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)