellstern[1], Luis Weiss[1], Alexandra Köpf[1], Michael Wischert[1], Tanishi Verma[1], Stephan Welte[1,2], Ralf Klemt[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]CZS Center QPhoton

Current efforts in analogue quantum simulation aim to increase the interaction strengths between trapped particles in order to probe long-range interactions and correlations on the microscopic scale. By reducing the separation between dysprosium atoms trapped in optical lattices made from UV (~360nm) light, a large enhancement of the magnetic dipole-dipole interaction can be achieved, albeit with a higher required imaging resolution for quantum gas microscopy.

To implement imaging techniques that overcome the diffraction limit to resolve particles only 180nm apart, we plan to use long lived excited states trapped at magic wavelengths. Such knowledge of the ground and excited state atomic polarizabilities depend on the strength and positions of transitions in the vicinity of the trapping wavelength. Here, we present a characterization of multiple weak UV transitions in dysprosium on a thermal atomic beam. We measure isotope shifts, hyperfine splittings and lifetimes of such transitions by using the known strong 421nm transition as a probe, amplifying signal detection by a factor of ~600 compared to detection via standard absorption or fluorescence spectroscopy.

Q 35.4 Wed 12:00 HS PC

Dirac-Fock Rechnungen von Manganese Kα and Kβ Energien — •Khalid Rashid — Dept of Mathematics, QAU, Islamabad, Pakistan

Die 3d K Energien und Intensitäten von Mn I bis Mn VIII und deren Satallien Linien in Anwesenheit von eimem Loch in der 2p und 3p Schallen werder in multikonfiguration Dirac-Hartree- Fock Nährng berechnet.(MCDF). Diese Methode erlaubt die Behandlung von Drehimpuls Kopplung von äusseren und inneren Elektronen. Dudurch entstehen recht komplexex K Spektrum. Untersucht wurde die Fälle, Mn 3d54s2 gibt es durch die Kopplung von 1s1 mit 3d5 zwei Anfangszustände 5S2 (j=2) und 7S3 (J=3). Durch die Kopplung von 2p1 mid 3d5 gibt es zu J=1, 17 Zustände; zu J=2,12 Zustände; zu J=3, 5 Zustände, zu J=4, 1 Zustand. Dies eegibt zu J=1, 17 Übergänge; zu J=2, 24 Übergänge; zu J, 8 Übergänge, zu J=1, 1 Ubergang. Ähnliche Analysen haben wir ausgeführt für Mn I bis Mn VIII in Anwesenheit von einem Loch in der 2p Schale. und für ein Loch in der 3p Schale. Aus diesen gerechneten Daten werden durch Lorentz fits Spektren um die gemessenen Spektren zu interpretieren

Q 35.5 Wed 12:15 HS PC

Buffer Gas Stopping Cell for Extraction of ^{229}Th Ions for Nuclear Clock Development — •Srinivasa Arasada[1], Florian Zacherl[1], Keerthan Subramanian[1], Jonas Stricker[2,3], Valerii Andriushkov[2,4], Yumiao Wang[1], Nutan Kumari Sah[1], Ke Zhang[1], Ferdinand Schmidt-Kaler[1], Dmitry Budker[1,2,4], Christoph Düllman[2,3,4], and Lars von der Wense[1] — [1]Institut für Physik, Johannes Gutenberg Universität, Mainz, Germany — [2]Helmholtz Institute Mainz, Germany — [3]Department of Chemie, Johannes Gutenberg-Universität Mainz, Germany — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

The isomeric state of ^{229}Th offers a unique opportunity for precision spectroscopy due to its exceptionally low excitation energy, making it most suitable for developing nuclear clocks with unprecedented accuracy. The isomeric state in ^{229}Th can be populated via a 2% decay branch during α decay of ^{233}U. Here we outline our plans for extracting thorium ions from a ^{233}U recoil-ion source using a buffer gas stopping cell. The system utilizes ultra-pure helium gas to minimize substantial losses caused by charge exchange or molecular formation. The extracted Th^{3+}ions are subsequently loaded into a Paul trap together with laser-cooled ^{40}Ca^{+} ions for spectroscopic interrogation.

This project is being supported by the BMBF Quantum Futur II Grant Project 'NuQuant'(FKZ 13N16295A).

Q 35.6 Wed 12:30 HS PC

Towards a Precision Measurement of the ^{229m}Th Isomeric Lifetime via Hyperfine Structure Laser Spectroscopy — •Kevin Scharl, Markus Wiesinger, Georg Holthoff, Tamila Teschler, Mahmood I. Hussain, and Peter G. Thirolf — Ludwig-Maximilians-Universität München

The development of a nuclear clock based on the unusually low-lying isomeric transition in ^{229}Th at 8.355733554021(8) eV [Zhang et al., *Nature* **633**, 63-70 (2024)] is of high interest for several research fields from precision metrology over geodesy to dark matter research.

In the recent past, several milestones towards the nuclear clock were reached via VUV spectroscopic measurements of ^{229}Th in a solid state environment. In contrast to that, the LMU thorium nuclear clock setup uses $^{229(m)}$Th ions confined in a cryogenic Paul trap and sympathetically Doppler cooled with co-trapped ^{88}Sr^{+} ions. This approach allows for an alternative and more precise measurement of the vacuum ionic half-life of the isomeric state which so far is reported to be 1400^{+600}_{-400}s [Yamaguchi et al., *Nature* **629**, 26-66 (2024)].

In this talk on the LMU experimental setup, we focus on the electronic hyperfine structure spectroscopy of $^{229(m)}$Th^{3+} ions as an efficient way to distinguish between the two nuclear states. Moreover, the scheme for the isomeric state readout necessary for the realization of a nuclear clock and the measurement of the isomeric lifetime is presented.

This work was supported by the European Research Council (ERC) (Grant agreement No. 856415) and BaCaTec (7-2019-2).

Q 35.7 Wed 12:45 HS PC

Collinear laser spectroscopy of helium-like $^{12-14}$C^{4+} — •Emily Burbach[1], Kristian König[1], Aaron Bondy[2], Gordon Drake[2], Phillip Imgram[3], Patrick Müller[4], Wilfried Nörtershäuser[1], Xiao-Qiu Qi[5], and Julien Spahn[1] — [1]TU Darmstadt, Germany — [2]University of Windsor, Canada — [3]KU Leuven, Belgium — [4]University of California, USA — [5]Zhejiang Sci-Tech University, China

Light helium-like systems are ideal test cases for nuclear and atomic structure calculations as they exhibit a greatly varying nuclear structure and are accessible for high-precision ab-initio calculations. In an ongoing effort, it is planned to determine absolute and differential nuclear charge radii, R_C and $\delta\langle r^2\rangle$, of the light elements Be to N by purely using collinear laser spectroscopy and non-relativistic quantum electrodynamics calculations in the helium-like ions. As a first step, the $1s2s\,^3\mathrm{S}_1 \to 1s2s\,^3\mathrm{P}_J$ transitions in $^{12-14}$C^{4+} were determined using the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA) at the Technical University of Darmstadt. In those measurements a significant splitting isotope shift (SIS) was observed. It is defined as the difference in fine-structure splittings between different isotopes of the same atom after averaging over the hyperfine structure. It is compared to the theoretical SIS, which is determined by the relativistic finite nuclear mass and recoil contributions to the energy [1], which provides a clear test of the experimental accuracy. This project is supported by DFG (Project-ID 279384907 - SFB 1245).

[1] L.-M. Wang et al. Phys. Rev. A 95, 032504 (2017).

Q 36: Ultra-cold Atoms, Ions and BEC III (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: KlHS Mathe

Invited Talk Q 36.1 Wed 11:00 KlHS Mathe

Microscopy of matter wave emission into a two-dimensional structured reservoir — •Felix Spriestersbach[1,2], Jan Geiger[1,2], Valentin Klüsener[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

We realize a quantum simulator of an open quantum system using ultracold bosonic strontium atoms trapped in a state-dependent, cavity-enhanced, two-dimensional optical lattice. Atoms in a metastable excited state are tightly trapped by the optical lattice, while ground-state atoms experience a weak periodic potential, enabling tunneling between neighboring lattice sites. Coupling the two states initiates the emission of matter waves, which are represented by the itinerant ground-state atoms. In the optical lattice, the matter waves show a dispersion relation akin to photons in nanophotonic structures. We can precisely control the energy of the matter waves by adjusting the detuning of the optical coupling. We measure the energy-dependent momenta by mapping momentum space to real space followed by read out using microscopy. Using this high level of control, we can alter the emission dynamics depending on the detuning of the coupling. These results demonstrate the possibility of experimentally investigating open quantum systems in two dimensions.

Q 36.2 Wed 11:30 KlHS Mathe

Quadrupole Coupling of Circular Rydberg Qubits to Inner Shell Excitations — •Aaron Götzelmann, Einius Pultinevicius, Moritz Berngruber, Christian Hölzl, and Florian Meinert — 5. Physikalisches Institut, Universität Stuttgart, Germany

Divalent atoms provide excellent means for advancing control in Rydberg atom-based quantum simulation and computing due to the second optically active valence electron available. Particularly promising in this context are circular Rydberg atoms, for which long-lived ionic core excitations can be exploited without suffering from detrimental autoionization. Here, we report the implementation of electric quadrupole coupling between the metastable $4D_{3/2}$ level and a very high-n ($n = 79$) circular qubit, realized in doubly excited ^{88}Sr atoms prepared from an optical tweezer array. We measure the kHz-scale differential level shift on the circular Rydberg qubit via beat-node Ramsey interferometry comprising spin echo. Observing this coupling requires coherent interrogation of the Rydberg states for more than 100μs, which is assisted by tweezer trapping and circular state lifetime enhancement in a black-body radiation suppressing capacitor. Further, we find no noticeable loss of qubit coherence under continuous photon scattering on the ion core, paving the way for laser cooling and imaging of Rydberg atoms.

In my contribution I will show the measurements of the weak electron-electron interaction and our endeavors on employing this for direct fluorescence imaging of circular Rydberg atoms.

Q 36.3 Wed 11:45 KlHS Mathe

Shapiro steps in driven atomic Josephson junctions — •Vijay Singh[1], E. Bernhart[2], M. Röhrle[2], H. Ott[2], G. Del Pace[3], D. Hernandez-Rajkov[3], N. Grani[3], M. Frometa Fernandez[3], G. Nesti[3], J. A. Seman[4], M. Inguscio[3], G. Roati[3], L. Mathey[5], and Luigi Amico[1] — [1]QRC, TII, Abu Dhabi, UAE — [2]RPTU Kaiserslautern, Germany — [3]LENS, University of Florence, Italy — [4]UNAM Mexico — [5]ZOQ and IQP, Universität Hamburg, Germany

We report the observation of Shapiro steps in atomic Josephson junctions formed by coupling two ultracold atom clouds. As predicted in the theoretical proposal, periodic modulation of the position of the tunneling barrier induces Shapiro steps in the dc current-chemical potential characteristic. Experiments on a Josephson junction of ^{87}Rb atoms display Shapiro steps in the current-potential characteristic, exhibiting universal features and providing key insight into the microscopic dissipative dynamics associated with phonon emission and soliton nucleation. Experiments with strongly-interacting Fermi superfluids of ultracold atoms also show the creation of Shapiro steps in the current-potential characteristics, with their height and width reflecting the external drive frequency and the junction nonlinear response. Direct measurements of the current-phase relationship reveal the underlying dissipation mechanism via the emission of vortex-antivortex pairs. These results establish a significant connection between superconducting and atomic Josephson dynamics, with unprecedented control and flexibility over physical parameters. Finally, our results lay the foundation for the development of new atomtronic devices and sensors.

Q 36.4 Wed 12:00 KlHS Mathe

Modeling thermodynamic and dynamic properties of Bose-Einstein condensate bubbles in microgravity — •Brendan Rhyno[1,2], Timothé Estrampes[1,3], Gabriel Müller[1], Charles Garcion[1], Eric Charron[3], Jean-Baptiste Gerent[4], Nathan Lundblad[4], Smitha Vishveshwara[2], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover — [2]University of Illinois at Urbana-Champaign — [3]Université Paris-Saclay — [4]Bates College

The study of Bose-Einstein condensate (BEC) bubbles has received increasing attention in recent years. We discuss our efforts to model the properties of such systems in view of the current Cold Atom Lab experiments and the prospects of realizing BEC bubbles in the microgravity environment of the Einstein-Elevator at the Leibniz University of Hanover. Using an isotropic ‘bubble trap’ potential, we explore both the thermodynamic and dynamic inflation of dilute Bose-condensed bubbles. In the thermodynamic treatment, adiabatic inflation from an initial filled spherical BEC into a large thin spherical shell leads to condensate depletion. In the dynamic treatment, we study the non-equilibrium expansion and contraction of the system in the vicinity of the BEC phase transition. We conclude by discussing how our work can inform the ongoing experimental efforts.

Q 36.5 Wed 12:15 KlHS Mathe

Controlled Dynamical Tunneling in Bichromatic Optical Lattices with a Parabolic Trap — •usman ali[1], martin holthaus[2], and torsten meier[1] — [1]Department of Physics, Paderborn University, Warburger Strasse 100, D-33098 Paderborn, Germany — [2]Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg, Germany

We investigate dynamical tunneling of non-interacting ultracold atomic wave packets in the combined potential generated by the superposition of a one-dimensional periodic optical lattice and a parabolic trap. The parabolic lattice potential exhibits strongly localized eigenstates in the regime where the curvature of the periodic lattice exceeds the bandwidth of the uniform periodic lattice. The localization of these states is similar to Wannier-Stark localization in the presence of a locally static force, which gives rise to dynamics resembling Bloch oscillations. Furthermore, due to the symmetry of the parabolic lattice, these eigenstates are nearly two-fold degenerate. The tiny energy splitting between symmetry-related pairs located at opposite ends of the parabolic lattice results in tunneling times that exceed experimentally realizable time scales. We demonstrate that the inclusion of an additional weak optical lattice allows one to control the tunneling times while preserving the states. Thereby controllable dynamical tunneling is achieved, where the Bloch-oscillating wave packet dynamically tunnels between opposite ends of the weakly bichromatic parabolic optical lattice.

Q 36.6 Wed 12:30 KlHS Mathe

Effects of (non)-magnetic disorder in quasi-1D singlet superconductors — •Giacomo Morpurgo and Thierry Giamarchi — Department of Quantum Matter Physics, University of Geneva, Geneva, Switzerland

We study the competition between disorder and singlet superconductivity in a quasi-one-dimensional (1D) system. We investigate the applicability of the Anderson theorem, namely that time-reversal conserving (non- magnetic) disorder does not impact the critical temperature, by opposition to time-reversal breaking disorder (magnetic). To do so, we examine a quasi-1D system of spin 1/2 fermions with attractive interactions and forward scattering disorder using field theory (bosonization). By computing the superconducting critical temperature (Tc), we find that, for nonmagnetic disorder, the Anderson theorem also holds in the quasi-1D geometry. In contrast, magnetic disorder has an impact on the critical temperature, which we investigate by deriving renormalization group equations describing the competition between disorder and interactions. Computing the critical temperature as a function of disorder strength, we observe different regimes depending on the strength of interactions. We discuss possible platforms where this can be observed in cold atoms and condensed matter.

Q 36.7 Wed 12:45 KlHS Mathe

Chiral Magnetic Effect in Optical Lattices — •Sabhyata Gupta and Luis Santos — Institut für Theoretische Physik - Leibniz Universität Hannover

The Chiral Magnetic Effect (CME) is a quantum phenomenon in which an electric current is generated along the direction of an applied magnetic field in the presence of a chiral imbalance between right- and left-handed fermions. This effect arises due to the chiral anomaly, where the conservation of chiral charge is violated in quantum field theories involving gauge fields. CME plays a pivotal role in revealing topological fluctuations in QCD matter during heavy-ion collisions and has applications in studying the baryon asymmetry in the early universe. However, its experimental exploration in a controlled setting remains challenging due to the complexity of the underlying quantum dynamics. Here, we propose an experimental realization of the CME using ultracold atoms trapped in optical lattices. By implementing a Rice-Mele-like model through spin-orbital coupling and laser-assisted tunneling, our scheme creates a tunable platform to simulate quench dynamics and emulate chiral asymmetry in the presence of magnetic field interactions. This approach bridges the gap between high-energy physics and quantum simulation, enabling precise control over parameters such as fermion masses and magnetic fields, and providing insights into non-equilibrium effects like chirality flipping and mass-induced axial current relaxation

Q 37: Polaritonic Effects in Molecular Systems II (joint session MO/Q)

Time: Wednesday 11:00–13:00 Location: HS XV

Q 37.1 Wed 11:00 HS XV

Boundary conditions and violations of bulk-edge correspondence in a hydrodynamic model — Gian Michele Graf[1] and •Alessandro Tarantola[1,2] — [1]Institut für Theoretische Physik, Wolfgang-Pauli-Str. 27, 8093 Zürich, Switzerland — [2]German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

Bulk-edge correspondence is a wide-ranging principle that applies to topological matter. According to the principle, the distinctive topological properties of matter, thought of as extending indefinitely in space, are equivalently reflected in the excitations running along its boundary. Indices encode those properties, and their values, when differing, are witness to a violation of that correspondence. We address such violations, as they occur in a hydrodynamic context. The model concerns a shallow layer of fluid in a rotating frame and provides a local description of waves propagating either across the oceans or along a coastline; it becomes topological when suitably modified at short distances. The edge index is sensitive to boundary conditions, hence exhibiting a violation. Here we present a classification of all (local, self-adjoint) boundary conditions. They come in four families, distinguished in part by the degree of their underlying differential operators. Generally, both the correspondence and its violation are typical. Across families though, the maximally possible amount of violation can vary with their degree. Several indices of interest are charted for all boundary conditions. A single spectral mechanism for the onset of violations is furthermore identified, and the role of a symmetry investigated.

Q 37.2 Wed 11:15 HS XV

Cavity-mediated electron-electron interactions: Renormalizing Dirac states in graphene — •Hang Liu[1], Francesco Troisi[1], Hannes Huebener[1], Simone Latini[1,2], and Angel Rubio[1,3] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Germany — [2]Technical University of Denmark, Denmark — [3]The Flatiron Institute, USA

Accurately modeling the interaction between electrons in materials and photon modes within dark cavities is crucial for predicting and understanding cavity-induced phenomena. In this work, we developed the photon-free quantum electrodynamics Hartree-Fock and configuration-interaction frameworks to model the coupling between electrons in crystalline materials and cavity photon modes. We applied these theoretical approaches to investigate the graphene coupled to different types of cavity modes. For a circularly polarized mode, a topological Dirac gap emerges due to cavity-mediated local and nonlocal electron interactions. In contrast, a linearly polarized mode induces a topologically trivial Dirac gap as a result of the cavity-mediated nonlocal electron interactions. Notably, when two cavity modes are introduced, the Dirac cones can remain gapless, but the Fermi velocity is renormalized through cavity-induced nonlocal electron interactions. Our non-perturbative approaches can capture the critical role of cavity-induced nonlocal electron-electron interactions in renormalizing Dirac states in graphene. These new theoretical frameworks pave the way for accurately predicting and exploring novel cavity-induced phenomena in a broader range of material systems.

Q 37.3 Wed 11:30 HS XV

Quantum algorithms for QED systems — •Francesco Troisi[1], Simone Latini[2], Heiko Appel[1], Ivano Tavernelli[4], and Angel Rubio[1,3] — [1]MPSD, Hamburg, Germany — [2]Department of Physics, DTU, Lyngby, Denmark — [3]CCQ, Flatiron Institute, Simons Foundation, NYC, USA — [4]IBM Quantum, IBM Research, Zurich, Säumerstrasse 4, 8803 Rüschlikon, Switzerland

Controlling the properties of matter is a central theme in modern science. Optical cavities provide a promising approach to controlling them by coupling the electronic transitions to the confined photons inside the cavity, making the photonic and electronic states inseparable. The polaritonic states are obtained, which due to the strong coupling regime, cannot be described by the perturbative approach. On a classical computer, this introduces big computational challenges as the QED matrix grows exponentially with the number of photonic modes and Fock states. Quantum Computing is a promising tool for studying such systems as adding one cavity mode requires as little as one qubit. Due to the complexity of the physics in materials or complex molecules, we approach the cavity QED problem with a simpler system, such that we can learn the challenges in a controlled environment. In this work we couple a two-level matter system to many cavity modes, and we focus on studying a well-known physical phenomenon, the spontaneous emission, where excited atoms emit photons upon returning to their ground state. Despite its simplicity, one can still observe many features such as the Rabi oscillations and the decay rate making it an ideal candidate for approaching QED problems.

Q 37.4 Wed 11:45 HS XV

Control of cavity dissipations across the insulator-to-metal transition in 1T-TaS$_2$ — •Giacomo Jarc[1], Angela Montanaro[1], Shahla Yasmin Mathengattil[2,3], Enrico Rigoni[1,3], and Daniele Fausti[1] — [1]Department of Physics, FAU Erlangen-Nürnberg Erlangen, Germany — [2]Department of Physics, Università di Trieste, Trieste, Italy — [3]Elettra Sincrotrone, Basovizza (Trieste), Italy

Using optical cavities resonant with material excitations enables controlling light-matter interaction in both the regimes of weak and strong coupling. We study here the coupling of low-energy excitations in the charge-density-wave (CDW) material 1T-TaS$_2$ across its insulator-to-metal transition when embedded into tetahertz Fabry-Pérot cryogenic cavities. In the dielectric state, we reveal the signatures of a multimode vibro-polariton mixing, with the polariton modes inheriting character from all the CDW phonons as a consequence of the cavity-mediated hybridization. The multimode vibrational strong coupling is suppressed across the insulator-to-metal transition as a consequence of the optical dissipations introduced by the free charges, and a vibrational weak coupling regime is observed in proximity of the phase transition. When the cavity frequency is tuned within the spectral range of the continuum Drude excitation, we reveal that the quality factor of the cavity, which quantifies the dissipations of the coupled system, decreases passing from the insulating to the metallic state. Our evidences points to a scenario in which the free charges can effectively couple to the cavity field and subsequently modify the collective light-matter coupling.

Q 37.5 Wed 12:00 HS XV

Chirality and Dimensionality in the Ultrastrong Light-matter Coupling Regime — •Rémi Avriller[1] and Cyriaque Genet[2] — [1]University of Bordeaux, CNRS, LOMA, UMR 5798, F-33405 Talence, France. — [2]University of Strasbourg and CNRS, CESQ and ISIS, UMR 7006, F-67000 Strasbourg, France

We unveil the key-role of dimensionality in describing chiroptical properties of molecules embedded inside an optical Fabry-P*erot cavity.

For a 2D-layer configuration, we show that the interplay between molecular chirality and spatial dispersion of the cavity-modes, results in a gyrotropic coupling at the origin of a differential shift in polaritonic energy spectra. This differential shift is proportional to the gyrotropic coupling, while for 3D bulk-aggregate configurations it is shown to vanish.

We interpret physically the former 2D-chiral effect by analogy with the classical Newtonian motion of a fictitious particle in presence of 3D restoring force, and static magnetic field. The gyrotropic coupling is shown to directly perturbate the anholonomy angle of the classical trajectories, and the fictitious particle undergoes cyclotron gyrations upon entering the ultrastrong light-matter coupling regime.

Q 37.6 Wed 12:15 HS XV

The complex interplay of collectivity, locality and temperature in polaritonic chemistry — •Dominik Sidler[1,2,3], Michael Ruggenthaler[2,3], Jacob Horak[2,3], Thomas Schnappinger[4], and Angel Rubio[2,3,5] — [1]Paul Scherrer Institut, Villigen, Switzerland — [2]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [3]The Hamburg Center for Ultrafast Imaging, Hamburg, Germany — [4]Stockholm University, Stockholm, Sweden — [5]The Flatiron Institute, New York, USA

Despite significant theoretical progress over the past years, still, no consensus has been achieved about the physically relevant mechanism in polaritonic chemistry. Based on ab initio simulations and analytic results, we will explore and identify physical mechanisms that shine light on the interplay of collective strong coupling with local chemical changes. For its detailed microscopic understanding, degeneracies and cavity-induced local polarization patterns seem to play a crucial role. To capture those effects accurately, a fully self-consistent description is vital, since perturbation theory can lead to qualitatively erroneous predictions. Eventually, we demonstrate that the thermal statistic is altered non-trivially by collective strong coupling in optical cavities. Therefore, novel computational methods are required to simulate polaritonic chemistry accurately.

Q 37.7 Wed 12:30 HS XV

Controlling Plasmonic Catalysis via Strong Coupling with Electromagnetic Resonators — Jakub Fojt, Paul Erhart, and •Christian Schäfer — Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden

Plasmonic excitations decay within femtoseconds, leaving nonthermal (often referred to as *hot*) charge carriers behind that can be injected into molecular structures to trigger chemical reactions that are otherwise out of reach - a process known as plasmonic catalysis. In this talk, we demonstrate that strong coupling between resonator structures and plasmonic nanoparticles can be used to control the spectral overlap between the plasmonic excitation energy and the charge injection energy into nearby molecules. Our atomistic description couples real-time density-functional theory self-consistently to an electromagnetic resonator structure via the radiation-reaction potential [1,2]. Control over the resonator provides then an additional knob for nonintrusively enhancing plasmonic catalysis [3], here more than 6-fold, and dynamically reacting to deterioration of the catalyst - a new facet of modern catalysis.

[1] C. Schäfer and G. Johansson, PRL 128, 156402 (2022). [2] C. Schäfer, J. Phys. Chem. Lett. 2022, 13, 6905-6911. [3] J. Fojt, P. Erhart, C. Schäfer, Nano Lett. 2024, 24, 11913-11920.

Q 37.8 Wed 12:45 HS XV

Role of Symmetry in Charge Transfer Complexation under Vibrational Strong Coupling — •Anjali Jayachandran, Cyriaque Genet, and Thomas Ebbesen — University of Strasbourg, CNRS, ISIS and icFRC, 8 Allée Gaspard Monge, 67000 Strasbourg, France

The relation between symmetry and chemical reactivity has been explored for a long time. We reported earlier that symmetry also plays a key role in charge transfer (CT) complexation reactions under vibrational strong coupling (VSC) (1). We have now extended this study to a variety of donors and acceptors to gain further insight into how symmetry is acting on VSC. The experiments were conducted using the three isomers of trimethylbenzene (methyl groups in the 1,3,5; 1,2,4 and 1,2,3 positions on the benzene ring) as the donors with acceptors such as iodine, chloranil and 2,3-dichloro-5,6-dicyano-1,4-benzoquinone. It is observed that under vibrational strong coupling, there are large changes in the equilibrium constant, coefficient of absorption and the thermodynamic parameters for the different isomers. The changes seen in these parameters are dependent on the symmetry of the vibrational mode that is coupled to the IR cavity modes as well as the overall symmetry of the molecule. The result of this study confirms the relevance of symmetry in chemical reactivity under VSC and should be taken into consideration to steer reactions towards a desired outcome in this regime. 1. Y. Pang, A. Thomas, K. Nagarajan, R. M. A. Vergauwe, K. Joseph, B. Patrahau, K. Wang, C. Genet, T. W. Ebbesen, Angew. Chem. Int. Ed. 2020, 59, 10436.

Q 38: Members' Assembly

Time: Wednesday 13:15–14:15 Location: AP-HS

All members of the Quantum Optics and Photonics Division (FV Q) are invited to attend. Suggestions for discussion topics should be sent to the Speaker of FV Q before the meeting.

Q 39: Photon BEC

Time: Wednesday 14:30–16:30 Location: HS V

Q 39.1 Wed 14:30 HS V

Kardar-Parisi-Zhang Universality in a Two-Dimensional Photon Bose-Einstein Condensate — •Joshua Krauss and Axel Pelster — Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany

Recent experimental and numerical studies reveal that exciton-polariton condensates in an asymmetric Lieb lattice belong to the KPZ universality class [1]. However, achieving stable KPZ scaling requires a negative polariton mass, restricting experiments to one-dimensional lattices. Photon Bose-Einstein condensates offer offer a promising realization in two dimensions without a lattice.

We describe the dynamics of a photon BEC using a stochastic generalized Gross-Pitaevskii equation coupled to a stochastic rate equation for the bath of dye molecules [2]. Following Refs. [2,3], we incorporate a continuum analogue of incoherent hopping processes, which occur in photon BEC lattices. Using methods from exciton-polariton studies [1], we approximately map these dynamics to the KPZ equation. Additionally, we show that incoherent hopping significantly enhances effective photon-photon interactions for realistic experimental parameters.

[1] Q. Fontaine et alii, Nature **608**, 687 (2022).

[2] V. N. Gladilin and M. Wouters, Phys. Rev. A **101**, 043814 (2020).

[3] V. N. Gladilin and M. Wouters, Phys. Rev. Lett. **125**, 215301 (2020).

Q 39.2 Wed 14:45 HS V

Dissipative dynamics and entanglement signatures of photon Bose-Einstein condensates in multiple microcavities — •Aya Abouelela[1] and Johann Kroha[1,2] — [1]Univeristy of Bonn, Germany — [2]University of St. Andrews, UK

Quantum gases of photons have proven to be a versatile platform for investigating various quantum effects in many-body systems, including Bose-Einstein condensation, quantum coherence and entanglement. In this work, we investigate the driven-dissipative dynamics of open photon Bose-Einstein condensates (BEC) in a single-mode microcavity filled with dye molecules using the Lindblad master-equation approach. Two distinct types of dynamics are observed, a quasi-stationary condensate, which loses coherence after a sufficiently long time, and a lasing regime with finite condensate density in the steady state. We compute a phase diagram, which includes both the BEC and lasing regimes as a function of the experimentally tunable parameters, i.e., the external pumping power and the photon detuning frequency. We explore the possible entanglement signatures in a system of two coupled microcavities. The cavities are coupled via direct photon, as well as, molecule-assisted tunneling and the system can be proven to describe two-mode Gaussian states. We use the von Neumann entropy to quantify the degree of mutual information between the two states. Lastly, we utilize the covariance matrix to study the violation of the Peres-Horodecki criterion which implies inseparability of states, and consequently, entanglement.

Q 39.3 Wed 15:00 HS V

Photon condensates in anisotropic traps: Dimensional crossover — •Kirankumar Karkihalli Umesh[1], Julian Schulz[2], Sven Enns[2], Julian Schmitt[1], Martin Weitz[1], Georg von Freymann[2,3], and Frank Vewinger[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstrasse 8, 53115 Bonn, Germany — [2]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern Landau, 67663 Kaiserslautern, Germany — [3]Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany

Recent advances in confinement technology based on 3D Direct Laser Writing (DLW) of nanostructures for dye-filled microcavities have allowed for an observation of a dimensional crossover in a bosonic system, namely non-interacting bosons (Nat. Phys. 20, 1810-1815 (2024)). In our system, photons are trapped in microscopic structures, and they thermalise by radiative coupling to a heat bath of dye molecules. In this system, we have observed the softening of the phase transition to a Bose-Einstein condensate when crossing from a harmonically trapped gas in a 2D to a 1D system. The technology used has the potential to realise arbitrary potentials for light, including lattice structures and traps with large trapping frequencies, allowing us to engineer interesting potential landscapes for photons to explore physics which has been inaccessible until now. We will present our latest results on lattice structures required to observe non-Hermitian dynamics-induced vortices in non-interacting bosons (Phys. Rev. Lett. 125, 215301 (2020)).

Q 39.4 Wed 15:15 HS V

Field-theoretical description of driven-dissipative photon Bose-Einstein condensates — •Roman Kramer[1], Michael Kajan[1], and Johann Kroha[1,2] — [1]Physikalisches Institut, Universität Bonn — [2]University of St. Andrews, United Kingdom

We formulate a Schwinger-Keldysh field theory to treat the non-Markovian dynamics of driven-dissipative quantum systems coupled to a reservoir. This is done by introduction of auxiliary particles, which assign an indiviual quantum field to each reservoir state, as developed in [1]. We apply the formalism to a driven-dissipative photon Bose-Einstein condensate (BEC) coupled to a reservoir of dye molecules with electronic and vibronic excitations in an optical microcavity, as observed experimentally in [2]. The emergence of a photon BEC is then achieved by inclusion of $U(1)$ symmetry-broken photon fields, which thermalize due to coupling to the molecules described by auxiliary particles. We find that the condensed parts of the photon modes dynamically synchronize and form a single BEC. This formalism can be extended to multiple coupled cavities.

References:
[1] T. Bode, M. Kajan et al. *Phys. Rev. Res.* **6**, 10.1103 (2024).
[2] J. Klaers, J. Schmitt, F. Vewinger et al. *Nature* **468**, 545 (2010).

Q 39.5 Wed 15:30 HS V

Quantum gases of light in ring potentials — •Patrick Gertz, Leon Espert Miranda, Andreas Redmann, Kirankumar Karkihalli Umesh, Frank Vewinger, and Martin Weitz — Institute for Applied Physics, University of Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Optical quantum gases in material-filled microcavities provide exquisite experimental control over dimensionality, shape of the energy landscape or the coupling to reservoirs, which opens the door to investigate novel states of matter both in and out of equilibrium. Here we report on the experimental realization of a quantum gas of photons in ring-shaped potentials within a dye-filled optical microcavity. The trapping potential for the cavity photons is provided by imprinting static nanostructures on the surface of one of the cavity mirrors using a controlled laser-induced delamination of the dielectric mirror coating. We have achieved the quasi-1D, periodically closed confinement of photon gases in ring potentials and performed initial, characterizing measurements of spatial and spectral distributions. Prospects of this work include studies of both the Kibble-Zurek mechanism for photon condensates and of optical flux qubits.

Q 39.6 Wed 15:45 HS V

Observation of Coherent oscillations in lattices for photon condensates — •Peter Schnorrenberg[1], Daniel Ehrmanntraut[1], Nikolas Longen[1], Purbita Kole[1], Kevin Peters[1], and Julian Schmitt[1,2] — [1]Universität Bonn, IAP, Wegelerstr. 8, 53115 Bonn — [2]Universität Heidelberg, KIP, Im Neuenheimer Feld 227, 69120 Heidelberg

Exploring coherent dynamics of quantum gases trapped in periodic lattice potentials enables the microscopic study of fundamental phenomena, e.g., from condensed matter physics. Previous work with ultracold atoms or exciton-polaritons has focused on closed or far-from-equilibrium systems, respectively. Bose-Einstein condensates of photons in dye-filled microcavities, on the other hand, offer a new approach to access coherent dynamics of bosons in variable lattice potentials due to the possible coupling to the enviroment, e.g., from gain, loss, or reservoirs. Here we present measurements of the coherent dynamics of photon condensates trapped in periodic lattice potentials inside a dye-filled microcavity. By recording the time-resolved photon density, we observe Rabi oscillations in double well traps, which we validate by independent spectroscopic measurements, for variable tunneling rates. Moreover, we explore the emergence of Bloch oscillations in larger lattices, consisting of several sites. Our experimental scheme paves the way to investigate the crossover from coherent to incoherent dynamics in the presence of dephasing from reservoirs, which could provide new insights into quantum transport.

Q 39.7 Wed 16:00 HS V

Imprinting reconfigurable topological states for photon condensates — •Kevin Peters[1], Nikolas Longen[1], Purbita Kole[1], Daniel Ehrmanntraut[1], Peter Schnorrenberg[1], and Julian Schmitt[1,2] — [1]Universität Bonn, Institut für Angewandte Physik, Wegelerstrasse 8, 53115 Bonn, Germany — [2]Universität Heidelberg, Kirchhoff Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg

Previous studies in topological photonics have mostly focused on Hermitian engineering of the photonic band structure, with topological properties largely fixed in fabrication. However, recent theoretical work has proposed topological states of light arising solely from non-Hermiticity in a priori trivial lattices. Experimentally, such states have recently been observed in plasmonic waveguide arrays, although still predetermined in fabrication.

Here, I will present numerical evidence illustrating topological phases arising in 1D arrays of photon condensates through tunable gain and loss. Our system comprises dye-filled optical microcavities, coherently coupled by spatially uniform hopping. Tunable gain and loss are achieved by site-resolved pumping of dye molecule reservoirs. For suitable gain and loss, we observe a bulk band gap and spatially localized end states. Additionally, tunability of the lattice potential provides control over Hermitian properties of our system. Competing Hermitian and non-Hermitian effects lead to a rich phase diagram with various numbers of end states. Our approach allows for highly tunable and reconfigurable topological states of light.

Q 39.8 Wed 16:15 HS V

Optically tuneable lattice potentials for Bose-Einstein condensates of photons — •Nikolas Longen[1], Purbita Kole[1], Daniel Ehrmanntraut[1], Peter Schnorrenberg[1], Kevin Peters[1], and Julian Schmitt[1,2] — [1]Universität Bonn, IAP, Wegelerstr. 8, 53115 Bonn, Germany — [2]Universität Heidelberg, KIP, Im Neuenheimer Feld 227, 69120 Heidelberg

The concept of periodic potentials plays a key role in solid state physics, giving rise to emergent classical and quantum phases in materials with intricate system properties, such as topological band structures. Correspondingly, the precise control of lattice potentials for quantum gases of atoms, polaritons, or photons enables the simulation of a wide range of complex physical systems. Here, we present the realisation of tuneable lattice potentials for Bose-Einstein condensates of photons within dye-filled optical microcavities. A static lattice potential is created by imprinting localised indents on high-reflectivity cavity mirrors, in which the photons are trapped. By irradiating one of the cavity mirrors with a laser beam shaped by a spatial light modulator, we locally modulate the temperature of the dye medium. Exploiting the thermo-optic response of the dye solution, we demonstrate the reversible tunability of the potential energy of the photon condensates at individual lattice sites. The tunability is characterised by its spatial, temporal and power dependence on the heating laser pattern. Creating and tuning potentials for photon Bose-Einstein condensates in lattices using this method permits the reconfigurable creation of band structures for light, particularly those of topologically non-trivial character.

Q 40: Quantum Optics and Nuclear Quantum Optics II

Time: Wednesday 14:30–16:30 Location: AP-HS

Q 40.1 Wed 14:30 AP-HS

From click counts to photon numbers — •Suchitra Krishnaswamy, Fabian Schlue, Laura Ares, Vladymir Dyachuk, Michael Stefszky, Benjamin Brecht, Christine Silberhorn, and Jan Sperling — Paderborn University, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Photon-number measurements are a cornerstone in quantum photonics, making photon-number-resolving detectors an essential tool. Because of wider accessibility, imperfect detectors, one of them being click detectors, are often used. Click detectors register a click irrespective of the number of incoming photons, and no click otherwise, thus displaying statistical properties different from common detection models. Utilizing click counting theory, photon statistics were reconstructed via an analytic pseudo-inversion method. Theoretically, this approach can be extended to higher click-number-resolving detectors. A reconfigurable time-bin multiplexing, click-counting detector is experimentally implemented. We gauge the success of the pseudo-inversion by applying the Mandel and binomial parameters that help in distinguishing quantum statistics.In the case of coherent light (classical-nonclassical boundary), both parameters are highly sensitive measures, hence a perfect way to gauge the reconstruction performance. Additionally, we apply a deconvolution technique to account for detection losses.

Q 40.2 Wed 14:45 AP-HS

Interference effects in an electron-driven quantum emitter — •Hebrew Crispin[1] and Nahid Talebi[2] — [1]Christian-Albrechts-Universität, Kiel, Germany — [2]Christian-Albrechts-Universität, Kiel, Germany

Cathodoluminescence spectroscopy has emerged as a platform for studying the quantum aspects of light on the nanoscale. Since the experimental demonstration of photon anti-bunching and super-bunching effects by electron excitations, considerable efforts have been devoted towards understanding the electron-matter interactions and the light emission in cathodoluminescence. A theoretical description of the observed photon statistics has been provided by several authors. However, the majority of these approaches rely on classical models. In addition, the electron-beam-excitations of only two-level systems has been the focus so far. Here, we propose a theoretical framework for cathodoluminescence from a multi-level quantum emitter. Modeling the electron-beam-excitation as an incoherent broadband field driving the emitter, we obtain a quantum optical master equation for the system. We show that the presence of different transition pathways can give rise to quantum interference effects. The induced interference significantly modifies the emitter dynamics and the time-dependent spectra. We find that the interference is sensitive to the excitation rate, the initial coherence, and the excited level splitting. Our model reveals the possibility of electron-beam-induced quantum interferences in cathodoluminescence emission and provides a framework to explore quantum optical effects in electron-driven multi-level systems.

Q 40.3 Wed 15:00 AP-HS

Evaluating the quality of heralded photon-number states with high-order moments — •Daniel Borrero Landazabal and Kaisa Laiho — German Aerospace Center (DLR), Institute of Quantum Technologies, Wilhelm-Runge-Str. 10, 89081 Ulm, Germany

Typically, the fidelity and second-order correlation function $g(2)$ are used to characterize number states. While the fidelity gives insights on the purity, a low $g(2)$-value indicates a low multiphoton contributions of the target state. However, the fidelity is not straightforward to measure in an experimental setup, and $g(2)$ ignores the vacuum component, which degrades the state quality. In this work, we propose and numerically demonstrate that the photon-number parity represents a practical and improved tool in state characterization, when accessed via the higher-order factorial moments of photon number [1]. By taking into account imperfections of photon counting systems [2], we successfully simulate the characteristics of heralded number states up to three photons from a twin beams generated in a non-linear optical process of parametric down-conversion. Furthermore, we express our results in an easy experimentally accessible parameter space, which allows identifying optimal regions for the number-state generation with high-quality.

[1] K. Laiho et al., "Measuring higher-order photon correlations of faint quantum light: a short review", Phys. Lett. A 435, 128059 (2022).

[2] J. Sperling et al., "True photocounting statistics of multiple on-off detectors", Phys. Rev. A 85, 023820 (2012).

Q 40.4 Wed 15:15 AP-HS

Distance of pure two-mode Gaussian states and the validity of the rotating wave approximation — •Tim Heib — Theoretical Physics, Universität des Saarlandes, 66123 Saarbrücken, Germany — Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, 52425 Jülich, Germany

We quantify the deviation of arbitrary pure two-mode Gaussian states that evolve through different dynamics from a common quantum state, where the dynamics are induced by quadratic Hamiltonians. We show that this distance is fully determined by the first and second moments of the statistical distribution of the number of excitations created from the vacuum during an appropriate effective time evolution.

We employ these results exemplary for the rotating wave approximation and provide proof for its viability under suitable initial conditions.

Q 40.5 Wed 15:30 AP-HS

Heralded squeezed coherent state superpositions via optical catalysis — •Roger Kögler[1], Elnaz Bazzazi[1], Ananga Datta[1], Julian Nauth[2], Nathan Walk[2], Marco Schmidt[1], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstraße 15, 12489, Berlin, Germany — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

Non-Gaussian states of light are strong candidates for fault tolerant-encoding and error correction in future quantum computation implementations. Their experimental generation, however, remains challenging and relies in different quantum state engineering techniques. In this work, we investigate a photon catalysis-like protocol and its suitability for generating high-amplitude squeezed coherent state superpositions (SCSS) in optical platforms. The method involves the interference of squeezed and Fock states at a beamsplitter, followed by a photon number resolving (PNR) detection in one of the output modes. The remaining mode is thereby projected into a state determined by the resource states, the beamsplitter splitting ration, and the PNR outcome. Analytical results are used to evaluate different output states and their overlap with target SCSS states. The impact of losses on the protocol is studied using numerical simulations, with results visualized in phase-space representations. This study is conducted in parallel with its experimental implementation, aiming toward the optical tomography of catalyzed states.

Q 40.6 Wed 15:45 AP-HS

Characterization of multimode linear optical devices using single photon and two-photon correlation measurements — •Cheeranjiv Pandey, Kai Hong Luo, Simone Atzeni, Fabian Schlue, Florian Lütkewitte, Jan-Lucas Eickmann, Mikhail Roiz, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, D-33098, Germany

Photonics has emerged as a promising platform for implementing various quantum computational and communication schemes. At the heart of many such schemes lie multimode linear optical devices, composed of integrated arrays of beam splitters and phase shifters. Previous works have demonstrated that any arbitrary unitary matrix can be decomposed into an array of beam splitters and phase shifters. Consequently, these devices can implement any unitary transformation between input and output channels by precisely controlling the beam splitters' transmittivities and the phase shifts introduced by the phase shifters. However, such devices often deviate from their ideal behavior due to fabrication imperfections and thermal cross-talk between components. As a result, precise characterization of these devices is critical to ensure their effective functionality in various applications. We showcase our ongoing research focused on developing characterization techniques that will allow us to reconstruct the transformation matrix of a multimode linear optical device by means of single-photon and two-photon

correlation measurements.

Q 40.7 Wed 16:00 AP-HS

Enhancement in stimulated Raman with squeezed states of light — •Shahram Panahiyan[1,2], Frank Schlawin[1,2,3], and Dieter Jaksch[1,2,3] — [1]University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, Hamburg D-22761, Germany

The stimulated Raman process (SRP) is a critical technique in microscopy and spectroscopy, enabling applications such as real-time imaging of living cells and organisms [1,2]. Given the significance of SRP for photosensitive materials, there is considerable interest in enhancing its resolution without relying on high-intensity laser fields. To address this challenge, we leverage squeezed states of light, which exhibit reduced quantum fluctuations and improved signal-to-noise ratios, to investigate SRP. Our study highlights the benefits of utilizing squeezed light to enhance the precision of SRP measurements and compares its performance to that of classical light fields. [1] R. B. de Andrade et al., Optica 7, 470 (2020). [2] C. A. Casacio et al., Nature 594, 201 (2021)

Q 40.8 Wed 16:15 AP-HS

Relation between optical quantum computers and quantum computers — •Jannes Ruder[1] and Hans-Otto Carmesin[1,2,3] — [1]Gymnasium Athenaeum, Harsefelder Straße 40, 21680 Stade — [2]Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — [3]Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

Quantum computers use linear superposition and entanglement, in order to solve appropriate problems much faster than electronic computers. Some optical quantum computers use the qubits the orbital angular momentum and polarization, as well as the universal set of quantum gates consisting of the Hadamard gate, the CNOT - gate and the $\frac{\pi}{4}$ - gate.

While the light sources of quantum computers are single photon sources, the light sources of optical computers are lasers. Accordingly, optical computers can be built in a more straight forward, cheap and elegant manner than optical quantum computers. So the question arises, whether optical computers can solve tasks at a rapidity similar to that of optical quantum computers.

For it, we show theoretically and experimentally that optical computers can use the same above mentioned qubits and the same universal set of quantum gates as optical quantum computers.

Q 41: Quantum Technologies (Color Centers and Ion Traps) I (joint session Q/QI)

Time: Wednesday 14:30–16:30 Location: HS Botanik

Invited Talk Q 41.1 Wed 14:30 HS Botanik

Integration of fiber Fabry-Perot cavities for sensing applications and cavity optomechanics — •Hannes Pfeifer[1], Lukas Tenbrake[2], Carlos Saavedra[3], Florian Giefer[2], Jana Blechmann[2], Johanna Stein[2], Daniel Stachanow[2], Dieter Meschede[2], Karol Krzempek[4], Randall Goldsmith[3], Witlef Wieczorek[1], Stefan Linden[2], and Sebastian Hofferberth[2] — [1]Chalmers University of Technology, Gothenburg, Sweden — [2]University of Bonn, Germany — [3]University of Wisconsin-Madison, USA — [4]Wroclaw University of Science and Technology, Poland

Since their first realization during the 2000s, fiber-based Fabry-Perot cavities (FFPCs) have found their way into an increasing manifold of optical experiments. Driven by the accessibility of their optical mode volume, quantum systems down to single atoms and up to macroscopic mechanical oscillators have been interfaced through FFPCs. Besides their unique features: the strong miniaturization, direct fiber coupling, and large optical access; key challenges such as their experiment integration, coupling efficiency, susceptibility to mechanical vibration, and thermal load remain. In my talk, I will report on the developments from the Bonn Fiber Lab addressing these issues, with a focus on the integration of sensing applications and cavity optomechanics experiments within FFPCs. I will touch upon the realization of highly sensitive readout schemes for gas spectroscopy and single molecule detection, and discuss the structural integration of mechanical resonators using direct laser writing. Finally, I will discuss the prospects of using FFPCs to interface and manipulate mechanical multimode systems.

Q 41.2 Wed 15:00 HS Botanik

Ion trap chips for two-dimensional coupling experiments — •Michael Pfeifer[1,2], Simon Schey[1,3], Fabian Anmasser[1,2], Jakob Wahl[1,2], Matthias Dietl[1,2], Marco Valentini[2], Marco Schmauser[2], Michael Pasquini[2], Eric Kopp[2], Philip Holz[4], Martin van Mourik[4], Thomas Monz[2,4], Christian Roos[2], Clemens Rössler[1], Yves Colombe[1], and Philipp Schindler[2] — [1]Infineon Technologies Austria AG, Villach, Austria — [2]University of Innsbruck, Innsbruck, Austria — [3]Stockholm University, Stockholm, Sweden — [4]Alpine Quantum Technologies GmbH, Innsbruck, Austria

Ion trap quantum processors need two-dimensional connectivity between ions to harness their full potential **[1]**. We report on industrially fabricated ion trap chips designed to investigate radial and axial double-well potentials as building blocks of two-dimensional scalable architectures. The coupling between ions in the double-wells on the chips can be tuned by variation of the radial and/or axial separations.

The ion trap chips are fabricated on dielectric substrates - Fused Silica and Sapphire - at Infineon Technologies **[2,3]**. We discuss the design and fabrication of the ion traps as well as recent developments.

[1] M. Valentini *et al.*, arXiv:2406.02406 (2024)
[2] S. Auchter *et al.*, Quantum Sci. Technol. **7**, 035015 (2022)
[3] P. Holz *et al.*, Adv. Quantum Technol. **3**, 2000031 (2020)

Q 41.3 Wed 15:15 HS Botanik

Integrated Cryo-Electronics for Scalable 2D Surface Ion Traps — •Fabian Anmasser[1,2], Mohammad Abu Zahra[3,4], Matthias Brandl[3], Klemens Schueppert[2], Jens Repp[3], Matthias Dietl[1,2], Yves Colombe[2], Clemens Roessler[2], Philipp Schindler[1], and Rainer Blatt[1,5] — [1]Institute for Experimental Physics, Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Infineon Technologies AG, Neubiberg, Germany — [4]Technical University of Munich, Germany — [5]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria

2D surface ion traps provide a promising foundation for building scalable quantum computers. However, as the number of ions increases, so does the number of independently controllable electrodes, leading to a "wiring challenge". Current surface traps require individual routing of electrodes out of the cryogenic system, which becomes impractical for traps with over 1000 qubits.

We present a solution to the wiring challenge by integrating cryogenic electronics underneath a surface ion trap. Our approach involves a control chip that multiplexes 37 inputs to 199 DC electrodes, enabling control of a large number of electrodes with reduced connections. The surface trap is glued on top of the control chip, with electrical connections made using gold wire bonds. Initial Ca+ ion trapping trials have been conducted, and future steps include measuring heating rates and exploring advanced DC shuttling techniques. This work paves the way for scalable surface ion trap devices, bringing us closer to a practical quantum computer.

Q 41.4 Wed 15:30 HS Botanik

Micro fabricated ion trap with integrated optics — •Jakob Wahl[1,2], Alexander Zesar[1,3], Marco Schmauser[2], Martin van Mourik[2], Marco Valentini[2], Klemens Schüppert[1], Clemens Rössler[1], Philipp Schindler[2], and Christian Roos[2] — [1]Infineon Technologies Austria — [2]Universität Innsbruck — [3]Technische Universität Graz

Trapped ions have shown great promise as a platform for quantum computing, with long coherence time, high fidelity quantum logic gates, and the successful implementation of quantum algorithms. However, to take trapped-ion quantum computers from laboratory setups to practical devices for solving real-world problems, the number of controllable qubits must be increased while improving error rates. One of the major challenges for scaling trapped-ion quantum computers is the need to switch from free-space to integrated optics, to achieve lower drift and vibrations of light relative to the ion, and therefore more stable and scalable ion-addressing.

In this talk, we show an ion trap produced at Infineon's industrial

semiconductor facilities that has integrated femtosecond laser-written waveguides. We show details of the fabrication and present recent measurements and results on the performance of the trap. We compare the trapping behavior with and without the integrated features that expose dielectric to the ion, and potentially increase stray fields and heating rates. This work paves the way towards ion traps with robust and integrated ion addressing.

Q 41.5 Wed 15:45 HS Botanik

Advancements in Ultra-High Vacuum Technology for Trapped Ion Quantum Computing — •Helin Özel, Tabea Stroinski, Julian Harald Wiener, Felix Stopp, Björn Lekitsch, and Ferdinand Schmidt-Kaler — Johannes Gutenberg University, Mainz, Germany

We present experimental results on advancements in ultra-high vacuum (UHV) technology to support the development of next-generation quantum processor systems for continuous and stable operation at room-temperature. Our research focuses on improving UHV technology by applying innovative coating techniques. We optimize the pumping speed and achieve improved pressure levels alongside with reduced degassing rates, which are essential for maintaining the stability of quantum systems. Additional improvements address optical alignment and in-vacuum designs to support long-term operation. For preservation of qubit coherence we use three layers of Mu-metal shielding against magnetic noise, while a Halbach magnet configuration is employed to generate a stable magnetic quantization field. These advancements will enhance the reliability and operation quality of the trapped ion processor.

Q 41.6 Wed 16:00 HS Botanik

Implementing the SUPER Scheme for Tin-Vacancy Spin Qubit Manipulation and Entanglement — •Cem Güney Torun[1], Mustafa Gökçe[1], Thomas K. Bracht[2], Mariano Isaza Monsalve[1], Sarah Benbouabdellah[1], Özgün Ozan Nacitarhan[1], Marco E. Stucki[1,3], Domenica Bermeo Alvaro[1,3], Matthew L. Markham[4], Tommaso Pregnolato[1,3], Joseph H. D. Munns[1], Gregor Pieplow[1], Doris E. Reiter[2], and Tim Schröder[1,3] — [1]Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Condensed Matter Theory, Department of Physics, TU Dortmund, 44221 Dortmund, Germany — [3]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany — [4]Element Six, Harwell, OX110 QR, United Kingdom

We investigate the SUPER scheme, a detuned coherent excitation method enabling spectral separation of excitation and emission fields, for spin qubit inversion in tin-vacancy center in diamond. Simulations show high-fidelity inversion of spin superposition is achievable with optimized parameters, while spin T_1 measurements confirm that the broadband pulses do not induce significant spin mixing. Additionally, we propose a spin-spin entanglement protocol leveraging broadband excitation to encode photons in the frequency domain, enabling remote entanglement generation.

Q 41.7 Wed 16:15 HS Botanik

Coupling of alkali vapors and rare gases for quantum memories — •Denis Uhland[1], Norman Vincenz Ewald[2,3], Alexander Erl[2,3], Andrés Medina Herrera[3], Wolfgang Kilian[3], Jens Voigt[3], Janik Wolters[2,4], and Ilja Gerhardt[1] — [1]Leibniz University Hannover, Institute of Solid State Physics, Light and Matter Group, Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt, Institute of Optical Sensor Systems, Berlin — [3]Physikalisch-Technische Bundesanstalt, 8.2 Biosignals, Berlin — [4]Technische Universität Berlin, Institute of Optics and Atomic Physics, Berlin

Optical quantum memories allow for the storage and retrieval of quantum information encoded in photons. Despite using an optical interface for photons stored in collective spin excitation via EIT with milliseconds storage time [1], hot mixtures of alkali and rare gas atoms can achieve coherence times up to several hours [2], resulting from spin-exchange collisions, where the optically addressable alkali metals couple to the nuclear spin of the rare gas. R. Shaham et al. [3] discussed how to achieve strong coupling between the electron spin of potassium and the nuclear spin of helium, allowing for efficient spin transfer. We follow the proposed scheme to achieve strong coupling between a hot ensemble of rubidium and xenon, which paves the way towards an efficient quantum memory device and fundamental studies of spin dynamics. [1] L. Esguerra *et al.*, Phys. Rev. A (2023) 107, 042607, [2] C. Gemmel *et al.*, Eur. Phys. J. D (2010) 57, 303, [3] R. Shaham *et al.*, Nat. Phys. L (2022), Vol. 18, No. 5

Q 42: Open Quantum Systems I (joint session Q/QI)

Time: Wednesday 14:30–16:15 Location: HS I

Invited Talk Q 42.1 Wed 14:30 HS I

Effective Lindblad master equations for atoms coupled to dissipative bosonic modes — •Simon Balthasar Jäger — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We develop atom-only Lindblad master equations for the description of atoms that couple with and via dissipative bosonic modes. We employ a Schrieffer-Wolff transformation to decouple the bosonic from the atomic degrees of freedom in the parameter regime where the decay of the bosonic degrees is much faster than the typical relaxation time of the atoms. In this regime we derive the transformation which includes the most relevant retardation effects between the bosonic and the atomic degrees of freedom. After the application of this transformation, the effective Lindblad master equation is obtained by tracing over the bosonic degrees of freedom and captures the atomic interactions and dissipation mediated by the bosons. We use this approach to derive Lindblad master equations which can describe the phase transitions, steady states, and dynamics in the dissipative Dicke model. In addition, we show that such master equations can be used in presence of resonant periodic driving and predict the formation and stabilization of dissipative Dicke time crystals. We also discuss how to extend the theory to describe systems with continuous symmetries where descriptions with the Redfield master equation fail. Our work provides general methods for the efficient theoretical description of retarded boson-mediated interactions and dissipation.

Q 42.2 Wed 15:00 HS I

Accurate Master Equation Formalism for Molecular Quantum Optics Systems — •Burak Gurlek[1], Claudiu Genes[2], and Angel Rubio[1,3] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany — [3]Center for Computational Quantum Physics, The Flatiron Institute, New York, USA

Molecules are compact, hybrid quantum systems that provide access to electronic, vibrational and spin degrees of freedom spanning a broad range of energy and time scales. They already been shown to realize efficient single-photon sources and nonlinear quantum optical element, and hold great promise for advancing quantum technologies. These developments require a thorough understanding of complex molecular interactions in open quantum settings, typically modeled using the standard Lindblad master equation formalism.

In this work, we demonstrate that strong optomechanical interactions in an important class of dye molecules lead to couplings between reservoirs within the standard master equation framework, resulting in erroneous predictions. To address this, we derive a dressed master equation, and recover previous experimental observations. We complement this with analytical expressions for spectral observables derived from quantum Langevin equations, using a standard master equation in the polaron frame. Our results highlight the importance of strong optomechanical interactions in molecular systems and demonstrate how to accurately account for these effects in the dynamics of open molecular quantum system.

Q 42.3 Wed 15:15 HS I

Open system dynamics with quantum degenerate gases — •Julian Lyne[1,2], Nico Bassler[2,1], Kai Phillip Schmidt[2], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Staudtstraße 7, D-91058 Erlangen, Germany

An ensemble of coupled two-level quantum emitters may display collective radiative effects such as super- and subradiance. Such systems are usually treated within the standard open system theory of quantum optics, where small emitter separations lead to collective decay channels and coherent dipole-dipole interactions. This approach can be extended to the quantum degenerate regime [1], where there is an interplay between the particle statistics and the effects brought on by the cooperative radiative response. In the quantum degenerate regime already for independent emitters the rate of spontaneous emission can be enhanced for bosons, as intuitively expected by the symmetrization condition of the wavefunction, and may be completely suppressed for fermions, owing to the Pauli exclusion principle. We present our recent work investigating radiative properties of harmonically trapped fermionic and bosonic atomic gases using a master equation approach, where we investigate some restricted many-body scenarios and employ cumulant expansion methods.

[1] M. Lewenstein et al., Physical Review A 50, 2207 (1994).

Q 42.4 Wed 15:30 HS I

Collective excitations of dissipative time crystals — •Gage Harmon[1], Giovanna Morigi[1], and Simon Jäger[2] — [1]Saarland University — [2]University of Bonn

We present a Floquet-theoretic description of atoms interacting periodically with a dissipative optical cavity. We derive an effective atom-only master equation, valid in the bad cavity regime. Using this theory, we analyze the excitation spectrum of the atoms across the transition from a normal phase to a time-crystalline phase. We identify features in the excitation spectra, such as mode softening when crossing a continuous equilibrium transition, that suggest a dynamical phase transition. We then analyze the excitation spectra when the periodic drive crosses a bistable regime and observe sudden jumps in the oscillation frequencies and relaxation rates. Finally, we discuss how these results can be detected experimentally by probing the cavity with an additional monochromatic drive. Our work provides important tools for analyzing the response of dynamical out-of-equilibrium phases.

Q 42.5 Wed 15:45 HS I

Continuous similarity transformations for Lindbladians — •Lea Lenke and Kai Phillip Schmidt — FAU Erlangen-Nürnberg

The established approach of perturbative continuous unitary transformations (pCUTs) constructs effective block-diagonal quantum many-body Hamiltonians as a perturbative series. We extend the pCUT method to similarity transformations – dubbed pcst^{++} – allowing for more general and non-Hermitian operators [1]. We apply the pcst^{++} method to the Lindbladian describing the dissipative transverse field Ising chain. In the subsequent treatment of the obtained effective Lindbladian, we take advantage of its block-diagonal structure and perform a linked-cluster expansion obtaining results that are valid in the thermodynamic limit. In the next step, we aim at generalizing the method of directly evaluated enhanced perturbative continuous unitary transformations (deepCUTs) to non-Hermitian operators.

[1] L. Lenke, A. Schellenberger, and K. P. Schmidt, "Series expansions in closed and open quantum many-body systems with multiple quasiparticle types", Phys. Rev. A 108, 013323 (2023).

Q 42.6 Wed 16:00 HS I

Heat transport between small spherical objects — •Nico Strauss and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, 34132 Kassel, Germany

The second law of thermodynamics dictates that heat naturally flows from warm to cold objects, thereby providing a direction of time [1]. In the context of quantum optics within nonreciprocal media [2], an arrow of time is alternatively provided by the observation that optical paths cannot be reversed. How are these two notions compatible at the level of quantum electrodynamics?

To address this question, we investigate nanoscale heat transfer between three small spherical media that display a temperature gradient of $T_3 > T_2 > T_1$ [3]. We express the result in terms of the spheres' polarizabilities and analyze the impact of various material properties and external fields on the heat transfer occurring between the spheres, as well as their interplay with the second law of thermodynamics in the near-field regime.

[1] Volokitin, A. I., Persson, B. N. J. Rev. Mod. Phys. **4**, 79 (2007).
[2] S. Y. Buhmann, et al, New J. Phys. **14**, 083034 (2012).
[3] K. Joulain, et al, Surface Science Reports **57**, 59*112 (2005).

Q 43: Ultracold Matter (Bosons) III (joint session Q/A)

Time: Wednesday 14:30–16:30 Location: WP-HS

Q 43.1 Wed 14:30 WP-HS

Out of equilibrium superfluid density evolution of dipolar Bose-Einstein condensate in ramped up disorder — •Rodrigo P A Lima[1,2], Milan Radonjić[3,4], and Axel Pelster[5] — [1]Universidad de Castilla-La Mancha, Spain — [2]Universidade Federal de Alagoas, Brazil — [3]Universität Hamburg, Germany — [4]University of Belgrade, Serbia — [5]Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

We study the evolution of the superfluid density of an ultracold Bose gas in a ramped-up weak random potential. The bosons are assumed to interact not only through an isotropic short-range contact interaction [1], but also through an anisotropic long-range dipole-dipole interaction. We determine the disorder ensemble averaged components of the superfluid density parallel and perpendicular to the dipole direction. In particular, we discuss how their reversible and irreversible contributions depend on both the dipolar interaction strength and the ramp-up time.

[1] M. Radonjić and A. Pelster, SciPost Phys. **10**, 008 (2021).

Q 43.2 Wed 14:45 WP-HS

Coupled Higgs-Goldstone dynamics in the Bose-Hubbard model — •Thomas Hauschild[1], Ulli Pohl[1], Sayak Ray[1], and Johann Kroha[1,2] — [1]Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews KY16 9SS, United Kingdom

The realization of a Mott-superfluid transition in the Bose-Hubbard model using ultracold bosons in an optical lattice led to exploring many aspects of non-equilibrium physics over the past decade. These include collective excitations of the Bose-Einstein condensate near the Mott transition. We investigate the dynamics of these Higgs and Goldstone modes beyond the harmonic approximation using the field theory approach [1]. The coupling of the modes is analogous to the one in a Bosonic Josephson junction [2], and, thus, can possibly yield phase space dynamics like in a mathematical pendulum. In the long wavelength limit, we obtain the equations of motion for the coupled condensate amplitude and phase modes. In particular, we investigate the transition from a low-amplitude oscillation with spontaneously broken, localized phase to a running-phase mode.

[1] K. Sengupta, N. Dupuis, Phys. Rev. A, **71**, 033629 (2005).
[2] A. Smerzi, S. Fantoni, S. Giovanazzi, S. R. Shenoy, Phys. Rev. Lett, **79**, 4950 (1997).

Q 43.3 Wed 15:00 WP-HS

Chaotic phase of the tilted Bose-Hubbard model — Pilar Martín Clavero[1] and •Alberto Rodríguez[1,2] — [1]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain — [2]Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, E-37008 Salamanca, Spain

We present an energy-resolved map of the many-body chaotic phase of the tilted Bose-Hubbard model at unit filling as a function of the tilt F, interaction strength U and tunneling energy J. Our results are based on the analysis of spectral statistics and of eigenvector structure via generalized fractal dimensions. While quantum chaos intuitively disappears for sufficiently large tilts, we demonstrate that a non-vanishing finite tilt can enlarge the extension of the ergodic region, as compared to the $F = 0$ case [1]. We furthermore characterize the chaotic regime in U-F space around the energy of the Fock state with homogeneous density, typically used in experimental studies.

[1] P. M. Clavero, "Chaotic Phase of the Bose-Hubbard Hamiltonian in an external static field". BSc Thesis. Universidad de Salamanca

(2024).

Q 43.4 Wed 15:15 WP-HS

Propagation of two-particle correlations across the chaotic phase for interacting bosons — •Óscar Dueñas Sánchez[1,2] and Alberto Rodríguez[1,2] — [1]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain — [2]Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, E-37008 Salamanca, Spain

We study the dynamical manifestation of the chaotic phase in the time-dependent propagation of experimentally relevant two-particle correlations for one-dimensional interacting bosons by means of a conveniently defined two-particle correlation transport distance ℓ. Our results show that the chaotic phase induces the emergence of an effective diffusive regime in the asymptotic temporal growth of ℓ, characterized by an interaction dependent diffusion coefficient, which we estimate [1]. We investigate the origin of such behaviour by analysing the spatial and temporal evolution of two-particle correlations, where we see a clear correspondence between a general change in their profile and the emergence of the diffusive regime.

[1] O. Dueñas, D. Peña and A. Rodríguez, arXiv:2410.10571

Q 43.5 Wed 15:30 WP-HS

Suppression of Floquet Heating in a Driven Bose-Hubbard Chain via Bath-Engineering — •Lorenz Wanckel and André Eckardt — Technische Universität Berlin, Institut für Theoretische Physik, 10623 Berlin, Germany

Floquet engineering is a crucial control technique in ultracold quantum gas experiments, enabling the creation of effective Hamiltonians with properties that are otherwise difficult to achieve, such as topological nontrivial band structures. However, in isolated systems, these effective descriptions break down at long times due to Floquet heating and the stabilization by dissipation into a bath is generally an open question, as is the asymptotic state of driven dissipative systems. We investigate a driven Bose-Hubbard model and attempt to mitigate heating through weak dissipative coupling to a bath. We assess heating effects by analyzing the population of the ground state of the effective Hamiltonian in the asymptotic state, obtained from the Born-Markov master equation. Our analysis identifies two sources of heating and demonstrates how to choose parameters to effectively suppress heating.

Q 43.6 Wed 15:45 WP-HS

Anomalous non-thermal fixed point in a quasi-2d dipolar Bose gas — •Niklas Rasch[1], Wyatt Kirkby[1,2], Lauriane Chomaz[2], and Thomas Gasenzer[1,3] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227 — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226 — [3]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16

This work focuses on anomalous non-thermal fixed-points (NTFP) in the temporal evolution of a 2d dipolar Bose gas, exhibiting slow, subdiffusive coarsening characterized by algebraic growth of a characteristic length scale $L(t) \sim t^{\beta}$ with $\beta \ll 1/2$. Sampling from various initial vortex configurations, we evolve the Bose gas using the semi-classical truncated-Wigner approach. For a highly dilute gas, anomalous scaling prevails, with an exponent $\beta \sim 1/5$, for various dipolar strengths and tilting angles. For late times or strong dissipation we observe the transition into diffusive scaling with $\beta = 1/2$. In the quantum regime, realised for typical experimental parameters, we also find anomalously slow scaling, albeit with more fluctuations than in the classical limit. Within a quasi-2d setting, we analyze the dependence of the scaling exponents on the anisotropic and long-range nature of the dipolar interaction. Further, we investigate the role of vortex (anti-)clustering and find both strong clustering as well as anti-clustering throughout the anomalous scaling regime. Our results support the universal nature of the anomalous NTFP and hint towards three-vortex collisions as the primary source for the subdiffusive coarsening.

Q 43.7 Wed 16:00 WP-HS

Conformal symmetry as a resource for improved parameter estimation in the nonlinear Schrödinger equation — David B. Reinhardt[1], Dean Lee[2], •Wolfgang P. Schleich[3,4], and Matthias Meister[1] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Facility for Rare Isotope Beams and Department of Physics and Astronomy, Michigan State University, USA — [3]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Germany — [4]Hagler Institute for Advanced Study at Texas A&M University, USA

The conformal symmetry of the non-linear Schrödinger equation (NLSE) unifies the stationary and time-dependent travelling-wave solutions of the one-dimensional cubic-quintic NLSE, the cubic NLSE and LSE. Any two systems that are classified by the same single number called the cross-ratio are related by this symmetry [1]. Here, we show that the symmetry serves as a powerful resource in parameter estimation from noisy empirical data, significantly enhancing results through the application of an optimization afterburner that exploits the conformal symmetry with random transformation coefficients. The conformal afterburner optimization finds the true global minimum more reliably compared with a standard fitting approach with randomized initial guesses. The new method demonstrates that group transformations can enhance the performance of search algorithm and therefore has far reaching practical applications for nonlinear physical systems. [1] Reinhardt et al., arXiv:2306.17720 (2023)

Q 43.8 Wed 16:15 WP-HS

Gapless Hartree-Fock-Bogoliubov Theory for Bose-Bose Droplets — •Alexander Wolf[1,2], Maxim Efremov[2], and Axel Pelster[3] — [1]Institute of Quantum Physics and Center for Integrated Quantum Science and Technology (IQ^{ST}), Ulm University, Ulm, Germany — [2]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [3]Department of Physics and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Kaiserslautern, Germany

By generalizing the gapless Hartree-Fock-Bogoliubov theory for one component [1] to a Bose-Bose mixture, we develop a quantum droplet theory that unifies existing approaches. In addition to the condensate densities and depletions, both intra- and interspecies exchange as well as anomalous correlations are considered as variational parameters. The latter two require taking into account that two atoms in a Bose-Einstein condensate do not scatter in vacuum but inside a medium that dresses the collisions. We solve the resulting set of algebraic self-consistency equations at zero temperature for the special case of two identical components. Surprisingly, the equilibrium densities of the quantum droplets obtained with our approach perfectly agree with the results of quantum Monte-Carlo simulations [2] for all interspecies interactions with one minor discrepancy.

[1] N. P. Proukakis *et al.*, Phys. Rev. A **58**, 2435 (1998).
[2] V. Cikojević *et al.*, Phys. Rev. A **99**, 023618 (2019).

Q 44: Quantum Networks (joint session QI/Q)

Time: Wednesday 14:30–16:45 Location: HS VIII

Invited Talk Q 44.1 Wed 14:30 HS VIII

Generating entangled states in quantum networks — •Nikolai Wyderka[1], Justus Neumann[1], Tulja Varun Kondra[1], Kiara Hansenne[2], Lisa T. Weinbrenner[2], Hermann Kampermann[1], Otfried Gühne[2], and Dagmar Bruss[1] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany — [2]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

Which states can be generated in quantum networks? We investigate this question in n-partite quantum networks connected by bipartite sources, assuming local operations and shared randomness (LOSR). We show that for many target states, the question can be reduced to the tripartite network scenario.

Consequently, we show that for the class of multipartite graph states, the reducibility is connected to the task of Greenberger-Horne-Zeilinger (GHZ) state extraction. Here, one asks whether n parties that share a graph state and are distributed into three groups can create a GHZ state shared between them using only group-local unitary operations. We show that for each connected graph state, it is always possible to find a tripartition that yields at least one GHZ state.

Finally, we exploit our findings to derive fidelity bounds on states preparable in LOSR networks with any graph state by deriving strong fidelity bounds in tripartite quantum networks.

Q 44.2 Wed 15:00 HS VIII

Designing a Microwave-to-Optical Transducer based on a High-Overtone Bulk Acoustic-Wave Resonator — •Tom Schatteburg[1,2], Maxwell Drimmer[1,2], Rodrigo Benevides[1,2], Samuel Pautrel[1,2], Hugo Doeleman[1,2], Benjamin Neubauer[1,2], Luca Ben Herrmann[1,2], and Yiwen Chu[1,2] — [1]Department of Physics, ETH Zürich, Zurich, Switzerland — [2]Quantum Center, ETH Zürich, Zürich, Switzerland

Microwave to optical transducers convert quantum states from platforms such as superconducting circuits into the thermal noise-free optical regime, promising a route towards a quantum network using telecom fibers as links. A widespread approach is to use a mechanical resonator as intermediate system that couples to both microwaves and optical photons. High-overtone bulk acoustic-wave resonators (HBARs) are a platform for which both electromechanical and optomechanical strong coupling as well as optomechanical ground state operation has been demonstrated. Here we present the design and intermediate results of building a microwave to optical transducer which uses an HBAR as intermediary. We demonstrate the insensitivity to laser light absorption of the acoustic mode as key advantage of the HBAR, and outline the path to combining microwave, acoustics and optics into one system. We discuss overcoming the challenges that arise when building the transducer, such as making high-frequency superconducting qubits, multimode dynamics, cryogenic alignment, and developing new materials.

