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

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

Invited Talk Q 16.1 Mon 17:00 KlHS Mathe

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

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

Q 16.2 Mon 17:30 KlHS Mathe

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

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

Q 16.3 Mon 17:45 KlHS Mathe

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

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

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

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

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

Q 16.4 Mon 18:00 KlHS Mathe

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

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

Q 16.5 Mon 18:15 KlHS Mathe

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

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

Q 16.6 Mon 18:30 KlHS Mathe

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

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

Q 16.7 Mon 18:45 KlHS Mathe

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

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