Atomic Physics Division
Fachverband Atomphysik (A)

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Overview of Invited Talks and Sessions

(Lecture halls GrHS Mathe, KlHS Mathe, HS PC; Poster Tent)

Invited Talks

A 1.1	Mon	11:00–11:30	KlHS Mathe	**Spatially dependent polarization spectroscopy with structured light modes** — •Riaan Philipp Schmidt, Richard Aguiar Maduro, Anton Peshkov, Sonja Franke-Arnold, Andrey Surzhykov
A 1.2	Mon	11:30–12:00	KlHS Mathe	**Circular dichroism in multiphoton ionization of resonantly excited helium ions near channel closing** — •Niclas Wieland, Rene Wagner, Markus Ilchen, Nicolas Douguet, Philipp Schmidt, Klaus Bartschat, Michael Meyer
A 2.1	Mon	11:00–11:30	HS PC	**Towards an optical atomic clock based on Ni^{12+}** — •Malte Wehrheim, Lukas J. Spiess, Shuying Chen, Alexander Wilzewski, Piet O. Schmidt, José R. Crespo Lopez-Urrutia
A 3.1	Mon	17:00–17:30	KlHS Mathe	**QRydDemo - A Rydberg atom quantum computer demonstrator** — •Jiachen Zhao, Christopher Bounds, Christian Hölzl, Manuel Morgado, Govind Unnikrishnan, Achim Scholz, Julia Hickl, Sebastian Weber, Hans-Peter Büchler, Simone Montangero, Jürgen Stuhler, Tilman Pfau, Florian Meinert
A 4.1	Mon	17:00–17:30	HS PC	**Precision Measurements to Test Theory at ALPHATRAP** — •Matthew Bohman, Fabian Heisse, Charlotte König, Ivan Kortunov, Jonathan Morgner, Victor Vogt, Klaus Blaum, Stephan Schiller, Sven Sturm
A 6.1	Tue	11:00–11:30	GrHS Mathe	**Water Window HHG continua driven by sub-cycle, nonsinusoidal IR Pulses** — •Fabian Scheiba, Miguel Silva, Giulio Maria Rossi, Roland E. Mainz, Maximilian Kubullek, Rafael d. Q. Garcia, Franz X. Kärtner
A 7.1	Tue	11:00–11:30	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, •Philipp Wessels-Staarmann
A 12.1	Wed	11:00–11:30	HS PC	**A planar rotor in an ion crystal** — •Monika Leibscher, Ferdinand Schmidt-Kaler, Christiane P. Koch
A 13.1	Wed	11:00–11:30	KlHS Mathe	**Microscopy of matter wave emission into a two-dimensional structured reservoir** — •Felix Spriestersbach, Jan Geiger, Valentin Klüsener, Immanuel Bloch, Sebastian Blatt
A 16.1	Wed	14:30–15:00	HS PC	**Entanglement in the motional degree of freedom created in ultracold collisions** — •Yimeng Wang, Christiane Koch
A 17.1	Wed	14:30–15:00	GrHS Mathe	**Time Resolved Diffractive Imaging of Laser Induced Dynamics in Materials** — •Tom Böttcher, Richard Altenkirch, Stefan Lochbrunner, Christian Peltz, Thomas Fennel, Franziska Fennel
A 25.1	Thu	11:00–11:30	GrHS Mathe	**Circular Dichroic Attosecond Transient Absorption Spectroscopy** — •Lauren Drescher, Nicola Mayer, Kylie Gannan, Jonah Adelman, Stephen Leone

A 26.1	Thu	11:00–11:30	KlHS Mathe	**Breaking the barrier of resolution in broadband spectroscopy** — •Jérémie Pilat, Bingxin Xu, Theodor W. Hänsch, Nathalie Picqué
A 27.1	Thu	11:00–11:30	HS PC	**High precision spectroscopy of trilobite Rydberg molecular series** — •Richard Blättner, Markus Exner, Rohan Srikumar, Matt Eiles, Peter Schmelcher, Herwig Ott
A 31.1	Thu	14:30–15:00	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, José R. Crespo López-Urrutia

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 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 Precision Measurements at the Intersection of Atomic and Nuclear Physics (SYPM)

See SYPM for the full program of the symposium.

SYPM 1.1	Wed	14:30–15:00	HS 1+2	**Probing new bosons and nuclear structure with ytterbium isotope shifts** — •Tanja Mehlstäubler, Chih-Han Yeh, Henning Fürst, Laura Dreissen
SYPM 1.2	Wed	15:00–15:30	HS 1+2	**Probing the Stars: Nuclear Astrophysics with Stable and Radioactive Ion Beams** — •Ragandeep Singh Sidhu
SYPM 1.3	Wed	15:30–16:00	HS 1+2	**Precision measurements and metrology applications at the borderline between atomic and nuclear physics** — •Adriana Pálffy
SYPM 1.4	Wed	16:00–16:30	HS 1+2	**Atomic parity violation: the seventh decade** — •Dmitry Budker

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 New Avenues in Molecular Alignment and Orientation (SYAO)

See SYAO for the full program of the symposium.

SYAO 1.1	Fri	14:30–15:00	HS 1+2	**Ultralong-range Rydberg molecules: Rotational hybridization, control of alignment and orientation, and Rydberg blockade** — •Rosario González-Férez
SYAO 1.2	Fri	15:00–15:30	HS 1+2	**Quantum control of molecular rotation** — •Dominique Sugny
SYAO 1.3	Fri	15:30–16:00	HS 1+2	**Strong-Field Ionization and Electron Rescattering Probabilities in the Molecular Frame** — •Jochen Mikosch, Martin Garro, Narayan Kundu, Horst Rottke, Killian Dickson, Varun Makhija, Federico Branchi, Felix Schell, Mark Mero, C P Schulz, Serguei Patchkovskii, Marc Vrakking
SYAO 1.4	Fri	16:00–16:30	HS 1+2	**Coherent rotational control of gas phase molecular dipoles by concerted Terahertz and Near-IR pulses** — •Sharly Fleischer

Sessions

A 1.1–1.6	Mon	11:00–13:00	KlHS Mathe	**Atomic Systems in External Fields I**
A 2.1–2.7	Mon	11:00–13:00	HS PC	**Precision Spectroscopy of Atoms and Ions I (joint session A/Q)**
A 3.1–3.7	Mon	17:00–19:00	KlHS Mathe	**Ultra-cold Atoms, Ions and BEC I (joint session A/Q)**
A 4.1–4.7	Mon	17:00–19:00	HS PC	**Precision Spectroscopy of Atoms and Ions II (joint session A/Q)**
A 5.1–5.8	Mon	17:00–19:00	HS I PI	**Ultracold Matter (Bosons) I (joint session Q/A)**
A 6.1–6.5	Tue	11:00–12:30	GrHS Mathe	**Attosecond Physics I (joint session A/MO)**
A 7.1–7.7	Tue	11:00–13:00	KlHS Mathe	**Ultra-cold Atoms, Ions and BEC II (joint session A/Q)**
A 8.1–8.8	Tue	11:00–13:00	HS I PI	**Ultracold Matter (Bosons) II (joint session Q/A)**
A 9.1–9.34	Tue	14:00–16:00	Tent	**Poster – Ultra-cold Atoms, Ions and BEC (joint session A/Q)**
A 10.1–10.6	Tue	14:00–16:00	Tent	**Poster – Ultra-cold Plasmas and Rydberg Systems (joint session A/Q)**
A 11.1–11.65	Tue	14:00–16:00	Tent	**Poster – Cold Atoms and Molecules, Matter Waves (joint session Q/A/MO)**
A 12.1–12.7	Wed	11:00–13:00	HS PC	**Precision Spectroscopy of Atoms and Ions III (joint session A/Q)**
A 13.1–13.7	Wed	11:00–13:00	KlHS Mathe	**Ultra-cold Atoms, Ions and BEC III (joint session A/Q)**
A 14.1–14.7	Wed	11:00–12:45	GrHS Mathe	**Interaction with VUV and X-ray light I (joint session A/MO)**
A 15	Wed	13:15–13:45	HS 6	**Members' Assembly**
A 16.1–16.7	Wed	14:30–16:30	HS PC	**Collisions, Scattering and Correlation Phenomena I**
A 17.1–17.6	Wed	14:30–16:15	GrHS Mathe	**Interaction with Strong or Short Laser Pulses I (joint session A/MO)**
A 18.1–18.5	Wed	14:30–15:45	KlHS Mathe	**Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)**
A 19.1–19.8	Wed	14:30–16:30	WP-HS	**Ultracold Matter (Bosons) III (joint session Q/A)**
A 20.1–20.5	Wed	17:00–19:00	Tent	**Poster – Atomic Clusters**
A 21.1–21.8	Wed	17:00–19:00	Tent	**Poster – Atomic Systems in External Fields**

A 22.1–22.7	Wed	17:00–19:00	Tent	**Poster – Attosecond Physics**
A 23.1–23.10	Wed	17:00–19:00	Tent	**Poster – Interaction with Strong or Short Kaser Pulses (joint session A/MO)**
A 24.1–24.6	Wed	17:00–19:00	Tent	**Poster – Interaction with VUV and X-ray light**
A 25.1–25.5	Thu	11:00–12:30	GrHS Mathe	**Attosecond Physics II (joint session A/MO)**
A 26.1–26.7	Thu	11:00–13:00	KlHS Mathe	**Precision Spectroscopy of Atoms and Ions V (joint session A/Q)**
A 27.1–27.6	Thu	11:00–12:45	HS PC	**Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)**
A 28.1–28.8	Thu	11:00–13:15	HS XV	**Cluster and Nanoparticles I (joint session MO/A)**
A 29.1–29.7	Thu	11:00–12:45	HS V	**Ultracold Matter (Fermions) I (joint session Q/A)**
A 30.1–30.8	Thu	14:30–16:30	GrHS Mathe	**Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)**
A 31.1–31.7	Thu	14:30–16:30	KlHS Mathe	**Precision Spectroscopy of Atoms and Ions VI (joint session A/Q)**
A 32.1–32.5	Thu	14:30–15:45	HS PC	**Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)**
A 33.1–33.3	Thu	17:00–19:00	Tent	**Poster – Collisions, Scattering and Correlation Phenomena (joint session A/MO)**
A 34.1–34.1	Thu	17:00–19:00	Tent	**Poster – Atomic Collisions and Ultracold Plasmas**
A 35.1–35.21	Thu	17:00–19:00	Tent	**Poster – Precision Spectroscopy of Atoms and Ions (joint session A/Q)**
A 36.1–36.1	Thu	17:00–19:00	Tent	**Poster – Correlation Phenomena**
A 37.1–37.11	Thu	17:00–19:00	Tent	**Poster – Highly Charged Ions and their Applications**
A 38.1–38.7	Fri	11:00–12:45	GrHS Mathe	**Ultra-cold Atoms, Ions and BEC V (joint session A/Q)**
A 39.1–39.8	Fri	11:00–13:00	KlHS Mathe	**Highly Charged Ions and their Applications**
A 40.1–40.7	Fri	11:00–13:00	HS XV	**Cluster and Nanoparticles II (joint session MO/A)**
A 41.1–41.7	Fri	11:00–13:00	HS V	**Ultracold Matter (Fermions) II (joint session Q/A)**

Members' Assembly of the Atomic Physics Division

Wednesday 13:15–13:45 HS 6

A 1: Atomic Systems in External Fields I

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

Invited Talk A 1.1 Mon 11:00 KlHS Mathe
Spatially dependent polarization spectroscopy with structured light modes — •Riaan Philipp Schmidt[1,2], Richard Aguiar Maduro[3], Anton Peshkov[1,2], Sonja Franke-Arnold[3], and Andrey Surzhykov[1,2,4] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Mathematische Physik, Technische Universität Braunschweig, Germany — [3]School of Physics and Astronomy, University of Glasgow, United Kingdom — [4]Laboratory for Emerging Nanometrology Braunschweig, Germany

During recent years, a number of studies have been performed to investigate the interaction of matter with structured light modes. These studies paved the way for the application of such modes in optical traps and tweezers, classical and quantum communication, as well as atomic magnetometers [1]. In the course of the latter work, it was observed that the transmission of structured-light polarization components through the atomic sample is very sensitive to the frequency of the incident radiation. To provide the theoretical background for polarization spectroscopy with structured beams, we perform calculations in the framework of the density matrix approach and the Liouville-von Neumann equation. For illustration purposes, we apply our general theory to the $5s\,^2S_{1/2}\,(F=3) - 5p\,^2P_{3/2}\,(F=4)$ transition in Rb^{85}. Based on the results of our calculations, we find that the spatially dependent transmission pattern allows for the analysis of laser frequency. This opens up new opportunities for the application of structured light in laser frequency locking schemes.
[1] F. Castellucci et al., PRL 127, 233202 (2021)

Invited Talk A 1.2 Mon 11:30 KlHS Mathe
Circular dichroism in multiphoton ionization of resonantly excited helium ions near channel closing — •Niclas Wieland[1], Rene Wagner[1], Markus Ilchen[1], Nicolas Douguet[2], Philipp Schmidt[3], Klaus Bartschat[4], and Michael Meyer[3] — [1]Department of Physics, Universität Hamburg — [2]Department of Physics, University of Central Florida — [3]European X-Ray Free-Electron Laser Facility — [4]Department of Physics and Astronomy, Drake University

Circulardichroism (CD) in photoionization experiments offers a unique window into the dynamics of light-matter interaction, enabling the study of symmetry, resonances, and transient states of matter. In this talk, I will present our investigation of the CD of photoelectrons generated by near-infrared (NIR) laser pulses through multiphoton ionization of excited He^+ ions in the 3p (m = +1) state, prepared by circularly polarized extreme ultraviolet (XUV) pulses. By comparing co- and counter-rotating NIR pulse configurations relative to the XUV polarization, we observe a complex dependence of CD on the laser intensity and polarization. These effects are linked to Freeman resonances, selectively influenced by dichroic AC-Stark shifts, which alter the photoionization pathways.

Through experimental results and numerical simulations based on the time-dependent Schrödinger equation, we identify the mechanisms driving this variation in CD. Our findings emphasize the role of intermediate resonances in steering photoionization dynamics and highlight He^+ as a benchmark system for exploring fundamental dichroic effects.

A 1.3 Mon 12:00 KlHS Mathe
Can Atoms Learn How to Read? — •Maurice Beringuier[1,2] and Thomas Pfeifer[1,2] — [1]Max Planck Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Universität Heidelberg, Grabengasse 1, 69117 Heidelberg

Motivated by the potential speed gains of using physical systems for computations we investigate the ability of atomic systems to perform machine-learning tasks.

As in the previous work of Pfeifer et al. (2024, New J. Phys. 26 093018), data and tunable weights are introduced to a simulated atom via the spectral phases of time-dependent electric fields. We compare gradient-free optimization methods and the use of differentiable simulators in their effectiveness to train atoms on the textbook task of recognizing handwritten digits.

We analyze the influence of physical parameters such as the amplitude of the electric field and the level structure of the atoms on its performance on the task.

We identify different phases in the parameter landscape, characterized by the (in-)ability of the atom to learn and correlate these phases with measures that quantify vulnerability to overfitting.

A 1.4 Mon 12:15 KlHS Mathe
Fluctuation-induced Bistability of Fermionic Atoms Coupled to a Dissipative Cavity — •Luisa Tolle[1], Ameneh Sheikhan[1], Thierry Giamarchi[2], Corinna Kollath[1], and Catalin-Mihai Halati[2] — [1]Physikalisches Institut, University of Bonn, Germany — [2]DQMP, University of Geneva, Switzerland

We investigate the steady state phase diagram of fermionic atoms subjected to an optical lattice and coupled to a high finesse optical cavity with photon losses. The coupling between the atoms and the cavity field is induced by a transverse pump beam. Taking fluctuations around the mean-field solutions into account, we find that a transition to a self-organized phase takes place at a critical value of the pump strength.

In the self-organized phase the cavity field takes a finite expectation value and the atoms show a modulation in the density.

Surprisingly, at even larger pump strengths two self-organized stable solutions of the cavity field and the atoms occur, signaling the presence of a bistability. We show that the bistable behavior is induced by the atoms-cavity fluctuations and is not captured by the the mean-field approach.

A 1.5 Mon 12:30 KlHS Mathe
Novel Hilbert-space approach to mixed classical-quantum systems — •Sebastian Ulbricht[1,2], Marcel Reginatto[2], and Andrés Darío Bermúdez Manjarres[3] — [1]Institut für Mathematische Physik, Technische Universit* at Braunschweig, Mendelssohnstraße 3, 38106 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt PTB, Bundesallee 100, 38116 Braunschweig, Germany — [3]Universidad Distrital Francisco José de Caldas, Cra. 7 No. 40B-53, Bogotá, Colombia

In a mixed classical-quantum system, one part of a physical system is described by quantum theory, while the other part is treated classically. Such hybrid theories are effective to approximate large quantum systems, for instance in the field of quantum many-body calculations or in quantum chemistry. In addition, they can be utilized to investigate whether quantum systems interacting via classical fields, such as classical gravity, can be realized in nature. In this talk, a Hilbert-space formalism for classical particles and its consistent extension to hybrid systems is presented. In our recent publication [1], we show that this novel approach is not equivalent to other approaches to mixed classical-quantum systems, especially regarding quantum systems interacting via a classical mediator. This finding has important implications for the applicability of no-go theorems addressing the issue of whether gravity must be quantized.

[1] A.D. Bermúdez Manjarres, M. Reginatto, and S. Ulbricht, Eur. Phys. J. Plus 139, 780 (2024)

A 1.6 Mon 12:45 KlHS Mathe
Comment on the Sommerfeld Fine Structure Constant tension — •Manfred Geilhaupt — University of Applied Sciences HS Niederrhein

In todays physics, the fine-structure constant (alpha) is a fundamental physical constant which quantifies the strength of the electromagnetic interaction between elementary charged particles. The constant alpha was introduced in 1916 by Arnold Sommerfeld. However, alpha still is an unsolved theoretical and even experimental physical problem up to now! Alpha from atomic interferometric experiments shows a large difference compared to their high accuracy:

1. 2018 Parker et al. 1/137.035999046(27), atomic interferometer experiment Science* 13 Apr 2018:Vol. 360, Issue 6385, pp. 191-195
2. 2020 Morel et al. 1/137.035999206(11), atomic interferometer experiment Nature 588, 61*65 (2020)
3. 2018 Codata 1/137.035999084(15), quantum hall experiment. The 2011 last experimental von Klitzing constant RK=25812.807442(30)Ohm accuracy can be increased by an order of magnitude today. https://doi.org/10.1098/rsta.2011.0198
4. 2019 form Codata given alphaC= 1/137.035999177(21) 2019 from Codata given alphaRKC=1/137.035999127 based on RKC= 25812.807450(00)Ohm (exact defined) does not match. The presenta-

tion contains two answers to the question about tension. (A. Einstein: Ein Problem kann man nicht mit der Denkweise lösen, durch das es entstanden ist.)

A 2: Precision Spectroscopy of Atoms and Ions I (joint session A/Q)

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

Invited Talk A 2.1 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 López-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)

A 2.2 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

A 2.3 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.

A 2.4 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.

A 2.5 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.

A 2.6 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.

A 2.7 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)

A 3: Ultra-cold Atoms, Ions and BEC I (joint session A/Q)

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

Invited Talk A 3.1 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.

A 3.2 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

A 3.3 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.

A 3.4 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.

A 3.5 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].

A 3.6 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.

A 3.7 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.

A 4: Precision Spectroscopy of Atoms and Ions II (joint session A/Q)

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

Invited Talk A 4.1 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.

A 4.2 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).

A 4.3 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.

A 4.4 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).

A 4.5 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.

A 4.6 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.

A 4.7 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.

A 5: Ultracold Matter (Bosons) I (joint session Q/A)

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

A 5.1 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).

A 5.2 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.

A 5.3 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)

A 5.4 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).

A 5.5 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).

A 5.6 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.

A 5.7 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.

A 5.8 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.