Q 44.3 Wed 15:15 HS VIII

Hollow-core light cage waveguides for atomic vapor quantum memories — •Esteban Gómez-López[1], Dominik Ritter[1], Jisoo Kim[2], Harald Kübler[3], Markus Schmidt[2,4], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, 12489, Berlin, Germany — [2]Leibniz Institute of Photonic Technology, 07745, Jena, Germany — [3]Universität Stuttgart, 70550, Stuttgart, Germany — [4]Otto Schott Institute of Material Research, 07743, Jena, Germany

Quantum memories play a fundamental role in synchronizing quantum network nodes. Using electromagnetically induced transparency (EIT) in hot atomic vapors provides easy-to-handle systems capable of storing light for up to seconds [1] and at the single photon level [2]. Recently we have shown that a novel photonic structure, a nanoprinted hollow-core light cage (LC), can enhance the effects of EIT when interfaced with Cs vapor, with the advantage of faster diffusion of atoms inside the core compared to other hollow-core structures [3]. In this work, we show the storage of faint coherent light pulses in the atomic medium confined within the core of the LC for hundreds of nanoseconds. The intrinsic efficiency of the memory was optimized by performing a parameter scan on the signal bandwidth and control power driving the memory. This paves the way towards an on-chip integrated module for quantum memories and as a platform for coherent interaction of light and warm atomic vapors. [1] Katz, O. and Firstenberg, O., Nat. Commun. 9, 2074 (2018). [2] Wolters, J., et al., Phys. Rev. Lett. 119(6), 060502 (2017). [3] Davidson-Marquis, F., et al., Light. Sci. Appl. 10, 114 (2021).

Q 44.4 Wed 15:30 HS VIII

Entanglement purification in multipartite quantum router setups with multiplexing — •Julia Alina Kunzelmann, Hermann Kampermann, and Dagmar Bruss — Heinrich Heine University Düsseldorf

Quantum routers are essential for transmitting quantum information over long distances in quantum networks. To enhance the entanglement distribution rate memory multiplexing can be used. However, quantum memories will decohere, which we compensate by entanglement purification. Our work presents an extended protocol that includes both multiplexing and entanglement purification. For entanglement purification, we use the protocol from Deutsch et al. (1996), which we apply pairwise to the quantum memories before performing GHZ measurements. Depolarized qubits in the quantum memories can be replaced or purified by new arriving qubits with higher fidelities. We analyze the fidelity of the distributed GHZ states under various network conditions. Further, we discuss different purification strategies based on our numerical simulations.

Q 44.5 Wed 15:45 HS VIII

Graph states fidelity bound in networks with local operation and shared randomness — •Justus Neumann[1], Tulja Varun Kondra[1], Nikolai Wyderka[1], Kiara Hansenne[2], Lisa Weinbrenner[2], Hermann Kampermann[1], Otfried Gühne[2], and Dagmar Bruss[1] — [1]Heinrich-Heine-Uinversität Düsseldorf — [2]Universität Siegen

We analyze quantum networks of spatially separated parties, where some parties are connected by quantum channels (links), enabling the distribution of pairwise entangled states. Additionally, each party has access to a shared classical random variable. Quantum states generated under these conditions are referred to as LOSR states (Local Operations and Shared Randomness). Characterizing this class of network states is often challenging, as determining whether a given state can be realized within a given network configuration is non-trivial. We derive an analytical upper bound on the fidelity of the set of LOSR states with any connected graph state, with particular emphasis on the GHZ state.

Q 44.6 Wed 16:00 HS VIII

Genuine networks bounds on distillable GHZ and conference key in pair-entangled networks — •Anton Trushechkin, Hermann Kampermann, and Dagmar Bruss — Heinrich Heine University Düsseldorf, Faculty of Mathematics and Natural Sciences, Institute for Theoretical Physics III, Universitätsstr. 1, Düsseldorf 40225

A fundamental problem of the bipartite entanglement theory is the derivation of upper bounds on distillable entanglement (EPR pairs) and distillable secret key if a source of bipartite (entangled) states is given and LOCC (local operations and classical communication) or LOPC (local operations and public communication) maps are allowed. The same fundamental problems arises in the network scenario. We consider networks where nodes are connected with bipartite entangled sources.

Obviously, GHZ or conference key distillation is not easier than EPR or bipartite secret key distillation between two subsets of nodes constituting an arbitrary bipartition of nodes. Thus, we can apply known bipartite bounds. The existing network bounds are based on this idea of bipartition.

In the present talk, we propose genuine network bounds on distillable GHZ and conference key in pair-entangled networks, i.e. which are not reduced to bipartitions of nodes. To do this, we introduce suitable LOCC and LOPC monotones originating from putting together ideas from classical and quantum information theory and graph theory.

Q 44.7 Wed 16:15 HS VIII

Collective quantum phases emerging in superconducting qubits networks — •Benedikt J.P. Pernack, Mikhail V. Fistul, and Ilya M. Eremin — Theoretische Physik III, Ruhr-Universität Bochum, Bochum 44801, Germany

We present a theoretical study of collective quantum phases occurring in exemplary vertex-sharing superconducting qubits networks, i.e., frustrated sawtooth chains of Josephson junctions embedded in a dissipationless transmission line. The building block of such networks is a triangular superconducting cell containing two 0-Josephson junctions and one π-Josephson junction. In the frustrated regime, the low-energy quantum dynamics of a single cell is governed by the presence of persistent currents flowing (anti)clockwise corresponding to (anti)vortex configurations. The direct embedding of π-Josephson junctions to the transmission line results in short- or long-range interactions between vortices and antivortices of different cells. Employing a variational approach the quantum dynamics of such qubits networks was mapped to an effective XX spin model where the exchange interaction between spins decays with distance as $x^{-\beta}$, and the local terms represent the coherent quantum superposition of vortex-antivortex pairs [1]. Combining exact numerical diagonalization and quasi-classical mean field approach, we identified various collective quantum phases such as the paramagnetic (P), compressible superfluid (CS) and weakly compressible superfluid (w-CS) states.

[1] B.J.P. Pernack, M.V. Fistul, I.M.Eremin, Phys. Rev. B 110, 184502 (2024).

Q 44.8 Wed 16:30 HS VIII

Towards a Suburban Quantum Network Link — •Pooja Malik[1,2], Florian Fertig[1,2], Yiru Zhou[1,2], Tommy Block[1,2], Maya Bueki[3], Tobias Frank[3], Gianvito Chiarella[3], Marvin Scholz[3], Pau Ferrera[3], Gerhard Rempe[3], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig- Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck Institut für Quantenoptik, Garching, Germany

Distributed quantum computing, quantum sensing and secure quantum communication are all much anticipated applications of quantum networks. The primary blocks of these networks are quantum nodes and the foremost task is to distribute entanglement between distant quantum nodes. Here we present a quantum node based on a single Rb87 atom capable of distributing entanglement between a single atom and a single photon over a 23 km deployed telecom fiber. To achieve transfer in commercial fiber network the single photons are converted to telecom wavelength to evade high attenuation loss at 780 nm. With active polarization compensation over the deployed fiber and long atomic coherence time of 7 ms [1] we measure atom-photon entanglement fidelity of more than 80%. This is a crucial step to realize a city-to-city scale quantum network link when, in the future, connecting to another Rb87 atom node at the remote end of fiber link [2]. [1] Y. Zhou et al., PRX Quantum 5, 020307, 2024 [2] M. Brekenfeld et al., Nature Physics 16, 647-651 (2020)

Q 45: Mechanical, Macroscopic, and Continuous-variable Quantum Systems (joint session QI/Q)

Time: Wednesday 14:30–16:15 Location: HS IX

Invited Talk Q 45.1 Wed 14:30 HS IX

Wave-Function Expansion with Optically Levitated Nanoparticles — •Martin Frimmer — ETH Zürich, Zürich, Switzerland

Optomechanical systems provide testbeds for applications ranging from quantum information processing to fundamental searches for potential limitations of quantum theory with increasingly large masses. All quantum optomechanical protocols require purification of the motional state of the mass under scrutiny. Staying in the realm of Gaussian states, the only pure state of motion of a harmonic oscillator is the quantum ground state. Accordingly, ground-state cooling has been the main aim of the opto-mechanics community. It has been achieved with the help of laser cooling and, for the vast majority of experiments, of cryogenic cooling. Only recently, first systems have demonstrated quantum optomechanics at room temperature. A promising experimental platform in this context are optically levitated nanoparticles. Their center-of-mass motion and also their orientation (in case of optically anisotropic particles) resemble harmonic-oscillator degrees of freedom of mechanical motion. In our work, we prepare the highest-purity opto-mechanical oscillator to date. By coupling the rotational degree of freedom of an optically levitated nano-cluster to an optical cavity, we cool the libration mode to a phonon occupation of 0.04 quanta. Notably, we set this purity record in a room-temperature experiment, opening the door towards high-purity quantum optomechanics without the need for cryogenic cooling.

Q 45.2 Wed 15:00 HS IX

Macroscopic quantum sizes of mechanical systems — •Benjamin Yadin[1] and Matteo Fadel[2] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

Whether quantum theory holds true in the macroscopic realm – or breaks down at some size scale – is unknown. Many experimental platforms are probing this question by creating quantum states of ever-increasing size, for example with high masses or involving entanglement between many particles. Measures of ‘macroscopicity’ are designed to quantify the extent to which a system displays quantum behaviour at a large scale; however, these are often difficult to clearly interpret or fail to apply to a large variety of systems and states.

Here, we propose two measures corresponding to properties originally identified as crucial by Leggett: the ‘extensive size’, measuring the spread of quantum coherence over a physical size scale; and the ‘entangled size’, quantifying many-body entanglement between constituent parts of the system. These measures are mathematically well-defined for any state and lower bounds are readily obtainable from experimental data. We demonstrate this through application to mechanical systems – using data from mechanical oscillators and molecular interferometers. As part of this, we show the dependence on temperature of many-body entanglement between atoms in an oscillator.

Q 45.3 Wed 15:15 HS IX

How non-classical is a quantum state? — •Martina Jung and Martin Gärttner — Friedrich-Schiller-Universität Jena, Germany

Non-classicality, defined in the sense of quantum optics, is a resource: If a non-classical state is superimposed with vacuum in a beamsplitter, the resulting state will be entangled. Hence, quantifying the non-classicality of a quantum state is crucial to gauge its potential for quantum advantage - for instance in a Boson Sampler. However, conventional non-classicality measures often fail as a practical tool in experimental setups.

Here, we implement a data-driven, devise-specific approach which quantifies the non-classicality of a state by the ability of a neural network to distinguish the state from a classical one. In this approach, snapshots from photon-number measurements are input to a permutation invariant Vision Transformer. By studying the model’s attention map, our goal is to identify signatures of non-classical states that might uncover yet unknown non-classicality witnesses.

Q 45.4 Wed 15:30 HS IX

Learning quantum states of continuous-variable systems — Francesco Mele[1], Antonio Mele[2], •Lennart Bittel[2], Jens Eisert[2], Vittorio Giovannetti[1], Ludovico Lami[3], Lorenzo Leone[2], and Salvatore Oliviero[1] — [1]NEST, Scuola Normale Superiore and Istituto Nanoscienze, Piazza dei Cavalieri 7, IT-56126 Pisa, Italy — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Institute for Theoretical Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, the Netherlands

Quantum state tomography, aimed at deriving a classical description of an unknown state from measurement data, is a fundamental task in quantum physics. In this work, we analyse the ultimate achievable performance of tomography of continuous-variable systems, such as bosonic and quantum optical systems. We prove that tomography of these systems is extremely inefficient in terms of time resources. On a more positive note, we prove that tomography of Gaussian states is efficient. To accomplish this, we answer a fundamental question for the field of continuous-variable quantum information: if we know with a certain error the first and second moments of an unknown Gaussian state, what is the resulting trace-distance error that we make on the state? Lastly, we demonstrate that tomography of non-Gaussian states prepared through Gaussian unitaries and a few local non-Gaussian evolutions is efficient and experimentally feasible.

Q 45.5 Wed 15:45 HS IX

Entanglement detection in continuous-variable systems using two states — •Elena Callus[1], Tobias Haas[2], and Martin Gärttner[1] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-Universität Jena, Germany — [2]Centre for Quantum Information and Communication, Université Libre de Bruxelles, Belgium

The Shchukin-Vogel hierarchy gives necessary conditions for the separability of continuous-variable systems in terms of moments of the mode operators. However, higher-order moments, which are essential for non-Gaussian entanglement detection, are hard to extract efficiently. While recent work has shown the general usefulness of multiple state copies for entanglement witnessing in this regard, the therein proposed measurement schemes require at least three copies that would need to be phase-matched and interfered simultaneously. In this work, we demonstrate the capabilities from using only two states that are interfered on a beam-splitter with variable phase and photon-number detectors. This allows us to access certain classes of moments of the mode operators up to arbitrarily high orders. With their associated separability criteria, we witness entanglement in non-Gaussian classes of N00N states, with arbitrarily large N, and two-mode Schrödinger cat states.

Q 45.6 Wed 16:00 HS IX

Detecting genuine non-Gaussian entanglement — •Serge Deside, Tobi Haas, and Nicolas Cerf — ULB, Brussels, Belgium

Efficiently certifying non-Gaussian entanglement in continuous-variable quantum systems is a central challenge for advancing quantum information processing, photonic quantum computing, and metrology. Here, we put forward continuous-variable extensions of the recently introduced entanglement criteria based on moments of the partially transposed state, together with simple readout schemes that require only passive linear optics and local particle number measurements over a handful of state replicas. Our method enables the detection of genuine non-Gaussian entanglement for relevant state families overlooked by all standard approaches, which includes the entire class of NOON states. Further, it is robust against realistic experimental constraints (losses, imperfect copies, and finite statistics), which we demonstrate by an in-depth simulation.

Q 46: Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)

Time: Wednesday 14:30–15:45 Location: KlHS Mathe

Q 46.1 Wed 14:30 KlHS Mathe

Fifth-force searches with the bound-electron *g* factor — •Zoltan Harman — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

High-precision measurements of the g factor of one- and few-electron ions and its isotope shifts offer a promising avenue for probing beyond-Standard-Model (BSM) physics [1]. By calculating the potential contribution of a hypothetical new force to the g-factor of H-like, Li-like, and B-like ions, we can derive constraints on the parameters of such a force. This approach leverages the advanced theoretical calculations of QED contributions to the bound-electron g-factor [2,3].

To enhance sensitivity to new physics, we focus on the weighted difference and, especially, the isotope shift of g-factors. We have found that a recent Penning-trap measurement of the isotopic shift of the g factors in $^{20}Ne^{9+}$ and $^{22}Ne^{9+}$ to sub-parts-per-trillion precision present a compelling alternative for setting bounds on BSM interactions [4]. Moreover, combining measurements from different isotopes of H-like, Li-like and B-like ions [1] at accuracy levels projected to be accessible in the near future, experimental results would constrain the new physics coupling constant further than the best current spectroscopic data and theory. – [1] V. Debierre, C. H. Keitel, Z. Harman, Phys. Lett. B **807**, 135527 (2020); [2] J. Morgner, B. Tu, C. M. König, *et al.,* Nature **622**, 53 (2023); [3] B. Sikora, V. A. Yerokhin, C. H. Keitel, Z. Harman, arXiv:2410.10421 (2024); [4] T. Sailer, V. Debierre, Z. Harman, *et al.,* Nature **606**, 479 (2022).

Q 46.2 Wed 14:45 KlHS Mathe

Raman Transition Techniques for High-Precision Experiments in Collinear Laser Spectroscopy — •Julien Spahn, Hendrik Bodnar, Kristian König, and Wilfried Nörtershäuser — Institute for nuclear physics, TU Darmstadt, Germany

Benefitting from the drastic compression of the velocity width through an electrostatic acceleration by several 10 kV and, hence, overcoming Doppler broadening, collinear laser spectroscopy is a fast technique for precision measurements on dipole-allowed transtions. Being constantly refined, the natural linewidth of the dipole transition starts becoming a limiting factor. Raman transitions have a two orders of magnitude smaller linewidth than dipole transitions. While various applications utilizing Raman transitions have emerged over the years, techniques exploiting Raman transitions in collinear laser spectroscopy have so far been limited to hyperfine structure studies [1].

This contribution will present the results of recent measurements of the $S_{1/2} \rightarrow D_{5/2}$ clock transition $^{88}Sr^{+}$ at COALA, used to benchmark the applied collinear Raman spectroscopy. The AC-Stark shift and two-photon Rabi oscillations were investigated, and the feasibility of performing laser spectroscopical HV measurements using a "Raman velocity filter" [2] was tested. Furthermore, an approach for Doppler-free collinear Raman spectroscopy employing two subsequent Raman transitions will be presented.

This project is supported by DFG (Project-ID 461079926).

[1] TP Dinneen et al., *Physical Review A*, 43, 1991
[2] A. Neumann et al., *Physical Review A*, 101, 2020

Q 46.3 Wed 15:00 KlHS Mathe

high-resolution spectroscopy of $^{173}Yb^{+}$ — •jian jiang[1], anna viatkina[1,2], saaswath JK[1], melina filzinger[1], martin steinel[1], burghard lipphardt[1], andrey surzhykov[1,2], and nils huntemann[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]TU Brauschweig, Braunschweig, Germany

Different isotopes of Yb^{+} have been employed in atomic clocks [1], quantum information processing [2], and new physics searches [3]. Owing to its large nuclear spin of 5/2, , $^{173}Yb^{+}$ is a particular promising candidate for advancing research in these areas compared to other isotopes [4,5,6]. However, $^{173}Yb^{+}$ is also relatively poorly investigated because of its complicated atomic structure.

In this talk, we will first discuss our approaches to overcome challenges in laser cooling and state preparation of a single $^{173}Yb^{+}$ ion confined in a Paul trap. We will then discuss measurements we have done for the hyperfine structure of the $^2S_{1/2}$ and $^2D_{3/2}$ states and the electric quadrupole clock transition between them. We will also discuss the ongoing search for the $^2S_{1/2} \rightarrow {}^2F_{7/2}$ electric octupole clock transition.

Reference [1] PRL. 116, 063001 (2016), [2]Nature 630, 613-618 (2024), [3] PRL 125, 123002 (2020), [4] APL 119, 214002 (2021), [5] PRA 93, 052517 (2016), [6] Phys. Rev. A 96, 012516(2017)

Q 46.4 Wed 15:15 KlHS Mathe

Characterizing tungsten emissivity and temperature stability of an atomic beam source for the Project 8 Experiment — •Brunilda Mucogllava[1], Martin Fertl[1], and Marco Röllig[2] for the KAMATE-Collaboration — [1]Johannes Gutenberg University Mainz — [2]Tritium Laboratory Karlsruhe

The Project 8 experiment seeks to make a neutrino-mass measurement with a sensitivity of 40 meV/c2 using cyclotron radiation emission spectroscopy of beta decay electrons from an atomic tritium source. To enable safe initial R&D, a Hydrogen Atom Beam Source (HABS) is used at the JGU Mainz test stand, where molecular hydrogen is dissociated inside a 1 mm tungsten capillary heated radiatively to 2300 K by a tungsten filament. The efficiency of dissociation is closely tied to the capillary's surface temperature, which depends on its thermal properties. The aging of both the tungsten filament and capillary alters their surface resistivity and emissivity, affecting the achievable temperature and complicating absolute temperature measurements. To address this, a calibration setup at the Tritium Laboratory Karlsruhe (TLK) was developed to measure tungsten emissivity using a near-infrared spectrometer and a single wavelength pyrometer. This talk will present findings on tungsten emissivity modeling and HABS temperature measurements, addressing challenges in device calibration, ultra-high vacuum conditions, and temperature stability.

Q 46.5 Wed 15:30 KlHS Mathe

Absolute rate coefficients from dielectronic recombination for the astrophysically relevant ion of Ne3+ at CRYRING@ESR — •E.-O. Hanu[1,3,10], M. Lestinsky[1], E. B. Menz[1,3,4], M. Fogle[2], S. Schippers[5,6], P.-M. Hillenbrand[1,5], M. Looshorn[5,6], S. Wang[5,6], R. Schuch[7], C. Brandau[1], K. Ueberholz[8], R. S. Sidhu[9], M. Tatsch[5,6], A. Biniskos[10], and T. Stoehlker[1,3,4] — [1]GSI, Darmstadt, Germany — [2]Dep. of Physics, Auburn University, USA — [3]HI Jena, Germany — [4]Uni Jena, Germany — [5]I. Physikalisches Institut, Uni Giessen, Germany — [6]HFHF, Giessen, Germany — [7]Dep. of Physics, Stockholm University, Sweden — [8]IKP, Uni Muenster, Germany — [9]School of Physics and Astronomy, University of Edinburgh, UK — [10]Uni Frankfurt am Main, Germany

Dielectronic recombination (DR) is a resonant electron capture process, critical in astrophysical plasmas. At CRYRING@ESR, pure ion beams are stored, cooled, and exposed to a monoenergetic electron beam, enabling high-precision DR measurements at low electron-ion interaction energies. These measurements are vital for understanding cold plasma environments. Neon, among the most abundant cosmic elements, appears in spectroscopic data of various astrophysical objects. We present preliminary results from DR experiments with N-like Ne3+

ions. Ions were injected from an ECRIS, accelerated to 2.23 MeV/u, stored, and electron-cooled in CRYRING with ~6 * 10^6 ions per cycle and ~10 s beam lifetimes. DR spectra were recorded over 0 - 24 eV, revealing strong resonances, especially below 0.5 eV, where rates approach those near the series limit (~24 eV).

Q 47: Cold Molecules and Cold Chemistry (joint session MO/Q)

Time: Wednesday 14:30–16:30 Location: HS XVI

Invited Talk Q 47.1 Wed 14:30 HS XVI

Cold and Controlled Reactive Collisions — •Jolijn Onvlee — Institute for Molecules and Materials, Radboud University, Nijmegen, The Netherlands

What exactly happens during a chemical reaction? Our aim is to investigate fundamental chemical reactions and their underlying dynamics at the full quantum level. To achieve this, we let individual molecules and atoms collide and react with each other in a crossed molecular beam machine.

We can precisely control the velocity and quantum state of a paramagnetic reactant before the collision by using a Zeeman decelerator. After the collision, we accurately probe the reaction products and their velocity vectors using laser-based techniques and velocity map imaging. This powerful combination of techniques allows for scattering experiments with extraordinary resolution.

Here, I will show how we use this approach to investigate the prototypical insertion reaction between excited sulfur atoms and hydrogen molecules in high detail and in unexplored energy regimes. With these experiments, we aim to provide a sensitive test for potential energy surfaces and scattering calculations used to describe the molecular reaction dynamics in this system. This will enable us to deepen our understanding of the intricate dynamics underlying a reaction.

Q 47.2 Wed 15:00 HS XVI

Low-energy collisions between two indistinguishable tritium-bearing hydrogen molecules: HT+HT and DT+DT — •Renat Sultanov — The University of Texas Permian Basin, Odessa, Texas, USA

Elastic and rotational energy transfer collisions between two tritium-containing hydrogen molecules are computed at low- and very low energies, down to ultra-cold temperatures: $T \simeq 10^{-8}$ K. A pure quantum-mechanical approach is applied. A high-quality global six-dimensional potential energy surface (PES) has been appropriately modified and used in these calculations. In the case of the symmetrical $H_2 + H_2$ or $D_2 + D_2$ collisions one can use the original H_4 PES as it is, i.e. without transformations. However, in the case of the non-symmetrical (or symmetry-broken) $HD + H_2/D_2$, $HT + HT$, $DT + DT$ scattering systems one should also apply the original H_4 potential (PES), but propagation (solution) of the Schrödinger equation runs (in this case) over the corrected Jacobi vector [1,2]. Elastic and state-selected inelastic cross sections and corresponding thermal rate coefficients will be presented.

1. R. A. Sultanov, D. Guster, S. K. Adhikari, Phys. Rev. A 85, 052702 (2012).
2. R. A. Sultanov, D. Guster, S. K. Adhikari, J. Phys. B 49 (2016) 015203.

Q 47.3 Wed 15:15 HS XVI

Dual-color microwave-dressing for collisional control in molecular dipolar Fermi gases — •Sebastian Eppelt[1,2], Shrestha Biswas[1,2], Christine Frank[1,2], Xing-Yan Chen[4], Weikun Tian[1,2], Immanuel Bloch[1,2,3], and Xin-Yu Luo[1,2] — [1]Max-Planck-Institute of Quantum Optics — [2]Munich Center for Quantum Science and Technology — [3]Ludwig-Maximilans-Universität — [4]Princeton University

Ultracold polar molecules are a promising platform for the exploration of exotic quantum matter, including topological dipolar p-wave superfluids, thanks to their long-range dipolar interactions. In this talk, we will present our work on microwave-dressing of fermionic ^{23}Na^{40}K molecules. Using a single, circularly-polarized, blue-detuned microwave field we can engineer intermolecular potential, where inelastic and elastic scattering tuneable via field-linked scattering resonance. This resonance is universal for systems with dipolar interactions and arises due to existence of a stable tetratomic bound state which we recently observed and characterized in our experiment. Adding a second, linearly polarized microwave field at a different frequency enables control of the long-range dipolar interaction by tuning the dipole-dipole scattering length. This improves our toolbox for creating ultracold, deeply-degenerate samples of dipolar fermionic molecules, necessary in our quest towards realizing a dipolar p-wave superfluid and beneficial for quantum simulations in optical lattices.

Q 47.4 Wed 15:30 HS XVI

Photoassociation Spectroscopy of RbYb near the Yb intercombination line — •Arne Kallweit — Uni Düsseldorf

Ultracold dipolar molecules constitute a promising system for the investigation of topics like ultracold chemistry, novel interactions in quantum gases, precision measurements and quantum information. Here we report on first experiments in our apparatus for the production of ultracold RbYb molecules. This setup constitutes an improvement of our old apparatus, where the interactions in RbYb and possible routes to molecule production have already been studied extensively. In the new setup a major goal is the efficient production of ground state RbYb molecules. We employ optical tweezers to transport individually cooled samples of Rb and Yb from their separate production chambers to a dedicated science chamber. Here we start to study interspecies interactions of different isotopes by overlapping crossed optical dipole traps. To explore the pathways towards ground state molecules we start with photoassociation spectroscopy near the intercombination line of Yb.

Q 47.5 Wed 15:45 HS XVI

Delta-Kick Collimation of Heteronuclear Feshbach Molecules — •Timothé Estrampes[1,2], Jose P. D'Incao[3,4], Jason. R. Williams[5], Éric Charron[2], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Institut für Quantenoptik, Germany — [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France — [3]JILA, NIST, and the Department of Physics,University of Colorado, Boulder, CO 80309, USA — [4]Department of Physics, University of Massachusetts Boston, Boston, MA 02125, USA — [5]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

Delta-Kick Collimation [Phys. Rev. Lett. 78, 2088 (1997)] is a well-known process in atomic physics that allows to drastically reduce the expansion energy of a cold sample by flashing an external potential during its release. Here, we theoretically explore the extension of this process to cold heteronuclear Feshbach molecules.

We first investigate the validity of neglecting the coupling between the center-of-mass motion and molecular vibrations. After establishing the domain of validity for this approximation, we use scaling approaches to estimate the achievable gains over a large range of temperature and density regimes. For typical external trap paramaters, the expansion energy of a thermal cloud could be reduced by a factor of 100, increasing to over 500 for a heteronuclear condensed molecule.

Q 47.6 Wed 16:00 HS XVI

Laser cooling of barium monofluoride molecules — •Marian Rockenhäuser[1], Felix Kogel[2], Tatsam Garg[1], Jakob Weiss[1] und Tim Langen[1] — [1]TU Wien, Atominstitut, Cold Molecules and Quantum Technologies — [2]Universität Stuttgart, 5. Physikalisches Institut

Barium monofluoride (BaF) molecules are sensitive probes for precision tests of fundamental symmetries. However, due to the high mass, comparatively narrow linewidth, resolved hyperfine structure, and potential branching losses through an intermediate electronic state, this molecular species is notoriously difficult to cool. We will report on the observation of Sisyphus-type forces in transversal cooling of 138BaF and the less abundant bosonic isotopologue 136BaF realizing the first isotopologue-selective laser cooling of molecules. Furthermore, we will discuss our progress towards cooling of the fermionic isotopologue 137BaF which involves optical cycling in a 112 level system. Our results are an important step towards using intense beams of barium monofluoride for precision measurement applications, including searches for the electron's electric dipole moment and nuclear anapole moments. We also expect the results to be useful for cooling other molecular species with complex level structure.

Q 47.7 Wed 16:15 HS XVI

High-flux cold lithium-6 and rubidium-87 atoms from compact two-dimensional magneto-optical trap — •Anwei Zhu[1,2], Yunxuan Lu[1,2], Xinyi Huang[1,2], Chenhao Ni[1,2], and Xinyu Luo[1,3] — [1]Max Planck Institute of Quantum Optics — [2]Ludwig Maximilian University of Munich — [3]Munich Center for Quantum Science and Technology

We report the development of a compact setup for producing Fermi gas of ultracold ^{6}Li^{87}Rb molecules, which integrates two 2D magneto-optical traps in series for each species with a short-distance lithium Zeeman slower. The Zeeman slower enhances the lithium flux by a factor of 50, achieving a high flux of 1×10^{10} atoms/s at a moderate oven temperature of 370 degrees. In addition, the rubidium flux reaches a value of 6×10^8 atoms/s. This advancement paves the way for the rapid production of double-degenerate lithium-rubidium atomic mixtures and large samples of ultracold ground-state fermionic lithium-rubidium molecules, providing a robust platform for investigating dipolar interaction and phase transition in ultracold regime.

Q 48: Poster – Quantum Optics, Technologies, and Optomechanics

Time: Wednesday 17:00–19:00 Location: Tent

Q 48.1 Wed 17:00 Tent

Spatial photon correlations using nearly dead time free ultra-high throughput single photon detection — Verena Leopold[1,2], Sebastian Karl[1], Jean-Pierre Rivet[3], Stefan Richter[1,2], •Iurii Datii[1], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, FAU Erlangen, Germany — [2]Photonscore GmbH, Magdeburg, Germany — [3]Observatoire de la Côte d Azur, Nice, France

Intensity interferometry recently benefitted from the improvements in single photon detection instrumentation. In this talk we present HBT measurements with a new kind of single photon detectors using a micro channel plate photo multiplier tube. The so called LINPix from Photonscore features an integrated constant fraction discriminator and enables a quantum efficiency of greater than 35% at a wavelength of 405 nm. Together with a matching time to digital converter (TDC), LINTag from Photonscore, the detection system is able to operate at ultra-high count rates of up to 100 MHz and at the same time maintains a very high timing resolution <50ps. With this setup, previously tested in the lab, we were able to perform spatial photon correlations of Vega at the C2PU telescope (15m baseline) at the Calern observatory, Nice, France.

Q 48.2 Wed 17:00 Tent

Multiplexing Color Centers in Silicon Carbide for Quantum Networks — •Sushree Swateeprajnya Behera[1,2], NienHsuan Lee[1,2], Jonah Heiler[1,2], Jonas Schmid[1,2], Leonard K.S. Zimmermann[1,2], Flavie Davidson-Marquis[1,2], Stephan Kucera[1], and Florian Kaiser[1,2] — [1]Luxembourg Institute of Science Education and Research (LIST), 4362 Esch-sur-Alzette Luxembourg — [2]University of Luxembourg, 4365 Esch-sur-Alzette, Luxembourg

Color centers in wide-bandgap semiconductors have developed as promising candidates for solid-state quantum emitters. Current experimental setups often rely on complex and resource-intensive cryogenic systems to control individual color centers. To address this challenge, we propose a scalable approach to multiplex divacancy color centers in silicon carbide within a single cryostat. Our strategy involves integrating confocal microscopy and fiber array coupling to efficiently interface multiple color centers with our photonic quantum chips. By leveraging the unique properties of color centers, we aim to implement multiplexed spin-photon entanglement experiments at the interface. This advancement will pave the way for the realization of large-scale quantum networks and quantum communication protocols.

Q 48.3 Wed 17:00 Tent

Custom Shack-Hartmann Sensor for Stellar Intensity Interferometry — •aleena nedunilath thomas, verena leopold, sebastine karl, and joachim von zanthier — AG Quantum Optics and Quantum Information, Friedrich-Alexander Universität Erlangen-Nürnberg, Germany

For stellar intensity interferometric measurements using single photon counting detectors and ultra narrow interference filters it is crucial to monitor the collimation of the wavefront. We therefore introduce a custom Shack-Hartmann wavefront sensor to monitor the collimation of our beam inside the optical setup during the observations at the telescope. The sensor is made of a Thorlabs fused silica microlens array (MLA150-7AR) with square lenslets focusing onto a ZWO ASI CMOS camera. The camera images are analysed using a self-developed software measuring slope deviations and calculating Zernike polynomial coefficients. The software employs a gradient-fitting algorithm optimised for square lenslet arrays, extracting critical lower-order Zernike coefficients. As a direct application for further observations the defocus coefficient was linked to the displacement of the secondary mirror of the telescope. This way the defocus can be directly optimised during the measurements.

Q 48.4 Wed 17:00 Tent

Towards spatial magnetic field mapping with electrodynamically trapped NV center diamonds for quantum technology applications at ambient conditions — •Apurba Das, Deviprasath Palani, Florian Hasse, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg i. Br.

Electro-dynamically trapped micro-diamonds with Nitrogen-Vacancy (NV) center defects offer a suitable platform for fundamental studies. Protected by the diamond crystal, the NV center quantum system can act as a robust quantum sensor for harsh environments. The use of a Stylus Paul trap[1] enhances the accessibility of the trapped systems to external fields, enabling precise control and manipulation of electronic (and motional) degree of freedom. We report our work using trapped micro-diamonds on a Stylus trap for magnetic field mapping, building upon previous works on scanning probe magnetometry. Operating at room temperature and ambient pressure, we use optical trapping techniques to deterministically load diamonds onto the Stylus trap. By customizing the trapping potential, we demonstrate controlled transport of diamonds to specific positions and precise local magnetic field scanning, inspired by prior work with trapped ions[2]. Our work combines nanotechnology's robustness with the precision of AMO physics, advancing scanning probe magnetometry and opening new possibilities for quantum sensing applications at ambient conditions.

[1] R. Maiwald et al, Nat. Phys 5, 551-554(2009)
[2] D. Palani et al, PRA 107, L050601(2023)

Q 48.5 Wed 17:00 Tent

Experiments towards strong coupling in an atom-optomechanical hybrid system — •Felix Klein[1], Jakob Butlewski[1], Alexander Schwarz[2], Klaus Sengstock[1], Roland Wiesendanger[2], and Christoph Becker[1] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

The advancement of modern quantum physics has catalyzed the development of hybrid quantum systems, which combine distinct quantum platforms to leverage their individual strengths. We present our latest results on achieving strong hybrid coupling between a micromechanical Si_3N_4 trampoline resonator and laser-cooled ^{87}Rb atoms. This coupling is mediated via a coherent light field, which reflects off the resonator to form an optical 1D lattice potential for the atoms. The optical losses along the beam path create an asymmetrically pumped lattice, inducing atomic density waves that destabilize the coupling for attractive lattice potentials. Implementing a compensation lattice allowed access to the attractive coupling regime, achieving a maximal cooperativity of $C_{\text{hybrid}} = 100 \pm 25$ at room temperature. Additionally, we incorporated a new high-finesse fiber cavity ($\mathcal{F} = 785$), significantly enhancing the coupling strength and achieving $C_{\text{hybrid}} = 5900 \pm 1300$ at room temperature. Further increasing the cavity finesse to $\mathcal{F} = 14500$ did not yield improvements in coupling strength, aligning with theoretical predictions.

Q 48.6 Wed 17:00 Tent

Remote sensing using an auxiliary quantum system — •Manuel Bojer[1], Jörg Evers[2], and Joachim von Zanthier[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Quantum Optics and Quantum Information, Staudtstr. 1, 91058 Erlangen, Germany — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

A key goal in the recently fast developing field of quantum sensing is the extraction of information about physical quantities with high precision using quantum features. Many different platforms or realisations of quantum sensors exist. A particular branch focuses on sensing tasks assisted by auxiliary systems, which aid for overcoming classical precision limits. In this work, we use the combined signal of a system of interest and a remote system, entangled with each other via measurements, to extract information that is otherwise difficult to access. The entire system consists of three identical atoms, where two atoms, representing the system of interest, are assumed to be close to each other such that they interact via the dipole-dipole interaction while the third atom is located at a distance $d \gg \lambda$ (with λ the atomic transition wavelength). Although the distant third atom does not directly interact with the collective two-atom subsystem, it can be used to alter the total systems emission properties via measurement-induced entanglement. We present different detection schemes employing Glauber's third-order photon correlation function to extract important parameters such as the separation d (with potentially $d \ll \lambda$) or the initial state of the two-atom subsystem.

Q 48.7 Wed 17:00 Tent

Identifying error sources of dipole-dipole coupling mediated two-qubit gates between NV-centers in diamond — •Florian Ferlemann[1,3], Timo Joas[2], Roberto Sailer[2], Philipp Vetter[2], Genko Genov[2], Fedor Jelezko[2,4], Ressa Said[2], Tommaso Calarco[1,3,5], and Matthias Müller[1] — [1]Peter Grünberg Institute - Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, 52428 Jülich, Germany — [2]Institute for Quantum Optics, Ulm University, 89081 Ulm, Germany — [3]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany — [4]Center for Integrated Quantum Science and Technology (IQST), Ulm University, 89081 Ulm, Germany — [5]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

To create a large spin register in diamond realizing a good entangling gate between NV centers can be crucial. Even though entanglement between a pair of NV centers has been observed, high two qubit gate fidelities have not yet been demonstrated. We investigate at which conditions the latter can be realized with a pair of NV centers at room temperature, taking into account that their axes are misaligned and the nuclear spins are non-initialized. We analyze the behavior of the gate errors under different Rabi frequencies and identify the error sources that limit the single-qubit and two-qubit gate fidelities, where we explicitly study the influence of the nitrogen nuclear spins on the two-qubit gates under dynamical decoupling sequences. In this context we demonstrate high two-qubit gate fidelities.

Q 48.8 Wed 17:00 Tent

Pure single-photon generation using pulsed SPDC in a monolithic cavity — •Xavier Barcons Planas[1,2], Helen M. Chrzanowski[2], Leon Messner[2], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Institute of Optical Sensor Systems, German Aerospace Center, Berlin, Germany — [3]Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Germany

Entangled states of multiple photons are essential for advancing the capabilities of photonic quantum technologies. The generation of large multi-photon entangled states requires light sources that provide highly pure photons with high efficiency (either deterministic or heralded), as these factors limit scalability. A common method is to herald single photons from photon-pair sources based on spontaneous parametric down-conversion (SPDC). While the multimode spatial and spectral nature of SPDC emission can constrain the heralding efficiency and purity, engineering techniques such as waveguide geometries [1], group velocity matching [2], and cavity resonators [3] can refine the output to exhibit single-mode behaviour. Here, we present a narrowband (170 MHz) single-photon source at the C-band based on pulsed SPDC in a monolithic crystal cavity. Pure and fiber-compatible single photons have been generated with 85% heralding efficiency.

[1] A. Christ *et al.*, Phys. Rev. A **80**, 033829 (2009)
[2] P. J. Mosley *et al.*, Phys. Rev. Lett. **100**, 133601 (2008)
[3] R. Mottola *et al.*, Opt. Express **28**, 3159 (2020)

Q 48.9 Wed 17:00 Tent

Click boson sampling — •Sitotaw Eshete, Torsten Meier, Polina Sharapova, and Jan Sperling — Paderborn University, Paderborn, Germany

Linear optical networks are essential building blocks for developing commercially accessible quantum technologies. Our work's primary objective is to approximate the permanent computation in boson sampling using cutting-edge click detection systems, which are used for both input state and network-output detection. Each input mode's click detectors herald multiphoton states, which are produced by parametric down-conversion sources. Then, the output click-counting distribution can be expressed as a linear combination of determinants of certain coefficient matrices that are based on the unitary network matrix together with additional parameters that are pertinent to the detection system. To get close to the precise value of the desired permanent, an exponentially growing number of these determinants must be calculated.

Q 48.10 Wed 17:00 Tent

3D printed microstructures for scalable coupling of SNSPDS on wafers — •Stefan Vorwerk[1], Johanna Biendl[1,2], Frederik Thiele[1,2], and Tim Bartley[1,2] — [1]Department of Physics, Paderborn University — [2]Institute for Photonic Quantum Systems

Due to their outstanding properties, such as a broad spectrum, low dark count rates, and high efficiency, SNSPDs have become the leading technology for single-photon detection. For achieving near unity detection efficiency with SNSPDs, low-loss coupling from the fiber to the detector must be ensured. For single-pixel devices, this is readily achieved using self-aligning zirconia sleeves. Nevertheless, this requires a deep-etch into the substrate, which may be detrimental or impossible in some substrates, and limits the packing density of detectors. We are exploring alignment techniques on arbitrarty substrates and wafers. To enhance coupling efficiency, we fabricate 3D printed nanostructures using 2-photon polymerization to align the fiber with the detector and provide mechanical stability. It is also possible to integrate additional optics, such as lenses or tapers, into the 3D printed structure. For an optimized fabrication process and the characterization of the printed structures, we investigate the optical properties and the mechanical stability of the polymer at cryogenic temperatures and test different coupler designs.

Q 48.11 Wed 17:00 Tent

Increasing the Efficiency of Microwave Coupling to NV Centers from Microstrip Transmission Lines — •Dennis Stiegekötter[1], Jens Pogorzelski[1], Ludwig Horsthemke[1], Frederik Hoffmann[1], Ann-Sophie Bülter[1], Markus Gregor[2], and Peter Glösekötter[1] — [1]FH Münster, Department of Electrical Engineering and Computer Science, Steinfurt, Germany — [2]FH Münster, Department of Engineering Physics, Steinfurt, Germany

Quantum technologies often rely on microwaves to excite electron spin state transitions. In the application of, e.g., magnetic field sensors or mobile experiment kits [1], a high MW intensity is needed and results in bulky signal sources. The required power of the source can be reduced by an optimal coupling and high return loss of the transmission line to the MW antenna close to the diamond sample. This study focuses on an efficient change of the electron spin state in nitrogen-vacancy (NV) centers in diamond using microstrip line structures. To enhance the effectiveness of this excitation, we aim to increase MW field intensity by optimizing the substrate thickness and adjusting the current density within the microstrip line. The challenge with the identified microstrip line is its deviation from the 50 Ω waveguide impedance, leading to microwave reflections. To circumvent this issue, a three-stage quarter-wave transformer is utilized, ensuring broadband matching to a 50 Ω network and minimizing reflection losses. [1] Stegemann, J.*et al.*Modular low-cost 3D printed setup for experiments with NV centers in diamond.*European Journal of Physics*44, 035402 (2023).

Q 48.12 Wed 17:00 Tent

Dynamics of optically levitated nanoparticle arrays — •Artur Bichs[1], Uroš Delić[2], and Benjamin A. Stickler[1] — [1]Institute for Complex Quantum Systems, Ulm University — [2]Vienna Center for Quantum Science and Technology, University of Vienna,

Optically levitated nanoparticles offer a promising platform for high-precision sensing and for exploring quantum physics with massive objects. Here, we study the dynamics of tweezer-levitated nanoparticles coupled via optical binding and via coherent scattering into a common cavity mode. We derive the corresponding quantum master equation for the joint nanoparticle array-cavity dynamics, study the linearized dynamics for two and three particles, and discuss implications for sensing and entanglement observations.

Q 48.13 Wed 17:00 Tent

Developing a database for UHV and XUHV suitable materials for use in quantum technologies — •Vanessa Galbierz[1], Pascal Engelhardt[1,2], Simone Callegari[1,3], Constantin Nauk[1,2], Benjamin Kraus[1], and Piet Schmidt[1,2] — [1]Physikalisch Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz University Hannover, 30167 Hannover, Germany — [3]currently with: VAT Vakuumventile AG, 9469 Haag, Switzerland

The lifetime and coherence time of atomic quantum systems is often limited by the achievable vacuum background gas pressure. Room-temperature vacuum systems reaching 10e-11 mbar can be easily built using mostly standard, off-the-shelf parts. However, this typically changes when the system is equipped with all components for a working in-vacuum experiment, such as ion-based optical clocks and quantum computers. Introduced materials can severely limit the achievable pressure. In addition, the outgassing behavior of new types of materials and parts produced with innovative methods, such as additive manufacturing, is often not yet known. We present a strategy to identify, measure and classify potentially suitable materials and their outgassing behavior to assess their suitability for use in UHV and XUHV. In this context, we introduce our two vacuum test benches, explain the measurement and evaluation methods used and show the first results of an emerging material database, which aims to provide standardized outgassing data for materials of different categories.

Q 48.14 Wed 17:00 Tent

SPDC photon pair source for Quantum Random Walk Application on an integrated quantum photonic processor — •Christoph Engelberg, Jonas Philipps, Evelyn Kimmerle, and Florian Elsen — Chair for Laser Technology, RWTH Aachen University

Photonic quantum computing (PQC) is emerging as a promising approach to quantum computing due to photons' near-decoherence-free nature, room temperature operation and high-precision manipulation. One crucial component for PQC are quantum light sources, which can be realized by spontaneous parametric down-conversion (SPDC) photon pair sources. A key requirement for such sources is a high indistinguishability of the photons.

In this work, an SPDC photon pair source at telecom wavelength is set up and characterized with an on-chip integrated quantum photonic processor (QPP). Furthermore, its practical suitability and performance for a potential use in the field of PQC is confirmed. By further performing spectral filtering, a Hong-Ou-Mandel (HOM) interference visibility of 98.41% was achieved. A high indistinguishability of the photons is thereby shown.

A possible PQC application are quantum random walks (QRWs) on a QPP, where a pair of indistinguishable photons is passed through a linear optical network. In a future step, this photon pair source will be used to experimentally and simulatively investigate the influence of the source properties on the performance of QRWs.

Q 48.15 Wed 17:00 Tent

Efficient Method for Selectively Loading Dielectric Nanoparticles onto Optical Tweezers in a Vacuum — •Luana Rubino[1,2], Zijie Sheng[1,2], Seyed Khalil Alavi[1,2], Moosung Lee[1,2], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Stuttgart, DE — [2]Center for Integrated Quantum Science and Technology (IQST), University of Stuttgart, Stuttgart, DE

Quantum levitodynamics is the field of research that studies the quantum motion of mesoscopic objects levitated, e.g., in optical tweezers. In this field, the so-called spraying method is conventionally used to load the particle to an optical trap stochastically, limiting the efficiency and selectivity of the trapping. To address this, we are developing an efficient method for selectively loading nanoparticles into an optical tweezer. This approach involves first selectively imaging the particles on a surface and then loading them into an optical tweezer, enabling the trapping only the particle of interest. The loading process is achieved through vibration-induced acceleration, which allows particles to be efficiently shoot into the tweezer. We present our recent progress toward achieving this goal.

Q 48.16 Wed 17:00 Tent

Evolution of correlations in superfluorescent bursts — •Yoan Spahn, Thomas Halfmann, and Thorsten Peters — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany

We experimentally study correlations in superfluorescent bursts emitted by a dilute, disordered ensemble of atoms inside a hollow-core fiber. Starting from an initially inverted effective two-level system, we measure the temporal evolution of the second-order coherence function of the light emitted into the waveguide mode. By varying the number of atoms as well as the decay rate, we are able to study correlations below and above threshold to collective emission. Tuning our system from individual to collective emission in the regime of multiple optical bursts, we observe a clear evolution of correlations between consecutive bursts.

Q 48.17 Wed 17:00 Tent

Design of a decorrelated PDC source at telecom wavelenghts in TFLN waveguides — •Ernst-Lukas Kuhlmann, Silia Babel, Laura Bollmers, Werner Ridder, Christian Golla, Sebastian Lengeling, Christof Eigner, Laura Padberg, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

Integrated quantum optics plays a key role in communication and computation and its most fundamental building block are single photons. A promising material platform for photonics in this field is thin-film lithium niobate (TFLN). While integrated optics in conventional lithium niobate profit from its wide transparency window and high nonlinearity, its application in a thin-film configuration additionally encompasses the potential for high conversion efficiencies due to large mode confinement. Therefore, TFLN is an excellent platform for the integration of photon pair sources. Here, we explore the use of periodically poled, MgO-doped TFLN for decorrelated type II parametric down-conversion(PDC) single photon telecom C band wavelength sources with a 0-degree phase matching angle. This offers the advantage to create pure signal photons in arbitrary temporal shapes. We examine the necessary geometry parameters for such a PDC source and the influence of these parameters on the spectral shape. Moreover, we discuss possibilities to reconstruct it with adaptive poling or by tapering the waveguide width. With this work, we aim to contribute to the development of more efficient and accessible quantum light sources.

Q 48.18 Wed 17:00 Tent

Mølmer-Sørensen Gates Robust to AC Shifts — •Erin Feldkemper — Institut für theoretische Physik, Leibniz Universität Hannover

In the past years the implementation of quantum gates has increased significantly. With the growing interest on fast and high-fidelity quantum gates, the interest in the optimization of these has grown as well. One of the key challenges is mitigating the AC Stark or Zeeman shift, which can arise in both laser-driven and microwave-driven gates, introducing errors which degrade the performance.

In this work, we focus on microwave-driven Mølmer-Sørensen gates and use the Magnus expansion in order to analyze the impact of the AC Zeeman shift on the gate performance. Starting from the full system Hamiltonian, we derived an effective Hamiltonian which includes the leading-order corrections induced by the AC Zeeman shift. This effective model was used for numerical simulations in order to validate the approximations made in the derivations and to gain insights into the gate*s fidelity and coherence properties. Here Kraus operators were implemented for the evaluation of the fidelity, while the von Neumann entropy was used to quantify entanglement and coherence degradation.

The control parameters can be optimized based on a cost function derived from the Magnus expansion. This optimization aims to further reduce the impact of the AC Zeeman shift and enhance gate fidelity.

Q 48.19 Wed 17:00 Tent

Zerovak: Compact and portable vacuum and laser system technology for cold atom experiments — •Nora Bidzinski[1], Bojan Hansen[1], David Latorre Bastidas[2], André Wenzlawski[2], Patrick Windpassinger[2], Ortwin Hellmig[1], and Klaus Sengstock[1] — [1]Institute for Quantum Physics, University of

Hamburg, 22761 Hamburg, Germany — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany

Performing ultra cold atom experiments outside a laboratory environment such as mobile platforms or space applications requires a compact and energy-efficient experimental setup.

Hence, we present a novel flange-free ultra-portable vacuum chamber without the necessity of an active getter pump. Choosing Zerodur, a glass ceramic with low helium and hydrogen permeability as well as very low thermal expansion coefficient, ensures maximum stability against thermal fluctuations due to environmental changes.

Further, we propose a compact and highly miniaturised laser system for cooling atoms including a method for substituting AOMs while maintaining full functionality.

Q 48.20 Wed 17:00 Tent

Towards standardized characterization of ion traps for industry and research — •Martin Hesse[1,3], Jan Kiethe[1], André Kulosa[1], Max Glantschnig[1,2,3], Christian Flasch[1,2,3], Nicolas Spethmann[1], and Martin Hesse[1,3] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Leibniz Universität Hannover, Hannover, Germany

Ion traps have evolved to be a mature technology for applications in quantum sensing and quantum computing. As this technology transforms from research objects into industrial applications, manufacturers require standardized comparisons of their quantum technology (QT) components to maintain worldwide competitiveness and strengthen their industrial development cycles. Here, the Quantum Technology Competence Center (QTZ) at PTB serves as a national hub to support German industry partners in the evaluation of their QT components.

Being one of the pillars of the QTZ, the user facility *Ion traps* offers an experimental testbed for the characterization of ion traps from academia and industry. This setup provides fully automated experiment control enabling user friendly operation for standardized measurement routines. As part of the European *Qu-Test* project we developed a data sheet for the characterization of ion traps in collaboration with Infineon Technologies Austria AG. This document summarizes the specifications of the ion traps under test for industry requirements and serves as a suggestion towards standardized benchmarking of ion traps.

Q 48.21 Wed 17:00 Tent

Prototype Cell Design for NV Based Current Monitoring of Zinc-Air Batteries — •Ghulam Raza[1], Juan Manuel Alvarez Cisneros[1], Jonas Homrighausen[1], Jan-Ole Thranow[2], Felix Winters[2], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Muenster. — [2]Department of Electrical Engineering and Computer Science, FH Muenster.

Zinc-air batteries are an attractive energy storage technology due to their high energy density, environmental friendliness, and cost-effectiveness. They are based on electrochemical reactions between zinc and oxygen from air offering a promising alternative to lithium-ion batteries. The addition of quantum sensors enable huge potential in monitoring internal dynamics of these batteries.

In this work we present a possible zinc-air battery cell design suitable for quantum sensors based on microdiamonds containing NV centers.The cell includes a zinc anode, nickel and gas discharge sheets for charging and discharging, and a KOH aqueous electrolyte. Additionally, it features an optical access to monitor the cell dynamics.

Q 48.22 Wed 17:00 Tent

Simultaneous Three Component Magnetometry Using NV Centers for Applications in Power Distribution Networks — •Frederik Hoffmann[1], Ann-Sophie Bülter[1], Ludwig Horsthemke[1], Jens Pogorzelski[1], Markus Gregor[2], and Peter Glösekötter[1] — [1]Dept. Electrical Engineering and Computer Science, FH Münster — [2]Dept. Engineering Physics, FH Münster

This poster presents a concept for current measurement in low and medium voltage power distribution networks. For current measurement, the concentric magnetic field around the current-carrying conductor can be measured using a nitrogen-vacancy quantum magnetic field sensor [1]. A bottleneck in current measurement systems is the readout electronics, which is usually based on optically detected magnetic resonance (ODMR) [2]. A new concept is presented here that tracks up to four resonances simultaneously for the detection of the three axis magnetic field components and the temperature. The electronics is based on FPGA (Red Pitaya). For this purpose, a plug-on board has been developed that allows to control the excitation laser, the generation of the microwaves, interfacing the photodiode and provides additional fast digital outputs.

[1] Pogorzelski, J., Horsthemke, L., Homrighausen, J., Stiegekötter, D., Gregor, M., & Glösekötter, P. (2024). Compact and Fully Integrated LED Quantum Sensor Based on NV Centers in Diamond. Sensors, 24(3), 743. [2] Schloss, J., Barry, J., Turner, M., & Walsworth, R. (2018). Simultaneous Broadband Vector Magnetometry Using Solid-State Spins. Phys. Rev. Appl., 10, 034044.

Q 48.23 Wed 17:00 Tent

An economic cryostat for quantum optical experiments — •Max Masuhr, Hazem Hajjar, Bo Deng, Babak Behjati, Kathrin Schumacher, and Daqing Wang — Institut für Angewandte Physik, Universität Bonn, Bonn, Germany

Many quantum optical experiments are susceptible to vibrations caused by the helium compression cycle in the cryostat, necessitating delicate vibration isolation designs. Here, we present the mechanical and electrical construction of a low-cost custom cryostat built around a commercial cold head that mitigates vibrations while allowing full access for quantum optical experiments. The cryostat houses a sample space, which includes a high-numerical-aperture lens for imaging single organic dye molecules. Utilizing the tandem displacement of the sample and the objective, vibrational effects on measured optical images are reduced. The design of this cryostat could be interesting for an extended range of quantum optical experiments on solid-state samples.

Q 48.24 Wed 17:00 Tent

Feedback cooling of levitated nanoparticles based on single photon detection — •Luis Kunkel Garcia, Henning Rudolph, and Klaus Hornberger — University of Duisburg-Essen, Faculty of Physics, Lotharstraße 1, 47057 Duisburg, Germany

Recent experiments demonstrate groundstate cooling of optically levitated nanoparticles by combining efficient homodyne detection of the scattered light with feedback [1,2]. Here, we theoretically analyze a scheme to optimally cool smaller nanoparticles into the quantum regime, provided that only single photon detection events of the scattered light intensity are available. The measurement rate then depends only on the square of the particle coordinate. This requires a Bayesian analysis of the entire history of the photon counts, in combination with a stochastic choice of the feedback force. We estimate the attainable temperature under realistic assumptions concerning the detection efficiency and dark count rates.

[1] Magrini et al., Real-time optimal quantum control of mechanical motion at room temperature. Nature 595, 373 (2021)

[2] Tebbenjohanns et al., Quantum control of a nanoparticle optically levitated in cryogenic free space. Nature 595, 378 (2021)

Q 48.25 Wed 17:00 Tent

Investigation of the role of pump noise on the generation of nonclassical light from optical parametric oscillators — •Sopio Bregadze, Roger A. Kögler, and Oliver Benson — Humboldt-Universität zu Berlin, Institut für Physik, Newtonstraße 15, 12489, Berlin, Germany

Photonic quantum technologies rely on nonclassical states of light, such as squeezed and Fock states. Optical parametric oscillators (OPOs) are widely used for the generation of such states, leveraging enhanced light-matter nonlinear interactions through optical feedback. A typical configuration consists of a bulk nonlinear medium place inside an optical cavity. In order to determine the OPO output state, the dynamics of an open quantum system must be analysed. Here, we numerically solve the equations of motion derived from a master equation formalism, and calculate the state covariance matrix. We present results for OPOs based on degenerated parametric down conversion operating below oscillation threshold. The impact of excess pump noise on the generated states is investigated, with focus on their squeezing levels and purity. The obtained results are compared with current experimental devices dedicated for the generation of single-mode vacuum squeezed states.

Q 48.26 Wed 17:00 Tent

Fiber-Cavity Enhanced Photon Emission from Defect Centers in hBN — •Manuel Stetter, Patrick Maier, and Alexander Kubanek — Institute for Quantum Optics, University Ulm, Germany

Realization of quantum photonic devices requires coupling single quantum emitters to the mode of optical resonators. We present a hybrid system consisting of a defect center in a hexagonal boron nitride (hBN) nanoparticle and a fiber-based Fabry Pérot cavity. Signal enhancement and strongly narrowed linewidths are achieved, which is owing to cavity funneling.

Q 48.27 Wed 17:00 Tent

Cavity enhanced free-electron-photon coupling in the recoil regime — •Nils Bode[1], Zhexin Zhao[1], Julian Litzel[1], Tomáš Chlouba[2], Manuel Konrad[1], and Peter Hommelhoff[1,3] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Center for Nanophotonics, NWO-Institute AMOLF, 1098 XG Amsterdam — [3]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

The fundamental role of integrated photonics in the recent advances of optical communication, biomedical applications, sensors, spectroscopy and quantum technologies has proven its versatility in various fields. Leveraging the possibilities of regular and metamaterial optical waveguide technology, we present simulations of the quantum interaction of low energy free electrons with cavity photons designed for the recoil regime. This regime is of special interest as the effects associated with the electron's recoil allow the construction of novel photonic states like deterministic single photon states, Greenberger-Horne-Zeilinger (GHZ) states, NOON states, squeezed vacuum, twin beams and many more. We further provide theoretical upper bounds for the free-electron-photon coupling for different materials and electron energies at various impact parameters. These upper bounds can be used to put the performance of simulated structures into perspective and validate the feasibility of proposed state construction schemes.

Q 48.28 Wed 17:00 Tent

Exploiting NV Center Spin Dynamics for Low-Temperature All-Optical Thermometry — •Jonas Homrighausen[1], Matthias Hollmann[1], Ludwig Horsthemke[2], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Münster — [2]Department of Electrical Engineering and Computer Science, FH Münster

The nitrogen vacancy center in diamond has been established as a promising tool to conduct temperature measurements down to the nanoscale for biomedical applications, microelectronics and material analysis. The protocols typically rely on either the spin-dependent fluorescence of the NV quantum system, manipulated by microwave frequencies [1], or the prominence of the zero-phonon line in the fluorescence spectrum [2]. The latter, all-optical approach however is sensitive to fluctuations in the fluorescence intensity and relies on spectral analysis, increasing the complexity.

Here, we explore an all-optical approach that avoids microwave-based spin manipulation and reduces susceptibility to intensity fluctuations. This method exploits the temperature dependent spin dynamics of the NV ground state in bulk material. We assess sensor performance as a temperature probe and discuss the sensitivity of this method. These advancements promise robust and reliable temperature measurements in harsh environments and offer seamless integration into all-optical NV magnetometers.

[1] Fujiwara, M. *et al. Sci. Adv.* **6**, eaba9636 (2020).
[2] Fukami, M. *et al. Phys. Rev. Appl.* **12**, 014042 (2019).

Q 48.29 Wed 17:00 Tent

Towards video-rate vector magnetometry based on polarimetric optically detected magnetic resonance — •Tofianme Sorgwe[1], Philipp Reuschel[1], Florian Sledz[1], Mario Agio[1,2], and Assegid Flatae[1] — [1]Laboratory of Nano-Optics, University of Siegen, 57072 Siegen, Germany — [2]National Institute of Optics (INO), National Research Council (CNR), 50019 Sesto Fiorentino, Italy

Vector magnetometry has various applications in navigation systems, precision metrology, and life sciences. Recently, optically detected magnetic resonances (ODMR) based on negatively charged nitrogen-vacancy (NV^-) color centers in diamond have been developed as a platform for magnetic sensing. However, most approaches require knowledge of the crystal axes and need an external magnetic bias field to measure the field's orientation or they rely on the use of single NV^- centers and require volumetric data sets. Here, we show vector magnetometry based on polarometric ODMR on ensembles of NV^- color centers without bias field [1]. By avoiding the complex dataset, we will be able to reach fast data acquisition, with implications for video-rate vector magnetometry.

[1] Philipp Reuschel, Mario Agio, and Assegid M. Flatae. Vector magnetometry based on polarimetric resonance. Advanced Quantum Technologies, 5 2022000777 (2022).

Q 48.30 Wed 17:00 Tent

Quantum interference in a Ti:LiNbO3 waveguide device as a tool for spectral shaping — •Jonas Babai-Hemati, Kai Hong Luo, Patrick Folge, Sebastian Lengeling, Philipp Mues, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

By exploiting optical interference, breakthroughs in research and metrology could be achieved. Traditional interferometers rely only on classical linear optical components, and therefore cannot benefit from quantum nature of light. Interferometers based on nonlinear optical components can utilize this potential by interference of quantum processes. This can lead to improved metrology properties and opens new possibilities in quantum state engineering. However, a free-space-based interferometer setup comes with challenges in stability and lacks scalability. To investigate the capability in state engineering of a fully integrated quantum interferometer, we fabricated an SU(1,1) like Ti:LiNbO3 waveguide based quantum interferometer device. The single waveguide structure is composed of two parametric down-conversion (PDC) sections separated by phase shifters (PS) and polarization converters (PC). With these modulators, the spectral shape of the quantum state resulting from the PDC-PDC interferences can be actively tailored. By theoretical and experimental study of this device, we explore the frame of tailorable states.

Q 48.31 Wed 17:00 Tent

Desorption-induced decoherence of nanoparticle motion — •Jonas Schäfer[1], Benjamin A. Stickler[2], and Klaus Hornberger[1] — [1]Faculty of Physics, University of Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany — [2]Institute for Complex Quantum Systems, Ulm University - Albert-Einstein-Allee 11, D-89069 Ulm, Germany

Levitated nanoparticles are well suited for sensing applications and fundamental tests of quantum theory [1,2]. Their center-of-mass motion can be prepared in the ground state [1] and future experiments will probe the quantum regime of their rotation dynamics [3]. Motivated by these experimental advances, we present the master equation describing the impact of desorption on their ro-translational quantum state. The Lindblad operators, which can be related to the local flux of desorbates from the particle surface, account for both the momentum and angular momentum kicks, as well as for the information contained in the anisotropy of the desorbate flux. For well localized states the dynamics can be characterized by a matrix of diffusion tensors (and a photophoretic force), known from classical treatments [4].

[1] Gonzalez-Ballestero, Aspelmeyer, Novotny, Quidant, and Romero-Isart, Science 374, eabg3027 (2021)
[2] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589-597 (2021)
[3] Gao, van der Laan, Zielińska, Militaru, Novotny and Frimmer, PRR 6, 033009 (2024)
[4] Martinetz, Hornberger, and Stickler, PRE 97, 052112 (2018)

Q 48.32 Wed 17:00 Tent

Robust and miniaturized Zerodur based vacuum systems for quantum sensing applications — •David Latorre Bastidas[1], Sören Boles-Herresthal[1], Nora Bidzinski[2], Bojan Hansen[2], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], and Patrick Windpassinger[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz — [2]Institute for Quantum Physics, Universität Hamburg

In recent years, quantum sensing technologies based on cold atoms have been proposed to solve existing problems in science and industry. To enhance the accessibility and robustness of these systems, we propose using Zerodur in the vacuum system. Zerodur is a glass ceramic with a negligible coefficient of thermal expansion (CTE), high mechanical strength, and low helium permeability, making it an ideal candidate for vacuum chambers. Its non-magnetizable and non-conductive properties allow for embedded wire structures within the vacuum chamber walls, enabling the generation of arbitrary 3D magnetic fields with high quality and minimal disturbances for atom cooling and trapping.

This poster focuses on the development of a passively pumped, stand-alone Zerodur vacuum chamber for quantum sensing applica-

tions, with an initial objective of demonstrating a MOT in a compact, shoebox-sized system. The chamber integrates non-evaporable getters and alkali metal dispensers activated by UV light. This system approach sets the foundation for future compact quantum sensors, offering significant potential for practical, real-world applications.

Q 48.33 Wed 17:00 Tent

Realization of adaptive poling in thin-film lithium niobate waveguides — •Tobias Babai-Hemati, Laura Bollmers, Michael Rüsing, Laura Padberg, and Christine Silberhorn — University of Paderborn, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn

Quantum technologies rely on internal quantum networks. As a result, all components- such as storage, fiber, and sensors- require frequency converters to handle the differences in frequencies.

In this work, the chosen platform is thin-film lithium niobate (TFLN). It has large nonlinear properties and a high effective refractive index contrast with SiO_2. In TFLN, we realize frequency conversion with quasi-phase matching which is the periodic inversion of the crystal structure using an electric field. However, phase matching in TFLN waveguides is highly sensitive to variations in thin-film thickness of lithium niobate. We present a realization of adaptive poling (locally adapted periods) in TFLN to compensate for this effect. First, we measured the thin-film thickness profiles of a MgO-doped TFLN sample. Then, we simulated the corresponding poling periods, fabricated the devices, and poled with an electric field.

The poling results show that slight changes in the poling period do not significantly affect the homogeneity of the poled area with a single voltage pulse. In conclusion, this could allow for more efficient on-chip frequency conversions.

Q 48.34 Wed 17:00 Tent

Loss Analysis of a Massively Multiplexed Superconducting Nanowire Photon-Number-Resolving Detector — •Isabell Mischke[1], Timon Schapeler[1,2], Fabian Schlue[2,3], Michael Stefszky[2,3], Benjamin Brecht[2,3], Christine Silberhorn[2,3], and Tim J. Bartley[1,2] — [1]Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [2]Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [3]Integrated Quantum Optics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

Intrinsic photon-number resolution (PNR) has been shown by analyzing the rising edge of superconducting nanowire single-photon detector (SNSPD) electrical signals, which leads to easy accessibility of photon-number resolved measurements. Nevertheless, the overlap of the underlying distributions for different photon numbers limits the number of resolvable photons per SNSPD up to a few photons. Our work scales PNR up to thousands of photons by combining the intrinsic PNR of SNSPDs with temporal and spatial multiplexing. Specifically, we use eight spatial bins with 128 temporal bins each, for a total of 1024 bins. Each bin can resolve up to at least five photons. With detailed data analysis, the losses per bin can be calculated to determine the efficiency of the system and to increase the understanding of its behavior. This knowledge will enable further investigations of the multiplexing system in the future.

Q 48.35 Wed 17:00 Tent

Using a Microfabrication Platform for Direct Laser Writing of NV-Centers and Optical Interfacing on Diamond — •Marina Peters[1], Jonas Homrighausen[1], Ghulam Raza[1], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Münster — [2]Department of Electrical Engineering and Computer Science, FH Münster

Nitrogen-vacancy (NV) centers in diamond have proven to be an important resource for applications such as quantum computing and quantum sensing. The precise, deterministic placement of NV centers and their reliable optical coupling is of particular importance. Direct laser writing (DLW) of NV centers in diamond enables high spatial placement control with minimal damage to the lattice [1].

Here we investigate the potential of fabricating NV centers by femtosecond laser pulse treatment using a commercially available microfabrication platform. This offers the opportunity to integrate multiple fabrication processes into a single workflow: precise surface marking for alignment and referencing, the generation of a pattern of NV centers within the diamond lattice, and the fabrication of micro-optical components such as microlenses and waveguides on the diamond substrate for efficient fluorescence extraction and packaging.[2] This approach has the potential to simplify the production and improve the scalability of highly integrated diamond-based quantum devices.

[1] Chen, Y.-C. et al. Optica 6, 662667 (2019). [2] Bogucki, A. et al. Light Sci. Appl. 9, 48 (2020).

Q 48.36 Wed 17:00 Tent

Manufacture high-finesse fiber Fabry-Perot cavities for quantum information processing — •Johannes Berger[1], Matthias Michalek[1], Constantin Grave[1], Isabelle Safa[1], Marvin Holten[1], and Julian Leonard[1,2] — [1]TU Wien, Atominstitut, Vienna Center for Quantum Science and Technology (VCQ), Vienna, Austria — [2]Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria

Fiber Fabry-Perot cavities (FFPCs) are integral to numerous scientific and technological applications, such as cavity quantum electrodynamics experiments, tunable optical filters, cavity-based spectroscopy of gases and many more. Our team has established an advanced, automated fabrication system for creating curved mirrors on the endfacets of optical fibers. The curvature is precisely formed with a CO2 laser, while the reflective coating is applied externally. By using an acousto-optic modulator (AOM), the beam pulse can be manipulated as required to improve the desired fiber ablation. In our setup, white light interferometry is incorporated to monitor and measure the created profile throughout the production process, allowing for iterative optimization. This approach aims to produce high finesse cavities, which are essential for many quantum simulation setups like the currently build setup of our group, that uses an tweezer-loaded array of neutral atoms inside a FFPC.

Q 48.37 Wed 17:00 Tent

Design and characterization of a laser system for airborne gravimetry — •Alisa Ukhanova[1], Julia Pahl[1], Markus Krutzik[1,2], and the AeroQGrav team[1,3,4,5,6,7,8,9] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut (FBH), Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]LUH, Hannover — [4]DLR, Hannover — [5]TUB, Braunschweig — [6]BKG, Leipzig — [7]TUC, Clausthal — [8]Geo++ GmbH, Garbsen — [9]iMAR Navigation GmbH, Ingbert

The *AeroQGrav* project strives to demonstrate a long-term stable air-born gravimeter, with a higher spatial and temporal resolution and a better long-term stability compared to the existing commercial solutions.

We develop the compact and robust modular flight laser system. Three modules will provide the light fields for laser cooling of 87Rb atoms in 2D- and 3D-magneto optical traps, Raman interferometry, and state detection during the flight. This poster explains our design and assembly, presents results of characterization and outlines requirements caused by the aircraft conditions.

This project is supported by the VDI Technologiezentrum GmbH with funds provided by the Federal Ministry of Education and Research (BMBF) under grant number 13N16518.

Q 48.38 Wed 17:00 Tent

Industrial clock laser system for quantum applications with fractional frequency instability below 6E-16 at 1 s — •Dewni Pathegama, Filippo Bregolin, and Florian Schäfer — TOPTICA Photonics AG, Lochhamer Schlag 19, 82166, Graefelfing (Munich), Germany

In recent years, there has been an increasing demand for industries to provide compact laser systems with robust design and minimal operational oversight. For quantum computing and optical clocks, coherence times of up to one second are required, corresponding to a fractional frequency instability below 2E-15 for averaging times between 0.1 s and 100 s.

Here we present the latest results from TOPTICA transportable, rack mounted ultra-stable clock laser system. We confirm that our laser system meets these criteria by comparing it against two reference lasers via an optical frequency comb and a frequency counter. We measure an absolute fractional frequency instability of 6E-16 between 0.1 s and 10 s averaging time (modified Allan deviation, lambda counting, 10 ms gate time), and a linear drift of < 150 mHz/s over two days. For averaging times below 10 ms (shorter than the minimum gate time of the counter), we use delayed self-heterodyne method.

To understand the physical limits of the system, we characterise the effect of seismic and acoustic vibrations, optical power fluctuations, and fiber noise on the instability. In conclusion, we confirm that our clock laser system is a suitable system for quantum applications in the field that is reliably reproducible.

Q 48.39 Wed 17:00 Tent

Higher-order photon correlations with trapped ion crystals — •Zyad Shehata[1], Benjamin Zenz[2], Ansgar Schaefer[2], Maurizio Verde[2], Stefan Richter[1], Joachim von Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Department Physik, FAU Erlangen Nürnberg — [2]QUANTUM, Institut für Physik, JGU mainz

Light scattering from trapped ion crystals displays unexpected photon statistical effects, translating particular geometric arrangements into specific higher-order spatio-temporal photon correlations. Experimentally, background-free coherent scattering on Ca+ ions has been achieved using a two-photon transition via the 32D5/2 metastable state and the narrow quadrupole transition 42S1/2*32D5/2. This process enables spin-selective excitation, allowing far-field imaging of the crystals' spin states via the first-order correlation function g(1). Expanding beyond g(1), we explore higher-order photon correlations that reveals improved imaging as well as super- and sub-radiant phenomena, featuring distinct spatio-temporal emission patterns through entanglement in the ion arrays. We present theoretical predictions as well as detailed calculations on the photon count rates and the signal-to-noise ratios for the m-photon detection events g(m) in particular configurations.

Q 48.40 Wed 17:00 Tent

Coherent Control of NV Centers Utilizing the Red Pitaya Platform — •Matthias Hollmann[1], Jonas Homrighausen[1], Naja Livia Bruczyk[1], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Münster — [2]Department of Electrical Engineering and Computer Science, FH Münster

Nitrogen-vacancy (NV) centers in diamond have emerged as important tools for quantum sensing, with applications ranging from magnetic field to temperature measurements. Achieving high sensitivity in such applications requires precise coherent spin control.However, conventional lab-based setups often rely on bulky, advanced, and costly components, limiting accessibility and scalability. Therefore cost effective and compact sensing platforms are getting more important for research and industry [1]. In this work, we investigate the use of the Red Pitaya platform -a commercial off-the-shelf (COTS), customizable, and cost-effective FPGA platform- as an alternative solution. This versatile hardware enables both signal generation and acquisition necessary for measuring T_1 and T_2 times in NV centers. The setup demonstrates a promising compact and cost effective alternative to conventional systems, suitable for magnetic and temperature sensing. It paves the way for portable, low-cost solutions in quantum sensing applications and can be adapted for different usecases and measurement environments. [1] Stiegekötter D. et al, Microcontroller-optimized measurement electronics for coherent control applications of NV centers. Sensors 24, 3138 (2024)

Q 48.41 Wed 17:00 Tent

Recent Advances in Low-Cost 3D Printed Experiment Kits for Quantum Education — •Leon Sievert[1], Marina Peters[1], Dennis Stiegekötter[2], Jonas Homrighausen[1], Nils Haverkamp[3], Peter Glösekötter[2], Stefan Heusler[3], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Münster, Germany — [2]Department of Electrical Engineering and Computer Science, FH Münster, Germany — [3]Institute of Physics Education Research, University of Münster

The growing interest in quantum technology in society and industry is met by an increasing demand in quantum education. This results in a need for low-cost, versatile and resilient experimental setups for research and teaching purposes.To approach this challenge, an open innovation platform has been proposed [1,2]. This combines an open-source, 3D printable setup, with low-cost hardware in a modular, tactile cube aesthetic. The freely positionable experiment parts are placed on a reliable grid structure. Experiments to measure optically detected magnetic resonance (ODMR) in microdiamond NV center ensembles[3] are a large use case for this setup. In this work, we present two major advances: A wireless module based on ESP32 was used to simplify the visualization process of sensor data [1]. Additionally, the educational setup was improved for coherent control experiments in NV center ensembles using a low-cost microcontroller setup [4]. [1] www.O3Q.de [2] www.quantumminilabs.de[3] Stegemann, J. et al. European Journal of Physics 44 (2023)[4] Stiegekötter D. et al, Sensors 24, 3138 (2024)

Q 48.42 Wed 17:00 Tent

Simple Rate Equation Model to Simulate the Fluorescence Lifetime of NV Ensembles in Microdiamond Powder — •Glen Neiteler[1], Ludwig Horsthemke[2], Naja Livia Burczyk[1], Sarah Kirschke[1], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Münster University of Applied Sciences, Stegerwaldstr. 39, 48565 Steinfurt, Germany — [2]Department of Electrical Engineering and Computer Science, FH Münster University of Applied Sciences, Stegerwaldstr. 39, 48565 Steinfurt, Germany

In the past few years, the nitrogen-vacancy (NV) center in diamond was the subject of extensive and promising research in the fields of quantum computing, quantum key distribution and quantum sensing. Recently, we experimentally investigated the fluorescence lifetime of the excited state of NV ensembles in microdiamond powder for application in all-optical quantum sensors [1]. To gain insights into the spin dynamics of NV ensembles in microdiamond powder, we simulate the fluorescence lifetime with a simple rate equation model.

[1] Horsthemke, L., et al. Excited-state lifetime of NV centers for all-optical magnetic field sensing. Sensors 24, 2093 (2024).

Q 48.43 Wed 17:00 Tent

Towards Electrode-integrated Fiber Cavities for Ion Trapping and Quantum Computation — •Tuncay Ulas, Luca Graf, Lasse Irrgang, and Ralf Riedinger — Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg

Quantum technologies are increasingly capturing the interest of researchers. Trapped-ion systems are a leading platform for quantum computation, offering high-fidelity operations and scalability. We present an ion trap design that integrates optical fiber cavities into the electrode structure. This integration enables precise control of the cavity geometry, enhancing ion-photon coupling and supporting the development of scalable architectures for quantum technologies.

Q 48.44 Wed 17:00 Tent

Adhesive- Mounted Optics for Relaxometry with NV- centers in Nanodiamonds for Biomedical Applications — •Ann Maria Tom[1], Marina Peters[1], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Muenster, Germany — [2]Department of Electrical Engineering and Computer Science, FH Muenster, Germany

Relaxometry with NV centers in nanodiamonds has emerged as a vital tool for detecting free radicals in medical diagnostics.[1] The transition of relaxometry to industrial applications faces challenges in optical optimization. This work explores an improved optical setup for these biomedical applications.

Key advancements include addressing optical challenges such as precise alignment, coupling efficiency, and robustness for industry-relevant scenarios. The use of glued optics and fiber-coupled solutions is explored to enhance system stability and scalability.[2] These improvements aim to bridge the gap between lab-based setups and practical industrial implementations, enabling more effective use of relaxometry in biomedical applications.

Q 48.45 Wed 17:00 Tent

Towards quantum mirrors based on 2D subwavelength atomic arrays — •Julian Lyne[1,2], Nico Bassler[2,1], Kai Phillip Schmidt[2], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Staudtstraße 7, D-91058 Erlangen, Germany

Two-dimensional subwavelength arrays of quantum emitters have been shown to exhibit interesting optical properties, enabling perfect reflection of an incoming field as well as control over its polarization, phase, and helicity [1,2]. While such properties are already fully described by classical coupled dipole models, for incident fields of increased intensities, the quantum nature of the quantum emitters comes into play, as double excitation of an individual emitter is not possible. We investigate such regimes where the two-dimensional array can induce photon-photon interactions owing to the effective hardcore interaction. To this aim, we tailor the dipolar interaction as recently proposed in Ref. [3]. The manipulation of the emitters' dipole orientation and/or relative emitter-emitter separation allows for the confinement of excitations towards the center of the array and thus enhance photon-photon interactions. We show here the operation of such an array within the double excitation manifold.

[1] E. Shahmoon et al., Physical Review Letters 118, (2017).
[2] N. S. Baßler et al., Optics Express 31, 6003 (2023).
[3] M. Cech, I. Lesanovsky, and B. Olmos, Physical Review A 108, (2023).

Q 48.46 Wed 17:00 Tent

Temporal-to-spatial mode demultiplexing of single photons for quantum information processing — •Fuad Raed Jubran Haddad[1,2,3], Xavi Barcons Planas[1,4], and Janik Wolters[1,2,3] — [1]Technische Universität Berlin — [2]Deutsches Zentrum für Luft- und Raumfahrt — [3]PTB — [4]Humbodlt-Universität zu Berlin

Photonic quantum information processing needs the supply of many simultaneous input photons, separated into spatial modes. Single photon sources, such as SPDC sources or semiconductor quantum dots, typically produce time-separated photons in a single mode. By leveraging resonant electro-optic modulators (r-EOMs) to manipulate photon polarization, photons can be directed into optical paths of varying lengths [1]. This method enables the conversion of time-separated photons into spatially-separated photons, facilitating time-to-spatial demultiplexing, which is essential for interfacing with multimode photonic quantum processors. We report on our efforts to realize an efficient time-to-spatial demultiplexer for single photons, allowing to provide up to 8 photons simultaneously.

[1] C. Antón, et al., Optica 6, 1471-1477 (2019)

Q 48.47 Wed 17:00 Tent

High-fidelity Stimulated Raman adiabatic passage — •Julian Dimitrov and Nikolay Vitanov — Center for Quantum Technologies, Faculty of Physics, Sofia University, James Bourchier 5 blvd., 1164 Sofia, Bulgaria

We present a comparative study of various approaches toward high-fidelity Stimulated Raman adiabatic passage (STIRAP). This technique for population transfer in a three-state quantum system is widely used because of its robustness to errors in the driving fields and the fact that the intermediate state is unpopulated in the adiabatic limit. Its main drawbacks are the large pulse areas needed to achieve adiabaticity and the necessity for a two-photon resonance between the two end states, which make it difficult to achieve very high population transfer efficiency. Here we compare two main approaches to high-efficiency STIRAP: by using pulse shaping of the driving fields and by using composite sequences. We assume that only two fields are present and discard the often used third field, which introduces unnecessary redundancy.

Q 48.48 Wed 17:00 Tent

Hanbury Brown-Twiss interference of electrons in free space — •Florian Fleischmann[1], Mona Bukenberger[2], Raul Corrêa[3], Anton Classen[4], Simon Semmler[1], Marc-Oliver Pleinert[1], and Joachim von Zanthier[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Quantum Optics and Quantum Information, 91058 Erlangen, Germany — [2]ETH Zürich, Department of Environmental Systems Science, 8092 Zürich, Switzerland — [3]Federal University of Minas Gerais, Departamento de Física, 31270-901 Belo Horizonte, Brazil — [4]University of Utah, Health Science Core, UT 84112 Salt Lake City, USA

We investigate the spatial second-order correlation function of two scattering electrons in a Hanbury Brown-Twiss like experiment. First, we consider semi-classically the effects of the Pauli exclusion principle and Coulomb repulsion on the expected correlation pattern. This is followed by a full quantum-mechanical treatment of the problem, where we separate the system into relative and center-of-mass coordinates in analogy to the Hydrogen atom ansatz. While the center-of-mass system is described as a free particle, the relative system contains the Coulomb scattering process which translates into an effective one-particle problem. We expand the respective initial state of the electrons in the eigenstates of the corresponding Hamiltonian and evolve the system in time. After the scattering process, the function is evaluated in the far field. We present the formal solution of the problem and discuss the current state of the numerical investigations.

Q 48.49 Wed 17:00 Tent

Spin Control of Silicon-Vacancy Centers in Nanodiamonds — •David Opferkuch, Andreas Tangemann, Marco Klotz, and Alexander Kubanek — Institute for Quantum Optics, University Ulm, Germany

Due to presumed high scalability, spin qubits in solid state hosts are promising candidates for the realization of quantum networks. As such, negatively charged silicon-vacancy-centers (SiV-) in nanodiamond (ND) combine the good spin properties of diamond with the good optical properties of group-IV defects. We are using highly strained SiV- hosted in ND, which demonstrate orbital ground state splittings exceeding 1THz. Thus, phonon induced dephasing of the spin qubit is mitigated at liquid Helium temperatures. Here, we present our current results on electron spin characterization and control of a SiV- in ND at liquid Helium temperatures as well as the characterization and control of coupled C13 nuclear spins.

Q 48.50 Wed 17:00 Tent

Separation of Rubidium Isotopes for Atomic Vapor Cell Production — •Timon Damböck[1], Robert Löw[2], and Ilja Gerhardt[1] — [1]light and matter group, Institute for Solid State Physics, Leibniz University of Hannover, Appelstrasse 2, 30167 Hannover — [2]5th Institute of Physics, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

In the past years, the fundamental research on atomic vapor quantum (sensing) systems made huge progress. With rising request of industrial applications for those systems, the demand for a production of high purity atomic vapor cells has increased. Although the used alkali metals (e.g. rubidium) are cheap and easily available, most of those quantum systems require purified isotopes for better control and higher sensitivity. The purification methods for isotopes are mostly inefficient and expensive, which limits the availability of enriched alkali isotopes on the market. This affects the cost and the advance from the transfer of scientific knowledge to industrial applications. To overcome this limitations, we propose an apparatus for the in–atomic–vapor–cells enrichment of rubidium isotopes using lasers, which can be used for the production of purified vapor cells from the natural abundance of the isotopes on. Combined with an outstanding collection efficiency, this could serve as a sustainer for the development of industrial applications using atomic vapor cells.

Q 48.51 Wed 17:00 Tent

Emission statistics and strong-field energy spectra for electron photoemission from nanometric needle tips using non-classical light — •Jonathan Pölloth[1], Jonas Heimerl[1], Andrei Rasputnyi[2], Stefan Meier[1], Maria Chekhova[1,2], and Peter Hommelhoff[1,2,3] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), 91058 Erlangen — [3]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

Typical strong-field experiments investigate the interaction between intense classical light and matter, e.g. atoms or metal surfaces. This allows us to explore the electron dynamics in such a strong coherent light field. However, it is intriguing to study the influence of the driving state of light on strong-field effects. The development of intense sources of non-classical light such as bright squeezed vacuum (BSV) has made such studies experimentally feasible and thus established a new approach to the emerging field of strong-field quantum optics. When investigating nonlinear electron photoemission from needle tips using either coherent or BSV light, it was shown that the electron emission statistics is inherited from the photon statistics of the driving state of light [1]. Here, we will present these results as well as the first measurements of strong-field electron energy spectra driven by BSV. The study of these spectra allows to investigate also the strong-field electron dynamics in such an intense non-classical state of light.

[1] J. Heimerl *et al.*, Nat. Phys. **20**, 945-950 (2024)

Q 48.52 Wed 17:00 Tent

Towards spatial demultiplexed feedforward of photon number states — •Niklas Schröder[1], Frederik Thiele[1,2], Niklas Lamberty[1,2], Thomas Hummel[2], Sebastian Lengeling[3], Christof Eigner[2], Christine Silberhorn[3], and Tim Bartley[1,2] — [1]Department of Physics, Paderborn University,Warburger Str. 100, Paderborn, 33098, Germany — [2]Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, Paderborn, 33098, Germany — [3]Integrated Quantum Optics Group, Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, Paderborn, 33098, Germany

Measurement based manipulation of single photons enables many quantum photonic protocols. This can be achieved by measuring incident single photons and then controlling an electro-optic modulator. To do this efficiently, we combine integrated photonics and superconducting nanowire single photon detectors (SNSPD). We are working on a device which sorts heralded Fock states into different spatial modes. We start by measuring the photon number of the idler mode of a spontaneous parametric down-conversion source (SPDC) with a quasiphoton-number-resolving SNSPD. Based on the result, we will route the signal photons in an electro-optic demultiplexer via a cascade of couplers from a single input channel to four output channels, which correspond to a specific Fock state.

Q 48.53 Wed 17:00 Tent

Optical setup for co-trapping Yb^+ and Ba^+ ions in a cryogenic trapped-ion quantum computer — •Ernst Alfred Hackler, Daniel Busch, Patrick Huber, Dorna Niroomand, and Christof Wunderlich — Universität Siegen, Siegen, Germany

A novel cryogenic (4K) trapped ion quantum computer with integrated cryogenic control electronics (BMBF funded project ATIQ) requires an optical set-up for delivering laser light to cool and state selectively prepare and detect Yb^+ and Ba^+ ions. Here, we present the development process and simulation of all key components of this optical set-up. A major challenge in designing optics for the above-mentioned purpose is the wide wavelength range, which causes significant differences in dispersion and absorption for a given material. First, we introduce a new overlapping unit, which combines nine different wavelengths ranging from UV to near-IR in two separate arms. Second, we describe the achromatic beam delivery system, which transports the combined laser beams from the overlapping unit to the ions confined in a planar, micro-structured Paul trap within the cryostat. Third, we present a newly developed reflective imaging system based on a Schwarzschild objective designed by the Institute of Quantum Optics from Leibniz Universität Hannover that enables simultaneous imaging of all wavelengths in the experiment into one focal plane, in which the camera is placed. Since only two fluorescence wavelengths are relevant for state selective detection while all other wavelengths, along with stray light from the environment, presents background noise, we have designed a specifically tailored double bandpass filter to optimize detection.

Q 48.54 Wed 17:00 Tent

Experimental set up for Trapped-Ion Experiments Using a Microfabricated Surface Paul Trap — •Radhika Goyal, Tobias Pootz, David Stuhrmann, Celeste Torkzaban, and Christian Ospelkaus — Institute for Quantum Optics LUH, Hannover, Germany

With state of the art coherence times as well as gate fidelity demonstrations, trapped ions have become a cornerstone in the world of quantum computing. Ions can be trapped using various schemes, out of which microfabricated Surface Paul traps stand distinguished in QC applications for their compactness and scalability.

To house such a trap, we present a cryogenic vacuum setup designed for enhanced ion confinement and reduced environmental noise. The system features a custom-built cryostat operating at temperatures below 10 K and achieving ultra-high vacuum (UHV) levels of the order of 10e-8 mBar.

The system features multiple optical viewports for laser addressing, high-frequency RF electronics for trap operation, as well as an optical system to image the ions. This poster will detail the design, challenges, and performance benchmarks of the system, offering insights into its application in cutting-edge quantum research.

Q 48.55 Wed 17:00 Tent

Miniaturizing optical resonators: Fiber-based Fabry-Perot cavities. — •Usman Adil[1,2], Franziska Haslinger[2], Michael Förg[2], Thomas Hümmer[2], Jonathan Noé[2], and Manuel Nutz[2] — [1]LMU München — [2]Qlibri GmbH

Microscopic optical resonators have proven to be a versatile tool through their ability to enhance light-matter interaction. Constructing the mirrors on the end-facets of optical fibers offers a compact and tunable solution with intrinsic fiber coupling: Fiber Fabry-Perot Cavities (FFPCs). Successful experimental examples/applications range from non-destructive qubit readout in quantum information processing over sensing applications of gases or liquids to the usage as frequency filter for optical signals. Here, we present the prototype of a readily available FFPC and provide first insights on fiber alignment and positioning. Core parameters like finesse, length, stability and mode matching are analyzed/presented as a function of fiber type, mirror shape and coating properties.

Q 48.56 Wed 17:00 Tent

Investigating Autofluorescence in Optical Fibers — •Alexander Bukschat, Stefan Johansson, Dennis Lönard, Isabel Cardoso Barbosa, Jonas Gutsche, and Artur Widera — Physics Department and State Research Center OPTI- MAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Autofluorescence describes the glow of photoactive substances when exposed to light. The autofluorescence that occurs in glass fibres often has a disruptive effect in experiments with miniaturized fluorescence-based sensors whose spectral ranges overlap. As the factors influencing the autofluorescence of glass fibers tend to receive little attention, we will now investigate and discuss in more detail. Not only the type of glass fiber plays a major role, but also the materials used, radii of curvature, contamination or errors during coupling. Our results thus resemble a guideline for the design and handling of glass fibers for miniaturized sensors.

Q 48.57 Wed 17:00 Tent

Towards microwave-to-telecom transduction based on Erbium crystals — •Mayssane Selmani and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

Superconducting qubits are among the most developed platforms for quantum information processing; however, they cannot be connected over long distances using microwave photons. Thus, the development of a device capable of converting microwave to optical photons at telecommunication wavelengths with high efficiency and bandwidth would be a key enabler for the communication between remote quantum computers. To realize such a transducer, we explore two different systems:

First, we investigate erbium doped crystals which can have well-suited optical and microwave properties for efficient transduction depending on the host material. The Erbium is integrated into resonators with high quality factor for both transitions.

Second, on the other end of the concentration scale, we explore stoichiometric crystals, in which Erbium is integrated as part of the lattice and not as a dopant. This results in a high concentration of erbium spins without compromising the inhomogeneous broadening. At low temperatures, these crystals order antiferromagnetically and display magnon modes that can be used for transduction.

We will present first results of both approaches and discuss their prospects for high-efficiency transduction.

Q 48.58 Wed 17:00 Tent

Advanced fiber-optic interfaces – fiber cavities and beyond — •Florian Giefer, Benedikt Beck, Daniel Stachanow, Lukas Tenbrake, Sebastian Hofferberth, and Hannes Pfeifer — Institute of Applied Physics, University of Bonn, Germany

Applications for fiber Fabry-Perot cavities (FFPCs) reach from the miniaturization of existing cavity QED systems to novel use-cases in optomechanics, sensing, laser technology and many more. In this contribution we present an overview over our current research on fiber interfaces and FFPCs in the Bonn Fiber Lab.

We showcase our progress in the development of fiber cavity interfaced micro-mechanical resonators that are fabricated via 3D direct laser writing, including Q-factor optimization techniques like dissipation dilution and glassy structures with higher intrinsic Q. We present a scannable vacuum-integrated fiber cavity setup for probing high quality-factor mechanical resonators for experiments with multi-resonator structures.

We further investigate the behavior of optically pumped dye molecules in fiber cavities for the development of a miniaturized, directly fiber coupled and widely tunable dye laser system.

For interfacing cold atoms we present our development of a miniaturized fiber to fiber setup with a free space slot in between. The needed fiber collimation lens system is fabricated with a 3D direct laser writing system (Nanoscribe) and will be used in an experiment to interface Rydberg Atoms.

Q 49: Poster – Photonics, Lasers, and Applications

Time: Wednesday 17:00–19:00 Location: Tent

Q 49.1 Wed 17:00 Tent

Application of a fs-laser-written Mach-Zehnder interferometer for characterisation of hydrogels — •Johannes Schnegas[1], Karo Becker[2], Alexander Szameit[2], and Udo Kragl[1,3] — [1]Universität Rostock, Institut für Chemie, Albert-Einstein-Str. 3a, 18059 Rostock, Deutschland — [2]Universität Rostock, Institut für Physik, Albert-Einstein-Straße 23-24, 18059 Rostock, Deutschland — [3]Universität Rostock, Department LL&M, Albert-Einstein-Straße 25, 18059 Rostock, Deutschland

Integrated optics offers a significant advantage in the design of miniaturised optical sensors for applications such as chemical sensing. An example of these devices is the integrated optical interferometer, such as the Mach-Zehnder interferometer (MZI). Many examples are provided in the literature, such as protein characterisation, methane detection, and concentration measurement. In this work, an fs-laser-written MZI fabricated in fused silica is presented, which is composed of two waveguides combined by evanescent field couplers. One part of each interferometer arm runs close below the glass surface. A sensor area was created by exposing one of these via mechanical polishing, while the other interferometer arm serves as a reference. A liquid sample applied to the sensor area results in a shifted phase to which the interferometer responds with a change in the output intensity. The integrated optical MZI will be used to characterise hydrogels, which are 3D polymer networks that can take up a large amount of water and have a large field of applications. The effect of water the uptake on the refractive index was investigated in this study.

Q 49.2 Wed 17:00 Tent

Towards enhanced homodyne detection with a squeezed local oscillator — •Aishi Barua[1,2], Lorenzo M. Procopio[1,2], Laura Ares[1,2], Jan Sperling[1,2], and Tim J. Bartley[1,2] — [1]Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, Paderborn, Germany — [2]Department of Physics, Paderborn University, Warburger Str. 100, Paderborn, Germany

Homodyne detection, a well-known technique in the field of quantum optics, serves as a powerful measurement method for continuous-variable quantum states, by typically utilizing a strong coherent local oscillator to establish a stable phase reference. By squeezing either the local oscillator or the probe signal field, quantum noise can be reduced below the standard quantum limit, thereby enhancing the sensitivity of homodyne detection We present a novel approach aimed to enhance homodyne detection by implementing bright squeezed light as the local oscillator, a concept that remains unexplored. For measurement we aim to use photon-number-resolving detectors instead of linear photodiodes for intensity correlations at the single-photon level. We discuss our progress, future goals and feasibility of this approach.

Q 49.3 Wed 17:00 Tent

Noise cancelling in solid-state lasers — •Thomas Konrad[1], Tobias Steinle[1], Roman Bek[2], Michael Scharwaechter[2], Matthias Seibold[2], Andy Steinmann[1], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Twenty-One Semiconductors GmbH, Allmandring 3, 70569 Stuttgart

Fast and precise measurements are key for many challenging laser applications, such as biological and biomedical imaging. The precision is limited by the noise of the systems we use. Once the measurement precision reaches the laser noise level, the measurement time must be increased quadratically for further improvement. Especially with biological samples, a significant longer measurement time can alter the specimen and/or results. Therefore, exploiting the optimum noise characteristic of the driving source is superior to increasing measurement time.

In this work, we investigate noise reduction of a solid-state laser in the spectroscopically relevant 1 kHz - 10 MHz frequency range. Our approach is to reduce the noise in the oscillator itself instead of using a subsequent noise eater. It is the laser resonator that couples the lasers characteristic properties such as output power, optical spectrum, pulse duration, and therefore, consistent noise reduction of all properties must take place within the resonator itself. To reduce the noise, we use a second high-speed gain medium in the cavity whose pump is controlled by a PID feedback loop.

Q 49.4 Wed 17:00 Tent

Optical design and tolerance analysis of additively manufactured optical interfaces for spin qubits — •Lucas Kirchbach and Andreas Stute — Technische Hochschule Nürnberg Georg Simon Ohm

Readout efficiency is crucial in all optical quantum technologies that employ single qubits or single quantum emitters. One of those systems is the nitrogen vacancy (NV-Center) in diamond, where total internal reflection at the diamond surface severely limits the photon yield. Recent efforts for enhancing the collection efficiency of single NV-Centers include shaping the diamond surface to a hemisphere or printing solid-immersion lenses (SIL) on top of it. In order to further improve the photon collection efficiency, we intend to additively manufacture polymer lenses on top of the crystal via multi-photon lithography. This works presents multiple optical designs based on 3D-printed polymer lenses and discusses their performance, robustness and scalability via simulation of their optical, thermal and mechanical properties. We also present a method to determe lens geometries based on a differential equation approach.

Q 49.5 Wed 17:00 Tent

Towards photonic interference with VV centres on industrial-compatible SIC-OI chips — •NienHsuan Lee[1,2], Sushree Swateeprajnya Behera[1,2], Jonas Schmid[1,2], Leonard Zimmermann[1,2], Jonah Heiler[1,2], Flavie D. Marquis[1,2], Stephan Kucera[1], and Florian Kaiser[1,2] — [1]MRT Department, Luxembourg Institute of Science and Technology, Belval, Luxembourg — [2]Department of Physics and Materials Science, University of Luxembourg, Belval, Luxembourg

Colour centres in solid-state materials are promising for quantum communication, offering robust optical and spin properties. However, scaling up the experiment from single colour centres to plethora of colour centres on chips remains a significant challenge. Here, we present an approach to fabricating photonic quantum chips with divacancy (VV) centres in silicon carbide (SiC). By utilizing SiC-on-insulator (SiC-OI) substrates, we could establish a robust and industry-compatible design for scalable quantum technologies. Our method integrates VV centres into photonic structures, enabling efficient spin-photon interactions and chip-scale integration. With these chips, our ambition is to perform photonic interference experiments to entangle neighbouring VV centres on a chip.

Q 49.6 Wed 17:00 Tent

Metasurfaces Meet Multicore Fibers: A Platform for Generating Complex States of Light. — •Rahaf Ismail and Markus A. Schmidt — Leibniz Institute of Photonic Technology, Jena, Germany

This research combines nano-printed metasurfaces with multicore fibers to generate orbital angular momentum (OAM) beams. Using 3D nano-printing, microprisms were fabricated and tested on planar substrates, SMF-28 single-core fibers, and multicore fibers. Experimental results showed precise deflection angles, with deviations within 1.5 degrees. Current work focuses on validating uniform deflection from multicore fibers, paving the way for efficient light manipulation and OAM beam generation.

Q 49.7 Wed 17:00 Tent

Optimized Fabry-Perot Resonators for strong coupling between excitons in Ruddlesden-Popper Perovskite to cavity photons — •Prabhdeep Singh[1], Maximilian Black[1], Sara Darbari[2], and Nahid Talebi[1] — [1]Institute of Experimental and Applied Physics, Kiel University, Kiel 24098, Germany — [2]Nano-Sensors and Detectors Lab., Faculty of Electrical and Computer Engineering, Tarbiat Modares University, Tehran

Ruddlesden-Popper Perovskites (RPPs), due to their quasi-two dimensional layered structure and quantum confinement effects host excitons with typically high binding energies. In this study we model a Fabry-Perot resonator designed to study the coupling between excitons and cavity photons. The cavity features a multilayer structure of gold (and silicon nitride as reflective layers, enclosing a central chamber comprising an air gap and RPP as the active medium. Utilizing the transfer matrix method, we calculate reflection, transmission, and absorption spectra as functions of incident angle and photon energies. The results demonstrate strong coupling between the Fabry-Perot cavity resonances and the RPP excitons around the energy of 2.34 eV. Integrated reflection coefficient across incident angles (0-40°) used to simulate the microscope objectives, capture the angular dependence effects and features the energy split associated with the strong-coupling effect. The study demonstrates the importance of the resonator design for studying exciton-photon hybridization and its application in optoelectronic devices.

Q 49.8 Wed 17:00 Tent

The photoluminescence of transparent glass-ceramics based on ZnO nanocrystals Co-doped with Lanthanide elements Eu3+, Yb3+ ions. — •Moursi Abu Bieh[1] and Grigory Arzumanyan[2] — [1]Photo Chemistry Department, Egyptian National Research Center, El-Behoos Street, Giza, Cairo, Egypt — [2]Dubna, Russia

Transparent glasses of the K2O.ZnO.Al2O3.SiO2 Chemical Formula which is Co-doped with Eu2O3 and Yb2O3 were prepared by the melt-quenching technique. transparent zincite ZnO glass ceramics were obtained by secondary heat treatment methods at 860°C.At 860°C, traces of Eu Oxyapatite will appear in addition to ZnO nanocrystals. The average crystal size obtained from the X-ray diffraction data was found to range between 14 and 35 nm. The absorption spectra of the initial glasses are composed of an absorption edge and absorption bands due to the electronic transitions of Eu ions. With heat-treatment, the absorption edge pronouncedly shifts to the visible spectral range. The luminescence properties of glass and glass-ceramics were studied by measuring their excitation and emission spectra at 300, 78, and 4.2 K. Changes in the luminescence properties of the Eu-related excitation and emission bands were observed after heat-treatments at 680°C and 860°C. ZnO nanocrystals showed both broad luminescence (400-850 nm) and free-exciton emission near 3.3 eV at room temperature. upconversion luminescence spectrum of initial glass was obtained under excitation of the 976 nm laser source.

Q 49.9 Wed 17:00 Tent

Exciton-Plasmon Coupling at the Borophene/ZnO Interfaces Unraveled by Cathodoluminescence Spectroscopy — •Bharti Garg[1], Masoud Taleb[1], Yaser Abdi[2], and Nahid Talebi[1] — [1]Institute for Experimental and Applied Physics, Kiel University, Kiel, Germany — [2]Department of Physics, University of Tehran, Tehran, Iran

Borophene, a two-dimensional atomic sheet of boron, exhibits unique anisotropic in-plane polaritons in the visible spectral range [1] . In this work, we leverage advanced deep-subwavelength cathodoluminescence spectroscopy to investigate the coupling of the plasmons of borophene with the excitons of ZnO nanorods at the borophene/ZnO interface. Our results show that the near-band-edge emission (exciton transition) in ZnO nanorods is enhanced at the borophene/ZnO interface attributed to a coupling between ZnO excitons and borophene plasmons. Additionally, an emission around 800 nm is observed in the cathodoluminescence spectrum, corresponding to the plasmon-polariton peak of borophene, with a modified and reduced bandwidth and stronger luminescence peak, that is due to the coherent interactions between excitons and plasmon polaritons. Interestingly, high-resolution cathodoluminescence hyperspectral imaging from different interfaces of borophene/ZnO shows that the cathodoluminescence of the borophene/ZnO interface strongly depends on the crystallographic direction of the borophene attached to ZnO nanorods due to the anisotropic electrical and optical behavior of borophene. [1]arXiv preprint arXiv:2404.13609v

Q 49.10 Wed 17:00 Tent

Transport, alignment and focusing of a VUV laser beam for nuclear laser excitation of a single ^{229}Th ion — •Tamila Teschler[1], Georg Holthoff[1], Daniel Moritz[1], Kevin Scharl[1], Markus Wiesinger[1], Stephan Wissenberg[1,2], and Peter G. Thirolf[1] — [1]Ludwig-Maximilians-Universität München (LMU) — [2]Fraunhofer Institute for Laser Technology (ILT)

Direct frequency-comb spectroscopy represents a promising way for narrowband nuclear laser excitation. The combination of a VUV frequency comb being developed at Fraunhofer ILT and the cryogenic Paul trap operated at LMU Munich as part of an ERC Synergy project, aims to enable the excitation of the isomeric first excited state in ^{229}Th using laser radiation with $\lambda \approx 148$ nm. This advancement is an important step towards the realization of a nuclear clock based on the unique properties of ^{229}Th, which could provide extraordinary precision for timekeeping and potentially offers insights into new physics beyond the Standard Model. In this device, the single-ion nuclear clock relies on the irradiation of a single, laser-cooled ^{229m}Th^{3+} ion with a narrowband frequency comb. The goal is to achieve a VUV focus with a diameter of about 3 μm, to provide sufficient laser radiation intensity for driving nuclear Rabi oscillations. To achieve this, selecting the proper optical components is essential to minimize optical aberrations and power losses. Transport, alignment and focusing of a VUV laser beam from the generation site to the trapped ions will be presented. Funding: ERC Synergy project Thorium Nuclear Clock, Grant Agreement No. 856415.

Q 49.11 Wed 17:00 Tent

Towards Accurate Group Index Measurement in Lithium Niobate Waveguide Resonator — •Stefan Kazmaier and Kaisa Laiho — German Aerospace Center (DLR e.V.), Institute of Quantum Technologies, Wilhelm-Runge-Str. 10, 89081 Ulm, Germany

Lithium niobate (LN) is one of the most used materials in nonlinear quantum optics for the generation of quantum light. The spectral properties of the generated states are influenced by the group indices of the interacting modes, since they ultimately dictate the so-called joined spectral amplitude. However, the group index is often only simulated instead of measured accurately, which may lead to wrong conclusions. Therefore, we show a linear optical measurement of the group index and the optical losses in a peridodically-poled LN waveguide (WG). For that purpose, we measure the transmission spectrum of a LN WG resonator, allowing us to determine the birefringence of the group index for varying wavelengths and temperatures [1]. Altogether, our results help in interpreting the spectral properties of quantum states more accurately.

[1] Hofstetter and Thornton Opt. Lett. 22 1831-1833 (1997)

Q 49.12 Wed 17:00 Tent

Tunable Pulsed UV-Laser System for Laser Cooling of Highly Charged Bunched Ion Beams Employing Walk-Off Compensation — •Tamina Grunwitz[1], Benedikt Langfeld[1,2], and Thomas Walther[1,2] — [1]TU Darmstadt — [2]HFHF Campus Darm stadt, Department for Atomic and Plasma Physics

Laser cooling of bunched ion beams is a promising technique for narrowing the relative momentum distribution of highly charged ions in accelerators. To achieve efficient laser cooling at the new SIS100 of the GSI FAIR facility, in addition to a continuous laser, two pulsed lasers are planned to be used which, due to their spectral bandwidth, can cool a large part of the ion ensemble. For a flexible application all laser systems should be continuoulsy tunable in their wavelength in the UV region. In this contribution, we present our tunable pulsed laser system in the UV range of 257 nm. In order to achieve a high tunability of the whole system, the wavelength in the IR can be continouly tuned over a range of 3 nm around a centre wavelength of 1030 nm. With the use of two SHG stages, the IR light can be converted into the UV regime. Automated phasematching (critical) of the used BBO crystal allows continuous tuning of the UV wavelength. To compensate the beam offset due to wavelength change, a walk-off compensated setup of two BBO crystals is used, which provides a better stability of the UV beam position during tuning. In this work, we will present our most recent results regarding the automatic tuning of the wavelength in the UV with this setup, as well as the beam movement with change in wavelength

Q 49.13 Wed 17:00 Tent

Towards coherent dipole-dipole coupling: cryogenic single molecule spectroscopy of DBATT dimers — •Tim Hebenstreit[1,2], Siwei Luo[1,2], Michael Becker[1], Alexey Shkarin[1], Aleksandr Oshchepkov[3], Konstantin Amsharov[3], Jan Renger[1], Tobias Utikal[1], Vahid Sandoghdar[1,2], and Stephan Götzinger[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich Alexander University Erlangen-Nuremberg, Erlangen, Germany — [3]Department of Chemistry, Martin-Luther-University Halle-Wittenberg, Halle, Germany

Coherently coupled molecules are an interesting resource for quantum optics and quantum information processing, providing access to sub- and superradiant states. Such pairs of molecules have previously been found by tedious search routines, since molecules are randomly doped into the host matrix at low concentrations. To address this issue, our approach is to use a newly developed chemical synthesis method that can connect two emitters with a linker that is less than 2 nm in length. Here, we present cryogenic single molecule spectroscopy studies on 2,3,8,9- dibenzanthanthrene (DBATT) dimers. By embedding these dimers in shock-frozen tetradecane matrices, we demonstrate lifetime-limited linewidths of DBATT dimers that also exhibit similar fluorescence spectra as isolated DBATT molecules. Our results are a first step towards a routine investigation of cooperative phenomena using molecular dimers.

Q 49.14 Wed 17:00 Tent

Label-free single nanoparticle sensing with a high-finesse microcavity — •Shalom Palkhivala, Larissa Kohler, and David Hunger — Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany

Since many biochemical processes occur in aqueous environments, the sensing and characterisation of single, unlabelled particles in water is of interest in fields of science such as biophysics and chemistry.

We demonstrate an open-access optofluidic platform for the label-free sensing of nanoparticles in aqueous suspension, using a fibre-based Fabry-Perot microcavity with high finesse (5×10^4 in water) [1]. By monitoring interactions between diffusing nanosystems and the optical cavity field, the dynamics of the nanosystems can be investigated. The analysis of diffusion dynamics allows us to measure the hydrodynamic size of single particles with diameters of down to a few nanometers.

Furthermore, the rotational dynamics of anisotropic particles are investigated by interrogating orthogonal polarization modes of the cavity. Thus, the rotation of single nanorods could be tracked with high temporal resolution (~ 10 ns), which is orders of magnitude faster than most other current techniques.

As an application of our sensor to the field of biosensing, we demonstrate the measurement of proteins, and detect single DNA "origami" structures.

[1] Kohler, L. et al. Nat Commun 12, 6385 (2021).

Q 49.15 Wed 17:00 Tent

Quantum photonics using color centers in a diamond membrane coupled to a photonic structure — •Surena Fatemi[1], Jan Fait[1], Roy Konnoth Ancel[2], Aurelie Broussier[2], Philipp Fuchs[1], Christophe Couteau[2], and Christoph Becher[1] — [1]Fachrichtung Physik, Universität des Saarlandes, Campus E2.6, 66123, Saarbrücken, Germany — [2]Light, nanomaterials, nanotechnologies (L2n), Université de Technologie de Troyes, 10004 Troyes, France

In recent years, color centers in wide band-gap materials have garnered significant attention for their exceptional properties in quantum technologies. Among these, group-IV color centers in diamonds are particularly promising due to their long spin coherence times and excellent optical characteristics, such as narrow emission lines, high spectral stability, and bright single-photon emission.

A major challenge in realizing quantum devices based on color centers is the inefficient out-coupling of photon emission from the diamond, leading to low extraction rates. To address this, we study group-IV color centers in diamond membranes coupled to TiO2-based photonic waveguides. Using Finite-Element-Method simulations and Monte-Carlo optimization, we optimize membrane geometry, coupling interfaces, and waveguide structures to enhance photon out-coupling and achieve high photon rates. The optimized structures will then be fabricated and experimentally characterized, enabling the practical implementation of efficient quantum devices.

Q 49.16 Wed 17:00 Tent

Floquet Topological Engineering in Graphene: Towards Ultrafast Device Control — •Selina Nöcker[1], Daniel Lesko[1], Weizhe Li[1], and Peter Hommelhoff[1,2] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

Topological insulators offer exciting prospects for both fundamental research and technological applications. Irradiation with strong laser light allows dressing any material into a non-equilibrium state known as a Floquet topological insulator. Graphene is a highly symmetric 2D material with exceptional properties and provides an ideal platform to explore laser-engineered topological phenomena. Upon irradiation with a circularly polarized pulse, we induce a topological phase transition to an inversion symmetric and time reversal symmetry-broken Chern insulator. With a phase-locked optical second harmonic field, we probe the sub-cycle properties measuring phase-dependent photocurrents. For this, we use strong few-cycle pulses generated from normal-dispersion highly nonlinear fibers. We employ precise control over their carrier-envelope-phase and two-color phase delay, enabling attosecond control of the Floquet topological state. The dressed graphene exhibits intriguing optical responses, including photocurrent circular dichroism and an all-optical anomalous Hall current. Our work highlights the potential of using short laser pulses to manipulate electronic states within matter, paving the way for ultrafast device engineering in graphene and other 2D materials.

Q 49.17 Wed 17:00 Tent

Probing quantum non-reversability in photonic waveguide systems — •Bashar Karaja, Nico Fink, Viviane Bauer, James Anglin, and Christina Jörg — Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau

We investigate the onset of irreversibility in a quantum system emulating a Bose-Hubbard model with interactions [1], implemented within a photonic waveguide platform. Our goal is to uncover the origins of irreversibility at the quantum level. To address this, we prepare the system in an initial state and subject it to an adiabatic time evolution that is precisely reversed at the midpoint. Irreversibility is quantified by the system's inability to return to its initial state, despite the exact time-reversal of the system's Hamiltonian. Given that numerous studies have demonstrated the feasibility of replicating quantum-optical effects in photonic waveguide systems [2], we apply this model to a setup of two coupled Kerr-nonlinear waveguides. By gradually increasing the on-site potential difference -controlled through the waveguide radius - and reversing this process midway, we analyze the waveguide output under varying input conditions of intensity and phase distribution. Additionally, we aim to investigate the role of time-varying intensity profiles (e.g., pulses) in shaping the irreversibility threshold of the system.

[1] Bürkle, R., Vardi, A., Cohen, D. et al., Sci Rep 9, 14169 (2019).
[2] Longhi, S., Laser & Photon. Rev. 3:243-261 (2009).

Q 49.18 Wed 17:00 Tent

Nonlinear Spectroscopy of CdTeSe/ZnS Quantum Dots in a Single-Photon Fluorescence-Microscopy Setup — •Raphael Wichary and Tobias Brixner — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

We present measurements on commercial CdTeSe/ZnS core–shell quantum dots in a single-photon fluorescence microscope. Different methods of sample preparation, as well as the influence of oxygen and the excitation power on the stability of the sample in two-dimensional electronic spectroscopy experiments are explored. Comparisons are made between the behavior of clusters of multiple quantum dots and single quantum dots.

Different techniques are tried out to eliminate higher-order contamination of nonlinear signals.

Q 49.19 Wed 17:00 Tent

Using Rh6G as sensitizer in commercial photoresins for two-step-absorption lithography — •Sabrina Hammel[1], Georg von Freymann[1,2], and Christina Jörg[1] — [1]Physics Department and Research Center OPTIMAS RPTU Kaiserslautern-Landau, Kaiserslautern, Deutschland — [2]Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany

A widely used technique for creating arbitrary 3D structures at the micron scale is Direct Laser Writing (DLW), which uses the nonlinear process of Two-Photon Absorption (2PA). In 2PA, the simultaneous absorption of two photons excites a photoinitiator molecule, triggering a polymerization reaction. A recently shown technique, Two-Step-Absorption (TSA) [1], achieves similar resolution to 2PA, but needs only a simple cw-laser diode instead of a pulsed fs-laser. In TSA, the virtual state in 2PA is replaced by a real electronic state with a relatively long lifetime. So far, TSA lithography typically requires special photoresins consisting of appropriately chosen photoinitiators, scavengers and monomers. To also make commercial photoresins usable for TSA, we examine the use of a photosensitizer [2], Rhodamine 6G (Rh6G). Rh6G undergoes the TSA process, subsequently transferring energy to the photoinitiator in the commercial resin. By incorporating photosensitizers, we aim to make TSA more versatile, using existing commercial materials with minimal modification.

[1] V. Hahn, T. Messer, N.M. Bojanowski et al., Nat. Photon. 15, 932-938 (2021).
[2] D.T. Meiers et al., Adv. Eng. Mater. 25:2370037 (2023).

Q 49.20 Wed 17:00 Tent

Observation of the Spin Hall Effect of Light in Confocal Microscopy — •Anton Lögl[1], Wenze Lan[1], Meryem Benelajla[2], Clemens Schäfermeier[2], Khaled Karrai[2], and Bernhard Urbaszek[1] — [1]Institute for Condensed Matter Physics, Technische Universität Darmstadt, 64289 Darmstadt, Germany — [2]attocube systems AG, Eglfinger Weg 2, 85540 Haar, Germany

In the quantum picture of light the two spin states of photons correspond to right- and left-handed cicrular polarizations σ^+ and σ^-. Depending on the chirality of its circular polarization, the trajectory of a circularly polarized beam will shift above or below the plane of incidence when reflected off a surface. This Imbert-Fedorov shift is due to spin-orbit coupling of light upon each reflection and is typically several orders of magnitude smaller than the photon wavelength. For this reason, it has up to now required complex detection schemes and hence limiting detailed experimental investigations and practical applications. Here, we present a novel method to directly observe the spin-orbit coupling of light in confocal microscopy.

Q 49.21 Wed 17:00 Tent

Tunable Focusing Metalens on a Fiber with Two Cores — •Jun Sun[1], Malte Plidschun[1], Jisoo Kim[1], Torsten Wieduwilt[1], and Markus A. Schmidt[1,2,3] — [1]Leibniz Institute of Photonic Technology, Albert-Einstein-Str. 9, 07745 Jena, Germany — [2]Otto Schott Institute of Material Research, Friedrich Schiller University Jena, Fraunhoferstrasse 6, 07743 Jena, Germany — [3]Abbe Center of Photonics and Faculty of Physics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany

We propose a novel approach for fast, power-controlled spatial focus shape modulation through an all-fiber-integrated system utilizing a 3D nanoprinted intensity-sensitive hologram. This hologram enables dynamic control of focus geometric ellipticity by modulating the power distribution between the modes of a dual-core fiber. The resulting power-dependent interference pattern alters the hologram's intensity distribution, achieving precise focus shape control. Our study encompasses computational design, advanced 3D nanoprinting, and fiber fabrication, demonstrating the feasibility of this monolithic solution. Experiments and simulations validate its high-speed modulation capability, with promising applications in optical manipulation, laser micromachining, telecommunications, etc.

Q 49.22 Wed 17:00 Tent

Cryogenic spectroscopy of single molecules in the blue wavelength region — •Tianyu Fang, Ricardo Alvarez, Babak Behjati, Max Masuhr, Bo Deng, Delia Siedenberg, Kathrin Schumacher, and Daqing Wang — Institut für Angewandte Physik, Universität Bonn, Bonn, Germany

Various polycyclic aromatic hydrocarbon (PAH) molecules have been studied for quantum optical investigations in the green to near-infrared wavelength range. Detecting narrow-linewidth molecular transitions in the blue wavelength region can open new possibilities for single PAH molecules in quantum optics. Here, we report on fluorescence spectroscopy of perylene molecules in various host-guest systems at cryogenic temperatures. The emission properties of perylene in crystal matrices of anthracene, dibenzothiophene and biphenyl are measured and evaluated. In addition, we report on the detection of single perylene molecules adsorbed on hexagonal boron nitride (hBN) and benchmark their emission linewidth and photostability.

Q 49.23 Wed 17:00 Tent

Limits for coherent optical control of quantum emitters in hexagonal Boron Nitride — •Alexander Pachl[1], Michael K. Koch[1,2], Vibhav Bharadwaj[1,3], and Alexander Kubanek[1,2] — [1]Institut for Quantum Optics, University Ulm, 89081 Ulm, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, 89081 Ulm, Germany — [3]Department of Physics, Indian Institute of Technology Guwahati, 781039 Guwahati, Assam, India

Single Photon emitters hosted in hexagonal Boron Nitride (hBN) are promising candidates for integration into upcoming quantum optical technologies. Some of these emitters show a very interesting and promising optical property of Fourier transform limited linewidth up to room temperature [1,2]. This can be explained by out-of-plane distorted defects, which show a weak coupling to low energy in-plane phonon modes [3]. This enables coherent optical driving and the observation of optical Rabi oscillations up to elevated temperatures as demonstrated in our most recent work [4].

[1] A. Dietrich et al., Physical Review B, Vol. 98 (2018)
[2] A. Dietrich et al., Physical Review B, Vol. 101 (2020)
[3] M. Hoese et al., Science Advances, Vol. 6 (2020)
[4] M. Koch et al., Communications Materials, Vol. 5 (2024)

Q 49.24 Wed 17:00 Tent

Tunable cw UV Laser for Cooling of Relativistic Bunched Ion Beams — •Florian Stein, Jens Gumm, Denise Schwarz, and Thomas Walther — TU Darmstadt

Experiments with highly charged ions at relativistic energies are of great interest for many atomic and nuclear physics experiments at accelerator facilities. To decrease the longitudinal momentum spread and emittance, laser cooling has proven to be a powerful tool. In this work we present a cw UV laser system operating at 257.25nm for ion beam cooling at ESR in Darmstadt. The laser system can be scanned mode-hop free, via two SHG stages, over 20GHz with a 50 Hz scan rate. In our latest measurements we achieve a power of 2.45W in the UV regime employing a novel elliptical focussing cavity to reduce the degradation effect in BBO. The laser system will be used to minimize the final ion beam momentum spread and, therefore, the ion bunch length.

Q 49.25 Wed 17:00 Tent

Frequency Response of Surface Bragg Gratings for Monolithic Extended Cavity Diode Lasers — •Sten Wenzel, Olaf Brox, Jörg Fricke, Igor Nechepurenko, and Andreas Wicht — Ferdinand-Braun-Institut (FBH), Gustav-Kirchhoff-Straße 4, 12489 Berlin

Monolithic extended cavity diode lasers (mECDL) are a compact, robust and efficient light source with ultra-low frequency noise well suited for optical quantum technologies such as optical atomic clocks and quantum sensors based on atom interferometry. The extended propagation section results in a narrow longitudinal mode spacing of the cavity. Hence, the frequency selective element utilized to establish single mode operation, in this case a distributed Bragg reflector (DBR), must provide a spectrally narrow resonance with a width of the order of a few tens of GHz. We achieve this by a DBR with a small coupling coefficient and increased length of 2 mm. Since the spectral characteristics of a DBR scale with its length, uncertainties in the grating design, which arise from potential shortcomings in the modeling or technological implementation, may lead to significant deviations between the expected (simulated) and real performance. We therefore developed and implemented a method for the characterization of the spectral reflectance and transmission of such gratings in ridge-waveguides by laser spectroscopy. In this work, we present our findings and compare our measurement results with the theoretical prediction.

Q 49.26 Wed 17:00 Tent

SiV centers in nanodiamonds for quantum networks — •Kathrin Schwer[1], Marco Klotz[1], Andreas Tangemann[1], David Opferkuch[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik Universitat Ulm — [2]Universite Francois Rabelais de Tours

Combining conventional photonic systems with the good optical and spin properties of group IV defects in diamond puts a platform for quantum technologies into reach. Here, we present measurements of characteristic properties of SiV centers in nanodiamond in comparison with bulk diamond. This reveals key benefits of a nanostructured defect host for future integration into photonic-enhancing structures, e.g. cavities.

Q 49.27 Wed 17:00 Tent

Fiber-Interfaced Hollow-Core Light Cage: A Novel Lab-on-Fiber Platform — •Wenqin Huang[1], Diana Pereira[1,2], Jun Sun[1], Matthias Zeisberger[1], and Markus A. Schmidt[1,3,4] — [1]Leibniz Institute of Photonic Technology, Albert-Einstein-Str. 9, 07745 Jena, Germany — [2]i3N & Physics Department, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal — [3]Abbe Center of Photonics and Faculty of Physics, Friedrich Schiller University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [4]Otto Schott Institute of Material Research, Friedrich Schiller University Jena, Fraunhoferstr. 6, 07743 Jena, Germany

We present an innovative platform for fiber-integrated photonic devices by incorporating hollow-core light cages (LCs) onto fibers using 3D nanoprinting. Two LC geometries, featuring record-high aspect ratio polymer strands, were fabricated directly onto step-index fibers, providing unique lateral access to the core and showcasing excellent optical properties. The anti-resonance effect within these structures enables precise spectral transmission and efficient light confinement, validated through strong experimental agreement with theoretical models. This work highlights the small-core geometry, which achieves high fringe contrast and exceptional reproducibility. The fiber-interfaced LCs introduce a platform with potential in diffusion-based sensing, environmental analysis, nanoscience, and quantum technologies. The mechanical stability, achieved through customized support structures, ensures durability without compromising performance, enabling practical use in demanding environments.

Q 49.28 Wed 17:00 Tent

Quantum lattice solitons in a two-dimensional Harper-Hofstadter model — •Hugo Gerlitz, Julius Bohm, and Michael Fleischhauer — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern

Since the discovery of the integer quantum Hall effect, topological 2D lattice models have attracted significant interest in many-body physics. These models can be simulated using ultra-cold atoms in optical lattices [1]. Recent experiments were able to investigate lattice solitons in waveguides with nonlinear Kerr media [2].

In one-dimensional systems a quantum mechanical description of solitons in topological lattice models is typically done by exact diagonalization and tensor network approaches. These approaches are strongly limited by the system size and thus less efficient in higher dimensions. The examination of a reduced Hilbert-space to describe the 1D solitons was succesful in reproducing well known quantities like effective Chern numbers and Wilson loops. Motivated by this we here present the reduced quantum mechanical description of an interacting two-dimensional Harper-Hofstadter model and investigate the emerging soliton properties.

[1]: I. Bloch, Rev. Mod. Phys. 80, 885 (2008)
[2]: Jürgensen et. al., Nature 596, 63-67 (2021)

Q 49.29 Wed 17:00 Tent

Chiral Landau Levels and Fermi-Arcs of Weyl Points under Pseudomagnetic Fields — Sachin Vaidya[1], •Alaa Bazayeed[2], Mikael Rechtsman[3], Adolfo Grushin[4], Marin Soljačić[1], and Christina Jörg[2] — [1]Department of Physics, Massachusetts Institute of Technology, Cambridge, USA — [2]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [3]Department of Physics, The Pennsylvania State University, USA — [4]Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, France

Weyl materials are 3D topological systems characterized by Weyl points - singularities in momentum space where two energy bands touch. These Weyl points act as monopoles of Berry curvature, giving rise to surface states known as Fermi arcs, which connect projections of opposite-chirality Weyl points. Under the application of a magnetic field, the energy bands become quantized into discrete levels known as Landau levels (LL). Due to the chirality and topology of the Weyl points, the linearly dispersing zeroth LL are also chiral. In this work, we investigate the influence of pseudo-magnetic fields (e.g., those arising from strain) on Weyl systems. These fields couple to the Weyl points in a chirality-dependent manner, such that the dispersion of all zeroth LLs share the same chirality. In this case, we find that the Fermi arcs disperse in the opposite direction and provide the opposite chirality required to satisfy the fermion doubling theorem. This system thus separates the two chiralities between the surface and the bulk. We explore this behavior in a photonic model system consisting of stacks of silicon and SiO_2 layers with controlled thickness variations.

Q 49.30 Wed 17:00 Tent

Thin disk single frequency Ruby laser for metrology — •Sönke Metelmann[1], Luca Diedrich[1], Thomas Müller-Wirts[2], Carsten Reinhardt[1], Walter Luhs[3], and Bernd Wellegehausen[4] — [1]University of Applied Sciences Bremen — [2]TEM-Messtechnik — [3]Photonics Engineering Office — [4]Institut für Quantenoptik - Leibniz University Hannover

In recent contributions [1-2], 405 nm diode laser pumped cw single frequency operation of a ruby laser have been presented in linear and ring laser configurations, showing the potential for metrology applications. In this contribution, we report on laser performance, using different commercially available few- to single-mode laser diodes, which can be driven with optical output powers up to 1.5 W. The Ruby laser performance, e.g. slope efficiency, thermal and spectral properties and linewidth measurements will be presented. With a thin disk ruby crystal of only 0.5 mm, an ultra-compact single frequency laser has been realized, delivering up to 15 mW at a diode pump power of 500 mW. Features of this laser system and investigations on frequency stability and linewidth, using interferometric and beat frequency techniques will be presented and discussed.

[1] W. Luhs and B. Wellegehausen, "Diode pumped cw ruby laser," OSA Continuum 2, 184-191 (2019)
[2] W. Luhs and B. Wellegehausen, "Diode pumped compact single frequency cw ruby laser", J. Phys. Communications 7 (2023) 055007

Q 49.31 Wed 17:00 Tent

Studying the transport of optical modes carrying OAM in coupled waveguides — •Max Weber[1], Julian Schulz[1], Christina Jörg[1], and Georg von Freymann[1,2] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, 67663 Kaiserslautern, Germany

In solid state physics, electrons are described by Bloch states, which contain a spin and an orbital angular momentum (OAM) degree of freedom. Due to the spin-orbit coupling, the Spin Hall Effect (SHE) is based on the more fundamental Orbital Hall Effect (OHE). The SHE is well known and widely studied. The importance of the OAM for transport processes has been neglected. To study this effect, the explicit example of a polarized tin-tellurium layer is used. To examine the transport phenomena that depend on the orbital degree of freedom, a model system of waveguides is created. By analogy of the Schrödinger equation and the Helmholtz equation, the coupling of the electrons in the atoms can be related to the coupling of the light in the waveguides. We use optical waveguide modes with OAM to examine how transport phenomena depend on the orbital degree of freedom. To show that the OAM is coupled to the momentum of the excited wave packet, the lattice is excited with a wave packet with positive and negative OAM. We observe a change in the group velocity of the wave packet when the sign of the input OAM is switched. Thus, the momentum and the OAM are coupled.

Q 49.32 Wed 17:00 Tent

Deterministic positioning of nanocrystals in polymer waveguides with direct-laser-writing — •Thomas Utz[1], Artur Widera[1], and Georg von Freymann[1,2] — [1]Physics Department RPTU Kaiserslautern-Landau, Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany

In order to observe collective emission, it is necessary to localise the emitters in each direction to a length that is smaller than their emission wavelength. In the present study, nitrogen vacancy (NV) centers in nanodiamonds were used as emitters. The NV centers provide a well-controlled system for studying the collective emission. It is essential to achieve precise positioning of the two nanodiamonds in order to create optimal conditions for observing collective emission. We present a method for the fabrication of nanodiamond-doped waveguides that fulfil the conditions required for collective emission. The waveguides are fabricated in a heterostructure approach using the direct-laser-writing (DLW) process. In the initial phase of the process, the waveguide structures are written into a photopolymer without nanodiamonds, leaving small gaps in the waveguide to position the nanodiamonds in the next step. After development, a polymer containing nanodiamonds is used. The material is exposed only at the position of the gap to close the gap and incorporate the nanodiamonds. The volume fraction of nanodiamonds is selected in order to achieve an average of one nanodiamond per gap. After development, waveguides are fabricated with nanodiamonds in the desired position.

Q 49.33 Wed 17:00 Tent

Status of Laser Cooling at the FAIR SIS100 — •Denise Schwarz[1], Jens Gumm[1], Benedikt Langfeld[1], Tamina Grunwitz[1], Danyal Winters[2], Sebastian Klammes[2], and Thomas Walther[1,3] — [1]TU Darmstadt — [2]GSI Darmstadt — [3]HFHF Darmstadt

Bunched relativistic ion beams with a narrow momentum distribution are essential for precision experiments at modern accelerator facilities. Laser cooling presents a promising approach to further reduce the relative momentum distribution of such ion beams.

Previous experiments at the Experimental Storage Ring (ESR) at GSI have demonstrated the effectiveness of both continuous-wave (cw) and pulsed UV laser in minimizing the relative momentum distribution of bunched relativistic ion beams. To enhance cooling performance, a novel approach of integrating three laser systems - one cw and two pulsed lasers - has been proposed for application at the FAIR SIS100 accelerator. Successful implementation of this strategy requires the optimization of spatial, temporal, and energy overlap between the three laser beams and the ion beam.

This work explores the principles of laser cooling with a multi-laser configuration, with a particular emphasis on achieving precise spatial overlap between the laser and ion beams. Additionally, the critical role of active laser beam stabilization in ensuring consistent overlap is addressed.

Q 49.34 Wed 17:00 Tent

Examination of structures in transparent materials using scanning acoustic microscopy (SAM) — •Cornelia Bauer[1], Max Steudel[1], Max-Jonathan Kleefoot[2], Sebastian Funken[2], and Anne Harth[1] — [1]Center of Optical Technologies, Aalen University, Aalen — [2]Laserapplicationcenter, Aalen University, Aalen

Scanning acoustic microscopy is a non-destructive measuring technique to examine biological samples and non-transparent brittle materials. It enables the detection of internal structures and defects without causing damage. An transducer emits ultrasonic waves, which are reflected at acoustic impedance changes. The reflected signal is detected after a specific time delay by the transducer, thereby providing information regarding impedance alterations [1]. In this study, the goal is to investigate micro-scale volume modification in transparent materials using SAM. Inital results include successful measurements of laser modification in bulk fused silica glasses, demonstrating the potential of this approach for high-resolution material analysis [2]. [1] Hyunung Yu. Applied microscopy, 50(1):25, 2020. [2] Max Steudel and et al. Optics express, 32(11):19221*19229, 2024.

Q 49.35 Wed 17:00 Tent

An Interface Concept for Ion Quantum Computer: Fiber-Based Cavities for Enhanced Optical Connection — •Luca Graf[1], Lasse Irrgang[1], Tuncay Ulas[1], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg

The development of quantum computers promises to solve computational complex problems in the future that cannot be solved with classical computers. Just as in conventional computing clusters, quantum computers must also be networked in a scalable way. We present an innovative concept for an interface that has been specially developed for ion traps. This approach uses special coated fiber-based cavities to establish an efficient optical connection between ion traps. Furthermore, this approach can be used to couple optical qubits, such as entangled photons, with ions in the trap.

Q 49.36 Wed 17:00 Tent

Implementation of a laser system for alkali vapor MEMS cell activation — •Janice Wollenberg[1], Julien Kluge[1,2], Daniel Emanuel Kohl[1], Andreas Thies[2], Klaus Döringshoff[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik - Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut(FBH), Leibniz-Institut für Höchstfrequenztechnik

We present a laser system designed for the activation and characterization of rubidium vapor MEMS cells. Utilizing these mm-scale cells is a cruicial step towards chip-scale optical frequency references based on two-photon spectroscopy of rubidium at 778 nm. Our approach involves employing a high-power laser at 1064 nm to activate a rubidium dispenser pill, which is contained in one of the MEMS cells chambers. After activation, the pill releases elementary rubidium and micro-channels guide the rubidium vapor into a second chamber for spectroscopy. We use Doppler-free saturation spectroscopy of the D2 transition at 780 nm to characterize the cells. The outcomes of this work are expected to help produce rubidium cells for optical clocks. This involves further refinement and testing cell geometries, channel configurations, and relevant cell parameters, as well as the implementation of automated setup processes. This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971, 50WM2164, 50WM2169.

Q 49.37 Wed 17:00 Tent

Collective Driving of Many-Photon Quantum States — •Gabriela Carla Silva Militani[1], Moritz Kaiser[1], René Schwarz[1], Ria Krämer[2], Stefan Nolte[2], Philip Poole[3], Dan Dalacu[3], Gregor Weihs[1], and Vikas Remesh[1] — [1]Institute for Experimental Physics, University of Innsbruck, Technikerstrasse 25d, 6020 Innsbruck, Austria — [2]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany — [3]National Research Council Canada, Ottawa, ON K1A 0R6, Canada

This work aims to present the simultaneous excitation of two uncoupled InP/InAsP quantum dots embedded in a nanowire. Our excitation method is the two-photon excitation adiabatic rapid passage, by which both dots are excited to their biexciton state and subsequently emit polarization-entangled photon pairs in a cascade. In this scheme, a pulsed laser tuned to the two-photon resonance is chirped using a custom-designed chirped fiber Bragg grating (CFBG). The resulting spectral phase variation induces an adiabatic population transfer in the dot. Because of this, the biexciton state population does not exhibit Rabi rotations under a pulse area scan. In other words, our excitation method is robust and insensitive to laser power and frequency fluctuations. Taking advantage of this, we simultaneously excite both dots and demonstrate the generation of two pairs of entangled photon states. Our work paves the way for the scalable generation of multiphoton entangled states for advanced quantum technology applications.

Q 49.38 Wed 17:00 Tent

Violating the thermodynamic uncertainty relation in the three-level laser — •Sander Stammbach — Universität Basel, Basel, Schweiz

Heat engines are devices that convert thermal energy into useful work under continuous, cyclic operation. The prime example of a quantum heat engine is the three-level laser (or maser) [1]: an incoherent pump process plays the role of a heat reservoir, providing thermal energy to create a population inversion. At the same time, the lasing transition leads to useful work output in the form of stimulated emission into a coherent driving field that is usually treated as a time-dependent coherent amplitude. Here, we consider a model in which the three-level system is placed in a single-mode cavity that is externally driven by coherent light. Making use of the framework of full counting statistics [2], we investigate the fluctuating energy currents of the system as a function of the drive. We also evaluate the thermodynamic uncertainty relation (TUR) [3] and identify the quantum regimes of operation in which its classical bound can be violated. In previous studies without cavity, these regimes could result in an enhanced output power, i.e., a quantum advantage. Our findings suggest that this is no longer the case in a cavity.

Q 49.39 Wed 17:00 Tent

Coherent Control in Size Selected Semiconductor Quantum Dot Thin Films — •Victor Kärcher[1], Tobias Reiker[1], Pedro F. M. G. da Costa[2], Andrea S. S. de Camargo[3], and Helmut Zacharias[1] — [1]48149, Münster, Uni Münster — [2]São Carlos Institute of Physics, University of São Paulo, São Carlos - SP 13566-590, Brazil, — [3]Federal Institute for Materials Research and Testing (BAM), 12489 Berlin

We introduce a novel technique for coherent control that employs resonant internally generated fields in CdTe quantum dot (QD) thin films at the L-point. The bulk band gap of CdTe at the L-point amounts to 3.6 eV, with the transition marked by strong Coulomb coupling. Third harmonic generation is used to control quantum interference of three-photon resonant paths between the valence and conduction bands. Different thicknesses of the CdTe QDs are used to manipulate the phase relationship between the external fundamental and the internally generated third harmonic, resulting in either suppression or strong enhancement of the resonant third harmonic, while the non-resonant components remain nearly constant. This development could pave the way for new quantum interference based applications in ultrafast switching of nanophotonic devices.

Q 49.40 Wed 17:00 Tent

Towards three-dimensional confinement of the electron beam inside dielectric laser accelerators — •Manuel Konrad[1], Stefanie Kraus[1], Leon Brückner[1], Julian Litzel[1], Zhexin Zhao[1], Tomas Chlouba[1,2], Roy Shiloh[1,3], and Peter Hommelhoff[1,4] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Center for Nanophotonics, AMOLF, 1098 XG Amsterdam — [3]Institute of Applied Physics, Hebrew University of Jerusalem (HUJI), Jerusalem, Israel

— [4]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

While classical particle accelerators typically utilize metal cavities driven by radio-frequency fields to create the accelerating fields, dielectric laser accelerators (DLA) adapt the same concepts to dielectric structures driven by high repetition rate laser pulses. Alternating phase focusing (APF) is employed so that the electron beam stays confined inside the acceleration channel [1]. After we successfully applied this concept to gain phase space control over the electron in one longitudinal and one transversal direction [2], we have recently shown coherent acceleration of electrons. By keeping the beam confined in a 500 um long structure, we were able to accelerate the electrons from 28.4 to 40.7 keV in a scanning electron microscope [3]. We will show how the APF scheme can be expanded to full 3D confinement and discuss how it is affected by illuminating the structure from the top.

[1] Niedermayer et al., PRL 121, 214801 (2018) [2] Shiloh et al., Nature 597, 498 (2021) [3] Chlouba et al., Nature, 622, 476 (2023)

Q 49.41 Wed 17:00 Tent

Coherent Optical Control of Semiconductor Quantum Dots — •Charlie Evagora[1], Rene Schwarz[1], Saimon da Silva[2], Armando Rastelli[2], Doris Reiter[3], Vikas Remesh[1], and Gregor Weihs[1] — [1]Institute for Experimental Physics, University of Innsbruck, Technikerstrasse 25d, 6020 Innsbruck, Austria — [2]Institute of Semiconductor Physics, Johannes Kepler University Linz, Altenbergerstr. 69, A-4040 Linz, Austria — [3]Condensed Matter Theory, Department of Physics, TU Dortmund, 44221 Dortmund, Germany

The development of quantum technologies is heavily dependent on reliable sources of single photons with near perfect indistinguishability. In recent years, semiconductor quantum dots (QD) have become a viable platform with high brightness, tunability, and deterministic mode of operation.

The most prominent scheme for QD excitation is the Rabi scheme, using an on-resonance pulse to invert the emitter population. Despite guaranteeing near perfect photon properties, it is counterproductive in terms of brightness, necessitating extra filtering procedures.

Given this context, an alternative scheme that has gained particular interest is the Swing-UP of quantum EmitteR (SUPER) scheme, which uses 2 red-detuned pulses to drive population inversion. This scheme was realised by our group for a GaAs/AlGaAs system, which has subsequently been implemented by numerous other groups for a variety of platforms. Here we report detailed investigation on the detuning dependence of photon indistinguishability and photon number purity under SUPER excitation.

Q 49.42 Wed 17:00 Tent

Integrated Photonic Quantum Walks for Universal Computation — •Lasse Wendland[1], Florian Huber[2,3,4], Benedikt Braumandl[2,3,4], and Jasmin Meinecke[1,2] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, 10623, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Department für Physik, Ludwig-Maximilians-Universität, München, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), München, Germany

As the quantum mechanical analog of a classical random walk, quantum walks offer a powerful framework for advancing various modern quantum technologies. Furthermore, quantum walks can be viewed as a model of computation. In 2009, Andrew M. Childs demonstrated that any quantum circuit can be efficiently simulated by a simple quantum walk on a sparse graph. Although the graph associated with a quantum walk computation is exponentially large in the number of qubits and therefore cannot be efficiently implemented using spatially separated vertices, this model can still serve as a useful testbed for studying quantum walk computations. In our research, we leverage the inherent stability, compactness, and versatility of photonic waveguide arrays as a platform for exploring these computations.

Q 49.43 Wed 17:00 Tent

Investigation of the valence electronic structure and dynamics of nanostructured materials via high-order harmonic generation — Agata Azzolin[2,5], •Noah Tettenborn[1,5], Sani Harouna-Mayer[3], Oliviero Cannelli[2,5], Yogesh Mahor[3], Francesco Caddeo[3], Andrea Trabattoni[2,4,5], Terry Mullins[2,5], Vincent Wanie[2,5], Dorota Koziej[3], and Francesca Calegari[1,2,5] — [1]University of Hamburg — [2]Desy, Hamburg — [3]Institute for Nanostructure and Solid State Physics, University of Hamburg — [4]Leibniz University Hannover — [5]Center for Free-Electron Laser Science, Hamburg

In previous works, HHG has been shown to be a suitable tool for characterizing valence potentials in bulk systems [1]. Here, we aim to establish this technique as a complementary, all-optical, in-situ tool to characterize nanoengineered transition metal oxides, mapping their response across different ordering scales.

Preliminary experimental data exploring excitations at different wavelengths, intensities, and polarizations will be presented for different ordered systems. The results are supported by simulations done in the framework of TDDFT for different crystal structures, incident intensities, wavelengths, and polarizations. These are used to predict the reconstructive capabilities at different configurations.

[1] Lakhotia et al., Nature, 2020, https://doi.org/10.1038/s41586-020-2429-z

Q 49.44 Wed 17:00 Tent

Engineering mirrors on the nanoscale: Cavity fiber mirrors by Qlibri — •Franziska Haslinger, Michael Förg, Manuel Nutz, Jonathan Noé, and Thomas Hümmer — Qlibri GmbH, Munich, Germany

Tunable optical-fiber-based micro-cavities offer a variety of applications such as sensing (Jiang, 2001), manipulation of solid-state systems (Dufferwiel, 2015), quantum information processing (Grinkemeyer, 2024), and absorption microscopy (Hümmer, 2016). The key component of such a system is an optical fiber with a precise spherically shaped depression in its end facet. This has previously not been manufacturable with reproducible results on a large scale.

Here, we present a fabrication method for high quality fibers to use in an open micro-cavity system utilizing laser induced thermal ablation and dielectric coating. With hundreds of shots, only ablating a few nanometers per shot, the resulting symmetry and fiber geometry are reproducible and reliable. Precise tuning of properties such as the mode volume, mode-matching and very short and very long operable cavity lengths is thus possible.

Tailoring their geometrical and optical properties allows to adapt to a variety of experimental needs. In selected experiments we demonstrate the performance of these fibers in state-of-the-art micro-cavity applications.

Q 49.45 Wed 17:00 Tent

Quantum Sensing with Nanodiamonds — •Zeeshan Nawaz Khan[1], Wanrong Li[1], Mike Johannes[1], Oliver Benson[1], and Masazumi Fujiwara[2] — [1]Insitute for Physics, HU Berlin, Germany — [2]Okayama University, Okayama, Japan

Nitrogen Vacancy (NV) NV centers in diamond, due to their compact size and operation at room temperature, are strong candidates for quantum sensing applications, i.e., magnetic field or temperature sensing. In our lab, we are developing a scanning confocal microscope setup which is optimized for diamond magnetometry in living cells at room temperature. Based on our previous work with C. Elegans [1], we will now focus on plant cells in collaboration with the *Integrative Center - Life in Space at Time*, IZ-LIST, at Humboldt-University. We present first results with our setup on the temperature dependence of optically detected magnetic resonance (ODMR). Practical issues such as sensitivity and fluorescence background in plant cells will be discussed. Future studies aim at the investigation of heat management in biological systems on the cellular level.