A 6: Attosecond Physics I (joint session A/MO)

Time: Tuesday 11:00–12:30 Location: GrHS Mathe

Invited Talk A 6.1 Tue 11:00 GrHS Mathe

Water Window HHG continua driven by sub-cycle, nonsinusoidal IR Pulses — •Fabian Scheiba[1,2,3], Miguel Silva[1,2], Giulio Maria Rossi[1,3], Roland E. Mainz[1,2,3], Maximilian Kubullek[1,2], Rafael d. Q. Garcia[1,2], and Franz X. Kärtner[1,2,3] — [1]Center for Free-Electron Laser Science CFEL and Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany — [2]Physics Department, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

We present the next milestone of our infrared (IR) Parametric Waveform Synthesizer (PWS), that is the generation of HHG continua in the Water Window (WW) spectral region, up to 450 eV. The IR driver pulses are characterized to a pulse duration of 2.8 fs at 1.6 μm central wavelength and an update of the attosecond beamline apparatus enables for high pressure phase matching in Helium and Neon gases. The PWS allows for sub-cycle control of the HHG process and following control of the HHG spectra. Scans of the given phase parameters of the driving electric field show a strong dependence of the generated HHG and therefore unmatched tuning capabilities. Furthermore, calibrated measurements of the HHG yield allows us to claim a significant efficiency increase comapared to a few cycle sinusoidal driver pulse.

A 6.2 Tue 11:30 GrHS Mathe

Towards AI-enhanced online-characterization of ultrashort X-ray free-electron laser pulses — •Thorsten Otto[1,2,4], Kristina Dingel[2], Lars Funke[3], Sara Savio[3,4], Lasse Wülfing[3,4], Bernhard Sick[2], Wolfram Helml[3], and Markus Ilchen[1,4] — [1]Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany — [2]University of Kassel, Intelligent Embedded Systems, Wilhelmshöher Allee 73, 34121 Kassel, Germany — [3]Technische Universität Dortmund, Fakultät für Physik, Maria-Göppert-Mayer-Straße, 44227 Dortmund, Germany — [4]Universität Hamburg, Institut für Experimentalphysik, Luruper Chaussee 149 22761 Hamburg

X-ray free-electron lasers provide ultrashort X-ray pulses with durations typically in the order of femtoseconds, but recently even entering the attosecond regime. The technological evolution of XFELs towards well-controllable light sources for precise metrology of ultrafast processes can only be achieved using new diagnostic capabilities for characterizing X-ray pulses at the attosecond frontier. The spectroscopic technique of photoelectron angular streaking has successfully proven how to non-destructively retrieve the exact time-energy structure of XFEL pulses on a single-shot basis. By using deep learning algorithms, we show how this technique can be leveraged from its proof-of-principle stage towards routine diagnostics at XFELs providing precise feedback in real time.

A 6.3 Tue 11:45 GrHS Mathe

Extracting RABBITT-like phase information from time dependent transient absorption spectra — •Julian Jakob[1], Cornelia Bauer[1], Murat-Jakub Ilhan[1], Divya Barthi[2], Christian Ott[2], Thomas Pfeifer[2], Klaus Bartschat[3], and Anne Harth[1] — [1]Center for Optical Technologies, Aalen University, Aalen, Germany — [2]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [3]Department of Physics and Astronomy, Drake University, Des Moines, IA 50311, USA

We investigate transient absorption spectroscopy by exploring how the spectral phase of the attosecond pulse train modulates the optical density signal. The process is driven by the interaction of extreme ultraviolet (XUV) and near-infrared (NIR) fields, with their relative time delay playing a crucial role in shaping the dynamics [1]. As demonstrated in Reconstruction of Attosecond Beating by Interference of Two-Photon Transitions (RABBITT) experiments, the XUV phase can be measured by examining the photoionization electron spectrum as a function of the time delay between the XUV and NIR fields [2]. Similarly, the spectral phase of the XUV field imprints itself in oscillations of the optical density, which occur at twice the NIR frequency ($2\omega_{\mathrm{NIR}}$). Using a few-level model, we simulate the quantum dynamics and validate our findings by solving the time-dependent Schrödinger equation (TDSE) for atomic hydrogen. This approach reveals how the spectral phase modulates the optical density, thereby providing a direct link to the underlying attosecond electron dynamics. [1] Holler, Phys. Rev. Lett. 106, 123601 (2011), [2] Hentschel, Nature 414, 509-513 (2001)

A 6.4 Tue 12:00 GrHS Mathe

In silico approach for understanding experimental sub-cycle driven high harmonic generation from XUV to soft X-rays. — •Rafael de Q. Garcia[1,2], Maximilian Kubullek[1,2], Miguel Silva[1,2], Roland E. Mainz[1,2,3], Fabian Scheiba[1,2,3], Giulio M. Rossi[1,3], and Franz X. Kärtner[1,2,3] — [1]Center for Free-Electron Laser Science CFEL and Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany — [2]Physics Department, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

High harmonic generation (HHG) has since long been used for generating tabletop XUV to soft X-ray isolated attosecond pulses used for ultrafast science. However, as the pulses driving HHG get shorter, achieving even sub-cycle duration, new challenges are faced both experimentally and theoretically to understand which electric field is producing HHG and how phase-matching of HHG actually happens in a medium. To answer these questions, we combine an in situ pulse characterization technique with a 1D optical and HHG-field propagation code. With these two tools, we simulate the outcomes of an experiment performed with our parametric waveform synthesizer, which drives HHG with either few-cycle or synthesized sub-cycle pulses, under different macroscopic conditions. It is shown, that this method enables qualitative and quantitative agreement between experiment and simulation, answering fundamental questions about sub-cycle driven HHG such as efficiency increase and plasma propagation effects.

A 6.5 Tue 12:15 GrHS Mathe

The Quantum Superluminality of Tunnel-ionization — •Ossama Kullie — University of Kassel, Institute of Physics

In our tunnel-ionization model presented in previous work[1,2,3,4], we showed that adiabatic and nonadiabatic tunnel-ionization time amounts to determine the barrier time-delay with good agreement with the attoclock measurement and that it corresponds to the dwell time and the interaction time. In the present work, we show that the barrier time-delay for H-like atoms with large nuclear charge can be superluminal (quantum superluminality), which can be validated experimentally using the attoclock scheme. We discuss the quantum superluminality for the different experimental calibrations of the attoclock. [1] O. Kullie, submitted to J. Phys. Comm. (2024). [2] Ossama Kullie and Igor Ivanov, Ann. of Phys 464, 169648 (2024). [3] O. Kullie, Phys. Rev. A 92, 052118 (2015). [4] O. Kullie. J. Phys. Commun. 2 065001 (2018).

A 7: Ultra-cold Atoms, Ions and BEC II (joint session A/Q)

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

Invited Talk A 7.1 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.

A 7.2 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.

A 7.3 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.

A 7.4 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.

A 7.5 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.

A 7.6 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.

A 7.7 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.

A 8: Ultracold Matter (Bosons) II (joint session Q/A)

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

A 8.1 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.

A 8.2 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.

A 8.3 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.

A 8.4 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.

A 8.5 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.

A 8.6 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.

A 8.7 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.

A 8.8 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)

A 9: Poster – Ultra-cold Atoms, Ions and BEC (joint session A/Q)

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

A 9.1 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.

A 9.2 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)

A 9.3 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)

A 9.4 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.

A 9.5 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.

A 9.6 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.

A 9.7 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.

A 9.8 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.

A 9.9 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.

A 9.10 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.

A 9.11 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.

A 9.12 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.

A 9.13 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.

A 9.14 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.

A 9.15 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.

A 9.16 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.

A 9.17 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.

A 9.18 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.

A 9.19 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.

A 9.20 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.

A 9.21 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.

A 9.22 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)

A 9.23 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.

A 9.24 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.

A 9.25 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.

A 9.26 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.

A 9.27 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.

A 9.28 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.

A 9.29 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)

A 9.30 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.

A 9.31 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.

A 9.32 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.

A 9.33 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.

A 9.34 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)

A 10: Poster – Ultra-cold Plasmas and Rydberg Systems (joint session A/Q)

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

A 10.1 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.

A 10.2 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.

A 10.3 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.

A 10.4 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.

A 10.5 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).

A 10.6 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.

A 11: Poster – Cold Atoms and Molecules, Matter Waves (joint session Q/A/MO)

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

A 11.1 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.

A 11.2 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.

A 11.3 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)

A 11.4 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)

A 11.5 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.

A 11.6 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)

A 11.7 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

A 11.8 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.

A 11.9 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.

A 11.10 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.

A 11.11 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.

A 11.12 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.

A 11.13 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.

A 11.14 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 Subaşi[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.

A 11.15 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.

A 11.16 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).

A 11.17 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.

A 11.18 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.

A 11.19 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).

A 11.20 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.

A 11.21 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.

A 11.22 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.

A 11.23 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 $\lambda = 1064\,\text{nm}$ 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 $t_{\text{evap}} = 1.3\,\text{s}$ 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.

A 11.24 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.

A 11.25 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.

A 11.26 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.

A 11.27 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

A 11.28 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)

A 11.29 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.

A 11.30 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.

A 11.31 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.

A 11.32 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

A 11.33 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.

A 11.34 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.

A 11.35 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.

A 11.36 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

A 11.37 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.

A 11.38 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.

A 11.39 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 1×10^5 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.

A 11.40 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) $^1S_0 \to$ (5s5p) $^1P_1$ 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.

A 11.41 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 $5\cdot10^6$ 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.

A 11.42 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.

A 11.43 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)

A 11.44 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.

A 11.45 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**

A 11.46 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.

A 11.47 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)

A 11.48 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.

A 11.49 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.

A 11.50 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.

A 11.51 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.

A 11.52 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.

A 11.53 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.

A 11.54 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.

A 11.55 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)

A 11.56 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.

A 11.57 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.

A 11.58 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.

A 11.59 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)

A 11.60 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.

A 11.61 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)

A 11.62 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.

A 11.63 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.

A 11.64 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.

A 11.65 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.

A 12: Precision Spectroscopy of Atoms and Ions III (joint session A/Q)

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

Invited Talk A 12.1 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.

A 12.2 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.

A 12.3 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.

A 12.4 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

A 12.5 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).

A 12.6 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).

A 12.7 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 $1s2s\,^3S_1 \to 1s2s\,^3P_J$ 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).

A 13: Ultra-cold Atoms, Ions and BEC III (joint session A/Q)

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

Invited Talk A 13.1 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.

A 13.2 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.

A 13.3 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.

A 13.4 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.

A 13.5 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.

A 13.6 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.

A 13.7 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

A 14: Interaction with VUV and X-ray light I (joint session A/MO)

Time: Wednesday 11:00–12:45 Location: GrHS Mathe

A 14.1 Wed 11:00 GrHS Mathe

High-resolution photoelectron spectroscopy with broad bandwidth pulses from high-harmonic sources — •Sarang Dev Ganeshamandiram[1], Tobias Witting[2], Ulrich Bangert[1], Daniel Uhl[1], Lauren Drescher[2], Benjamin Maingot[2], Oleg Kornilov[2], Frank Stienkemeier[1], Marc J.J. Vrakking[2], and Lukas Bruder[1] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany — [2]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

Extreme ultraviolet time-resolved photoelectron spectroscopy (XUV-TRPES) is a promising emerging method to study molecular dynamics. However, XUV pulses generated by high harmonic generation (HHG) exhibit very broad spectra, which leads to low spectral resolution in PES experiments, especially involving molecules.

Here, we explore a new approach of Fourier-Transform (FT) based XUV-PES that provides high spectral resolution, while temporal resolution is retained. This approach avoids the photon broadening problem and can disentangle the photoelectrons produced by different harmonics within the HHG spectrum. As model systems serve Rb atoms, and N_2 and O_2 molecules.

A 14.2 Wed 11:15 GrHS Mathe

Coherent control of strongly driven quantum dynamics using shaped extreme ultraviolet pulses — •Lukas Bruder — Institute of Physics, University of Freiburg, Germany

The shaping of femtosecond light fields with pulse shapers is a powerful technique enabling the control of quantum dynamics with high selectivity. While the technique is well established in the visible to infrared domain, comparable methods do not exist at shorter wavelengths in the XUV or X-ray domain. We have recently demonstrated the first coherent control experiment using pulse shaping in the XUV domain [1]. We show high fidelity quantum control of Rabi dynamics in helium atoms. In particular, the selective suppression of the two-photon ionization rate could be demonstrated and the strong dressing of continuum states was revealed, which is otherwise difficult to access at long wavelengths.

The results originate from the joint effort of many international laboratories and of a large number of researchers[1], whose work is gratefully acknowledged.

[1] F. Richter et al., arXiv:2403.01835 (2024)

A 14.3 Wed 11:30 GrHS Mathe

Exceptional points at x-ray wavelengths — •Fabian Richter[1], Lars Bocklage[2], Ralf Röhlsberger[2], Xiangjin Kong[3], and Adriana Pálffy[1] — [1]Julius-Maximilians-Universität Würzburg — [2]Deutsches Elektronen Synchrotron DESY, Hamburg — [3]Fudan University, Shanghai

Non-Hermitian Hamiltonians effectively describe dissipative systems, exhibiting phenomena absent in the Hermitian realm. Exceptional Points (EPs) are a prime example of this. At EPs not only the complex eigenvalues, but also the eigenvectors coalesce and sensitivity to perturbations is drastically enhanced. This concept has recently advanced in optics, where non-Hermitian eigenstates arise through optical gain and loss [1]. So far, these concepts have been mostly discussed in the optical regime. Similar control of x-rays is desirable due to their

superior penetration power, high focusability and detection efficiency.
Here, we investigate non-Hermitian x-ray photonics in thin-film cavities with Mössbauer nuclei under grazing-incidence x-ray radiation. These cavities present loss that can be controlled via adjustment of the cavity geometry and the incidence angle of the x-rays [2]. The application of a magnetic hyperfine field enables tuning the system towards EPs. We theoretically determine the magnetic field strength at which an EP occurs and predict qualitatively distinct behavior in the time spectrum at higher and lower field strengths. Analysis of experimental data confirms these predictions.

[1] L. Feng et al., Nature Photon. 11, 752-762 (2017).
[2] J. Evers, K. P. Heeg, Phys. Rev. A 88, 043828 (2013).

A 14.4 Wed 11:45 GrHS Mathe

Superradiant Parametric Mössbauer Radiation Source — •Ze-an Peng, Christoph H. Keitel, and Jörg Evers — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

Mössbauer nuclei facilitate a broad range of applications due to their extremely narrow resonance at x-ray frequency. However, it also renders a strong excitation via x-rays challenging. Here, we propose to construct a superradiant parametric Mössbauer radiation source, which is based on coherently modulated electron bunches exiting from x-ray free-electron laser (XFEL) undulator and passing through a crystal containing Mössbauer isotopes. Due to the constructive interference between the virtual-photon fields of different electrons in a single XFEL electron bunch, the intensity of Mössbauer radiation generated from the crystal can be boosted superradiantly, which scales with the square of electron number of XFEL electron bunch. This tremendous superradiant boost of Mössbauer radiation is also realized by a new geometry we proposed, which can be optimized by experimentally simple ways. Our study bears potential to enable coherent Mössbauer pump-probe spectroscopy, as well as nonlinear Mössbauer optical effects triggered by coherent XFEL electron beam.

[1] O. D. Skoromnik, I. D. Feranchuk, J. Evers, and C. H. Keitel, Phys. Rev. Accel. Beams 25, 040704 (2022).

A 14.5 Wed 12:00 GrHS Mathe

Single-shot electron spectroscopy of highly transient matter — •Sara Savio[1], Lars Funke[1], Niclas Wieland[2], Thorsten Otto[3], Lasse Wuelfing[1], Markus Ilchen[2,3], and Wolfram Helml[1] — [1]Technische Universitaet — [2]University of Hamburg — [3]Deutsches Elektronen-Synchrotron

Core-level photoionization is the process of absorbing a photon by an atom or molecule, ejecting an electron from one of its inner shells and creating a vacancy. This vacancy is then filled through various relaxation processes, which can lead to the emission of secondary electrons or energy redistribution within the system. We explore the generation of double-core holes (DCH) in gaseous neon atoms, which have a very short lifetime, using intense and ultrashort pulses on the attosecond scale at the European XFEL. The ultrafast electron dynamics are mapped on a single-shot basis using an electron time-of-flight (eTOF)spectrometer. Non-invasive systematic pulse characterization using the angular streaking technique provides spectral and temporal information about the ionizing XFEL pulses with attosecond resolution. We conduct a comprehensive study of how the contribution of DCH channels varies with beam parameters, including pulse duration, pulse energy, and the centres of the reconstructed spectra. Examining the electronic structure of the core-ionized system before relaxation, combined with the detailed information about the ionizing pulse, provides valuable insights into the nonlinear photoabsorption and the ultrafast process at extreme intensities on the time scales of electron dynamics.

A 14.6 Wed 12:15 GrHS Mathe

Cavity-controlled X-ray emission spectra — •Shu-Xing Wang[1,2], Xin-Chao Huang[3], Zhe-Qian Zhao[4], Xi-Yuan Wang[4], and Lin-Fan Zhu[4] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Giessen, Germany — [2]Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung, Campus Gießen, 35392 Giessen, Germany — [3]FXE instrument, European XFEL, Schenefeld 22869, Germany — [4]University of Science and Technology of China, Hefei, 230026, China

We report on the X-ray emission spectra from a thin-film cavity sample, measured using a von Hamos spectrometer at the GALAXIES beamline of the SOLEIL synchrotron radiation facility in Paris. The cavity consists of a multilayer structure: 21.8 nm Pt / 203.3 nm C / 29.4 nm WSi2 / 201.0 nm C / 144.6 nm Pt, deposited on a silicon substrate. X-ray emission spectra covering the Lα emission lines of W were recorded by scanning the incident X-ray energy across 10160-10240 eV (L_3 edge of W) at grazing angles near the first cavity mode. Our measurements reveal the collective Lamb shift and superradiant enhancement associated with the inner-shell transition. Notably, by concentrating on the resonant X-ray emission channel, we suppress the influence of the absorption edge, which might otherwise obscure the observed quantum optical effects.

A 14.7 Wed 12:30 GrHS Mathe

Measurement of resonant nuclear phase shift with a double-waveguide nano-interferometer — •Leon Merten Lohse[1,2,3], Ralf Röhlsberger[4,5,6,1,3], and Tim Salditt[2] — [1]The Hamburg Centre for Ultrafast Imaging, Hamburg — [2]Georg-August-Universität Göttingen — [3]Deutsches Elektronen-Synchrotron DESY, Hamburg — [4]Friedrich-Schiller-Universität Jena — [5]Helmholtz-Institut Jena — [6]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt

The phase of an electromagnetic wave is shifted upon scattering off atoms, coherently accumulating to result in the macroscopic index of refraction. In optical waveguides, propagating photons are spatially confined and can be coupled to resonant atoms in a controllable way. We interferometrically measured the phase shift that an ultrathin layer of ^{57}Fe Mössbauer nuclei coherently imprints onto x-ray photons propagating through a single-mode x-ray waveguide. Using the extracted phase shift, we were able to accurately quantify the coupling strength between individual photons and nuclei. Based on this, one can envision to actively control the phase in nanophotonic devices.

A 15: Members' Assembly

Time: Wednesday 13:15–13:45 Location: HS 6

All members of the Atomic Physics Division are invited to participate.

A 16: Collisions, Scattering and Correlation Phenomena I

Time: Wednesday 14:30–16:30 Location: HS PC

Invited Talk A 16.1 Wed 14:30 HS PC

Entanglement in the motional degree of freedom created in ultracold collisions — •Yimeng Wang and Christiane Koch — Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

Despite cold collisions being one of the most important tools of demonstrating quantum features and manipulating the particles, entanglement generated during the cold collision processes has been comprehensively studied only for the internal structures. The relative motion between the particles, which is crucial to the resonance phenomena and reactive processes, has been rarely discussed in entanglement literature because of its high dimensionality and complexity. In this project, we quantify the motional entanglement between two particles generated in ultracold collisions by computing the inter-particle purity. We reexam the formal scattering theories by using the Gaussian wave packets as pre-collision states, and then demonstrate the time evolutions of the scattered wave packets and the time-dependent inter-particle purity. We compare the degree of entanglement generated under different initial conditions, then study the influences from resonance states, and finally discuss the efficiency of different entanglement witnesses.