Q 50: Ultracold Matter (Fermions) I (joint session Q/A)

Time: Thursday 11:00–12:45 Location: HS V

Q 50.1 Thu 11:00 HS V

Erbium-Lithium: towards a new quantum mixture experiment — Alexandre De Martino, Kiesel Florian, Karpov Kirill, •Jonas Auch, and Christian Gross — University of Tübingen, Tübingen, Germany

The goal of this Erbium-Lithium mixture experiment, is to lower the current temperature limit for fermions. One key for this shall be the strong mass imbalance, as we use heavy bosonic erbium atoms as a heat reservoir for the light fermionic lithium atoms. While trapping erbium in a shallow trap at 1064 nm, we want to utilize the tuneout wavelength of erbium at 841 nm. This enables an additional, narrow trap for lithium. In addition to this cooling aspect, the combination of erbium and lithium enables polaron physics, with heavy dopants of erbium in an lithium environment.

Q 50.2 Thu 11:15 HS V

Spectral structure and dynamics of partially distinguishable fermions on a lattice — •Caroline Stier, Edoardo Carnio, Gabriel Dufour, and Andreas Buchleitner — Albert-Ludwigs-Universität Freiburg

We study the fermionic many-body quantum dynamics generated by a Hubbard-like Hamiltonian with nearest neighbour interaction and a continuously tunable level of distinguishability of the particles. For not strictly indistinguishable fermions, distinct invariant symmetry sectors of the many-body Hilbert space are populated, with tangible impact on the many-body dynamics. We identify the regime of tunneling and interaction strengths where the many-body eigenstates acquire ergodic structure, and investigate how the interplay between dynamical instability and partial distinguishability affects the evolution of the many-body counting statistics.

Q 50.3 Thu 11:30 HS V

Building a programmable quantum gas microscope — •Isabelle Safa[1], Sarah Waddington[1], Tom Schubert[1], Rodrigo Rosa-Medina[1], and Julian Leonard[1,2] — [1]Atominstitut TU Wien, Stadionallee 2, 1020 Wien, Austria — [2]Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria

Ultracold atoms in optical lattices offer a versatile platform for simulating and probing strongly correlated quantum matter. While quantum gas microscopy techniques have enabled unprecedented single-site resolution, key remaining challenges of the field are still posed by rigid lattice configurations and slow cycle times.

Here, we present our ongoing efforts to tackle these issues by designing and building a next-generation quantum gas microscope for fermionic and bosonic lithium atoms. Our approach relies on atom-by-atom assembly in small lattice systems by means of auxiliary optical tweezers, combined with all-optical cooling techniques to facilitate sub-second experimental cycles. The holographic projection of a blue-detuned, short-spacing lattice will provide reconfigurability and fast tunneling dynamics, leading to diverse research avenues for our new project, from the simulation of Bose- and Fermi-Hubbard models with unconventional geometries to strongly correlated topological phases.

Q 50.4 Thu 11:45 HS V

A versatile Quantum Gas Platform - Heidelberg Quantum Architecture — •Tobias Hammel, Maximilian Kaiser, Daniel Dux, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Heidelberg, Germany

Programmable quantum simulation and computation with ultracold quantum systems requires the combination of sophisticated functionalities that have to work all at the same time, in particular including high precision optical potentials.

With our new experimental platform, we present a solution which helps to manage this increasing complexity. This platform is characterized by optical modules which can be implemented into the experiment plug-and-play in a fast, repeatable and predictable way.

In this talk our implementation of the platform is presented including optical modules generating dipole traps, tweezers, an optical accordion and box potentials. Furthermore, we present first experimental results realized within this platform.

Q 50.5 Thu 12:00 HS V

Fate of the Higgs mode in confined fermionic superfluids — •René Henke[1], Cesar R. Cabrera[1], Hauke Biss[1], Lukas Broers[2], Jim Skulte[2], Hector Pablo Ojeda Collado[2], Ludwig Mathey[1,2], and Henning Moritz[1] — [1]Institut für Quantenphysik, Universität Hamburg — [2]Zentrum für optische Quantentechnologien, Universität Hamburg

In superconductors and superfluids, the order parameter characterizes the phase coherence and collective behavior of the system. Fluctuations in the phase and amplitude of the order parameter give rise to the Goldstone and Higgs modes, respectively. In confined systems, these dynamics as well as the static properties of superfluids are expected to change dramatically. As an example of the latter, shape resonances in nano wires and films are predicted to enhance the superfluid gap and raise T_c.

Here, I will report on the observation of a hybridization between Higgs and breathing oscillations in a quasi-2D fermionic superfluid. When modulating the confinement, we observe a well-defined collective mode throughout the BEC-BCS crossover. In the BCS regime, the excitation energy follows twice the pairing gap, as expected for an amplitude oscillation, drops below it in the strongly correlated regime, and approaches the breathing mode frequency, in excellent agreement with an effective field theory for order parameter dynamics. The mode vanishes when approaching the superfluid critical temperature. Our results provide insights into the complex interplay between confinement-induced effects and fundamental excitations in reduced dimensions.

Q 50.6 Thu 12:15 HS V

Quantum Computation with fermionic Li-6 atoms in optical lattices — •Johannes Obermeyer[1], Petar Bojović[1], Si Wang[1], Marnix Barendregt[1], Dorothee Tell[1], Immanuel Bloch[1,2], Titus Franz[1], and Timon Hilker[3] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Ludwig-Maximilians-Universität, München, Germany — [3]University of Strathclyde, Glasgow, UK

In our quantum gas microscope, we load fermionic Li-6 atoms into isolated double wells in optical superlattices. By precisely controlling the relative phase and intensity of the superlattices, we encode single- and two-qubit gates within these isolated double-wells, which constitute the building blocks for digital, fermionic quantum computation. Site-resolved measurement of spin and density allows us to fully characterize the initial state preparation and the quantum gate fidelity. In this talk, I will present how we realized high-fidelity SWAP$^\alpha$ two-qubit gates with over one hundred atoms. We demonstrate long coherence and stability of the qubit and we characterize main error mechanisms. These results hold substantial promise for quantum computation tasks, including the simulation of electronic systems like molecular structures.

Q 50.7 Thu 12:30 HS V

Exploring Integer and Fractional Quantum Hall states with six rapidly rotating Fermions — •Paul Hill, Johannes Reiter, Jonas Drotleff, Philipp Lunt, Maciej Galka, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

The quantum Hall effect features remarkable states that due to their exotic topological properties and strongly correlated nature have stimulated a rich body of research going far beyond the condensed matter community, where the effect was originally discovered. The effect manifests in two forms: the integer (IQH) and fractional (FQH) quantum Hall effect, distinguished by the significance of repulsive particle interactions. In earlier experiments, we have realized a two-particle Laughlin (FQH) state by rapidly rotating two interacting spinful fermions confined in a tight optical tweezer. Building on this technique, we now present first results for a larger system consisting of six particles: the realization of a two-component IQH state comprising 3+3 spinful fermions. Through imaging of the individual atoms, we capture snapshots of the many-body density and observe a hallmark feature of IQH states–a uniform flattening of the particle density distribution. Our result not only highlights the scalability of the approach but also paves the way for studying FQH states due to the tunability of the interactions between the particles. This brings within reach the realization of a three-particle Laughlin state and the observation of a quantum phase transition between IQH states of weakly interacting fermions and FQH states of interacting bosonic molecules.

Q 51: Quantum Computing and Simulation I (joint session Q/QI)

Time: Thursday 11:00–13:00 Location: AP-HS

Q 51.1 Thu 11:00 AP-HS

Simulating scalar quantum field theories on integrated photonics platforms — •Mauro D'Achille[1], Martin Gärttner[1], and Tobias Haas[2] — [1]Friedrich Schiller Universität, Jena, Germany — [2]Université Libre de Bruxelles, Bruxelles, Belgium

Photonic multimode systems are an emerging quantum simulation platform ideally suited for emulating non-equilibrium problems in quantum field theory. I will present a new decomposition*for the time evolution generated by a large class of field-theoretic quadratic Hamiltonians*in terms of optical elements. The peculiarity of this decomposition consists in the way the time parameter is taken into account. Indeed, for such a class, it is always possible to decouple the time evolution in time-dependent phase shift transformations by means of a proper time-independent symplectic transformation composed by squeezers and beam splitters. I will conclude with physically relevant examples and applications aimed to analyze and simulate how the entanglement entropy associated to local and non-local theories spreads over time.

Q 51.2 Thu 11:15 AP-HS

Photonic Qubit Z-Gate Scheme from Scattering with Atomic Vapors in a 1D Waveguide Slot — •Evangelos Varvelis and Joachim Ankerhold — Institute for complex quantum systems, University of Ulm

Photonic quantum computing offers a promising platform for quantum information processing, benefiting from the long coherence times of photons and their ease of manipulation. This paper presents a scheme for implementing a deterministic Z-gate for frequency-encoded photonic qubits, leveraging a silicon slot waveguide filled with thermal rubidium vapor. This system enhances atom-photon interactions via the Purcell effect, allowing dynamic control of nonlinearity at the few-photon level while operating efficiently at room temperature. Using a transfer matrix approach, we develop a protocol for Z-gate operation, demonstrating its robustness against non-waveguide mode coupling and disorder. Finally, we will relax the idealized assumption of monochromatic light in favor of finite bandwidth pulses. Despite these realistic considerations, our results indicate high fidelity for the proposed Z-gate.

Q 51.3 Thu 11:30 AP-HS

Modeling Fabrication Tolerances in RF Junctions for Register-Based Trapped-Ion Quantum Processors — •Florian Ungerechts[1], Rodrigo Munoz[1], Janina Bätge[1], Mohammad Masum Billah[1], Axel Hoffmann[1,2], Giorgio Zarantonello[1,3], and Christian Ospelkaus[1,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Germany — [3]QUDORA Technologies GmbH, Braunschweig, Germany — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Radiofrequency (RF) junctions are crucial elements for enabling two-dimensional structures in the Quantum Charge-Coupled Device (QCCD) architecture and are thus essential for scaling trapped-ion quantum processors. As the resulting pseudopotential and its attributes depend on the specific junction geometry, they are susceptible to fabrication tolerances. To address this challenge, our study incorporates common microfabrication errors, including feature over- and underexposure and corner rounding, into the simulation models. Utilizing this comprehensive toolset, we evaluate an optimized RF X-junction in a surface-electrode trap, assessing its robustness against typical errors encountered in the multilayer microfabrication process.

Q 51.4 Thu 11:45 AP-HS

Local Control in a Sr quantum computing demonstrator — •Kevin Mours[1,3], Eran Reches[1,3], Robin Eberhard[1,3], Dimitrios Tsevas[1,3], Zhao Zhang[1,3], Lorenzo Festa[1,3], Max Melchner[1,2,3], Andrea Alberti[1,2,3], Sebastian Blatt[1,2,3], Johannes Zeiher[1,2,3], and Immanuel Bloch[1,2,3] — [1]Max-Planck Institut für Quantenoptik, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 Munich, Germany — [3]Munich Center for Quantum Science and Technology, 80977 Munich, Germany

Digital quantum simulations and quantum error correction protocols require the application of local gates. We demonstrate such local control in a neutral atom array platform by locally shifting the qubit's frequency using off-resonant light. We show precise, highly parallel, local Z-rotations with low crosstalk. Together with global X-rotations, which have been optimized for minimizing motional entanglement using optimal control, this approach can be used to locally implement universal single-qubit operations.

Q 51.5 Thu 12:00 AP-HS

Programmable Fermionic Quantum Simulation with Ground-State Optical Tweezer Arrays — •Jin Zhang[1], Naman Jain[1], Marcus Culemann[1,2], Kirill Khoruzhii[1,2], Jun Ong[1], Xinyi Huang[1], Pragya Sharma[1], and Philipp Preiss[1,3] — [1]Max Planck Institute of Quantum Optics, Garching — [2]Ludwig-Maximilians-Universität, Munich — [3]Munich Center for Quantum Science and Technology

Programmable quantum simulation using ultracold fermions in optical lattices has emerged as a powerful approach to investigating many-body phenomena and non-equilibrium dynamics. Nonetheless, the initialization of arbitrary quantum states remains a significant challenge. Recent advances in optical tweezer arrays offer a promising solution for creating programmable initial states. Leveraging the reconfigurability of tweezers, atoms can be arranged into arbitrary spatial configurations. When combined with optical lattices and site- and spin-resolved imaging techniques, this setup establishes an ideal platform for quantum information studies. In this presentation, we demonstrate the rapid and high-fidelity preparation of optical tweezer arrays, achieving deterministic trapping of fermionic atom pairs in the motional ground state of each tweezer. We showcase spin-dependent free-space imaging, efficient loading and evaporation protocols, as well as deterministic control of atom numbers within the tweezer arrays. These advancements expand the scope of quantum simulation beyond ground-state Hubbard physics, enabling exploration of quantum chemistry and fermionic quantum information processing.

Q 51.6 Thu 12:15 AP-HS

Towards cavity-mediated entanglement within an atomic array — •Johannes Schabbauer[1], Stephan Roschinski[1], Franz von Silva-Tarouca[1], and Julian Leonard[1,2] — [1]TU Wien, Atominstitut, Vienna Center for Quantum Science and Technology (VCQ), Stadionallee 2, 1020 Wien, Austria — [2]Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria

Creating multi-particle entangled states deterministically is one of the big challenges for quantum information processing. While this was achieved locally in several systems, for instance with arrays of optical tweezers using Rydberg interactions between atoms, we set up an experiment to engineer non-local interactions between single atoms in optical tweezers by strong coupling to an optical cavity. In our experiment we reach the single-atom strong-coupling regime using a fiber cavity (C=80). Our cavity setup also enables good optical access for high resolution microscopes, which are used for trapping, site-resolved imaging and addressing of single atoms in optical tweezers. Our experiment enables us to study multi-particle entangled states and many-body systems with programmable interactions. The dispersive shift of the cavity resonance can be used to perform non-destructive measurements and to implement protocols for dissipative state preparation.

Q 51.7 Thu 12:30 AP-HS

Neutral Ytterbium atoms in optical tweezers for quantum computing and simulation — •Jonas Rauchfuss[1], Tobias Petersen[1], Nejira Pintul[1], Clara Schellong[1], Jan Deppe[1], Carina Hansen[1], Koen Sponselee[1], Alexander Ilin[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center of Optical Quantum Technologies University of Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg

In recent years, neutral atoms have emerged as a promising platform for quantum computing and quantum simulation, featuring scalable and highly coherent quantum systems with high-fidelity single-atom control as well as engineerable strong long range interactions. We use the alkaline-earth-like element ytterbium, whose fermionic isotope ^{171}Yb features a rich level structure, allowing e.g. for optical trapping and manipulation of Rydberg states, as well as metastable states, offering the realisation of sophisticated qubit schemes.

In this talk, we introduce our experimental setup, show characterisations of tweezer loading and imaging, and present our current progress towards building a neutral-atom quantum simulator. We further present efforts to overcome known limitations of current quantum computation and simulation platforms, like arbitrary atom addressing techniques and efficient suppression of servo induced laser noise for highest fidelity excitation schemes.

Q 51.8 Thu 12:45 AP-HS

Eigen-SNAP gate of two photonic qubits coupled via a transmon — •Marcus Meschede[1] and Ludwig Mathey[1,2,3] — [1]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

In the pursuit of robust quantum computing, bosonic qubits encoded in cavity modes have emerged as a promising platform. Full control over single bosonic qubits can be achieved through bosonic mode displacement drives and the driving of a dispersively coupled ancilla. However, the implementation of two-qubit gates depends heavily on the specifics of the coupling between the two bosonic modes. Building on the design of the selective number-dependent phase (SNAP) gate for the single cavity system, we extend this concept to develop the eigen-SNAP gate. This gate operates on the eigenmodes of the two coupled bosonic modes. Using the eigen-SNAP gate, we implement an entangling gate on a system of two logical bosonic qubits. Further, we use numerical optimization to determine the optimal version of the entangling gate $\sqrt{\mathrm{SWAP}}$. The fidelities of these optimal protocols are limited by the coherence times of the system's components. The entangling gate is compatible with bosonic error-correctable encodings and is agnostic to the specific encoding within this class of logical qubits, paving the way to continuous variable quantum computing.

Q 52: Nuclear Clocks

In 2024, direct laser excitation of the 229-Th nuclear clock transition was achieved by three research groups. These breakthroughs have led to several orders of magnitude of improvement in the energy constraint of this nuclear state. With this knowledge, the implementation of a nuclear clock has started with a rapid succession of laser, ion trap and host material developments. A nuclear clock promises very high accuracy and stability as well as interesting applications in fundamental physics. This session highlights these exciting development with two invited and four contributed talks.

Time: Thursday 11:00–13:00 Location: HS Botanik

Invited Talk Q 52.1 Thu 11:00 HS Botanik

Recent progress towards the development of a ^{229}Th-based nuclear optical clock — •Lars von der Wense — Johannes Gutenberg-Universität Mainz

The development of a nuclear optical clock based on spectroscopy of the first nuclear excited state of the ^{229}Th isotope has long been in the scientific focus[1]. Significant progress has been made in the year 2024, when three independent research groups reported success in laser spectroscopy of this previoulsy elusive nuclear state[2,3,4]. In this talk, I will provide a review of the recent developments in the field, with a special focus on the JILA experiment[4], where direct frequency comb spectroscopy of the transition was achieved. In addition, I will provide an overview on the activities underway at the University of Mainz, where we are investigating the options for cw laser spectroscopy of the nuclear transition based on light generated via quasi-phase matching in $BaMgF_4$.

[1] L. von der Wense et al., Eur.Phys.J. A, 56:277 (2020).
[2] J. Tiedau et al., PRL 132, 182501 (2024).
[3] R. Elwell et al., PRL 133, 013201 (2024).
[4] C. Zhang et al., Nature 633, 63 (2024).

This work is supported by the BMBF Quantum Futur II Grant Project "NuQuant" (FKZ 13N16295A).

Q 52.2 Thu 11:30 HS Botanik

Towards a solid-state VUV CW Laser for the ^{229}Th Nuclear Clock — •Keerthan Subramanian[1], Nutan Kumari Sah[1], Florian Zacherl[1], Srinivasa Pradeep Arasada[1], Valerii Andriushkov[2,3], Yumiao Wang[1], Ke Zhang[1], Jonas Stricker[1,2,3], Christoph Düllmann[1,2,3], Dmitry Budker[1,2,3], Ferinand Schmidt-Kaler[1], and Lars von der Wense[1] — [1]Johannes Gutenberg Universität Mainz — [2]Helmholtz Institut Mainz — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH

In the entire nuclear energy landscape consisting of nearly 3300 isotopes and 176000 energy levels, ^{229}Th is the only isotope featuring an unusually low lying isomer with an energy 8.4eV above the ground state. Recent developments have succeeded in laser exciting this 148.3 nm Vacuum UltraViolet (VUV) transition and have paved the way for the development of a nuclear clock which is expected to outperform state of the art atomic clocks. VUV radiation precludes the use of compact, commercial tunable laser sources. It also limits the number of crystals which (a) are VUV-transparent, (b) have a significant nonlinear coefficient, and (c) are amenable to some form of (quasi-)phase matching. Here we present progress towards this goal of developing a compact solid-state frequency doubled Continuous Wave (CW) laser in periodically poled $BaMgF_4$. This key technological development would enable the realization of a nuclear clock which is expected to have profound implications for tests of fundamental physics. This work is supported by BMBF Quantum Futur II Grant Project "NuQuant" (FKZ13N16295A)

Q 52.3 Thu 11:45 HS Botanik

Towards Continuous-Wave Laser Excitation of the ^{229}Th Nuclear Isomer Sympathetically Cooled with Ca Ions — •Ke Zhang[1], Valerii Andriushkov[3,4], Yumiao Wang[1,2], Keerthan Subramanian[1], Srinivasa Pradeep Arasada[1], Florian Zacherl[1], Nutan Kumari Sah[1], Jonas Stricker[1,3], Christoph E. Düllmann[1,3,4], Dmitry Budker[1,3,4,5], Ferdinand Schmidt-Kaler[1], and Lars von der Wense[1] — [1]University of Mainz, Germany — [2]Fudan University, China — [3]Helmholtz Institute Mainz, Germany — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany — [5]University of California, USA

We propose an experimental scheme for the laser excitation of the nuclear isomeric state in the $^{229}Th^{3+}$ ion system, a significant challenge in nuclear and atomic physics. Thorium ions are generated from a recoil ion source and guided into a Paul trap using a radio frequency quadrupole (RFQ) guide and a mass filter. Sub-Doppler-cooled $^{40}Ca^{+}$ ions are used to sympathetically cool the thorium ions to their motional ground state, where the ions are deeply confined in the Lamb-Dicke regime. A continuous-wave laser, stabilized to match the nuclear transition energy, will be employed to drive the isomeric transition. This experimental scheme aims to demonstrate the feasibility of precision nuclear spectroscopy in sympathetically cooled ion systems, paving the way for ion-based nuclear optical clocks and advancing fundamental physics research. This work is supported by the DFG Project 'TACTICa' (grant agreement no. 495729045) as well as the BMBF Quantum Futur II Grant Project 'NuQuant' (FKZ 13N16295A).

Q 52.4 Thu 12:00 HS Botanik

Buffer Gas Stopping Cell for Extraction of ^{229}Th Ions for Nuclear Clock Development — •Srinivasa Pradeep Arasada[1], Florian Zacherl[1], Keerthan Subramanian[1], Jonas Stricker[1,2], Valerii Andriushkov[2,3], Yumiao Wang[1,4], Nutan Kumari Sah[1], Ke Zhang[1], Ferdinand Schmidt-Kaler[1], Dmitry Budker[1,2,3,5], Christoph E Düllmann[1,2,3], and Lars von der Wense[1] — [1]Johannes Gutenberg Universität Mainz, Germany — [2]Helmholtz Institute Mainz, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [4]Fudan University, Shanghai, China — [5]Department of Physics, University of California, Berkeley, USA

The isomeric state of ^{229}Th offers a unique opportunity for precision spectroscopy due to its exceptionally low excitation energy, making it most suitable for developing nuclear clocks with unprecedented accuracy. The isomeric state in ^{229}Th can be populated via a 2% decay branch during α decay of ^{233}U. Here we outline our plans for extracting thorium ions from a ^{233}U recoil-ion source using a buffer gas stopping cell. The system utilizes ultra-pure helium gas to minimize substantial losses caused by charge exchange or molecular formation. The extracted Th^{3+}ions are subsequently loaded into a Paul trap via a radio frequency quadrupole (RFQ) guide and Quadrupole Mass Spectrometer(QMS), where they are co-trapped with laser-cooled $^{40}Ca^+$ ions for spectroscopic interrogation.

This project is supported by the BMBF Quantum Futur II Grant Project 'NuQuant'(FKZ 13N16295A).

Q 52.5 Thu 12:15 HS Botanik

Construction and Commissioning of a Closed-Cycle Xenon-Recycling System for HHG-based VUV Lasers — •Georg Holthoff, Tim Teuner, and Peter G. Thirolf — Ludwig-Maximilians-Universität, München, Deutschland

We discuss the need for and design, construction and commissioning of a closed-cycle Helium:Xenon-recovery system designed to scavenge, filter and recompress variable mixtures of Helium and Xenon (up to 9:1) to pressures of up to 100 bar for use in High-Harmonic Generation (HHG) based Vacuum Ultraviolet (VUV) laser-light generation. The relevant components of the system, i.e. first collection from the HHG enhancement-resonator chamber where the gas is used and its filtering at ambient pressure, second, compression to the planned operating range of 60 bar in two stages and third final filtering and pressure stabilization, as well as the control system, are discussed. Subsequently, the commissioning results are presented. They include operational tests of components, leak testing using different methods and gases (aiming for a total recovery efficiency of about 98%), as well as mass-spectrometric analysis of residual gasses at different stages of the system. Characterization results are acquired in a closed-loop test setup, using a borosilicate gas-injection nozzle of dimensions similar to those in the designated VUV frequency-comb laser. Instead of the HHG enhancement resonator of this laser, the injection chamber of the test loop is comprised of an additional small vacuum chamber to not endanger the laser components during commissioning of the gas-recycling system.
Supported by the European Research Council (ERC): Grant 856415.

Invited Talk Q 52.6 Thu 12:30 HS Botanik

Making a solid-state nuclear optical clock — •Kjeld Beeks[1,2], Luca Toscani de Col[2], Ira Morawetz[2], Rahul Singh[1], Michael Bartokos[2], Thomas Riebner[2], Fabian Schaden[2], Georgy Kazakov[2], Tomas Sikorsky[2], Thomas LaGrange[1], Fabrizio Carbone[1], and Thorsten Schumm[2] — [1]École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland — [2]TU Wien, Vienna, Austria

The first nuclear excited state or isomer of ^{229}Th has an extremely low energy (8.4 eV/148 nm) and long lived (1750 s) excited state. This is a platform for a future extremely precise nuclear optical clock, on the 10^{-17} level for Th doped in CaF_2. Owing to its nuclear nature, it would be a new sensitive probe for fundamental physics. Recently, a string of successes led to nuclear spectroscopy on the 300 kHz level. The successes hinges on the development of a highly doped VUV transparent CaF_2 crystal, doped with the radioactive ^{229}Th. In this talk I will elaborate on how the crystal platform was originally developed and characterized: Crystal growth and crystal healing. More recently, an indication appeared why previous attempts of excitation in a crystal were unsuccessful: The nuclear excitation quenches through an interaction with the solid-state environment. I will further report a diverse array of new measurements and calculations characterizing the interaction and the solid-state environment of $^{229}Th{:}CaF_2$ crystals. These measurements and calculations show we can control the interaction of the nucleus with its environment. With every characterization, and every simulation, the solid-state nuclear clock comes a step closer.

Q 53: Matter Wave Interferometry II

Time: Thursday 11:00–13:00 Location: HS I

Q 53.1 Thu 11:00 HS I

Bayesian optimization for state engineering of quantum gases — •Gabriel Müller, Victor Jose Martinez-Lahuerta, and Naceur Gaaloul — Leibniz University Hannover, Institute for Quantum Optics, Hannover, Germany

State engineering of quantum objects is a central requirement for precision sensing. When the quantum dynamics can be described by analytical solutions or simple approximation models, optimal state preparation protocols have been theoretically proposed and experimentally realized. For more complex systems such as interacting quantum gases, simplifying assumptions do not apply anymore and the optimization techniques become computationally impractical. Here [1], we propose Bayesian optimization based on multi-output Gaussian processes to learn the physical properties of a Bose Einstein condensate within few simulations only. We evaluate its performance on an optimization study case of diabatically transporting the quantum gas while keeping it in its ground state. Within a few hundred executions, we reach a competitive performance to other protocols. This paves the way for efficient state engineering of complex quantum systems including mixtures of interacting gases or cold molecules.

[1] Gabriel Müller *et al* 2025 *Quantum Sci. Technol.* **10** 015033

Q 53.2 Thu 11:15 HS I

Robust Double Bragg Diffraction via Detuning Control — •Rui Li[1,2], Victor Martinez-Lahuerta[1], Stefan Seckmeyer[1], Naceur Gaaloul[1], Klemens Hammerer[2], and QUANTUS-1 Team[1,3,4] — [1]Leibniz University Hanover, Institute of Quantum Optics, Hannover, Germany — [2]Leibniz University Hanover, Institute of Theoretical Physics, Hannover, Germany — [3]Humboldt-Universität zu Berlin, Institut für Physik, Berlin, Germany — [4]University Bremen, Center of Applied Space Technology and Microgravity, Bremen, Germany

We present a new theoretical model and numerical optimization of double Bragg diffraction (DBD), a widely used technique in atom interferometry. Using the effective Hamiltonians derived in our theoretical model, we investigate the impacts of AC-Stark shift and polarization errors on the double Bragg beam-splitter efficiency, along with their mitigations through detuning control. Notably, we design a linear detuning sweep that demonstrates robust DBD efficiency exceeding 99.5% against polarization errors up to 8.5%. Moreover, we develop an artificial intelligence-aided optimal detuning control protocol, showcasing enhanced robustness against both polarization errors and Doppler effects. Recently, we have experimentally achieved the proposed detuning-sweep DBDs in the QUANTUS-1 BEC Laboratory situated in Bremen and have observed their enhanced efficiency and robustness compared to the traditional DBDs. Finally, we propose a construction of a full Mach-Zehnder type gravimeter using detuning-sweep DBD pulses for enhanced contrast.

Q 53.3 Thu 11:30 HS I

Squeezing Enhancement in Atom Interferometers Based on Bragg Diffraction — •Julian Günther[1,2], Jan-Niclas Kirsten-Siemss[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Using entanglement for N-particle states in matter wave interferometers allows one to outperform the standard quantum limit of $\frac{1}{\sqrt{N}}$ for the uncertainty in the phase measurement. We consider the use of one-axis twisted, spin squeezed atomic states in a Bragg Mach-Zehnder interferometer. We evaluate the phase uncertainty in the phase measurement taking into account the fundamental multi-port and multi-path nature of the Bragg processes, and determine optimally squeezed states for a given geometry. We show, that Gaussian pulses need to be chosen carefully with respect to the squeezing strength and momentum distribution of the incoming particles to benefit from the entanglement.
This project was funded within the QuantERA II Programme that has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with

funding organisation DFG (project number 499225223).

Q 53.4 Thu 11:45 HS I

Simulation of atomic diffraction through a nanograting — •Matthieu Bruneau[1,2], Julien Lecoffre[1], Ayoub Hadi[1], Charles Garcion[1,2], Nathalie Fabre[1], Eric Charron[3], Gabriel Dutier[1], Quentin Bouton[1], and Naceur Gaaloul[2] — [1]Laboratoire de physique des lasers, Université Sorbonne Paris Nord, Villetaneuse, France — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [3]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France

Tremendous advancements in cold atom physics have transformed atomic interferometry into a powerful tool for precision measurements.

This work models an experiment involving the diffraction of cold argon atoms through a transmission nanograting, where the observed pattern is intrinsically related to short-range Casimir-Polder (C-P) forces. Accurate modeling of these forces is critical for exploring non-Newtonian gravitational effects and advancing nanotechnology.

Using a quantum numerical model combined with QED calculations, we validate experimental data and achieve a state-of-the-art determination of the atom-surface potential strength parameter, $C_3 = 6.87 \pm 1.18$ meV·nm^3. Sensitivity is constrained primarily by nanograting geometry. To enhance precision, we are implementing a scanning angle method and extending our 1D model to a 2D framework with new QED calculations to fully characterize the 2D C-P potential.

This work is supported by DLR funds from the BMWK (50WM2450A QUANTUS-VI).

Q 53.5 Thu 12:00 HS I

Robust Bragg diffraction for atom interferometers using optimal control theory — •Victor Jose Martinez Lahuerta[1], Jan-Niclas Kirsten-Siemss[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Institut of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany — [2]Leibniz University Hannover, Institute for Theoretical physics, Hannover, Germany

Algorithms from the field of artificial intelligence (AI) and machine learning have been used in recent years to efficiently solve multidimensional problems. In physics, these algorithms are applied with increasing success, e.g., to solve the Schrödinger equation for many-body problems, or used experimentally to generate ultracold atoms and control lasers. Here we report on our results obtained optimizing Bragg diffraction with optimal control theory. Great progress has been achieved recently in sensitivity and robustness under certain vibrations, accelerations, and experimental problems. Nevertheless, we focus on the accuracy of the interferometer by minimizing the diffraction phase in a close-to-ideal scenario accounting for a finite temperature of the BEC and the multi-path nature of high-order Bragg diffraction.

Q 53.6 Thu 12:15 HS I

Local Measurement Scheme of Gravitational Curvature using Atom Interferometers — •Michael Werner[1,2], Ali Lezeik[2], Dennis Schlippert[2], Ernst Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Light pulse atom interferometers (AIFs) are exquisite quantum probes of spatial inhomogeneity and gravitational curvature. Moreover, detailed measurement and calibration are necessary prerequisites for very-long-baseline atom interferometry (VLBAI). Here we present a method in which the differential signal of two co-located interferometers singles out a phase shift proportional to the curvature of the gravitational potential. The scale factor depends only on well controlled quantities, namely the photon wave number, the interferometer time and the atomic recoil, which allows the curvature to be accurately inferred from a measured phase. As a case study, we numerically simulate such a co-located gradiometric interferometer in the context of the Hannover VLBAI facility and prove the robustness of the phase shift in gravitational fields with complex spatial dependence. We define an estimator of the gravitational curvature for non-trivial gravitational fields and calculate the trade-off between signal strength and estimation accuracy with regard to spatial resolution. As a perspective, we discuss the case of a time-dependent gravitational field and corresponding measurement strategies.

Q 53.7 Thu 12:30 HS I

All-optical squeezed BEC generation for microgravity operation — •Jan Simon Haase[1] and The INTENTAS Team[1,2,3,4,5,6,7] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Transport- und Automatisierungstechnik, Leibniz Universität Hannover — [3]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology Ulm — [4]Ferdinand-Braun-Institut Berlin — [5]Institut für Angewandte Physik,Technische Universität Darmstadt — [6]Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Satellitengeodäsie und Inertialsensorik, Hannover — [7]Humboldt Universität zu Berlin

Atom interferometers serve as high-precision sensors for quantities like acceleration, rotation, or magnetic fields. The sensitivity of atom interferometers is greatly enhanced by long interrogation times, as they are available in spaceborne applications. Second-long interrogation times favor the employment of atomic Bose-Einstein condensates (BECs) with their well-controlled spatial mode and their slow expansion rates. The sensitivity can be increased even further by employing squeezed atomic ensembles that enable measurements beyond the standards quantum limit. The INTENTAS project develops a source of entangled atoms that can be tested under microgravity conditions. Microgravity is provided by Hannover's Einstein Elevator, which offers up to 4s of free fall. A key feature is the fast all-optical BEC generation which is performed in a crossed-beam optical dipole trap. In this talk, the status of the project will be presented which includes fast BEC generation on ground and first results from microgravity tests.

Q 53.8 Thu 12:45 HS I

Theory of multi-axis atom interferometric sensing for inertial navigation — •Christian Struckmann, Knut Stolzenberg, Ernst M. Rasel, Dennis Schlippert, and Naceur Gaaloul — Leibniz University Hannover, Institute of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany

Quantum sensors based on the interference of matter waves provide a highly sensitive and stable measurement tool for inertial forces with applications in geodesy, navigation, or fundamental physics. Conventional atom interferometers, however, can only measure inertial forces along a single axis, yielding information about one acceleration and one rotation component. To fully characterize the motion of a moving body, an inertial measurement unit must capture the acceleration and rotation along three perpendicular directions. Extending this atom interferometric measurement scheme to multiple components would normally require subsequent measurements along various spatial directions.

In this contribution, we present the theory behind PIXL (Parallelized Interferometers for XLerometry), a novel method to operate a quantum sensor based on a 2D array of Bose-Einstein Condensates enabling multi-axis sensing through simultaneously operated single-axis atom interferometers [K. Stolzenberg et al., arXiv:2403.08762 (2024)]. We detail the multi-dimensional scaling of the inertial phases as well as the capabilities of such a multi-axis measurement unit.

Q 54: Quantum Sensing II (joint session Q/QI)

Time: Thursday 11:00–12:45 Location: HS I PI

Invited Talk Q 54.1 Thu 11:00 HS I PI

New Opportunities for Sensing via Continuous Measurement — •Dayou Yang, Susana F. Huelga, and Martin B. Plenio — Institute of Theoretical Physics, University of Ulm, Ulm, Germany

The continuous monitoring of driven-dissipative quantum optical systems provides key strategies for the implementation of quantum metrology, with prominent examples ranging from the gravitational wave detectors to the emergent driven-dissipative many-body sensors. Fundamental questions about the ultimate performance of such a class of sensors remain open—for example, how to perform the optimal continuous measurement to unlock their ultimate precision; how to effectively enhance their precision scaling towards the Heisenberg limit? In this talk I will present our recent theoretical efforts towards answering these questions. In the first part I will present a universal backaction evasion strategy for retrieving the full quantum Fisher information from the nonclassical, temporally correlated fields emitted by generic open quantum sensors, thereby to achieve their fundamental precision limit. In the second part I will introduce dissipative criticality as a resource for nonclassical precision scaling for continuously monitored open quantum sensors, by establishing universal scaling laws of the quantum Fisher information in terms of critical exponents of generic dissipative critical points.

Q 54.2 Thu 11:30 HS I PI

Efficient simulations for long time dynamics of interacting quantum gases — •Annie Pichery and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Ultra-cold atomic ensembles are a prime choice for sources in quantum sensing experiments. In the case of atom interferometry, long interrogation times are highly desirable to obtain high precision results. This requires a great control of the input states in term of size and position dynamics, as well as an efficient description of the dynamics along the different steps of the evolution time.

Space provides an environment where atom clouds can float for extended times of several seconds, as well as miscibility conditions not possible on ground. However, simulating such dynamics of single species Bose-Einstein Condensates (BEC) or interacting dual species BEC mixtures presents computational challenges due to the long expansion times and centre of mass motion induced by a displacement of the atom clouds. In this contribution, we present scaling techniques to overcome these limits. We focus also on simulation methods to interpret experiments with non-harmonic potentials or including effects of wavefront aberrations during the pulse sequences of atom interferometry.

Q 54.3 Thu 11:45 HS I PI

Measuring Beam Displacements via Weak Value Amplification — •Carlotta Versmold[1,2,3], Jan Dziewior[1,2,3], Florian Huber[1,2,3], Lev Vaidman[4], and Harald Weinfurter[1,2,3] — [1]Ludwig-Maximilians-Universität, Germany — [2]Max-Planck-Institut für Quantenoptik, Germany — [3]Munich Center for Quantum Science and Technology, Germany — [4]Tel-Aviv University, Israel

Weak value amplification enables precise measurement of a laser beam's small angular and spatial displacements using interferometric setups. While traditionally limited to detecting displacements inside the interferometer, we present a system that detects external beam displacements through amplification in the dark port of the interferometer. Simultaneously, the beam can be spatially filtered since displacements are suppressed in the bright port. Using a Sagnac-type interferometer with a dove prism in one arm, external displacements are mirrored in this arm, which induces a relative deflection between the two interferometer arms, shifting the center of mass of the interference pattern. This shift is given by the initial displacements amplified by the weak value of the pre- and postselected interferometer states. With an amplification by a factor of up to 20, this experiment clearly demonstrates and also extends the applicability of the weak value measurement methods.

Q 54.4 Thu 12:00 HS I PI

Probing free-electron-photon entanglement with quantum eraser experiments — •Jan-Wilke Henke[1,2], Hao Jeng[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]University of Göttingen, 4th Physical Institute, Göttingen, Germany

Quantum entanglement is central to most emerging quantum technologies including quantum computation and sensing. While the interaction of free electrons with optical fields is expected to induce free electron-photon entanglement [1,2], its demonstration remains an outstanding challenge.

In this presentation, we propose a tangible experiment for generating and verifying quantum entanglement between free electrons and photons based on quantum erasure [3]. We introduce the basic concept, before describing possible implementations employing multiple electron beams in an electron microscope and demonstrating selected experimental key aspects. Finally, we discuss extending this scheme to entanglement tests and generating electron-electron entanglement. Such a demonstration of electron-photon entanglement will be a cornerstone of free electron quantum optics and could enable quantum-enhanced sensing in electron microscopy.

[1] O. Kfir, Phys. Rev. Lett. 123, 103602 (2019); [2] A. Konečńa, F. Iyikanat, and F. J. García de Abajo, Sci. Adv. 8, eabo7853 (2022); [3] J.-W. Henke, H. Jeng & C. Ropers, arXiv:2404.11368 (2024)

Q 54.5 Thu 12:15 HS I PI

Theoretical treatment of a closed-loop excitation scheme for phase-sensitive RF E-field sensing using Rydberg atom-based sensors — •Matthias Schmidt[1,2], Stephanie Bohaichuk[1], Vijin Venu[1], Harald Kübler[1,2], and James P. Shaffer[1] — [1]Quantum Valley Ideas Laboratories, 485 Wes Graham Way, Waterloo, ON N2L 0A7, Canada — [2]5. Physikalisches Institut and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

In this talk, we present theoretical work aimed at understanding radio frequency phase measurement using all-optical, atom-based electric field sensors. Atom-based radio frequency field sensors have a number of applications in communications, radar and test and measurement. All of these applications benefit from being able to detect phase, but Rydberg atom-based sensors in the steady state are square law detectors. We investigate closed-loop excitations in cesium that preserve phase information in a probe laser signal transmission amplitude coupled to one transition of the loop. Insight into the mechanisms that enable phase determination is gained by analyzing the closed-loop processes. We developed an experimental protocol that allows to measure the amplitude and phase of the incident RF wave over a wide range of parameters. Furthermore, we apply the weak probe approximation to the Lindblad-master equation and find an analytic expression for the absorption coefficient. With this expression, we gain a deeper understanding of the multi-photon interference and how this applies to phase readout in the atom-based radio frequency sensors.

Q 54.6 Thu 12:30 HS I PI

A localized impurity in a mesoscopic system of SU(N) fermions — Juan Polo[1], Wayne Jordan Chetcuti[1], Anna Minguzzi[2], •Andreas Osterloh[1], and Luigi Amico[1] — [1]TII, QRC, Abu Dhabi, UAE — [2]Université Grenoble Alpes, CNRS, LPMMC, Grenoble, France

We investigate the effects of a static impurity, modeled by a localized barrier, in a one-dimensional mesoscopic system comprised of strongly correlated repulsive SU(N)-symmetric fermions. For a mesoscopic sized ring under the effect of an artificial gauge field, we analyze the particle density and the current flowing through the impurity at varying interaction strength, barrier height and number of components. We find a non-monotonic behaviour of the persistent current, due to the competition between the screening of the impurity, quantum fluctuations, and the phenomenon of fractionalization, a signature trait of SU(N) fermionic matter-waves in mesoscopic ring potentials. This is also highlighted in the particle density at the impurity site. We show that the impurity opens a gap in the energy spectrum selectively, constrained by the total effective spin and interaction. Our findings hold significance for the fundamental understanding of the localized impurity problem and its potential applications for sensing and interferometry in quantum technology.

Q 55: Decoherence and Open Quantum Systems (joint session QI/Q)

Time: Thursday 11:00–12:45 Location: HS II

Invited Talk Q 55.1 Thu 11:00 HS II

Quantum-Classical Hybrid Theories - Feedback Control and Environment Purification — •Patrick P. Potts — University of Basel, Switzerland

Quantum-classical hybrid theories describe scenarios where quantum degrees of freedom interact with classical degrees of freedom. The need for such theories becomes particularly clear in feedback control, where classical measurement outcomes are fed back to a quantum system to influence its dynamics. Additionally, quantum-classical hybrid theories can be used to model a quantum system interacting with a large but finite-sized environment. In this case, the classical degree of freedom can be the magnetization of the environment.

I will present two examples of quantum-classical hybrid theories. The quantum Fokker-Planck master equation (QFPME) that describes continuous feedback control and the extended microcanonical master equation (EMME) that describes a qubit coupled to a bath of two-level systems. The QFPME allows for obtaining analytical results for feedback scenarios that previously were only accessible using numerical methods. The EMME allows for keeping track of the magnetization of the bath, as well as the classical correlations between system and bath. These methods will be illustrated with simple but relevant examples.

Q 55.2 Thu 11:30 HS II

Emergent decoherent histories from first principles — •Philipp Strasberg — Instituto de Física de Cantabria (IFCA), Santander, Spain

I overview recent progress about the emergence of decoherent histories from first principles, i.e., without the use of ensembles or approximations to the Schroedinger dynamics — akin to approaches in pure state statistical mechanics. After briefly reviewing the importance of decoherent histories to understand a unitarily evolving quantum Universe, I show that generic (non-integrable) many-body systems are characterized by an exponential suppression of interference effects (as a function of the particle number of the system) whereas integrable systems are characterized by a much weaker form of decoherence. I conclude with an outlook about how (long) (de/re)coherent histories shape the structure of the Multiverse, a hitherto unappreciated phenomenon.

Q 55.3 Thu 11:45 HS II

Quantum synchronization of twin limit-cycle oscillators — •Tobias Kehrer[1], Parvinder Solanki[2], and Christoph Bruder[1] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

Limit cycles in classical systems are closed phase-space trajectories to which the system converges regardless of its initial state. Their quantum counterparts have been proposed for open quantum systems, exhibiting steady-state phase-space representations with ring-like structures of stable radius but no phase preference. The synchronization of such quantum systems has been studied extensively in the past decade, where an external drive can localize the phase of the steady state. Unlike in classical systems, quantum synchronization can exhibit coherence cancellations, leading to a synchronization blockade.

In this work, we propose a quantum system whose classical analogue features two limit cycles. In the classical analogue, the system can end up in either one of the limit cycles, defined by their basins of attraction and choice of initial states. In the quantum system, both limit cycles coexist independently of the initial state, i.e., the Wigner function of the steady state features two rings. Adding an external drive to a single oscillator, its limit cycles localize to distinct phases, exhibiting different synchronization behaviors within the same system. Furthermore, we demonstrate that coupling two such twin limit-cycle oscillators leads to simultaneous synchronization and synchronization blockades between different limit cycles of oscillator A and B.

Q 55.4 Thu 12:00 HS II

Exact Floquet Dynamics of Strongly Damped Open Quantum Systems — •Konrad Mickiewicz, Valentin Link, and Walter T. Strunz — Institut für Theoretische Physik, Technische Universität Dresden, D-01062, Dresden, Germany

Recent developments in simulating open quantum systems utilize Matrix Product Operator (MPO) representations to capture the temporal correlations of strongly coupled non-Markovian environments. A novel highly effective approach based on infinite MPO methods [1] yields a semigroup propagator for the open system evolution. We present how this semigroup structure can be exploited to efficiently describe periodically driven dynamics in the presence of strongly interacting environments. In particular, we are able to construct an exact Floquet propagator, enabling the direct extraction of asymptotic Floquet states without resorting to real-time evolution. We apply our results to the driven spin-boson and two-spin-boson models. In the latter, we show that the amount of entanglement generated between the qubits can be increased significantly via local driving of the system. [1] V. Link, H.-H. Tu, and W. T. Strunz, "Open quantum system dynamics from infinite tensor network contraction" Phys. Rev. Lett. 132, 200403 (2024)

Q 55.5 Thu 12:15 HS II

Open System Semigroup Dynamics beyond the Lindblad Class — •Nadine Diesel, Charlotte Bäcker, and Walter Strunz — TUD Dresden University of Technology, Dresden, Germany

Open quantum systems are of interest in many fields of study, e.g., quantum computation and quantum optics. A powerful tool in treating dissipation in open quantum system dynamics are quantum master equations. The Lindblad (GKSL) master equation is well-known for ensuring completely positive dynamical semigroup evolution, a natural framework for physical dynamics. However, is it possible to extend the class of semigroup generators beyond the Lindblad framework? We relax the strict requirement of complete positivity by introducing the concept of local (complete) positivity. Here, dynamics are defined as locally (completely) positive if a nonempty proper subset of initial states give rise to (completely) positive quantum dynamics. We analyze the existence of such dynamics for qubits and examine their potential physical implications.

Q 55.6 Thu 12:30 HS II

Entanglement phase transitions in boundary-driven open quantum systems — •Darvin Wanisch[1,2], Nora Reinić[1,2], Daniel Jaschke[1,2,3], Pietro Silvi[1,2], and Simone Montangero[1,2,3] — [1]Dipartimento di Fisica e Astronomia "G. Galilei", Università di Padova, I-35131 Padova, Italy — [2]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Padova, I-35131 Padova, Italy — [3]Institute for Complex Quantum Systems & Center for Integrated Quantum Science and Technology, Ulm University, 89069 Ulm, Germany

We present a numerical framework based on tree tensor networks that enables large-scale simulations of open quantum many-body systems and the efficient computation of entanglement monotones. We apply this framework to a paradigmatic open-system problem, the boundary-driven XXZ spin-chain. Our results demonstrate the framework's capability to probe entanglement in open systems and distinguish it from correlations with the environment. Furthermore, we find that the system undergoes entanglement phase transitions in both the coupling to the environment and the anisotropy parameter. Regarding the latter, our results connect the known transport regimes of the model to different entanglement phases, i.e., separable, area-law, and volume-law. Our work paves the way toward exploring entanglement in open systems, a necessary step for the development of scalable quantum technologies.

Q 56: Precision Spectroscopy of Atoms and Ions V (joint session A/Q)

Time: Thursday 11:00–13:00 Location: KlHS Mathe

Invited Talk Q 56.1 Thu 11:00 KlHS Mathe

Breaking the barrier of resolution in broadband spectroscopy — •Jérémie Pilat[1,2], Bingxin Xu[1,2], Theodor W. Hänsch[1,3], and Nathalie Picqué[1,2] — [1]Max-Planck Institute of Quantum Optics, Garching, Germany — [2]Max Born Institute, Berlin, Germany — [3]Ludwig-Maximilian University of Munich, Faculty of Physics, München, Germany

We provide the first experimental demonstration of a new type of spectroscopy with theoretically unlimited resolution and spans, which opens up new opportunities in broadband spectroscopy. We use a dual-comb spectrometer, where two frequency combs of narrow, equidistant lines with slightly different line spacing beat on a photodetector. Optical frequencies are mapped to measurable radiofrequencies. While dual-comb spectroscopy has existed for over a decade, we experimentally exploit here that its fundamentally different operation principle for the first time: as a pure time-domain spectrometer, it encounters no geometric limitations. As an illustration, combs of a narrow line spacing of 2.5 MHz are harnessed for sampling the 5S-SP transitions of Rubidium over a span of 130 GHz. More than 50000 comb lines are resolved in a single measurement of just one second. To achieve this resolution with a Fourier transform spectrometer, one would need a delay line of 60 m, and for a dispersive spectrometer, a grating of 60 m length.

Q 56.2 Thu 11:30 KlHS Mathe

R&D towards an atomic tritium source for future neutrino mass experiments — •Caroline Rodenbeck for the KAMATE-Collaboration — Karlsruher Institut für Technologie, IAP-TLK

A purely kinematic way of measuring the neutrino mass is precision spectroscopy of the tritium beta-decay spectrum at its endpoint. Experiments following this approach have so far used tritium in its molecular form. The associated molecular final state distribution effectively broadens the spectrum and thus reduces the sensitivity on the neutrino mass.

For future experiments aiming for sensitivities as low as the lower boundaries obtained by neutrino oscillation experiments (e.g., $0.05\,\mathrm{eV/c^2}$ in case of inverted ordering), atomic tritium sources are needed. Before it is practical to carry out a neutrino mass experiment with an atomic tritium source, key challenges such as multi-stage cooling of an atomic tritium beam to a few mK and magnetic trapping of atoms have to be solved.

The Karlsruhe Mainz Atomic Tritium Experiment (KAMATE) aims to benchmark different types of atomic dissociators and to demonstrate primary cooling stages. KAMATE is a collaboration of JGU and of KIT's Tritium Laboratory Karlsruhe (TLK) which currently hosts the KATRIN experiment. Additionally, there are plans to extend the collaboration to build an atomic tritium demonstrator.

The talk gives an overview of the current plans and results within KAMATE and of the vision for a future atomic tritium demonstrator.

Q 56.3 Thu 11:45 KlHS Mathe

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.

Q 56.4 Thu 12:00 KlHS Mathe

Towards entanglement-enhanced quantum metrology with cold ^{88}Sr atoms — •Sofus Laguna Kristensen[1,2], Akhil Kumar[1,2], Klavdia Kontou[1,2], Ka Hui Goh[1,2], Saumya Shah[1,2], Trofim Ruzaikin[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 Munich, Germany — [3]Ludwig-Maximilians-Universität, 80799 Munich, Germany

Optical lattice clocks operating with ultra cold strontium or ytterbium offer unprecedented precision and accuracy in timekeeping. With fractional frequency uncertainties down to the 10^{-18} level, they enable scientific and technical advances from fundamental physics to global positioning systems. In our group we are developing a next-generation optical atomic clock, where spin squeezing of optically trapped ^{88}Sr atoms will allow us to surpass the standard quantum limit of the atomic interrogation. To improve the short-term stability of the atomic clock, our experiment aims to demonstrate low-latency optical qubit readout made possible by rapid and direct imaging of the ground and metastable clock states.

In this talk I will discuss the progress of the experiment, presenting our latest results of lattice trapping and spectroscopy of the clock transition in ^{88}Sr, and discuss the next steps towards rapid-readout entanglement-enhanced quantum metrology.

Q 56.5 Thu 12:15 KlHS Mathe

Ab initio calculations of the hyperfine structure of fermium — •Joseph Andrews[1,2], Jacek Bieroń[3], Per Jönsson[4], Sebastian Reader[1,2], and Michael Block[1,2] — [1]Helmholtz-Institut Mainz, Mainz, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [3]Jagiellonian University, Kraków, Poland — [4]Malmö University, Malmö, Sweden

Fermium ($Z = 100$) is one of the two heaviest atoms for which experimental spectroscopic data exists, residing at the forefront of atomic and nuclear physics research. Over the past twenty years, it has been the subject of extensive theoretical and experimental investigation. Nuclear multipole moments are required to verify existing nuclear models, and one of the most accurate methods to determine nuclear dipole and quadrupole moments is to combine measured nuclear coupling constants with calculated deduced electric field gradients. Calculations were initially performed on its lighter homologue erbium where experimental results exist to determine the predictive accuracy of our model. Hyperfine interaction constants A and B of Er I and Fm I are investigated using the multiconfigurational Dirac-Hartree-Fock (MCDHF) method, involving over five million configuration state functions. Results of the ground state $5f^{12}7s^2$ ($4f^{12}6s^2$) of both neutral atoms are presented and compared to previous calculations and experiments.

Q 56.6 Thu 12:30 KlHS Mathe

Transportable optical clock for remote comparisons — •Saaswath J. K.[1], Martin Steinel[1], Melina Filzinger[1], Jian Jiang[1], Thomas Fordell[2], Kalle Hanhijärvi[2], Anders Wallin[2], Thomas Lindvall[2], Burghard Lipphardt[1], Ekkehard Peik[1], Nils Huntemann[1], and the Opticlock consortium[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]VTT Technical Research Centre of Finland Ltd, National Metrology Institute VTT MIKES, P.O. Box 1000, 02044 VTT, Finland

We report on a transportable and user-friendly optical clock that uses the $^2S_{1/2}-^2D_{3/2}$ transition of a single trapped ^{171}Yb$^+$ ion at 436 nm as the reference. The system, called Opticlock, has been developed in an industry-lead collaboration. As a first step towards remote comparisons, the frequency instability of Opticlock has been improved by reducing the dead time, and its systematic uncertainty has been reduced by direct measurements of the AC magnetic field. Furthermore, a frequency comb was integrated into the system to provide clock output at 1.5 μm. In August 2024, Opticlock traveled to Finland to be compared with the ^{88}Sr$^+$ clock at VTT MIKES. A first inspection of the measurement data, with an overall uptime of 90 %, indicates proper operation of both clocks and will allow the frequency ratio to be determined with a statistical uncertainty below 1×10^{-17}. The results pave the way for future key comparisons of high-performance optical clocks using transportable standards as an alternative to satellite-based techniques and fiber links, yielding significant contributions to the milestones towards the redefinition of the SI second.

Q 56.7 Thu 12:45 KlHS Mathe

Trapping electrons and Ca+ ions with dual-frequency Paul trap — Vladimir Mikhailovskii[1], •Natalija Sheth[1], Yuzhe Zhang[1], Hendrik Bekker[1], Günther Werth[2], Guofeng Qu[3], Zhiheng Xue[4], K. T Satyajith[5], Qian Yu[6], Neha Yadav[6], Hartmut Häffner[6], Ferdinand Schmidt-Kaler[7], and Dmitry Budker[1,2,6] — [1]Helmholtz-Institut Mainz, GSI Helmholtzzentrum fur Schwerionenforschung, Mainz, Germany — [2]Johannes Gutenberg-Universitat, Mainz, Germany — [3]. Institute of Nuclear Science and Technology, Sichuan University, Chengdu, China — [4]University of Science and Technology of China, Hefei, China — [5]Nitte, Mangalore, India — [6]Department of Physics, University of California, Berkeley, USA — [7]QUANTUM, Institute für Physik, Johannes Gutenberg-Universitat, Mainz, Germany

Radiofrequency traps are well recognized for their ability to co-trap charged particles with different mass-to-charge ratios, such as different ion species, even atomic and molecular ones, or ions with charged nanoparticles [1]. At the AntiMatter-On-a-Chip project we currently work on cotrapping electrons and ions. In this report we present results on trapping electrons and Ca$^+$ ions with a trap similar to the one described in [2]. Trapping of electrons is achieved by applying 1.6 GHz to the resonator while trapping Ca$^+$ ions is achieved by applying 2 MHz to DC electrodes. The influence of dual-frequency operation on trapping stability and the lifetime of trapped particles were studied.

1. D. Bykov, et al. arXiv:2403.02034
2. C. Matthiesen et al, Phys. Rev. X; 11, 011019 (2021)

Q 57: Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)

Time: Thursday 11:00–12:45 Location: HS PC

Invited Talk Q 57.1 Thu 11:00 HS PC

High precision spectroscopy of trilobite Rydberg molecular series — •Richard Blättner[1], Markus Exner[1], Rohan Srikumar[2], Matt Eiles[3], Peter Schmelcher[2], and Herwig Ott[1] — [1]RPTU Kaiserslautern-Landau — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg — [3]Max Planck Institut für Physik komplexer Systeme

Trilobite Rydberg molecules consist of a highly excited Rydberg atom and a perturber atom in the electronic ground state. The underlying binding mechanism is based on the scattering interaction between the Rydberg electron and the perturber. These molecules exhibit extreme properties: their dipole moments are in the kilo-Debye range, and their molecular lifetimes may exceed the lifetimes of the close by atomic Rydberg states. We use three-photon photoassociation and a reaction microscope to perform momentum-resolved spectroscopy on trilobite ^{87}Rb Rydberg molecules for principal quantum numbers $n = 22, 24, 25, 26, 27$. The large binding energies and the high spectroscopic resolution of 10^{-4} allow us to benchmark theoretical models. Previous models relied on exact diagonalization, which suffered from basis-dependent convergence problems. Using a recent basis-independent theoretical method based on Green's functions, which accounts for all relevant spin interactions, we fit the measured spectra. This enables a new estimate of the involved low-energy scattering lengths. However, with the precision of our experiment, we encounter conceptual issues, suggesting that the fundamental modeling of the molecular Hamiltonian has reached the limits of its predictive power.

Q 57.2 Thu 11:30 HS PC

Impact of micromotion on the excitation of Rydberg states of ions in a Paul trap — Wilson Santana Martins[1], •Joseph William Peter Wilkinson[1], Markus Hennrich[2], and Igor Lesanovsky[1,3] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Department of Physics, Stockholm University, SE-106 91 Stockholm, Sweden — [3]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Trapped ions are among the most advanced platforms for quantum simulation and computation. Their capabilities can be further enhanced by making use of electronically highly excited Rydberg states. So far, most experimental and theoretical studies focus on the Rydberg excitation of ions in Paul traps. These generate confinement by a combination of static and oscillating electric fields, which need to be carefully aligned to minimize micromotion. In this talk, we briefly discuss the results in Ref. [1], which aim to understand the impact of micromotion on the Rydberg excitation spectrum when the symmetry axes of the electric fields do not coincide. This is important in the case of field misalignment and is inevitable for Rydberg excitations in 2D and 3D ion crystals. We developed a model describing a trapped Rydberg ion, which we solved using Floquet and perturbation theory. We calculated the excitation spectra and analyzed in which parameter regimes energetically isolated Rydberg lines persist, which are an important requirement for conducting coherent manipulations.

[1] W. S. Martins et al., arXiv:2410.24047 (2024)

Q 57.3 Thu 11:45 HS PC

Resonant stroboscopic Rydberg dressing: electron-motion coupling and multi-body interactions — •Chris Nill[1,2], Sylvain de Léséleuc[3,4], Christian Gross[5], and Igor Lesanovsky[1] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Institute for Applied Physics, University of Bonn, Wegelerstraße 8, 53115 Bonn, Germany — [3]Institute for Molecular Science, National Institutes of Natural Sciences, 444-8585 Okazaki, Japan — [4]RIKEN Center for Quantum Computing (RQC), 351-0198 Wako, Japan — [5]Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

Rydberg dressing traditionally refers to a technique where interactions between cold atoms are imprinted through the far off-resonant continuous-wave excitation of high-lying Rydberg states. Dipolar interactions between these electronic states are then translated into effective interactions among ground state atoms. Motivated by recent experiments, we investigate two dressing protocols, in which Rydberg atoms are resonantly excited in a stroboscopic fashion [1]. The first one is non-adiabatic, meaning Rydberg states are excited by fast pulses. In this case, mechanical forces among Rydberg atoms result in electron-motion coupling, which generates effective multi-body interactions. In the second, adiabatic protocol, Rydberg states are excited by smoothly varying laser pulses. We show that also in this protocol, substantial multi-body interactions emerge.

[1] C. Nill et al., arXiv:2411.10090 (2024).

Q 57.4 Thu 12:00 HS PC

A Floquet-Rydberg quantum simulator for confinement in $\mathbb{Z}_2$ gauge theories — •Enrico Domanti[1,2,3], Dario Zappalà[3,4], Alejandro Bermudez[5], and Luigi Amico[1,2,3] — [1]Technology Innovation Institute, Abu Dhabi, United Arab Emirates — [2]University of Catania, Catania, Italy — [3]INFN-Sezione di Catania, Catania, Italy — [4]Centro Siciliano di Fisica Nucleare e Struttura della Materia, Catania, Italy — [5]Instituto de Fisica Teorica, UAM-CSIC, Madrid, Spain

Recent advances in the field of quantum technologies have opened up the road for the realization of small- scale quantum simulators of lattice gauge theories which, among other goals, aim at improving our understanding on the non-perturbative mechanisms underlying the confinement of quarks. In this work, considering periodically-driven arrays of Rydberg atoms in a tweezer ladder geometry, we devise a scalable Floquet scheme for the quantum simulation of the real-time dynamics in a $\mathbb{Z}_2$ LGT, in which hardcore bosons / spinless fermions are coupled to dynamical gauge fields. Resorting to an external magnetic field to tune the angular dependence of the Rydberg dipolar interactions, and by a suitable tuning of the driving parameters, we manage to suppress the main gauge-violating terms and show that an observation of gauge-invariant confinement dynamics in the Floquet-Rydberg setup is at reach of current experimental techniques. Depending on the lattice size, we present a thorough numerical test of the validity of this scheme using either exact diagonalization or matrix-product-state algorithms for the periodically-modulated real-time dynamics.

Q 57.5 Thu 12:15 HS PC

Chirality Signatures in Atomic Rydberg States – Experimental State Preparation — •Stefan Aull[1], Steffen Giesen[2], Miles DeWitt[1], Moritz Göb[1], Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Experimental Physics 1, Institute of Physics, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Berger Group, Institute of Chemistry, University of Marburg, Hans-Meerwein-Str. 4. 35043 Marburg, Germany — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

A protocol for the preparation of chiral orbital Rydberg states in atoms is presented. It has been shown theoretically that using a suitable superposition of hydrogen wave functions, it is possible to construct a state with chiral signature, e.g. in the probability density or probability current density [1]. Circular Rydberg states can be generated and subsequently manipulated with tailored RF pulses under the influence of electric and magnetic fields, so that the desired chiral superposition of hydrogen-like states with corresponding phases can be prepared. The results are intended to be used for chiral discrimination [2] of molecules. The experimental progress is presented. This contribution is a continuation of the submission "Chirality Signatures in Atomic Rydberg States – Conditions and Symmetry Considerations".

[1] A. F. Ordonez and O. Smirnova, Phys. Rev. A, 99, 4, 43416 (2019).
[2] S. Y. Buhmann et al., New J. Phys., 23, 8, 8 (2021).

Q 57.6 Thu 12:30 HS PC

Chirality Signatures in Atomic Rydberg States – Conditions and Symmetry Considerations — •Steffen M. Giesen[1], Stefan Aull[2], Miles Dewitt[2], Moritz Göb[2], Peter Zahariev[2], Kilian Singer[2], and Robert Berger[1] — [1]Chemistry Department, Philipps-Universität Marburg, Hans-Meerwein-Str. 4. 35043 Marburg — [2]Experimental Physics 1, Institute of Physics, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Chirality in the electronic structure of bound systems is regularly associated with the three-dimensional spatial distribution of nuclei in molecules. But also in atomic systems, states with chiral signatures can be formed as superpositions of the achiral eigenstates of hydrogenic systems, either due to parity-violating effects [1] or through careful state preparation [2].

We use linear combinations of hydrogenic functions as model systems to identify the conditions for the quantum numbers and relative phases that lead to chirality in such a superposition. Moreover, we show which minimal selection of states enable which diverse chiral signatures and report simple rules for the composition of states with specific chiral signatures. Our model system most naturally applies to Rydberg states, especially in atoms, but can also further the understanding of chirality in molecules and chiral potentials. This topic is continued in the submission "Chirality Signatures in Atomic Rydberg States – Experimental State Preparation".

[1] I. B. Zel'Dovich, Sov. Phys. JETP, 6, 1958, 1184.
[2] A. F. Ordonez and O. Smirnova, Phys. Rev. A, 99, 2019, 043416.

Q 58: Quantum Communication II: Implementations (joint session QI/Q)

Time: Thursday 14:30–16:30 Location: HS IX

Q 58.1 Thu 14:30 HS IX

Darmstadt quantum local area network (DaQLAN) — •Maximilian Tippmann[1], Florian Niederschuh[1], Maximilian Mengler[1], Erik Fitzke[2], Oleg Nikiforov[2], and Thomas Walther[1] — [1]TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt — [2]Deutsche Telekom Technik GmbH, Darmstadt, Deutschland

Quantum computers can threaten today's IT infrastructure e.g. by implementing Shor's algorithm. Quantum key distribution (QKD) enables users to share a random secret, thus offering resilience against such attacks by choosing other cryptographic primitives. Many QKD systems based on various protocols have been tested. Often, these protocols are susceptible to drifts in the properties of the transmission link (e.g. changing polarization) and do not offer scalability to more than two users, hence, they are not ideal for real-world applications. We present a city-wide field test of our star-shaped QKD network enabling scalability to more than 100 users. A central untrusted node acts as a photon pair source. The phase-time coding protocol makes our setup independent of polarization drifts in the transmission links. We show results with four parties all being placed at different locations within the city and connected via field-deployed fibers exchanging pairwise keys. Our system features a complete post-processing allowing to generate real-time secure keys. Additionally, we demonstrate the plug-and-play flexibility of our network by showcasing various operation modes and combinations of receiver pairs.

Q 58.2 Thu 14:45 HS IX

A Compact Receiver for Polarisation Encoded BB84 Quantum Key Distribution — •Michael Steinberger[1,2], Moritz Birkhold[1,2], Michael Auer[1,2,3], Adomas Baliuka[1,2], Harald Weinfurter[1,2,4], and Lukas Knips[1,2,4] — [1]Ludwig Maximilian University (LMU), Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Universität der Bundeswehr, Neubiberg, Germany — [4]Max Planck Institute of Quantum Optics (MPQ), Garching, Germany

Quantum Key Distribution (QKD) provides secure exchange of shared secret keys, solely by exploiting the laws of quantum mechanics. Free-space optical communication allows for a range of different QKD use-cases, including short ground-to-ground links for urban environments up to key exchange with stallites. Current hardware uses telescopes with complex optics and highly efficient single-photon detection devices. To make QKD suitable for scenarios offering less space and profiting from a higher degree in mobility, our goal is to develop a very compact and integrated detection system for polarization-encoded BB84 QKD. We show how using a CMOS single photon avalanche detector array (provided by the Technical University of Vienna) with new compact electronics - trading in performance - the scalability and integrability can be clearly increased. Together with a microoptics based concept this enables a miniaturized polarisation analysis unit (PAU) on the millimeter scale.

Q 58.3 Thu 15:00 HS IX

Optical system for bi-directional tracking in free-space quantum key distribution link — •Akhil Gupta[1,4], Michael Auer[1,3,4], Michael Steinberger[1,4], Adomas Baliuka[1,4], Moritz Birkhold[1,4], Manpreet Kaur[1,2,4], Harald Weinfurter[1,2,4], and Lukas Knips[1,2,4] — [1]Ludwig Maximilian University of Munich, Munich, Germany — [2]Max Planck Institute of Quantum Optics, Garcing, Germany — [3]Universität der Bundeswehr München , Munich, Germany — [4]Munich Center for Quantum Science and Technology, Munich, Germany

Quantum Key Distribution (QKD) offers a secure alternative to traditional cryptographic algorithms to generate shared secret keys. We aim to establish a secure ground-to-ground communication on the few kilometers scale using simple and sturdy systems. This talk highlights the critical role of telescopes in free-space communication, enabling efficient signal transmission and reception. Our symmetrical telescope design functions as both transmitter and receiver, optimized for 850 nm (QKD signal) and 1550 nm (tracking, synchronization, and classical communication). The system addresses atmospheric challenges to ensure bidirectional stability, enabling low-loss transmission for reliable and secure quantum communication.

Q 58.4 Thu 15:15 HS IX

Frequency conversion in a hydrogen-filled hollow core fiber — •Anica Hamer[1], Frank Vewinger[2], Thorsten Peters[3], and Simon Stellmer[1] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, Germany — [2]Institut für Angewandte Physik, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, Germany — [3]Institut für Angewandte Physik, Technische Universität Darmstadt, Darmstadt, Germany

Quantum networks, as envisioned for quantum computation and quantum communication applications, are based on a hybrid architecture. Such a layout may include solid-state emitters and network nodes based on photons as so-called flying qubits. This concept requires an efficient and entanglement-preserving exchange of photons between the individual components, which often entails frequency conversion of the photon.

Our approach is based on coherent Stokes Raman scattering (CSRS) in a dense molecular hydrogen gas. This four-wave mixing process sidesteps the limitations of nonlinear crystals, it is intrinsically broadband and does not generate an undesired background. We present broadband and polarization-preserving frequency conversion in a hydrogen-filled anti-resonant hollow-core fiber between 863 nm (InAs/GaAs quantum dots) and the telecom O-band. Disparate from related experiments that employ a pulsed pump field, we here take advantage of two coherent continuous-wave pump fields.

Q 58.5 Thu 15:30 HS IX

QUBE-II: Compact and economical satellite-based quantum key distribution — •Joost Vermeer for the QUBE-II-Collaboration — Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen, Germany — Max Planck Institute for the Science of Light (MPL), Staudtstr. 2, 91058 Erlangen, Germany

The range of fiber-based quantum key distribution (QKD) systems is limited by the fiber's attenuation. To overcome this limit, several projects have been started in the past decade to develop satellite-based QKD systems. The cost of these systems is for a large part determined by the size, weight and power of the satellite.

Built upon predecessor mission QUBE, the goal of the QUBE-II mission is to use a small 8U CubeSat ($10 \times 20 \times 40$ cm^3) to perform QKD between the CubeSat and a ground station. Two integrated QKD transmitters implement polarization- and phase-encoded versions of the BB84 decoy protocol. Random optical quantum states are generated using a photonic integrated onboard quantum random number generator and transmitted to the ground station using an 80 mm optical telescope. For post-processing the same optical path is used to establish a bidirectional classical data link.

In this work, we will present the nominal operations of the QUBE-II mission. We will discuss the requirements needed for a successful QKD link and a secure quantum key, the effect hardware limitations have on the requirements and the effect these requirements have on the hardware design.

Q 58.6 Thu 15:45 HS IX

QKD satellite QUBE - Launched and commissioned — •Moritz Birkhold für die QUBE Konsortium-Kollaboration — Ludwig Maximilian University, Munich, Germany — Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 Munich, Germany

Since its inception in 1984, ongoing efforts have been made to bring the distinct advantages of Quantum Key Distribution (QKD)- secure generation of a cryptographic key-into practical use outside of laboratory environments. With the emergence of larger and longer fiber-based QKD networks used in urban environments, solutions for a truly global QKD backbone are being sought. Using satellites as trusted nodes can offer this solution.

The QUBE missions attempt to achieve downlink QKD with small nanosatellites using the CubeSat platform. Extensive development produced energy-efficient electronics and highly compact, robust optics based on vertical-cavity surface-emitting lasers and integrated photonics, to make this scalable form factor usable. The first of these satellites QUBE, a pathfinder mission towards QKD with nanosatellites, was launched in August 2024 and is currently in the comissioning phase, allowing for the first QKD experiments in Q1 of 2025. We will show the most recent progress of the project, most recent ground measurements as well as updates on the measurement campaign, that will lead towards the sucessor mission QUBE 2, a nanosatellite with full QKD capabilities.

Q 58.7 Thu 16:00 HS IX

Pulse shape optimization against Doppler shifts and delays in optical quantum communication — •Emanuel Schlake[1,2,3], Roy Barzel[1,2], Dennis Rätzel[1,2], and Claus Lämmerzahl[1,2] — [1]ZARM, University of Bremen, 28359 Bremen, Germany — [2]Gauss-Olbers Space Technology Transfer Center, University of Bremen, 28359 Bremen, Germany — [3]Department of Communications Engineering, University of Bremen, 28359 Bremen, Germany

High relative velocities and large distances in space-based quantum communication with satellites in lower earth orbits can lead to significant Doppler shifts and delays of the signal impairing the achievable performance if uncorrected. We analyze the influence of systematic and stochastic Doppler shift and delay in the specific case of a continuous variable quantum key distribution (CV-QKD) protocol and identify the generalized correlation function, the ambiguity function, as a decisive measure of performance loss. Investigating the generalized correlations as well as private capacity bounds for specific choices of spectral amplitude shape (Gaussian, single- and double-sided Lorentzian), we find that this choice has a significant impact on the robustness of the quantum communication protocol to spectral and temporal synchronization errors. We conclude that optimizing the pulse shape can be a building block in the resilient design of quantum network infrastructure.

Q 58.8 Thu 16:15 HS IX

Dynamic Polarization State Preparation for Single-Photon Quantum Cryptography — •Anastasios Fasoulakis, Koray Kaymazlar, Martin von Helversen, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Quantum Key Distribution (QKD) is the most developed application in the field of quantum information science. Prepare-and-measure type protocols thereby rely on a fast, random qubit-state preparation. In this contribution we discuss our progress in the development of fast polarization-state encoders for single-photon implementations of BB84-QKD as well as cryptographic primitives beyond QKD. Using high-bandwidth free-space optical as well as fiber-based electro-optical modulators in combination with commercial and self-built control-electronics, solid-state quantum light sources emitting at different wavelengths can be modulated. We characterise and optimise the system's performance in terms of its extinction ratio and repetition rate and gauge its potential applications in future QKD systems.

Q 59: Ultra-cold atoms, ions and BEC IV (joint session A/Q)

Time: Thursday 14:30–16:30 Location: GrHS Mathe

Q 59.1 Thu 14:30 GrHS Mathe

Dark energy search using atom interferometry in microgravity — •Sukhjovan Singh Gill[1], Magdalena Misslisch[1], Charles Garcion[1], Alexander Heidt[2], Ioannis Papadakis[3], Vladimir Schkolnik[3], Christoff Lotz[2], Sheng-Wey Chiow[4], Nan Yu[4], and Ernst Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germay 30167 — [2]Institut für Transport- und Automatisierungstechnik, Leibniz Universität Hannover, Hannover, 30167, Germany — [3]Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany 12489 — [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA 91109

The nature of dark energy is one of the biggest quests of modern physics and is crucial for explaining the accelerated expansion of the universe. In the chameleon theory, a scalar field is proposed, which is hidden due to a screening effect in the vicinity of bulk masses to make the model concord with observations. DESIRE project studies the chameleon field model using Bose-Einstein condensates of ^{87}Rb atoms as a source in a microgravity environment. The Einstein-Elevator at Leibniz University Hannover provides 4 seconds of microgravity time for multiloop atom interferometry to search for phase contributions induced by chameleon fields influenced by variations in mass density.

Bloch oscillations are intended to transport the BEC from the atom chip to the test-mass to perform atom interferometry. Landau-Zener and Wannier-Stark models are employed to simulate losses during transport for precise selection of the lattice depth, detuning, and pulse shape for an efficient transport.

Q 59.2 Thu 14:45 GrHS Mathe

Quantum Monte Carlo simulations of hardcore bosons with repulsive dipolar density-density interactions on two-dimensional lattices — •Robin Rüdiger Krill[1,2], Jan Alexander Koziol[2], Calvin Krämer[2], Anja Langheld[2], Giovanna Morigi[1], and Kai Phillip Schmidt[2] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Department für Physik, Friedrich-Alexander Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany

We study the extented Bose-Hubbard model, describing bosons in optical lattices that interact with long-range repulsive forces. The forces are algebraically decaying with the distance, the Bose-Hubbard model is extended by adding a repulsive density-density interaction term. We determine the quantum phase diagram for hard-core bosons using a Stochastic Series Expansion quantum Monte Carlo algorithm, where we develop a sampling procedure to account for the long-range interactions in directed loop updates. We then determine the phase diagram on the two-dimensional square and triangular lattice, where a mean-field study predicts rich quantum phase diagrams including a devil's staircase of solid phases and a plethora of exotic lattice supersolids [1].

[1] J. A. Koziol, G. Morigi, K. P. Schmidt, SciPost Physics 17.4 (2024)

Q 59.3 Thu 15:00 GrHS Mathe

Engineering Atomic Interactions using Floquet-Feshbach Resonances — •Alexander Guthmann, Felix Lang, Louisa Marie Kienesberger, Krishnan Sundararajan, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

Scattering resonances are fundamental in physics, governing dynamics from high-energy nuclear fusion to the low-energy regime of ultracold quantum gases. Magnetically tunable Feshbach resonances have revolutionized the study of ultracold atomic systems by enabling precise control over interaction strengths. However, their dependence on static magnetic fields limits their flexibility, particularly in complex systems such as multi-component quantum gases. In this talk, we present the experimental realization of Floquet-Feshbach resonances in a gas of lithium-6 atoms, achieved through strong magnetic field modulation at MHz frequencies. This periodic modulation creates new scattering resonances where dressed molecular states intersect the atomic threshold. Furthermore, using a two-color driving scheme, we demonstrate tunable control over resonance asymmetries and suppress inelastic two-body losses caused by Floquet heating. These advancements offer a versatile tool for tailoring atomic interactions, paving the way for quantum simulations of complex many-body systems and the exploration of exotic quantum phases.

Q 59.4 Thu 15:15 GrHS Mathe

Constrained dynamics in the two-dimensional quantum Ising model — •Luka Pavesic[1,2], Daniel Jaschke[1,2,3], and Simone Montangero[1,2] — [1]Dipartimento di Fisica e Astronomia 'G. Galilei', via Marzolo 8, I-35131 Padova, Italy — [2]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Padova, I-35131 Padova, Italy — [3]Institute for Complex Quantum Systems, Ulm University, Albert-Einstein-Allee 11, 89069 Ulm, Germany

We numerically investigate the dynamics of the quantum Ising model on two-dimensional square lattices up to 16x16 spins. In the ordered phase, the model is predicted to exhibit dynamical constraints. This leads to confinement of elementary excitations and slow thermalization.

The dynamical constraints are strongly related to the presence of domain walls. We explore how the nature of confined excitations governs the evolution of domain walls, and investigate quantum coarsening of competing domains.

The results demonstrate the ability to numerically capture dynamics of large two-dimensional interacting systems. We foresee many interesting extensions of the presented work, numerically or experimentally. As the most direct avenues, we propose the investigation of quantum coarsening, and false vacuum decay in two dimensions.

Q 59.5 Thu 15:30 GrHS Mathe

Quasiparticle Properties of Long-range Impurities in a Bose Condensate — •Taha Alper Yogurt and Matthew Eiles — Max Planck Institute for the Physics of Complex Systems Nöthnitzer Straße 38 01187 Dresden

Atomic impurities inside of a Bose condensate facilitated the study of Fröhlich polarons, wherein impurity-bath interactions are considered only to linear order. The tunability of interactions enabled the exploration of attractive and repulsive polaron regimes, requiring interactions beyond Fröhlich (BF) model. In this regime, polaron dynamics intertwine with few-body physics, as short and long-range impurities support single or multiple bound states. Characterizing an impurity as a quasiparticle across various regimes and the determination of its quasiparticle properties have attracted significant interest. Here we employ two complementary methods to compute the quasiparticle properties of the contact, ion, and Rydberg impurities in the BF model. First, we use an ansatz in the form of a coherent state of the condensate excitations. The coherent-state amplitudes for zero momentum are calculated to determine the energy and quasiparticle weights, followed by solving the implicit equation for a moving impurity to obtain the effective mass. The second method treats the impurity as a slowly moving external potential and solves the Gross-Pitaevskii (GP) equation, assuming small perturbations around a uniform density. By expanding the GP energy in powers of the impurity velocity, we derive an analytical expression for the BF effective mass of the contact impurities, consistent with the former approach.

Q 59.6 Thu 15:45 GrHS Mathe

Engineering tunable synthetic fluxes with Raman-coupled Bose mixtures in an accordion optical lattice — •Andreas Michael Meyer[1], Ignacio Pérez-Ramos[1], Rémy Vatré[1], Sarah Hirthe[1], and Leticia Tarruell[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain

The Harper-Hofstadter model describes two-dimensional charged particles in a lattice in a perpendicular magnetic field. For interacting particles, it features exotic phases like the lattice analog of the fractional quantum Hall states. So far, realizations of these strongly-interacting systems using neutral cold atoms have been limited to few particles.

We report on our progress towards an interacting many-body realization of the Harper-Hofstadter model. It is based on a Raman-coupled bosonic spin mixture where the two spin states can be thought of as lattice sites in a synthetic dimension. Placing the spin mixture in a one-dimensional optical lattice, we can obtain a ladder system and realize a minimal instance of the model. The Raman coupling further results in complex tunneling rates giving rise to a synthetic flux through the ladder. It is governed by two competing length scales: the lattice spacing and the wavelength of the recoil momentum of the Raman transition.

Here, we present our experiment with optical lattices of adjustable lattice spacing. We can thus realize ladder systems pierced by arbitrary fluxes and probe their spectrum using spin-injection techniques.

Q 59.7 Thu 16:00 GrHS Mathe

Parallel entangling gates on a 2D ion-trap lattice — •Lennart Kämmle, Ralf Riedinger, and Ludwig Mathey — University of Hamburg

In current trapped-ion quantum computers ion traps are commonly arranged in a (quasi-)linear configuration. However, this setup is hardware-intensive, limiting the scalability.

In this project we study several versions of 2D geometrics and control setups to improve the efficiency and scalability of trapped-ion quantum computers.

Specifically, we explore the geometric constraints of a 2D ion-trap lattice as well as schemes to apply the Mølmer-Sørensen entangling gate on multiple individual lattice sites in parallel by using local rotations.

Going forward we point out strategies regarding beam leakage and single-site selectivity, to improve the fidelity of parallel quantum entanglement gates in trapped-ion systems.

Q 59.8 Thu 16:15 GrHS Mathe

Phase transitions and dissipation in one-dimensional supersolids. — •Chris Bühler, Alicia Biselli, and Hans Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, DE-70550 Stuttgart, Germany

Quantum fluctuations in one dimensions prevent the appearance of long-range order for a continuous symmetry even at zero temperature. Furtherure, the nucleation of quantum phase slips can have significant influence on the phase diagram and transport properties. Here, we study the influence of quantum phase slips on the phase diagram of a one-dimensional supersolid as they can be realized with Dysprosium atoms. We demonstrate the appearance of a novel quantum phase transition from the supersolid to the superfluid phase and study in detail its influence on transport properties.

Q 60: Precision Spectroscopy of Atoms and Ions VI (joint session A/Q)

Time: Thursday 14:30–16:30 Location: KlHS Mathe

Invited Talk Q 60.1 Thu 14:30 KlHS Mathe

Characterization of an XUV Frequency Comb by Spectroscopy of Rydberg States — •Lennart Guth, Jan-Hendrik Oelmann, Tobias Heldt, Janko Nauta, Nick Lackmann, Anant Agarwal, Lukas Matt, Thomas Pfeifer, and José R. Crespo López-Urrutia — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

We aim to use ultra-narrow transitions in highly charged ions (HCI) for novel frequency standards and fundamental physics studies. These transitions occur in the extreme ultraviolet (XUV), where narrow-bandwidth laser sources are unavailable. To address this, we built an XUV frequency comb that transfers coherence from a near-infrared (NIR) comb to the XUV via high harmonic generation (HHG) [1,2]. Using intra-cavity HHG, our system generates harmonics up to 40 eV with μW power in each order.

We propose resonance-enhanced two-photon spectroscopy as a preliminary test towards spectroscopy of HCI, aiming to resolve individual teeth of our XUV comb and characterize its properties. In this approach, we excite neutral argon with one photon from a referenced 13^{th} harmonic comb tooth to a Rydberg state, followed by ionization with a narrow-bandwidth continuous wave NIR laser. We then use velocity-map imaging to record the momentum of the released electrons, allowing us to identify the resonant Rydberg state.

[1]Opt. Express 29, Issue 2, pp. 2624-2636 (2021)
[2]Rev. Sci. Instrum. 95, 035115 (2024)

Q 60.2 Thu 15:00 KlHS Mathe

Simulating coupled oscillators in a Penning trap for

(anti-)proton g-factor measurements — •Nikita Poljakov[1], Jan Schaper[1], Julia Coenders[1], Yannick Priewich[1], Juan Manuel Cornejo[1], Stefan Ulmer[3,4], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN, Japan — [4]Heinrich-Heine-Universität Düsseldorf, Germany

The BASE collaboration tests CPT symmetry via high-precision measurements of the (anti-)proton charge-to-mass ratio [1] and g-factor [2]. To improve g-factor sampling rates, we are developing quantum logic spectroscopy [3] with a laser-cooled $^9Be^+$ ion in a cryogenic Penning trap. This requires cooling the $^9Be^+$ ion and (anti-)proton to their motional ground states. Key milestones include optical sideband spectroscopy [4], ground-state cooling of a single $^9Be^+$ ion [5], and fast adiabatic transport [6]. We aim to couple an (anti-)proton to a cooled $^9Be^+$ ion via Coulomb interaction in a double-well potential created by a microfabricated trap. Here, we present project updates and simulations of coupled $^9Be^+$ ions and a single $^9Be^+$ ion coupled to an (anti-)proton.

[1] M.J. Borchert et al., Nature 601 (2022) [2] C. Smorra et al., Nature 550 (2017) [3] P.O. Schmidt et al., Science 309 (2005) [4] J.M. Cornejo et al., Phys. Rev. Res. 5 (2023) [5] J.M. Cornejo et al., Phys. Rev. Res. 6 (2024) [6] T. Meiners et al., Eur. Phys. J. Plus 139 (2024)

Q 60.3 Thu 15:15 KlHS Mathe

Probing parity violating interactions beyond the Standard Model with molecular spectroscpy — •Konstantin Gaul — Helmholtz Institute Mainz, Staudingerweg 18, 55128 Mainz

Dark spin-1 bosons, such as dark photons or Z' bosons, are particularly interesting dark matter (DM) candidates which are predicted by several theories that extend the Standard Model (SM). The Z' boson could act as a possible link between visible matter and DM and would be a source for a violation of parity beyond the SM [1]. Studying such parity violating interactions over a broad range of boson masses M is challenging for common low-energy dark matter detection methods [2]. In contrast, experiments based on internal interactions of atoms or molecules are sensitive to *long* range interactions $M \to \infty$, as well as interactions at much *shorter* range on the scale of atomic sizes $M \gtrsim 10^3\,\mathrm{eV}/c^2$ and even down to nuclear sizes $M \gtrsim\sim 10^8\,\mathrm{eV}/c^2$ and could, therefore, provide a versatile platform to study parity violating dark matter [2]. An abundance of close-lying states of opposite parity, which can enhance parity violating interactions by several orders of magnitude, renders polar linear molecules and chiral molecules particularly interesting for this purpose [3,4]. In this contribution the sensitivity of current molecular experiments to Z' bosons and prospects of future experiments will be discussed from a theory perspective.

[1] A. Alves et al., JHEP. 2014, 63 (2014).
[2] L. Cong et al, arXiv, hep-ph, 2408.15691 (2024).
[3] K. Gaul et al. PRL 125, 123004; PRA 102, 032816 (2020).
[4] Baruch et al., PRResearch 6, 043115 (2024).

Q 60.4 Thu 15:30 KlHS Mathe

Accurate isotope shift measurements in the 5s→5p and 4d→5p lines of Sr+ — •Julian Palmes, Kristian König, Hendrik Bodnar, Patrick Müller, Imke Lopp, Julien Spahn, and Wilfried Nörtershäuser — Institut für Kernphysik, TU Darmstadt, Germany

Accurate measurements of different transition frequencies in multiple isotopes allow for the determination of the isotope shift and thus the calculation of the field-shift ratio F_i/F_j , which is an important parameter to compare experimental results with state-of-the-art atomic structure calculations. In 2016, Shi et al. [1] measured the F_{D2}/F_{D1} field shift ratio in Ca^+ to be above theoretical boundaries set by the hydrogenic model, which set off a series of measurements in Ca^+ [2], Ba^+ [3] and now Sr^+ at the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA) at the Technical University of Darmstadt. We report absolute frequency measurements of the stable Sr^+ isotopes of the $5s \to 5p$ and the $4d \to 5p$ transitions. A King plot analysis was performed to extract the field shift ratio F_{D2}/F_{D1}, and utilizing the $4d \to 5p$ transitions, ring closures were formed for self-consistency. Additionally, this method allowed for a precise observation of the hyperfine splitting of the $^{87}Sr^+$ isotope, which is the first step for the investigation of the magnetic octupole moments at the BICEPS trap. Funding by BMBF under contract 05P21RDFN1 is acknowledged.

[1] Shi et al., Applied Physics B 123, 2 (2016)
[2] Müller et al., Physical Review Research 2.4 (2020)
[3] Imgram et al., Physical Review A 99.1 (2019)

Q 60.5 Thu 15:45 KlHS Mathe

High resolution spectroscopy of Mossbauer materials using Ptychography — •Ankita Negi[1], Lars Bocklage[1], Leon Merten Lohse[1], Sven Velten[1], Guido Meier[2], Ralf Röhlsberger[3], and Christina Brandt[4] — [1]Deutsches Elektronen Synchrotron, Hamburg, Germany — [2]Max Planck Institute for the structure and dynamics of matter, Hamburg, Germany — [3]Friedrich Schiller Universität Jena, Jena, Germany — [4]Universität Greifswald, Greifswald, Germany

Mössbauer spectroscopy is a technique for measuring atomic-level magnetic and chemical properties of materials. The "Mössbauer effect" allows nuclei to absorb or emit gamma radiation without losing energy to the lattice. Advances in synchrotron sources have enabled measurements of nuclear resonant scattering (NRS) of synchrotron gamma-ray pulses, offering better sensitivity and faster data collection compared to spectroscopy with traditional radioactive sources. However, extracting spectral information from a single time-domain NRS measurement is challenging and requires extensive modeling. To address this, we modify the setup and use multiple overlapping NRS measurements to extract both the transmission spectrum and phase. Our approach, inspired by phase retrieval algorithms in ptychography, frames the problem as a one-dimensional phase retrieval. We demonstrate the robustness of our method with ^{57}**Fe**-enriched samples, showing that, unlike traditional Mössbauer spectroscopy, our technique overcomes bandwidth limitations of gamma-ray sources, offering new possibilities for research with modern X-ray sources and other Mössbauer isotopes.

Q 60.6 Thu 16:00 KlHS Mathe

Improvement of the bound-electron g-factor theory after completion of two-loop QED calculations — •Bastian Sikora, Vladimir A. Yerokhin, Christoph H. Keitel, and Zoltán Harman — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

The bound-electron g-factor in hydrogenlike ions can be measured and calculated with high precision. In a recent collaboration, the experimental and theoretical g-factors of the bound electron in hydrogenlike tin were found to be in excellent agreement [1]. However, the theoretical uncertainty is orders of magnitude larger than the experimental uncertainty due to uncalculated QED binding corrections at the two-loop level.

In our new work, we report the completed calculation of QED Feynman diagrams with two self-energy loops contributing to the g-factor using the Furry picture approach, i.e. taking into account the electron-nucleus interaction exactly [2]. We demonstrate that our results allow a significant improvement of the total theoretical uncertainty of the bound-electron g-factor.

Our calculations will enable improved tests of QED in planned near-future experiments, e.g. at ALPHATRAP and ARTEMIS, and are relevant for the determination of fundamental constants as well as searches for physics beyond the standard model using heavy ions.

[1] J. Morgner, B. Tu, C. M. König, et al., Nature 622, 53 (2023)
[2] B. Sikora, V. A. Yerokhin, C. H. Keitel and Z. Harman, arXiv:2410.10421v1 [physics.atom-ph]

Q 60.7 Thu 16:15 KlHS Mathe

Development of a non-collinear enhancement resonator for a VUV frequency comb nuclear clock laser — •Stephan H. Wissenberg[1,2,3], Johannes Weitenberg[1,4], Akira Ozawa[4], Tamila Teschler[2], Mahmood I. Hussain[3], Peter G. Thirolf[3], Hans-Dieter Hoffmann[1], and Constantin L. Haefner[1,2] — [1]Fraunhofer ILT, Aachen — [2]RWTH Aachen University, Aachen — [3]LMU, Munich — [4]MPQ, Garching

229-Thorium is unique in possessing a nuclear transition energy accessible by current laser technology, making it suitable for a nuclear clock's operation. To drive the nuclear transition, we are building a vacuum-ultraviolet (VUV) frequency comb at 148 nm, derived from a high-power infrared frequency comb via resonator-assisted high-harmonic generation (HHG). Our design features a non-collinear enhancement resonator where two intersecting circulating beams enable efficient geometric output-coupling of the VUV beam. Synchronizing and aligning these beams poses a challenge. We describe a resonator design employing wedge mirrors which avoids the need for separate mirrors for the two circulating beams, providing intrinsic synchronization and alignment. We provide detailed characterization measurements using a cw-laser to showcase the versatility of this non-collinear resonator design. Furthermore, cylindrical mirrors are incorporated to modify the focus's ellipticity, reducing cumulative plasma effects. Achieved ellipticities of $\epsilon > 3$ do not compromise the resonator's enhancement factor of >50. Work supported by the ERC Synergy Grant 'Thorium-NuclearClock' (Grant 856415).

Q 61: Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)

Time: Thursday 14:30–15:45 Location: HS PC

Q 61.1 Thu 14:30 HS PC

Lamb-Dicke Dynamics of Rydberg Atoms in Optical Tweezers — •Aslam Parvej[1,2], Lia Kley[1,2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany

Neutral Rydberg atoms trapped in optical tweezer arrays provide a platform for quantum simulators and computation. In this study, we investigate the dynamics of the Lamb-Dicke-coupled internal states of the atoms, which form the logical qubits, in conjunction with the motion of the optical tweezers across different parameter regimes. In this setup, the logical qubit is coupled to a laser with a Rabi frequency, while each atom is also harmonically trapped with a trap frequency. The impact of coherent motion of the optical tweezers on collective non-equilibrium dynamics of the Rydberg atom is explored for varying Lamb-Dicke parameters and resonant Rabi frequencies.

Q 61.2 Thu 14:45 HS PC

Calculating Rydberg interactions with pairinteraction-next — •Johannes Mögerle[1], Frederic Hummel[2], Henri Menke[3], and Sebastian Weber[1] — [1]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, Germany — [2]Atom Computing, Inc., Berkeley, California — [3]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

Rydberg atoms are utilized in a variety of experimental applications, including quantum simulations, ultracold chemistry, and quantum information. Their strong and highly tunable interactions via external fields and their inter-atomic distance vector make them a powerful platform for these applications. Many of these experiments are conducted with such high precision that perturbative calculations of the interaction potentials are insufficient, and exact calculations are needed.

In this talk, we present a new version of the pairinteraction software, a tool for calculating the interaction potentials between two Rydberg atoms in arbitrary fields, as well as interesting properties like dipole matrix elements and effective Hamiltonians. The updated pairinteraction version now includes simulations of alkaline earth atoms, described by multichannel quantum defect theory (MQDT), leading to larger Hilbert spaces. These calculations are now feasible due to the improved performance of the C++ backend. Additionally, the new version features a Python package that abstracts the C++ backend, providing users with a high-level and easy-to-use Python interface.

Q 61.3 Thu 15:00 HS PC

Functional Rydberg Complexes in the VdW Model — •Simon Fell — ITP 3 - Uni Stuttgart

We consider the construction of functional Hilbert spaces characterized by local constraints as the low-energy sector of a microscopic system of Rydberg atoms. The construction of such Hilbert spaces provides a path towards the realization of quantum phases with topological order or geometric programming in the NISQ era. We consider realistic, algebraic decaying Van der Waals (VdW) interactions and compare with previous studies performed within the PXP blockade approximation. We present tools to tackle the residual interactions and introduce a versatile set of efficient elementary building blocks to implement the constraints, both in two and in three dimensions. We illustrate the limitations imposed by the VdW interactions on lattice realizations of string-net Hilbert spaces with loop degrees of freedom on the Rydberg platform.

Q 61.4 Thu 15:15 HS PC

Nonlinear effects on the transport of fractional charges in quantum wires — •Flavia Braga Ramos[1], Rodrigo Gonçalves Pereira[2], Sebastian Eggert[1], and Imke Schneider[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 Experimental, Universidade Federal do Rio Grande de 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.

Q 61.5 Thu 15:30 HS PC

Ground State Cooling of a Single Beryllium Ion in a Superconducting Paul Trap — •Stepan Kokh, Vera M. Schäfer, Elwin A. Dijck, Christian Warnecke, José R. Crespo López-Urrutia, and Thomas Pfeifer — Max-Planck-Institut für Kernphysik, Heidelberg

Spectroscopy of ions and atoms for generalized King Plot analysis allows for the search of new physics, such as unknown particles or forces, using one of the most precisely measurable quantities, the transition frequency of an atom. Employing highly charged ions (HCI) greatly increases the number of available transitions through the different charge states [1]. This method requires high precision. Therefore, suppression of external perturbations is essential. Our superconducting Paul trap shields external fields by 57 dB, a level comparable to dedicated magnetically shielded rooms [2]. However, the current setup limits our secular frequencies due to thermal effects in the Paul trap resonator. Therefore, we operate only in an intermediate Lamb-Dicke regime at $\eta = 0.84$. We demonstrate how we nevertheless achieve ground-state cooling of a single beryllium ion with 80 % ground-state population in the given setup as a first step towards quantum logic spectroscopy of HCI.

[1] Nils-Holger Rehbehn, et al., Phys. Rev. Lett. 131, 161803 (2023)
[2] Elwin A. Dijck, et al., Rev. Sci. Instrum. 94, 083203 (2023)

Q 62: Poster – Quantum Information Technologies (joint session Q/QI)

Time: Thursday 17:00–19:00 Location: Tent

Q 62.1 Thu 17:00 Tent

Design of a tweezer setup for rearrangement and addressing of single atoms in an optical cavity — •Micha Kappel, Raphael Benz, Sebastián Alejandro Morales Ramirez, Vincent Beguin, Krishna Relekar, and Stephan Welte — 5. Physikalisches Institut, Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Neutral atoms coupled to an optical cavity are a promising platform for implementing quantum network nodes. To realize network nodes with multiple stationary atomic qubits, it is crucial to position and address the atoms precisely within the cavity mode. We present an optical design utilizing two two-dimensional acousto-optical deflectors to create optical tweezers capable of trapping arrays of Rubidium atoms inside the cavity. This setup not only facilitates precise atom trapping but also enables individual addressing and rearrangement of the atoms.

To mitigate the inevitable atom losses during operation, we propose the inclusion of a reservoir containing additional atoms in a tweezer array outside the cavity mode. These extra atoms can be used to replenish lost atoms within the cavity. We describe our optical setup and discuss experimental techniques and challenges.

Q 62.2 Thu 17:00 Tent

Characterization and development of the Saarbrücken fiber link for memory-based quantum communication protocols — •Christian Haen[1], Max Bergerhoff[1], Jonas Meiers[1], Stephan Kucera[2], and Jürgen Eschner[1] — [1]Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken — [2]Luxembourg Institute of Science and Technology (LIST), Belveaux, Luxembourg

Deployed telecom glass fiber networks offer a basis for the wide-scale development of quantum networks, but characteristics of existing fibers, such as large loss and arrival time or polarization drifts through environmental exposure, must be addressed.

Previously, we demonstrated and characterized quantum network protocols on a 14-km long urban dark fiber link in Saarbrücken by transmitting photons from an SPDC source [1]. Now, we report on characterizing and developing the fiber link to allow for quantum network protocols using photons emitted by a $^{40}Ca^+$ single-ion quantum memory, in order to demonstrate atom-photon entanglement and, based on this, device-independent quantum key distribution under realistic conditions.

[1] S.Kucera et al., npj Quantum Inf 10, 88 (2024)

Q 62.3 Thu 17:00 Tent

Two-cavity-mediated photon-pair emission by one atom — •Tobias Frank, Gianvito Chiarella, Pau Farrera, and Gerhard Rempe — Max Planck Institute for Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching bei München

Single atoms coupled to high-finesse Fabry-Perot cavities provide a versatile quantum network node, enabling efficient generation, storage, and manipulation of photonic qubits with high fidelity. A key focus of ongoing research is to scale either the number of atoms coupled to the cavity or the number of cavity modes interacting with each atom. Our group achieved the latter by using two optical fiber based cavities which couple independently to a single atom in the high atom-photon cooperativity regime. This enables new quantum communication schemes, in which photonic qubits are either tracked by nondestructive qubit detection or received by an heralded quantum memory. In our recent work, we demonstrate an on-demand photon pair generation scheme [1] in which a single atom with three energy levels in a ladder configuration couples to two optical fiber cavities, generating photon pairs with an in-fiber emission efficiency of $\eta_{pair} = 16(1)\%$. We study the correlation properties of the emitted light and simulate the regime of strong atom-photon coupling, in which the atom emits photon pairs without populating the intermediate state. We propose a scenario to observe such a double-vacuum-stimulated effect experimentally.

[1] G Chiarella, T Frank, P Farrera, G Rempe. Optica Quantum Vol. 2, Issue 5, pp. 346-350 (2024)

Q 62.4 Thu 17:00 Tent

Device-independent quantum key distribution with atom-photon entanglement for an urban fiber link — •Jonas Meiers, Christian Haen, Max Bergerhoff, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Quantum cryptographic protocols offer physical security through no-cloning or entanglement. Following the entanglement-based quantum key distribution protocol of [1], we present our device-independent implementation with a $^{40}Ca^+$-ion as quantum memory. The protocol requires four atomic bases and two photonic bases and allows us to create a quantum key with security verification via the Bell parameter. We employ polarization entanglement between a single trapped $^{40}Ca^+$ ion and an emitted photon at 854 nm, generated via the $P_{3/2} \rightarrow D_{5/2}$ transition [2]. The photon is frequency-converted to the telecom band, enabling its transmission over our 15-km-long urban fiber link across Saarbrücken [3]. The fiber link has been characterized and stabilized for the transmission of polarization-encoded qubits. The projected qubits are error-corrected via a cascade algorithm to create the secure key and enable secure communication between the two nodes.

[1] R. Schwonnek et al., Nat. Commun. 12, 2880 (2021)
[2] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[3] S.Kucera et al., npj Quantum Inf. 10, 88 (2024)

Q 62.5 Thu 17:00 Tent

Quantum Network Nodes with Cold Atoms in Optical Cavities — •Raphael Benz, Sebastián Alejandro Morales Ramírez, Micha Kappel, Vincent Beguin, Krishna Relekar, and Stephan Welte — 5. Physikalisches Institut, Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany.

The practical implementation of a quantum network remains an outstanding challenge pursued across various hardware platforms. Cold neutral atoms trapped in a high-finesse optical cavity have proven to be a promising platform due to the strong atom-light interaction and the controllability of the system. However, current implementations are limited to a few atoms in the cavity. The ability to position and individually control an array of atoms using optical tweezers opens the possibility of extending this platform to multi-qubit quantum network nodes. We present the plans of our group in Stuttgart to realize such a multi-qubit quantum network node. Several experiments are envisioned with this system, including photon-mediated quantum information processing between intra-cavity atoms, the generation of highly entangled photonic cluster states, and the creation of optical Gottesman-Kitaev-Preskill states.

Q 62.6 Thu 17:00 Tent

Setup and calibration of a single-photon spectrometer — •Jannis Sode, David Lindler, Marlon Schäfer, Tobias Bauer, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

Fiber-based quantum networks consist of spin-photon interfaced quantum memory nodes utilizing flying qubits with wavelengths in the low-loss telecom bands. These photons are either directly generated via optical transitions or transducted using quantum frequency conversion. This enables communication and transfer of quantum states via preexisting optical fiber infrastructure. Due to the small signal level of the transmitted quantum states of light, it is mandatory to explore and control the noise sources in the transmission channels.
To this end, an exact spectral analysis of signals on the single-photon level is necessary to determine the spectral noise distribution. However, commercially available spectrometers typically have a small detection efficiency at infrared wavelengths.
In this contribution, we present the setup of a spectrometer able to measure single-photon signals in the telecom wavelength range (1500-1600 nm) using superconducting nanowire single photon detectors with high detection efficiency. We discuss the overall efficiency as well as the accuracy of the spectrometer.

Q 62.7 Thu 17:00 Tent

Towards fiber-integrated quantum frequency conversion in PPLN waveguides — •Felix Rohe, Marlon Schäfer, Tobias Bauer, David Lindler, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

Quantum frequency conversion to the low-loss telecom bands is a key enabling technology for long-range fiber-based quantum networks. While many state-of-the-art conversion devices use free-space coupling to nonlinear waveguides, for applications outside of a controlled lab environment, a more robust and compact design is desirable. One approach would be to substitute the free-space optics in favor of a fiber-based coupling scheme.

Here, we present the coupling of a solid-core photonic crystal fiber (PCF) to a periodically-poled lithium niobate (PPLN) waveguide. PCF are promising candidates for a fiber-integrated design because of their ability to simultaneously guide waves with a large difference in wavelength in the fundamental mode. We show coupling efficiencies of 637 nm signal and 2162 nm pump fields, as well as conversion efficiency and pump-induced noise rate for the difference frequency generation 637 nm - 2162 nm = 903 nm.
As an outlook, we present a concept for an "all-fiber" two-stage quantum frequency converter for NV-resonant photons, that does not use free-space optics. A two-stage conversion scheme was shown to yield very low noise rates in the conversion of SiV-resonant photons [1].

[1] Schäfer, M. et al., Adv Quantum Technol. 2023, 2300228

Q 62.8 Thu 17:00 Tent

Fabricating Tapered Optical Fibres for Quantum Networks — •Lasse Jens Irrgang[1], Timo Eikelmann[1], Mara Brinkmann[1], Tuncay Ulas[1], Donika Imeri[1,2], Konstantin Beck[1], Sunil Kumar Mahato[1], Rikhav Shah[1,2], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

On the journey towards a quantum internet, the development of reliable quantum repeaters and quantum end-nodes is essential. Particularly well suited for usage as quantum bits for storing and processing quantum information in these applications are silicon vacancies in diamond. Crucial for this approach is a coupling of photonic quantum channels to the diamond, where the latter serves as a waveguide.

A recent solution for this challenge, outshining traditional methods, is the so-called adiabatic mode coupling using optical fibres. In this technique, a tapered optical fibre is positioned in contact with the top surface of the diamond waveguide, enabling highly efficient adiabatic coupling of light between the two waveguides. Presented here, is an automated etching setup for the fabrication of these tapered fibres. The silica glass etching process is based on hydrofluoric acid solution. The developed automated etching setup evidentially facilitates the fabrication of linearly tapered fibres with smooth etched surfaces. The customizable taper extends up to a few millimetres, corresponding to an angle of less than one degree between the fibre's centre axis and the tapered surface.

Q 62.9 Thu 17:00 Tent

Setup of a rack-mounted ion trap with integrated cavity — •Lara Becker[1], Jolan Costard[1], Stephan Kucera[1,2], and Jürgen Eschner[1] — [1]Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken — [2]Luxembourg Institute of Science and Technology, Belveaux, Luxembourg

For the realization of quantum networks, quantum repeaters [1] overcome the distance limitations due to propagation loss in direct transmission. Interfaces between single trapped ions and single photons [2] are promising building blocks for implementing a quantum repeater.

We are setting up a multi-segment Paul trap for $^{40}Ca^+$ ions with an integrated fiber cavity to increase the photon collection and generation efficiency of the interface. The trap consists of two laser-machined and metal-coated ceramic ferrules, into which the fiber cavity with sub-mm spacing is integrated. With its compact design, the trap-cavity system including the vacuum chamber, control electronics, ablation laser and photo-ionization laser will be stored in a single transportable rack. Its future implementation will enable quantum repeater protocols [3] over the Saarbrücken fiber link [4].

[1] H.-J. Briegel, et al., Phys. Rev. Lett. 81, 5932 (1998)
[2] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[3] M. Bergerhoff, et al., Phys. Rev. A 110, 032603 (2024)
[4] S. Kucera, et al., npj Quantum Inf. 10, 88 (2024)

Q 62.10 Thu 17:00 Tent

AlGaAs Bragg Reflection Waveguides as Single and Entangled Photon Pair Source — •Akriti Raj[1], Tobias Bauer[1], David Lindler[1], Quankui Yang[2], Thorsten Passow[2], and Christoph Becher[1] — [1]Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken — [2]Fraunhofer-Institut für Angewandte Festkörperphysik IAF, Tullastr. 72, 79108 Freiburg

True single and entangled photon pair sources are crucial elements for applications in quantum technologies. Such sources may be realized by AlGaAs Bragg reflection waveguides, generating correlated single photon pairs through the process of spontaneous parametric down conversion (SPDC) [1]. The material AlGaAs is our preferred choice as the nonlinear medium because it features a high nonlinear coefficient, allows for room temperature operation and has the advantage of being a non-birefringent material. By using a type II SPDC process where the downconverted photons are orthogonally polarised to each other, the produced photons are inherently polarisation entangled eliminating the need for any additional entanglement setup [2]. We here present photon generation rates of 4×10^7 pairs/s/mW from these waveguides. The purity of the produced single photons is quantified by measuring the heralded $g^{(2)}(0) = 0.0017$ at ≈ 0.28 mW pump power. The photons show 91.9% entanglement fidelity with the $|\psi^+ >$ Bell state and 90% purity. We thus realize a room temperature entangled pair photon source at 1546 nm that is already coupled in a standard single-mode telecom fiber for further applications. [1] F. Appas et al., J. Light. Technol. 40 (2022). [2] R. T. Horn et al., Sci. Rep. 3.1 (2013).

Q 62.11 Thu 17:00 Tent

Low Noise Quantum Frequency Conversion of Telecom Photons to SnV-Resonant Wavelengths — •David Lindler, Tobias Bauer, Marlon Schäfer, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

Tin-Vacancy-Centers (SnV) in diamond represent a promising candidate for quantum nodes in quantum communication networks, featuring excellent optical and spin coherence [1,2]. To exchange the information between these nodes over long distances through optical fiber links, the spin state of the SnV-Center is transfered onto single photons. These photons are then converted into the low-loss telecom bands via quantum frequency down-conversion, to avoid the problem of high loss in fibers in the visible wavelength regime. After travelling trough the fiber, the reverse process, converting telecom photons back to the SnV-resonant wavelength, allows the photons to interact with another SnV-based quantum node once again.

We here present a two-stage low noise scheme for quantum frequency conversion of the telecom photons back to the SnV-resonant wavelength based on difference frequency generation in PPLN waveguides. The two step process drastically reduces noise at the target wavelength compared to the single step process [3]. We will present initial results on the conversion efficiency, conversion-induced noise count rates and the frequency stabilization of the mixing laser.

[1] J. Görlitz et al., npj Quant. Inf. 8, 45 (2022).
[2] I. Karapatzakis et al., Phys. Rev. X 14, 031036 (2024).
[3] M. Schäfer et al., Adv Quantum Technol. 2300228 (2023).

Q 62.12 Thu 17:00 Tent

Phase as the Measurement Quantity in Optically Detected Magnetic Resonance Setups With NV Centers — •Ludwig Horsthemke[1], Jonas Homrighausen[2], Ann-Sophie Bülter[1], Jens Pogorzelski[1], Dennis Stiegekötter[1], Frederik Hoffmann[1], Markus Gregor[2], and Peter Glösekötter[1] — [1]Department of Electrical Engineering and Computer Science, FH Münster — [2]Department of Engineering Physics, FH Münster

Measurements of optically detected magnetic resonance (ODMR) with nitrogen-vacancy (NV) centers usually observe the fluorescence intensity while applying a microwave radiation of varying frequency. We propose the phase between the excitation and the fluorescence as an alternative measurement quantity, offering a higher immunity to intensity fluctuations.

The fluorescence decay dynamics of NV centers act as a low pass filter in the frequency domain which changes its frequency response at the application of a resonant MW radiation. Upon intensity modulation of the excitation light at a frequency around 13 MHz we observe a contrast in the phase between excitation and fluorescence. We have previously shown that the phase has a high immunity to intensity fluctuations in all-optical magnetometry setups since we avoid the misinterpretation of changes in fluorescence intensity as changing magnetic fields [1]. In this work, we show the application of the phase measurement in a continuous wave ODMR setup.

[1] Horsthemke, L., et al. Excited-State Lifetime of NV Centers for All-Optical Magnetic Field Sensing. Sensors 24, 2093 (2024).

Q 62.13 Thu 17:00 Tent

Sol-gel process for bonding thin-film diamond — •Nick Brinkmann[1,2], Sunil Mahato[1,2], Rikhav Shah[1], Donika Imeri[1,2], Leonie Eggers[1,2], Konstantin Beck[1], Lasse Irrgang[1], and Ralf Riedinger[1,2] — [1]University of Hamburg, Faculty of Mathematics, Informatics and Natural Sciences, Department of Physics, Institute for Quantum Physics, Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Diamond nanophotonic structures hold immense potential for breakthroughs in quantum infomations technologies and are a leading platform for developing quantum memory chips.

One challenge in the development of nanophotonic structures lies in the reliable transfer and bonding of single crystal diamond thin-films onto suitable substrates.

Here we present an innovative and scalable method that utilizes a sol-gel process, which holds promise for efficiently and securely managing the transfer of these thin-film diamonds.

This method can elevate the fabrication of nanophotonic structures on diamonds, which can serve as interfaces between the spins of color centers, such as SiV, and photons.

Thus, it contributes to a new possibility for integrating such structures into photonic networks, promising significant advances in quantum optics and communication.

Q 62.14 Thu 17:00 Tent

Nanophotonic Quantum Network Nodes - Imaging of cryogenic Nanophotonics — •Leonie Eggers[1,2], Timo Eikelmann[1], Donika Imeri[1,2], Caius Niemann[1], Konstantin Beck[1], Rikhav Shah[1], Mara Brinkmann[1], Lasse Irrgang[1], Nick Brinkmann[1,2], Sunil Mahato[1,2], and Ralf Riedinger[1,2] — [1]Zentrum für Optische

Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Silicon vacancies (SiV) in diamond combined with nanophotonic cavities are a promising platform for network-based quantum solid-state processors, due to their optically addressable spin transition and high noise tolerance. Paired with a fiber network this can enable efficient long-distance quantum communication and a modular approach to building larger quantum processors.

As temperature below 300 mK are needed for the SiV to have long-lived spin degrees of freedom, we show a high- resolution confocal imaging system that can image the nanophotonics on the diamond samples inside a cryostat. This improves our ability to couple optical fibers to the nanophotonics in-situ while operating the cryostat, enabling our research on building nanophotonic quantum network.

Q 62.15 Thu 17:00 Tent

Resolving the Low-Field Ambiguity in All-Optical Magnetometry in Resource Constrained Devices — •Ann-Sophie Bülter[1], Ludwig Horsthemke[1], Jens Pogorzelski[1], Dennis Stiegekötter[1], Frederik Hoffmann[1], Sarah Kirschke[2], Markus Gregor[2], and Peter Glösekötter[1] — [1]Department of Electrical Engineering and Computer Science, FH Münster — [2]Department of Engineering Physics, FH Münster

Machine learning algorithms offer a promising solution for unambiguous magnetic field determination in all-optical fluorescene intensity measurements with nitrogen-vacancy (NV) centers, addressing the ambiguity below 8 mT [1].

To continue this work, we exploit the dependency of the phase and the magnitude of the fluorescence on both the magnetic field and frequency, applying advanced regression techniques. The primary focus of our study is to investigate the effect of feature engineering to enhance the accuracy of magnetic field determination. By comparing the results of feature-engineering approaches with those using raw data alone, we demonstrate the potential of machine learning for precise and reliable magnetic field measurements in all-optical magnetic field sensing. Additionally, we assess the resource efficiency of these methods to ensure their feasibility for the implementation on a microcontroller.

[1] Horsthemke, L., et al. Towards Resolving the Ambiguity in Low-Field, All-Optical Magnetic Field Sensing with High NV-Density Diamonds. Engineering Proceedings 68, 8 (2024).

Q 62.16 Thu 17:00 Tent

Diamond Membrane with Strained SiV Color Centers Coupled to a Fabry-Perot Microcavity — •Robert Berghaus[1], Florian Feuchtmayr[1], Selene Sachero[1], Gregor Bayer[1], Julia Heupel[2], Tobias Herzig[3], Jan Meijer[3], Cyril Popov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Universität Ulm — [2]Institute of Nanostructure Technologies and Analytics, University of Kassel — [3]Felix Bloch Institute for Solid State Physics, University Leipzig

Group IV color centers in diamond, such as silicon vacancy (SiV), are promising for quantum optics because of their optical transitions, spin access, and good coherence properties. SiV centers typically require millikelvin temperatures, but increasing the ground state splitting improves coherence, allowing operation at higher temperatures. Here, we demonstrate the integration of a single-crystal diamond membrane into a high-finesse microcavity (F = 3000), achieving significant lifetime shortening with a Purcell factor of 2.2 in a liquid helium atmosphere. Absorption and strain spectroscopy confirm enhanced ground-state splitting, paving the way for a spin-photon interface.

Q 62.17 Thu 17:00 Tent

Flex-PCB Integrated Quantum Sensor With NV Centers in Diamond (FleQS) — •Jens Pogorzelski[1], Jonas Homrighausen[2], Ludwig Horsthemke[1], Ann-Sophie Bülter[1], Frederik Hoffmann[1], Dennis Stiegekötter[1], Markus Gregor[2], and Peter Glösekötter[2] — [1]Department of Electrical Engineering and Computer Science, FH Münster — [2]Department of Engineering Physics, FH Münster

The utilisation of nitrogen-vacancy (NV) centers in diamond microcrystals for quantum magnetometry represents a promising approach for the development of sensitive, integrated magnetic field sensors [1]. Nevertheless, the cost and complexity of the technology have thus far limited its application. This study presents the most compact, fully integrated quantum sensor based on LED excitation, which represents an evolution of previous designs [2]. The sensor integrates all essential components, including a pump light source, photodiode, microwave antenna, optical filters and fluorescence detection, in a compact system that requires no external optical adjustments. The assembly is constructed on a flexible, foldable printed circuit board with surface-mounted components and a laser-cut optical filter. The PCB is folded and moulded. Furthermore, the random alignment of the NV axes is determined. The result is a 3.8x3.1 mm sensor head with a sensitivity of 68 nT/Hz^1/2, representing a miniaturization of quantum magnetometers.

[1] Stürner, F.M. et al., 2021. Advanced Quantum Technologies 4.
[2] Pogorzelski, J. et al., 2024. Sensors 24, 743.

Q 62.18 Thu 17:00 Tent

Quantum frequency conversion device for single photons from SnV centers in diamond — •Marlon Schäfer, David Lindler, Tobias Bauer, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

Most quantum emitters exhibit optical transitions in the visible to near-infrared spectral region. In fiber-linked quantum networks, these photons need to be converted to low-loss telecom bands at 1550 nm through nonlinear three-wave mixing in periodically-poled lithium niobate waveguides to minimize transmission losses.

To make this technology viable for real-world applications, quantum frequency converters must operate robustly outside laboratory conditions without human intervention. Here, we explore automatic beam alignment and path stabilization for a device that converts single photons from tin-vacancy (SnV) centers in diamond using a two-stage scheme. Such a two-stage scheme was recently shown to successfully circumvent pump-induced noise for the conversion of single photons from silicon-vacancy centers in diamond [1].

[1] Schäfer, M. et al., Adv. Quantum Technol. 2023, 2300228.

Q 62.19 Thu 17:00 Tent

Towards a spin-exchange collision-based optical quantum memory in noble-gas spins — •Alexander Erl[1,2], Norman Vincenz Ewald[1,2], Andrés Medina Herrera[2], Denis Uhland[3], Wolfgang Kilian[2], Jens Voigt[2], Ilja Gerhardt[3], and Janik Wolters[1,4] — [1]DLR, Institute of Optical Sensor Systems, Berlin — [2]PTB, 8.2 Biosignals, Berlin — [3]LUH, Institute of Solid State Physics, Hannover — [4]TUB, Institute of Optics and Atomic Physics, Berlin

A critical limitation on current room-temperature quantum memory systems [1] is the maximum achievable storage time on the order of a few μs, which must be extended for various quantum communication applications, such as unforgeable quantum tokens for authentication. We report on our first steps towards a long-lived quantum memory with an all-optical interface based on a mixture of ^{129}Xe noble gas and ^{133}Cs alkali metal vapor, both confined in a glass cell at near room temperature. The interface relies on EIT, implemented through a Λ-scheme in the Zeeman sublevels of the long-lived hyperfine ground states of ^{133}Cs, coupled to an excited state via the D_1 line at 895 nm [2]. Spin-exchange collisions in the strong coupling regime are envisioned to transfer the stored information from the alkali vapor to the noble gas [3]. The coherence time of ^{129}Xe, which can extend up to several hours [4], offers the potential for long-term storage of quantum information in collective atomic excitations. [1] M. Jutisz et al., arXiv:2410.21209 (2024) [2] G. Buser et al., PRX, 020349 (2022) [3] O. Katz et al., PRA 105, 042606 (2022) [4] C. Gemmel et al., EPJ D 57, 303-320 (2010)

Q 62.20 Thu 17:00 Tent

Optimal control solutions for nuclear spin polarization of nitrogen-vacancy (NV) centers in diamond — •René Wolters[1], Matthias Müller[1], Felix Motzoi[1], and Tommaso Calarco[1,2] — [1]Forschungszentrum Jülich GmbH, Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Germany

The topic of nuclear spin polarization in colour center platforms, including NV centers in a diamond lattice or silicon carbide, has attracted considerable interest in recent years. This is due to the favourable conditions for quantum sensory devices and the storage of quantum states that are enabled by the long coherence time of the nuclear spins and their operability at room temperature. The defining characteristic of colour centers is that the electronic spin state of the center can be both initialized and read out via laser irradiation in the visible wavelength spectrum. Dynamical nuclear polarization (DNP) techniques are employed with the objective of transferring the spin polarization from the electronic to the surrounding nuclear spins. We employ quantum optimal control to optimize DNP pulses in terms of both time and error resilience, with regard to the polarization of single or few well-defined nuclear spins in a weak magnetic field which can be addressed and controlled individually. The weak magnetic field permits longer coherence times and simpler implementation with fewer errors. Furthermore, we investigate how to polarize the nuclear spins with the minimal possible number of initializations of the electron spin, to reduce disruption of the laser irradiation.

Q 62.21 Thu 17:00 Tent

Frequency Stabilization of a Hybrid SnV-^{40}Ca^{+} Interface at Telecom Wavelengths — •Tobias Bauer, David Lindler, Max Bergerhoff, Jürgen Eschner, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

In quantum networks, the synchronization of dissimilar quantum nodes requires precise frequency control and efficient wavelength conversion. We demonstrate a platform combining optical frequency comb technology with quantum frequency conversion to integrate SnV color centers in diamond and trapped ^{40}Ca^{+} ions into a common telecom-wavelength framework.

Our setup employs two mutually stabilized frequency combs as precise frequency references for all system lasers at each node. We characterize the system with classical light by stabilizing the excitation lasers at the SnV (619 nm) and ^{40}Ca^{+} (854 nm) system wavelengths to their respective frequency combs. These lasers are then frequency-converted to a common telecom wavelength (1550 nm) using pump lasers that are likewise referenced to the combs. The successful operation of our complete stabilization scheme is demonstrated through beat note measurements between the converted lasers at the telecom wavelength, verifying the frequency precision required for future quantum network applications.

Q 62.22 Thu 17:00 Tent

Automated Electrode Routing Routine for Surface Electrode Paul Traps for Quantum Computing — •Axel Hoffmann[1], Florian Ungerechts[2], Rodrigo Munoz[2], Janina Bätge[2], Masum Billah[2], Maximilian Kanz[1], Dirk Manteuffel[1], and Christian Ospelkaus[2,3] — [1]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstr. 9A, 30167 Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100,38116 Braunschweig, Germany

Trapped-ion quantum processors based on surface electrode Paul traps with integrated microwave conductors for near-field quantum control are a promising approach for scalable quantum computers. Due to increasing complexity of the processor chip models numerical analysis of the cause-effect relationship becomes challenging. In a complex multi-zone processor chip architecture, it is known that the electrode routing affects the ion transport, trapping and state control. To overcome these challenges already in the first design step, an automated electrode routing routine is proposed. Applying an iterative Method of Moments simulation process, cross-talk can be avoided while keeping the computational costs feasible. Challenges and benefits compared to straight forward approaches are discussed.

Q 62.23 Thu 17:00 Tent

Towards quantum computation with Sr atom arrays — •Eran Reches[1,3], Kevin Mours[1,3], Robin Eberhard[1,3], Dimitrios Tsevas[1,3], Zhao Zhang[1,3], Lorenzo Festa[1,3], Max Melchner[1,2,3], Andrea Alberti[1,2,3], Sebastian Blatt[1,2,3], Johannes Zeiher[1,2,3], and Immanuel Bloch[1,2,3] — [1]Max-Planck Institut für Quantenoptik, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 Munich, Germany — [3]Munich Center for Quantum Science and Technology, 80977 Munich, Germany

We report on the recent progress of the MQV quantum computing demonstrator based on neutral Sr atoms trapped in arrays of optical tweezers. We have shown high-fidelity detection, single- and two-qubit operations as well as state-of-the-art vacuum-limited lifetime in a non-cryogenic platform. We further present our ongoing work on the realization of highly parallel atom moves, setting the stage for future implementations of brickwall-type digital circuits.

Q 62.24 Thu 17:00 Tent

Towards fully chip-integrated optical and near-field microwave control of trapped-ion qubits — •Mohammad Masum Billah[1,2], Florian Ungerechts[1], Rodrigo Munoz[1], Janina Bätge[1], Axel Hoffmann[1,4], Giorgio Zarantonello[1,3], Christopher Reiche[1,2], and Christian Ospelkaus[1,2,5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover — [3]QUDORA Technologies GmbH — [4]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover — [5]Physikalisch-Technische Bundesanstalt

To fully harness the capabilities of surface-electrode trapped ion quantum computers, a large number of qubits is essential. Scalable ion traps are critical for accommodating these qubits, but also require a significant number of free-space lasers for qubit state preparation as well as for readout, cooling and optical quantum gates. While microwave near-field gate operations can reduce the need for the latter lasers, achieving full scalability necessitates the integration of optical waveguides and grating couplers within the trap chip for effective qubit control. This integration poses novel challenges in ion trap design and the microfabrication processes used to create the corresponding chips. Our study addresses key issues such as the impact of optical windows in the chip on trapping potentials, DC shuttling operations, and specifically, the effects on microwave near-field interactions. We further explore the implications of these integrations and discuss the increasing complexity in fabricating such highly integrated ion traps.

Q 62.25 Thu 17:00 Tent

Hybrid Quantum Photonics With One Dimensional Photonic Crystal Cavities and Silicon Vacancy Centers In Nanodiamonds — Lukas Antoniuk[1], Niklas Lettner[1,2], •Tim Mülleneisen[1], Anna P. Ovvyan[3,5], Daniel Wendland[3], Viatcheslav N. Agafonov[4], Wolfram H.P. Pernice[3,5], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Universite F. Rabelais, 37200 Tours, France — [5]Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Scaling up current quantum hardware to large numbers of their qubit building blocks is the one of the most pressing challenges in modern quantum technologies. To achieve this, one could separate qubits physically and mediate interaction between them by flying qubits. However, therefore one requires high interaction strength between the stationary and flying qubits. Here, we summarize our efforts to combine silicon nitride photonics and negatively charged silicon vacancy centers hosted in nanodiamonds to achieve this and build up a scalable interface between light and matter on the basis of this hybrid approach.

Q 62.26 Thu 17:00 Tent

Progress towards a novel apparatus for unit testing of ion transport and quantum logic protocols in context of QVLS-Q1 — Christian Joohs[1,2], Markus Duwe[1,2], •Alexander Onkes[1,2], Hardik Mendpara[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig

We report on the progress of the QVLS-Q1 supporting experiment. It is being developed to test and characterize ion transport and EIT cooling. The trap is a surface electrode Paul trap, which means that the trapped ions have two-dimensional freedom of movement above the trap. It comprises a register-like design with different zones for trapping, storage, readout and quantum logic operations (termed QCCD architecture [1,2]). Here we report on updates of the experimental setup, specifically on progress of the optical and vacuum setup. Furthermore, we present the first steps towards a cloud interface to allow easy access for future collaborations.

[1] D.J. Wineland et al., J. Res. Natl. Inst. Stand. Technol. 103, 259 (1998)

[2] D. Kielpinski et al., Nature 417, 709 (2002)

Q 62.27 Thu 17:00 Tent

Fermionic State Preparation and Imaging in Tweezer Arrays — •Kirill Khoruzhii[1,3], Naman Jain[1], Marcus Culemann[1], Jin Zhang[1], Xinyi Huang[1], Pragya Sharma[1], Jun Ong[1], and Philipp Preiss[1,2] — [1]Max Planck Institute of Quantum Optics, Garching — [2]Ludwig-Maximilians-Universität, Munich — [3]Munich Center for Quantum Science and Technology

We demonstrate a platform for deterministic preparation of ultracold fermionic lithium-6 atoms in a tweezer array, combined with rapid and high-fidelity free-space spin-resolved imaging. This system enables programmable initialization of atomic arrays, providing a foundation for hybrid tweezer/lattice experiments and quantum simulation. Atoms are loaded into a tweezer array generated by two orthogonally oriented acousto-optic deflectors (AODs). Using magnetic field gradients for controlled atom spilling, we prepare pairs of spin-up and spin-down atoms in the ground state of each tweezer with over 90% success rate. The entire experiment cycle is completed in under 2 seconds. Uniformity of the AOD-generated tweezer array is ensured through model-based optimization, achieving intensity homogeneity to within 1% for arrays up to 10x10 tweezers. This consistency is crucial for reliable state preparation. For imaging, counter-propagating resonant beams illuminate the atoms for 20 μs and enable free-space single atom detection with a fidelity exceeding 95%. Spin states are distinguished by polarization-dependent fluorescence, with photons spatially separated and directed to the camera. This platform will be used to realize a fermionic many-body interferometer.

Q 62.28 Thu 17:00 Tent

Developing a photon-pair source for quantum repeaters — •Henning Mollenhauer — DLR Berlin-Adlershof, Berlin — TU-Berlin, Berlin

We are reporting on the development of a photon-pair source for signal and idler photons at 894nm and 1550nm. The underlying process is spontaneous parametric down-conversion (SPDC) inside a periodically poled KTP crystal. To achieve spectrally pure and narrow-band characteristics for signal and idler photons our ppKTP crystal is designed as a monolithic cavity [1]. Pulsed pump light at 567nm for the SPDC process is produced in sum frequency generation from the target wavelengths. For the future we plan to interface our photon source with a single-photon quantum memory [2], to build a demonstrator of a quantum repeater. [1] Mottola et al. (2020) [2] Jutisz et al. (2024)

Q 62.29 Thu 17:00 Tent

Tin-vacancy centers in photonic crystal cavities in diamond — •Daniel Bedialauneta Rodriguez, Tim Turan, Nina Codreanu, and Ronald Hanson — Delft University of Technology

Color centers in diamond are a promising platform for realizing quantum networks as a spin-photon interface that also gives access to naturally occurring 13C memory qubits. The nitrogen-vacancy (NV) center has been successfully used to realize a three-node quantum network. However, its low emission rate of coherent photons and sensitivity to surface charges makes scaling to more nodes difficult.

The tin-vacancy (SnV) center has emerged as a compelling alternative due to its favorable optical properties and compatibility with nanophotonic structures. Here, we present the integration of SnV centers into photonic crystal cavities. These cavities promise to enhance the light-matter interaction, ultimately boosting the rate of entanglement between nodes. We measure cavity properties at cryogenic temperatures and demonstrate in-situ frequency tuning through gas desorption. We use this technique to probe the cavity-SnV system.

Q 62.30 Thu 17:00 Tent

Neutral Ca fluorescence during ablation loading for surface ion traps — •David C Stuhrmann[1], Radhika Goyal[1], Tobias Pootz[1], Sascha Agne[2], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Surface electrode ion traps are well suited for building a scalable quantum computer because ions trapped in a Paul trap can have long coherence times combined with high fidelities. For trapping 40Ca+ ions I need to generate a stream of individual ions reaching the trap center. This is achieved by a laser ablation process together with a two step photo-ionization which uses a resonant 423nm laser and free-running 375nm laser. As a measure of the amount of released Ca atoms from ablation I study neutral Ca fluorescence with the 423nm resonant transition. The time resolved fluorescence signal is used to scan the laser powers and positions. A frequency scan of the 423nm beam shows how many atoms of a certain velocity class get released and that a detuning of 500 MHz or less are desirable. The signal strength is also used for finding the optimal horizontal and vertical position of ablation laser as well as determining the ablation threshold. The results show that our ablation setup is suited for generating Ca+ ions and that we can adjust our various laser parameters.

Q 62.31 Thu 17:00 Tent

Transport through a 1D channel with an epitaxial GaAs quantum dot in its vicinity — •Selma Delić[1,2], Paola Atkinson[3], Xuelin Jin[1,2], Nataliya Demarina[1], Detlev Grützmacher[1,2], and Beata Kardynał[1,2] — [1]PGI, Forschungszentrum Jülich, 52428 Jülich, Germany — [2]2 Department of Physics, RWTH, 52074 Aachen, Germany — [3]Institut des Nano Sciences de Paris, CNRS UMR 7588, Sorbonne Université, 75005 Paris, France

Gate-defined quantum dots (GDQD) in GaAs/AlGaAs heterostructures host spin qubits which are potentially scalable and which, thanks to the direct bandgap of GaAs, may be addressable optically. High fidelity transfer of quantum information from a photon to the electron spin in the gated qubit can be mediated by photon absorption in a self-assembled GaAs quantum dot (SAQD) [1] followed by adiabatic transfer of the photo-generated electron into the GDQD [2].

In this contribution, we present the results of our studies of the transport and optical properties of nanostructures defined by gates in GaAs/AlGaAs heterostructures with embedded SAQDs. SAQDs are tunnel coupled to the gated nanostructures. We study the effect of the quantum states in the SAQD on the electron transport characteristics of a 1D channel. Further, we discuss the impact of the lateral alignment of the gates relative to the SAQD on the device characteristics. Based on our findings, we present a potential design of the heterostructures for the spin-photon interface and the design of the devices.

[1] P. Atkinson et al., Jrn. Appl. Phys. 112, 054303 (2012)
[2] B. Joecker et al., Phys. Rev. B 99, 205415 (2019)

Q 62.32 Thu 17:00 Tent

Fabrication and Characterization of Photonic Nanostructures in Diamond for Quantum Applications — •Jonathan Ensslin, Colin Sauerzapf, Oliver von Berg, Rainer Stöhr, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart

The unique optical properties and long-lived spin coherence times of color centers in diamond make them a promising platform for quantum technologies [1]. This work focuses on the fabrication and characterization of photonic nanostructures, such as free-standing optical waveguides, capable to enhance collection efficiency [2] and spin-photon interaction [3]. Fabrication techniques, including anisotropic reactive ion beam etching (RIBE), were optimized to achieve precise control over waveguide dimensions and etch profiles, highlighting the advances of RIBE over inductively coupled plasma etching [4, 5]. By tailoring etching parameters, stable processes for both straight and angled etches were developed, improving reproducibility and selectivity. We investigated etch rates, angular dependencies, and mask material selectivity. These developments pave the way for creating diamond nanostructures capable of hosting color centers, ultimately facilitating their integration with optical cavities. Future work includes optical characterization of the structures and the fabrication of defect-hosting waveguides for scalable quantum devices. [1] M. Pompili et al., Science 372, 259-264, (2021) [2] M. Krumrein et al., ACS Photonics 11 (6), 2160-2170, (2024) [3] L. Childress et al., Science Advances, vol. 4, no. 1, pp. 12-18, (2021) [4] H. A. Atikian et al., APL Photonics 2 (5), 051301, (2017) [5] C. Chia et al., Opt. Express 30, 14189-14201 (2022)

Q 62.33 Thu 17:00 Tent

Towards experimental implementation of a free-space continuous-variable quantum key distribution scheme with unidirectional modulation of squeezed states — •Jan Schreck[1,2], Thomas Dirmeier[1,2], Kevin Jaksch[1,2], and Christoph Marquardt[2,1] — [1]Max Planck Insitute for the Science of Light, Erlangen, Germany — [2]Chair of Optical Quantum Technologies, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Continuous-variable quantum key distribution (CV-QKD) offers a chance to create quantum-safe cryptography. Polarization is a promising degree of freedom to encode QKD signals in free-space optical (FSO) links. Furthermore, a experimental CV-QKD implementation by unidirectional modulation of polarization squeezed states of light can increase CV-QKD's resilience to channel noise and finite post-processing efficiency. In addition, supression of information leakage to potential eavesdroppers is possible. This work presents our idea of a quantum signal source generating squeezed states of light and the concept of the optical sender and receiver.

Q 62.34 Thu 17:00 Tent

Multiplexing and Signal Optimization in Surface-Electrode Ion Trap Quantum Processors — •Janina Bätge[1], Florian

Ungerechts[1], Rodrigo Munoz[1], Mohammad Masum Billah[1], Axel Hoffmann[1,2], Giorgio Zarantonello[1,3], and Christian Ospelkaus[1,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Germany — [3]QUDORA Technologies GmbH, Braunschweig, Germany — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Scaling up ion trap quantum processors requires efficient management of control signals for the increasing number of control electrodes. We present three methods to minimize the number of signals by controlling multiple electrodes with shared inputs. The first method uses a bucket brigade for ion storage. The second employs switching electronics to sequentially charge multiple electrodes with a single signal. The final method uses switches to multiplex the control signals for ion transport through an X-junction. In this approach, it is crucial to optimize the assignment of electrodes to signals and determine the minimal number of signals needed for efficient shuttling.

Q 62.35 Thu 17:00 Tent

Efficient simulation workflow for designing micro-structured planar Paul traps — •Kais Rejaibi, Dorna Niroomand, Patrick Huber, Rodolfo Muñoz Rodriguez, and Christof Wunderlich — Department of Physics, School of Science and Technology University of Siegen, 57068 Siegen, Gemany

When developing novel micro-structured traps for quantum science with trapped ions, design considerations include, for instance, precise ion shuttling, suppressing micromotion, and ensuring robust quantum state control in quantum experiments. To be able to efficiently design novel traps, we have developed a simulation workflow that uses the Boundary Element Method (BEM) to accurately model electric fields from complex electrode geometries such as microfabricated surface ion traps incorporating the Magnetic Gradient Induced Coupling (MAGIC) scheme and effectively handling open boundary conditions with low computational overhead.

By applying solid harmonics decomposition to the simulated fields, we identify and mitigate higher-order multipole components that lead to residual micromotion and other effects. This process allows us to iteratively refine electrode designs and generate precise voltage control configurations, optimizing micromotion compensation and improving ion transport. Our approach focuses on simulation and analytical techniques for designing ion traps capable of reliable shuttling through varying magnetic fields. By streamlining the development process, we enhance the performance of traps, contributing to more robust and scalable implementations in quantum computing applications.

Q 62.36 Thu 17:00 Tent

Single qubit addressing in a 2D array of neutral Ytterbium atoms — •Clara Schellong[1], Tobias Petersen[1], Nejira Pintul[1], Jonas Rauchfuss[1], Jan Deppe[1], Carina Hansen[1], Till Schacht[1], Frederik Mrozek[1], Koen Sponselee[1], Alexander Ilin[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center of Optical Quantum Technologies University of Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg

Neutral atoms have shown to be a promising candidate for building large scale quantum computers and quantum simulators, with fast high-fidelity single and two-qubit gates as well as flexible initialisation and readout. Recently, alkaline earth (-like) atoms such as Ytterbium (Yb) have shown to offer promising ways to overcome some of the main challenges on the road to scalable and flexible quantum simulators with decent effective circuit depth. Additionally, an optical coherent qubit mapping scheme enables mid-circuit measurements and advanced error correction techniques.

We will present different manipulation and addressing techniques for optimised and spatially resolved single- and two-qubit operations in a two-dimensional array of neutral Yb atoms.

Q 62.37 Thu 17:00 Tent

Real-time QKD with a deterministic sub-poissonian Source on an Intercity Scale — •Joscha Hanel[1], Jingzhong Yang[1], Jipeng Wang[1], Vincent Rehlinger[1], Zenghui Jiang[1], Frederik Benthin[1], Tom Fandrich[1], Jialiang Wang[1], Fabian Klingmann[2], Raphael Joos[3], Stephanie Bauer[3], Sascha Kolatschek[3], Ali Hreibi[4], Eddy Rugeramigabo[1], Michael Jetter[3], Simone Portalupi[3], Michael Zopf[1,5], Peter Michler[3], Stefan Kück[4], and Fei Ding[1,5] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover — [2]Fraunhofer-Institut für Photonische Mikrosysteme, Dresden — [3]Institut für Halbleiteroptik und Funktionelle Grenzflächen, IQST and SCoPE, University of Stuttgart — [4]Physikalisch-Technische Bundesanstalt, Braunschweig — [5]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover

While quantum key distribution (QKD) is among the most mature quantum technologies today, it remains a considerable challenge to achieve practical transmission rates over long distances with sub-poissonian photon sources. However, use of such sources is desirable in the long run, as they facilitate integration into future receiver-based networks.

We present a polarization-based BB84-QKD system using a quantum dot (QD) as a bright, pure, and deterministic single photon source that emits into the telecom C-band. We employ active polarization stabilization and both spectral and temporal filtering to demonstrate positive secure key rates in the kbit/s range for transmission distances on the intercity scale.

Q 62.38 Thu 17:00 Tent

Sparse Optimization of Two-Dimensional Terahertz Spectroscopy — •zhengjun wang — University of Hamburg Institute for Quantum Physics Luruper Chaussee 149 22761 Hamburg

two-dimensional terahertz spectroscopy (2DTS) is a low-frequency analogue of two-dimensional optical spectroscopy that is rapidly maturing as a probe of a wide variety of condensed matter systems. However, a persistent problem of 2DTS is the long experimental acquisition times, preventing its broader adoption. A potential solution, requiring no increase in experimental complexity, is signal reconstruction via compressive sensing. In this work, we apply the sparse exponential mode analysis (SEMA) technique to 2DTS of a cuprate superconductor. We benchmark the performance of the algorithm in reconstructing the terahertz nonlinearities and find that SEMA reproduces the asymmetric photon echo lineshapes with as low as a 10

Q 62.39 Thu 17:00 Tent

Simulating a Many-Body System with Waveguide Arrays — •Florian Huber[1,2,3], Benedikt Braumandl[1,2,3,4], Carlotta Versmold[1,2,3], Jan Dziewior[1,2,3], Robert Jonsson[5], Johannes Knörzer[6], Alexander Szameit[7], and Jasmin Meinecke[1,2,3,8] — [1]Max-Planck-Institut für Quantenoptik, Germany — [2]Ludwig-Maximilians-Universität, Germany — [3]Munich Center for Quantum Science and Technology, Germany — [4]Technische Universität München, Germany — [5]Nordita, KTH Royal Institute of Technology and Stockholm University, Sweden — [6]ETH Zurich, Switzerland — [7]Universität Rostock, Germany — [8]Technische Universität Berlin, Germany

Waveguide arrays, femtosecond laser-written into fused silica, are a versatile, still well-controllable simulation platform. If the distance between the laser written channels is large compared to the transversal mode size of each waveguide the system can be described by a nearest neighbor coupling Hamiltonian. The possibility to change the propagation and coupling constants in the manufacturing process allows the simulation of a large class of tridiagonal Hamiltonians. In our case the coupling and propagation constants of the waveguide array describing a giant atom system can be found by applying a Lanczos transformation to its interaction Hamiltonian. We report on the current progress of the simulation of oscillating bound states of a giant atom coupled to a waveguide using waveguide arrays as a simulation platform.

Q 62.40 Thu 17:00 Tent

A Photonic-Integrated Quantum-Random Number Generator — •Ömer Bayraktar[1,2], Jonas Pudelko[1,2], Laurenz Ottmann[1,2], Christoph Pacher[3], Winfried Boxleitner[3], and Christoph Marquardt[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Max Planck Insitute for the Science of Light, Erlangen, Germany — [3]AIT Austrian Institute of Technology GmbH, Center for Digital Safety & Security, Vienna, Austria

Quantum-random number generators (QRNG) are key componenents for quantum-key distribution systems. In addition, compared to conventional true-random number generators, they offer advantages in generation rate and modelling of the entropy source.

We present an experimental QRNG based on balanced homodyne detection of the quantum-optical vacuum state. This QRNG is designed for operations under the restrictive requirements of a 3U CubeSat.

The optical part of the QRNG is monolithically integrated on an

Indium-Phosphide photonic-integrated circuit and is placed on a 10x10 cm^2 printed-circuit board accomodating necessary electronics. We show first conclusive results obtained with this system and discuss its operation in space.

Q 62.41 Thu 17:00 Tent

SiV assisted photonic quantum computing — •Konstantin Beck[1], Donika Imeri[1,2], Lasse Irrgang[1,2], Leonie Eggers[1,2], Nick Brinkmann[1,2], Sunil Kumar Mahato[1,2], Rikhav Shah[1], Roman Schnabel[1,2], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Silicon vacancy centers in diamond (SiV) have shown great potential for applications in quantum sensing and quantum communication, due to their optically addressable spin transitions and stability against noise. At temperatures below 300 mK, the SiV has a long-lived spin degree of freedom that enables its use as a qubit for quantum information applications. By efficiently interfacing squeezed photons to the SiV, error-resilient optical Gottesman-Kitaev-Preskill (GKP) states can be created, which enable fault-tolerant continuous variable (CV) quantum computation.

We present a conceptual framework for an efficient telecom squeezed light interface for SiV and the subsequent creation of optical GKP cluster states. Key aspects, such as quantum frequency conversion of squeezed states and spin dependent reflection off the SiV as well as the theoretical implications of using optical GKP qubits in 2D-cluster states for CV quantum computing are highlighted.