A 16.2 Wed 15:00 HS PC

Recoil-Ion and Electron Momentum Spectroscopy of Anion Neutral Interactions at a Cryogenic Ion Storage Ring — •Michael Schulz, Felix Herrmann, Weiyu Zhang, David Chicharro, Alexander Dorn, Manfred Grieser, Florian Grussie, Holger Kreckel, Oldrich Novotny, Florian Trost, Andreas Wolf, Thomas Pfeifer, Claus Dieter Schröter, and Robert Moshammer — Max-Planck-Institut für Kernphysik Heidelberg

We have measured momentum analyzed recoil ions and ejected electrons in triple coincidence with projectiles neutralized in collisions of slow anions with atoms. The experiment was performed at the Heidelberg cryogenic storage ring. From the data we extracted multiple differential cross sections for electron loss from the projectile (detachment) and for detachment accompanied by single and double target ionization (DI and DDI). Surprisingly large DI (and DDI) to detachment cross section ratios were found. Furthermore, in the differential momentum distributions of electrons ejected in DI we only observe signatures of a correlated mechanism while uncorrelated channels appear to be insignificant. This is also surprising because the projectile energy is well below the threshold for the correlated mechanism and DI is kinematically possible only because of the initial momentum distribution of the electrons in their initial bound states.

A 16.3 Wed 15:15 HS PC

Towards Light Scattering Experiments in Dense Dipolar Gases — •Rhuthwik Sriranga, Marvin Proske, Ishan Varma, Chung-Ming Hung, Dimitra Cristea, and Patrick Windpassinger — Johannes-Gutenberg Universität Mainz

In ultracold atomic ensembles where interatomic spacing is smaller than the wavelength of scattered light, direct matter-matter coupling through electric and magnetic interactions significantly influence system dynamics, challenging the approximation of atoms as independent emitters. We study the role of magnetic dipole-dipole interactions (DDI) in the cooperative behavior of dense atomic ensembles using dysprosium, which has the highest ground-state magnetic moment (10 Bohr magnetons). Our light-scattering experiments probe these effects in thermal and degenerate dense dipolar media.

This presentation details progress in generating ultradense cold dysprosium clouds, including optical transport of atoms into a home-built science cell enabling precise cloud manipulation. The cell's compact design allows tight dipole trapping with a high numerical aperture objective made in-house. We also discuss the impact of optical dipole trap polarization on atomic lifetime and outline future experiments to uncover collective effects, advancing the study of cooperative quantum phenomena.

A 16.4 Wed 15:30 HS PC

Electron-Impact Ionization of La^{1+} with a new Scan-System — •B. Michel Döhring[1,2], Alexander Borovik Jr.[1], Kurt Huber[1], and Stefan Schippers[1,2] — [1]Justus-Liebig-Universität Gießen — [2]Helmholtz Forschungsakademie Hessen für Fair, GSI Helmholtzzentrum für Schwerionenforschung, Campus Gießen

Recently, we commissioned a new scanning system for the measurement of electron-impact ionization cross sections in a crossed-beams geometry. Here, we present experimental results for single, double and triple electron-impact ionization of La^{1+} ions, with impact energies starting from the ionization threshold and ranging up to 2000 eV. As compared to previous single-ionization measurements [1], we have extended the energy range by a factor of two. The results are geared towards providing atomic data for kilonova modelling and may be another good opportunity to apply our hybrid method for the calculation of electron-impact ionization cross sections [2] in future works.

[1] A. Müller et al., Phys. Rev. A **40**, 3584 (1989)
[2] F. Jin et al., Eur. Phys. J. D **78**, 68 (2024)

A 16.5 Wed 15:45 HS PC

A Novel Compton Telescope for Polarimetry in the MeV Range — •Tobias Over[1,2,3], Thomas Krings[4], Wilko Middents[1,2,3], Uwe Spillmann[1], Günter Weber[1,2], and Thomas Stöhlker[1,2,3] — [1]Helmholtz Institute Jena, Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [3]Friedrich Schiller University Jena, Jena, Germany — [4]Forschungs Zentrum Jülich, Jülich, Germany

For photon energies from several tens of keV up to a few MeV, Compton polarimetry is an indispensable tool to gain insight into subtle details of fundamental radiative processes in atomic physics. Within the SPARC collaboration [1] several segmented semiconductor detectors have been developed that are well suited for application as efficient Compton polarimeters. For photon emission processes in the hard x-ray regime these kind of detectors enable revealing photon polarization effects in great detail [2]. In our presentation, a novel Compton telescope detector that will enable us to extend to photon energies up to the MeV range will be presented. In particular, we will discuss new experimental possibilities in the higher energy range.

[1] Th. Stöhlker et al. Nucl. Instrum. Methods Phys. Res. B 365 (2015) 680.
[2] K.H. Blumenhagen et al. New J. Phys. 18 (2016) 119601.

A 16.6 Wed 16:00 HS PC

Polarization effects in the Compton scattering from atomically bound electrons — •Wilko Middents[1,2,3], Günter Weber[1,2], Tobias Over[1,2,3], Alexander Gumberidze[2], Philip Pfäfflein[1,2,3], Uwe Spillmann[2], and Thomas Stöhlker[1,2,3] — [1]Helmholtz Institute Jena, Jena, Germany — [2]GSI, Darmstadt, Germany — [3]Friedrich Schiller University Jena, Jena, Germany

Precise studies of the linear polarization for Compton scattered photons open the unique opportunity for a detailed test of the impulse approximation for energetic photon matter interaction. Compton scattering is the inelastic scattering of a photon from an electron, in which the scattered photon carries a lower energy than the incident photon. The energy of the scattered photon depends on the scattering angle. For scattering from bound electrons, the resulting Compton scattering peak is broadened due to the momentum distribution of the electrons leading to a Doppler shift of the incident and scattered photons. Additionally, we expect the electron momentum distribution to influence the scattered photon polarization such, that the linear polarization will vary across the Compton peak.

We performed an experiment at the synchrotron facility PETRA III at DESY in Hamburg, in which we scattered the highly polarized hard x ray beam from a gold target. We analyzed the scattered radiation under several scattering angles with a special interest to the linear polarization of the scattered radiation. We will show the result of the analysis of the Compton scattered radiation and compare it to a simulation developed in the framework of the impulse approximation.

A 16.7 Wed 16:15 HS PC

Three-charged-particle systems in the framework of coupled coordinate-space few-body equations — •Renat Sultanov — The University of Texas Permian Basin, Odessa, Texas, USA

We study three-charged-particle low-energy elastic collision and particle-exchange reaction with special attention to the systems with Coulomb and an additional nuclear interaction employing a close-coupling expansion scheme to a set of coupled two-component few-body equations [1]. First we apply our formulation to compute low-energy elastic scattering phase shifts for the $d+(t\mu^-)_{1s}$ collision, which is of significant interest for the muon-catalyzed-fusion D-T cycle. Next, we study the particle-exchange reaction $d+(pX^-) \to p+(dX^-)$ with the long lived elementary heavy lepton stau X^- which can play a critical role in the understanding of the Big-Bang nucleosynthesis and the nature of dark matter.

We also study the total cross sections and rates for two particle-exchange reactions involving antiprotons ($\bar{p}$), deuteron (d) and triton (t), e.g., $\bar{p}+(d\mu)_{1s} \to (\bar{p}d)_{1s}+\mu^-$ and $\bar{p}+(t\mu)_{1s} \to (\bar{p}t)_{1s}+\mu^-$, where μ^- is a muon. The effect of the final state short-range strong ($\bar{p}d$) and ($\bar{p}t$) nuclear interaction is significant in these reactions, which increases the reaction rates by a factor of ≈ 3. Additionally (if time permits), a 3-body $\bar{p}+Mu$ collision will be discussed, where Mu is a muonium atom [2].

1. R. A. Sultanov and S. K. Adhikari, Phys. Rev. C 107, 064003 (2023).
2. R. A. Sultanov and D. Guster, J. Phys. B 46, 215204 (2013).

A 17: Interaction with Strong or Short Laser Pulses I (joint session A/MO)

Time: Wednesday 14:30–16:15 Location: GrHS Mathe

Invited Talk A 17.1 Wed 14:30 GrHS Mathe
Time Resolved Diffractive Imaging of Laser Induced Dynamics in Materials — •Tom Böttcher, Richard Altenkirch, Stefan Lochbrunner, Christian Peltz, Thomas Fennel, and Franziska Fennel — Institute of Physics and Department of Life, Light and Matter, University of Rostock, 18051 Rostock, Germany

Micromachining with ultrashort laser pulses is widely used for industrial applications. In contrast to picosecond and nanosecond lasers, ultrashort laser pulses allow precise material modifications due to local electronic excitation on timescales well below electron-ion equilibration times and thermal dissipation. However, the underlying processes leading to target modification and ablation after ultrashort laser pulse excitation are still insufficiently understood.

We present an experimental method to study the excitation and relaxation processes in thin gold films using femtosecond to nanosecond single-shot pump probe coherent diffractive imaging. The target is a 30 nm-thick, free-standing gold foil, which is excited using an 800 nm femtosecond pump pulse. The dynamics in the excited foil are imaged after a variable time delay using a 400 nm femtosecond probe pulse which creates a diffraction image that is captured by a CMOS camera. A phase retrieval algorithm is used to reconstruct the 2D spatial and time resolved exit field at the target position from the captured diffraction images. Dynamics are monitored up to 2 ns, providing access to ultrafast excitation (fs-ps regime) as well as melting and ablation dynamics (ps-ns regime).

A 17.2 Wed 15:00 GrHS Mathe
Ionization and Fragmentation of Polyatomic Molecules in Intense Laser Fields using a Reaction Microscope — •Martin Garro, Narayan Kundu, Horst Rottke, Arne Senftleben, and Jochen Mikosch — Institut für Physik, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

As attosecond science advances into the study of polyatomic molecules, the many-electron and non-adiabatic phenomena in strong-field ionization (SFI) become relevant. A fundamental question concerns the population of electronically excited states of the cation in the intense field, in particular whether these processes are direct or sequential. We study ionization and fragmentation of polyatomic molecules in intense laser fields experimentally with a Reaction Microscope. Coincidence detection of electron and ion momenta reveal detailed insights into the underlying physics. This presentation highlights our recent work on SFI of 1,3-butadiene, n-butane, and 1-butene, in which the intensities and wavelengths were varied. We observe qualitative changes of experimental observables as a function of these parameters, which we interpret as transition between non-sequential and sequential excitation processes.

A 17.3 Wed 15:15 GrHS Mathe
Machine learning for retrieval of the time-dependent internuclear distance in a molecule from photoelectron momentum distributions: fully quantum mechanical approach — •Nikolay Shvetsov-Shilovski and Manfred Lein — Leibniz Universität Hannover

We use a neural network for retrieval of the time-varying bond length in a dissociating one-dimensional H_2^+ molecule based on photoelectron momentum distributions (PMDs) from strong-field ionization. In contrast to our previous study [1], the motion of the atomic nuclei is treated fully quantum mechanically, i.e., PMDs are obtained from the solution of the time-dependent Schrödinger equation for the wavefunction depending on both the electron coordinate and the internuclear distance. We show that the neural network can recognize the time-dependent bond length with a good accuracy. Therefore, machine learning can be applied for time-resolved molecular imaging.

[1] N. I. Shvetsov-Shilovski and M. Lein, J. Phys. B: At. Mol. Opt. Phys. 57, 06LT01 (2024).

A 17.4 Wed 15:30 GrHS Mathe
Harmonic generation with topological edge states and electron-electron interaction — •Siamak Pooyan and Dieter Bauer — Institute of Physics, Rostock University, 18051 Rostock, Germany

It has been found previously that the presence or absence of topological edge states in the Su-Schrieffer-Heeger (SSH) model has a huge impact on harmonic generation spectra. More specifically, the yield of harmonics for harmonic orders that correspond to photon energies below the band gap is many orders of magnitude different in the trivial and topological phase. It is shown in this work that this effect is still present if electron-electron interaction is taken into account, i.e., if a Hubbard term is added to the SSH Hamiltonian. To that end, finite SSH-Hubbard chains at half filling are considered that are short enough to be accessible to exact diagonalization but already showing edge states in the topological phase. We show that the huge difference in the harmonic yield between the trivial and the topological phase can be reproduced with few-level models employing only the many-body ground state and a few excited many-body states.

A 17.5 Wed 15:45 GrHS Mathe
High-harmonic generation in weakly coupled organic molecular systems — •Falk-Erik Wiechmann[1,2], Samuel Schöpa[1], Lina Marie Bielke[1], Felipe Morales[3], Serguei Patchkovskii[3], Maria Richter[3], Dieter Bauer[1], and Franziska Fennel[1,2] — [1]Intitute of physics, University of Rostock, 18059 Rostock, Germany — [2]Department of Life, Light and Matter, University of Rostock, 18059 Rostock — [3]Max Born Institute (MBI) for Nonlinear Optics and Short Pulse Spectroscopy, 12489 Berlin, Germany

We introduce organic molecular crystals (OMCs) as a novel target class for high-harmonic Generation (HHG), bridging the gap between gas phase and solid state high-harmonic spectroscopy. In OMCs, neighboring molecules experience a weak van-der-Waals coupling, considerably smaller compared to the covalent or ionic bonds in previous solid-state target. However, this finite coupling leads to *solid like* features, e.g. a delocalization of the electronic states over several unit cells. Additionally, the perfect inherent alignment of all molecules makes OMCs an ideal target class for HH spectroscopy of large organic molecules, as it avoids the need for extremely challenging alignment techniques that have so far prevented corresponding measurements in the gas phase. With a fundamental 4000 nm mid-IR beam reaching 0.67 TW/cm2 we demonstrate that HHG from Pentacene crystals is possible without imposing physical damage. We find that the harmonic-generation process is driven by collective intermolecular effects and not by the response of non-interacting aligned molecules.

A 17.6 Wed 16:00 GrHS Mathe
A theoretical perspective on high-harmonic generation in organic molecular crystals — •Samuel Schöpa[1], Lina Bielke[1], Falk-Erik Wiechmann[1], Felipe Morales[2], Serguei Patchkovskii[2], Maria Richter[2], Franziska Fennel[1], and Dieter Bauer[1] — [1]Intitute of physics, University of Rostock, 18059 Rostock — [2]Max Born Institute (MBI) for Nonlinear Optics and Short Pulse Spectroscopy, 12489 Berlin

We investigate the underlying mechanism of high-harmonic generation (HHG) in the novel target class of organic molecular crystals (OMCs). Compared to covalent and ionic-bonded solids, the molecules that bond to form OMCs are much more weakly coupled, which is reflected in an energy band structure dominated by single-molecule excitations and charge-transfer states of neighbouring molecules. But does the intramolecular response of the aligned molecules dominate the HHG process? Or can we exploit HH spectroscopy to study the solid-state properties of OMCs, which are characterized by the intermolecular couplings? We addressed this by simulating the HHG process using full time-dependent density-functional theory (TD-DFT) for different polarizations of the driving field and compared it with experimental results. We find in both, that the rotation of the driver polarization reveals maxima in the harmonic yield when the polarization is aligned with the axes connecting neighbouring molecules. A simple tight-binding model shows, that lower harmonic orders are primarily governed by the intramolecular response, while higher orders depend mainly on the intermolecular coupling.

A 18: Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)

Time: Wednesday 14:30–15:45 Location: KlHS Mathe

A 18.1 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).

A 18.2 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

A 18.3 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)

A 18.4 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.

A 18.5 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).

A 19: Ultracold Matter (Bosons) III (joint session Q/A)

Time: Wednesday 14:30–16:30 Location: WP-HS

A 19.1 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).

A 19.2 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).

A 19.3 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).

A 19.4 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

A 19.5 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.

A 19.6 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.

A 19.7 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)

A 19.8 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 (IQST), 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).

A 20: Poster – Atomic Clusters

Time: Wednesday 17:00–19:00 Location: Tent

A 20.1 Wed 17:00 Tent

Ab-initio study of the transition pathways for single and double interstital solute (H, N, O, H-H, N-N and O-O) within bcc refractory metals (Mo and Nb) — •Henry Elorm Quarshie[1], Henry Martin[1,2], Eric Kwabena Kyeh Abavare[1], and Alessandra Continenza[3] — [1]Department of Physics, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana — [2]Center for Scientific and Technical Computing, National Institute for Mathematical Sciences, Kumasi, Ghana — [3]Dipartimento di Scienze Fisiche e Chimiche, Universita degli studi dell'Aquila, L'Aquila, Italy

This study investigates the diffusion pathways of single (H, N, O) and double (H-H, N-N, O-O) interstitial solutes in bcc molybdenum (Mo) and niobium (Nb). The aim is to understand how atmospheric gases rich in H, O, and N interact with metals. Ab-initio calculations were performed to determine equilibrium parameters, dissolution energetics, charge transfer, minimum energy paths, and diffusion coefficients. Single solutes exhibited site preferences, with H favouring tetrahedral sites (t-sites), N preferring octahedral sites (o-sites), and O showing material-dependent behaviour linked to the deformation behaviour of Mo and Nb. Diffusion energy barriers ranged from 0.10 eV to 1.34 eV, aligning with experimental results. The study also examined double interstitial solutes and found that a second solute significantly reduces activation energies, enhancing diffusion in most configurations, except for Mo-O. This effect is due to the second solute's influence on local lattice relaxations and interstitial interactions. The work further reveals that a second solute can alter the preferred diffusion pathways.

A 20.2 Wed 17:00 Tent

Design and Analysis of Metal-Organic Frameworks for Enhanced Water Purification — •Abdul Rahman Junior Mohammed[1] and Henry Martin[1,2] — [1]Department of Physics, Kwame Nkrumah University of Science and Technology — [2]Center of scientific and Technical Computing, National Institute for Mathematical Sciences Kumasi Ghana

This work is dedicated to the computational design and analysis of Metal-Organic Frameworks with the purpose of improving water purification processes. Increased concern about water quality, considering a wide range of contaminants, calls for urgent action toward efficient and sustainable methods of purification. Advanced computational capabilities involved in this study include molecular dynamics, density functional theory, and machine learning techniques employed to optimize structural properties and performance of selected MOFs. The synthesis and characterization of new MOFs, such as UiO-66-NH2, possessing very good adsorption properties for pollutants of various origins, including heavy metals, dyes, and VOCs, are among the focuses of this work. We investigate how the variation of temperature, pressure, and interaction solvent through the simulation of different conditions of synthesis can impact stability and effectiveness. It follows that the tailored design of MOFs significantly improves their adsorptive efficiency and stability in an aqueous environment. Moreover, the embedding of ML techniques will allow the predictive modeling of MOF performances to enable them to identify crucial features of MOF structures responsible for enhancement in the purification capability.

A 20.3 Wed 17:00 Tent

Reconstructing the anisotropic expansion of a laser driven nanoplasma — •Paul Tuemmler[1], Felix Gerke[2], Christian Peltz[1], Hendrik Tackenberg[1], Björn Kruse[1], Bernhard Wassermann[2], Thomas Fennel[1], and Eckart Rühl[2] — [1]University of Rostock, D-18059 Rostock, Germany — [2]Freie Universität Berlin, D-14195 Berlin, Germany

Coherent diffractive imaging (CDI) at X-ray free-electron lasers (FELs) has evolved into a well-established method for the structural investigation of unsupported nanoparticles. This inherently static method can be readily adopted to time-dependent studies by incorporating a second pulse in a pump-probe scheme.

In a recent experiment at LCLS, we utilized this method to study the fundamental process of free plasma expansion into vacuum using the example of laser-pumped SiO_2 nanospheres. The resulting plasma expansion rapidly and isotropically softens the initial surface density step. This, in turn, increases the radial decay of the scattering signal eventually precluding meaningful measurements due to a diminishing signal-to-noise ratio within only a few hundred femtoseconds [1].

Here, we present the results of a follow-up experiment at the European XFEL where we revisited SiO_2 as a target, but operated in a weaker excitation regime. This approach allowed us to record images over far longer timescales and revealed a strong anisotropic expansion dynamic, as predicted by theory [2].

[1] C. Peltz *et al.*, New J. Phys. **24**, 043024 (2022).
[2] C. Peltz *et al.*, Phys. Rev. Lett. **113**, 133401 (2014).

A 20.4 Wed 17:00 Tent

Towards experimental studies of interatomic Coulombic electron capture (ICEC) — •Andre Miranda Rocco Giraldi and Alexander Dorn — Max Planck Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

This work targets the experimental detection of an environment assisted atomic decay mechanism [1], referred to in literature as excitation transfer ionization. The process constitutes the resonant excitation of a neon atom in a cluster by electron impact to a 2p5 3s or 2p5 3p state (excitation energy on the range of 16 to 19 eV), and subsequent deexcitation by ionizing a neighboring Ar atom (ionization potential of 15.8 eV). This reaction has been evidenced by laser-induced excitation of neon, but remains to be detected by means of an electron beam as the excitation mechanism. The confirmation of such process could provide insight into the role of the atomic environment on energy transfer and help gather information about ICD- and ICEC-like reactions. Presently we are adapting an electron and ion momentum spectrometer (reaction microscope) and are optimizing the formation of neon-argon dimers or bigger mixed clusters which requires the determination of the optimal conditions (nozzle temperature, gas pressure and mixing ratio). First results will be presented.