Q 62.42 Thu 17:00 Tent

Towards the scale-up of a large-scale quantum computer based on Yb-ions — •Saptarshi Biswas[1], Ivan Boldin[1], Benjamin Bürger[1], Nora Daria Stahr[2,4], Radhika Goyal[2], Patrick Huber[1], Eike Iseke[3,4], Friederike J. Giebel[3,4], Lukas Kilzer[2], Nila Krishnakumar[3,4], Rodolfo Muñoz Rodriguez[1], Tobias Pootz[2], Kais Rejaibi[1], David Stuhrmann[2], Jacob Stupp[2,4], Konstantin Thronberens[3,4], Celeste Torkzaban[2], Pedram Yaghoubi[1], Christian Ospelkaus[2,3,4], and Christof Wunderlich[1] — [1]Department of Physics, School of Science and Technology University of Siegen, 57068 Siegen, Gemany — [2]Gottfried Wilhelm Leibniz Universität, Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Laboratory of Nano and Quantum-Engineering, Hannover, Germany

We present the status of a cryogenic (4K) experimental set-up for quantum computing with radio frequency (RF)-controlled trapped ions. It incorporates a novel micro-structured planar Paul trap with integrated micromagnets and we report on the characterization of the first trap generation to be used in this set-up. Also, progress in developing laser cooling techniques for mixed Yb^+-Ba^+ crystals is reported.

Q 62.43 Thu 17:00 Tent

A cryogenic apparatus for scalable quantum computation with surface ion traps — •Marco Schmauser[1], Marco Valentini[1], Michael Pasquini[1], Jakob Wahl[1,2], Eric Kopp[1], Philipp Schindler[1], Thomas Monz[1], and Rainer Blatt[1] — [1]Universität Innsbruck, Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria

Trapped-ion quantum systems are promising candidates for future quantum computing applications. Current trapped ion quantum computing systems in the quantum optics group in Innsbruck are built on a macroscopic linear trap and thus are limited to a maximal number of about 20 ions. Microfabricated surface traps are a popular approach to achieve scalability since they allow for a modular design in which one quantum computing processor consists of many microtraps. We built a cryogenic apparatus to realize fast testing and characterization of such microfabricated traps. The cryostat cools down the trap to a temperature of around 5K within several hours which allows the integration of superconducting materials, for example in the context of superconducting photon detectors, into the trap. Additionally, the integration of the trap via a standardized socket significantly reduces the time to exchange the chips. The setup features 100 DC electrodes and 6 RF electrodes with two independent resonators to enable axial and radial shuttling operations and 21 in-vacuum fibers for all wavelengths of 40Ca+ ions which pave the way for integrating optics into the trap chips. For our first experiments we glue a block of borofloat glass with an inscribed waveguide for 729nm light on top of a surface trap.

Q 62.44 Thu 17:00 Tent

A rack-mounted narrow-band photon pair-source for interfacing with an atomic quantum memory — •Leon Messner[1,2], Mathilde Kakuschke[1,3], Benjamin Maass[2,3], Helen Chrzanowski[4], and Janik Wolters[2,3,1] — [1]Advanced Quantum Light Sources UG, Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Berlin, Germany — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — [4]Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany

We present the implementation and performance analysis of a portable, rack-mounted photon-pair source for coupling to a ladder-type quantum memory in room-temperature Cesium vapor

The photon source [1] is generating photon-pairs with a bandwidth of 250 MHz, compatible to the linewidth and frequency needs of the atomic storage media. It has high coupling and heralding efficiencies up to 45%.

This allows research into crucial applications and fundamental questions of photon synchronization and shaping using a ladder-type quantum memory in warm alkali vapor [2]. Their fast and noise-free operation make them an ideal component for on-demand storage and retrieval of quantum information in photonic infrastructures.

[1] Mottola, R. et al., Optics Express **28**, 3159-3170 (2020)
[2] Maaß, B. et al., Phys. Rev. Applied **22**, 044050 (2024)

Q 62.45 Thu 17:00 Tent

Studying multifrequency optical lattices for quantum simulation — •Jonathan Bracker[1], Luca Asteria[1,2,5], Marcel Nathanael Kosch[1], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2,4] — [1]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [4]Department of Physics, TU Dortmund University, 44227 Dortmund, Germany — [5]University of Kyoto, Kyoto, Japan

The multifrequency scheme for optical lattices [1] offers a stable and highly tunable approach for generating complex lattice geometries. Here I present some results of my master's thesis, where I performed numerical simulations of the eigenspectrum and Kapitza-Dirac dynamics for a 5-fold symmetric quasiperiodic optical lattice, revealing localization properties and spectral features. Additional Kapitza-Dirac simulations and preliminary absorption images for a non-separable 3D multifrequency lattice are presented as a first step toward exploring these lattice configurations.

[1] M. Kosch et al., Phys. Rev. Research 4, 043083 (2022)

Q 63: Poster – Quantum Information (joint session QI/Q)

Time: Thursday 17:00–19:00 Location: Tent

Q 63.1 Thu 17:00 Tent

Classicality, Markovianity and local detailed balance in isolated quantum systems — •Philipp Strasberg — Instituto de Física de Cantabria (IFCA), Santander, Spain

This poster reviews how the familiar description of stochastic thermodynamics, based on classical Markov processes obeying local detailed balance, emerges from an underlying quantum description from first principles. Here, "first principles" means that we avoid ensemble averages and any assumptions breaking the unitarity of the underlying quantum dynamics (e.g., Born or Markov approximations). Connections to a general approach of thermodynamic entropy (production) and the structure of the Multiverse are also indicated.

Q 63.2 Thu 17:00 Tent

Intensity Stabilization in Fiber Amplifiers: Effects on Phase Noise, Linewidth, and Qubit Coherence — •Jia-Yang Gao, Jasper Phua Sing Cheng, Morteza Ahmadi, and Manas

Mukherjee — Centre for Quantum Technologies, National University of Singapore

Intensity noise is a factor limiting the coherence time of qubits in trapped ion quantum systems. Previously, we observed that using a Thulium-doped fiber amplifier (TDFA) introduces intensity fluctuations to the input seed laser, thus limiting the coherence time. To address this issue, we developed an intensity stabilization setup for a 1762 nm laser used for quadrupole transition, employing an acousto-optic modulator (AOM) with an electrical feedback servo. Our results demonstrate that this setup can reduce intensity noise by up to 20 dB from DC to 10 kHz without introducing additional phase noise and broadening the linewidth to the input signal. The phase noise and linewidth of the laser was analyzed using delayed self-heterodyne interferometry (DSHI). We also cross-check the stabilized beam using a single ion in our ion trap setup. Based on the Rabi oscillation results at different power levels, we observe an improvement in coherence time.

Q 63.3 Thu 17:00 Tent

Preparation and Control of Logical Qubits in the Hyperfine Structure of ^{173}Yb$^+$ — •Selena-Maria Bota, Monika Leibscher, and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

Recent research proposes robust encoding of quantum information in high angular momentum atomic or molecular states, where the logical qubits are protected against most common errors [1]. Such codewords can be built in the hyperfine structure of trapped ^{173}Yb$^+$, namely using metastable states in the $^2F^0_{7/2}$ manifold [2]. This work focuses on the preparation of such robust qubits with sequences of microwave pulses. We present a theoretical description of the atom's hyperfine structure and the transitions between hyperfine levels driven by time-dependent magnetic fields. We furthermore simulate the population dynamics driven by sequences of microwave pulses and optimise the pulse sequences in order to excite the desired codewords.

[1] Jain, Shubham P., et al. "Æ codes." arXiv preprint arXiv:2311.12324 (2023).

[2] Xiao, Di, et al. "Hyperfine structure of Yb+ 173: Toward resolving the Yb 173 nuclear-octupole-moment puzzle." Physical Review A 102.2 (2020): 022810.

Q 63.4 Thu 17:00 Tent

Measurable Entanglement lower bounds for Cold Atom Quantum Simulators using kinetic operators — •Maike Reckermann[1], Niklas Euler[1,2], and Martin Gärttner[1] — [1]Institut für Festkörpertheorie und Optik, Friedrich-Schiller-Universität Jena, Deutschland — [2]Physikalisches Institut, Universität Heidelberg, Deutschland

The entanglement dimension plays a key role for understanding quantum many-body phenomena such as topological order, recently realized with cold atoms in lattice geometries. However, for cold atom quantum simulators, determining the entanglement spectrum from measurements is a challenge for experiments as it generally requires the full reconstruction of the quantum state.

Here, we propose a new method to bound the entanglement dimension, which is the number of non-zero values in the spectrum, using the information contained in the measurement of kinetic operators in double wells, which was recently pioneered with ultracold bosonic atoms in a 2D optical lattice. Using also positivity constraints, non-measured elements of the density matrix can be bounded through the fidelity to a reference state, that is optimized in post-processing. We show through numerical simulations, that the entanglement dimension can be lower bound by information form the new measurement operators for a few body system with 2 distinguishable particles in a 1D lattice.

The protocol to bound the entanglement dimension with this measurement method is more efficient than previous methods and could be generalized to a 2D lattice or to create bounds on other observables.

Q 63.5 Thu 17:00 Tent

Polarization Independent Frequency Conversion into the UV — •Katrin Schatzmayr, Anica Hamer, and Simon Stellmer — Rheinische Friedrich Wilhelms Universität Bonn

As the performance of quantum computers grows, quantum networks become more significant. A possible implementation of such a network is a hybrid architecture based on solid state emitters, network nodes, and photons serving as flying qubits. This exchange often requires frequency conversion of the photons while preserving entanglement.

We have successfully developed a polarization-independent frequency conversion setup based on nonlinear crystals that converts photons from the wavelength of a quantum dot at 853 nm (InAs/GaAs) to the wavelength of trapped Yb+ ions at 370 nm.

Q 63.6 Thu 17:00 Tent

Comparative analysis of loan risk forecasting using quantum machine learning and classical machine learning models — •Mohammed Mustapha Adamu[1,2], Peter Nimbe[1], and Abdul Razak Nuhu[1] — [1]Department of Computer Science and Informatics, University of Energy and Natural Resources — [2]Savannah Regional Health Directorate

Non-performing loans present a significant challenge to financial institutions, driven by the complexity of the dataset, default probability, and default correlation(Bellotti et al., 2019). To mitigate this risk, this study investigates the potential of Classical Machine Learning (ML) and Quantum Machine Learning (QML) algorithms for forecasting loan risk. Using a dataset from Kaggle, we conducted a comparative analysis between Support Vector Machine (SVM) and Quantum Support Vector Machine (QSVM). Our result using a dataset of 12,368 records and 12 features shows that the QSVM model outperformed SVM, with a higher true positive rate (93.2.%) and true negative rate (87.6%), demonstrating better performance in identifying both default and non-default cases. Additionally, QSVM exhibits a lower false negative rate indicating its superior ability to minimize clients likely to default. The AUC score of 1.0 for the QSVM further demonstrates its exceptional ability in loan prediction. While the dataset used allowed for a solid comparison, QSVM demonstrated its capacity to continue improving with larger datasets, showing its scalability and strong potential application in loan risk forecasting especially with larger datasets.

Q 63.7 Thu 17:00 Tent

Surgical Procedure Recognition Using Quantum Machine Learning — •Abdul Razak Nuhu[1,2], Peter Nimbe[1], Mohammed Mustapha Adamu[1], and Eliezer Ofori Odei-Lartey[2] — [1]Department of Computer Science and Informatics, UENR, P. O. Box 214, Sunyani, Ghana — [2]Kintampo Health Research Centre, Kintampo, Ghana

Surgical procedure recognition is a critical field in robotic-assisted surgery that focuses on identifying complex surgical tasks like suturing, needle passing, and knot tying. This research explores Quantum Machine Learning (QML) algorithms, specifically the Quantum Support Vector Classifier (QSVC), to analyze surgical gestures more effectively than traditional methods. Using the JIGSAWS dataset with 76 motion characteristics, the study compared QSVC performance against a conventional Support Vector Classifier (SVC) using metrics like accuracy, precision, recall, and F1-score. The results demonstrated that QML-derived models significantly outperform classical machine learning techniques in processing surgical kinematic data. The research suggests that QML has transformative potential in surgical robotics and gesture recognition, particularly as quantum computing advances. By providing more sophisticated analysis of surgical procedures, this approach promises to enhance real-time surgical support, improve medical education, and ultimately develop more context-aware surgical systems that could improve patient care.

Q 63.8 Thu 17:00 Tent

Photon Fusion Analysis with Imperfect Sources — •Ruolin Guan and Klemens Hammerer — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

Photon fusion, a process integral to various quantum technologies, relies heavily on the availability of high-quality photon sources. However, real-world implementations often contend with imperfect sources, introducing inefficiencies and challenges in optimizing fusion outcomes. We explore theoretical frameworks and practical simulations to quantify the impact of imperfections on fusion success rate and outcomes. This work enhances the reliability of photon fusion in practical scenarios.

Q 63.9 Thu 17:00 Tent

Witnessing quantum memory in dynamics using quantum processors — •Krishna Palaparthy, Charlotte Bäcker, and Walter Strunz — TUD Dresden University of Technology, Dresden, Germany

Quantum simulations on noisy quantum computers can help us understand the role of quantum memory in quantum dynamics, for quantum computations and information processing tasks. To demonstrate local disclosure of quantum memory on the NISQ quantum processors, our simulation makes use of a collision model of sequentially applied two-qubit unitaries realizing the dynamics of a non-Markovian amplitude-damping channel. We investigate the relaxation dynamics and its influence on the entanglement dynamics with ancilla that are crucial for the proof of quantum memory.

Q 63.10 Thu 17:00 Tent

Quantum vs. classical: A comprehensive benchmark study for time series prediction using variational quantum algorithms — •Tobias Fellner[1], David Kreplin[2], Samuel Tovey[1], and Christian Holm[1] — [1]Institute for Computational Physics, University of Stuttgart — [2]Fraunhofer Institute for Manufacturing Engineering and Automation (IPA)

Recently, a wide range of variational quantum algorithms have been proposed for time series processing, promising potential advantages in handling complex sequential data. However, whether and how these quantum machine learning models outperform established classical approaches remains unclear. In this work, we conduct a comprehensive benchmark study comparing a variety of classical machine learning models and variational quantum algorithms for time series prediction. We evaluate their performance on time series prediction tasks of chaotic systems of varying complexity. Our results show that in many cases quantum machine learning models are able to achieve prediction accuracies comparable to classical models. At the same time, we also discuss the current practical value as well as the limitations of variational quantum algorithms for time series forecasting.

Q 63.11 Thu 17:00 Tent

Efficient simulation of microscopic master equations using tensor product states — •Junyi Zhang, André Eckardt, and Alexander Schnell — Technische Universität Berlin

In this work, we address the efficient simulation of global master equations by mapping them to local form. We utilize a novel local Redfield master equation in Lindblad form [1]. By leveraging tensor network methods and quantum trajectory algorithms, we describe steady states and explore transport in boundary-driven systems. Through characterization of the current, we examine how interactions and external fields influence transport properties of an XXZ spin chain in presence of finite-temperature reservoirs. This provides insights into dissipative dynamics in quantum many-body systems. This approach offers a computationally feasible alternative for analyzing large Hilbert spaces without full density matrix propagation, allowing us to extend the applicability of rigoriusly derived master equations in complex quantum systems.

[1] A. Schnell, arXiv:2309.07105 (2023)

Q 63.12 Thu 17:00 Tent

Synchronizing Detector Dead Times to Accelerate Quantum Key Distribution — •Maximilian Mengler, Maximilian Tippmann, and Thomas Walther — TU Darmstadt, Institute for Applied Physics, 64289 Darmstadt

Most Quantum-key-distribution setups consist of photon detection systems with multiple single-photon detectors. Upon measuring a photon these detectors will enter a dead time but due to security reasons only events that are registered when all detectors are ready may contribute to a key for various protocols, e.g. BBM92. This especially constrains systems relying on cheaper detectors like single-photon-avalanche-diodes because of the detectors' long dead times. At high detection rates, two detectors might block each other alternately with one detector entering a new dead time before the other finished its own. We implement a method that utilizes inverse gating signals sent to all detectors upon registration of an incident photon. This leads to the synchronization of the detectors' dead time and ensures that all the detectors are active for the maximum amount of time. We tested this method with our QKD system for various losses between the receiving parties and investigated its effect. In doing so, we were able to increase the secure key rate by up to 75%.

Q 63.13 Thu 17:00 Tent

Implementing post-processing algorithms for a star-shaped quantum key hub — •Tobias Liebmann, Maximilian Tippmann, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

The recent advances in quantum computing pose a threat to the security of conventional cryptographic algorithms like the Rivest-Shamir-Adleman (RSA) public key scheme. In particular, Shor's algorithm makes it possible to decode such encryption in polynomial time. Quantum key distribution (QKD) offers a solution to this problem, which not only provides computational security like post-quantum cryptography but information theoretic security. However, to ensure this level of security, the exchanged raw quantum keys must undergo a detailed post-processing procedure. We present recent advances regarding the implementation of the post-processing algorithms on our star-shaped QKD network.

Q 63.14 Thu 17:00 Tent

A quantum-network register assembled with optical tweezers in an optical cavity — •Matthias Seubert[1], Lukas Hartung[1], Stephan Welte[1,2], Emanuele Distante[1,3], and Gerhard Rempe[1] — [1]Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [3]CFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels, Barcelona, Spain

Quantum networks offer great potential for secure communication, distributed computing, and precision sensing. However, optical losses and errors between distant nodes make quantum information exchange slow and unreliable. One solution is to use more qubits as a register at each node, allowing multiplexed communication and error correction.

We present recent results [1] demonstrating the potential of a platform that integrates optical tweezer arrays with a macroscopic optical cavity for scalable quantum network nodes. By assembling one- and two-dimensional registers of up to 6 atoms, we address each individual atom to generate atom-photon entanglement via vacuum-stimulated Raman adiabatic passages. As the number of qubits in the register increases, the entanglement fidelity remains constant, an indication of scalability. By generating atom-photon entanglement in a multiplexed manner, we achieved a source-to-detection probability of up to ∼90% per run. This is an important step towards the deterministic distribution of entanglement in networks.

[1] L. Hartung et al. Science Vol 385, Issue 6705 pp. 179-183 (2024)

Q 63.15 Thu 17:00 Tent

Three axis magnetic field control setup for nitrogen-vacancy color center magnetometry — •Ricky-Joe Plate, Jan Thieme, Bernd Bauerhenne, and Kilian Singer — Experimental Physics I, Institute of Physics, University of Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

Nitrogen-vacancy (NV) centers in diamond provide a promising platform for room-temperature quantum sensing and information processing owing to their unique optical and spin properties and precise fabrication methods allowing for photonic structures such as nano pillars [1]. Precise quantum magnetometry requires an accurate and stable adjustment of the external magnetic field. Our solution incorporates a motorized magnetic system that allows for precise angular alignment relative to the NV-axis and offers adjustable magnetic field strengths. The system is engineered to be highly stable against external disturbances, ensuring consistent and reliable operation over extended measurement periods. Additionally, a custom designed algorithm performs optimal alignment of the magnetic field with regard to the NV center axis.

[1] Schmidt, A., Bernardoff, J., Singer, K., Reithmaier, J.P. and Popov, C. (2019), Fabrication of Nanopillars on Nanocrystalline Diamond Membranes for the Incorporation of Color Centers. Phys. Status Solidi A, 216: 1900233.

Q 63.16 Thu 17:00 Tent

Atom-Photon entanglement across a metropolitan network — •Maya Büki[1], Tobias Frank[1], Marvin Scholz[1], Gianvito Chiarella[1], Pau Farrera[1], Pooja Malik[2], Yiru Zhou[2], Florian Fertig[2], Harald Weinfurter[1,2], and Gerhard Rempe[1] — [1]Max-Planck-Institute of Quantum Optics, Garching, Germany — [2]Ludwig-Maximilians-University, Munich, Germany

Building a scalable quantum network is a key challenge in quantum information science. A critical step in this endeavor is the establishment of robust quantum links capable of transmitting entangled quantum states over long distances. Here, we present the successful demonstration of atom-photon entanglement over a distance of 23 km, spanning the Munich metropolitan area. Within this scope, we can efficiently entangle the spin states of Rubidium (Rb) atoms with optical polarization qubits. This experiment addresses critical challenges, including transmission losses through optical fiber, polarisation drifts and noise. By leveraging quantum frequency conversion from $\lambda_{\mathrm{Rb}} = 780$ nm to the telecom band and tailored filtering techniques, we successfully preserved entanglement fidelity over the link. By converting back the wavelength of the photon to 780 nm it might be possible to write the qubit information onto a heralded quantum memory consisting of a Rubidium atom inside two crossed optical fiber cavities [1]. With this goal in mind we made a first but decisive step towards a real world quantum network link within the Munich metropolitan area.

[1] M. Brekenfeld et al. Nat. Phys. 16, 647 - 651 (2020)

Q 63.17 Thu 17:00 Tent

Solving optimization problems on quantum systems. — •Kapil Goswami[1], Rick Mukherjee[1,2], Herwig Ott[3], and Peter Schmelcher[1,4] — [1]The Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Quantum Center, The University of Tennessee, 701 East Martin Luther King Boulevard, Chattanooga, USA — [3]Department of Physics and Research Center OTIMAS, RPTU Kaiserslautern-Landau, Kaiserslautern, Germany — [4]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Germany

Solving industry-related optimization problems using classical computers is challenging as they are NP-hard. The current quantum computers are characterized by limited qubits, high levels of noise, and imperfect gates. Hence, exploring resource-efficient encoding schemes can lead to practical quantum advantage. These problems are formulated either as a quadratic unconstrained binary optimization (QUBO) or integer programming (IP). Our first work provides a novel framework to solve QUBO problems such as Maximum Cut (Max-Cut) and Maximum Independent Set (MIS) on the Rydberg platform with local-light shifts, providing a favorable scaling of the number of atoms with problem size compared to existing schemes. In our second work, an algorithm is introduced that directly solves an IP problem using a single atom. Specifically, we use multi-levels of a Rydberg atom and selectively transfer the population between the Rydberg manifolds to find the optimal solution. Both of the quantum algorithms utilize quantum optimal control to reach the solution of the problems.

Q 63.18 Thu 17:00 Tent

Generation and characterization of entangled photon source through the spontaneous parametric down conversion — •Chandana Rao Attigadde Shashikirana[1,2,3], Umakant D Rapol[1], and Anindita Bannerjee[2] — [1]Indian Institute of Science Education and Research, Pune, India — [2]Centre for Development of Advanced Computing (CDAC), Pune, India — [3]Department of Computer Science, Paderborn University, Warburger str.100, 33098, Paderborn, Germany

The work is on the generation and characterization of an entangled photon source using a type-1 crossed Beta-Barium Borate (BBO) crystal through spontaneous parametric down-conversion (SPDC), with a focus on understanding the quantum entanglement phenomenon.

Various experimental tests, including the Hanbury Brown and Twiss (HBT) experiment, visibility measurements, the Clauser Horne-Shimony-Holt (CHSH) inequality, and polarization correlation measurements, were conducted to characterize the entangled photon source. Additionally, the quantum state tomography technique was used to reconstruct the density matrix of the entangled photons.

The results show that the source generates entangled, single photons, which violate the Bell inequality as evidenced by the CHSH parameter of 2.629. The concurrence value of 0.708 and linear entropy of 0.244 provide estimates of the degree of entanglement and the noise present in the entangled photons, respectively.

Q 63.19 Thu 17:00 Tent

Multi-Pass Quantum Process Tomography — •Stancho Stanchev and Nikolay Vitanov — Center for Quantum Technologies, Faculty of Physics, Sofia University, James Bourchier 5 blvd., 1164 Sofia, Bulgaria

We introduce a method to enhance the precision and accuracy of Quantum Process Tomography (QPT) by mitigating errors caused by state preparation and measurement (SPAM), readout, and shot noise. Instead of performing QPT on a single gate, we propose applying QPT to a sequence of multiple applications of the same gate. The method involves the measurement of the Pauli transfer matrix (PTM) by standard QPT of the multipass process, and then deduce the single-process PTM by two alternative approaches: an iterative approach which in theory delivers the exact result for small errors, and a linearized approach based on solving the Sylvester equation. We apply the method to CNOT gate tomography, as well as to evaluate the quality of single-qubit composite gates, constructed by composite pulses and compare them to pre-existing gates. We assess the method's performance through simulations on IBM Quantum, using IBM Simulator and real quantum processors.

Q 63.20 Thu 17:00 Tent

Surface-electrode ion trap testing apparatus for the QTZ at PTB — •Marco Bonkowski[1], Sebastian Halama[1], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

One of the main challenges in performing useful quantum computations outside of purely academic interest is the need for a higher number of high-fidelity qubits. Surface-electrode ion traps have the potential to be a suitable solution for this scalability problem. [1] The ongoing research in this field often requires complicated, expensive setups and highly trained personnel which proves to be challenging for smaller facilities. The quantum technology competence center (QTZ) at the Physikalisch-Technische Bundesanstalt will support the industrial development of quantum technology by providing the necessary infrastructure to test and characterize quantum components such as ion traps. Our group has developed a cryogenic ion trap apparatus for trap testing that was first set up at the LUH and will be used to verify the results of the QuMIC project and then will be transferred to the QTZ. Within the QuMIC project highly integrated BiCMOS chips are developed and used for the microwave generation in the microwave near-field approach [2] to control the qubits. We describe the setup of the apparatus and the associated laser system for trapping beryllium ions.

[1] Chiaverini et al., Quantum Inf Comput 5, 419-439 (2005)
[2] Ospelkaus et al., Phys. Rev. Lett. 101, 090502 (2008)

Q 63.21 Thu 17:00 Tent

Continuous-variable QKD with rate-adaptive error correction for the QuNet initiative — •Stefan Richter[1,2], Hüseyin Vural[1,2], Lukas Eisemann[1,2], Jan Schreck[1,2], Kevin Jaksch[1,2], Ömer Bayraktar[1,2], Thomas Dirmeier[1,2], Wenjia Elser[1,2], Dominique Elser[1,2], and Christoph Marquardt[1,2] — [1]Lehrstuhl für Optische Quantentechnologien, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Max-Planck-Institut für die Physik des Lichts, 91052 Erlangen, Germany

Continuous-variable quantum key distribution (CV-QKD) offers a way to establish symmetrically encrypted secure communication over untrusted channels and backed by security proofs not reliant on assumptions of mathematical complexity. Here, we present our progress on implementating a CV-QKD system designed for metropolitan fiber optical links, which was deployed as part of a large-scale technology demonstration in October 2024 for the QuNet initiative. Our approach is based on discrete modulations (DM) of coherent states and optical homodyne detection, with separate and free-drifting sender and receiver lasers. As such, it is similar and widely compatible with modern fiber optical communication techniques. We discuss some of the unique technical challenges associated with deploying our prototype in a larger network, as well as our proposed mitigations. Secret key rates attained with a complete post-processing stack based on fixed rate error correction are contrasted with the results of using a novel rate-adaptive implementation instead, highlighting the practical advantages of the latter.

Q 63.22 Thu 17:00 Tent

What can we learn from the phase of the momentum wave function? — •André Knoll[1], Leon Cohen[2], and Wolfgang Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany — [2]Department of Physics, Hunter College of the City University of New York, 695 Park Ave., New York, NY 10065, United States of America

Due to the Born rule of quantum mechanics, the amplitude of the wave function is often emphasized, while the phase is frequently overlooked. However, a closer examination reveals that the phase, particularly when encoded by the Fourier transform of position space, contains critical information about the original wave function. Building on signal processing techniques introduced by Oppenheim et al. in 1981 (Proc. IEEE, 69, 5, pp. 529-541), we adapt and extend these methods to

the quantum mechanical framework. In particular, we show that even when we replace the amplitude of the momentum wave function by a constant, the phase of the momentum wave function allows a partial reconstruction of the position wave function. Our findings underscore the fundamental role of the phase in Fourier-based transformations, offering new insights into quantum mechanics and potential applications in quantum information science.

Q 63.23 Thu 17:00 Tent

AQuRA: A software package for simulating quantum computing with continuous variables — •Sebastian Luhn and Matthias Zimmermann — DLR e.V., Institut für Quantentechnologien, Ulm

There are a variety of simulation tools for digital quantum computers based on qubits. However, simulation tools for analog quantum computers based on continuous-variable quantum systems (e.g. the position of a quantum particle) are rare. Indeed, simulating these quantum systems also comes with a huge demand for computational power. Here we present a self-build simulation package that can calculate a huge variety of continuous quantum systems on powerful HPC hardware as well as on a local pc. Our software does support many well-known codes like GKP or cat codes and offers several predefined gates for simulating operations acting on single and multiple quantum systems.

Q 63.24 Thu 17:00 Tent

Spectral Compatibility and Analytical Constraints in Quantum Marginal Problems — •van Dellen Lea, Wyderka Nikolai, Bruss Dagmar, and Kampermann Hermann — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Germany

The compatibility of quantum marginals, or reduced density matrices, is a cornerstone of quantum mechanics, underlying phenomena like entanglement and non-locality. A fundamental variant of this problem concerns the compatibility of spectra, rather than the reduced density matrices themselves. Specifically, given eigenvalues $\vec{\lambda}_{AB}$ and $\vec{\lambda}_{BC}$ for subsystems AB and BC, the task is to determine whether there exists a joint quantum state ρ_{ABC} such that its reduced density matrices $\rho_{AB} = tr_C(\rho_{ABC})$ and $\rho_{BC} = tr_A(\rho_{ABC})$ exhibit these spectra. If such a state exists, the spectra are deemed compatible; otherwise, they are incompatible.

Recently, a hierarchy of semidefinite programs was developed to address this challenge [1]. This hierarchy is complete and provides dimension-free certificates of incompatibility for all local dimensions.

In this work we present additional analytical conditions for spectral compatibility, by solving the second level of the hierarchy. From this, we systematically derive spectral compatibility constraints for multipartite qudit systems and relate them to inequalities of linear entropies.

[1]: F. Huber, N.Wyderka, arXiv:2211.06349

Q 63.25 Thu 17:00 Tent

Super-Heisenberg scaling of the quantum Fisher information using spin-motion states — •Venelin Pavlov and Peter Ivanov — St. Kliment Ohridski University of Sofia, James Bourchier 5 blvd, 1164 Sofia, Bulgaria

We propose a spin-motion state for high-precision quantum metrology with super-Heisenberg scaling of the parameter estimation uncertainty using a trapped ion system. Such a highly entangled state can be created using the Tavis-Cummings Hamiltonian which describes the interaction between a collective spin system and a single vibrational mode. Our method relies on an adiabatic evolution in which the initial motional squeezing is adiabatically transferred into collective spin squeezing. In the weak squeezing regime, we show that the adiabatic evolution creates a spin-squeezed state, which reduces the quantum projective noise to a sub-shot noise limit. For strong bosonic squeezing we find that the quantum Fisher information follows a super-Heisenberg scaling law $\propto N^{5/2}$ in terms of the number of ions N. Furthermore, we discuss the spin squeezing parameter which quantifies the phase sensitivity enhancement in Ramsey spectroscopic measurements and show that it also exhibits a super-Heisenberg scaling with N. Our work enables the development of high-precision quantum metrology based on entangled spin-boson states that lead to faster scaling of the parameter estimation uncertainty with the number of spins.

Q 63.26 Thu 17:00 Tent

Thermodynamic Consistency of Markovian Embeddings of Open Quantum Systems — •Shreesha S. Hegde, Adrian Romer, and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

The Surrogate Hamiltonian is an approximation method used to simulate open quantum systems [1]. Here, an infinite bath is represented by a surrogate bath made up of a finite number of two-level systems that strongly interact with the system we are interested in. This is then simulated as a closed system. As expected, this model works only for short simulation times before recurrences are seen in the system due to the unitary evolution of the system and the surrogate bath.

The Stochastic Surrogate Hamiltonian is a Markovian embedding technique that improves on this greatly by implementing a stochastic reset of the surrogate modes to their original thermal state. This is done as a way of mimicking the steady thermal state in an infinite bath and allows for extended simulation times [2]. However, implementing this scheme under conditions that are consistent with thermodynamics can be computationally expensive. We aim to achieve an approximate realization of these conditions under which we can still attain a thermodynamically consistent steady state on the system.

[1] Baer et al., J. Chem. Phys. 106, 8862 (1997)
[2] Katz et al., J. Chem. Phys. 129, 034108 (2008)

Q 63.27 Thu 17:00 Tent

Wigner Negativity and Nonclassicality — •Michael E. N. Tschaffon and Matthias Freyberger — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany

The Wigner function is a well-established tool in quantum physics to study quantum states in phase space. It serves as a quantum analogue of a classical probability distribution. However, in contrast to its classical counterpart it can obtain negative values, which are thus naturally associated with nonclassical features, that is, nonclassicality, of the underlying quantum state. The relation between these negative values, i.e., Wigner negativity, and nonclassicality is quantitatively not well understood. For this purpose, we examine Wigner negativity for bipartite states. We show that, using Bell inequalities with a pseudo spin, nonclassical correlations are monotonically related to Wigner negativity. In particular, we separate the part of Wigner negativity contributing to nonclassical correlations from the one already present in single particle nonclassicality. As a consequence, we find that Wigner negativity is not sufficient to have nonclassical correlations.

Q 63.28 Thu 17:00 Tent

Composite pulses for robust ensemble based quantum tokens with Nitrogen Vacancy color centers — •Jan Thieme, Josselin Bernardoff, Ricky-Joe Plate, Bernd Bauerhenne, and Kilian Singer — Experimental Physics I, Institute of Physics, University of Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

We report on both analytical and experimental outcomes related to the application of tailored composite pulses [1] to effectively address ensembles of nitrogen-vacancy color centers within a novel ensemble based protocol for quantum tokens [2]. Utilizing analytical techniques specific to the Rosen-Zener excitation model, we have developed broadband excitation profiles to compensate for experimental fluctuations in resonance frequency and pulse area. This is especially important for a quantum token application with ensembles. These custom pulses are applied using an arbitrary waveform generator to precisely control individual NV color centers [3]. Future work aims to enhance this strategy to further reduce the susceptibility to technical limitations, thereby improving the overall robustness and effectiveness of the protocol [4].

[1] G. T. Genov, D. Schraft, T. Halfmann and N. V. Vitanov, Phys. Rev. Lett. 113, 043001 (2014). [2] K. Singer, C. Popov,B. Naydenov, Verfahren zum Erstellen eines Quanten-Datentokens (DE 10 2022 107 528 A1) DE-Patent (2023) [3] A. Schmidt, J. Bernardoff, K. Singer, J. P. Reithmaier and C. Popov, Physica Status Solidi A, 216, 1900233 (2019). [4] G. T. Genov, M. Hain, N. V. Vitanov, and T. Halfmann, Phys. Rev. A, 101, 013827(2020)

Q 63.29 Thu 17:00 Tent

Efficient tensor network simulation of open quantum systems with realistic environments — •Matteo Garbellini, Valentin Link, and Walter Strunz — Institut für Theoretische Physik, Technische Universität Dresden, D-01062, Dresden, Germany

We utilize novel numerical techniques for open quantum systems in order to simulate qubit dynamics in experimentally realized quantum devices. Our approach is based on a recently introduced tensor network based method that efficiently generates auxiliary environments for non-Markovian Gaussian baths [1]. In this framework, the combination of multiple noise sources still has exponential scaling. We overcome this issue by employing a matrix product state representation for the system-and-bath degrees of freedom and then performing real-time evolution via TEBD. As an example problem we consider a recent experiment where a Landau-Zener sweep was performed in a superconducting flux qubit [2]. By carefully taking into account both transverse and longitudinal noise, we reach excellent quantitative agreement with the experimental data over large parameter regimes.

[1] Link, V., Tu, H.H., & Strunz, W. Open Quantum System Dynamics from Infinite Tensor Network Contraction. Phys. Rev. Lett., 132, 200403 (2024)

[2] Lupascu, A. et al. Dissipative Landau-Zener tunneling: crossover from weak to strong environment coupling, arXiv:2207.02017v1 (2022)

Q 63.30 Thu 17:00 Tent

Blind Grover Search for Gate-based Quantum Computers — •Alexander Sauer[1], Alexander von Consbruch[2], and Matthias Zimmermann[1] — [1]DLR e.V., Institute of Quantum Technologies, Ulm — [2]University of Göttingen

While quantum computers might offer several computational benefits, their application within a quantum network is also of interest in regard to privacy, data protection and computational security. One promising application is blind quantum computing, where a client with limited quantum capacities utilizes the computational power of a quantum computer located at a quantum computing center without revealing any information about the computation or data involved. Several schemes for blind quantum computation have emerged, with the most advanced relying on measurement-based quantum computing [1]. However, many current quantum computer designs are based on gate-based state manipulation. While blind quantum computing is also possible in this scenario, it requires a permanent exchange of quantum information between client and server [2]. To reduce the communication overhead for the involved parties, we study a relaxed scenario of blind quantum computing, where the server gets some information about the algorithm. In particular, we propose a protocol to hide an n-qubit Grover search algorithm by utilizing additional qubits on a quantum server which are initialized by the clients.

[1] Fitzsimons, J. F. (2017), npj Quantum Information, 3(1), 23.

[2] A. Childs, A. (2005), Quantum Inform. Comput., 5, 456-466.

Q 63.31 Thu 17:00 Tent

Metrology for magnetic moments in transmission electron microscopes — •Michael Gaida[1], Santiago Beltran Romero[2,3], Stefan Nimmrichter[1], Dennis Rätzel[4], and Philipp Haslinger[2,3] — [1]Universität Siegen, Adolf-Reichwein-Straße 2a, 57076 Siegen, Deutschland — [2]Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [3]University Service Centre for Transmission Electron Microscopy, TU Wien, Wiedner Hauptstraße 8-10/E057-02, 1040 Wien, Austria — [4]ZARM, Unversität Bremen, Am Fallturm 2, 28359 Bremen, Germany

In transmission electron microscopy (TEM), an electron beam passes through a thin sample layer, producing an interference pattern that reveals atomic-scale structures. While TEM is well-established, quantum metrology offers potential enhancements. Building on the experimental proposal in reference [1], which aims to detect individual quantum spins' magnetic moments using electron beams, we extend the analysis to include scattering dynamics in the paraxial high-energy regime. We calculate the quantum Fisher information for estimating magnetic moments using analytical and numerical methods, comparing it to classical methods with position-resolving electron detectors. Our goal is to determine the experimental conditions required to detect a single Bohr magneton with focused electron beams.

[1]P. Haslinger, S. Nimmrichter, and D. Rätzel, Spin resonance spectroscopy with an electron microscope, QST 9, 035051 (2024).

Q 63.32 Thu 17:00 Tent

Scalable, high-fidelity all-electronic control of trapped-ion qubits — •Clemens Löschnauer, Jacopo Mosca Toba, Amy Hughes, Steven King, Marius Weber, Raghavendra Srinivas, Roland Matt, Rustin Nourshargh, David Allcock, Chris Ballance, Clemens Matthiesen, Maciej Malinowski, and Thomas Harty — Oxford Ionics, Oxford, United Kingdom

The central challenge of quantum computing is implementing high-fidelity quantum gates in a scalable fashion. Our all-electronic qubit control architecture combines laser-free gates with local tuning of electric potentials to enable site-selective single- and two-qubit operations in multi-zone quantum processors. Chip-integrated antennas deliver control fields common to all qubits, while voltages applied to local tuning electrodes adjust the position and motion of ions in each zone, thus enabling local coherent control. We experimentally implement low-noise, site-selective single- and two-qubit control in a microfabricated 7-zone ion trap, demonstrating 99.99916(7)% fidelity for single-qubit gates, and two-qubit Bell state generation with 99.97(1)% fidelity. These results validate the path to directly scaling these techniques to large-scale quantum computers based on electronically controlled trapped-ion qubits.

Q 63.33 Thu 17:00 Tent

Towards a real-time controlled cryogenic eight qubit quantum processor — •Erik Dunkel[1], Kevin Rempel[1], Sebastian Halama[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Hannover — [2]Physikalisch-Technische Bundesanstalt, Braunschweig

Ions confined by surface-electrode Paul traps represent a promising technology for quantum computing and quantum simulation. In our group, the qubits are encoded in two hyperfine levels of $^9Be^+$ ions and controlled by trap-integrated microwave conductors, which allow us to manipulate both the internal and motional states of the ions.

We will implement a cryogenic linear ion-trap array for eight ions with all electrical supplies necessary to apply microwave currents, DC- and RF-voltages. The trap array allows linear transport of ions, features independent storage zones and a detection register.

In addition, we will report on the status of the ongoing future-proof upgrade to the ARTIQ control system. This enables nanosecond timing pulse generation, radio-frequency synthesis and data acquisition executed on a dedicated FPGA hardware and interfaced with a Python-based programming language.

Q 63.34 Thu 17:00 Tent

Mitigation of longitudinal electric field components in a tweezer-sized standing-wave optical dipole trap — •Florian Fertig[1,2], Pooja Malik[1,2], Yiru Zhou[1,2], Chengfeng Xu[1,2], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Long coherence times are vital for large-scale quantum networks to distribute high-quality entanglement. Single atoms, trapped optically in an optical dipole trap (ODT), with an efficient light-matter interface for atom-photon entanglement have shown to be an excellent system for future quantum nodes. However, dephasing from fluctuations of external magnetic fields, but also effective magnetic fields arising from longitudinal electric field components in tightly focused tweezer beams (beam waist $w_0 \approx 2\mu m$), currently limit the coherence time.

Here, we present the successful implementation and characterization of a novel, tweezer-sized standing-wave ODT for single neutral atoms. This trap geometry effectively mitigates these effective magnetic fields. By overlapping two counterpropagating ODT beams, we create a standing wave, where the effective magnetic fields from each beam cancel each other out. Our measurements confirm the significant reduction of longitudinal field components, resulting in an increase in coherence time. Additionally, this trap architecture holds potential for multiplexing applications, offering a pathway to higher entanglement rates and enhanced quantum processing capabilities.

Q 63.35 Thu 17:00 Tent

Integration of 3D glass structures for scalable trapped-ion quantum computing — •Victoria Schwab[1,2], Klemens Schueppert[2], Max Glantschnig[2,4], Alexander Zesar[2,5], Adrian Woyke[2,6], Philipp Hurdax[3], Bernhard Lamprecht[3], Marco Valentini[1], Marco Schmauser[1], and Philipp Schindler[1] — [1]Institute for Experimental Physics, Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Johanneum Research Materials, Weiz, Austria — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [5]Karl-Franzens Universität Graz, Graz, Austria — [6]École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

Trapped-ion quantum computing is one of the most promising platforms in quantum information processing, where qubits are realized as energy levels of single ionized atoms. The preparation, manipulation and read out of the states are driven by laser light, requiring the implementation of optical access into the ion trap.

We present the fabrication route of an ion trap with multiple metal layers on a structured glass substrate. In cooperation with Johanneum Research, the glass substrate is structured by employing a selective laser etching technique, such that it allows additional optical access through the backside of the trap and thus higher flexibility in the laser setup. At Infineon Technologies in Villach, the implementation of the fabrication flow for multi-metal deposition is realized. Future steps include the prototype testing and development of the high optical access laser setup, contributing to making scalable ion traps a reality.

Q 63.36 Thu 17:00 Tent

Observing Product of Weak Values — •Vinay Tumuluru[1,2,3], Jan Dziewior[1,2,3], Carlotta Versmold[1,2,3], Florian Huber[1,2,3], Lev Vaidman[4], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80797 München — [2]MPI für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]Munich Center for Quantum Science and Technology (MCQST), 80797 München — [4]Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Israel

When a quantum system which was weakly coupled to a measuring 'pointer' system is suitably pre- and post-selected, one can observe a large shift in the state of the pointer. This shift is characterised by the 'weak value' of the pre- and post-selected system [1]. Weak values can be realised via optical interferometers where the path degree of freedom (system) is coupled with the transverse mode of the optical beam (pointer) [2]. Additionally, the polarisation degree of freedom can instead be employed as the system and coupled to the same pointer. This enables multiple systems to interact with the pointer individually and simultaneously. Interesting cases are explored, such as when weak values corresponding to each interaction are complex, but their product is real. Furthermore, a potential entanglement between the observed degrees of freedom can in turn lead to the violation of the product rule of weak values [3]. Ref: [1] Y. Aharonov et al, PRL. 60, 1351 (1988) [2] P. B. Dixon et al, PRL. 102 (2009) [3] X. Xu et al, PRL. 122, 100405 (2019)

Q 63.37 Thu 17:00 Tent

Range of operation and oversqueezed regime of squeezing transfer as means of generating spin-entangled states in trapped ions — •Nadezhda Markova — Center for Quantum Technologies, Department of Physics, Sofia University, Bulgaria

A state is regarded as both squeezed along the direction $\vec{n}_3$ and entangled when the parameter $\xi^2(\vec{n}_3) < 1$ [2]. A necessary and sufficient condition for entanglement is given by $\chi^2 = \frac{N}{F_Q} < 1$ [2], where F_Q is the QFI.

We calculate and compare these parameters for a spin-entangled state in an ion trap. The state in question is generated by transferring squeezing from the motional to the spin degree of freedom. This is achieved by applying the Tavis-Cummings Hamiltonian for a particular time and results in a nonclassical spin state [1].

We compare the parameters ξ^2 and χ^2 as a function of the squeezing parameter r and the number of ions N by simulating the system's evolution using the QuTip library. We identify the oversqueezed regime and the range of operation of the aforementioned procedure.

[1] R. J. Lewis-Swan, J. C. Zu*niga Castro, D. Barberena, and A. M. Rey. Exploiting nonclassical motion of a trapped ion crystal for quantum-enhanced metrology of global and differential spin rotations. Phys. Rev. Lett.

[2] L. Pezzé and A. Smerzi. Entanglement, nonlinear dynamics, and the Heisenberg limit. Phys. Rev. Lett.

Q 63.38 Thu 17:00 Tent

Consistent Strong-Coupling Quantum Master Equations from Dynamical Maps — •Anton Braun, André Eckardt, and Alexander Schnell — Technische Universität Berlin, Institut für Theoretische Physik

One of the most basic quantum master equations describing the interaction between a quantum system and its environment is the Redfield equation. It is, however, well known that it violates complete positivity and leads to incorrect steady states for non-weak coupling. Following up on work by Becker et al. [1], modifications to the Redfield equation are investigated that combat these issues by introducing a correction term that steers the dynamics towards the correct steady state. To this end, we study the exact solution of the Caldeira-Leggett model and show that the corresponding dynamical map can be obtained by combining Redfield theory with ideas from the formalism of periodically refreshed baths. In this way, divergence of the Redfield dynamical map for long times is cured by instead recursively evolving to a shorter time. Finally, the correction term of Ref. [1] can then be recovered from the so-obtained dynamical map. This gives a completely novel perspective on the long-standing issues of the Born-Markov approximation.

[1] Phys. Rev. Lett. 129, 200403 (2022)

Q 63.39 Thu 17:00 Tent

Quantum algorithms to solve partial differential equations in battery modelling — •David Steffen[1,2], Albert Pool[1,2], Michael Schelling[1,2], and Birger Horstmann[1,2,3] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Wilhelm-Runge-Str. 10, 89081 Ulm — [2]Helmholtz Institute Ulm, Helmholtzstr. 11, 89081 Ulm — [3]Department of Physics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm

Mathematical models of electrochemical systems as batteries or fuel cells consist of sets of coupled nonlinear partial differential equations. We present variational quantum algorithms to simulate these systems on a quantum computer. The spacetime solution can be obtained as the ground state of a Feynman-Kitaev Hamiltonian evaluated via quantum nonlinear processing units (QNPUs) [1] or the system is encoded through feature maps and solved with Differentiable Quantum Circuits (DQC) [2].

These algorithms can be used on different scales from continuum modelling on cell level to molecular dynamics and thus bridging the gap to quantum chemistry which is another promising field of quantum computing in battery research.

[1] Pool, A.J. et al, Phys. Rev. Res. 2024, 6, 033257

[2] Kyriienko, O. et al., Phys. Rev. A 2021, 103, 052416

Q 63.40 Thu 17:00 Tent

The role of the zero mode on the entanglement dynamics of harmonic chains — •Stefan Aimet[1] and Spyros Sotiriadis[2] — [1]Freie Universität Berlin, Berlin, Germany — [2]University of Crete, Heraklion, Greece

In this submission, we investigate the role of a special zero mode feature on the evolution of entanglement under global quench dynamics of harmonic chains.

Q 63.41 Thu 17:00 Tent

Quantum robustness of the toric code in a parallel field on the honeycomb lattice — •Viktor Kott, Matthias Mühlhauser, Jan Alexander Koziol, and Kai Phillip Schmidt — Chair of Theoretical Physics V, Friedrich-Alexander-Universität, Erlangen, Germany

We study the quantum robustness of topological order in the toric code on a honeycomb lattice under a uniform parallel field. For a field in the z-direction, the system maps to the transverse-field Ising model on the honeycomb lattice, showing a second-order quantum phase transition in the 3D Ising* universality class. A positive x-field similarly maps to a ferromagnetic transverse-field Ising model on the triangular lattice, with the same phase transition. In contrast, a negative x-field maps to a frustrated antiferromagnetic model, leading to a 3D XY* transition and a first-order transition to a polarized phase at higher field values. These findings, confirmed by quantum Monte Carlo and series expansions, apply to both honeycomb and triangular lattices, revealing critical behaviors and potential multi-critical points.

Q 63.42 Thu 17:00 Tent

Householder reflections in the Hilbert space of ions trapped in Paul trap — •Vasil Vasilev and Nikolay Vitanov — Department of Physics, Sofia University, James Bourchier 5 boulevard, 1164 Sofia, Bulgaria

This work investigates the ways of generating Householder reflections in the Hilbert space of ions trapped in Paul trap. The Householder reflection is a powerful approach for matrix manipulation in classical data analysis. Here we explore its use in quantum information processing for the creation of arbitrary unitary matrices. In previous publications, an arbitrary Householder transformation is produced either by using different couplings in an N-pod system, for which, however, the Hilbert space is non-scalable [1], or in a scalable Hilbert space but for equal couplings [2,3]. Here we discuss the more general situation of constructing Householder reflections with different couplings in a scalable Hilbert space. The ultimate objective is to construct C^n-phase gates which can be used as native implementations of Householder reflections and hence for efficient decomposition of unitary matrices. The proposed concept can also be used for physical synthesis of arbitrary random matrices. We explore their Haar measures and present a comparison with the Givens rotations method.

[1] Peter A. Ivanov and Nikolay V. Vitanov Phys. Rev. A 77, 012335
[2] Peter A. Ivanov, Nikolay V. Vitanov and Martin B. Plenio Phys. Rev. A 78, 012323
[3] S. S. Ivanov, P. A. Ivanov, I. E. Linington, and N. V. Vitanov Phys. Rev. A 81, 042328

Q 63.43 Thu 17:00 Tent

Onset of Quantum Thermalization in Jahn-Teller model. Stochasticity in ergodic quantum systems. — •Yoana Chorbadzhiyska and Peter Ivanov — Sofia University, Sofia, Bulgaria

In the present work, we investigate the onset of quantum thermalization in a system governed by the Jahn-Teller Hamiltonian which describes the interaction between a single spin and two bosonic modes. We find that the Jahn-Teller model exhibits a finite-size quantum phase transition between the normal phase and two types of super-radiant phase when the ratios of spin-level splitting to each of the two bosonic frequencies grow to infinity. We test the prediction of the eigenstate thermalization hypothesis (ETH) in the Jahn-Teller model. We validate the diagonal part of the hypothesis utilizing various measures. Further, we focus on the statistical properties of the off-diagonal matrix elements and consider an alternative indicator for the validity of this aspect of the ETH. We discuss briefly the theory behind the derivation of the indicator and comment on the application of this theory to the quantum parameter estimation in ergodic systems.

Q 63.44 Thu 17:00 Tent

Characterization and mitigation of optical side-channels in QKD — •Evelyn Edel[1], Moritz Birkhold[1,2], Lukas Knips[1,2,3], Sebastian Melik[4], and Harald Weinfurter[1,2,3] — [1]Ludwig Maximilian University, Munich, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Max Planck Institute of Quantum Optics, Garching, Germany — [4]University of Gdańsk, Gdańsk, Poland

Unlike classical key distribution methods reliant on computationally hard problems, quantum key distribution (QKD) achieves information-theoretic security by the principles of quantum mechanics. The decoy-state BB84 protocol offers a practical scheme for realizing free-space QKD sender modules, allowing the use of highly attenuated laser pulses as a photon source. Yet, device imperfections could make side channel attacks by an eavesdropper possible. This work presents a characterization of spectral side channels in our sender module, arising from imperfect spectral overlap. For pulse generation, the module under investigation hosts four vertical-cavity surface-emitting lasers (VCSELs) in a monolithic array, one for each polarization state. Using a spectrometer also in combination with a streak camera, we analyze the spectral behavior and time-dependent variations of these diodes for different bias and modulation currents. To minimize the resulting side channels, Peltier modules are tested for cooling individual diodes. This setup will allow us to identify VCSEL arrays with the best spectral overlaps and quantize the information leaked to an eavesdropper, facilitating the future optimization of our modules.

Q 63.45 Thu 17:00 Tent

Quantum search with resetting — •Sayan Roy, Emma King, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D- 66123 Saarbrücken, Germany

Search problems are prevalent in science and nature. Algorithms incorporating resetting mechanisms, where the system randomly or periodically resets to its initial state, have demonstrated improved efficiency in search tasks within both classical and quantum domains [1]. In this contribution, we consider resetting protocols for quantum walks in one dimension with nearest-neighbor hopping and determine the time the walker needs to reach a given target for different implementations of the resetting procedure. We then discuss how the results may be generalized to lattices of higher dimensions and different site connectivity.

[1]. M.R. Evans, S.N. Majumdar and G. Schehr, J. Phys. A: Math. Theor. **53**, 193001.

Q 63.46 Thu 17:00 Tent

Off-resonant dipole-phonon interaction for quantum information processing with molecular rotors — •Leonel O. Stenkhoff, Monika Leibscher, and Christiane P. Koch — Freie Universität Berlin

Encoding quantum information in molecular ions requires a mechanism allowing for cooling and control of rotational quantum states. To this end, the dipole-phonon interaction of molecular and atomic ions co-trapped in a linear Paul trap is utilized. Resonant dipole interaction occurs when the rotational energy splitting is comparable to the eigenfrequency of a normal mode of the trap. Off-resonant dipole-phonon coupling scales with the trap frequency and the dipole moment of the molecule and can become the dominant part of the interaction if the molecule has a particular large dipole moment, as we demonstrate for the example of a trapped cytochrome complex. The prospects of cooling rotational quantum states via off-resonant dipole coupling are also discussed, which is particularly interesting for systems, where no resonant dipole-phonon interaction is observed in the range of achievable trap frequencies.

Q 63.47 Thu 17:00 Tent

Pulse shaping strategies: smooth sine-based pulses for enhanced stability and super power broadening with two tunable types of pulses — •Ivo Mihov and Nikolay Vitanov — Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier blvd, 1164 Sofia, Bulgaria

This study explores two approaches to pulse shaping for qubit dynamics. First, smooth sine pulses are investigated as alternatives to rectangular pulses, minimizing power broadening, reducing sidebands, and avoiding truncation issues. Two analytic solutions, based on Weber's parabolic cylinder functions and a simplified asymptotic approach, are derived and validated on IBM Quantum processors, confirming the predicted effects.

In contrast, the study also examines two novel pulse families designed to enhance power broadening, creating "super power broadening." These pulse shapes – quadratic and even-power pulses – amplify non-adiabaticity at the pulse edges, enabling more sensitive interactions for applications such as EIT, quantum tomography, and nonlinear optics. These pulse shaping strategies, tested on IBM Quantum processors, offer new tools for optimizing quantum state manipulation, broadening interaction frequencies, and improving spectroscopy techniques.

Q 63.48 Thu 17:00 Tent

Simulating Chemistry with Fermionic Optical Superlattices — •Jin Zhang[1], Fotios Gkritsis[2], Daniel Dux[3], Naman Jain[1], Christian Gogolin[2], and Philipp Preiss[1,4] — [1]Max Planck Institute for Quantum Optics, Garching — [2]Covestro Deutschland AG, Leverkusen — [3]Physikalisches Institut der Universitat Heidelberg — [4]Munich Center for Quantum Science and Technology, Munich

Computational chemistry requires finding the ground states of strongly correlated electrons in molecular orbitals. Quantum algorithms and computers promise to provide such ground state energies for molecular systems whose size is beyond the reach of classical numerical methods. One approach is to translate molecular structure problems to fermionic quantum simulators, which naturally obey the fermionic exchange symmetries found in nature. We show that quantum number preserving Ansatze for variational optimization in quantum chemistry find an elegant mapping to ultracold fermions in optical superlattices. Using native Hubbard dynamics, trial ground states of molecular Hamiltonians can be prepared and their molecular energies measured in the lattice. The scheme requires local control over interactions and chemical potentials and global control over tunneling dynamics, but foregoes the need for shuttling operations or long-range interactions. Our work enables the application of recent quantum algorithmic techniques, such as Double Factorization and quantum Tailored Coupled Cluster, to present-day fermionic optical lattice systems with significant improvements in the required number of experimental repetitions. We provide detailed quantum resource estimates for hardware experiments.

Q 63.49 Thu 17:00 Tent

Sparse Optimization of Quantum Fourier Transform Spectroscopy — •Chinmay Sangavadekar[1], Zhengjun Wang[1,2], and Frank Schlawin[1,2,3] — [1]University of Hamburg, Luruper Chaussee 149, Hamburg, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

Nonlinear interferometers are of fundamental importance for quantum-enhanced photonic sensing. They enable sensing in the infrared regime at low photon flux and without the need of detecting infrared photons. Here we present a theoretical model for quantum Fourier transform spectroscopy with nonlinear interferometers. We further explore how sparse optimization may reduce the necessary number of measurements and thereby speed up data acquisition.

Q 63.50 Thu 17:00 Tent

Modeling spin initialization in highly strained silicon-vacancy centers — •Michael Gstaltmeyr, Marco Klotz, Andreas Tangemann, and Alexander Kubanek — Institute for Quantum Optics, University Ulm, Germany

Spin qubits in solid state hosts are, due to their promise of scalability, candidates for the realization of quantum networks. The good spin properties of diamond paired with the optical properties of group-IV defects make them of special interest. We are using highly strained Silicon-Vacancy centers in nanodiamonds to mitigate phonon induced electron spin dephasing at liquid helium temperature. However, high strain introduces challenges in optical spin initialization, as additional transitions closely interact with the initialization pathway, complicating the traditional three-level pump model. This work explores these interactions and proposes improved methods to characterize the system.

Q 63.51 Thu 17:00 Tent

Quantum Generative Modelling with Conservation Law based Pretraining — •Akash Malemath[1,2], Yannick Werner[3], Paul Lukowicz[1,3], and Maximilian Kiefer-Emmanouilidis[1,2,3] — [1]Department of Computer Science and Research Initiative QCAI, RPTU, Kaiserslautern-Landau — [2]Department of Physics, RPTU, Kaiserslautern-Landau — [3]DFKI Kaiserslautern

Abstract:

Compared to the recent advancements in classical generative AI, quantum generative models still lack the capability to generate complex data effectively. One of the greatest challenges in classical AI is developing systems that extract fundamental relationships from large datasets and encode them into suitable embeddings. In quantum generative AI, these concepts are still in early stages and are mostly learned using classical methods.

In this work, we evaluate embeddings inspired by conservation laws as a pretraining step, applying them to simple quantum generative models like the Quantum Circuit Born Machine (QCBM). This implicit generative model is well-suited for reproducing target distributions and is simple enough to demonstrate the benefits of pretraining. Specifically, we explore pretraining using the particle number distribution and system Hamiltonian within the QCBM, aiming to model target distributions with reduced effort. Our analysis of pretraining in QCBM focuses on its impact on model convergence and accuracy, using metrics such as Kullback-Leibler (KL) divergence, and compares pretrained models with those trained normally.

Q 63.52 Thu 17:00 Tent

Cluster-additivity of perturbative discrete product of unitaries and applications to the variational quantum eigensolver — •Max Hörmann, Harald Leiser, Sumeet Sumeet, and Kai Phillip Schmidt — Chair for Theoretical Physics V, FAU Erlangen-Nürnberg, Germany

We explore the cluster-additivity properties of a perturbatively defined unitary transformation $U = U_1 \cdot \ldots \cdot U_n$, where each successive order in perturbation theory introduces an additional unitary operator U_n [1]. We establish connections to continuous unitary transformations and compare this approach with globally defined transformations, such as the projective cluster-additive transformation [2]. Furthermore, we emphasize the striking parallels between this transformation and ansätze commonly employed in the variational quantum eigensolver algorithm. Building on this, we propose a variational extension of the transformation, expanding its applicability beyond the perturbative framework. Finally, we assess whether this transformation can effectively construct good initial guesses for larger systems by leveraging information from smaller subsystems.

[1] N. Datta, J. Fröhlich, L. Rey-Bellet and R. Fernández, Low-temperature phase diagrams of quantum lattice systems. II. Convergent perturbation expansions and stability in systems with infinite degeneracy, Helv. Phys. Acta 69(5-6), 752 (1996).

[2] M. Hörmann and K. P. Schmidt, Projective cluster-additive transformation for quantum lattice models, SciPost Phys. 15, 097 (2023).

Q 63.53 Thu 17:00 Tent

Employing Two-Photon Interference to Secure QKD Against Optical Side Channels — •Franziska Divkovic[1], Moritz Birkhold[1,2], Harald Weinfurter[1,2,3], and Lukas Knips[1,2,3] — [1]Ludwig Maximilian University, Munich, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Max Planck Institute of Quantum Optics, Garching, Germany

Quantum Key Distribution (QKD) provides a key advantage over classical cryptography by enabling secure communication without the risk of unnoticed eavesdropping on the quantum channel. However, in real devices, side channels - additional degrees of freedom (DOFs) correlated with the one used to encode the key - can allow eavesdroppers to extract information. If not quantified, these side channels can compromise the security of the QKD scheme.

A key assumption in the security proof is the phase randomization of consecutive pulses representing the same symbol. Indistinguishable pulses, which are phase-randomized, prevent attacks by ensuring no information can be extracted from alternate DOFs. To verify whether this criterion is met, the interference of these pulses is investigated. Additionally, the interference of pulses representing different symbols is analyzed to assess their indistinguishability across all except polarization. The visibility of the interference pattern serves as a key metric for quantifying pulse indistinguishability and security. This is achieved using a fiber-based interferometer with a delay line in one arm and a polarization-cleaning mechanism. This research provides insights for defining specifications and developing tests to secure against attacks.

Q 63.54 Thu 17:00 Tent

Robust VECSEL for Controlling trapped Magnesium Ions — •Tobias Spanke, Lennart Guth, Philip Kiefer, Lucas Eisenhart, Deviprasath Palani, Apurba Das, Florian Hasse, Jörn Denter, Mario Niebuhr, Ulrich Warring, and Tobias Schätz — Physikalisches Institut, Albert-Ludwigs-Universität, Freiburg

Trapped ions present a promising platform for quantum simulations and quantum sensing. Versatile and robust laser systems with narrow bandwidth and high power and intensity stability are required at UV range of 280 nm to reliably load and control this platform. The latest systems for Mg^+, Be^+ ions are based on vertical external cavity surface-emitting lasers (VECSEL) [1] in the near-infrared. A new generation of air-cooled systems is proposed to decrease bandwidth and increase stability while mitigating expensive temperature control systems. With the goal of measuring magnesium ions at a frequency stability of 200 kHz ($\lambda \approx 1120$ nm, P = 2 W with $\lambda \approx 280$ nm at the experiment) with high accuracy. We aim at further development of the VECSEL into a compact, stable, and user-friendly "turnkey" system.

[1] Burd, S. et al.(2016), VECSEL systems for generation and manipulation of trapped magnesium ions, Optica Vol. 3, Issue 12, pp. 1294-1299 (2016)

Q 63.55 Thu 17:00 Tent

Complexity: chaos, regular, and complex — •Adisorn Panasawatwong, Jan-Michael Rost, and Ulf Saalmann — MPI-PKS

We are developing a machine learning-based approach to extract meaningful information from noisy physical observables. Distinguishing signal from noise in chaotic systems is a significant challenge. Our primary goal is to introduce a novel method for quantifying the inherent complexity of these signals, similar to resolution functions used in standard data analysis. A key aspect of our approach is to assign zero complexity to systems that exhibit either extreme regularity or extreme chaos. We designed machine learning networks specifically tailored to uncover hidden patterns within these noisy observables. This approach aims to enhance our ability to extract critical information from a wide range of applications, from classical noise to the complex quantum systems that produce noisy, intricate data sets.

Q 63.56 Thu 17:00 Tent

Efficient quantum control by composite ultrastrong field — •Kremena Parashkevova and Nikolay Vitanov — Center for Quantum Technologies, Faculty of Physics, Sofia University, James Bourchier 5 blvd., 1164 Sofia, Bulgaria

We present a study on coherent quantum control of a qubit by an ultrastrong driving field in the regime where the rotating-wave approximation cannot be applied. The resulting counter-rotating term makes traditional quantum control methods, such as resonant, adiabatic and shortcut techniques, unable to achieve high control accuracy. We identify the recently developed universal composite pulses as the only quantum control method which successfully maintains very high accuracy even in this ultrastrong coupling regime.

Q 63.57 Thu 17:00 Tent

Towards Scalable Quantum Computing with Trapped Ions: Single-Ion Addressing and Efficient Cooling — •Robin Strohmaier, Daniel Wessel, Alexander Müller, Jonas Vogel, Björn Lekitsch, and Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Trapped ions are a leading platform for scalable and fault-tolerant quantum computing. In this work, we present two critical advancements toward realizing scalable quantum computing with linear crystals of ions: precise single-ion addressing and efficient near-ground-state cooling of ion crystals.

Single ion addressing of the spin qubit in $^{40}Ca^{+}$ is achieved using a crossed acousto-optic deflector (AOD) setup. This system utilizes a tightly focused 400 nm laser beam to drive stimulated Raman transitions between spin states. We demonstrate a beam focus of $1\,\mu$m, enabling low crosstalk between neighboring ions. Additionally, we implement several ground state cooling schemes which can be used within sequences as well. This enables longer gate sequences and hence deeper algorithms. Combined with our new developed, SLE fabricated, glass trap and its low heating rates, these advancements support the handling of ion crystals with tens of ions, paving the way for operations involving multiple logical qubits. These results mark significant progress toward scalable quantum computation with trapped ions.

Q 63.58 Thu 17:00 Tent

Noisy Rydberg Quantum Gates — •Santiago Higuera Quintero[1], Sebastian Weber[1], Katharina Brechtelsbauer[1], Nicolai Lang[1], Tilman Pfau[2], Florian Meinert[2], and Hans Peter Büchler[1] — [1]Institute for Theoretical Physics III and IQST, University of Stuttgart, 70550 Stuttgart, Germany — [2]Institute of Physics and IQST, University of Stuttgart, 70550 Stuttgart, Germany

Modelling noise processes in noisy intermediate-scale quantum (NISQ) devices plays an important role in designing hardware and algorithms in the journey for scalable quantum computers. In this era, classical emulators of quantum systems can help to better understand typical errors in quantum information processing which arise from coupling to the environment and experimental limitations. We present a noise analysis of our gate protocols and determine relevant Kraus maps under typical noise sources to Rydberg-based platforms, such as: photon recoil, laser and thermal noise. Finally, we provide an overview of our online platform that provides users the opportunity to try out our gate-based emulator of the Rydberg quantum computer of the QRydDemo project and get familiar with its native gate operations.

Q 63.59 Thu 17:00 Tent

Quantum systems driven by nonclassical light treated using the hierarchy of pure states — •Vladislav Sukharnikov[1], Stasis Chuchurka[1], and Frank Schlawin[2] — [1]Department of Physics, Universität Hamburg, 22761 Hamburg, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany

Quantum systems driven by nonclassical light fields have garnered significant attention, particularly in light of recent breakthroughs in high-harmonic generation using nonclassical light sources. Developing a comprehensive theoretical framework for these systems would be highly beneficial. However, the inherent complexity of the problem limits a fully general treatment. In this work, we investigate the interaction between an atomic system and nonclassical light, such as squeezed light, examining the dynamic evolution of both the atomic system and the field. To tackle this challenging problem, we employ a hierarchy of pure states to model the coupling to the field, which is treated as a non-Markovian bath. This method allows for parallelization and effectively treats multimode structure of the field, providing deeper insights into the underlying dynamics and expanding our understanding of these complex systems.

Q 63.60 Thu 17:00 Tent

Exploring Long-Range Interactions in Quantum Many-Body Systems — •Antonia Duft, Patrick Adelhardt, and Kai Phillip Schmidt — Friedrich-Alexander Universität Erlangen-Nürnberg

Long-range interactions play a crucial role in many quantum many-body systems and might influence their dynamics, critical behavior, and phases of matter. Experimentally, algebraically decaying long-range interactions $\sim r^{-(d+\sigma)}$ are relevant in various quantum-optical platforms, including ultracold atoms, trapped ions, and Rydberg atom arrays which can also serve as analogue quantum simulators. However, their theoretical treatment poses challenges compared to short-ranged systems. To address these, we utilize the method of perturbative Continuous Unitary Transformations (pCUT)combined with classical Monte Carlo (MC) techniques. A linked-cluster expansion is set up for long-range interactions using white graphs and the embedding is handled in a MC algorithm. This approach enables the extraction of high-order series expansions of physical quantities in the thermodynamic limit. The pCUT+MC approach can be employed to tackle a multitude of systems, including paradigmatic models like the spin-1/2 transverse field Ising model, XY model, and Heisenberg model. We further apply the method to spin-1 Heisenberg systems.

Q 63.61 Thu 17:00 Tent

Is Localization a security threat in Quantum Machine Learning? — •Yannick Werner[1], Nikolaos Palaiodimopoulos[1,2], Omid Faizy[2,3], Nico Piatkowski[4], Paul Lukowicz[1,2], and Maximilian Kiefer-Emmanouilidis[1,2] — [1]DFKI Kaiserslautern — [2]RPTU Kaiserslautern-Landau — [3]Sorbonne Université, Paris — [4]Fraunhofer IAIS, Sankt Augustin

As Quantum Machine Learning (QML) becomes more developed and widely used in commercial applications, addressing its security risks is essential. We examine Quantum Neural Networks (QNNs) as disordered quantum systems to explore whether effects like Many-Body Localization (MBL) could impact QNN tasks such as classifying or generating data. It has been shown, that applying a simple cyclic permutation after embedding the data and before readout can recover complex classical data from the measurements of a single disorder realization [1]. This suggests that a trained QNN, which effectively represents such a single disorder realization, could be vulnerable to exposing sensitive data it is supposed to classify. For instance, an eavesdropper might recover sensitive input data from stolen measurement results, a risk that is non-existent with classical classifiers. To address this, we analyse shallow variational quantum circuits with nearest-neighbour interactions and strongly varying weights, where MBL dynamics are expected. We assess their vulnerability to data recovery and examine the balance between expressibility, trainability, and security risks in QNN designs.

[1]arXiv:2409.16180v1 (2024).

Q 63.62 Thu 17:00 Tent

Gradient magnetometry with atomic ensembles — •Iagoba Apellaniz[1], Iñigo Urizar-Lanz[1], Zóltan Zimborás[1,2,3], Philipp Hyllus[1], and Géza Tóth[1,3,4] — [1]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P. O. Box 644, ES-48080 Bilbao, Spain — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, DE-14195 Berlin, Germany — [3]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, HU-1525 Budapest, Hungary — [4]IKERBASQUE, Basque Foundation for Science, ES-48013 Bilbao, Spain

We study gradient magnetometry with an ensemble of atoms with arbitrary spin. We calculate precision bounds for estimating the gradient of the magnetic field based on the quantum Fisher information. For quantum states that are invariant under homogeneous magnetic fields, we need to measure a single observable to estimate the gradient. On the other hand, for states that are sensitive to homogeneous fields, a simultaneous measurement is needed. We present a method to calculate precision bounds for gradient estimation with a chain of atoms or with two spatially separated atomic ensembles. We also consider a single atomic ensemble with an arbitrary density profile, where the atoms cannot be addressed individually, and which is a very relevant case for experiments. Our model can take into account even correlations between particle positions. While in most of the discussion we consider an ensemble of localized particles that are classical with respect to their spatial degree of freedom, we also discuss the case of gradient metrology with a single Bose-Einstein condensate.

Q 63.63 Thu 17:00 Tent

A Weak Measurement Based Toy Model to Probe Quantum Properties in a Cosmological Setting — •Joel Huber[1,2,3], Časlav Brukner[3], and Igor Pikovski[4] — [1]Universität Siegen — [2]ETH Zurich — [3]IQOQI Vienna — [4]Stevens Institute of Technology

Probing quantum properties in cosmology could offer profound insights into the fundamental nature of the universe. We present a novel perspective on the detectability of quantum properties in cosmology. Firstly, we motivate a set of fundamental limitations inherent to observational cosmology and translate them into operational constraints for a general quantum system. We then propose a toy model and show how the limitations can be successfully circumvented by studying weakly coupled pointer degrees of freedom. We find that the non-commutativity of observables can be inferred by comparing measurement statistics, even though limited by the weakness of the measurements. This result can provide a hint but not conclusive evidence, for the quantum nature of the system. Finally, we investigate generalised Leggett-Garg inequalities, which separate classical from non-classical temporal correlations. We demonstrate that they cannot be violated using three consecutive weak measurements while remaining agnostic about the underlying interactions.