[1] Gokhberg, K. and Cederbaum, L.S. (2009). Environment assisted electron capture. Journal of Physics B: Atomic, Molecular and Optical Physics.

A 20.5 Wed 17:00 Tent

Disentangling hard x-ray induced relaxation mechanisms in atomic clusters using multiparticle coincidence spectroscopy — •Niklas Golchert[1], Yusaku Terao[1], Emilia Heikura[1], Madhusree Roy-Chowdhury[1], Minna Patanen[2], Oksana Travnikova[3], Arno Ehresmann[1], and Andreas Hans[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett Str. 40, 34132 Kassel, Germany — [2]Nano and Molecular Systems Research Unit, Faculty of Science, University of Oulu, PO Box 3000, Oulu 90014, Finland — [3]Sorbonne Université, CNRS, UMR 7614, Laboratoire de Chimie Physique-Matière et Rayonnement, F-75005 Paris, France

Understanding the response of dense media to high-energetic photons, explicitly in the context of biological radiation damage, is essential for the targeted use of radiation therapy and the fundamental knowledge on electron correlations alike. Noble gas clusters often serve as prototype systems for fundamental research on dense media. For the analysis of the involved processes, electron spectroscopy is a sensitive tool, which is, however, challenged by the increasing number of possible mechanisms that accompany large amounts of stored energy. We employed multielectron-photon coincidence spectroscopy to investigate the behavior of prototypical argon clusters upon deep inner-shell ionization with hard x-rays to disentangle the consecutive relaxation mechanisms that may or may not involve neighboring constituents of a conglomerate of particles.

A 21: Poster – Atomic Systems in External Fields

Time: Wednesday 17:00–19:00 Location: Tent

A 21.1 Wed 17:00 Tent

Electron-Phonon Coupling and Molecular Dynamics in Rydberg Atom Arrays — •Simon Euchner, Wilson S. Martins, and Igor Lesanovsky — Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

Rydberg atoms held in optical tweezers feature electronic and vibrational degrees of freedom which can be brought into interaction in a controllable way. Therefore, these systems enable the investigation of dynamical phenomena, similar to those studied in molecular physics, but on exaggerated length and time scales. Beyond certain coupling strengths the vibrational motion becomes unstable, and we derive the critical values. Moreover, we investigate quantum corrections to the ground state energy, which are not captured by the Born-Oppenheimer approximation. Finally, we propose a protocol to prepare molecular states whose structure is strongly affected by the electron-phonon coupling. This shows that trapped Rydberg atom arrays indeed offer a versatile platform for the study of dynamical quantum phenomena that link to molecular physics.

A 21.2 Wed 17:00 Tent

Phase diagram and emergent phenomena in a nonequilibrium three-level Rydberg atom-cavity system — •Paul Haffner[1], Igor Lesanovsky[1,2], and Federico Carollo[3] — [1]Institut für 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 — [3]Centre for Fluid and Complex Systems, Coventry University, Coventry, CV1 2TT, United Kingdom

Atom-cavity systems are the focus of extensive research due to their rich nonequilibrium dynamics and potential applications in quantum technologies. Here, we investigate a nonequilibrium atom-cavity in which interacting Rydberg states are excited by a combination of the cavity-field and a laser. Using a mean-field approximation, we derive and analyze the nonlinear differential equations governing the system's dynamics. The long-time steady state reveals three distinct phases—stationary states, dark states, and time crystals—with secondorder phase transitions separating them. A stability analysis confirms the robustness of these phases. Finally, we identify a specific fine-tuned condition under which electromagnetically induced transparency accompanied by a dark state emerges.

A 21.3 Wed 17:00 Tent

Quantum orbit theory applied to HATI spectra from metallic nanotips — •Timo Wirth[1], Stefan Meier[1], Jonas Heimerl[1], and Peter Hommelhoff[1,2] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Department Physik, Ludwigs-Maximilians-Universität München (LMU), 80799 München

Quantum orbit theory naturally resembles the three-step model for high order above-threshold ionization (HATI). Unlike its classical realization, quantum orbit theory contains the full quantum mechanical information from the strong-field approximation (SFA) and is therefore suitable to explain electron interference effects. Every contribution in quantum orbit theory is connected to an electron trajectory. The metal boundary condition of the nanotip is accounted for through a selection of quantum orbits while near-field effects are discussed in comparison with TDSE simulations. We apply quantum orbit theory to a HATI measurement of a tungsten nanotip illuminated with laser pulses at a central wavelength of 1550 nm. We find clear signs of intracycle interference. We discuss the spectral positions and the magnitude of these interference signals in terms of quantum orbits.

A 21.4 Wed 17:00 Tent

Design and realisation of magnetic field coils for quantum network node experiments — •Vincent Beguin, Raphael Benz, Sebastián Alejandro Morales Ramirez, Micha Kappel, Krishna Relekar, and Stephan Welte — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

The Implementation of a quantum communication network is a challenging task which is addressed in several hardware platforms. Among these, neutral atoms coupled to optical cavities offer a promising approach for realizing quantum networks, with potential applications ranging from distributed quantum computing to secure quantum communication. For these applications, it is crucial to establish well-defined conditions in the spatial region where the atoms are located. In particular, precise control over external magnetic field is essential, as the application of a constant guiding field along the cavity axis is a prerequisite for most experimental protocols.

Here we present the design and implementation of a set of three rectangular magnetic field coils arranged in a Helmholtz configuration. The coils are oriented in three spatial directions, enabling compensation of the Earth's magnetic field and the application of a guiding field along the cavity axis. We characterize important characteristics of our setup, including the heating effects and the field homogeneity within the central region between the coils.

A 21.5 Wed 17:00 Tent

Leveraging of self-supervised machine learning over supervised machine learning for crystalline materials properties prediction. — •Moses Adasariya — Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana

The accurate prediction of material properties is essential for the progress of materials science. However, the limited availability of labeled datasets presents a considerable obstacle. This research investigates the capabilities of self-supervised learning (SSL) models to overcome this challenge by utilizing the bulk unlabeled data available for predicting the properties of crystalline materials. Three SSL models were assessed alongside four different supervised learning (SL) model their ability to predict bandgap, formation energy, bulk modulus, and shear modulus. The findings revealed that SSL models consistently outperformed or equaled the performance of SL models across all evaluated tasks. CrysAtom was identified as the most effective model, achieving improvement percentage of 15.1% over orbital graph convolutional neural network (OGCNN) for bandgap, and 9.7% for formation energy over OGCNN. The other SSL models, CT-Barlow and CT-SimSiam, also demonstrated competitive results, particularly in the predictions of bandgap and formation energy. These results underscore the potential of SSL models to diminish dependence on labeled datasets while preserving high levels of prediction accuracy

A 21.6 Wed 17:00 Tent

Photoelectron emission from silver clusters on substrates — •Mikhail Bednov and Dieter Bauer — Institute of Physics, University of Rostock, Germany

We investigate the photoelectron emission from silver clusters of 5 to 15 nanometers in size, deposited on silica substrates with a thin oxidation layer. The particles are illuminated by an 800 nm laser with an intensity of approximately $10\,\mathrm{GW/cm^2}$.

The field distribution is calculated classically using the Green's dyadic method, which provides a good description of electric field enhancement around the particle. This allows us to identify areas of highest field enhancement and calculate the rate of field decay from the particle.

Quantum simulations based on time-dependent density functional theory are performed in one dimension, along the direction of dominant electron emission from corners of the particle where the field enhancement is largest. The aim of these studies is to elucidate the role of the plasmon resonance in the emission process.

A 21.7 Wed 17:00 Tent

Velocity-map imaging of strong-field ionization in standing waves — •Tobias Heldt, Jan-Hendrik Oelmann, Lennart Guth, Lukas Matt, Anant Agarwal, Thomas Pfeifer, and José R. Crespo López-Urrutia — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

To study nonlinear light-matter interactions like multiphoton or tunnel ionization, intense light fields are essential. We employ a femtosecond enhancement cavity to achieve intensities over $10^{13}\,\mathrm{W/cm^2}$ at a 100 MHz repetition rate using a near-infrared frequency comb. The bow-tie cavity supports counter-propagating pulses, forming a transient standing wave at the focus. Here, a gas nozzle and velocity-map imaging (VMI) spectrometer are integrated to analyze the angular distribution of emitted photoelectrons [1].

At the antinodes of the standing wave, constructive interference leads to a doubling of the maximum intensity compared to single pulse operation. Additionally, the ionization region along the beam propagation is reduced because it no longer depends on the Rayleigh length but on the < 200 fs overlap of the pulses. This reduction of the focal volume allows momentum imaging without electrostatic focusing [2]. Furthermore, the electrons are diffracted by the structured ponderomotive potential of the standing wave. This phenomenon, known as the Kapitza-Dirac effect, changes the momentum and angular distribution of the photoelectrons.

[1] J.-H. Oelmann et al., Rev. Sci. Instrum., 93(12), 123303 (2022)
[2] T. Heldt et al, Opt. Lett. 49, 6825-6828 (2024).

A 21.8 Wed 17:00 Tent

Generalized Moyal Product in Time-Dependent Electromagnetic Fields — •Arjit Shankar Banerjee[1,2], Andre G. Campos[1], and Christoph H. Keitel[1] — [1]Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany — [2]Indian Institute of Science Education and Research (IISER) Tirupati, 517507 Tirupati, Andhra Pradesh, India

The Wigner - Weyl Transformation provides a framework to represent Quantum Mechanical Systems in terms of phase space variables x and p. The Moyal formula defines a nontrivial composition rule that relates the operator product in terms of their Weyl symbols. However, in the presence of electromagnetic fields, the canonical momentum becomes gauge-dependent, but the corresponding operators generally are gauge-independent. Thus, we must redefine the gauge-independent Weyl symbols and the composition rules. While previous works focused on time-independent magnetic fields, we have developed a generalized Moyal product valid for time-dependent electromagnetic fields. An application of the generalized Moyal Product is in the case of Open Quantum Systems, where we are calculating the Lindblad operator in the Foldy-Wouthuysen representation.

A 22: Poster – Attosecond Physics

Time: Wednesday 17:00–19:00 Location: Tent

A 22.1 Wed 17:00 Tent

Towards attosecond temporal resolution with split-and-delay units at FLASH — •Matthias Dreimann, Michael Wöstmann, Tobias Reiker, Victor Kärcher, and Helmut Zacharias — Center for Soft Nanoscience, Universität Münster, Germany

The development of ultrashort FEL pulses with few-fs and sub-fs pulses is a research field in the FEL community with promising applications. One of these applications are pump/probe experiments with ultrashort FEL pulses, as the temporal dynamic of the system is a key to the fundamental understanding of its underlying physics. Split-and-delay units have extensively contributed in this type of experiments, typically providing 'jitterless' temporal resolution in the range of some hundred attoseconds. Considering the sub-femtosecond pulse duration of recent ultrashort pulses a further improvement of the temporal resolution is mandatory.In this contribution we propose methods to improve the temporal resolution of split-and-delay units down to some attoseconds.

A 22.2 Wed 17:00 Tent

Bilobran-Angelo entropic distance in coherently and incoherently-driven high-harmonic generation — •Arlans Juan Smokovicz de Lara, Ulf Saalmann, and Jan-Michael Rost — Max-Planck-Institute für Physik komplexer Systeme

Since its discovery, high harmonic generation (HHG), as a process nonlinear in the number of photons, has been realized with intense *classical* light. Recently, progress has been made towards a quantum mechanical description of the harmonic modes, enabling the creation of nonclassical intense light pulses [1], which promises new quantum effects in the interaction with matter. In particular, thanks to said quantum description of the modes, we can now treat interesting quantum mechanical properties, for instance the realism of measurements in the context of the Bilobran-Angelo entropic distance [2]. We will present first results of said quantity in the contexts of coherently-driven [3] and incoherently-driven [4] in HHG in pristine graphene.

[1] M. Lewenstein, M. F. Ciappina, E. Pisanty, J. Rivera-Dean, P. Stammer, Th. Lamprou and P. Tzallas, Nature Physics **17**, 1104 (2021).
[2] A. L. O. Bilobran and R. M. Angelo, EPL **112** 40005 (2015).
[3] J. Rivera-Dean, P. Stammer, A. S. Maxwell, Th. Lamprou, A. F. Ordóñez, E. Pisanty, P. Tzallas, M. Lewenstein and M. F. Ciappina, Phys. Rev. B **109**, 035203 (2024).
[4] P. Stammer, Phys. Rev. Research **6**, L032033 (2024).

A 22.3 Wed 17:00 Tent

A Beamline for soft X-ray attosecond spectroscopy — •Naglis Kriunas[1,2], Fabian Scheiba[1,3,4], Rafael d. Q. Garcia[1,3], Maximilian Kubullek[1,3], Miguel Silva[1,3], Roland E. Mainz[1,3,4], Giulio Maria Rossi[1,4], and Franz X. Kärtner[1,3,4] — [1]Center for Free-Electron Laser Science CFEL and Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany — [2]School of Chemistry, University of Edinburgh, The King's Buildings, West Mains Road, Edinburgh EH9 3JJ, UK — [3]Physics Department, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [4]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

We present the layout of our newly developed attosecond beamline. To improve the soft X-ray detection, we implemented a high efficiency reflective zone plate spectrometer. A differentially pumped transient absorption cell allows for gas phase experiments with organic molecules. Our sub-cycle parametric waveform Synthesizer (PWS) [1] allows for sub-fs pump duration in multi-photon/strong-field interaction. This, jointly with tunable isolated attosecond pulses with photon energies from the XUV up to 450 eV enables attosecond resolution in both, pump and probe. A precise dispersion management scheme and phase stabilization paves the way for quantum control in photochemical reactions.

[1] Rossi, G.M. et al. Sub-cycle millijoule-level parametric waveform

synthesizer for attosecond science. Nat. Photonics 14, 629-635 (2020). https://doi.org/10.1038/s41566-020-0659-0

A 22.4 Wed 17:00 Tent

High harmonic generation in a non-Hermitian Su-Schrieffer-Heeger chain — •Milad Jangjan and Dieter Bauer — Rostock university, Rostock, Germany

Investigating high harmonic generation (HHG) in the One-Dimensional Su-Schrieffer-Heeger (SSH) model with gain and loss is very interesting because it combines nonlinear optical response (HHG) and non-Hermitian physics. We carry out numerical simulations to study how the transmission of energy changes and the gain and loss dynamics affect the band structure, and polarization currents, which are on the very basis of HHG. Our findings show that gain/loss affects the harmonic spectra, the cutoff energies, and some harmonics significantly differ from the response of the Hermitian SSH model. In addition, we identify the trait characteristics of exceptional points in the HHG spectrum, which is a new way to probe non-Hermitian physics through ultrafast nonlinear optics. In this study, we have not only improved our understanding of HHG in non-Hermitian systems but also introduced new ways of making tunable ultrafast light sources and examining topological signatures in materials that are gain/loss-engineered.

A 22.5 Wed 17:00 Tent

Photoemission Timing of Xe adsorbed on Pt(111) over a wide range of Xe layers — •Sven-Joachim Paul[1], Luc Tremel[1], Jasper Aeschlimann[1], Peter Feulner[2], and Reinhard Kienberger[1] — [1]Chair for laser and x-ray physics, E11, Technische Universität München, Germany — [2]Surface and Interface Physics, E20, Technische Universität München, Germany

We report on attosecond streaking measurements of the electron photoemission process from the platinum (111) surface covered by xenon.

Attosecond streaking enables measuring relative time delays in photoemission from energetically different bound electronic states. This experiment addresses three states: Xe4d, Xe5s, and the Pt valence band.

Photoemission delays in these states have been observed for surface coverages ranging from 0.25 monolayers to 11 monolayers.

From a coverage of 3 monolayers, the Xe5s state became visible, enabling an internal delay measurement of the Xe states even without the need for the platinum valence band as a reference.

As xenon is a dielectric medium, the streaking field already acts in the adsorbed layers. Therefore, these measurements are more similar to gas phase measurements than experiments, which only address states of metals. On top of that, by comparing the photoemission delays for different layer thicknesses, the penetration depth of the streaking field can be estimated.

A 22.6 Wed 17:00 Tent

Noise Parametrization and Simulation for Attosecond Streaking — •Luc-Fabrice Tremel, Sven-Joachim Paul, Maximilian Forster, and Reinhard Kienberger — Chair for laser and x-ray physics E11, Technische Universität München, Germany

We address the extraction of noise parameters from attosecond streaking measurements and their influence on the performance of the restricted time-dependent Schrödinger equation (rTDSE) algorithm for photoemission time delay retrieval. The development and application of noise parameter extraction techniques reveal an energy and target-specific behavior of multiplicative noise not accounted for in previous works. This insight and the retrieved parameters from real attosecond streaking measurements allow a refinement of streaking simulation methods. Using these simulations to study the influence of noise on the rTDSE method confirm that an increase in noise results in a broader spread of retrieved delays but no directional shift, affirming the application of the rTDSE retrieval method for the analysis of attosecond streaking measurements. The developed tools allow future projects to be based on spectrograms more closely resembling those observed in the experiment.

A 22.7 Wed 17:00 Tent

A rigorous and universal approach for highly-oscillatory integrals in attosecond science — •Anne Weber[1], Job Feldbrugge[2], and Emilio Pisanty[1] — [1]Attosecond Quantum Physics Laboratory, King's College London, WC2R2LS London, UK — [2]Higgs Centre for Theoretical Physics, University of Edinburgh, UK

Light-matter interactions within the strong-field regime, such as high-harmonic generation, typically give rise to highly-oscillatory integrals,which are often solved using saddle-point methods. Not only do these methods promise a much faster computation, but they also inform a more intuitive understanding of the process in terms of quantum orbits, as the saddle points correspond to interfering quantum trajectories (think Feynman's path integral formalism). Despite these advantages, a sound understanding of how to apply saddle-point methods to highly-oscillatory integrals in a rigorous way, and with algorithms which work uniformly for arbitrary configurations and laser drivers, remains lacking. This hinders our ability to keep up with state-of-the-art experimental setups which increasingly rely on tightly-controlled laser waveforms. Here, I will introduce the key ideas of Picard-Lefschetz theory – the foundation of all saddle-point methods – and their implementation. Using high-harmonic generation and above-threshold ionisation as examples, I will show how those ideas provide a robust framework for the fast computation of integrals, as well as a widely-applicable algorithm to derive the relevant semiclassical quantum orbits that underlie the physical processes.

A 23: Poster – Interaction with Strong or Short Kaser Pulses (joint session A/MO)

Time: Wednesday 17:00–19:00 Location: Tent

A 23.1 Wed 17:00 Tent

Towards Multidimensional XUV Spectroscopy Combined with Spectral Interferometry — •Lina Hedewig[1,2], Carlo Kleine[1], Felix Wieder[1,2], Christian Ott[1,2], and Thomas Pfeifer[1,2] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Ruprecht-Karls-Universität Heidelberg, 69120 Heidelberg, Germany

Using up to two infrared (IR) and two extreme ultraviolet (XUV) ultrashort pulses we are currently implementing a method for multi-dimensional XUV spectroscopy combined with spectral interferometry to gain further insight into gas-phase quantum dynamics of atoms and molecules.

The setup is based on a four-quadrant split-and-delay mirror allowing independent time delay control of each beam. In situ phase correction results in an effective interferometer stability of 1.5 attoseconds. One XUV pulse excites an electronic wave-packet in the target generating a coherent dipole response. This wave-packet is strongfield coupled by the two IR pulses, leading to control of state-specific quantum dynamics as well as the signal's diffraction towards the remaining fourth beam for a nearly background-free detection. To additionally extract the dipole response's phase, the second XUV beam serves as local oscillator for heterodyned spectral interferometry. The additional phase information compared to classical transient absorption opens up a plethora of possibilities like pulse reconstruction beyond the single-atom response, improved robustness against detector intensity noise and dipole reconstruction for short dipole lifetimes.

A 23.2 Wed 17:00 Tent

Universal Behavior of Tunneling Time and Disentangling Tunneling Time and Barrier Time-Delay in Attoclock Experiments — •Ossama Kullie[1] and Igor Ivanov[2] — [1]Theoretical Physics, Department of Mathematics and Natural Science, University of Kassel, Germany — [2]Department of Fundamental and Theoretical Physics, Australian National University, Australia

In a model we showed that the (tunnel-ionization) time-delay measured by the attoclock experiment can be described accurately in adiabatic and nonadiabatic field calibrations. Moreover, the barrier tunneling time-delay itself can be determined from the difference between the time-delay of adiabatic and nonadiabatic tunnel-ionization, showing good agreement with experimental results. What is particularly striking and interesting is that we have shown that the tunneling time exhibits a universal behavior with disentangled contributions. In Addition, we find that the weak measurement limit, the barrier time-delay corresponds to the Larmor-clock time and the interaction time within the barrier. [1] Submitted to J. Phyis. Comm. (2024). [2] Kullie and

I. Ivanov, Annals of Physics 464, 169648 (2024). [3] Kullie, Phys. Rev. A 92, 052118 (2015).

A 23.3 Wed 17:00 Tent

Towards Imaging Electron Dynamics in Solids with Attosecond Resolution — •Matthias Meier[1], Martin Reh[1], Yuya Morimoto[2], Francesco Tani[3], and Peter Hommelhoff[1,3,4] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]RIKEN Cluster for Pioneering Research (CPR) and RIKEN Center for Advanced Photonics (RAP), Japan — [3]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [4]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

The understanding and precise control of electron dynamics in solids plays a key role for the development of new technologies. However, investigating the time-resolved dynamics on the timescale of femto- to attoseconds proves to be a persistent challenge. One way to overcome this issue is by optically probing the dynamics on the very same timescale. For this aim, isolated attosecond pulses (IAP) present a sharp and distinct measurement tool which is ideally suited to investigate these ultrafast mechanisms. Here, we present the pulse compression of 20μJ pulses at a central wavelength of 1030 nm and a width of 225 fs down to few cycle pulses which are used to generate XUV light by driving a high-harmonic generation process. Adjusting the stabilized carrier-envelope phase together with a short-pass filter allows to generate IAP. Combining the IAP with a copy of the driving field in an ultrashort pump-probe scheme enables the observation of electron dynamics in the attosecond time scale.

A 23.4 Wed 17:00 Tent

Strong-Field Ionization and Laser-Driven Electron Recollision of Molecules studied in a Reaction Microscope — •Narayan Kundu[1], Martin Garro[1], Janko Janko Umbach[1], Horst Rottke[1], Tobias Witting[2], Arne Senftleben[1], and Jochen Mikosch[1] — [1]Institut für Physik, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany — [2]Ultrafast XUV-Physics, Max Born Institute (MBI), Max-Born-Straße 2A, 12489 Berlin, Germany

Reaction microscopes (REMIs) are among the most powerful spectrometers in experimental AMO physics. In a REMI, the momentum of multiple electrons and ions resulting from an event can be measured in coincidence. Here we present experiments on isolated molecules, which are ionized with an intense, femtosecond laser field. In current work on Strong-Field Ionization of 1,3-butadiene, n-butane, and 1-butene molecules, we varied intensities and wavelengths. We observe qualitative changes of experimental observables as a function of these parameters, which we interpret as transition between non-sequential and sequential excitation processes in the intense field. We also present our progress towards using Strong-Field Ionization as a probe mechanism for molecular dynamics and on laser-driven elastic rescattering in a chiral molecule. Furthermore, we have set up a post-compression scheme to significantly reduce the pulse duration of the laser pulses from our commercial regenerative amplifier, based on a gas-filled hollow-core fiber with pressure gradient and chirped mirrors.

A 23.5 Wed 17:00 Tent

Electron-nuclear dynamics in dissociative strong-field ionization of D_2 — •Paul Winter and Manfred Lein — Leibniz University Hannover, Germany

In a neutral diatomic molecule, the removal of an electron by a strong field is a much faster process than the subsequent breakup of the ionized molecule, primarily due to the significant difference in mass between the rapidly moving electrons and the considerably heavier nuclei. This mass disparity also suggests that during strong-field ionization with a linearly polarized pulse, the rescattering electron may not significantly affect molecular dynamics. If, however, electrons rescatter inelastically with the core, vibrational excitation could take place [1].

To explore this mechanism, we have developed a non-Born-Oppenheimer model in which we solve the time-dependent Schrödinger equation (TDSE), treating the electron in two dimensions and the internuclear motion in one dimension. Additionally, we have incorporated the first excited state of the ionized molecule to account for typical dissociation phenomena such as bond-softening and above-threshold dissociation (ATD). With this model, we can calculate photoelectron momentum distributions (PMDs) as a function of the kinetic energy release of the nuclei, paving the way for detailed studies of coupled electron-nuclear dynamics.

[1] S. Hell, G.G. Paulus, M. Kübel, private communication

A 23.6 Wed 17:00 Tent

Modeling controlled sub-wavelength plasma formation in dielectrics — •Julia Apportin, Christian Peltz, Björn Kruse, Benjamin Liewehr, and Thomas Fennel — Institute for Physics, Rostock, Germany

Laser induced damage in dielectrics due to short pulse excitation plays a major role in a variety of scientific and industrial applications, such as the preparation of 3D structured evanescently coupled wave-guides [1] or nano-gratings [2]. The corresponding irreversible material modifications predominantly originate from higher order nonlinearities like strong field ionization and plasma formation, which makes their consistent description imperative for any kind of theoretical modelling aiming at improving user control over these modifications. In particular the associated feedback effects on the field propagation can have drastic implications.

We developed and utilized a numerical model, that combines a local description of the plasma dynamics in terms of corresponding rate equations for ionization, collisions and heating with a fully electromagnetic field propagation via the Finite-Difference-Time-Domain method, adding self-consistent feedback effects like the sudden buildup of plasma mirrors. Here we present recent numerical results regarding the creation and control of sub-wavelength gratings formed at the rear side of pure and gold-coated fused silica films.

[1] L.~Englert et al, Opt. Express 15, 17855-17862 (2007)
[2] M. Alameer et al, Opt. Lett. 43, 5757-5760 (2018)

A 23.7 Wed 17:00 Tent

Cross-process interference in single-cycle electron emission from nanotips — •Anne Herzig, Thomas Fennel, and Lennart Seiffert — Institute of Physics, University of Rostock, 18059 Rostock, Germany

Photoelectron spectra from strong-field ionization show features like energy cutoffs and interference patterns, influenced by direct and backscattered electrons [1]. The typical cut-offs at $2\,U_p$ and $10\,U_p$ can be explained within the famous three-step model, while quantum inter- and intracycle interferences are typically associated with self-interference of direct or backscattered, respectively [2,3]. However, also cross-process interference (CPI) between direct and backscattered electrons could reveal further insights. To isolate CPI, competing effects from self-interference must be suppressed, achievable with single-cycle laser pulses [4] that confine electron emission to a single optical period. Metallic nanotips further enhance this by restricting electron motion to one half-space, ensuring strong backscattering [5]. Quantum simulations predict CEP-dependent photoelectron spectra with distinct interference patterns. An extended trajectory model confirms these features originate from CPI, offering insights into the underlying physical mechanisms.

[1] F. Krausz et al., Reviews of Modern Physics 81, 163-234 (2009)
[2] F. Lindner et al., Physical Review Letters 95, 040401 (2005)
[3] D.G. Arbó et al., Physical Review A 74, 063407 (2006)
[4] M.T. Hassan et al., Nature 530, 66-70 (2016)
[5] S. Zherebtsov et al., Nature Physics 7, 656-662 (2011)

A 23.8 Wed 17:00 Tent

Pulsed standing waves at 100 MHz repetition rate for multiphoton ionization experiments — •Jan-Hendrik Oelmann, Tobias Heldt, Lennart Guth, Lukas Matt, Thomas Pfeifer, and José R. Crespo López-Urrutia — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

We investigate multiphoton ionization (MPI) at high laser intensity (10^{13} W/cm^2) and high repetition rate (100 MHz) using a novel polarization-insensitive enhancement cavity for amplified near infrared frequency comb laser pulses. A velocity-map imaging (VMI) spectrometer is integrated into the cavity and allows measuring photoelectron angular distributions (PADs) [1]. By turning the laser polarization axis, we were able to tomographically reconstruct 3D PADs from xenon MPI, revealing resonant Rydberg states during ionization [2].

Additionally, the bow-tie cavity supports counter-propagating pulses forming an intense standing wave at the cavity focus. We use the intrinsic nanometric structure of this standing light field to study and control photoemission from a sharp tungsten tip at the nanometer scale [3]. For gas-phase ionization studies, colliding pulses offer the advantage of reducing the interaction volume at the focus and doubling the intensity [4].

[1] J. Nauta *et al.*, Opt. Lett. 45, 2156 (2020). [2] J.-H. Oelmann *et al.*, Rev. Sci. Instrum., 93(12), 123303 (2022). [3] T. Heldt *et al.*, Nanophotonics, 2024. [4] T. Heldt *et al.*, Opt. Lett. 49, 6825-6828 (2024)

A 23.9 Wed 17:00 Tent

High-Harmonics Spectroscopy of Vibrating Chains — •Gabriel Caceres-Aravena and Dieter Bauer — Institute of Physics, University of Rostock, 18051 Rostock, Germany

In this work, we study the High-Harmonic Generation (HHG) of the laser-driven Su-Schrieffer-Heeger (SSH) chain where the electrons are coupled to the local phonons. The electron dynamics is implemented using the tight-binding approximation and the electron-phonon interaction is implemented through the Holstein model, where the local vibrations of ions are approximated to be solutions of the quantum harmonic oscillator. In our simulations we observe that the electrons move accelerated by the electric field from the driving laser, as expected, and also we observe that the phonons move following the electron movement, showing the existence of a polaron. Also, when we introduce phonons to the system, we observe from the eigenenergy spectrum that new states emerge. Transitions to these new states allow for more efficient harmonic generation for certain harmonic orders.

A 23.10 Wed 17:00 Tent

Probing electron dynamics in gases and pulse characterization using an interferometric Velocity Map Imaging setup — •Pranav Sreekumar[1], David Schmitt[1], Sven Fröhlich[1], Uwe Morgner[1], Milutin Kovacev[1], and Andrea Trabattoni[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Center for Free-Electron Laser Science CFEL, DESY Hamburg

The strong-field ionization of rare gases using intense fs laser pulses results in characteristic spectra for photoelectrons in the momentum and energy space. It has been shown that such signatures contain holographic information which can be obtained experimentally with high spatial resolution using a Velocity Map Imaging (VMI) spectrometer for photoelectrons. However, the interpretation of these velocity maps is not straightforward as they often contain signatures arising from multiple phenomena and the isolation of individual signatures is a significant challenge.

In this poster, we will present our setup of an interferometric beamline coupled into a VMI. With our setup, we aim to extract the sub-optical cycle photoelectron holographic signatures, which promises to offer information on electron dynamics within atoms occurring at sub-to-few fs timescales. Besides this, we also demonstrate the capability to perform in-situ pulse characterization, utilizing the higher-order nonlinearity associated with strong-field ionization [1].

[1] Geffert et al., Optics Letters 47.16, 3992-3995 (2022)

A 24: Poster – Interaction with VUV and X-ray light

Time: Wednesday 17:00–19:00 Location: Tent

A 24.1 Wed 17:00 Tent

Nuclear resonant scattering at X-ray free electron lasers — •Luis Yagüe Bosch and Jörg Evers — Max-Planck Institut für Kernphysik, Heidelberg, Germany

Forward scattering experiments on resonant Mössbauer nuclei using X-rays delivered by synchrotron radiation facilities are well established and can be fully described by existing quantum optical models. However, recent experiments at the EuXFEL with high spectral flux densities have revealed unexpected "anomalies" in nuclear resonant scattering (NRS) from samples containing ^{57}Fe Mössbauer nuclei. We explore modifications of the quantum optical models to explain the observed discrepancies. This may pave the way for deeper understanding of, and availability of new tools for Mössbauer spectroscopy.

A 24.2 Wed 17:00 Tent

Collective hyperfine splitting in resonant x-rays scattering — •Fabian Richter[1], Lars Bocklage[2], Ralf Röhlsberger[2], Xiangjin Kong[3], and Adriana Pálffy[1] — [1]Julius-Maximilians-Universität Würzburg — [2]Deutsches Elektronen Synchrotron DESY, Hamburg — [3]Fudan University, Shanghai

In an ensemble of identical atoms, cooperative effects like superradiance may alter the decay rates and shift the transition energies from the single-atom value by the so-called collective Lamb shift. While such effects in ensembles of two-level systems are well understood, realistic multi-level systems are more difficult to handle. Mössbauer nuclei in x-ray thin-film cavities are a clean quantum optical system in which the collective Lamb shift has been observed [1].

Here, we present a quantitative study of systems of ^{57}Fe nuclei under the action of an external magnetic field, where a collective contribution to the Zeeman level splitting appears, leading to measurable deviations from the single-atom magnetic hyperfine structure. We have developed a theoretical formalism to describe single-photon superradiance in multi-level systems and have identified three parameter regimes, two of which exhibit measurable deviations in the radiation spectrum compared to the case of single-nucleus magnetic-field-induced splitting [2]. Based on this theoretical framework, we analyze experimental data that show such deviations, which may be consistent with the predicted parameter regimes.

[1] R. Röhlsberger et al., Science 328, 1248 (2010).
[2] X. Kong and A. Pálffy, Phys. Rev. A 96, 033819 (2017).

A 24.3 Wed 17:00 Tent

Nuclear excitation in ^{229}Th using Laguerre-Gauss beams — •Alexander Franz, •Janek Bergmeier, Tobias Kirschbaum, and Adriana Pálffy — Julius-Maximilians-Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Twisted light refers to light carrying orbital angular momentum along its direction of propagation. In combination with its spatially inhomogeneous intensity profile, this form of light has been studied in relation to atom-light interaction. As one application, twisted light can be used in quantum metrology to minimize the unwanted light shift in atomic clock transitions [1]. A promising alternative to atomic clocks is a clock based on the ^{229}Th nucleus and its unique 8.4 eV transition [2]. It is thus intriguing to investigate the interaction of thorium with twisted light.

In a first attempt we have described Bessel beams interacting with ^{229}Th for solid-state and ion targets [3]. Here, we build upon that work by considering more realistic Laguerre-Gauss beams. Two aspects are investigated. First, we address the temporal excitation dynamics of a single ion as a function of impact parameter. Second, we model the propagation dynamics and investigate the case of two-pulse driving in a Λ coupling scheme [4]. Thereby we focus on the effects of a Laguerre-Gauss control beam.

[1] R. Lange *et al.*, Phys. Rev. Lett. **129**, 253901 (2022).
[2] C.Zhang *et al.*, Nature **633**, 63-70 (2024).
[3] T. Kirschbaum *et al.*, arXiv: 2404.13023 (2024).
[4] H. R. Hamedi *et al.*, Opt. Lett. **46**, 17, pp.4204-4207 (2021).

A 24.4 Wed 17:00 Tent

Numerical study of IR-laser dressing signatures in coherent diffractive imaging — •Tom von Scheven, Björn Kruse, and Thomas Fennel — Institute of Physics, University of Rostock, Albert-Einstein-Str. 23-24, D-18059 Rostock, Germany

Single-shot coherent diffractive imaging (CDI) enables the capture of a full diffraction image of a nanostructure using a single flash of XUV or X-ray light. The resulting scattering image encodes both the geometry and the optical properties of the target. So far, this method has mainly been employed for ultrafast structural characterization [1]. However, CDI can also be utilized to resolve ultrafast optical property changes caused by e.g. transient excitation from nonlinear scattering [2], or by illumination with a second ultra-short laser pulse.

Here, we explore the expected signatures for the latter case theoretically, where simultaneous exposure to a strong IR field can induce transient optical properties. To this end, the effective optical properties emerging from the laser dressing must be determined and used to describe the resulting scattering process, which we model using the well-known Mie-solution. We extract the effective optical properties from the dipole response of a local quantum description based on an atom-like solution of the time-dependent Schrödinger equation. The identification of the states and processes responsible for these properties and the corresponding features in the diffraction image is performed by a systematic comparison with results for a few-level system.

[1] I. Barke *et al.*, Nat. Commun. **6**, 6187 (2015)
[2] B. Kruse *et al.*, J. Phys.: Photonics **2**, 024007 (2020)

A 24.5 Wed 17:00 Tent

Electron-Photon Coincidence Measurements at Synchrotron Facility MAX IV during TRIBs operation mode — •Johannes Viehmann[1], Niklas Golchert[1], Yusaku Terao[1], Adrian Krone[1], Arno Ehresmann[1], Antti Kivimäki[2], Noelle Walsh[2], and Andreas Hans[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]MAX IV Laboratory, Lund University, Fotongatan 8, 224 84 Lund, Sweden

Coincidence measurements are an important experimental tool in atomic or molecular physics. Our group has used electron-photon coincidence measurements to investigate rare gas clusters after synchrotron irradiation. More specifically, electron times-of flight and photon counts (UV-VUV) are recorded between two consecutive synchrotron pulses.

However, to employ these coincidence measurements using electron time-of-flight detection techniques at synchrotron facilities requires so-called single bunch operation mode. This mode offers the needed time spacing in between synchrotron excitation pulses. Nevertheless, the lower synchrotron intensities makes this mode unattractive for many users not reliant on this kind of time resolution.

Transverse Resonance Island Buckets (TRIBs) is an operation mode where a pseudo-single bunch in addition to conventional multi bunch is accessible for users by aligning beamline optics to the respective orbitals of the bunches. Here, we present the first results from coincidence measurements during TRIBs operation mode at MAX IV.

A 24.6 Wed 17:00 Tent

Probing few femtosecond dynamics in thin solids using a table top extreme ultraviolet transient absorption spectroscopy — •Monalisa Mallick[1], Tobias Helk[1], Zichen Xie[1], Rudrakant Sollapur[1], Michael Zürch[1,2], and Christian Spielmann[1] — [1]Institute of Optics and Quantum Electronics, Friedrich Schiller University, 07743 Jena, Germany — [2]Department of Chemistry, University of California, Berkeley, 94720, USA

In 2D materials like transition metal dichalcogenides and thin metallic films, nanoscale dimensions strongly affect the processes like carrier and phonon relaxation and scattering timescale. We are developing an extreme ultraviolet (XUV) spectroscopy system which offers element and site-specific sensitivity and high temporal resolution. It employs a pump-probe scheme, where samples are excited by few-cycle near-infrared (NIR) pulses and probed with broadband XUV pulses. Transient absorption changes near the absorption edges of metals or chalcogens are recorded to reveal the underlying few femtosecond-scale dynamics.To generate few-cycle pulses, 40 fs, 800 nm pulses from a commercial Ti:Sapphire laser are compressed using a neon-filled hollow-core fiber (HCF).The dispersion is compensated using dielectric chirped mirrors, achieving pulse durations as short as ~5 fs. These pulses enable broadband XUV generation via high harmonic generation (HHG) in argon gas, producing radiation spanning 30-100 eV. By employing a recirculating HHG gas, and active beam pointing stabilization at the fiber entrance, the system demonstrates stability for over 12 hours.

A 25: Attosecond Physics II (joint session A/MO)

Time: Thursday 11:00–12:30 Location: GrHS Mathe

Invited Talk A 25.1 Thu 11:00 GrHS Mathe

Circular Dichroic Attosecond Transient Absorption Spectroscopy — •Lauren Drescher[1,2], Nicola Mayer[2,3], Kylie Gannan[1], Jonah Adelman[1], and Stephen Leone[1] — [1]Department of Chemistry, University of California, Berkeley, California 94720, USA — [2]Max-Born-Institut, Max-Born-Str. 2A, 12489, Berlin, Germany — [3]Attosecond Quantum Physics Laboratory, Department of Physics, King's College London, Strand, London, WC2R 2LS, United Kingdom

The angular momentum of light couples to matter via the total angular momentum. By limiting possible orbital angular momentum states, circular polarized light can be used to enact spin-specificity onto the optical excitation of matter, even within isotropic media. We leverage this effect in our method of circular dichroic attosecond transient absorption spectroscopy to prepare and measure spin-specific coupling with attosecond temporal precision. This principle is demonstrated using co- and counter-rotating two-color excitation of helium Rydberg states, showing the effect of dipole selection and propensity rules in the selective excitation of spin-specific states. Our methods allows to study the dynamic of spin-specific excitations and gives insight into the orbital character of excited states through their interaction with circular polarized two-color fields. Furthermore we demonstrate that, given a known model system, our method allows to measure the polarization state of attosecond extreme ultraviolet (XUV) pulses in-situ and in an all-optical setup.