Q 63.64 Thu 17:00 Tent

Towards a quantum processor with non-local interactions and programmable connectivity. — •Franz von Silva-Tarouca[1], Stephan Roschinski[1], Johannes Schabbauer[1], and Julian Léonard[1,2] — [1]TU Wien, Atominstitut, Vienna Center for Quantum Science and Technology (VCQ), Austria — [2]Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria

Quantum computers and simulators are especially promising for tackling problems that require a high degree of entanglement. However, the efficient and deterministic generation of many-body entanglement still poses a challenge.

We report on progress towards building a quantum processor based on an array of single atoms trapped in optical tweezers and strongly coupled to a high-finesse fiber cavity. The cavity enables non-local interactions, mediated by the joint coupling of the atoms to the cavity mode. Microscopic addressing via the optical tweezers allows for tuning this coupling for each atom, enabling programmable connectivity. This, combined with other established techniques in cavity quantum information processing, provides us with an extensive experimental toolkit for generating many-body entanglement and a variety of quantum computation and simulation experiments.

Q 63.65 Thu 17:00 Tent

Quantum simulator with 40 nuclear spins in diamond — •Christina Ioannou — Qutech, TuDelft, Netherlands

Individually controllable ^{13}C nuclear spins in diamond, associated with a single NV-center, can be used to realise a quantum simulator for the observation of many-body quantum phenomena. On this poster I will discuss the capabilities of the platform such as collective initialisation with dynamic nuclear polarisation, individual spin control and readout as well as global pulses, which make up a comprehensive toolbox for studying many-body phenomena under a range of tunable Floquet Hamiltionians. Applications of this quantum simulator include observing novel phases of matter such as discrete time crystals, studying the thermalisation a many-body 3D-coupled spin system under Floquet driving, Hamiltonian engineering and estimating entanglement entropies with randomised measurements.

Q 63.66 Thu 17:00 Tent

Quantum strategies for rendezvous and domination tasks on graphs with mobile agents — •Giuseppe Viola[1] and Piotr Mironowicz[2,3,4] — [1]University of Siegen, Siegen, Germay — [2]University of Gdansk, Gdansk, Poland — [3]Stockholm University, Stockholm, Sweden — [4]Gdansk University of Technology, Gdansk, Poland

This work explores the application of quantum non-locality, a renowned and unique phenomenon acknowledged as a valuable resource. Focusing on a novel application, we demonstrate its quantum advantage for mobile agents engaged in specific distributed tasks without communication. The research addresses the significant challenge of rendezvous on graphs and introduces a new distributed task for mobile agents grounded in the graph domination problem. Through an investigation across various graph scenarios, we showcase the quantum advantage. Additionally, we scrutinize deterministic strategies, highlighting their comparatively lower efficiency compared to quantum strategies. The work concludes with a numerical analysis, providing further insights into our findings.

Q 63.67 Thu 17:00 Tent

Optimal control of arbitrary perfectly entangling gates for open quantum systems — •Adrian Romer, Daniel Reich, and Christiane P. Koch — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany

Perfectly entangling gates (PE) are crucial for various applications in quantum information. One method to realize these gates is with the help of an external control field, whose concrete shape is found using optimal control theory. Instead of optimizing the shape that realizes a specific gate, the optimization target can be extended to the full set of PE. This increases the flexibility of optimization and allows to find the best PE from the set of all PE. First, we show that it is possible to construct the unitary part of an unknown coherent evolution by propagating specifically talilored density matrices. We then extend this construction method to approximate the unitary part of a non-unitary evolution. Lastly, we employ this method to superconducting qubits, where we numerically find optimized control fields that generate maximally entangled states for a desired gate duration, even if dissipation is present in the system.

Q 63.68 Thu 17:00 Tent

Phase Space Dynamics of Continuous-Variable, Open Bosonic Systems with Generative Neural Quantum States — •Ege Görgün — Institut für Festkörpertheorie und Optik, Jena, Deutschland

Simulating the dynamics of interacting many-body quantum systems poses a significant challenge due to the exponential complexity scaling with system size. In this work, we derive the quantum master equation for phase space quasi-probability distributions across a diverse set of open bosonic systems, providing an analytical foundation for tracking their dynamics. We then present a neural quantum state (NQS) ansatz based on an invertible neural network (INN) trained within a time-dependent variational principle (TDVP) framework, offering a versatile approach for modelling the phase space dynamics of a broad class of continuous-variable systems. Leveraging the inherent invertibility of INNs, our model provides a robust architecture that can serve not only as a Monte Carlo sampler but also enable direct access to probability distributions over time through latent space dynamics.

Q 63.69 Thu 17:00 Tent

Correlations in non Markovian Open Quantum System Dynamics — •Isabelle McEntee, Adrian Romer, and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

Open quantum systems are complex and not easily described. To simulate these dynamics with an equation of motion, we must make many assumptions, in particular weak system bath coupling and Markovianity. This work focuses on two methods that do not make these assumptions and allow for the simulation of correlations that occur in non Markovian dynamics. The first is called the Surrogate Hamiltonian method (Baer & Kosloff, 1997, The Journal of Chemical Physics), here the number of bath modes that interact with our system is limited to create a smaller, finite surrogate bath. This method treats correlations through different configurations of bath excitations. The second method (Chin et al., 2010, Journal of Mathematical Physics), involves mapping system and bath onto a semi-infinite chain which is evaluated using the Density Matrix Renormalization Group (DMRG) technique. This technique allows for correlations to be treated through tensor decomposition. Both methods truncate the bath and thus the system-bath correlations. We study and compare how correlations are built in these two approaches.

Q 64: Poster – Precision Spectroscopy of Atoms and Ions (joint session A/Q)

Time: Thursday 17:00–19:00 Location: Tent

Q 64.1 Thu 17:00 Tent

Highly Charged Heavy Ions for Quantum Logic Spectroscopy and Novel Optical Clocks — •Lukas Kau[1,2,3], Nadine Homburg[1,2,3], Zoran Andelkovic[1], Thomas Stöhlker[1,2,3], and Peter Micke[1,2,3] — [1]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt — [2]Helmholtz Institute Jena — [3]Friedrich Schiller University Jena

Heavy, highly charged ions (HCI), such as hydrogen- or lithium-like ions, possess unique properties that make them ideal for probing the fundamental laws of physics. These simple atomic systems offer forbidden optical transitions in their hyperfine structure and extreme electromagnetic fields to which their bound electrons are exposed.

We are developing a versatile platform for quantum logic spectroscopy of heavy HCI (e.g. $^{207}Pb^{81+}$ with a clock transition at 1020 nm). To achieve this, we are leveraging on recent advancements in precision spectroscopy [1] and clock operation [2] with medium-light HCI of intermediate charge state ($^{40}Ar^{13+}$) and the heavy-ion accelerator chain of GSI for ion production and deceleration. Quantum logic spectroscopy, carried out in a cryogenic Paul trap, has the potential to improve the accuracy of optical hyperfine-structure transitions by many orders of magnitude to enable unprecedented tests of fundamental physics.

[1] P. Micke et al., *Nature* **578**, 60–65 (2020), [2] S. A. King et at. *Nature* **611**, 43–47 (2022).

Q 64.2 Thu 17:00 Tent

Development of a CW Laser System at 185 nm — •Felix Waldherr[1], Jonas Gottschalk[2], and Simon Stellmer[2] — [1]Universität Heidelberg, Germany — [2]Rheinische Friedrich-Wilhelms-Universität Bonn, Germany

Generating stable and high-power deep ultraviolet (DUV) light is a formidable challenge, where recent advancements in laser technology motivate new attempts to reach wavelengths below 200 nm. We develop a DUV laser system based on two VECSEL lasers, which are frequency converted via multiple stages of sum-frequency generation, to produce light at 185 nm. Once operational, the system will be used for spectroscopy of mercury transitions and to explore molecular oxygen transitions in the Schumann-Runge bands, with implications for fundamental physics and astrochemistry.

Q 64.3 Thu 17:00 Tent

Precise solution of Dirac equation and the calculation of the electron bound-g-factor for H_2^+ molecular ion — •Ossama Kullie[1], Hougo D. Nogueira[2], and Jean-Philippe Karr[2,3] — [1]Mathematics and Natural Sciences. University of Kassel, 34132 Kassel, Germany — [2]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, Paris, France. — [3]Université d'Évry-Val d'Essonne, Evry, France

A new generation of experiments is aiming at performing high-resolution spectroscopy of molecular hydrogen ions H_2^+ in Penning traps [2]. In these experiments the internal state of the molecule is detected via the dependence of spin-flip transition frequencies on vibrational and rotational degrees of freedom. This requires precise knowledge of these transition frequencies, which depend on the g-factor of the bound electron in the molecule. In the present work we calculate the relativistic g-factor using relativistic wave functions obtained by solving the Dirac equation for H_2^+ with high precision in the Born-Oppenheimer approximation [3,4]. Together with nonadiabatic and recoil corrections at the leading order [5] evaluated by solving the three-body Schrödinger equation [6] as well as leading radiative corrections, these results allow for very accurate predictions of the bound-electron g-factor. [1] M. R. Schenkel et. al. Nat. Phys. 20, 383 (2024). [2] E. G. Myers, PRA 98, 010101(R) (2018). [3] O. Kullie et. al. PRA 105, 052801 (2022). [4] H. D. Nogueira et. al. PRA 105, L060801 (2022). [5] J.-Ph. Karr, PRA 104, 032822 (2021). [6] V. I. Korobov, Mol. Phys. 116, 93 (2018).

Q 64.4 Thu 17:00 Tent

Towards a Monolithic Linear Paul Trap for Cryogenic Quantum Logic Clocks — •Nadine Homburg[1,2,6], Lukas Kau[1,2,6], Stepan Kokh[3], Jacob Stupp[4], Malte Werheim[5], Vera Schäfer[3], Fabian Wolf[5], Piet O. Schmidt[4,5], and Peter Micke[1,2,6] — [1]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt — [2]Helmholtz Institute Jena — [3]Max Planck Institute for Nuclear Physics, Heidelberg — [4]Leibniz University Hannover (LUH) — [5]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig — [6]Friedrich Schiller University Jena

Quantum logic spectroscopy (QLS) enables optical frequency metrology with atomic and molecular ions that are promising for novel optical clocks and tests of fundamental physics but lack optical E1 transitions for laser cooling and state detection. QLS is based on two-ion crystals, which necessitate the use of linear Paul traps. Imperfections in trap geometry due to manufacturing, assembly, or cryogenic cool-down can cause axial micromotion, which cannot be compensated for and has been identified as a leading systematic effect in a previous trap design. Addressing this limitation, we report on simulation-based studies of a new linear Paul trap, based on a monolithic design by PTB and LUH. We explore an asymmetric and symmetric drive that can be provided by a superconducting YBCO step-up resonator. Additional features of the novel design include independent DC electrodes to allow mode coupling via parametric modulation of the trapping field. These design enhancements offer significant potential for improving the accuracy of future quantum logic clocks.

Q 64.5 Thu 17:00 Tent

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.

Q 64.6 Thu 17:00 Tent

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.

Q 64.7 Thu 17:00 Tent

Spectroscopy on the 657nm and 456nm calcium clock transitions in a heat pipe — •Andreas Reuss, David Röser, Frederick Wenger, Hans Kessler, and Simon Stellmer — Physikalisches Institut, Universität Bonn

Alkaline-earth metals have become the system of choice in atomic clocks and quantum computing devices. Among these elements, calcium appeals to both the atomic physics community, owing to the availability of suitable clock transitions, as well as to the nuclear physics community, as the calcium nucleus is particularly *hard* and isotopes disperse around two nuclear shell closures.

Two clock transitions, very different in character, are available: the spin-forbidden 657-nm intercombination line and the 458-nm quadrupole transition.

We are preparing for co-located, simultaneous spectroscopy of these two transitions using a Ramsey-Bordé scheme on a beam of atoms.

For preparation, we have performed spectroscopy of these transition in a heat pipe and will report on these studies.

Q 64.8 Thu 17:00 Tent

Excited-state magnetic properties of carbon-like calcium — •Shuying Chen[1], Lukas J. Spiess[1], Alexander Wilzewski[1], Malte Wehrheim[1], Jan Gilles[1,2], Andrey Surzhykov[1,2], Erik Benkler[1], Melina Filzinger[1], Martin Steinel[1], Nils Huntemann[1], Charles Cheung[3], Sergey G. Porsev[3], Andrey I. Bondarev[4,5], Marianna S. Safronova[3], José R. Crespo López-Urrutia[6], and Piet O. Schmidt[1,7] — [1]Physikalisch-Technische Bundesanstalt, Germany — [2]Technische Universität Braunschweig, Germany — [3]University of Delaware, USA — [4]Helmholtz-Institut Jena, Germany — [5]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany — [6]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [7]Leibniz Universität Hannover, Germany

Highly charged ions (HCI) are good probes for fundamental physics and the construction of high-precision optical clocks. The low number of electrons allows for possible precise theoretical calculations, which can be compared to accurate measurements. Magnetic properties, including the linear Zeeman shift, characterized by the g-factor, and the second order Zeeman shift, characterized by the C2 coefficient, are such feature. In this contribution, we demonstrate an excited-state g-factor measurement of Ca^{14+} via the estimation of the magnetic field using a co-trapped Be^{+} ion and compare the result to theoretical calculations, finding excellent agreement. Furthermore, we measured the C2 coefficient and verified the predicted small second-order Zeeman shift in HCI. The technique presented here can be extended to other HCIs.

Q 64.9 Thu 17:00 Tent

Addressed excitation and coherent manipulation of Rydberg states in a linear ion string — •Robin Thomm, Harry Parke, Natalia Kuk, Marion Mallweger, Vinay Shankar, Ivo Straka, and Markus Hennrich — Department of Physics, Stockholm University, Sweden

Rydberg excitation of trapped ions is a novel and promising approach for quantum sensing, simulation, and computation. Building on our previous demonstrations of coherent single-ion Rydberg excitation (Higgins *et al.* PRL 119, 220501 (2017)), zero-polarizability states (Pokorny *et al.* arXiv:2005.12422 (2020)) and a two-qubit gate (Zhang *et al.* Nature 580, 345-349 (2020)), we report recent progress toward integrating these achievements for addressed Rydberg excitation in linear ion strings. Key advancements include electromagnetically induced transparency (EIT) cooling of $^{88}Sr^{+}$ ions, the implementation and characterization of single-ion addressing for the two-photon Rydberg excitation lasers, and the dressing of different Rydberg states via microwave radiation. Additionally, I will present first experimental results on coherent manipulation of Rydberg states with microwaves and the realization of a two-qubit gate in a linear ion string.

Q 64.10 Thu 17:00 Tent

A cyclotron detector for (anti-)protons in a cryogenic Penning trap — •Yannick Priewich[1], Jan Schaper[1], Nikita Poljakov[1], Julia Coenders[1], Juan Manuel Cornejo[1], Stefan Ulmer[3,4], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN, Japan — [4]Heinrich-Heine-Universität, Düsseldorf, Germany

As part of the BASE collaboration, the BASE Hannover experiment aims to contribute to CPT symmetry tests [1-3] by using quantum logic techniques for g-factor measurements of (anti-)protons with $^{9}Be^{+}$ as cooling and logic ion [4]. Towards this, temperature control and transport of $^{9}Be^{+}$ ions have been extensively studied in a cryogenic Penning trap [5,6]. In our next measurement run, we aim to study the coupling of a single proton and a single $^{9}Be^{+}$ ion in a double-well potential in a designated so-called “micro-coupling trap” [4].

In this contribution, we will show the design and development of a cryogenic resonator and low-noise amplifier circuit for detection and cooling of the cyclotron motion of (anti-)protons in a Penning trap as well as upgrades to our Penning trap stack.

[1] G. Schneider et al., Science 358, 1081 (2017) [2] C. Smorra et al., Nature 550, 371 (2017) [3] M.J. Borchert et al., Nature 601, 53 (2022) [4] J. M. Cornejo et al., New J. Phys. 23, 073045 (2023) [5] J. M. Cornejo et al., Phys. Rev. Research 6, 033233 (2024) [6] T. Meiners et al., Eur. Phys. J. Plus 139, 262 (2024)

Q 64.11 Thu 17:00 Tent

Spectroscopy of Titanium and Molecular Ions — •Maximilian J. Zawierucha[1,2], Till Rehmert[1,2], Piet O. Schmidt[1,2], and Fabian Wolf[1] — [1]Physikalisch-Technische Bundesanstalt — [2]Leibniz Universität Hannover

Extending quantum control to increasingly complex systems is crucial for advancing quantum technologies and fundamental physics. Molecules for example offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well suited for the study of fundamental physics. However, the additional degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, state preparation and detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy. In addition to the single molecular ion, one well-controllable atomic ion is co-trapped, coupling strongly to the molecule via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection. Using a far detuned Raman laser and Ca^{+} as a logic ion, we have implemented a quantum logic scheme for coherent manipulation of Zeeman states in the a^4F ground state of titanium ions. With this we are able to determine the ion's finestructure state, prepare a Zeeman edge-state and precisely measure the g-factors of titanium. The developed techniques are applicable to a wide range of complex ionic systems and are currently being transferred to enable control over MgH^{+} molecular ions.

Q 64.12 Thu 17:00 Tent

Precision X-Ray Spectroscopy of Kα transitions in He-like Uranium using Metallic Magnetic Calorimeter Detectors — •Daniel A. Müller[1,3], Philip Pfäfflein[1,2,3], Marc O. Herdrich[1,3], Felix M. Kröger[1,2,3], Michael Lestinsky[2], Daniel Hengstler[4], Andreas Fleischmann[4], Christian Enss[4], Günter Weber[2,3], and Thomas Stöhlker[1,2,3] — [1]HI-Jena, Jena — [2]GSI, Darmstadt — [3]FSU, Jena — [4]KIP, Heidelberg

He-like ions, as the simplest atomic multibody system, provide a unique testing ground for the interplay of the effects of electron-electron correlations and quantum electrodynamics (QED) in various field strengths. Especially heavy highly charged ions are ideal for probing higher order QED terms, where experiments with ions at nuclear charge states $Z > 54$ currently are not available. An X-ray spectroscopy study of He-like uranium ions has been performed at the electron cooler of the storage ring CRYRING@ESR at GSI Darmstadt, using detectors of the maXs series, developed within the SPARC collaboration. Those detectors are a powerful tool for spectroscopy, measuring photons of a few keV to over 100 keV allowing the simultaneous investigation of Balmer-like and Kα transitions. The application of detectors in forward and backward direction furthermore enabled the determination of the Doppler shift. The achieved spectral resolution of better than 90 eV at X-ray energies close to 100 keV reveals the substructure of the Kα1 and Kα2 lines for the first time. This breakthrough paving the way for future tests of bound-state QED and many-body effects in extreme field strengths is presented in the poster.

Q 64.13 Thu 17:00 Tent

Construction and characterization of an atomic gas jet — •anant agarwal, lennart guth, jan-hendrik oelmann, tobias heldt, lukas matt, josé r. crespo lópez-urrutia, and thomas pfeifer — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Spectroscopy of the narrow band transitions of highly charged ions (HCI) which lie in the extreme-ultraviolet (XUV) regime offers opportunities for next generation atomic clocks and precision studies of fundamental constants. To enable these studies, we developed an XUV frequency comb using cavity-enhanced high-harmonic generation, driven by a 100 MHz near-infrared frequency comb [1]. We plan to perform two-photon spectroscopy of neutral argon atoms prior to probing the HCI transitions with our XUV frequency comb in order to characterize the properties of the comb. Our two-photon spectroscopy scheme uses one comb tooth of the 13th harmonic to excite a Rydberg state and a CW NIR laser to further ionize the argon. The freed electrons are subsequently measured using a velocity-map imaging setup. We will discuss the construction and characterization of an atomic gas jet, which plays a crucial role in the setup by enabling Doppler-free delivery of argon atoms, and present first results towards the argon excitation.

[1] Opt. Express 29, 2624-2636 (2021)

Q 64.14 Thu 17:00 Tent

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.

Q 64.15 Thu 17:00 Tent

Detection of Ultra-light Dark Matter with a Network of Cavities — •Luis Hellmich[1,2], Cigdem Issever[1,2], Ullrich Schwanke[2], and Steven Worm[1,2] — [1]DESY Zeuthen, Zeuthen, Deutschland — [2]Humboldt-Universität zu Berlin, Berlin, Deutschland

The measurement of the temporal variation of fundamental constants would be strong evidence for new physics. In particular, many different theories predict the variation of the fine-structure constant α and proton-to-electron mass ratio μ. Optical atomic clocks and cavities are high precision measurement devices, which are sensitive to variations of the fundamental constants. In this work, we are investigating the sensitivity of a network of cavities to variations of fundamental constants induced by ultra-light dark matter (ULDM). ULDM is expected to oscillate coherently on macroscopic length scales. We are exploring the possibility to detect such oscillations with a network of spatially separated cavities. The proposed setup could detect frequencies in the sub-Hz regime, making it possible to constrain dark matter masses m $> 10^{-14}$ eV. We present projected limits on the scalar coupling to Standard Model particles for a few benchmark scenarios and compare them to existing constraints from equivalence principle tests.

Q 64.16 Thu 17:00 Tent

Digital Pulse Shape Analysis for Metallic-Magnetic Calorimeters (MMC) — •Johanna H. Walch[1,2], Marc O. Herdrich[1,2,3], Philip Pfäfflein[1,3], Günter Weber[1,3], Daniel A. Müller[1,2], Daniel Hengstler[4], Andreas Fleischmann[4], Christian Enss[4], and Thomas Stöhlker[1,2,3] — [1]HI-Jena, Jena — [2]FSU, Jena — [3]GSI, Darmstadt — [4]KIP, Heidelberg

In the recent years, cryogenic MMCs have emerged as excellent single photon detectors, exhibiting a broad spectral acceptance range and a high energy resolution of $E/\Delta E_{FWHM} \approx 6000$ [1]. Together with an adequate rise time, they represent a superb opportunity for fundamental research in atomic physics. However, the MMC absorbs a photon, generating a signal depending on its energy. The shape depends on the intrinsic detector response, noise and artefacts. To optimise performance, relevant pulse features must be extracted while suppressing noise. Several techniques involving finite impulse response (FIR) filters have been explored. Additional correction techniques are needed to mitigate the effects of integrated non-linearity and temperature drift of analog-to-digital converters gain. Finally, the drift in sensor sensitivity due to temperature fluctuations of the substrate must be considered. This work presents an overview of the involved steps and compares several FIR filter-based techniques. Two filters of particular interest for MMCs are the moving window deconvolution algorithm (Herdrich [2]) and the optimal filter (Fleischmann [3]). [1] J. Geist. PhD thesis, 2020; [2] M. O. Herdrich. PhD thesis, 2023; [3] A. Fleischmann. PhD thesis, 2003

Q 64.17 Thu 17:00 Tent

Recent advances at the AntiMatter-On-a-Chip (AMOC) project — •Vladimir Mikhailovskii[1], Natalija Sheth[1], Yuzhe Zhang[1], Hendrik Bekker[1], Günther Werth[2], Guofeng Qu[3], Zhiheng Xue[4], K. T Satyajith[5], Qian Yu[6], Neha Yadav[6], Hartmut Häffner[6], Ferdinand Schmidt-Kaler[7], and Dmitry Budker[1,2,6] — [1]Helmholtz-Institut Mainz, GSI Helmholtzzentrum fur Schwerionenforschung, Mainz, Germany — [2]Johannes Gutenberg-Universitat, Mainz, Germany — [3]Institute of Nuclear Science and Technology, Sichuan University, Chengdu, China — [4]University of Science and Technology of China, Hefei, China — [5]Nitte, Mangalore, India — [6]Department of Physics, University of California, Berkeley, USA — [7]QUANTUM, Institute für Physik, Johannes Gutenberg-Universitat, Mainz, Germany

AMOC aims at production of antihydrogen by confining positrons and antiprotons in the same radiofrequency (RF) trap [1]. The general project workflow includes development of a RF trap for cotrapping e^+ and p^-, and their sources. The current stage is focused on testing the dual-frequency RF trap with e^- and Ca^+ ions, and development of low energy e^+ source. The RF trap used is a linear one made of 3 printed boards [2] and is capable of trapping e^- and Ca^+. For low energy e^+ production, we plan to use a Na-22 source with moderator and a buffer gas trap. In this report, we give an overview of the project, main experimental and simulation results, and discuss future steps.

1. N. Leefer, et al. Hyperfine Interact 238, 12 (2017)
2. C. Matthiesen et al, Phys. Rev. X; 11, 011019 (2021)

Q 64.18 Thu 17:00 Tent

Artificial clock transitions with trapped $^{40}Ca^+$ ions. — •Kai Dietze[1,2], Lennart Pelzer[1,2], Ludwig Krinner[1,2], Fabian Dawel[1,2], Johannes Kramer[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30157 Hannover, Germany

State-of-the-art optical atomic clocks based on trapped ions achieve unprecedented precision but often require long averaging times to reduce the statistical uncertainty, compared to neutral atom clocks. The measurement uncertainty is usually limited by the quantum projection noise. It can be reduced by either extended probe times with the clock laser and/or simultaneous probing of multiple ions. By employing interrogation schemes that create a decoherence free subspace (DFS) against frequency shifts on the clock transitions, the effects of external noise and transition broadening, common in multi-ion systems, can be mitigated. We demonstrate a continuous dynamical decoupling sequence engineering a the clock transition in $^{40}Ca^+$ to be insensitive against magnetic field noise and the quadrupole shift, making the simultaneous probing of multiple ions feasible [1]. Additionally, we present our experimental results of a frequency reference based on two entangled ions within a DFS, achieving near-lifetime-limited interrogation times and surpassing the sensitivity limits of uncorrelated measurement protocols.

[1] L. Pelzer *et al.*, PRL 133, 033203 (2024)

Q 64.19 Thu 17:00 Tent

Probing physics beyond the standard model using ultracold mercury — •Thorsten Groh, Sascha Heider, and Simon Stellmer — Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn

Mercury, being one of the heaviest laser-coolable elements, is an ideal platform for beyond standard model physics like baryon asymmetry searches [1]. Additionally excellent for isotope shift spectroscopy [2, 3] it possesses five naturally occuring bosonic isotopes, all of which we laser cool in our lab.

We report on deep-UV isotope shift spectroscopy of all stable bosonic mercury isotopes on multiple transitions, where we observe strong deviations from linearity. Furthermore, we report on recent improvements and upgrades to the machine for transferring magneto-optically trapped mercury atoms to a high power optical dipole trap giving an outlook to beyond state-of-the-art measurements of the atomic electric dipole moment of mercury.

[1] Graner PRL 116,161601 (2016)
[2] Delaunay, PRD 96, 093001 (2017)
[3] Berengut, PRL 120, 091801 (2018)

Q 64.20 Thu 17:00 Tent

Trapping and sympathetic cooling of Thorium ions with Calcium — •Valerii Andriushkov[1,2], Yumiao Wang[3,4], Nutan Kumari Sah[3], Florian Zacherl[3], Ke Zhang[3], Keerthan Subramanian[3], Srinivasa Pradeep Arasada[3], Jonas Stricker[1,2,3], Dennis Renisch[1,2,3], Lars von der Wense[3], Christoph E. Düllmann[1,2,3], Ferdinand Schmidt-Kaler[3], and Dmitry Budker[1,2,3,5] — [1]Helmholtz Institute Mainz, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [3]Johannes Gutenberg Universität Mainz — [4]Fudan University, Shanghai, China — [5]Department of Physics, University of California, Berkeley, USA

The TACTICa [1] (Trapping and Cooling of Thorium Ions via Calcium) experiment aims to use ion trapping techniques for precision isotope shift measurements and to explore the nuclear structure of Th. In addition, ^{229}Th ions can also be used as a platform for direct laser spectroscopy of its first nuclear excited state and the development of a nuclear optical clock. This work is conducted in collaboration with the NuQuant project, which recently partnered with TACTICa. Since direct laser cooling of Th ions in a Paul trap is inefficient, sympathetic cooling using calcium ions is employed. Our goal is to implement quantum logic spectroscopy on the Th^{+}-Ca^{+}, enabling high-precision spectroscopy of Th transition. This work is supported by the DFG Project 'TACTICa' (grant agreement no. 495729045) and the BMBF Quantum Futur II Grant Project 'NuQuant' (FKZ 13N16295A).

[1] K. Groot-Berning et al., Phys. Rev. A 99, 023420 (2019)

Q 64.21 Thu 17:00 Tent

JAC – A toolbox for (just) atomic computations — •Stephan Fritzsche — Helmholtz-Institut Jena, Germany — Friedrich-Schiller University Jena

Electronic structure calculations of atoms and ions have a long tradition in physics with applications from basic research to precision spectroscopy, and up to the realm of astrophysics. With the Jena Atomic Calculator (JAC), I here present a modern (relativistic) atomic structure code for the computation of atomic amplitudes, properties as well as a large number of excitation and decay processes. JAC [1,2] is based on Julia and provides an easy-to-use but powerful platform to extent atomic theory towards new applications. The toolbox is suitable for (most) open-shell atoms and ions across the periodic table of elements.

[1] S. Fritzsche. A fresh computational approach to atomic structures, processes and cascades. Comp. Phys. Commun., 240, 1 (2019), DOI:10.1016/j.cpc.2019.01.012. [2] S. Fritzsche. JAC: User Guide, Compendium & Theoretical Background. https://github.com/OpenJAC/JAC.jl, unpublished (02.11.2024).

Q 65: Poster – Cold Molecules (joint session MO/Q)

Time: Thursday 17:00–19:00 Location: Tent

Q 65.1 Thu 17:00 Tent

Delta-Kick Collimation of Heteronuclear Feshbach Molecules — •Timothé Estrampes[1,2], Jose P. D'Incao[3,4], Jason R. Williams[5], Éric Charron[2], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Institut für Quantenoptik, Germany — [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France — [3]JILA, NIST, and the Department of Physics,University of Colorado, Boulder, CO 80309, USA — [4]Department of Physics, University of Massachusetts Boston, Boston, MA 02125, USA — [5]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

Delta-Kick Collimation [Phys. Rev. Lett. 78, 2088 (1997)] is a well-known process in atomic physics that allows to drastically reduce the expansion energy of a cold sample by flashing an external potential during its release. Here, we theoretically explore the extension of this process to cold heteronuclear Feshbach molecules.

We first investigate the validity of neglecting the coupling between the center-of-mass motion and molecular vibrations. After establishing the domain of validity for this approximation, we use scaling approaches to estimate the achievable gains over a large range of temperature and density regimes. For typical external trap paramaters, the expansion energy of a thermal cloud could be reduced by a factor of 100, increasing to over 500 for a heteronuclear condensed molecule.

Q 65.2 Thu 17:00 Tent

Photoassociation Spectroscopy of RbYb near the Yb intercombination line — •Céline Castor, Christian Sillus, Arne Kallweit, and Axel Görlitz — Uni Düsseldorf

Ultracold dipolar molecules constitute a promising system for the investigation of topics like ultracold chemistry, novel interactions in quantum gases, precision measurements and quantum information. Here we report on first experiments in our apparatus for the production of ultracold RbYb molecules. This setup constitutes an improvement of our old apparatus, where the interactions in RbYb and possible routes to molecule production have already been studied extensively. In the new setup a major goal is the efficient production of ground state RbYb molecules. We employ optical tweezers to transport individually cooled samples of Rb and Yb from their separate production chambers to a dedicated science chamber. Here we start to study interspecies interactions of different isotopes by overlapping crossed optical dipole traps. To explore the pathways towards ground state molecules we start with photoassociation spectroscopy near the intercombination line of Yb.

Q 65.3 Thu 17:00 Tent

Casimir-Polder Force in a Nonlinear Medium — •Nicolas Schüler, Omar Jesús Franca Santiago, and Stefan Yoshi Buhmann — Institut für Physik, Universität Kassel

The discovery of the Casimir effect in 1948 [1] has, among others, created a new research field involving vacuum forces and fluctuations. The Casimir effect gives rise to the attractive Casimir force [2] between two neutral polarizable bodies in vacuum as well as to the Casimir-Polder force between a particle and a polarizable macroscopic body. In our work, we theoretically investigate the latter for a chiral molecule with three crossed electric dipole transitions. In order for these purely electric contributions to give rise to a chiral force, we consider the interaction with a chiral nonlinear medium. Using macroscopic quantum electrodynamics [3,4], we analytically calculate the resulting energy correction in third order perturbation theory as well as the Casimir-Polder force between an atom in its ground state and the field.

[1] Casimir, H. B. G.: On the attraction between two perfectly conducting plates, Proc. K. Ned. Akad. Wet. 51, 793 (1948)

[2] Casimir, H. B. G., Polder, D.: The influence of Retardation on the London-van der Waals Forces, Phys. Rev. 73, 4 (1948)

[3] Buhmann, S. Y.: Dispersion Forces I. Macroscopic Quantum Electrodynamics and Ground-State Casimir, Casimir-Polder and van der Waals Forces. (Springer, Berlin Heidelberg, 2012)

[4] Lindel, F., Bennett, R., Buhmann, S. Y.: Phys. Rev. A 102, 041701(R) (2020)

Q 65.4 Thu 17:00 Tent

Technology for spatially resolved spectroscopy of Rydberg states in nitric oxide — •Hanna Lippmann[1], Yannick Schellander[2], Fabian Munkes[1], Alexander Trachtmann[1], Florian Anschutz[1], Ettore Eder[1], Meriem Mavlutova[1], Robert Löw[1], Patrick Schalberger[2], Norbert Fruehauf[2], Harald Kübler[1], and Tilmann Pfau[1] — [1]5th Institute of Physics, University of Stuttgart, Germany — [2]Institute for Large Area Microelectronics, University of Stuttgart, Germany

High-resolution continuous-wave (cw) laser spectroscopy of nitric oxide (NO) molecules has been performed to study and characterize the energy-level structure. Special focus is on effects of electric fields on high Rydberg states. In contrast to theory, the measurements show states with no frequency shift. The reason for this effect is most likely an inhomogeneous electric field distribution. This is caused by field attenuations near the cell walls resulting from charge carrier accumulations on these. Therefore, Rydberg states near the cell walls experience a much lower electric field than expected. To further investigate the charge carrier effects and prove the given explanation, spatially resolved measurements of the ionization currents are performed. These kinds of measurements are enabled by an electrode / transimpedance amplifier array based on thin-film technology. The focus is on the creation of current to voltage converting circuits using amorphous indium gallium zinc oxide as semiconductor. The same technology can be used to efficiently detect the ground state transition laser or uv light in general.

Q 65.5 Thu 17:00 Tent

Towards cavity-control of a molecular quantum gas — Johannes Seifert, Marian Duerbeck, Nelson Werum, Lennard Reihs, Dalila Robledo, Juan Pablo Marulanda, Gerard Meijer, and •Giacomo Valtolina — Faradayweg 4-6, 14195 Berlin

We report on a new experimental apparatus for the creation of a dipolar quantum gas of atoms and molecules inside an high-finesse optical cavity. By coupling light to matter, we want to create and control new emergent particles, so-called molecular polaritons, that can display a different chemical reactivity with respect to the original system and use them to control chemical reactions at ultracold temperatures.

Q 65.6 Thu 17:00 Tent

Towards an ultracold Fermi gas of ^{6}Li^{87}Rb molecules — •Xinyi Huang[1,2], Yunxuan Lu[1,2], Anwei Zhu[1,2], Chenhao Ni[1,2], and Xinyu Luo[1,3] — [1]Max Planck Institute of Quantum Optics — [2]Ludwig Maximilian University of Munich — [3]Munich Center for Quantum Science and Technology

We present progress on developing a new setup for producing a Fermi gas of ^{6}Li^{87}Rb. Our next-generation ultracold bialkali polar molecule apparatus features a compact vacuum design and rapid cycling time. By incorporating a short-range lithium Zeeman slower into the 2D magneto-optical traps (MOT) for two species in series, we achieve an atomic loading rate of 1×10^{10} atoms/s for ^{6}Li and 6×10^8 atoms/s for ^{87}Rb, promising an excellent starting point for the rapid production of double-degenerate lithium-rubidium atomic mixtures. Additionally, we discuss theoretical predictions and experimental proposals for stimulated Raman adiabatic passage (STIRAP) of LiRb molecules to the vibrational ground state, a critical step in preparing a deeply degenerate Fermi gas of LiRb molecules.

Q 65.7 Thu 17:00 Tent

Construction of a cryogenic buffer gas source for slow, cold molecular beams — •Nick Vogeley[1], Bernd Bauerhenne[2], Danny George[1], Simon Schöps[1], and Daqing Wang[1] — [1]Institut für angewandte Physik, Universität Bonn, Bonn, Germany — [2]Institut für Physik, Universität Kassel, Kassel, Germany

We report on the construction of a cryogenic buffer gas beam source operating with helium reservoir pressure $P_0 \approx 10$ Pa and high throughput $J \approx 20$ sccm at $T_0 = 4$ K. This opens the possibility to work with higher molecular sample densities compared to the more conventional $P_0 < 0.1$ Pa machines present. The higher density also implies more efficient thermalization at a potentially increased rate of helium-molecule cluster formation, which may be investigated separately. We simulated the performance of this design in the hydrodynamic regime with a combination of computational fluid dynamics (CFD) and direct simulation Monte-Carlo (DSMC).

Q 65.8 Thu 17:00 Tent

Collisions in a quantum gas of bosonic ^{23}Na^{39}K molecules — •Mara Meyer zum Alten Borgloh[1], Jule Heier[1], Philipp Gersema[1], Kai Konrad Voges[3], Charbel Karam[2], Olivier Dulieu[2], Leon Karpa[1], and Silke Ospelkaus[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Université Paris- Saclay, CNRS, Laboratoire Aimé Cotton — [3]Centre for Cold Matter, Blackett Laboratory, Imperial College London

We present our experiments with quantum gases of polar ^{23}Na^{39}K molecules, discussing both atom-molecule and molecule-molecule collisions. In particular, we investigate the origins of loss processes in a cloud of chemically stable molecules and share our observations of magnetically tunable resonances between NaK and K. Furthermore, we outline a method for suppressing molecular loss by using a coherent two-photon transition to create a potential barrier, which prevents the colliding molecules from reaching the short-range.

Q 65.9 Thu 17:00 Tent

Merged-beams study of HD$^+$ with ground-term C Atoms reveals intramolecular kinetic isotope effect. — •L. Berger[1], F. Grussie[1], M. Grieser[1], Á. Kálosi[2,1], D. Müll[1], O. Novotný[1], A. Znotins[1], F. Dayou[3], X. Urbain[4], and H. Kreckel[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Columbia Astrophysics Laboratory, Columbia University, New York 10027, USA — [3]Sorbonne Université, Observatoire de Paris, PSL University, CNRS, LERMA, F-92195 Meudon, France — [4]Institute of Condensed Matter and Nanosciences, Université Catholique de Louvain, Louvain-la-Neuve, B-1248 Belgium

The reaction of HD$^+$ and ground-state C atoms has been studied in a merged-beams experiment at the Cryogenic Storage Ring (CSR) of the Max Planck Institute for Nuclear Physics in Heidelberg. The CSR is cooled by a closed-cycle liquid helium unit, thus reducing the blackbody radiation field strongly compared to room-temperature experiments. HD$^+$ is stored for up to 20 s in the CSR and cools radiatively to the vibrational ground state (within 0.5 s) and rotational states with $J \leq 3$ (after 5 s). In contrast to previous studies with internally excited H_2^+ and D_2^+ reacting with C, a significant increase in the absolute rate coefficient of the reaction is observed and the production of CH$^+$ is favored over CD$^+$ across all collision energies. Our experimental results agree well with our quasiclassical trajectory calculations based on two reactive potential energy surfaces for vibrationally relaxed HD$^+$ in its lowest rotational states. [1] F. Grussie, et al. Phys. Rev. Lett. 2024, 132.243001 [2] F. Grussie, et al. Phys. Rev. A 2024, 109.062804

Q 65.10 Thu 17:00 Tent

Two Robust Methods for Extracting an Electric-Field Distribution from Microwave Depletion Spectra — •Philipp Heinrich, Florian Jung, Jindaratsamee Phrompao, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Electrically trapped polyatomic polar molecules can be employed in a wide range of experiments, such as in the study of collisions, spectroscopy, and cooling. Towards this end, precise knowledge of the distribution of electric fields inside the trap is indispensable, because it determines spectroscopic lineshapes when driving microwave transitions. Thus, determining the electric-field distribution from spectroscopy measurements should be possible. However, a direct extraction of this property is rendered difficult, as in general more than one transition is resonant with a certain microwave frequency at different points inside the trap, i.e. in different electric fields.

Here, we present two robust and generic strategies to resolve this problem, each employing a different microwave transition. Microwave depletion spectra are obtained inside an electrostatic multipole trap using cold CH_3F molecules loaded from a cryofuge source [1]. From those, the electric-field distribution in the trap is deduced and shown to be in good agreement with a simulated distribution. We discuss how the results obtained can be generalized to other types of electrostatic traps.

[1] M. Koller *et al.*, Phys. Rev. Lett. **128**, 203401 (2022).

Q 65.11 Thu 17:00 Tent

Towards p-wave superfluids of microwave-shielded fermionic NaK molecules — •Weikun Tian[1,2], Shrestha Biswas[1,2], Sebastian Eppelt[1,2], Xingyan Chen[1,2], Christine Frank[1,2], Immanuel Bloch[1,2,3], and Xinyu Luo[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 Munich, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany

Degenerate quantum gases with long-range dipolar interactions open exciting opportunities to explore exotic quantum phases and the dynamics of quantum many-body systems. Ultracold polar molecules, in particular, provide a promising platform to realize these phases, including topological dipolar p-wave superfluidity.

In this poster, we present our recent progress in achieving precise control over the dipolar interactions of NaK molecules through microwave dressing. This technique enables us to engineer the shape and symmetry of the intermolecular potential, suppress inelastic collisions, and perform evaporative cooling to reach the deeply degenerate regime. We highlight the development of a high-power, ultra-low-phase-noise microwave system that facilitates double-microwave dressing and supports our progress toward realizing a p-wave superfluid with dipolar BCS pairing. These advancements pave the way towards uncovering novel quantum phases in dipolar systems.

Q 65.12 Thu 17:00 Tent

Advancements towards Zeeman slowing and trapping of CaF — •Timo Poll, Julius Niederstucke, Sebastian Anskeit, Mariia Stepanova, Paul Kaebert, Supeng Xu, Mirco Siercke, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover

Significant advancements have recently been achieved in direct laser cooling of molecules, bringing them to temperatures near absolute zero [1,2]. Nevertheless, the number of molecules that can be trapped from molecular beams using standard laser-based techniques remains a limiting factor in experiments [3,4]. In this work, we explain our strategies to enhance the molecular yield in these experiments. We present our experimental findings on the Zeeman slower developed for directly laser-coolable molecules, as proposed by our group [5], alongside the concepts and initial experimental efforts aimed at establishing a sub-Doppler cooling magneto-optical trap [6,7].

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[1] J. F. Barry et al. 2012

[2] Y. Wu et al. 2021

[3] S. Truppe et al. 2017
[4] L. Anderegg et al. 2017
[5] M. Petzold et al. 2018
[6] S. Xu et al. 2021
[7] S. Xu et al. 2022

Q 65.13 Thu 17:00 Tent

Towards magneto-optical trapping of molecules in the deep ultraviolet — •Lajos Palanki[1], Jionghao Cai[2], Carlos Alarcon-Robledo[1], Caleb Rich[1], Wei Wei Liu[1], José Eduardo Padilla-Castillo[2], Russel Thomas[2], Gerard Meijer[2], Sidney Wright[2], and Stefan Truppe[1,2] — [1]Centre for Cold Matter, Imperial College London — [2]Fritz Haber Institute, Berlin

In recent years, ultracold molecules have become a very promising platform for quantum information processing, studying quantum many-body physics and testing new physics beyond the Standard Model of particle physics.

Similar to alkaline earth (like) atoms (Yb, Sr, Cd) aluminium monofluoride (AlF), has a strong dipole-allowed transition (near 227.5 nm) to capture and cool a large number of molecules in a MOT and narrow spin-forbidden transitions for cooling to low temperatures in the μK range. This might allow trapping laser-cooled molecules at high enough densities to study collisions between the molecules and evaporative cooling to form a degenerate gas of polar molecules.

We present a new laser system based on Vertical External Cavity Surface Emitting Lasers (VECSELs) to generate high-power DUV light for laser cooling. We demonstrate its versatility by characterising the molecular source to produce an intense beam of AlF molecules and by capturing and cooling Cd atoms in a magneto-optical trap.

Q 65.14 Thu 17:00 Tent

Deep ultraviolet laser cooling of cadmium atoms and AlF molecules — •E. Padilla[1], J. Cai[1], S. Hofsäss[1], L. Palanki[2], R. Thomas[1], S. Kray[1], B. Sartakov[1], G. Meijer[1], S. Truppe[2], and S. Wright[1] — [1]Fritz-Haber-Institut der MPG, Faradayweg 4-6, 14195 Berlin, Germany — [2]CCM, Imperial, SW7 2AZ London, UK

Aluminium monofluoride (AlF) is a promising candidate for laser cooling and trapping at high densities. The primary laser cooling transition at 227.5 nm is extremely strong, highly vibrationally diagonal, and it is feasible to slow a molecular beam from 200 m/s to rest in 10 cm.

Since deep ultraviolet laser technology remains challenging, we first tested our experimental setup with a simple atomic system. The principal singlet-singlet transition from the electronic ground state in Cd, analogous to the laser cooling transition in AlF, lies conveniently near in wavelength at 229 nm. We demonstrate chirped frequency laser slowing on this transition using a buffer gas cooled Cd atomic beam, and load these atoms into a magneto-optical trap (MOT).

To study the efficacy of laser slowing AlF, we apply the pump-probe time-of-flight velocity measurement technique presented in [1]. This method relies only on rapid optical pumping of molecules between rotational levels of the electronic ground state, and allows efficiently measuring the velocity distribution in any rotational state. Applying chirped frequency laser slowing, we are able to slow molecules from 150 m/s to below 40 m/s in three different rotational states. This is the expected capture velocity of a molecular MOT of AlF.

[1] S Hofsäss *et al* 2021 *New J. Phys.* **23** 075001

Q 65.15 Thu 17:00 Tent

Experiments with continuous sources of AlF molecules — •Priyansh Agarwal[1], Sidney Wright[1], Pulkit Kukreja[1], Eduardo Padilla[1], Maximilian Doppelbauer[1], Russell Thomas[1], Xiangyue Liu[1], Sebastian Kray[1], Jionghao Cai[2], Boris Sartakov[1], Stefan Truppe[2], and Gerard Meijer[1] — [1]Fritz Haber Institute of the Max Planck Society, Faradayweg 4-6, 14195 Berlin, Germany — [2]Imperial College London, Exhibition Rd, South Kensington, London SW7 2AZ

The AlF molecule, subject to laser cooling and trapping efforts, has the advantage that it can be efficiently produced by a thermochemical reaction. Here we present a series of experiments on continuous molecular beam sources of AlF, primarily using the reaction between alumium metal and aluminium trifluoride vapour. We compare a compact AlF molecular beam oven operating near 900 K to a pulsed, laser ablation-based supersonic molecular beam. The continuous, far-field flux from the oven begins to exceed the peak brightness from the supersonic source for the v = 0, J = 7 level, and we show that an excellent signal-to-noise ratio can be obtained for high rotational levels in pulsed laser ionisation experiments. By injecting flux from the oven output into a cryogenic buffer gas cell, we cool the internal temperature to around 30 K and reduce the most probable forward velocity from 700 m/s to 260 m/s using Neon buffer gas. Furthemore, we demonstrate a molecular dispenser source, wherein the molecules thermalise to the laboratory temperature via collisions with vacuum walls of the experiment, generating a room temperature transient molecular vapour.

Q 66: Ultracold Matter (Fermions) II (joint session Q/A)

Time: Friday 11:00–13:00 Location: HS V

Invited Talk Q 66.1 Fri 11:00 HS V

Enhancing pair tunneling in the Hubbard model by Floquet engineering — •Andrea Bergschneider — Physikalisches Institut, University of Bonn, Bonn, Germany

The Fermi-Hubbard model has been very successful in describing quantum phases that emerge from the interplay between single-particle tunneling and on-site interaction. The simulation of phenomena in solid state systems, however, often requires additional coupling terms, such as explicit pair tunneling, which is exponentially suppressed in the simple Hubbard model.

We extend our optical lattice by a superlattice to go beyond the simple Fermi-Hubbard model. By time-periodic modulation of the system, we engineer an effective Hamiltonian with sizable explicit pair tunneling [1]. In our scheme suppresses single-particle tunneling while simultaneously realizing an effectively interacting systems tunable from a regime with density-assistant tunneling to pair tunneling. These findings may bring the realization of novel quantum phases based on pairing mechanisms within reach.

[1] Klemmer et al., arXiv 2404.08482, accepted in Phys. Rev. Lett.

Q 66.2 Fri 11:30 HS V

Using ultracold Fermi gases to theoretically probe atomic scattering properties — •Nikolai Kaschewski[1], Axel Pelster[1], and Carlos A. R. Sá de Melo[2] — [1]Department of Physics and Research Center OPTIMAS RPTU Kaiserslautern-Landau, Germany — [2]School of Physics, Georgia Institute of Technology, Atlanta, USA

In cold atomic gases microscopic details of interactions are thought to be irrelevant as the interaction range is much smaller than typical inter-particle spacings. Thus, in a degenerate quantum gas of neutral atoms interactions are modelled as contact interaction potentials ignoring properties besides scattering lengths. In other fields, for instance in nuclear physics, the shape of the interaction potential is believed to play a larger role due to high densities [1]. So far no methods currently exist to directly probe interatomic interactions as in nuclear physics.

Here we present a theoretical method to introduce leading-order effects of the interatomic potential shape, i.e. the effective range, by generalizing Bethe's theory of nuclear scattering [2] to ultracold atomic gases. Using a degenerate BCS-type Fermi gas at low temperature as an example we show, that the influence of the effective range for most thermodynamic properties adds a small correction to the zero-range theory. However, our qualitative investigation reveals that quantities, like correlation functions, capture the short-range behaviour of the gas and hence are sensitive to changes in the effective range parameter offering a prospect to measure the effective range.

[1] M. Jin, M. Urban and P. Schuck, Phys. Rev. C 82, 024911 (2010)
[2] H. A. Bethe, Phys. Rev. 76, 38 (1949)

Q 66.3 Fri 11:45 HS V

Nonequilibrium states in the periodically driven transverse field Ising model — •Larissa Schwarz[1], Simon B. Jäger[2], Imke Schneider[1], and Sebastian Eggert[1] — [1]Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663, Kaiserslautern, Germany — [2]Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We study the non-equilibrium dynamics of the one-dimensional transverse field Ising model under periodic driving. Using Floquet theory, we derive the steady states of the driven model for a fixed driving amplitude and identify Floquet modes that emerge from strong resonant dressing of the eigenstates of the undriven system. Studying the real time evolution and comparing it with Floquet theory, we find that the system evolves into superpositions of Floquet states, where the ramping rate of the driving amplitude influences the occupation of higher Floquet bands. We also compute the two-point correlation functions, which show oscillations in position space that can be tuned with the driving frequency. Our results highlight how periodic driving can be used to create complex non-equilibrium states.

Q 66.4 Fri 12:00 HS V

Strong correlations in a Fermi-Hubbard quantum simulator — •Dorothee Tell for the MPQ Fermi-Hubbard microscope experiment and theory-Collaboration — Max Planck Institute of Quantum Optics, Garching, Germany

In the low temperature regime of strongly-correlated materials, a variety of interesting effects can be observed, described theoretically by the Fermi Hubbard model. For example, since the discovery of cuprate high-temperature superconductors, both theoretical and experimental efforts have been made to identify this region in the phase diagram. We can explore the "pseudogap" phase at higher temperature and lower doping than the predicted superconductors, making it a precursor for their exploration.

Here we describe a quantum gas microscope with single-site and spin resolution which we use as a 2D Fermi Hubbard simulator. By preparing this system at various temperatures and doping levels we explore a parameter region where pseudogap signatures are expected to emerge. Various levels of doping the system with holes or doublons are demonstrated. Furthermore, we demonstrate precise thermometry using a comparison of experimental nearest-neighbor correlations and numeric determinant Quantum Monte Carlo simulations.

Q 66.5 Fri 12:15 HS V

Quantum gas microscopy of strongly correlated states in the pseudogap phase of the Fermi-Hubbard model — •Thomas Chalopin for the MPQ Fermi-Hubbard microscope experiment and theory-Collaboration — Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, Palaseau, France — Max Planck Institute of Quantum Optics, Garching, Germany

In correlated materials such as high-T_C cuprate superconductors, strong electron-electron interactions give rise to a rich low-temperature phase diagram which heavily depends on doping. The pseudogap phase, in particular, emerges in the underdoped region of cuprates below a temperature T^*, and is often considered to be a precursor of the superconducting state at lower temperature. Numerous theoretical and numerical studies have furthermore established the presence of a pseudogap in the Fermi-Hubbard model, a simplified model of interacting lattice fermions that captures some of the key properties of cuprates.

In this talk, I will present a systematic exploration of the Fermi-Hubbard model using a quantum gas microscope in a regime of parameters associated to the opening of a pseudogap. We measure sizable spin and charge connected correlations up to order 5 and reveal the emergence of a strongly correlated regime at low-temperature and low-doping which matches well theoretical predictions for T^*.

Q 66.6 Fri 12:30 HS V

Floquet-engineered pair transport in the Fermi Hubbard model — Friedrich Hübner[1], Christoph Dauer[2], Sebastian Eggert[2], Corinna Kollath[1], and •Ameneh Sheikhan[1] — [1]Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We investigate the transport properties of a Fermi-Hubbard chain with an impurity which is formed by a site with a periodically modulated chemical potential. We determine the transmission through this impurity in dependence of the modulation frequency and strength for a single particle and a pair of fermions. We find that the pair transmission has a very distinct behaviour from the single particle transmission. Different situations can occur, where only the single particle or the pair are transmitted or filtered out.

Q 66.7 Fri 12:45 HS V

Formation of Cavity-Polaritons via Higher-Order Van Hove Singularities — •Igor Gianardi[1], Michele Pini[2], and Francesco Piazza[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [2]Institute of Physics, Universität Augsburg, 86159 Augsburg, Germany

Polaritons are hybrid quasi-particles that blend matter and light properties. We consider their realization here through the hybridization of interband particle-hole excitations from an insulating phase with a cavity photon at sub-gap frequencies, where absorption is suppressed. The strength of the hybridization is driven by the Van Hove singularity in the joint density of states at the band gap: the stronger the singularity, the greater the photon hybridization with interband excitations. One way to enhance the Van Hove singularity strength is by reducing the system's dimensionality, such as using one-dimensional nanowires [1]. Alternatively, a promising approach involves tailoring a non-parabolic momentum dispersion of the bands around the gap to implement a higher-order Van Hove singularity (HOVHS). Building on this intuition, we propose to employ ultracold atom platforms and leverage the tunability of optical lattices to engineer two-dimensional gapped phases with non-trivial band dispersions at the gap. Our findings position ultracold atoms in cavities as an ideal platform to explore the emerging field of Van Hove polaritonics, opening a new route to quantum nonlinear optics.

[1] K. B. Arnardottir et al., Phys. Rev. B 87, 125408 (2013)

Q 67: Quantum Computing and Simulation II (joint session Q/QI)

Time: Friday 11:00–13:00 Location: AP-HS

Invited Talk Q 67.1 Fri 11:00 AP-HS

Towards Quantum Simulation with Qudits — •Martin Ringbauer — Universität Innsbruck, Institut für Experimentalphysik, Technikerstraße 25, 6020 Innsbruck

Current quantum computers and simulators are almost exclusively built for binary information processing, yet, nature rarely gives us two-level systems. This is true for our quantum information carriers, as well as for the systems we want to simulate with our quantum devices. I will discuss the opportunities and challenges of using the inherent multilevel Hilbert space of trapped ions for quantum computing information processing. This will be exemplified by recent experimental results for qudit-enhanced QIP, as well as native qudit quantum simulations.

Q 67.2 Fri 11:30 AP-HS

Tuning the qubit-qubit interaction for multi-qubit quantum gates — •Patrick H. Huber, Dorna Niroomand, Markus Nünnerich, Patrick Barthel, and Christof Wunderlich — Walter-Flex-Straße 3, 57072 Siegen

Internal hyperfine states of ions trapped in a common potential provide long-lived qubits that can be coupled via the ions' Coulomb interaction. A set of such qubits, analogous to a classical register, can be referred to as a quantum register. The Magnetic Gradient Induced Coupling (MAGIC) approach to quantum computing with trapped ions can provide an always-on, all-to-all Ising-type interaction between radio frequency-controlled qubits in such a quantum register [1,2]. The interaction strength is determined by the trapping potential and the applied magnetic field gradient. Here we present a novel method that allows for the tuning of the qubits' interaction without changing the trapping potential nor the magnetic field while simultaneously preserving the qubits' coherence. This method uses pulsed dynamical decoupling and is demonstrated experimentally in a quantum register of four laser-cooled $^{171}Yb^+$ qubits. It is used to synthesize an arbitrary coupling matrix within a quantum register and to generate non-interacting subregisters. Thus, this method opens up novel ways for efficiently synthesizing quantum algorithms on a trapped ion quantum computer. [1] A. Khromova *et al.*, Phys. Rev. Lett. 108, 220502 (2012). [2] P. Baßler *et al.*, Quantum 7, 984 (2023).

Q 67.3 Fri 11:45 AP-HS

Fast radio frequency-driven entangling gates for trapped ions — •Markus Nünnerich, Patrick Huber, Dorna Niroomand, and Christof Wunderlich — Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Gemany

Entangling gates are a fundamental component of any quantum processor, ideally operating at high speeds in a robust and scalable manner. Here, we experimentally investigate a novel radio frequency (RF)-driven two-qubit gate with trapped and laser cooled $^{171}Yb^+$ ions exposed to a static magnetic gradient field of 19 T/m that induces an effective qubit-qubit interaction (Magnetic Gradient Induced Coupling, MAGIC). The hyperfine states $|0\rangle \equiv |^2S_{1/2}, F=0, m_F=0\rangle$ and $|1\rangle \equiv |^2S_{1/2}, F=1, m_F=-1\rangle$ are used as qubits. We generate Bell states by applying continuously two RF driving fields, each one of them on resonance to one of the two qubit transitions. The phase of these driving fields is varied periodically yielding effectively a sequence of back-to back dynamical decoupling pulses. By adjusting the Rabi frequency induced by the driving fields, the effective coupling of the qubits to the ions' motional state is changed, and the entangling gate speed can be varied between ≈ 4 ms and $\approx 300\mu$s. Higher gate speeds are advantageous for achieving faster and deeper quantum algorithms. In currently used micro-structured traps with larger magnetic field gradients, gate speeds on par with laser-driven gates in trapped ions are expected.

Q 67.4 Fri 12:00 AP-HS

Coherent control of trapped-ion qubits and qumodes via phase-stable optical addressing — •Kai Shinbrough[1], Donovan J. Webb[1], Iver R. Øvergaard[1], Oana Băzăvan[1], Sebastian Saner[1], Gabriel Araneda[1], Raghavendra Srinivas[1,2], and Christopher J. Ballance[1,2] — [1]University of Oxford, Oxford, UK — [2]Oxford Ionics, Oxford, UK

Control over the phase of optical addressing beams in the trapped-ion platform allows for precise control of the coupling between spin and motional states of the ion. This control serves as a resource for fast, high-fidelity multi-qubit entangling gates, as well as for continuous variable quantum information processing using the motional state qumodes of single ions and ion chains. Here we report on a suite of qubit-qubit, qubit-qumode, and qumode-qumode interactions enabled by this phase control, including two-qubit gates faster than the speed limit imposed by off-resonant carrier coupling [1], non-Gaussian operations performed on the ion motional state [2,3] (which, along with a complete set of Gaussian operations, satisfy the Lloyd-Braunstein criterion for universal quantum computation [4]), and progress toward a linear chain of $^{40}Ca^+$ ions with individually addressed standing waves.

[1] S. Saner, O. Băzăvan, *et al.*, Phys. Rev. Lett. **131**, 220601 (2023).
[2] O. Băzăvan, S. Saner, *et al.*, arXiv:2403.05471 (2024).
[3] S. Saner, O. Băzăvan, *et al.*, arXiv:2409.03482 (2024).
[4] S. Lloyd, S. L. Braunstein, Phys. Rev. Lett. **82**, 1784 (1999).

Q 67.5 Fri 12:15 AP-HS

Integrated micromagnets for trapped ion quantum science — •Benjamin Bürger, Patrick Huber, and Christof Wunderlich — Universität Siegen, Walter-Flex-Straße 3, 57072 Siegen

We present the design and implementation of quasi-two-dimensional (2D) micromagnets tailored to generate an inhomogeneous static magnetic field. This field, when integegrated into a micro-structured ion trap, enables frequency-selective addressing of ions through radio frequency radiation (RF) and conditional quantum dynamics with trapped ions. We will integrate the magnet design into a planar Paul trap that is split into two types of regions: An interaction zone and a cooling/readout zone. The micromagnets are meticulously designed to produce high field gradients while maintaining a low absolute field strength, effectively minimizing decoherence induced by magnetic field noise within the qubit interaction zones. In the cooling/readout zones, the magnets are designed to generate a small homogeneous magnetic field to facilitate efficient Doppler cooling on larger strings. Furthermore, the magnetic field orientation is optimized to support both σ and π polarized RF-driven transitions in $^{171}Yb^+$ ions facilitating efficient cooling on the magnetic-field-insensitive π transition and utilizing the σ transition for gate operations.

Q 67.6 Fri 12:30 AP-HS

Towards a cryogenic trapped ion quantum demonstrator using cryogenic control electronics — •Dorna Niroomand[1], Daniel Busch[1], Kais Rejaibi[1], Ernst A Hackler[1], Rodolfo M Rodriguez[1], Patrick Huber[1], Garima Saraswat[2], Michael Johanning[2], and Christof Wunderlich[1] — [1]Department of Physics, School of Science and Technology University of Siegen, 57068 Siegen, Gemany — [2]eleQtron, 57072 Siegen, Germany

Trapped ion quantum computing platforms in cryogenic vacuum have the advantage of rapidly achieving ultra-high vacuum. This allows long ion storage times even in the relatively shallow trapping potential of surface-electrode Paul traps. In addition, it offers more flexibility in exchanging trap chips, making it feasible to study multiple generations of traps with different structure and experimental specifications. Here, I will discuss the progress towards building and operating a cryogenic (4 K) quantum demonstrator that includes low-noise cryogenic electronics to precisely control trapping potentials and enable shuttling of ions (BMBF-funded project ATIQ). En route towards scalable trapped ion quantum processors, multiple generations of microfabricated surface-electrode traps with integrated magnets and cryogenic control electronics will be investigated in this platform.

Q 67.7 Fri 12:45 AP-HS

Cooling a quantum annealer with a quantum field — •Raphael Menu and Giovanna Morigi — Universität des Saarlandes, Saarbrücken

We analyse the Landau-Zener dynamics of a qubit, which is simultaneously coupled to a dissipative auxiliary system. By tuning the coupling, the qubit dynamics ranges from a dephasing master equation to a strongly coupled qubit-auxiliary system, which is effectively a non-Markovian reservoir for the qubit. We determine the quantum trajectories in the different regimes and analyse the distribution of each trajectory in terms of the time-dependent probability of a diabatic transition. Depending on the strength of the coupling, we observe multipeaked configurations, which undergo transitions to narrow distributions. These transitions are signaled by a higher probability that a jump occurs. The behavior of the probability of a quantum jump as a function of the coupling and of the time of the sweep, in turn, allows us to shed light on the stages of the dynamics when the environment is detrimental and when instead it corrects diabatic transition. It shows, in particular, that memory effects can be beneficial in cooling a quantum system.

Q 68: Quantum Technologies (Color Centers and Ion Traps) II (joint session Q/QI)

Time: Friday 11:00–13:00 Location: HS Botanik

Invited Talk Q 68.1 Fri 11:00 HS Botanik

Multi-color excitation of quantum emitters — •Thomas Bracht — TU Dortmund, 44227 Dortmund, Germany

On-demand photon generation is essential for reliable quantum communication. Solid state quantum emitters have emerged as a promising platform, offering excellent photon properties and controllability.

In this talk, I introduce the Swing-UP of quantum EmitteR (SUPER) scheme, which enables excitation of a quantum emitter using two pulses of different colors, allowing for completely off-resonant, red-detuned excitation. This novel multi-color approach is advantageous as spectral filtering can be used to suppress the excitation laser, boosting the total photon yield. In a completely quantized picture, it corresponds to a two-photon process [1]. After its theoretical prediction [2], the SUPER scheme has been experimentally demonstrated in quantum dots [3] and other systems.

As an outlook, I show how this technique can be used to generate highly entangled photon pairs, which are an important building block in quantum information technology.

[1] Richter et al., arXiv:2405.20095 (2024) [2] Bracht et al., PRX Quantum 2, 040354 (2021) [3] Karli et al., Nano Lett. 22, 6567 (2022)

Q 68.2 Fri 11:30 HS Botanik

Measuring MHz charge dynamics in diamond with a tin-

vacancy color center — •Charlotta Gurr[1], Cem Güney Torun[1], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Color centers in diamond are influenced by electric noise from their diamond host material [1]. Free charge carriers being trapped and released from charge traps in the diamond lattice create a fluctuating electric field environment, shifting the color center's energy levels. The optical transitions are therefore rendered unstable, to the detriment of applications that require a source of indistinguishable photons. Little is known about the nature of the charge traps. Here, we develop a technique to investigate the charge process dynamics of single charges in diamond with MHz resolution, using a tin-vacancy color center. We find charge capture and release rates spanning two orders of magnitude within Hz and kHz, possibly revealing two different effects influencing the charge processes. Furthermore, we find that 520 nm illumination of the diamond sample influences the charge release rates more strongly than more energetic 445 nm illumination. We believe this to be caused by a two-step process leading to the release of charges from charge traps. These findings expand our understanding of charge traps in diamond as well as the processes responsible for capturing and releasing single charges.

[1] Pieplow, Torun et al., *Quantum Electrometer for Time-resolved Material Science at the Atomic Lattice Scale*, arXiv:2401.14290, 2024

Q 68.3 Fri 11:45 HS Botanik

Integration of group IV color centers in nanodiamonds in a tunable Fabry-Perot microcavity — •Selene Sachero, Robert Berghaus, Florian Feuchtmayr, and Alexander Kubanek — Institute for Quantum Optics, Ulm University, 89081 Ulm, Germany

Quantum repeater are essential building block to create a large scale quantum communication network. An ideal quantum repeater nodes efficiently link a quantum memory with photons serving as flying qubits. By coupling group IV vacancy defect centers in nanodiamonds (NDs) to an open Fabry-Perot cavity, such an interface can be created. As such a platform, we propose a fully tunable cavity composed by two Bragg mirrors which allows short cavity lengths down to $\approx 1\ /mu$m, and provides efficient coupling of the quantum emitter at liquid helium temperatures.

Here, we show the good optical properties of a single group IV emitter and its transfer, via nanomanipulation, to a Fabry-Perot cavity. The coupling of the emitter into the resonator is achieved maintaining an high finesse.

Moreover, we perform PL measurement at cryogenic temperatures and observe a lifetime reduction due to the Purcell factor.

Q 68.4 Fri 12:00 HS Botanik

Entanglement by path identity based on engineered photon pairs — •Richard Bernecker[1,2], Baghdasar Baghdasaryan[3], and Stephan Fritzsche[1,2] — [1]Institute for Theoretical Physics, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Helmholtz Institute Jena, Fröbelstieg 3, 07743 Jena, Germany — [3]Institute of Applied Physics, Friedrich Schiller University Jena, Albert-Einstein-Str. 6, 07745 Jena, Germany

Entangled photon pairs are essential for applications in quantum communication and distributed quantum computing. A convenient approach for entanglement generation is to coherently superimpose photon pairs created in multiple nonlinear crystals via spontaneous parametric down-conversion (SPDC). The entanglement emerges because no information is available about which crystal created the pair, provided the propagation paths of the photon pairs are overlapped. This path identity approach was experimentally demonstrated by overlapping separable orbital angular momentum modes using three nonlinear crystals and spiral phase plates. However, the number of nonlinear crystals governs the dimensionality of the entangled state, posing challenges for generating entanglement in large Hilbert spaces. Recently, we explored the direct generation of maximally entangled states via pump and crystal shaping in SPDC. In this contribution, we combine pump shaping techniques with the path identity approach to engineer high-dimensional entangled states. A key advantage of this method is the potential for increasing the scalability of the entanglement dimensionality without requiring additional crystals in the setup.

Q 68.5 Fri 12:15 HS Botanik

Enhanced atom-photon interactions based on integrated waveguides immersed in hot atomic vapor — •Annika Belz[1], Benyamin Shnirman[1,2], Xiaoyu Cheng[1], Harald Kübler[1], Hadiseh Alaeian[3], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Institut für Mikroelektronik Stuttgart (IMS-Chips), Stuttgart, Germany — [3]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, West Lafayette, USA

The combination of thermal atomic vapor with nanophotonic structures provides a unique platform for the manipulation of atom-photon and light induced atom-atom interactions and can exhibit large optical non-linearities, even at the few photon level.

We can further enhance these non-linearities via an enlarged Purcell factor using slot waveguides. We observe saturable repulsive interactions of the atoms within the slot as an intensity dependent blue shift. In order to verify the nature of the non-linearity in more detail we incorporate an integrated Mach-Zehnder interferometer to access also the non-linear phase shift.

Q 68.6 Fri 12:30 HS Botanik

Cavity-Enhanced Spin-Photon Interface for Single Tin-Vacancy Centers in Diamond — •Andras Lauko[1], Kerim Köster[1], Julia Heupel[2], Philipp Fuchs[3], Michael Kieschnick[4], Michael Förg[5], Thomas Hümmer[5], Cyril Popov[2], Jan Meijer[4], Christoph Becher[3], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Kassel — [3]Universität des Saarlandes — [4]Universität Leipzig — [5]Qlibri GmbH

Building a long-distance quantum network is one of the big challenges in the field of quantum communication, which requires the development of a quantum repeater.

Tin-vacancy centers in diamond are a rising candidate among color centers in diamond, having higher operating temperatures than silicon-vacancy centers and less prone to phonon-coupling relative to nitrogen-vacancy centers.

In our experiment, we integrate a diamond membrane into an open access fiber-based Fabry-Perot microcavity to attain emission enhancement in a single well-collectable mode. We present our fully tunable, cryogenic cavity platform operating in a tabletop dilution cryostat, and we achieve a picometer mechanical stability. The platform also allows for integration of a superconducting DC magnet and microwave antenna for spin manipulation.

We observe cavity-enhanced fluorescence signal of single, shallow-implanted tin-vacancy centers in diamond, showing Purcell-enhancement and thus higher emission rates and reduced excited state lifetimes.

Q 68.7 Fri 12:45 HS Botanik

Optimal Control for Quantum Technology with NV-Centers in Diamond — •Matthias Müller — Peter-Grünberg-Institute of Quantum Control (PGI-8), Forschungszentrum Jülich GmbH

Diamond-based quantum technology is a fast-emerging field with both scientific and technological importance. The performance relies on unique features like superposition and entanglement and depends on sophisticated mechanisms of control to perform the desired tasks. Quantum Optimal Control (QOC) has proven to be a powerful tool to accomplish this task. I will give a brief overview on the use of QOC for NV-centers in diamond [1], the CRAB algorithm for Optimal Control [2], the optimal-control software QuOCS [3] and report on recent applications toward quantum sensing and quantum computing [4,5,6].

[1] P. Rembold et al., AVS Quantum Sci. 2, 024701 (2020) [2] M. M. Müller et al., Rep. Prog. Phys. 85 076001 (2022) [3] M. Rossignolo et al. Comp. Phys. Comm. 291, 108782 (2023) [4] N. Oshnik et al., Phys. Rev. A 106, 013107 (2022) [5] N. Grimm et al., arXiv:2409.06313 (2024) [6] P. Vetter et al., npj Quantum Information 10 (1), 96 (2024)

Q 69: Open Quantum Systems II (joint session Q/QI)

Time: Friday 11:00–13:00 Location: HS I

Q 69.1 Fri 11:00 HS I

Controlling matter phases beyond Markov — •Baptiste Debecker, John Martin, and François Damanet — University of Liège, Liège, Belgium

Controlling phase transitions in quantum systems via coupling to reservoirs has been mostly studied for idealized memory-less environments under the so-called Markov approximation. Yet, most quantum materials and experiments in the solid state, atomic, molecular and optical physics are coupled to reservoirs with finite memory times. Here, using the spectral theory of non-Markovian dissipative phase transitions developed in the companion paper [Debecker, Martin, and Damanet (to be published)], we show that memory effects can be leveraged to reshape matter phase boundaries, but also reveal the existence of dissipative phase transitions genuinely triggered by non-Markovian effects.

Q 69.2 Fri 11:15 HS I

Markovianity in Quantum Thermodynamics: Principles and Practice — •Thomas Schulte-Herbrüggen[1], Emanuel Malvetti[1], Frederik vom Ende[2], and Gunther Dirr[3] — [1]Technical University of Munich (TUM) — [2]FU Berlin — [3]University of Würzburg

We connect quantum control theory with quantum thermodynamics for open Markovian systems. We sketch a *Markovianity Filter*, i.e. how to construct the Markovian counterparts of several types of quantum Thermal Operations (via Lie semigroups). By way of example, we parameterise the Markovian subset of maps within the set of all Thermal Operations.

As an application, we give inclusions in terms of d-majorisation for reachable sets of bilinear control systems, where coherent controls are complemented by switchable couplings to a thermal bath as additional resource.

Q 69.3 Fri 11:30 HS I

The quantum harmonic oscillator in a dissipative bath of anyon pairs — •Nils-Henrik Meyer[1], Michael Thorwart[1], and Axel Pelster[2] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

We determine the quantum statistical dynamics of a quantum mechanical harmonic oscillator coupled to a heat bath constructed of 1D anyons. For that, we use the quantum mechanical path integral of anyon pairs in one dimension introduced by Grundberg and Hansson [1]. These anyons are characterized by one statistical parameter entering in the dispersion relation of the heat bath. By this, we formally obtain a heat bath of free bosons which, however, couple nonlinearly to the system. By utilizing the smearing formula of Ref. [2], we find a direct nontrivial influence of the anyons on the spectral density and therefore the dynamics of the system up to second order in a perturbative approach. We show that the relaxation properties of the system are directly determined by the anyonic statistical parameter of the bath.

[1] J. Grundberg and T. H. Hansson. Mod. Phys. Lett. A **10**, 985 (1995).
[2] H. Kleinert, W. Kürzinger, and A. Pelster. J. Phys. A **31**, 8307 (1998).

Q 69.4 Fri 11:45 HS I

Microscopic model for a nonliner dissipative dielectric medium — •Nils Berhausen, Sascha Lang, and Stefan Yoshi Buhmann — Institut für Physik, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

Through nonlinear optical effects, such as the Kerr effect, it is experimentally possible to artificially generate spacetimedependent refractive index modulations via strong electric fields. Suitable experimental setups allow for generating backgrounds which affect the field dynamics similarly to nontrivial curved spacetimes. For instance, tabletop setups with refractive index modulations can give rise to photon pair creation that can be observed by the technique of electro-optic sampling in certain nonlinear crystals. In existing theoretical works, the dynamics of nonlinear optical media is usually described in a phenomenologically motivated extension of linear macroscopic electrodynamics, which does not necessarily cover the full quantum vacuum dynamics. In this talk, I will present first results on an alternative microscopic approach for nonlinear optical media. To incorporate nonlinearities, we describe the medium with anharmonic oscillators and allow those oscillators to nonlinearly couple to the electric field. The resulting model takes into account a number of nonlinear optical effects, including second-harmonic generation.

Q 69.5 Fri 12:00 HS I

Calculating two-time correlations for dissipative, interacting spin systems with phase space methods — •Jens Hartmann and Michael Fleischhauer — RPTU Kaiserslautern, Kaiserslautern, Germany

The recently developed Truncated Wigner Approximation (TWA) for spins [1,2] is a powerful technique to simulate dissipative, interacting spin systems with a large number of spins taking into account leading-order quantum effects. However, determining two-time correlations within phase space approaches is notoriously difficult. We here developed an efficient method to numerically calculate multi-time-correlations of strongly coupled spins and demonstrate its accuracy for different benchmark problems. Furthermore of special interest is the superradiant emission from atoms coupled to a waveguide, which can be described very well with our method [3]. We compute the second order correlation function of the emitted light for different times and see a good agreement between the theoretical and experimental data for the superradiant bursts and the corresponding behavior of the correlation function.

[1,2] C. Mink et al., 10.21468/SciPostPhys.15.6.233, PhysRevResearch.4.043136
[3] F. Tebbenjohanns et al., PhysRevA.110.043713

Q 69.6 Fri 12:15 HS I

Exploring non-Markovian dynamics in microwave spin control of group-IV color centers coupled to a phononic bath — •Mohamed Belhassen[1], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

Microwave control is a well-established technique for driving the electronic spin of diamond color centers. In our earlier work [1], we demonstrated that optimizing the orientation of the static magnetic field lifting the spin degeneracy and the polarization of the microwave field driving the spin, is essential for achieving efficient control conditions in a low strain environment. Expanding on this, we now incorporate the phononic bath, which introduces decay and decoherence to the qubit's quantum state. We examine the system dynamics using both Markovian and non-Markovian master equations, revisiting the interplay between magnetic and microwave field orientations and applied strain, with a focus on their impact on the qubit decay and decoherence times. We interpret our simulation results and compare them with the most recent experimental results. Finally, we assess the validity of the Born-Markov approximation and investigate how bath memory effects impact quantum state evolution.

[1] G. Pieplow, M. Belhassen, T. Schröder, Phys. Rev. B 109, 115409

Q 69.7 Fri 12:30 HS I

Non-Markovian dynamics of giant atificial atoms at finite temperature — •Mei Yu[1], Hai Chau Nguyen[1], Walter Strunz[2], Valentin Link[2], and Stefan Nimmrichter[1] — [1]University of Siegen, Siegen, Germany — [2]Dresden University of Technology, Dresden, Germany

Superconducting qubits, when coupled to either a meandering transmission line or to surface acoustic waves, enable the creation of giant artificial atoms. These atoms interact with the waveguide through two or more spatially separated contact points, providing a tunable platform to explore non-Markovian dynamics with significant memory effects beyond the atomic lifetime. Thus far, the non-Markovian characteristics of this system have been analyzed at zero temperature and validated experimentally [1]. In this work, we examine the influence of finite temperature on the non-Markovian behavior of giant atom dynamics. Contrary to intuitive expectations, we find that thermal effects can suppress the spontaneous emission decay rate rather than enhancing it.

[1] G. Andersson, B. Suri, L. Guo, T. Aref, and P. Delsing, Non-exponential decay of a giant artificial atom, Nature Physics 15, 1123 (2019).

Q 69.8 Fri 12:45 HS I

On the foundation of quantum physics — •Hans-Otto Carmesin — Gymnasium Athenaeum, Harsefelder Straße 40, 21680 Stade — Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

Quantum physics, QP, is a mystery, described by unexplained postulates (Hilbert et al., 1928). However, evident properties of volume in nature, corresponding to space and vacuum, provide the volume dynamics, VD (Carmesin 2023, 2024) - and the VD implies the postulates of QP. Moreover, the VD provides and explains the wave function as well as the Schrödinger equation, including generalizations. Naturally, the VD provides the value of the dark energy, properties of space and of vacuum, as well as the solution of the Hubble tension.

Furthermore, the VD implies many fundamental physical results.

Literature

Hilbert, D.; Nordheim, L.; Neumann, J v. (1928): Über die Grundlagen der Quantenmechanik. Mathematische Annalen, pp. 395-407.

Carmesin, H.-O. (2023): Geometrical and Exact Unification of Spacetime, Gravity and Quanta. Berlin: Verlag Dr. Köster.

Carmesin, H.-O. (2024): How Volume Portions Form and Found Light, Gravity and Quanta. Berlin: Verlag Dr. Köster.

More info: https://www.researchgate.net/profile/Hans-Otto-Carmesin

Q 70: Nanophotonics I

Time: Friday 11:00–13:00 Location: HS I PI

Q 70.1 Fri 11:00 HS I PI

Exciton-Phonon Interactions at hBN/Perovskites Interfaces — •Sara Darbari[1,2], Masoud Taleb[1], Leon Multerer[1], Yaser Abdi[1], and Nahid Talebi[1] — [1]Institute for Experimental and Applied Physics, Christian Albrechts University in Kiel, Kiel, Germany — [2]Electrical and Computer Engineering Faculty, Tarbiat Modares University, Tehran, Iran

2D perovskites have attracted significant interests due to their optical properties, especially high exciton binding energies at the room temperature. Despite higher stability in comparison with their 3D counterparts, 2D perovskites still suffer from photo-induced degradation that can be diminished by encapsulating them with other 2D materials like hexagonal boron nitride (hBN). hBN is a widegap and stable material, which is promising for quantum technologies owing to multiple classes of phonon-assisted quantum emitting defects. Here, we have transferred hBN on top of 2D Ruddlesden-Popper perovskite (RPP) flakes ((BA)2PbI4 with n=1), and investigated the hBN/RPP heterostructure by cathodoluminescence spectroscopy. Our results prove not only significantly retarded e-beam induced degradation of RPPs, but also an enhancement in the luminescent behavior at the excitonic wavelength of RPP and phonon sidebands. Furthermore, the excitonic peak bandwidth is reduced, coincident with a slight red shift. This sharp excitonic luminescent peak of hBN/RPP is detectable, when we excite the extruded parts of hBN, even micrometers away from the RPP edge. The observed behaviors are attributed to hBN phonons coupling to perovskite excitons in their heterostructure.

Q 70.2 Fri 11:15 HS I PI

Electron Beam Shaping with Ultrafast Plasmonic Rotors — •Fatemeh Chahshouri[1] and Nahid Talebi[1,2] — [1]Institute of Experimental and Applied Physics, Kiel University, 24098 Kiel, Germany — [2]Kiel, Nano, Surface, and Interface Science KiNSIS, Kiel University, 24098 Kiel, Germany

Recent advances in coherent quantum interactions between free-electron pulses and ultrafast laser-induced near-field oscillations have unlocked exciting possibilities for manipulating the electron wavepackets. In this study, we investigate the interaction between a slow electron beam and the rotating dipolar plasmon fields of a gold nanorod. By precisely controlling the phase offset between two orthogonal laser pulses with perpendicular polarizations, we generate plasmonic fields in the nanorod circulating in clockwise or counterclockwise directions. Our findings demonstrate that the rotational direction of these plasmons plays a critical role in modulating electron dynamics in both real and reciprocal space, significantly influencing its longitudinal and transverse recoil. Additionally, by synchronizing the interaction time of the electron wavepacket with these directional plasmonic oscillations, we observe alterations in the probability amplitude of the electron angular momentum. This strong directional dependence highlights the potential of rotating plasmons as a powerful tool for shaping electron wavepackets. These findings pave the way for advancements in ultrafast electron microscopy and spectroscopy, enabling coherent control of slow electron beams and contributing to the development of quantum information processing technologies.

Q 70.3 Fri 11:30 HS I PI

A high-throughput characterisation setup for colour centres in SiC — •Jonah Heiler[1,2], Flavie D. Marquis[1,2], Leonard K.S. Zimmermann[1,2], Sushree Swateeprajnya Behera[1,2], Nien-Hsuan Lee[1,2], Stephan Kucera[1], Jonathan Körber[3], Raphael Wörnle[3], Jörg Wrachtrup[3], and Florian Kaiser[1,2] — [1]Smart Materials Unit, Luxembourg Institute of Science and Technology, Belval, Luxembourg — [2]Department of Physics and Materials Science, University of Luxembourg, Belvaux, Luxembourg — [3]3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany

Optically active spins in solids, so-called colour centres, build a promising quantum technology platform, in parts due to their inherent spin-photon interface. Silicon carbide emerged as a popular host for colour centres due to its wafer-scale availability and its developed manufacturing processes. An ongoing challenge in the field, the low efficiency of the spin-photon interface, can be overcome using nanophotonic structuring. However, this process often leads to a degradation of the optical properties since it increases the susceptibility to surface charge noise. The conventional method to investigate these effects, confocal microscopy, by design, can only investigate a single emitter at a time. We report on the development of a widefield cryogenic microscope setup that allows for an investigation of 100–1000 colour centres in silicon carbide simultaneously. In our first investigation, we investigate divacancies in nanopillars, fabricated using a combination of e-beam lithography, ion implantation, and reactive ion etching.

Q 70.4 Fri 11:45 HS I PI

Skyrmion Bag Robustness in Plasmonic Bilayer and Trilayer Moiré Superlattices — •Julian Schwab[1], Florian Mangold[1], Bettina Frank[1], Timothy J. Davis[1,2], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and Integrated Quantum Science and Technology Center, University of Stuttgart, Germany — [2]School of Physics, University of Melbourne; Parkville Victoria 3010, Australia

Twistronics is studied intensively in twisted 2D heterostructures and its extension to trilayer moiré structures has proven beneficial for the tunability of unconventional correlated states and superconductivity in twisted trilayer graphene. Just recently, the concept of twistronics has been applied to plasmonic lattices with nontrivial topology, demonstrating that bilayer moiré skyrmion lattices harbor multi-skyrmion textures called skyrmion bags. Here, we explore the properties of plasmonic trilayer moiré superlattices that are created by the interference of three twisted skyrmion lattices. More specifically, we explore the properties of periodic superlattices and their topological invariants. We also demonstrate that twisted trilayer skyrmion lattices harbor the same skyrmion bags as twisted bilayer skyrmion lattices. We quantify the robustness of these skyrmion bags by the stability of their topological numbers against certain disturbance fields that leads to experimental designs for topological textures with maximum robustness.

Q 70.5 Fri 12:00 HS I PI

On the Development a Room-Temperature Quantum Register based on Modified Divacancies in 4H-SiC in Luxembourg — •Flavie D. Marquis[1,2], Jonah Heiler[1,2], Leonard Zimmermann[1,2], Raphael Wörnle[3], Jörg Wrachtrup[3], Stephan Kucera[1], and Florian Kaiser[1,2] — [1]MRT Department, Luxembourg Institute of Science and Technology (LIST), Belvaux, Luxembourg — [2]University of Luxembourg, 4365 Esch-sur-Alzette, Luxembourg — [3]3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany

Recent studies on the nature of modified divacancies in 4H silicon carbide (notably the PL6) have shown their remarkable stability under ambient conditions as well as readout contrast and count rates comparable to the nitrogen vacancy in diamond. Next steps towards quantum applications must now address the coherent control of nuclear spin qubit registers. Here, I will present the first steps towards the implementation of a few-qubit register at room-temperature. I will introduce different measurement methods based on pulsed EPR to brush a portrait of the spin-optical properties and capabilities of the divacancy-nuclear spin system. Technical realization of electron and nuclear spin control is also discussed. With this system, we strive to demonstrate small quantum algorithms, such as Grover and Deutsch-Josza.

Q 70.6 Fri 12:15 HS I PI

Plasmonic colors made easy: how ultra-thin metal films make bright colors — •Manuel Gonçalves — Ulm University - Inst. of Experimental Physics

Several different methods of plasmonic color generation have been demonstrated: nanostructured metal surfaces, metasurfaces based on particles and gratings, arrays of nanoparticles on a mirror, laser modification of deposited thin films. These methods are usually based on percolated films, with optical properties similar to those of bulk. However, when films of gold and silver of only few nanometers of average thickness are deposited on top of a mirror, vivid colors arise. The colors are only dependent on thickness of the spacer. Moreover, it was found that quantum-mechanical effects arise in the photoluminescence of crystalline gold UTMFs and they are advantageous in hot carrier generation and in nonlinear optics. A comparison between the optical properties of crystalline and polycrystalline UTMFs is provided.

Q 70.7 Fri 12:30 HS I PI

Active Physics-Informed Deep Learning: Surrogate Modeling for Non-Planar Wavefront Excitation of Topological Nanophotonic Devices — •Fatemeh Davoodi — Institute for Experimental and Applied Physics, Kiel, Germany

Topological plasmonics provides innovative ways to manipulate light by combining principles of topology and plasmonics, akin to topological edge states in photonics. However, designing such states is challenging due to the complexity of the high-dimensional design space. In this work, we introduce a supervised, physics-informed deep learning framework combined with surrogate modeling to design topological devices for specific wavelengths. By embedding physical constraints into the neural network training process, our model efficiently navigates the design space, significantly reducing simulation time and computational cost.

Additionally, we incorporate non-planar wavefront excitations to probe topologically protected plasmonic modes, introducing nonlinearity into the design and training process. Using this approach, we successfully design a topological device featuring unidirectional edge modes in a ring resonator operating at specific frequencies. This method demonstrates the effectiveness of integrating machine learning with advanced physical modeling for photonic device innovation, achieving high accuracy while optimizing computational efficiency.

Q 70.8 Fri 12:45 HS I PI

Luminescence thermometry based on photon emitters in nanophotonic silicon waveguides — Kilian Sandholzer[1,2], Stephan Rinner[1,2], Justus Edelmann[1,2], •Nilesh Goel[1,2], and Andreas Reiserer[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

The reliable measurement and accurate control of the temperature within nanophotonic devices is a crucial prerequisite for their application in classical and quantum technologies. Established approaches use sensors attached to the components, which offer a limited spatial resolution and thus impede the measurement of local heating effects. We study an alternative temperature sensing technique based on measuring the luminescence of erbium emitters directly integrated into nanophotonic silicon waveguides. To cover the entire temperature range from 295 K to 2 K, we investigate two approaches: The thermal activation of non-radiative decay channels for temperatures above 200 K and the thermal depopulation of spin- and crystal-field levels at lower temperatures. The achieved sensitivity is 0.22(4) %/K at room temperature and increases up to 420(50) %/K at approximately 2 K. Combining this with spatially selective implantation promises precise thermometry from ambient to cryogenic temperatures with a spatial resolution down to a few nanometers.

Q 71: Quantum Control II (joint session QI/Q)

Time: Friday 11:00–13:00 Location: HS II

Q 71.1 Fri 11:00 HS II

Optimally Controlled NMR in Electrochemistry: Overcoming Challenges and Turning Them into Opportunities — •Armin J. Römer[1,2], Johannes F. Kochs[1,2], Michael Schatz[1], Matthias Streun[1], Simone S. Köcher[1,3], and Josef Granwehr[1,2] — [1]Forschungszentrum Jülich GmbH, Institute of Energy Technologies, Fundamental Electrochemistry (IET-1), Jülich, Germany — [2]RWTH Aachen University, Aachen, Germany — [3]Fritz Haber Institute of the Max Planck Society, Berlin, Germany

Quantum optimal control is a versatile, powerful method to tailor nuclear magnetic resonance (NMR) experiments. With the growing importance of NMR on electrochemical systems, we present how optimal control can be used to address experimental challenges in complex setups, such as *operando* electrolysis. Particularly, conductive cell components cause magnetic field distortions due to shielding and eddy current effects, leading to reduced resolution, non-quantitative results, and possible artifacts. In a complementary approach, we combine ensemble optimal control with finite element method (FEM) simulations. We show how NMR setups are accurately modeled in FEM and how this knowledge is used to improve NMR measurements on an *operando* electrolysis setup. Furthermore, we demonstrate how an NMR measurement can be turned surface selective by exploiting the characteristic near-surface magnetic field distortions. We demonstrate how quantum optimal control enables new experiments, which provide additional information and insights of unparalleled detail into complex systems.

Q 71.2 Fri 11:15 HS II

Comparison of Gate-set evaluation metrics for closed-loop optimal control on nitrogen-vacancy center ensembles in diamond — •Thomas Reisser[3,4], Philipp J. Vetter[1,2], Maximilian G. Hirsch[1,2,5], Tommaso Calarco[3,4,6], Felix Motzoi[3,4], Fedor Jelezko[1,2], and Matthias M. Müller[3] — [1]Institute for Quantum Optics, Ulm University, 89081 Germany — [2]Center for Integrated Quantum Science and Technology (IQST), 89081 Germany — [3]Institute for Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, 52425 Germany — [4]Institute for Theoretical Physics, University of Cologne, 50937 Germany — [5]NVision Imaging Technologies GmbH, 89081 Germany — [6]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Italy

Precise control of a quantum system is a prerequisite for quantum information, quantum computing, and quantum metrology. Quantum gates on ensembles of nitrogen vacancy centers usually suffer from decoherence, large amplitude errors, imperfect state preparation and therefore limited total operation fidelity. Large state preparation and measurement errors can cause the typically used quantum process tomography to fail. We investigate the applicability of quantum process tomography, linear inversion gate-set tomography, randomized linear gate-set tomography, and randomized benchmarking as measures for closed-loop quantum optimal control experiments. Closed-loop optimizations are performed and evaluated with all measures to find a gate-set with universally improved performance and demonstrate the relative trade-offs between the methods.

Q 71.3 Fri 11:30 HS II

Spin control of highly-strained silicon-vacancy centers in

nanodiamonds — •Andreas Tangemann, Marco Klotz, and Alexander Kubanek — Institute for Quantum Optics, University Ulm, Germany

Spin qubits in solid state hosts are, due to their promise of scalability, candidates for the realization of quantum networks. The good spin properties of diamond paired with the optical properties of group-IV defects make them of special interest. We are using highly-strained silicon vacancy centers in nanodiamonds to mitigate phonon induced dephasing of the spin qubit at liquid Helium temperature, due to orbital ground state splittings exceeding 1THz. Here we show coherent control of the electron spin, access to a 13C nuclear spin via indirect control and nuclear spin single-shot readout, as well as coherent control over the optical dipole of the SiV centers. These techniques lay the foundation for future quantum network experiments with SiV centers at liquid Helium temperatures.

Q 71.4 Fri 11:45 HS II

Nuclear spin control with highly strained silicon-vacancy centers — •Marco Klotz, Andreas Tangemann, and Alexander Kubanek — nstitute for Quantum Optics, University Ulm, Germany

Spin qubits in solid state hosts are due to their promise of scalability candidates for the realization of quantum networks. The good spin properties of diamond paired with the optical properties of group-IV defects make them of special interest. We are using highly strained silicon vacancy centers to mitigate phonon induced electron spin dephasing at liquid Helium temperature. Here we show our current results on electron spin characterization. Furthermore, we use highly efficient electron spin driving to access, control and characterize coupled C13 nuclear spins. This paves the way for nuclear spin assisted quantum error correction and networking with group IV defects.

Q 71.5 Fri 12:00 HS II

Cryogenic microwave generator for quantum information processing with trapped ions — •Sebastian Halama[1], Peter Toth[2], Marco Bonkowski[1], and Christian Ospelkaus[1,3] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [2]Technische Universität Braunschweig, Institut für CMOS Design, Hans-Sommer-Str. 66, 38106 Braunschweig — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Scaling up quantum computers to a higher number of qubits while maintaining control of all qubit states is still a major challenge. Surface-electrode ion traps are a promising platform for such a large-scale quantum computer. With the microwave near-field approach [1], qubit control realized by microwave conductors that are integrated into the ion trap naturally scale with the trap itself. However, the microwave signal generation currently takes place outside of the vacuum chamber in which the ion trap is located. Here we report on the design of a cryogenic three-channel microwave generator with amplitude modulation capabilities and its co-integrating with a surface-electrode ion trap on a common chip carrier. We present first measurements taken with the cryogenic microwave generator and discuss further steps of the experiment.

[1] Ospelkaus et. al, Phys. Rev. Lett. **101**, 090502 (2008)

Q 71.6 Fri 12:15 HS II

Optimizing Rydberg Ensemble Dynamics: Double Excitation Suppression — •Vidisha Aggarwal[1,2], Boxi Li[1], Eloisa Cuestas[1], Robert Zeier[1], Felix Motzoi[1,2], and Tommaso Calarco[1,2,3] — [1]Peter Grünberg Institute-Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Koln, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

We propose an optimization strategy for Rydberg ensemble dynamics to suppress double excitations and enhance single-photon emission, crucial for quantum technologies like optical communication. Using a Rydberg 'superatom'-an ensemble of Rubidium-87 atoms in an optical cavity-we encode its internal state into an optical qubit [1]. While the Rydberg blockade ideally ensures single-photon emission, imperfections lead to double excitations, hindering controlled retrieval.

To address this, we use the Derivative Removal by Adiabatic Gate (DRAG) method, which introduces an auxiliary pulse to suppress unwanted transitions [2,3]. Though typically used with superconducting qubits, applying DRAG to neutral atoms demonstrates the versatility of quantum control techniques. This approach significantly improves the probability of obtaining just a single Rydberg excitation compared to the experimental pulse.

[1] V. Magro, A. Ourjoumtsev, et al. Nat. Photonics 17, 688*693 (2023). [2] F. Motzoi and F. K. Wilhelm, Phys. Rev. A 88, 062318 (2013). [3] B. Li, F. Motzoi et al., PRX Quantum 3, 030313 (2022).

Q 71.7 Fri 12:30 HS II

Motion-Insensitive Time-Optimal Control of Optical Qubits — •Léo Van Damme[1], Zhao Zhang[2], Amit Devra[1], Steffen J. Glaser[1], and Andrea Alberti[2] — [1]School of Natural Sciences, Technical University of Munich, Lichtenbergstrasse 4, D-85747 Garching, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Ultranarrow optical transitions, widely used in modern atomic clocks, are gaining significant attention for quantum computing applications. However, optical qubits are highly susceptible to motion-induced decoherence and photon-recoil heating, which, if unaddressed, pose critical barriers to the realization of large-scale quantum circuits.

In this work, we demonstrate that these effects can be controlled by modulating the phase of the driving laser field over time, for general quantum gates and arbitrary initial atomic states.

We have developed a method that reduces the problem of infinite motional states to a set of constraints on a two-level system. This dramatic simplification, combined with optimal control techniques, reveals that optimal solutions not only substantially improve gate fidelity and speed but are also feasible for practical implementation.

Q 71.8 Fri 12:45 HS II

Accelerated creation of NOON states with ultracold atoms via counterdiabatic driving — •Simon Dengis[1], Sandro Wimberger[2,3], and Peter Schlagheck[1] — [1]CESAM Research Unit, University of Liege, 4000 Liege, Belgium — [2]Istituto Nazionale di Fisica Nucleare (INFN), Sezione Milano Bicocca, Gruppo collegato di Parma, Italy — [3]Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università di Parma, Parco Area delle Scienze 7/A, 43124 Parma, Italy

A quantum control protocol is proposed for the creation of NOON states with N ultracold bosonic atoms on two modes, corresponding to the coherent superposition $|N, 0\rangle + |0, N\rangle$. This state can be prepared by using a third mode where all bosons are initially placed and which is symmetrically coupled to the two other modes. Tuning the energy of this third mode across the energy level of the other modes allows the adiabatic creation of the NOON state. While this process normally takes too much time to be of practical usefulness, due to the smallness of the involved spectral gap, it can be drastically boosted through counterdiabatic driving which allows for efficient gap engineering. We demonstrate that this process can be implemented in terms of static parameter adaptations that are experimentally feasible with ultracold quantum gases. Gain factors in the required protocol speed are obtained that increase exponentially with the number of involved atoms and thus counterbalance the exponentially slow collective tunneling process underlying this adiabatic transition. arXiv:2406.17545.

Q 72: Ultra-cold Atoms, Ions and BEC V (joint session A/Q)

Time: Friday 11:00–12:45 Location: GrHS Mathe

Q 72.1 Fri 11:00 GrHS Mathe

Interplay of topology and disorder in driven honeycomb lattices — Alexander Hesse[1,2,3], Johannes Arceri[1,2,3], •Moritz Hornung[1,2,3], Christoph Braun[1,2,3], and Monika Aidelsburger[1,2,3] — [1]Ludwig-Maximilians-Universitä Fakultät für Physik, München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

One of the most fascinating properties of topological phases of matter is their robustness to disorder [1]. While various methods have been developed to probe the geometric properties of Bloch bands with ultracold atoms [2], most fail in the presence of disorder due to their reliance on translational invariance. Here, we demonstrate that topological edge modes can be employed to detect a disorder-induced phase transition between distinct topological phases in a Floquet-engineered 2D optical honeycomb lattice.

[1] J. Zheng, et al., Floquet top. phase transitions, Phys. Rev. B (2024)

[2] N. R. Cooper, J. Dalibard, and I. B. Spielman, Topological bands, Rev. Mod. Phys. (2019)

Q 72.2 Fri 11:15 GrHS Mathe

Cold-atom simulator of a (2+1)D U(1) quantum link model — •Peter Majcen[1,2], Jesse J. Osborne[3], Bing Yang[4], Simone Montangero[1,2], Pietro Silvi[1,2], Philip Hauke[5], and Jad C. Halimeh[6,7] — [1]University of Padua, Italy — [2]INFN Padua, Italy — [3]University of Queensland, Australia — [4]Southern University of Science and Technology, China — [5]University of Trento, Italy — [6]MPI of Quantum Optics, Garching, Germany — [7]LMU, Munich, Germany

The modern description of elementary particles and their interactions is formulated in the language of gauge theories, making them of great interest in theoretical physics. However, first-principle calculations for understanding the emergent phenomena are not always feasible. Possible solutions to this challenge include formulating a Hamiltonian lattice gauge theory and studying it using tensor network techniques or quantum simulators that emulate the dynamics of the theory of interest. A suitable platform for such quantum simulators is ultra-cold atoms. In this work, we adopt a quantum link formulation of QED and present a mapping of a U(1) Quantum Link Model (QLM) for spin S=1 in (2+1)D to a bosonic superlattice. We then propose a scheme for the realization of the target QLM on an extended Bose-Hubbard optical superlattice. Using perturbation theory, we derive an effective description of the QLM and relate its parameters to those of the extended Bose-Hubbard model. To validate the mapping, we show the stability of gauge invariance and the fidelity between the quench dynamics of the extended Bose-Hubbard model and the target QLM, over all accessible evolution times.

Q 72.3 Fri 11:30 GrHS Mathe

Raman sideband imaging of potassium-39 in an optical lattice — •Scott Hubele[1,2], Yixiao Wang[1,2], Martin Schlederer[1,2], Guillaume Salomon[1,2], and Henning Moritz[1,2] — [1]Institute for Quantum Physics, University of Hamburg, Hamburg, Germany — [2]Hamburg Centre for Ultrafast Imaging, University of Hamburg, Hamburg, Germany

Understanding many-body quantum systems, both in and out of equilibrium, is often computationally challenging due to the large Hilbert space of the systems of interest. This makes quantum simulation very attractive, especially when the relevant observables and their correlations can be measured directly. The Bose-Hubbard model for instance, which describes interacting bosons in lattices, can be well simulated using ultracold atoms loaded into optical lattices. High-resolution imaging can then be used to resolve the occupation of each lattice site, in what is known as a quantum gas miscroscope. Here, we present our progress towards building a quantum gas microscope using ultracold potassium-39, to study the Bose-Hubbard model in 2D. We generate a 2D square lattice with a single 1064nm beam in a bowtie geometry and additionally confine the atoms along the vertical direction using a shallow-angle vertical lattice. To readout the system state following some time evolution of the system, we employ Raman sideband cooling at near-zero magnetic field to collect fluorescence on the D1 line. Characterization of our imaging scheme and progress towards single-site resolution is presented.

Q 72.4 Fri 11:45 GrHS Mathe

Floquet realization of large bosonic flux ladders in the strongly correlated regime — •SeungJung Huh[1,2,3], Alexander Impertro[1,2,3], Simon Karch[1,2,3], Irene Rodriguez[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

In this talk, we will present our results on studying a strongly correlated flux ladder using a neutral atom quantum simulator. After preparing half-filled lattice Cesium atoms with tunable interaction, we experimentally realize the artificial gauge field via laser-assisted tunneling. Measuring local particle currents in a single bond resolution allows us to investigate the ground state phase diagram of interacting Hofstader-Bose Hubbard in a ladder system. We find homogeneous chiral leg current as well as strongly suppressed rung current, a hallmark of Mott-Meissner phase. Finally, we estimate the effective temperature of our system by comparing small system exact diagonalization. This will open avenues to study strongly interacting topological phases such as fractional quantum Hall states.

Q 72.5 Fri 12:00 GrHS Mathe

Probing many-body quantum dynamics using subsystem Loschmidt echos — •Simon Karch[1,2,3], Alexander Impertro[1,2,3], SeungJung Huh[1,2,3], Irene Prieto Rodriguez[1,2,3], Souvik Bandyopadhyay[4], Zheng-Hang Sun[5], Wolfgang Ketterle[6], Markus Heyl[5], Anatoli Polkovnikov[4], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2,3] — [1]Fakultät für Physik, LMU, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]MCQST, Munich, Germany — [4]Department of Physics, Boston University, Boston, MA, USA — [5]Institute of Physics, University of Augsburg, Augsburg, Germany — [6]Department of Physics, MIT, Cambridge, MA, USA

The Loschmidt echo - the probability of a quantum many-body system to return to its initial state following a dynamical evolution - is a key quantity in statistical physics. However, it is typically exponentially small, posing significant challenges for experimental measurement. We introduce the subsystem Loschmidt echo, a quasi-local approximation that enables extrapolation to the full-system Loschmidt echo, even in very large systems. Utilizing quantum gas microscopy, we investigate both short- and long-time dynamics of the subsystem Loschmidt echo, demonstrating its ability to capture key features of the Loschmidt echo in a many-body quantum system. In the short-time regime, we use it to observe dynamical quantum phase transitions, while in the long-time regime, our method allows us to measure the inverse participation ratio (IPR), providing a quantitative measure of the dimension of accessible Hilbert space in ergodic and fragmented systems.

Q 72.6 Fri 12:15 GrHS Mathe

Fermionic quantum gates in optical lattices — •Timon Hilker — University of Strathclyde, Glasgow, UK

A fermionic quantum computer uses the occupation of Fermionic modes instead of qubits as the fundamental unit. Such a quantum computer would allow us to run quantum simulations of fermions more efficiently than spin-based quantum computers, which have to map fermionic exchange statistics to qubits via an overhead in resources and circuit depth.

Fermionic atoms in optical lattices have long been used successfully for analog quantum simulations. In this talk, I will discuss how to digitalise the motion and interaction of atoms with gates, and I will indicate how these can extend the current simulations of the Fermi Hubbard model towards hybrid analog-digital simulations, non-local interactions, and applications from material science and quantum chemistry.

Q 72.7 Fri 12:30 GrHS Mathe

Synthetic dimension-induced pseudo Jahn-Teller effect in one-dimensional confined fermions — •André Becker[1,2], Georgios M. Koutentakis[3], and Peter Schmelcher[1,2] — [1]Center for Optical Quantum Technologies, Department of Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Institute of Science and Technology Austria (ISTA), am Campus 1, 3400 Klosterneuburg, Austria

We demonstrate the failure of the adiabatic Born-Oppenheimer approximation to describe the ground state of a quantum impurity within an ultracold Fermi gas despite substantial mass differences between the bath and impurity species. Increasing repulsion leads to the appearance of nonadiabatic couplings between the fast bath and slow impurity degrees of freedom, which reduce the parity symmetry of the latter according to the pseudo Jahn-Teller effect. The presence of this mechanism is associated to a conical intersection involving the impurity position and the inverse of the interaction strength, which acts as a synthetic dimension. We elucidate the presence of these effects via a detailed ground-state analysis involving the comparison of ab initio fully correlated simulations with effective models. Our study suggests ultracold atomic ensembles as potent emulators of complex molecular phenomena.

Q 73: Quantum Technologies (Detectors and Photon Sources) (joint session Q/QI)

Time: Friday 14:30–16:15 Location: AP-HS

Q 73.1 Fri 14:30 AP-HS

Niobium-based plasmonic superconducting photodetectors for IR — •Sandra Mennle[1], Philipp Karl[1], Monika Ubl[1], Pavel Ruchka[1], Heidemarie Schmidt[2], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Germany — [2]Leibniz Institute of Photonic Technology, Albert-Einstein-Str. 9, 07745 Jena, Germany

In the last decade photon-based quantum technologies have become a fast-growing field of research, which requires fast and reliable detectors. Moreover, applications in the mid-IR like spectroscopy or astronomic photography are in need for highly efficient photodetection. For these applications superconducting nanowire photon detectors feature a great potential due to their high efficiency and sensitivity.

To enhance the absorption at larger wavelengths in the IR spectral range, we are using a plasmonic perfect absorber geometry to match the optical impedance of the detector to the incident light and to suppress any reflection. By design plasmonic resonances feature a large bandwidth, polarization sensitivity and can easily be spectrally tuned.

We present detectors which reach an absorption of over 95% for wavelengths up to 4 μm and demonstrate nanostructures with 90% absorption in 8-12 μm spectral range. This concept than can be extended to use not only one, but multiple detectors which then form a detector array i.e. a highly sensitive camera with plasmonically enhanced efficiency.

Q 73.2 Fri 14:45 AP-HS

Deep ultraviolet laser light for cluster interferometry — •Hannah Foltas, Richard Ferstl, Severin Sindelar, Bruno Ramírez-Galindo, Stefan Gerlich, Sebastian Pedalino, and Markus Arndt — University of Vienna, Faculty of Physics, Boltzmanngasse 5, Vienna, Austria

Matter-wave interferometry with massive nanoparticles may contribute to the understanding of the quantum-classical interface, and it can open new avenues for materials science or lithography at the nanoscale. Here we discuss the need for and recent progress in realizing a light source that can fulfill the requirements for photodepletion gratings for cluster matter-waves: A standing deep ultraviolet (DUV) light wave shall ionize metallic or dielectric nanoparticles in its antinodes by absorption of a single photon and thus form a measurement-induced diffraction grating. Ionization can be achieved if the photon energy exceeds the cluster ionization energy, which depends on the material, size and charge state of the particle. We target a wavelength below 230 nm and a photon energy of 5.4-5.5 eV, which will be sufficient to ionize clusters of vastly different density, such as sodium or gold and even insulating nanoparticles such as silicon. Starting from a TiSa laser beam at 900 - 920 nm (ca. 6 W) we first generate blue light with a power of $>$ 2.5 W behind an external cavity using an LBO crystal and a circular laser beam profile. This light is further doubled to $<$ 230 nm light in a second cavity with elliptical mode profile and using a BBO crystal. We demonstrate the usefulness of this light source in absorption tests on cluster beams.

Q 73.3 Fri 15:00 AP-HS

Ultra-small Nb-based plasmonic superconducting photodetectors arrays — •Philipp Karl[1], Sandra Mennle[1], Monika Ubl[1], Ksenia Weber[1], Pavel Ruchka[1], Mario Hentschel[1], Philipp Flad[1], Detlef Born[2], Heidemarie Schmidt[2], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Leibniz Institute of Photonic Technology, Albert-Einstein-Str. 9, 07745 Jena, Germany

Applications based on quantum technologies, such as quantum computing and quantum cryptography, require precise and highly efficient photodetection. We present a superconducting plasmonic perfect absorber detector.

The absorption of our plasmonic structures can be increased by utilizing the plasmonic perfect absorber principle, to achieve up to almost 100% absorption over a wide spectral range.

In addition, our concept is compatible with meander patterns to create scalable pixelated detector arrays. We demonstrate up to 64x64 pixel designs whose spectral range can be tuned from 1 μm up to 11 μm.

Q 73.4 Fri 15:15 AP-HS

Micro-Integrated ECDL-MOPA Laser Modules for Quantum Technology Applications — •Janpeter Hirsch, Martin Gärtner, Stephanie Gerken, Nora Goossen-Schmidt, Simon Kubitza, Norbert Müller, Max Schiemangk, Dian Zou, and Andreas Wicht — Ferdinand-Braun-Institut (FBH), Berlin, Germany

We present our next generation of micro-integrated ECDL-MOPA laser modules, each operating at a specific wavelength of 689, 767, 780, 794, and 922 nm, with adaptability to other wavelengths. The 767 nm module exemplifies their performance, delivering over 350 mW of fiber-coupled output power, a FWHM linewidth below 200 kHz at 1 ms timescales, and an extended mode-hop-free tuning range exceeding 100 GHz [1].

These modules are further designed with enhanced robustness to facilitate operation on mobile platforms and in space environments [2]. We will present results of preliminary mechanical stress testing, including shock tests at accelerations beyond 1000 g, to demonstrate their resilience and reliability under extreme conditions.

We acknowledge funding from Federal Ministry of Education and Research within the funding program "Quantum technologies - from basic research to market" under grant number 13N15724 and from DLR Space Administration / Federal Ministry for Economic Affairs and Climate Action under grant numbers 50WM2152, 50WM2176, 50WM2164, 50WM21694.

[1] J. Hirsch et al., in Proc. of SPIE Vol. 12912, 129120B (2024)
[2] D. Zou et al., in CLEO 2023, JTh2A.70 (2023)

Q 73.5 Fri 15:30 AP-HS

Superconducting nanowire detection of neutral atoms & molecules via their internal and kinetic energy in the eV range, Adv. Phys. Res. DOI: 10.1002/apxr.202400133 — Marcel Strauss[1], Ronan Gourges[3], Martin F. X. Mauser[1], •Linus Kulman[1], Mario Castaneda[3], Andreas Fognini[3], Armin Shayeghi[2], Philipp Geyer[1], and Markus Arndt[1] — [1]University of Vienna, Faculty of Physics & VDSP & VCQ, Boltzmanngasse 5, A-1090 Vienna — [2]University of Vienna, Faculty of Physics & VCQ, Boltzmanngasse 5, A-1090 Vienna and Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 — [3]Single Quantum, Rotterdamseweg 394, 2629 HH, Delft, The Netherlands

Superconducting nanowires have found many applications in photonics as single photon detectors. Here we explore their potential as quantum sensors for neutral matter at low energy. We find that they exhibit outstanding sensitivity both with regard to the detection of internal atomic excitations as well as to the impact of neutral molecules, here demonstrated for metastable atoms as well as supersonic beams of perfluorodecalin. For metastable atoms, the quantum yield of SNWDs compares well with that of secondary electron multipliers and they outperform secondary electron multipliers by orders of magnitude in the detection of neutral molecules at impact energies as low as 2 eV.

Q 73.6 Fri 15:45 AP-HS

A narrowband, decorrelated photon pair source based on a Ti:LiNbO$_3$ waveguide cavity — •Jasmin Sommer, Michelle Kirsch, Kai Hong Luo, Christof Eigner, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Many applications in quantum information processing require narrowband and spectrally pure photon pairs at telecom wavelength. We developed a source for such photon pairs exploiting cavity-enhanced parametric down conversion (PDC) in a periodically poled $LiNbO_3$ waveguide. With coated end-faces of the waveguide, a cavity is formed. The clustering due to different free spectral ranges for TE- and TM-modes leads to spectrally narrowband photon pair generation of the type II phase-matched PDC-process. To obtain decorrelated pairs, it is furthermore necessary to pump the PDC source with tailored pulses of around 775 nm wavelength with an adaptable pulse width in the nanosecond range. We designed a suitable pump source using an electro-optic modulator for pulse carving, fiber amplifiers to boost the signal and a second harmonic stage for conversion to the pump wavelength. Details on the design of the pump source as well as initial results obtained with the photon pair source will be presented.

Q 73.7 Fri 16:00 AP-HS

Investigation of AM-PM conversion noise in nonlinear extensions of a frequency comb — •Angelina Jaros[1], Mattias Misera[1], Thomas Puppe[2], Uwe Sterr[1], and Erik Benkler[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Gräfelfing

An application of optical frequency combs is the transfer of frequency stability from an ultra-stable laser to the interrogation laser of an optical atomic clock. The stability transfer is limited by noise added onto the frequency comb. Its source could be the conversion of amplitude modulation (AM) of the seed comb light to phase modulation (PM) noise during the nonlinear processes employed for spectral broadening of the comb spectrum to cover the desired target wavelengths.

We investigate this AM-PM conversion in an Er:fiber fs-laser with two identical nonlinear extension branches. Single-frequency cw lasers at the fundamental and target wavelengths are employed for the generation of RF beats containing the PM. A modulator is employed to introduce AM in one branch before its nonlinear conversion stage, and the differential PM between the two wavelengths is measured after the nonlinear conversion to suppress phase noise due to path-length variations. By comparing to the second, unmodulated branch seeded by the same fundamental comb, phase noise in the seed comb and frequency noise of the cw lasers are suppressed.

The results may lead to further reduction of phase noise added by the nonlinear conversion steps in optical frequency combs.

Q 74: Photonics II

Time: Friday 14:30–16:30 Location: HS Botanik

Q 74.1 Fri 14:30 HS Botanik

CMT-Driven Dual Fitting of 3D FDTD Bragg Grating Reflectance and Transmittance Data — •Yasmin Rahimof, Igor Nechepurenko, M. R. Mahani, and Andreas Wicht — Ferdinand-Braun-Institut (FBH)

Optical Bragg gratings are widely used in research of light-matter interactions and develop photonic devices. Their ability to precisely control wavelength, reflection and transmission characteristics makes them particularly useful in diode laser applications, ensuring reliable performance. The finite-difference time-domain (FDTD) method is widely recognized as one of the most precise techniques for simulating Bragg gratings, as it numerically solves Maxwell's equations. When implemented in 3D, FDTD method can accurately capture the complex interactions between light and intricate geometries or materials, resulting in more accurate simulation outcomes. On the other hand, Coupled Mode Theory (CMT) offers an analytical approach for modeling and predicting the optical response of Bragg gratings. While CMT lacks the dimensional details of 3D FDTD and is therefore generally less accurate, it can still effectively characterize the optical response. In this research, we aim to simultaneously fit the reflection and transmission spectra derived from 3D FDTD simulations with CMT. We investigate how CMT parameters change with different grating lengths. Furthermore, CMT allows us to predict the optical response of longer structures (up to 2 mm) based on data from much shorter structures, approximately 10 times smaller.

Q 74.2 Fri 14:45 HS Botanik

Speeding up the calculations of computer-generated holograms for complex 3D beam-shaping — •Tim-Dominik Gómez[1], Daniel Flamm[2], Pavel Ruchka[1], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Trumpf GmbH & Co KG, Ditzingen, Germany

Beams with spatially varying, non-Gaussian profiles are essential across diverse research fields, particularly in applications like imaging and material processing. These can be shaped with the help of diffractive or holographic optical elements, such as spatial light modulators or metasurfaces, which in many cases results in the restriction to phase-only optical elements. The resulting calculation of an appropriate phase mask for a specific 3D beam-shape necessitates the use of iterative Fourier transform algorithms (IFTA). For free-space propagation the number of 2D Fast Fourier transforms involved scale with the number of layers observed and is thus computationally intensive. For valid window sizes $>$ 1024 pixel, even current-gen CPUs require more than a second for the computation of around 100 of these 2D FFTs.

In this work, we therefore simulate free-space propagation through upwards of 500 layers on a current-generation NVIDIA 4090 GPU utilizing the angular spectrum method. We then implement, as well as compare a variety of IFTAs, identifying valid approaches and parameters. Further, we optimize memory allocation and parallelization for these approaches and aim to enable real-time processing for the control of the optical traps in Rydberg quantum computers.

Q 74.3 Fri 15:00 HS Botanik

3D printed needle-beam micro-endoscope for extended depth-of-focus intravascular OCT — •Pavel Ruchka[1], Alok Kushwaha[2], Jessica A. Marathe[3,4], Lei Xiang[2], Rodney Kirk[2,3], Joanne T. M. Tan[3,4], Robert A. McLaughlin[2,3], Peter J. Psaltis[3,4], Harald Giessen[1], and Jiawen Li[2,4] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany — [2]Institute for Photonics and Advanced Sensing, University of Adelaide, Adelaide, SA 5005, Australia — [3]Faculty of Health and Medical Sciences, University of Adelaide, Adelaide, SA 5005, Australia — [4]Lifelong Health Theme, South Australian Health and Medical Research Institute (SAHMRI), Adelaide, SA 5000, Australia

A fundamental challenge in endoscopy is creating small astigmatism-free fiber-optic probes that match the performance of larger systems, particularly in achieving high resolution and extended depth-of-focus (DOF). We present a novel approach using two-photon polymerization 3D printing to fabricate freeform beam-shaping endoscopic probes. Our design achieves 8 um resolution with a DOF exceeding 800 um at a central wavelength of 1310 nm. The 250 um-diameter probe is printed in a single step directly on the optical fiber. We demonstrate the device in intravascular optical coherence tomography imaging of living diabetic swine and ex vivo human arteries with atherosclerotic plaques. This is the first use of 3D-printed micro-optics in coronary arteries of living swine, closely resembling human anatomy.

Q 74.4 Fri 15:15 HS Botanik

Microcombs for Hyperspectral Holographic Imaging — •Stephan Amann[1,2], Edoardo Vicentini[2,3], Bingxin Xu[1,2], Chao Xiang[4], Yang He[5], Qiang Lin[5], John Bowers[4], Theodor Hänsch[2], Kerry Vahala[6], and Nathalie Picque[1,2] — [1]Max-Born Institute, Berlin, Germany — [2]Max-Planck Institute of Quantum Optics, Garching, Germany — [3]CIC nanoGUNE BRTA, Donostia-San Sebastian, Spain — [4]Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA, USA — [5]Department of Electrical and Computer Engineering, University of Rochester, NY, USA — [6]T.J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA, USA

Microcombs are broad optical spectra consisting of phase-coherent narrow laser lines, which are conveniently generated in high-Q optical microresonators. Due to their high coherence, broad optical bandwidth, and small footprint, microcombs have become attractive for applications such as low-noise microwave generation, optical communication and optical ranging. Digital holography is an interferometric imaging technique that gives access to both the amplitude and phase information of an object. The phase describes the three-dimensional profile of the object, while the amplitude encodes the absorption properties of the sample. By using a microcomb of 1 THz line spacing we can access the broad absorption features of condensed phase samples, measured at the comb line positions. This enables three-dimensional hyperspectral imaging and allows to discriminate the spectral properties of different plastic samples.

Q 74.5 Fri 15:30 HS Botanik

Low-loss and broadband all-fiber acousto-optic circulator — •Riccardo Pennetta, Martin Blaha, and Arno Rauschenbeutel — Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

The introduction of low-loss optical fibers probably represents the single most important advance in the growth of telecommunication systems. To meet our needs for secure communications, it is likely that our classical network will soon be operating alongside what is known as a quantum network. The latter is very sensitive to loss and thus poses constraints to the performance of current fiber components. In particular, recent quantum network prototypes underline the absence of low-loss nonreciprocal fiber-based devices. Here, we present a solution to this issue by realizing low-loss (0.81 dB), broadband (at least 50-GHz bandwidth), and high-extinction (up to 27 dB) circulators, based on Mach-Zehnder interferometers including so-called fiber null-couplers. The latter are directional couplers, whose splitting ratio can be controlled by launching acoustic waves along the coupling region. Fabricated from standard single-mode fibers and actuated electrically, these circulators can be made to fit any existing optical fiber networks and could turn out to be key for the transmission and processing of optically encoded quantum information.

Q 74.6 Fri 15:45 HS Botanik

Fabrication of Mode-Matched, Low-Loss Optical Micro-Resonators — •Patrick Maier, Manuel Stetter, and Alexander Kubanek — Institute for Quantum Optics, Ulm University, Germany

Fabry Perot cavities are essential tools for applications like precision metrology, optomechanics, and quantum technologies. A major challenge is the creation of mirror structures that allow the precise mapping of a wavefront (e.g. from a Gaussian beam) onto a glass surface, while providing high surface quality. We demonstrate the fabrication of customized Gaussian mode matched micro-cavity optics with a novel fabrication method, allowing customized geometrical parameters as well as smooth surfaces allowing coating limited Finesse F.

Q 74.7 Fri 16:00 HS Botanik

Measuring deviations from a perfectly circular cross-section of an optical nanofiber at the Ångström scale — •Jihao Jia, Felix Tebbenjohanns, Jürgen Volz, Arno Rauschenbeutel, and Philipp Schneeweiss — Humboldt-Universität zu Berlin, Germany

Tapered optical fibers (TOFs) with sub–wavelength–diameter waists, known as optical nanofibers, are powerful tools for interfacing quantum emitters and nanophotonics. This demands stable polarization of the fiber–guided light field. However, the linear birefringence resulting from Ångström–scale deviations in the nanofiber's ideally circular cross–section can lead to significant polarization changes within millimeters of light propagation.

Here, we experimentally investigate such deviations using two in-situ approaches. First, we measure the resonance frequencies of hundreds of flexural modes of the nanofiber, which can be thought of as a doubly clamped beam in this context. Assuming an elliptical cross-section with a and b, the differing second moments of area for vibrations along these axes result in a splitting of the resonance frequencies. By analyzing the measured resonance pairs, we estimate $|a-b| \approx 3$ Ångström for a nanofiber with a nominal diameter of 500 nm. An analytical model links this elliptical cross–section to the linear birefringence of the nanofiber. Second, we monitor the polarization of the guided light field along the nanofiber [1]. By analyzing the scattered light as a function of the axial position, we confirm the birefringence inferred from the flexural mode frequencies.

[1] IEEE J. Quantum Electron. 18, 1763 (2012)

Q 74.8 Fri 16:15 HS Botanik

Colloidal self-assembly for 3D second-harmonic photonic crystals — •Thomas Kainz[1,2], Ullrich Steiner[1,2], and Viola Vogler-Neuling[1,2] — [1]Adolphe Merkle Institute, University of Fribourg, Fribourg, Switzerland — [2]NCCR Bio-inspired Materials, University of Fribourg, Fribourg, Switzerland

Three-dimensional nonlinear photonic crystals can simultaneously generate different nonlinear processes, like second-harmonic generation (SHG) and other sum- and difference-frequency processes. However, creating large crystals in all three dimensions presents a considerable challenge, primarily due to the chemical inertness of metal oxides. This study shows the first demonstration of colloidal-crystal-templating into a second-order optical material. Different templates made of polystyrene opals are self-assembled from monodisperse nanospheres with tunable unit sizes. These are infiltrated with barium titanate sol-gel, which results after calcination in an inverse fcc network of tetragonal barium titanate. We fabricated samples with unprecedented sizes (above 3000 unit cells in x, y directions and 100 in z). The achieved reflectivity values are above 80 % throughout the fabrication. We can tune the final photonic bandgap over the whole optical range, matching it to material and setup requirements. We successfully replicated the photonic network into a second-order material and demonstrated, for the first time, a linear photonic band gap from a fully scalable three-dimensional photonic crystal made of a nonlinear optical material. This enables the experimental investigation of SHG within a bandgap, like inhibited spontaneous emission.

Q 75: Quantum Technologies (Solid State Systems) (joint session Q/QI)

Time: Friday 14:30–16:30 Location: HS I

Q 75.1 Fri 14:30 HS I

Low Temperature Spectroscopy of hBN Quantum Emitters — •Mouli Hazra[1], Manuel Rieger[2], Anand Kumar[1], Mohammad Nasimuzzaman Mishuk[1], Tjorben Matthes[1], Viviana Villafane[2,3], Jonathan J. Finely[2], and Tobias Vogl[1] — [1]Department of Computer Engineering, TUM School of Computation Information and Technology, Technical University of Munich, 80333 Munich, Germany — [2]Walter Schottky institute, School of Natural Sciences and MQST, Technical University of Munich, 85748 Garching, Germany. — [3]Walter Schottky Institute, School of Computation, Information and Technology and MQST, Technical University of Munich, 85748 Garching, Germany

Hexagonal boron nitride (hBN) hosts a large range of high quality single-photon emitters (SPEs) making it promising candidate for quantum technology applications. The practical integration of these emitters requires precise control of emission wavelengths, spatial localization, and directionality of those emitters. In this work, we have created localized, spectrally stable SPEs using electron beam irradiation without any pre- or post-treatment. To understand their chemical nature, we performed cryogenic experiments to minimize thermal broadening and gain insights into their optical and structural characteristics. We studied how excitation wavelength and temperature influence the emission. This work marks a significant step toward deterministic, high-quality SPEs in hBN, advancing integrated quantum photonic technologies.

Q 75.2 Fri 14:45 HS I

Towards on-chip microwave to telecom transduction using erbium doped silicon — •Daniele Lopriore and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology, 85748 Garching

The development of a device that converts microwave to optical photons at telecommunication wavelengths would be a key enabler for communication between remote quantum computers and would pave the way for the entanglement of distant superconducting qubits. We investigate ensembles of erbium dopants that exhibit coherent microwave [1] and optical transitions [2]. They can be used as a nonlinear medium mediating an efficient Raman conversion process [3]. High efficiencies require enhancing both the microwave and the telecom transitions with high quality factor resonators. We will present our progress towards low-loss manufacturing and measurements of the spin properties in erbium-doped silicon waveguides, and give an outlook towards the transduction efficiencies achievable with our approach. [1] A. Gritsch, et al. arXiv:2405.05351 (2024). [2] A. Gritsch, et al. Phys.Rev.X 12, 041009 (2022). [3] C. O'Brien, et al. Phys.Rev.Lett. 113, 063603 (2014).

Q 75.3 Fri 15:00 HS I

Hybrid Nanophotonic Spin-Photon Interface of Si_3N_4 Photonics and Silicon Vacancy Centers in Nanodiamonds — •Lukas Antoniuk[1], Niklas Lettner[1,2], Anna P. Ovvyan[3,5], Daniel Wendland[3], Viatcheslav N. Agafonov[4], Wolfram H.P. Pernice[3,5], and Alexander Kubanek[1,2] — [1]Institute for Quantum

Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Universite F. Rabelais, 37200 Tours, France — [5]Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Color centers in diamond have shown promising internal properties to be harnessed for quantum networks, secure quantum communication and distributed quantum computing. These applications require exchanging quantum information between stationary qubits and flying qubits, thus an efficient interface between them is needed. We base such an interface on negatively charged silicon vacancy centers (SiV^-) in nanodiamonds [1] and one-dimensional silicon nitride photonic crystal cavities. We present our progress on this hybrid platform which are access to the SiV^- qubit space [2] and control of optical coupling via nanomanipulation [3].

[1] Klotz et al., arXiv:2409.12645 [2] Lettner et al., ACS Photonics, 11(2):696-702 [3] Antoniuk et al., Physical Review Applied, 21(5):054032

Q 75.4 Fri 15:15 HS I

Deterministic preparation and retrieval of the dark state population in a quantum dot — •René Schwarz[1], Florian Kappe[1], Yusuf Karli[1], Thomas Bracht[2], Saimon Covre da Silva[3], Armando Rastelli[3], Vikas Remesh[1], Doris Reiter[2], and Gregor Weihs[1] — [1]Institute of Experimental Physics, University of Innsbruck, Innsbruck, Austria — [2]Condensed Matter Theory, Department of Physics, TU Dortmund, Dortmund, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria

Semiconductor quantum dots are arguably the most promising platform for future quantum technologies. Due to the confinement of charge carriers, a variety of photon states can be generated, making them a highly adaptable quantum platform. While state-of-the-art optical excitation methods target the so-called bright excitons or biexcitons, quantum dots also accommodate optically dark excitons, which are not directly accessible via optical excitation methods. The dark exciton states exhibit significantly slower decay rates compared to their bright counterparts, making them potential candidates for application in quantum information protocols that require control of quantum coherence over long time scales [1]. In this work, we perform a full magneto-optical characterization (in-plane magnetic field) as well as a deterministic preparation and retrieval of the dark exciton state population in a single GaAs/AlGaAs quantum dot emitting at ~ 800 nm using a combination of a magnetic field and chirped laser pulses [2]. [1] Phys. Rev. Lett. 94, 030502 (2005). [2] arXiv, 2404.10708 (2024)

Q 75.5 Fri 15:30 HS I

Spectroscopy and coherent manipulation of REI-based organic molecular systems for quantum information applications. — •Vishnu Unni C.[1], Evgenij Vasilenko[1], Nicholas Jobbitt[1], Xiaoyu Yang[1], Barbora Brachnakova[1], Senthil Kuppusamy[1], Timo Neumann[2], Mario Ruben[1], Michael Seitz[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]University of Tübingen, Tübingen, Germany

A europium-based molecular complex has recently shown [1] competing optical coherence time as that of europium-doped crystals. This opens the possibility of tailoring ligand fields to improve optical and spin properties to realize optically addressed spin qubits. We measure an improved photon echo coherence time of 3 μs at 4K, a narrow optical linewidth of 120 kHz, and a spin lifetime longer than an hour at 150 mK using spectral hole burning (SHB) in the complex reported in [1]. We measure spin inhomogeneous lines of the hyperfine transitions of the ground states. Simultaneously, we screen many organic complexes with improved branching ratios of up to 1.3% and characterize their hyperfine splittings of ground and excited states and optical coherence times. The self-assembly of molecular complexes into high-quality crystals is exploited to integrate them into fiber-based microcavities[2] which enhances emission rates by the Purcell effect. These results are important steps towards single ion experiments to realize optically addressable spin qubits.

[1] Serrano et al., Nature, 603, 241-246 (2022)
[2] Hunger et al., New J. Phys 12, 065038 (2010)

Q 75.6 Fri 15:45 HS I

Hybrid integration of silicon carbide color centers into photonic integrated circuitry — •Jan Riegelmeyer, Gerben Timmer, Keyuan Fang, Maurice van der Maas, Elena Volkova, Kees Koot, Ryoichi Ishihara, Tim Taminiau, and Carlos Errando Herranz — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands

Color centers in the solid-state are promising qubit candidates for quantum information processing, but scaling to practical systems requires significantly increasing the number of qubits within a single processing unit. A solution to this challenge is integrating color centers into photonic integrated circuits (PICs) for efficient and miniaturized photon collection, manipulation, and detection. However, traditional color center host materials like silicon carbide (SiC), lack well-established PIC technology, limiting scalability. Here, we address this limitation via the hybrid integration of SiC chiplets into silicon nitride (SiN) PICs using micro transfer printing. The chiplets are suspended structures fabricated from 4H-SiC-on-insulator containing photonic waveguides and cavities designed for the V2 color center. We optimized the geometry of chiplet and PIC to ensure reliable transfer printing and efficient optical transmission and demonstrate successful hybrid integration. While optimized for SiC color centers, our approach applies to other color center host materials.

Q 75.7 Fri 16:00 HS I

Building a weakly coupled nuclear spin register using the V2 color center in Silicon Carbide — •Pierre Kuna[1], Erik Hesselmeier-Hüttmann[1], Wolfgang Knolle[2], Florian Kaiser[3,4], Nguyen Tien Son[5], Misagh Ghezellou[5], Jawad Ul-Hassan[5], Vadim Vorobyov[1], and Jörg Wrachtrup[1,6] — [1]3rd Institute of Physics, IQST, and Research Center SCoPE, University of Stuttgart, Stuttgart, Germany — [2]Department of Sensoric Surfaces and Functional Interfaces, Leibniz-Institute of Surface Engineering (IOM), Leipzig, Germany — [3]Materials Research and Technology (MRT) Department, Luxembourg Institute of Science and Technology (LIST), 4422 Belvaux, Luxembourg — [4]University of Luxembourg, 41 rue du Brill, L-4422 Belvaux, Luxembourg — [5]Department of Physics, Chemistry and Biology, Linköping University, Linköping, Sweden — [6]Max Planck Institute for solid state physics, Stuttgart, Germany

The V2 color center in Silicon Carbide is a promissing candidate for scalable quantum networks due to its long coherence time, electrical compatibility, hosting two different and individually addressable nuclear spin bathes[1].

In this work, we resolve the nuclear spin environment of a single color center using Electron DOuble Nuclear Spin Resonnance (ENDOR) spectroscopy showing over ten addressable nuclear spins and demonstrate their individual initialisation and control. We furthermore show first results on the entanglement of two weakly coupled nuclear spins.

[1] Erik Hesselmeier et al. Phys. Rev. Lett. 132, 180804-May, 2024

Q 75.8 Fri 16:15 HS I

Purcell enhancement of single defects in silicon carbide coupled to a a fiber-based Fabry-Pérot microcavity — •Jannis Hessenauer[1], Jonathan Körber[2], Jawad Ul-Hassan[3], Georgy Astakhov[4], Wolfgang Knolle[5], Jörg Wrachtrup[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Germany — [2]3rd Institute of Physics, University of Stuttgart, Germany. — [3]Department of Physics, Chemistry and Biology, Linköping University, Sweden. — [4]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Germany. — [5]Leibniz-Institute of Surface Engineering (IOM), Germany.

The negatively charged silicon vacancy center (V2) in silicon carbide (SiC) has recently emerged as a promising realization of a solid-state spin-photon interface. Remarkably, it exhibits narrow optical linewidths, even when integrated into nanostructures, and at temperatures up to 20 K. However, only a small fraction of the light is emitted into the coherent zero-phonon line. An optical microcavity can be used to enhance this fraction via the Purcell effect. In this work, we integrate a three micron thin membrane of SiC containing color centers into a cryogenic fiber-based Fabry-Pérot-resonator. We study the cavity-membrane system and find excellent agreement with our model and minimal losses introduced by the membrane. We observe Purcell enhancement of the zero-phonon line, manifesting itself in a lifetime shortening and a strong zero-phonon line emission. Utilizing the spectral selectively of the cavity allows us to address individual defects in a spatially dense sample, which results in a high single photon purity.

Q 76: Nanophotonics II

Time: Friday 14:30–16:30 Location: WP-HS

Q 76.1 Fri 14:30 WP-HS

Towards a versatile Silicon-Carbide-on-Insulator Platform for Quantum Nanophotonics with Optically Active Spins — •Leonard K.S. Zimmermann[1,2], Flavie Davidson-Marquis[1,2], Jonah Heiler[1,2], Samuel C. Eserin[3], Stephen K. Clowes[3], Benedict N. Murdin[3], Stephan Kucera[1], and Florian Kaiser[1,2] — [1]Luxembourg Institute of Science and Technology (LIST), Esch-sur-Alzette, Luxembourg — [2]University of Luxembourg, Esch-sur-Alzette, Luxembourg — [3]Advanced Technology Institute, University of Surrey, Guildford, United Kingdom

Colour centres offer promising properties for quantum technologies, including controllable generation, processing, and tuning. Silicon carbide (SiC) is a promising material for a scalable nanophotonics platform, given its mature device technology. Recent demonstrations show color centers in SiC with good preserved spin-optical coherence and effective spin-photon interaction in nanophotonic devices. This allows SiC to combine multiple functionalities on a single chip, such as small quantum processors with quantum memories. The next steps are further developing the Silicon-Carbide-on-Insulator (SiCOI) platform on multiple fronts. Different insulator materials are investigated to increase the spin-photon interface efficiency and the first results from an ongoing implantation-annealing study to generate divacancy colour centres in 4H-SiC using a Helium-Neon-Focussed-Ion-Beam are shown.

Q 76.2 Fri 14:45 WP-HS

Nonlinear SnV-Based Electrometry for Material Science at the Atomic Lattice Scale — •Gregor Pieplow[1], Cem Güney Torun[1], Charlotta Gurr[1], Joseph H. D. Munns[1], Franziska M. Herrmann[1], Andreas Thies[2], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Ferdinand-Braun-Institut (FBH), Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

Quantum probes embedded in solid-state materials offer new and technologically relevant insights for materials science. While nitrogen-vacancy (NV) centers in diamond are well-established as in situ magnetometers and electrometers, we propose a novel approach to electrometry using group-IV vacancies (G4V), specifically the negatively charged tin vacancy (SnV) in diamond [1]. Unlike NV centers, G4V centers exhibit reduced sensitivity to linear Stark shifts, making them less susceptible to noise from distant charges. This property enables the detection of electric fields generated by charges near the sensor, allowing for the localization of charge traps at the diamond lattice scale, even in the presence of significant noise. By employing a rapid spectroscopic method, our approach enables the monitoring of environmental dynamics and the identification and colocalization of multiple charge traps using a single sensor probe. Additionally, we quantify the impact of charge noise on the SnV's optical coherence, investigate critical material properties, and outline strategies for material optimization.

[1] Pieplow G., et al. (2024) arXiv:2401.14290v1

Q 76.3 Fri 15:00 WP-HS

Advanced waveguide structures for quantum communication and computing in SiC — •Jonas Schmid[1,2], Flavie Davidson-Marquis[1,2], Nien-Hsuan Lee[1,2], Sushree Swateeprajnya Behera[1,2], Stephan Kucera[1], and Florian Kaiser[1,2] — [1]Luxembourg Institute for Science and Technology, Esch-sur-Alzette, Luxembourg — [2]University of Luxembourg, Esch-sur-Alzette, Luxembourg

Divacancies in silicon carbide (SiC) entail excellent quantum systems for quantum communication, based on the combination of quantum memories and photonic qubits. Significant challenges to overcome are the low efficiency of the optical interface and the integration into photonic chips. We address these issues through the optimization of the design in order to increase the efficiency of photonic circuits in SiC. Our approach involves SiC-on-insulator waveguide structures for the integration into photonic chips. With our designs, we ensure good coupling from the dipole emitter into the waveguide, as well as from the waveguide into the fiber. Further, robust and low-loss beam splitter designs are investigated. The successful implementation of this design will enable interference between divacancies on a quantum chip. This multiplexed spin-photon entanglement interface enables faster quantum communication rates.

Q 76.4 Fri 15:15 WP-HS

Controlling non-volatile shifts of high-Q resonances for nanobeam photonic crystal cavities — •Tim Buskasper[1,2,3], Mohammad Bilal Malik[1,2,3], David Lemli[1,2,3], and Carsten Schuck[1,2,3] — [1]Department for Quantum Technology, University of Münster, Heisenbergstr. 11, Münster, 48149, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]SoN - Center for Soft Nanoscience, Busso-Peus-Straße 10, 48149 Münster, Germany

Nanobeam photonic crystal cavities are critical for applications in nanoscale sensing, nonlinear optics, and light-matter interaction. However, achieving high-quality (Q) factors typically requires free-standing devices, and precise resonance tuning often relies on active elements with limited scalability.

Here, we show an order-of-magnitude improvement of Q-factors for nanobeam cavities made from tantalum pentoxide to 1.36×10^5 at $\lambda = 773.2\,\mathrm{nm}$ without the need of releasing the device from the substrate. Additionally, we demonstrate shifting of resonances by combining advanced nanophotonic design and high-resolution lithography with laser-assisted oxidation, thus achieving resonance overlap for a large number of resonators.

This approach is not restricted to tantalum pentoxide but can be adapted for other material platforms, like silicon-nitride-on-insulators. It paves the way for realizing large arrays of identical high-Q resonators.

Q 76.5 Fri 15:30 WP-HS

Telecom emitters in silicon slow-light waveguides — •Florian Burger[1,2], Stephan Rinner[1,2], Andreas Gritsch[2,1], Kilian Sandholzer[2,1], and Andreas Reiserer[2,1] — [1]Max Planck Institute of Quantum Optics, Quantum Networks Group, 85748 Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

In ground-based quantum networks, photons are exchanged via optical fibers to create entanglement between distant network nodes. To scale up these networks, efficient light-matter interfaces, which map the quantum state of a photon to that of a stationary quantum mechanical system, are required. Yet, a physical system that combines telecom wavelength emission for low-loss fiber transmission with sufficiently long coherence times for global-scale quantum links and straightforward scalability remains elusive. Here we show that erbium dopants in silicon, which fulfill these criteria [1], can be addressed individually when integrated into a photonic-crystal slow-light waveguide. Due to the broadband nature of the the slow-light effect in the waveguide, no technically involved tuning of the nanostructure is required to ensure efficient coupling. We also show how the slow-light effect modifies the lifetime of the investigated optical transition. Erbium-doped silicon slow-light waveguides could thus be a platform for robust on-chip quantum memories operating at telcom wavelengths in future quantum networks.

[1] A. Gritsch et al., 2024, arXiv:2405.05351.

Q 76.6 Fri 15:45 WP-HS

Long-Range Self-Hybridized Exciton-Polaritons in Two-Dimensional Ruddlesden-Popper Perovskites — •Maximilian Black[1], Mehdi Asadi[2], Parsa Darman[2], Sezer Seçkin[3], Finja Schillmöller[1], Tobias A. F. König[3], Sara Darbari[1,2], and Nahid Talebi[1] — [1]Institute of Experimental and Applied Physics, Kiel University, Kiel, Germany — [2]Nano-Sensors and Detectors Lab., Tarbiat Modares University, Tehran, Iran — [3]Leibniz-Institut für Polymerforschung Dresden e.V., Dresden, Germany

Ruddlesden-Popper perovskites combine excellent photoluminescence efficiency and high synthetic versatility with a crystal structure of stacked quantum wells that induces two-dimensional quantum confinement in the bulk crystal. This makes them exciting platforms for the study of exciton-polaritons, mixed states of excitons and localized photons. In this work, we present proof of long-range propagating exciton-polaritons in the cavity formed by the crystal itself, a phenomenon called self-hybridization. Bright-field spectroscopy reveals excitonic splitting and polaritonic bending of Fabry-Pérot mode dispersion, while photoluminescence spectroscopy shows multiple thickness-dependent polariton branches. Strikingly, local optical excitation below the exciton energy couples light directly to in-plane polaritonic modes, which transfer energy to lower-energy polaritons. The exciton-polaritons exhibit directed long-range propagation, as confirmed by FDTD simulations. Thus, we demonstrate that mesoscopic 2D Ruddlesden-Popper perovskite flakes serve as an effective system for exploring exciton-polaritons at room temperature.

Q 76.7 Fri 16:00 WP-HS

Transient energy distributions for photo-catalysis in plasmonic heterostructures — •Mathis Noell, Felix Stete, Matias Bargheer, and Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie

We investigate the dynamics of heat energy transfer following photon absorption by a gold palladium core-shell nanoparticle. This hybrid structure combines a highly efficient plasmonic antenna with catalytically active material, making it a promising platform for light energy harvesting in view of light-driven catalysis. We analyze energy dissipation after single-photon absorption and sequences of photon pulses, bridging towards continuous-wave irradiation via stochastic Markov chains of individual absorption events. Employing two- and three-temperature models, we track the transient energy flow and demonstrate that the Pd shell, due to its strong electron-phonon coupling, momentarily reaches the highest local energy density. The influence of interfacial thermal conductivity and coupling to the surrounding medium is also evaluated.

Q 76.8 Fri 16:15 WP-HS

Limits for coherent optical control of a quantum emitter in hexagonal Boron Nitride (hBN) — •Michael K. Koch[1,2], Vibhav Bharadwaj[1,3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, D-89081 Ulm, Germany — [3]Department of Physics, Indian Institute of Technology Guwahati, 781039 Guwahati, Assam, India

Single photon emitters are a crucial resource for upcoming quantum optic technologies. Hosted single photon emitters in hexagonal boron nitride (hBN) are ideal candidates for integration into hybrid quantum systems. One type of such emitter has demonstrated the remarkable property of Fourier transform-limited optical linewidth at cryogenic and even room temperature [1,2]. This characteristic is a manifestation of out-of-plane distorted emitters, which weakly couple to in-plane phonon modes. This results in the mechanical isolation of defect centers' orbitals [3], which enables coherent optical driving and the observation of optical Rabi oscillations at elevated temperatures [4].

[1] A. Dietrich et al., Physical Review B, Vol. 98 (2018)
[2] A. Dietrich et al., Physical Review B, Vol. 101 (2020)
[3] M. Hoese et al., Science Advances, Vol. 6 (2020)
[4] M. K. Koch et al., Communications Materials, Vol. 5 (2024)