A 25.2 Thu 11:30 GrHS Mathe

Attosecond Photon Diagnostics at Flash - A Dedicated Angular Streaking Beamline — •Lasse Wülfing[1], Lars Funke[1], Thorsten Otto[2], Sara Savio[1], Niclas Wieland[3], Markus Ilchen[3], and Wolfram Helml[1] — [1]Technische Universität Dortmund, Germany — [2]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [3]Universität Hamburg, Germany

The established scheme of angular streaking can characterize the temporal and spectral information of ultrashort X-ray pulses non-invasively. This is done by overlapping the pulses with a circularly polarized IR laser in a gaseous target and measuring the resulting angle dependent photo electron spectra with so called *Cookiebox*-type detectors.

We developed a new detector with optimized electron time of flight spectrometers for increased energy resolution and better overall performance. This experiment will be installed at a new diagnostics beamline at Flash 2 for a dedicated angular streaking setup.

We present an overall rundown of the experimental method and the new setup.

A 25.3 Thu 11:45 GrHS Mathe

In Search of Lost Tunneling Time — •Pablo Maier[1], Serguei Patchkovskii[1], Misha Ivanov[1,2,3], and Olga Smirnova[1,4] — [1]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Straße 2A, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Unter den Linden 6, 10117 Berlin, Germany — [3]Solid State Institute and Physics Department, Technion, Haifa, 32000, Israel — [4]Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany

The measurement of tunneling times in strong-field ionization has been the topic of much controversy in recent years, with the attoclock and Larmor clock being two of the main contenders for correctly reproducing these times. By expressing the attoclock as the weak value of temporal delay, we extend its meaning beyond the traditional setup. This allows us to calculate the attoclock time for a static one-dimensional tunneling model consisting of a binding delta potential and a constant electric field. We apply the Steinberg weak-value interpretation of the Larmor clock. Using this definition, we obtain the position-resolved time density during tunnel ionization, yielding a non-zero Larmor tunneling time. Our model allows us to derive the analogue of the position-resolved attoclock tunneling time. While non-zero at the tunnel exit, it vanishes at the detector, far away from the atom. Formally, this means that the attoclock does not measure the Larmor time, but instead a time closely related to the phase time.

A 25.4 Thu 12:00 GrHS Mathe

attosecond coherent control using nonlinear processes driven by a seeded FEL — •Sooraj R.S[1], Ioannis Makos[1], Michele Di Fraia[2], Oksana Plekan[2], Praveen Maroju[3], David Busto[3], S Hartweg[1], David Garzella[2], Kevin Prince[2], A Demidovich[2], Johan Mauritsson[3], Marvin Schmoll[1], Aaron Ngai[1], R Moshammer[4], C Medina[4], Muwaffaq Mourtada[4], T Pfeifer[4], Tamas Csizmadia[5], Debobrata Rajak[5], Klemen Bucar[6], Andrej Mihelic[6], Matjaz Zitnik[6], Uwe Thumm[8], Fernando M Garcia[7], Carlo Callegari[2], Elena Gryzlova[1], and Giuseppe Sansone[1] — [1]Albert Ludwigs Universität Freiburg,Germany — [2]Elettra Sincrotrone Trieste,Italy — [3]Lund University, Sweden — [4]MPI für Kernphysik Heidelberg,Germany — [5]ELI ALPS , Hungary — [6]Jožef Stefan Institute,Slovenia — [7]Universidad Autónoma de Madrid,Spain — [8]Kansas State University, USA

In this study, we investigate interference between two coherent pathways in two-photon double ionization (TPDI) of Ar, mediated by the $3s3p^65p$ and $3s3p^66p$[1] states, and in N_2 through the Hopfield resonances $3d\sigma_g$ and $3d\pi_g$[2]. Using phase-controlled XUV radiation from FEL FERMI, we record photoelectron spectra from TPDI to study how intermediate resonances affect the contrast and phase of oscillations from two nonlinear-coherent paths.This study highlights the critical role of intermediate resonances in controlling the interference dynamics of multiphoton ionization processes.[1] Elena V G et al. In: The Eu Phy Jo D 73 (2019)[2] M Reduzzi et al. In: Jo of Phy B:AMO Physics 49.6 (2016)

A 25.5 Thu 12:15 GrHS Mathe

A rigorous and universal approach for highly-oscillatory integrals in attosecond science — •Anne Weber[1], Job Feldbrugge[2], and Emilio Pisanty[1] — [1]Attosecond Quantum Physics Laboratory, King's College London, WC2R2LS London, UK — [2]Higgs Centre for Theoretical Physics, University of Edinburgh, UK

Light-matter interactions within the strong-field regime, such as high-harmonic generation, typically give rise to highly-oscillatory integrals, which are often solved using saddle-point methods. Not only do these methods promise a much faster computation, but they also inform a more intuitive understanding of the process in terms of quantum orbits, as the saddle points correspond to interfering quantum trajectories (think Feynman's path integral formalism). Despite these advantages, a sound understanding of how to apply saddle-point methods to highly-oscillatory integrals in a rigorous way, and with algorithms which work uniformly for arbitrary configurations and laser drivers, remains lacking. This hinders our ability to keep up with state-of-the-art experimental setups which increasingly rely on tightly-controlled laser waveforms. Here, I will introduce the key ideas of Picard-Lefschetz theory – the foundation of all saddle-point methods – and their implementation. Using high-harmonic generation and above-threshold ionisation as examples, I will show how those ideas provide a robust framework for the fast computation of integrals, as well as a widely-applicable algorithm to derive the relevant semiclassical quantum orbits that underlie the physical processes.

A 26: Precision Spectroscopy of Atoms and Ions V (joint session A/Q)

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

Invited Talk A 26.1 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.

A 26.2 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.

A 26.3 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.

A 26.4 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.

A 26.5 Thu 12:15 KlHS Mathe

Ab initio calculations of the hyperfine structure of fermium — •Joseph Andrews[1,2], Jacek Bieron[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.

A 26.6 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.

A 26.7 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)

A 27: Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)

Time: Thursday 11:00–12:45 Location: HS PC

Invited Talk A 27.1 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.

A 27.2 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)

A 27.3 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 Sci-

ences, 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).

A 27.4 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.

A 27.5 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).

A 27.6 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.

A 28: Cluster and Nanoparticles I (joint session MO/A)

Time: Thursday 11:00–13:15 Location: HS XV

Invited Talk A 28.1 Thu 11:00 HS XV

Pickup and reactions of molecules on clusters relevant for atmospheric processes — •Jozef Lengyel — Technical University of Munich, Garching, Germany

The uptake of molecules by preexisting clusters in molecular beams is demonstrated using two distinct experiments. In the first one, the doping of hydrated acid clusters with various molecules is investigated. Sticking efficiencies, including uptake cross sections, are determined using the combination of cluster mass spectrometry and velocity measurements. The combined experimental and computational approach provides insights into molecule-cluster collision dynamics, illustrated by a series of measurements involving diverse molecular interactions and steric effects. The second one focuses on the dissociation of nitric acid on large water clusters. While dissociation is often reported for clusters containing as few as five water molecules, it is shown that on nanometer-sized ice nanoparticles, dissociation occurs only to a limited extent, with the majority of nitric acid remaining undissociated on the ice surface.

A 28.2 Thu 11:30 HS XV

Imaging single sea salt aerosol nanoparticles — •Changji Pan for the Sea Salt Nanoparticle-Collaboration — Department of Physics, ETH Zurich, 8093, Zurich Switzerland

The influence of sea salt aerosol particles on atmospheric processes highly depends on their hygroscopicity and capacity as cloud condensation nuclei. These properties are highly related to the particle morphology and the distribution of chemical species inside these nanoparticles. Many studies, however, suffer from the averaging effect in ensemble measurements and the substrate interaction in deposited particles. We performed a direct measurement on in-flight individual sea salt aerosol nanoparticles by single-shot X-ray diffraction imaging at EuXFEL, to retrieve their inner structure and overall morphology as a function of particle size, chemical composition, and humidity.

A 28.3 Thu 11:45 HS XV

Optimized sample-delivery system for coherent-diffractive-imaging of proteins — •Stefanie Lenzen[1,2], Lukas V. Haas[1,3,4], Kevin Janson[1], Amit K. Samanta[1,3,4], and Jochen Küpper[1,2,3,4] — [1]Center for Free-Electron Laser Science (CFEL), Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Chemistry, Universität Hamburg — [3]Department of Physics, Universität Hamburg — [4]Center for Ultrafast Imaging, Hamburg

Determining the structure and dynamics of single native bionanoparticles, such as proteins, is still challenging. Several methods, including protein-crystallography and cryo-EM, focus on this challenge, but the biomolecule needs to be fixed, which might lead to structural disentegration, and the temporal resolution of these methods are limited. X-ray free-electron lasers (XFELs) provide ultrashort pulses, enabling diffraction before destruction, and a large number of photons, promising the observation of diffraction patterns *off* single nanoparticles. Aerodynamic-lens stacks were used to deliver collimated and focused particle beams for such experiments on large nanoparticles [1]. We optimized the sample injection and extended the use of particle beams toward smaller nanoparticles and protein complexes like apoferritin. This highlights the use of improved aerosolization methods together with optimized ALS injectors for small bio-nanoparticles. In addition, we present techniques for improved optical-scattering-based detection of proteins.

[1] Lena Worbs, Toward cryogenic beams of nanoparticles and proteins, *Dissertation*, Universität Hamburg (2022)

A 28.4 Thu 12:00 HS XV

Cryo-cooled beams of "small" macromolecules — •Jingxuan He[1,2,3], Lena Worbs[1,2], Surya Kiran Peravali[1,4], Armando D. Estillore[1], Amit K. Samanta[1,3], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science (CFEL), Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Germany — [3]Center for Ultrafast Imaging (CUI), Universität Hamburg, Germany — [4]Fakultät für Maschinenbau, Helmut-Schmidt-Universität,Germany

We demonstrated the preparation of cold and controlled beams of nanoparticles and macromolecules that are desired for x-ray single-particle-diffractive imaging (SPI) using the buffer-gas-cell (BGC) cooling and aerodynamic focusing techniques [1,2]. The cooling and control techniques we developed for SPI can be extended to experiments to study the electron dynamics in complex biomolecules on the few-femtosecond timescale [3]. Such ultrafast charge- and energy-transfer dynamics following electronic excitation were not revealed so far [4].

We present an approach toward investigating the time-resolved ultrafast dynamics in cryo-cooled proteins [1] induced by ultrashort UV/VIS pulses and advanced detection method including velocity-map-imaging using Timepix3 cameras [5].

[1] A.K. Samanta, *et al.*, *Struct. Dyn.* **7**, 024304 (2020)
[2] S.K. Peravali, *et al.*, *Comput. Fluids* **279**, 106346 (2024)
[3] M. Hervé, *et al.*, *Commun. Chem.* **4**, 124, (2021)
[4] H. Duan, *et al.*, *PNAS* **114**, 8493 (2017)
[5] H. Bromberger, *et al.*, *J. Phys. B* **55**, 144001 (2022)

A 28.5 Thu 12:15 HS XV

Temperature and adsorption dynamics of single nanoparticles in a cryogenic ion trap — •Björn Bastian, Sophia C. Leippe, Kleopatra Papagrigoriou, and Knut R. Asmis — Wilhelm Ostwald Institute, Leipzig University, Linnéstraße 2, D-04103 Leipzig

Characterization of nanoparticles without inhomogeneous broadening and interactions with the environment requires single particle techniques in the gas phase. Our group has shown the feasibility of single nanoparticle action spectroscopy (SNAS) in a cryogenic Paul-type ion trap [1], based on the adsorption of messenger atoms or molecules on the nanoparticle surface and their desorption driven by laser heating with rates that are proportional to the absorption cross section [2].

A quantitative understanding of the sorption dependent SNAS technique and temperature programmed desorption schemes to characterize surface interactions strongly depend on the surface temperature which is difficult to measure or estimate in such experiments. In a collaborative work, we could achieve a first *in situ* measurement using the temperature-dependent emission spectrum of core/shell CdSe/CdS quantum dots and capture the essential heating and cooling processes in a model [3]. The latter helps to estimate surface temperatures for different particles and experimental conditions which is used here to interpret the adsorption dynamics of oxygen on silica nanoparticles.

[1] B. Hoffmann et al., Mol. Phys. 122, e2210454 (2023). [2] B. Hoffmann et al., J. Phys. Chem. Lett. 11, 6051 (2020). [3] S. C. Leippe et al., J. Phys. Chem. C (accepted).

A 28.6 Thu 12:30 HS XV

Cluster beam technologies for matter-wave interferometry — •Severin Sindelar, Bruno Ramirez-Galindo, Sebastian Pedalino, Stefan Gerlich, and Markus Arndt — University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna

Metal nanoparticles are promising candidates for interferometric tests of the quantum superposition principle in the 1 MDa mass range. Cluster interferometry shall allow us to push the limit on quantum macroscopicity well beyond the state of the art and it shall open a window for quantum-enhanced measurements of properties of nanoscale materials.

The cluster beam shall last for a day, have a high brilliance of slow and neutral metal nanoparticles with masses up to 1 MDa and velocities below 30 m/s. The materials must have a work function compatible with single photon ionization using deep ultraviolet (DUV) laser light, ideally high polarizability and low magnetic susceptibility. Here we present our approach to such a cluster source: It is based on metal evaporation and cluster aggregation in an 80 K cold chamber, followed by an aerodynamic lens array.

While interference experiments shall work with neutral clusters, their identification and detection require singly charged particles, which we can select in a quadrupole mass spectrometer with subsequent Daly detection. We present the formation, ionization and spectroscopy of metal clusters, which have a low work function, high absorption cross section and high polarizability. We study their photo physics as a function of size, DUV laser wavelength and laser power to extract the properties that will be needed for interference experiments.

A 28.7 Thu 12:45 HS XV

Laser-induced alignment of macromolecules and nanoparticles — •Lukas Vincent Haas[1,2,3], Xuemei Cheng[1], Muhamed Amin[1], Stefanie Lenzen[1,3], Amit Kumar Samanta[1,2,3], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science (CFEL), Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Germany — [3]Center for Ultrafast Imaging (CUI), Universität Hamburg, Germany

X-ray free-electron lasers (XFELs) promise to enable the diffractive imaging of single molecules and nanoparticles, but image reconstruction remains a major bottleneck in achieving atomic spatial resolution[1]. Laser-induced alignment of nanoparticles and macromolecules during the diffractive imaging process has the potential to push resolution toward the atomic scale [2]. We present the quantitative computational modeling of nanoparticle alignment using classical mechanics and electrodynamics [3] along with the first experimental evidence of laser-induced alignment of tobacco mosaic virus (TMV) in an XFEL-compatible setup. The alignment was probed through optical scattering. A recently conducted XFEL experiment provides initial results on diffractive imaging of laser-aligned TMV. Comparing computational and experimental results, we conclude that a high degree of alignment is achieved for TMV in our experiments.

[1] K. Ayyer, et al., Optica 8(1) (2021)
[2] J. C. H. Spence, et al., Phys. Rev. lett. 92, 198102 (2004)
[3] M. Amin, et al., arXiv:2306.05870 [physics], (2023)

A 28.8 Thu 13:00 HS XV

Rotational Waver Packet Dynamics of Size-selected Neutral Clusters — •Jiaye Jin, Max Grellmann, Marcel Jorewitz, and Knut R. Asmis — Wilhelm-Ostwald-Institut für Physikalische und Theoretisch Chemie, Universität Leipzig, Leipzig, Germany

We report our results on rotational wave-packet dynamics for the mass-selected neutral clusters in a cryogenic ion trap probed by two-colors femtosecond pump-probe spectroscopy involving the negative-neutral-positive excitation scheme. To achieve this, a rotational wave packet is prepared via photodetachment of mass-selected cold anion using a first linearly polarized laser pulse. The rotation coherence is then probed using a second linearly polarized laser pulse, set either parallel or perpendicular to the polarization of the first pulse, ionizing the neutral molecule. The rotational anisotropy β is then calculated from the cation transients probed at different polarization angles.

Neutral boron cluster B_6 is chosen as the first experimental candidate. So obtained time-dependence of B_6^+ cation measured at parallel probing polarization shows typical J-type recurrences of the initial rotational wave packet at 68 ps, 135 ps, 210 ps and 275 ps. The rotational coherence is confirmed by following measurements using perpendicular polarization, where the recurrent cations signal show opposite intensity compared to the parallel probing. An effect rotational constants is thus obtained by 0.25 cm^{-1}, agreeing well with calculations. These results demonstrate the application in the coherent control for the orientation of mass-selected neutral molecules in a cryogenic ion trap.

A 29: Ultracold Matter (Fermions) I (joint session Q/A)

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

A 29.1 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.

A 29.2 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.

A 29.3 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.

A 29.4 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.

A 29.5 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.

A 29.6 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^{α} 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.

A 29.7 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.

A 30: Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)

Time: Thursday 14:30–16:30 Location: GrHS Mathe

A 30.1 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 multi-loop 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.

A 30.2 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)

A 30.3 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.

A 30.4 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.

A 30.5 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.

A 30.6 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.

A 30.7 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.

A 30.8 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.

A 31: Precision Spectroscopy of Atoms and Ions VI (joint session A/Q)

Time: Thursday 14:30–16:30 Location: KlHS Mathe

Invited Talk A 31.1 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)

A 31.2 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)

A 31.3 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 $M \gtrsim 10^3\,\text{eV}/c^2$ and even down to nuclear sizes $M \gtrsim\sim 10^8\,\text{eV}/c^2$ 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).

A 31.4 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)

A 31.5 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.

A 31.6 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]

A 31.7 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).

A 32: Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)

Time: Thursday 14:30–15:45 Location: HS PC

A 32.1 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.

A 32.2 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.

A 32.3 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.

A 32.4 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 do Norte, Natal, Brazil

We investigate the transport properties of one-dimensional systems beyond linear response, focusing on the fractionalization of propagating charges. Starting from a right-moving unit charge, we predict its evolution into at least three distinct stable parts: a fractionally charged particle with freeparticle dynamics, a left-moving signal, and a right-moving low-energy excitation, which can carry positive or negative charge depending on the interaction strength and energy regime. Our findings provide deep insights into the universal correlated nature of these emergent particles and pave the way for out-of-equilibrium transport measurements, offering a direct method to extract the interaction parameters governing correlations in the system.

A 32.5 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)

A 33: Poster – Collisions, Scattering and Correlation Phenomena (joint session A/MO)

Time: Thursday 17:00–19:00 Location: Tent

A 33.1 Thu 17:00 Tent

Light-induced correlations in cold dysprosium atoms — •Chung-Ming Hung, Ishan Varma, Marvin Proske, Rhuthwik Sriranga, Dimitra Cristea, and Patrick Windpassinger — Institut für Physik, Johannes Gutenberg Universität Mainz

When the average atomic distance in a cloud of ultracold atoms, is below the wavelength of the scattering light, a direct matter-matter coupling is introduced by electric and magnetic interactions. This alters the spectral and temporal response of the sample, where the atoms cannot be treated as individual emitters anymore. We intend to experimentally study light-matter interactions in dense dipolar media with large magnetic moments to explore the impact of magnetic dipole-dipole interactions on the cooperative response of the sample. With the largest ground-state magnetic moment in the periodic table (10 Bohr-magneton), dysprosium is the perfect choice for these experiments. This poster reports on the progress in generating dense, cold dysprosium clouds. We discuss the measures taken to optically transport the atoms into a home-built science cell by utilizing an air-bearing translation stage. The cell compact design allows for tight dipole trapping with a high numerical aperture objective. Finally, an outlook is provided on future measurements aimed at the collective response in the generated sample.

A 33.2 Thu 17:00 Tent

Electron Capture Dynamics and Momentum Reconstruction in Ion-Neutral Collisions of Molecular Oxygen Using the Trap-REMI — •Cristian Medina and Henri Lurtz — Saupfercheckweg 1, 69117 Heidelberg

We present the momentum reconstruction and Q-value of ion-neutral collisions involving molecular oxygen (O2+* - O2*). Coincidence measurements were performed using the Trap-REMI setup, which combines reaction microscopy (REMI) with an electrostatic ion beam trap. This configuration enables collisions between stored ion species and a neutral gas jet. For the first time, we provide a complete description of a molecular collision using this setup, advancing toward coincidence measurements of electron/ion/neutral products.

In addition, we analyzed ion bunch dynamics, mass spectrometry of the collision products, and its velocity distributions. The results primarily indicate an electron capture process, transferring an electron from the neutral molecule to the ion. These findings offer valuable insights into ion-neutral collision dynamics and lay the groundwork for extending the method to systems of higher complexity that have significant implications for molecular physics, astrophysics, and atmospheric studies. measurements

A 33.3 Thu 17:00 Tent

About Ion-neutral coincidence measurements on O_2-O_2^+ collisions using the Trap-REMI — •Henri Lurtz — Max Planck Institute of Nuclear Physics, Heidelberg, Germany

We present the study of ion-neutral collisions involving molecular oxygen (O2+ - O2) using the Trap-REMI setup. This apparatus integrates reaction microscopy (REMI) with electrostatic ion beam trapping, enabling coincidence measurements between stored ion species and a neutral gas jet. We report on the optimization of ion trap simulations, experimental setup refinements, and the characterization of a new electron cyclotron resonance (ECR) ion source. Additionally, we analyzed ion bunch dynamics, mass spectrometry of collision products, and velocity distributions from coincidence measurements. The results primarily indicate an electron capture process, transferring an electron from the neutral molecule to the ion. Furthermore, a novel bunch-splitting mechanism was observed at extended trapping times, attributed to the high space charge ratio within the ion bunch. These findings contribute valuable insights into ion-neutral collision dynamics and have implications for understanding molecular oxygen processes in astrophysics and atmospheric physics.

A 34: Poster – Atomic Collisions and Ultracold Plasmas

Time: Thursday 17:00–19:00 Location: Tent

A 34.1 Thu 17:00 Tent

Muonic anti-hydrogen formation three-body reaction — •Renat Sultanov — The University of Texas Permian Basin, Odessa, Texas, USA

A few-body formalism is applied for computation of two different three-charge-particle systems. The first system is a collision of a slow antiproton, $\bar{p}$, with a positronium atom: Ps= $(e^+e^)$ - a bound state of an electron and a positron. The second problem is a collision of $\bar{p}$ with a muonic muonium atom, i.e. true muonium - a bound state of two muons one positive and one negative: $\mathrm{Ps}_\mu = (\mu^+\mu^-)$. The total cross section of the following two reactions: $\bar{p} + (e^+e^-) \to \bar{H} + e^-$ and $\bar{p} + (\mu^+\mu^-) \to \bar{H}_\mu + \mu^-$, where $\bar{H} = (\bar{p}e^+)$ is anti-hydrogen and $\bar{H}_\mu = (\bar{p}\mu^+)$ is a muonic anti-hydrogen atom, i.e. a bound state of $\bar{p}$ and μ^+, are computed in the framework of a set of coupled two-component Faddeev-Hahn-type (FH-type) equations. Results for better known low energy μ^- transfer reactions from one hydrogen isotope to another hydrogen isotope in the cycle of muon catalyzed fusion (μCF) are also computed and will be presented.

A 35: Poster – Precision Spectroscopy of Atoms and Ions (joint session A/Q)

Time: Thursday 17:00–19:00 Location: Tent

A 35.1 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. $^{207}\mathrm{Pb}^{81+}$ 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 ($^{40}\mathrm{Ar}^{13+}$) 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).

A 35.2 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.

A 35.3 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).

A 35.4 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.

A 35.5 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 $\mathrm{U}^{\mathbf{90+}}$ 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 $1\,\mathrm{cm}^2$, an absorber thickness of $50\,\mu\mathrm{m}$, 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 μm 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.

A 35.6 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 × 4 mm and are equipped with 5 μm thick absorbers made of gold. This ensures a stopping power of at least 50 % for photon energies up to 20 keV. The expected energy resolution is 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.

A 35.7 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.

A 35.8 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.

A 35.9 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.

A 35.10 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 $^9Be^+$ as cooling and logic ion [4]. Towards this, temperature control and transport of $^9Be^+$ 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 $^9Be^+$ 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)

A 35.11 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.

A 35.12 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.

A 35.13 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)

A 35.14 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.

A 35.15 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.

A 35.16 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

A 35.17 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)

A 35.18 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)

A 35.19 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)

A 35.20 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)

A 35.21 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).

A 36: Poster – Correlation Phenomena

Time: Thursday 17:00–19:00 Location: Tent

A 36.1 Thu 17:00 Tent

Deep learning-based delay-line detector evaluation for ultrashort electron correlation measurements — •Tobias Volk[1], Marco Knipfer[1], Stefan Meier[1], Jonas Heimerl[1], Sergei Gleyzer[2], and Peter Hommelhoff[1,3] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Department of Physics and Astronomy, University of Alabama, Tuscaloosa, AL 35487, USA — [3]Department Physik, Ludwig-Maximilians-Universität München (LMU), 80799 München

The precise reconstruction of electron events using delay-line detectors is a challenging task, especially if multiple electrons arrive closely confined in space and time. Recently, deep learning-based reconstruction approaches have been shown to significantly outperform classical algorithms, reducing the dead radius by a factor of 8 while improving overall resolution [1]. Nevertheless, in this approach, precision as well as evaluation speed was still limited by the necessity to include classical algorithms into the reconstruction pipeline. Here we present an improved evaluation method that overcomes this limitation by enabling direct reconstruction of the electron's spatiotemporal positions from the analog input signals. We achieve further enhancements in the reconstruction accuracy and show initial steps towards live data processing. We showcase that our deep learning approach sets the stage for simultaneous investigation of temporal and spatial electron correlations for ultrafast emitted two-electron events, as well as number statistics measurements.

[1] Marco Knipfer et al., Mach. Learn.: Sci. Technol. 5 (2024)

A 37: Poster – Highly Charged Ions and their Applications

Time: Thursday 17:00–19:00 Location: Tent

A 37.1 Thu 17:00 Tent

Towards quantum gate with highly charged ion — •Shuying Chen[1], Lukas J. Spiess[1], Alexander Wilzewski[1], Malte Wehrheim[1], José R. Crespo Urrutia-López[2], and Piet O. Schmidt[1,3] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

Highly charged ions (HCI) are good candidates for constructing of high-precision optical clocks, due to low sensitivity to from external field perturbations. Long-lived clock states in HCI also offer promising prospects for highly-stable qubits for high-fidelity quantum gates. Furthermore, the engineering of entangled states in HCI enables the utilization of a decoherence-free subspace for magnetic field shift insensitivity or quadrupole moment measurements in HCI clocks. We present progress made in the construction of an entangled gate utilizing Ni^{12+}. Thus far, a three-ion crystal consisting of 2 Ni^{12+} and one Be^+ have been prepared for sympathetic cooling and quantum logic readout by splitting the initial larger crystal and removing the excess Be^+ ions.The three axial motional modes were successfully identified and ground state cooled. Read out of the states of the two HCI are performed using quantum logic on the logic transition. The two Ni^{12+} ions will be entangled through Mølmer-Sørensen gate.

A 37.2 Thu 17:00 Tent

Breit interaction in dielectronic recombination of hydrogenlike xenon ions — •Shu-Xing Wang[1,2], Carsten Brandau[1,3], Stephan Fritzsche[3,4,5], Sebastian Fuchs[1,2], Zoltán Harman[6,7], Christophor Kozhuharov[3], Alfred Müller[1], Markus Steck[3], and Stefan Schippers[1,2] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Giessen, Germany — [2]Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung, Campus Gießen, 35392 Giessen, Germany. — [3]GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany. — [4]Helmholtz-Institut Jena, 07743 Jena, Germany. — [5]Institut für Theoretische Physik, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany. — [6]Institut für theoretische Physik, Justus-Liebig-Universität Gießen, 35392 Giessen, Germany — [7]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

Electron-ion collision spectroscopy of the KLL dielectronic recombination (DR) resonances of hydrogenlike xenon ions was performed at a heavy-ion storage ring with a competitive resolving power with x-ray spectroscopy of inner-shell transitions in highly charged ions. The resonance strengths were measured on an absolute scale and compared with results from Multi-Configuration Dirac-Fock (MCDF) calculations. These are in excellent agreement with the experimental findings when considering QED effects on the resonance energies and the Breit interaction. A significant 25% increase was found for the strength of the first resonance group.

A 37.3 Thu 17:00 Tent

An ultra-stable optical reference cavity for spectroscopy of highly charged ions — •Ruben B. Henninger, Elwin A. Dijck, Vera M. Schäfer, Christian Warnecke, Stepan Kokh, Andrea Graf, José R. Crespo López-Urrutia, and Thomas Pfeifer — Max Planck Institut für Kernphysik, Saupfercheckweg 1, Heidelberg, Germany

To investigate the potential existence of a fifth force influencing interactions between electrons and neutrons, our research aims to employ highly charged ions (HCIs). In particular xenon, with its numerous spin-zero isotopes, represents a promising candidate for this investigation. The use of narrow linewidth lasers in the sub-Hertz regime is essential for achieving the required precision for the identification of new physics. This poster introduces an optical reference cavity with a 10 cm ULE spacer intended to stabilize spectroscopy lasers for different ions. We theoretically investigate the influence of crystalline mirror substrates on the thermal noise floor of the cavity and build a system with a projected noise floor of 3.6e-16 relative frequency uncertainty at one second. We present the design of the cavity housing and characterization measurements.

A 37.4 Thu 17:00 Tent

Laser spectroscopy of highly-charged ions in SpecTrap — •Rima Schüssler[1], Manuel Vogel[1], Volker Hannen[2], Andreas Solders[3], and Thomas Stöhlker[1,4,5] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [2]Univeristät Münster — [3]Uppsala Universitet — [4]Helmholtz Institute Jena — [5]Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena

Heavy highly charged ions (HCI) provide a unique possibility to test fundamental physics in the presence of extreme electromagnetic fields. To this end, the SpecTrap experiment, located at the HITRAP facility at GSI, plans to perform laser spectroscopy of (hyper-)fine structure transitions in HCIs in a Penning trap. Measurements will include the test of bound-state QED as well as the nuclear transition in ^{229}Th.

The HCIs are produced in the experimental storage ring at GSI and decelerated in the HITRAP facility, before being guided to the Penning trap. Within the trap they are cooled down by sympathetic cooling with laser cooled Mg^+ ions. The trap has optical access for lasers as well as to collect fluorescence of the HCIs

The whole experiment is currently being redesigned and the poster will show the current status as well as future plans.

A 37.5 Thu 17:00 Tent

The Positron Source at the Lsym Experiment — •Maria Pasinetti, Fabian Raab, Paul Holzenkamp, Andreas Thoma, Luca Falzoni, Bjoern-Benny Bauer, Sangeetha Sasidharan, and Sven Sturm — Max-Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

The Lsym experiment is a new cryogenic Penning trap experiment currently being designed at the Max-Planck-Institut fur Kernphysik of Heidelberg. The goal of Lsym is to conduct a stringent CPT test by comparing the properties of matter and antimatter with unprecedented precision by trapping simultaneously one electron and one positron in a Penning trap, thus performing a decoherence-free measurement. This project will present a few challenges, for instance the optimisation of positron production and accumulation, given a rather weak radioactive 22Na source (about 15 MBq). A positron trapping technique involving production of positronium atoms in a high Rydberg state is being tested; furthermore, an efficient detection method is being set up. As positrons follow a $\beta+$ decay energy spectrum, they must undergo a moderation stage before entering the trap: the positron is then cooled to the ground-state of motion in the center of the trap. This poster illustrates the principles and techniques that will be used for the positron source at Lsym.

A 37.6 Thu 17:00 Tent

Generation of Highly Charged Ions with a miniEBIT — •Finja Mayer, Stepan Kokh, Melina Gizewski, Yang Yang, Nadir Khan, Moto Togawa, Thomas Pfeifer, José R. Crespo López-Urrutia, and Vera M. Schäfer — Max-Planck-Institut für Kernphysik, Heidelberg

Is the fine structure constant really constant? The answer to this question calls for physical systems that are highly sensitive to potential variations of α over time. Particularly interesting are highly charged ions, since their energy levels and thus measurable atomic transition frequencies are subject to enhanced relativistic shifts, making them more sensitive to variations of α. However, the generation of HCIs is difficult, because the removal of electrons necessitates increasingly greater amounts of energy with increasing charge number of the ion. As a solution, the Electron Beam Ion Trap (EBIT) ionises injected atoms with accelerated electrons that are collimated by a strong magnetic field. The electromagnetic potential of the electron beam and several electrodes then confine these ions within the trap, thus allowing for higher charge states to be reached. This poster focusses on the precise structure of the EBIT, the design considerations involved, and the techniques used for construction.

A 37.7 Thu 17:00 Tent

Towards ground state cooling of mixed ion crystals in the intermediate Lamb-Dicke regime. — •Devanarayanan Rajeeb Kumar, Elwin A. Dijck, Stepan Kokh, Vera M. Schäfer, Christian Warnecke, José R. Crespo López-Urrutia, and Thomas Pfeifer — Max-Planck-Institut für Kernphysik, Heidelberg

Precision measurements are one of the approaches in the search for new physics. Using highly charged ions (HCIs) offers reduced systematic effects and an increased number of available transitions for generalized King plot analyses [1]. Implementing quantum logic spectroscopy [2] of an HCI co-trapped with a Be^+ ion for cooling and state readout requires ground-state cooling of the axial motional modes. Building upon our ground-state cooling of a single beryllium ion by pulsed sideband cooling including excitation of higher order sidebands, we report on our progress in achieving ground-state cooling of axial modes of mixed-species crystals, although our current trap operates only in an intermediate Lamb-Dicke regime with η as large as 0.8 for certain modes.

[1] Rehbehn et al., Phys. Rev. Lett. **131**, 161803 (2023)
[2] Schmidt et al., Science **309**, 749 (2005)

A 37.8 Thu 17:00 Tent

High-precision synchrotron laser spectroscopy of highly charged O, N and C in an EBIT — •Jonas Danisch[1], Marc Botz[1], Moto Togawa[1], Joschka Goes[1], Chintan Shah[1,3], Filipe Grilo[1,4], Awad Mohamed[2], Monica de Simone[2], Marcello Coreno[2], Thomas Pfeifer[1], and José Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]IOM-CNR, Trieste, Italy — [3]NASA/Goddard Space Flight Center, Greenbelt, USA — [4]LIBPhys, Lisbon, Portugal

Analysing X-ray observations from hot astrophysical plasmas depends on understanding the transitions of highly charged ions (HCI). In the absence of high-precision theoretical data for some HCIs, experimental studies on the ground are needed to obtain accurate data in order to benchmark and improve astrophysical models. To overcome this challenge in a laboratory environment, highly charged ions are generated and trapped with an electron beam ion trap (EBIT), while the ions are simultaneously excited with synchrotron radiation from a high-resolution beamline. The occurrence of photoexcitation can be observed using a silicon drift detector, while the process of photoionisation can be monitored using a time-of-flight measurement.

In this work we present the result at the Elettra synchrotron facility in Trieste, Italy for the investigation of line positions of $N^{2+} - N^{4+}$ as well of O^{1+}, O^{2+}. Moreover we search for the small isotopic shift ^{16}O - ^{18}O present in the resonant photoionization of Be-like oxygen O^{4+} driven by the K_α transition $1s^2 2s^2 \rightarrow 1s2s^2 2p_{3/2}$ and determined an experimental value of 2.56 ± 1.27 meV.

A 37.9 Thu 17:00 Tent

Optimising the efficiency of a beamline for highly charged ions — •Melina Gizewski, Stepan Kokh, Finja Mayer, Ruben Henninger, Elwin Dijck, José R. Crespo López-Urrutia, Thomas Pfeifer, and Vera M. Schäfer — Max Planck Institut für Kernphysik Heidelberg

Highly charged ions (HCIs) are one of the most suitable systems to measure variations in the fine structure constant α, due to increased relativistic shift of energy levels at high charge states.

Our planned experimental setup includes generating HCIs in an electron beam ion trap (EBIT) and then retrapping them in two Paul traps to perform spectroscopy and measure the relevant atomic transition frequencies. Especially when using rare elements such as Cf^{17+}, it is necessary to transport the HCIs from the EBIT to the Paul traps with the highest possible efficiency. Here the electrostatic bending in the beamline is of particular importance, since it severely limits the HCI transmission rates.

This poster will showcase simulations of different electrostatic bender designs and their corresponding beamlines.

A 37.10 Thu 17:00 Tent

A high NA imaging lens for imaging Coulomb crystals in a cryogenic Paul trap experiment — •Christian Warnecke[1,2], Elwin A. Dijck[1], Bettina Mörk[1], and José R. Crespo-López Urrutia[1] — [1]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [2]Heidelberg Graduate School for Physics, Heidelberg, Germany

Highly charged ions are promising candidates for studying beyond Standard Model phenomena and advancing frequency standards in the XUV regime. At the Max-Planck Institute for Nuclear Physics in Heidelberg, a novel quasi-monolithic superconducting quadrupole resonator is used as a Paul trap to provide a noise-free environment for quantum logic spectroscopy of highly charged ions. Due to the relatively large trap dimensions of approximately $220 \times 120 \times 120\,\mathrm{mm}^3$, a minimum working distance of 60 mm is required to collect photons for state readout. Additionally, measures were taken to minimize thermal blackbody radiation input to the 4K cooling stage. The imaging system, comprising six lenses thermally stabilized at 4K and 40K, achieves a numerical aperture of 0.4 and covers a $500\,\mu$m field of view at a design wavelength of 313 nm. We will discuss our approach and provide insights from current measurements.

A 37.11 Thu 17:00 Tent

Atomic computations for plasma and astro physics — •Stephan Fritzsche — Helmholtz-Institut Jena, Germany — Friedrich-Schiller University Jena

JAC [1], the Jena Atomic Calculator, has been developed for performing (relativistic) atomic structure calculations of different kind and complexity. In particular, this code has been designed and worked out to compute atomic processes and (plasma) rate coefficients, including photo ionization and recombination, electron-impact processes and several others. JAC automatically generates self-consistent fields and, hence, is suitable also for mass production of atomic data as they are frequently needed in plasma and astro physics. Moreover, we currently implement Saha-Boltzmann schemes to model equation-of-states under different plasma conditions.

[1] S. Fritzsche, Comp. Phys. Commun. 240 (2019) 1. [2] S. Fritzsche, P. Palmeri and S. Schippers, Atomic cascade computations. Symmetry (Basel) 13, 520 (2021).

A 38: Ultra-cold Atoms, Ions and BEC V (joint session A/Q)

Time: Friday 11:00–12:45 Location: GrHS Mathe

A 38.1 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)

A 38.2 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.

A 38.3 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.

A 38.4 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.

A 38.5 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.

A 38.6 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.

A 38.7 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.

A 39: Highly Charged Ions and their Applications

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

A 39.1 Fri 11:00 KlHS Mathe

Laser cooling simulations for the FAIR SIS100 — •Aleksandar Dimitrov[1], Thomas Walther[1,2], Peter Spiller[3], and Danyal Winters[3] — [1]Technische Universität Darmstadt — [2]HFHF Campus Darmstadt — [3]GSI Helmholtzzentrum für Schwerionenforschnug GmbH Darmstadt

At the FAIR heavy-ion synchrotron SIS100, it is planned to reduce the longitudinal momentum spread and the emittance of stored heavy-ion beams using laser cooling. For the understanding and optimization of bunched beam laser cooling (of relativistic highly charged ions) simulations play a critical role. In this work, laser cooling of bunched ion beams using both continuous and pulsed laser light, and their combination, is being investigated. The relevant parameters and their effects on the final beam properties are being studied. Insights from these simulations aim to enhance the efficiency of laser cooling for future SIS100 experiments.

A 39.2 Fri 11:15 KlHS Mathe

High-precision laboratory astrophysics with TES-microcalorimeter and EBIT — •Marc Botz[1], Luciano Gottardi[2], Martin de Wit[2], Liyi Gu[2], Jonas Danisch[1], Chintan Shah[1], Alexeï Molin[3], Francois Pajot[3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]SRON, Leiden, Netherlands — [3]IRAP, Toulouse, France

We have combined a state-of-the-art array of transition edge sensor (TES) x-ray microcalorimeters with an electron beam ion trap (EBIT) for providing laboratory spectroscopy benchmarks needed to analyze observational data from the recently launched X-ray satellite XRISM. In the EBIT we produce, trap and excite by electron impact the same highly charged ions that mission observes, and collect high dynamic range spectra with the TES-array having a resolution between 1.5eV and 4eV over a wide spectral bandwidth from 300eV to 13keV.

We present measurements on highly charged iron and sulfur ions, demonstrating the systems exceptional performance. Our data on the dielectronic recombination of different charge states of iron allow for the determination of K-alpha emission energies with outstanding precision. Measurements of the radiative recombination and Rydberg transitions of helium- and hydrogen-like sulfur up to the series limit allow us to infer their transition rates.

The research leading to these results has received funding from the European Union's Horizon 2020 Programme under the AHEAD2020 project (grant agreement n. 871158)

A 39.3 Fri 11:30 KlHS Mathe

Towards trapping positrons in the Lsym experiment — •Fabian Raab, Maria Pasinetti, Paul Holzenkamp, Andreas Thoma, Luca Falzoni, Björn-Benny Bauer, Sangeetha Sasidharan, and Sven Sturm — Max-Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

Lsym is a new cryogenic Penning trap experiment that intends to test the symmetry of matter and antimatter in the lepton sector. In particular, the experiment will test for differences in mass, charge and g-factor of the positron and electron to achieve the most precise test for a hypothetical CPT violation for leptons so far. In the experiment the trapped positron has to be cooled to its ground state of motion. Therefore, the trap assembly is cooled to about 300 mK, where the trap cavity is largely depleted from black-body photons around the cyclotron frequency of 140 GHz. In this presentation our recent steps towards trapping positrons as well as an update on the microwave filter, that will be used to counteract heating above the groundstate, will be illustrated.

A 39.4 Fri 11:45 KlHS Mathe

The microwave cavity Penning trap for the LSym projet — •Paul Holzenkamp, Björn-Benny Bauer, Luca Falzoni, Maria Pasinetti, Fabian Raab, Andreas Thoma, Sangeetha Sasidharan, and Sven Sturm — 69117 Heidelberg, Saupfercheckweg 1

LSym is a cryogenic Penning trap experiment, aiming to significantly improve the precision of CPT tests for the electron and positron. Specifically, we will look for an asymmetry in their charge-to-mass ratio as well as their g-factors or determine stringent limits.

The trap will be cooled to about 300mK to minimize transition rates out of the ground states of the cyclotron and axial motion, respectively. While the cyclotron motion cools via synchrotron radiation, for the axial motion, cavity assisted side-band cooling will be employed. Furthermore, the main Penning trap ("CavityTrap") not only should provide a highly harmonic trapping potential, but also needs to support efficient millimeter wave spin control drives at the Larmor frequency and axial sideband, while efficiently rejecting photons at the cyclotron frequency. Additionally, the CavityTrap should allow for the separation of the singly charged helium ion and the positron that are trapped together.

Numerical simulations are used to design the CavityTrap geometry in order to simultaneously fulfill the requirements for the microwave cavity structure and also optimize the electrostatic potential of the Penning trap.

I will show the current status of the LSym CavityTrap design.

A 39.5 Fri 12:00 KlHS Mathe

Broadband laser cooling of stored bunched relativistic carbon ions using a high repitition rate pulsed laser system — •Sebastian Klammes[1], Lars Bozyk[1], Michael Bussmann[2,3], Noah Eizenhöfer[4], Volker Hannen[5], Max Horst[4], Daniel Kiefer[4], Thomas Kühl[1,6], Benedikt Langfeld[4,7], Xinwen Ma[8], Wilfried Nörtershäuser[4,7], Rodolfo Sánchez[1], Ulrich Schramm[3,9], Mathias Siebold[2], Peter Spiller[1], Markus Steck[1], Thomas Stöhlker[1,6,10], Ken Ueberholz[5], Thomas Walther[4,7], Hanbing Wang[8], Weiqiang Wen[8], and Danyal Winters[1] — [1]GSI Darmstadt — [2]HZDR Dresden — [3]Casus Görlitz — [4]TU Darmstadt — [5]Uni Münster — [6]HI Jena — [7]HFHF Darmstadt — [8]IMP Lanzhou — [9]TU Dresden — [10]Uni-Jena

Laser cooling of relativistic bunched ion beams at storage rings has proven to be a powerful technique to obtain very small relative longitudinal momentum spreads (Δp/p ∼1E-6 range). This contribution will give an overview of the principle, which is based on resonant absorption (photon momentum & energy) in the longitudinal direction and subsequent spontaneous random emission (fluorescence & ion recoil) by the ions, combined with a moderate bunching of the ion beam. We will report on the curent status and results from the latest laser cooling beamtime at the ESR, where broadband laser cooling of bunched relativistic C^{3+} ion beams was successfully demonstrated for the first time using a sophisticated pulsed UV laser system with a very high repetition rate (∼9 MHz), variable pulse durations (166-734 ps), and high UV power (>250 mW).

A 39.6 Fri 12:15 KlHS Mathe

Cooling of heavy highly charged ions: The HITRAP-Penning Trap — •Dimitrios Zisis[1], Wilfried Nörtershäuser[1], Zoran Andelkovic[2], Frank Herfurth[2], Nils Stallkamp[2,3], Simon Rausch[1], Jonas Ködel[1], Gleb Vorobjev[2], Svetlana Fedotova[2], Sergiy Trotsenko[2], Dennis Neidherr[2], and Wolfgang Geithner[2] — [1]Institut für Kernphysik, TU Darmstadt, Schloßgartenstr. 9, Darmstadt, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Planckstr. 1, Darmstadt, Germany — [3]Institut für Kernphysik, Goethe University Frankfurt, Germany

The Highly charged Ions TRAP (HITRAP) located at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, is a facility for deceleration and cooling of ions that are produced at the accelerator complex thereby providing heavy, highly charged ions at low velocities and small energy distributions. Ion bunches consisting up to 10^8 ions are injected into HITRAP at energies of 4 Mev/u from the Experimental Storage Ring (ESR), which are then slowed down to 6 kev/u in the two-stages linear decelerator.

We present the current status of the cooling trap and the ongoing progress to demonstrate electron cooling of extended amounts of heavy HCI for the first time. During the last year, HCI coming from the accelerator complex were successfully trapped for the first time. Additional optimization is still required in order for cooling of online produced HCI to be cooled down to low temperatures.

A 39.7 Fri 12:30 KlHS Mathe

FOSS Precision Timing Control for Heavy Ion Cooling at HITRAP — •Jonas Ködel[1], Zoran Andelkovic[2], Svetlana Fedotova[2], Wolfgang Geithner[2], Henning Hegen[2], Frank Herfurth[2], Nikolaus Kurz[2], Dennis Neidherr[2], Wilfried Nörtershäuser[1], Simon Rausch[1], Nils Stallkamp[2,3], Sergiy Trotsenko[2], Gleb Vorobjev[2], Michael Wiebusch[2], and Dimitrios Zisis[1] — [1]Institut f. Kernphysik, TU Darmstadt, Schloßgartenstr. 9, Darmstadt, Germany — [2]GSI Helmholtzzentrum f. Schwerionenforschung, Planckstr. 1, Darmstadt, Germany — [3]Institut f. Kernphysik, Goethe University Frankfurt, Germany

Operating modern scientific apparatus requires smooth interaction of hard- and software. Industry standard software solutions offered by for-profit companies create unfavourable dependencies, locking experimenters into a walled garden that is hard to leave, and costly to stay in. We present the deployment of a **f**ree, **o**pen-**s**ource **s**oftware (FOSS) solution for control of the Penning trap of the **hi**ghly charged ion **trap** (HITRAP) during the most recent beamtime. HITRAP is located at GSI Darmstadt and allows deceleration and cooling of heavy, **h**ighly **c**harged **i**ons (HCI) down to 6 kev/u. Sympathetic cooling of HCI by concurrently stored electrons in a Penning trap is used as the final deceleration and cooling stage. The electrodes of the trap are switched in user-programmed patterns with nanosecond accuracy. Hard- and software of the trap control system are developed in-house. Their capabilities and the feasibility of a FOSS solution to experiment control are proven by their successful deployment during the recent beamtime.

A 39.8 Fri 12:45 KlHS Mathe

Experiments on Highly Charged Ions from S-EBIT II — •Rex Simon[1,2,3], Tino Morgenroth[1,2,3], Sonja Bernitt[1,2], Sergiy Trotsenko[2], Reinhold Schuch[2,4], and Thomas Stöhlker[1,2,3] — [1]Helmholtz Institute Jena, 07743 Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [3]IOQ, Friedrich-Schiller-University Jena, 07743 Jena, Germany — [4]Department of Physics, Stockholm University, 10691 Stockholm, Sweden

Electron Beam Ion Traps (EBITs) are versatile tools for investigating electron-ion interactions. Dielectronic recombination (DR) is a critical process that governs the ion charge-state equilibria in hot plasmas, with implications for theoretical models and plasma diagnostics [1]. Facilities such as CRYRING, ESR, and HITRAP [2] at GSI rely heavily on a steady supply of ions for experimental research. However, the dependence on the GSI accelerator limits operational flexibility, S-EBIT II emerged as a promising candidate to address this challenge, offering to be a local ion source for HITRAP and a standalone functionality for diverse experimental setups. By enabling local experiments such as ARTEMIS, and supporting advanced research into highly charged ion interactions, DR processes, and X-ray spectroscopy. Recent commissioning efforts include DR measurements with argon, alongside ongoing improvements to the electron gun and preparing to attach S-EBIT II

to HITRAP. References [1] Beilmann, C. et al., 2013, Phys. Rev. A, 88(6), 062706. [2] H.-J. Kluge et al., 2008, Progress in Particle and Nuclear Physics, 59, 100-115.

A 40: Cluster and Nanoparticles II (joint session MO/A)

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

Invited Talk A 40.1 Fri 11:00 HS XV

N_2 activation by transition metal clusters — Max Luczak, Christopher Wiehn, Daniela Fries, Niels Wolfgramm, Christoph van Wüllen, and •Gereon Niedner-Schatteburg — Fachbereich Chemie, RPTU Kaiserslautern-Landau

Size selected transition metal (TM) cluster cations and anions attach N_2 molecules under single collision cryo conditions, and they may or may not subsequently activate the adsorbates. Cryo kinetics and infrared spectra reveal details that serve to model the activation pathways by DFT calculations [1,2,3]. It shows that there is a quite general multi-step-pathway. Energetics vary by the particular TM but corresponding intermediates along the pathways seem quite similar amongst the investigated TMs. We aim to put these findings to the stage and present our current understanding for further discussions.

[1] Phys. Chem. Chem. Phys. **23**, 11345 (2021); DOI: 10.1039/D0CP06208A

[2] J. Chem. Phys. **159**, 164306 (2023); DOI: 10.1063/5.0157218

[3] J. Chem. Phys. **159**, 164303 (2023); DOI: 10.1063/5.0157217

A 40.2 Fri 11:30 HS XV

Dynamics of CO_2 activation by transition metal ions — •Marcel Meta, Maximilian E. Huber, Martin Wedele, and Marcel Meta — RPTU Kaiserslautern-Landau und Forschungszentrum OPTIMAS, Fachbereich Chemie, Kaiserslautern, Germany

Here, we present a joint experimental and theoretical study of the dynamics of ion-molecule reactions. We focus on the oxygen atom transfer (OAT) reaction between transition metal ions and carbon dioxide $M^+ + CO_2 \rightarrow MO^+ + CO$ (M^+=Ta^+,Nb^+,Zr^+) [1,2]. Indirect dynamics were observed for all reactions, despite the fact that the thermal rates are close to the collision rate and the reaction is exothermic in all cases. The investigated reactions have a multi-state character and require an inter-system crossing (ISC) for their occurrence. These findings indicate the presence of a bottleneck along the reaction. The nature of the bottleneck (submerged transition state versus ISC) was investigated in a collaborative effort.

In order to achieve this, angle and energy differential cross-sections were measured using 3D velocity map imaging at different collision energies. Thermal rate constants were obtained using selected ion flow tube (SIFT). These experimental findings were supplemented by high-level theory and trajectory simulations [3]. In addition, this approach allows us to make precise assertions regarding the distribution of energy. [1] M. E. Huber et al. 8670, 26, Phys. Chem. Chem. Phys. (2024). [2] M. Meta et al., 5524, 14, J. Phys. Chem. Lett (2023). [3] Y. Liu et al. J. Am Chem. Soc., 14182, 146 (2024).

A 40.3 Fri 11:45 HS XV

Insights into Facile Methane Activation by Transition Metal Ions via Intersystem Crossing — Marcel Meta, Maximilian Huber, •Maurice Birk, Martin Wedele, Boris Heeb, and Jennifer Meyer — RPTU Kaiserslautern-Landau, Fachbereich Chemie und Landesforschungszentrum OPTIMAS, Kaiserslautern, Germany

A model for processes like single atom catalysis can be the study of isolated transition metal ion molecule reactions in the gas phase [1,2]. Here, we present a study of kinetics and dynamics on the activation of methane (CH_4) by transition metal cations $M^+ + CH_4 \rightarrow MCH_2{}^+ + H_2$. The nominally spin-forbidden reaction requires intersystem crossing (ISC) to proceed. The impact of ISC on the dynamics is studied by collaborative effort combining experiment and theory.

We used crossed-beam velocity map imaging to measure differential cross sections for the carbene formation in the reaction with tantalum Ta^+ [3]. The reaction shows dominantly indirect dynamics which is associated to the formation of a long-lived intermediate complex. Experiments for Ta^+ are furthermore complemented by the reaction of CH_4 with zirconium Zr^+. In addition recent preliminary theoretical studies confirmed our observations regarding the reaction with Ta^+ and also revealed that the bottleneck of this reaction is ISC between the quintet and triplet states.

[1] D. K. Böhme, H. Schwarz, Angew. Chem. Int. Ed. 2005, 44, 2336; [2] H. Schwarz, Catal. Sci. Tech. 2017, 7, 4302; [3] M. Meta, Faraday Discuss. 2024, 251, 587

A 40.4 Fri 12:00 HS XV

Relaxation of solvated electrons in the presence of ammonia orbital vacancies — •Aaron Ngai[1], Dominique Dominique[2], Lukas Bruder[1], Wentao Chen[1], Aleksandr Demianenko[1], Michele Di Fraia[3], Katrin Dulitz[4], Ioannis Makos[1], Evangelos Miliordos[5], Sitanath Mondal[1], Oksana Plekan[6], Sooraj Rajendran[1], Fabian Richter[1], Niklas Scheel[7], Brendan Wouterlood[1], Bruce Yoder[2], Carlo Callegari[6], Marcel Mudrich[7], Giuseppe Sansone[1], Ruth Signorell[2], Frank Stienkemeier[1], and Sebastian Hartweg[1] — [1]Institute of Physics, University of Freiburg, Germany — [2]Department of Chemistry and Applied Biosciences, ETH Zürich, Switzerland — [3]CNR - Istituto Officina dei Materiali (IOM), S.S. 14, Km 163.5, 34149 Trieste, Italy — [4]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria — [5]Department of Chemistry and Biochemistry, Auburn University, AL, US — [6]Elettra - Sincrotrone Trieste S.C.p.A., Basovizza, Trieste, Italy — [7]Department of Physics and Astronomy, Aarhus University, Denmark

Solvated electrons in alkali-metal ammonia solutions are fascinating species that motivate fundamental and applied studies from different fields of research. In synthetic chemistry, these solvated electrons are used as powerful reducing agents in challenging reduction reactions [1]. From a physical perspective, they exhibit peculiar concentration-dependent properties and processes, such as the spin-pairing of solvated electrons and the phase transition to a metallic state at high concentrations [2]. Recently, a photoionization study of sodium-doped ammonia clusters, revealed the production of low-energy electrons from electron-transfer mediated decay of solvated electron pairs formed by optical excitation [3]. Motivated by the observation of this optically-triggered autoionization process, we performed a time-resolved photoelectron spectroscopy study of sodium-doped ammonia clusters with extreme ultraviolet radiation at the free-electron laser FERMI. I will present preliminary results of this study, which reveals the dynamics of solvated electrons in the vicinity of ammonia valence shell vacancies and the effects of excitations induced by ultraviolet light in these fascinating cluster systems.

[1] Birch, A.J. *J. Chem. Soc.*, **0**, 430-436 (1944)

[2] Zureck, E. *et al. Angew. Chem. Int. Ed.* **48**, 44 (2009)

[3] Hartweg, S. *et al. Science* **380**, 6650 (2023)

A 40.5 Fri 12:15 HS XV

Droplet shape and quantum vortices visualized by the spectral shape of the electronic band origin of phthalocyanine doped into superfluid helium nanodroplets — •Rupert Jagode and Alkwin Slenczka — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93053 Regensburg

With the help of X-ray diffraction, the global shape of superfluid helium droplets could be imaged [1]. In addition, the inner structure, which may consist of quantum vortices - a specific form of angular momentum in quantum liquids - also became visible. These findings provide a consistent interpretation for the evolution of the spectral shape at the electronic band origin of phthalocyanine with increasing droplet size. Both the droplet shape and the presence of quantum vortices should have an effect on the solvent shift of the electronic transitions of the dopant molecule. New lineshape studies were carried out with systematic variation of the effective droplet sizes and optical anisotropy studies. From these new data, some of the still open questions regarding a reversal of the solvent shift [2] as well as the imperfect reproducibility of the observed signal splitting [2] could be clarified. Obviously, electronic spectroscopy complements the observations from X-ray diffraction on droplet shapes and the presence of quantum vortices for a range of smaller droplet sizes, which are relevant as host systems in molecular spectroscopy.

[1] B. Langbehn et al., Phys.Rev.Lett. 121, 255301 (2018), A. Ul-

mer et al., Phys.Rev.Lett. 131, 076022 (2023). [2] S. Fuchs et al., J.Chem.Phys. 148, 144301 (2018).

A 40.6 Fri 12:30 HS XV

Broadband Femtosecond Transient Absorption Microscopy — •Magnus Frank, Chris Rehhagen, and Stefan Lochbrunner — Institute for Physics and Department of Life, Light and Matter, University of Rostock, 18051 Rostock, Germany

Organic crystalline micro- and nanostructures have become of great interest in the field of semiconductors and optoelectronics. In these applications the exciton dynamics play an important role and can determine the suitability of a certain structure. Femtosecond pump probe spectroscopy is the standard method for characterising exciton dynamics but its adoption for use on organic micro- and nanostructures is not without challenge. The main problem is increasing the spatial resolution to a level that a specific structure can be studied while maintaining a high signal to noise ratio. Additionally, tightly focussing spectrally broad light represents another challenge as chromatically compensated optics cannot be used with fs laser pulses. It is for these reasons that typically only single colour experiments are conducted.

In this work we present a transient absorption microscope that is capable of resolving singular nanostructures. We are able to reach a spatial resolution lower than 1 μm and a sub-100 fs time resolution while managing to cover nearly the whole visible spectrum as well as parts of the NIR.

A 40.7 Fri 12:45 HS XV

Time-resolved UV-vis Spectroelectrochemistry — •Nina Brauer[1], Ramisha Rabeya[1], Robert Francke[2], and Stefan Lochbrunner[1] — [1]Institute of Physics, University of Rostock, Germany — [2]Leibniz Institute for Catalysis, Rostock, Germany

Homogeneous electrocatalysis based on transition metal complexes holds great potential for carbon dioxide utilization. In order to develop an efficient catalytic system, detailed knowledge about each step of the complex reaction chain is highly desirable. Therefore, the identification of short-lived intermediates and the determination of their life-times is of crucial importance here.

Spectroelectrochemistry has proven to be a powerful experimental approach to determine the reaction dynamics during electrocatalytic processes. In this work, a time-resolved UV-vis spectroelectrochemistry setup is developed using laser pulses to achieve a time resolution of microseconds. In contrast to previous work, this enables precise detection of catalytic reaction rates down to the diffusion limit. In the experiment, a femtosecond supercontinuum is focused closely to the working electrode surface inside a custom electrochemical cell based on a quartz glass cuvette. Upon applying a potential step to the electrodes, the induced absorption change inside the diffusion layer is measured as a function of time.

A 41: Ultracold Matter (Fermions) II (joint session Q/A)

Time: Friday 11:00–13:00 Location: HS V

Invited Talk A 41.1 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.

A 41.2 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)

A 41.3 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.

A 41.4 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.

A 41.5 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^*.

A 41.6 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.

A 41.7 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)