A 31: Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)

Time: Thursday 14:30–16:30 Location: N 1

A 31.1 Thu 14:30 N 1

Stability of current-carrying Bose-condensed states in a hard-core Bose-Hubbard model with long-range hopping — •Yoshihiro Yabuuchi[1,2] and Ippei Danshita[2] — [1]Osaka Metropolitan University, Japan — [2]Kindai University, Japan

The technological progress in the platforms for long-range interacting spin systems have opened new possibilities for exploring emergent quantum many-body phenomena arising from the long-range nature of interactions. Rydberg atom arrays and trapped ions have allowed for realizing systems described by the spin-1/2 XY model with long-range spin-exchange interactions, in which the coupling strength decays algebraically as $\propto r^{-\alpha}$, where r is the distance between sites and α the decay exponent. Owing to the theoretical mapping between the spin-1/2 XY model and the hard-core Bose-Hubbard model, the long-range interaction in the former corresponds to the long-range hopping of hard-core bosons where the hopping amplitude decays as $\propto r^{-\alpha}$. We theoretically investigate how the long-range hopping affects the stability of current-carrying Bose-condensed states of hard-core bosons [1]. Within a mean-field theory, we find that the critical quasi-momenta for both Landau and dynamical instabilities decrease with decreasing α from a large value and vanishes at $\alpha = 3$, implying that long-range hopping reduces the stability of the current-carrying state. Near $\alpha = 3$, the critical quasi-momentum for the dynamical instability is proportional to $\Delta^{1+\Delta}$ with $\Delta = \alpha - 3$, meaning that the scaling exponent itself depends on Δ as a remarkable consequence of the long-range nature. [1] Y. Yabuuchi, and I. Danshita, arXiv:2511.14260

A 31.2 Thu 14:45 N 1

Quantum bubbles in the Einstein-Elevator facility at Leibniz University Hannover — •Charles Garcion[1], Timothé Estrampes[1], Brendan Rhyno[1], Jean-Baptiste Gérent[2], Eric Charron[3], Ernst Maria Rasel[1], Nathan Lundblad[2], and Naceur Gaaloul[1] — [1]Institute of Quantum Optics, Leibniz University Hannover,Welfengarten 1, 30167 Hanover, Germany — [2]Department of Physics and Astronomy, Bates College, Lewiston, ME, USA. — [3]Institut des Sciences Moléculaires d'Orsay, CNRS, Université Paris-sacay, F-91405, Orsay, France

Quantum bubbles atoms confined to a closed surface offer a unique platform for studying topological phenomena, including vortex dynamics and collective modes on curved manifolds. Creating these potentials requires RF-dressed states, where the direct interaction between atoms and the RF field makes the system highly sensitive to source noise. The Quantumania project targets these geometries using the MAIUS-1 payload in the Einstein-Elevator at Leibniz University Hannover. To ensure sufficient field quality, we have initiated the design of a custom RF source specifically to minimize heating and noise. We present the technical specifications of this new source and our strategy for antenna optimization. These efforts aim to achieve robust atom dressing in the Einstein-Elevator. Furthermore, characterizing these bubble potentials contributes to the optimization of experimental schemes within our collaboration with the Cold Atom Laboratory on the International Space Station.

A 31.3 Thu 15:00 N 1

Hilbert space fragmentation in driven-dephasing Rydberg atom array — tianyi yan, chunhei leung, and •weibin li — University of Nottingham, Nottingham NG7 2RD, United Kingdom

We investigate the onset and mechanism of Hilbert space fragmentation (HSF) in a chain of strongly interacting Rydberg atoms subject to local dephasing. It is found that the emergence of multiple long-lived metastable states is fundamentally tied to HSF of the driven-dephasing Rydberg atom system. We demonstrate that the manifesting HSF is captured by a dephasing PXP model that supports multiple degenerate zero modes. These modes form disconnected, block-diagonal subspaces of maximally mixed states, which consist of many-body spin states sharing the same symmetry. A key result is the identification of the underlying symmetry in the HSF, where conserved quantities in each subspace are defined by the consecutive double excitation addressing operator. Moreover, we show explicitly that the number of the fragmented Hilbert space grows exponentially with the chain length, following a modified Fibonacci sequence. Our work provides insights into many-body dynamics under dynamical constraints and opens avenues for controlling and manipulating HSF in Rydberg atom systems.

A 31.4 Thu 15:15 N 1

Discovery of atomic Shapiro steps — •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 L. Amico[1] — [1]QRC,TII,AbuDhabi, UAE — [2]RPTU Kaiserslautern, Germany — [3]LENS, University of Florence, Italy — [4]UNAM Mexico — [5]ZOQ and IQP, Universität Hamburg, Germany

I will discuss how Josephson effects arise in ultracold quantum systems and present recent theoretical predictions for driven atomic Josephson junctions [1]. Following this proposal, two leading experimental groups worldwide have independently observed Shapiro steps in atomic junctions for the first time [2, 3]. These experiments demonstrate deterministic, phase-locked transport in atomic circuits. Together, these advances establish driven atomic Josephson junctions as a versatile platform for atomtronics, quantum simulation, and quantum technology development.

[1] Singh, Polo, Mathey, Amico, PRL 133, 093401 (2024)

[2] Del Pace, Hernandez-Rajkov, Singh, Grani, Fernandez, Nesti, Seman, Inguscio, Amico, Roati, arXiv: 2409.03448 (2024)

[3] Bernhart, Röhrle, Singh, Mathey, Amico, Ott, arXiv: 2409.03340 (2024)

A 31.5 Thu 15:30 N 1

Bayesian Thermometry with Single-Atom Quantum Probes for Ultracold Gases — •Julian Fess, Luca Granert, Sabrina Burgardt, Silvia Hiebel, and Artur Widera — Department of Physics, University of Kaiserslautern-Landau, 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 31.6 Thu 15:45 N 1

Vortices in a 2D fermionic superfluid — •Hans Leonard Michel, Artak Mkrtchyan, Moritz von Usslar, René Henke, Cesar Cabrera, and Henning Moritz — Institut für Quantenphysik, Universität Hamburg, Hamburg, Germany

Quantised vortices are widely studied excitations in superfluid systems from helium to ultracold Bose Einstein condensates. While many experiments observed vortices in 3D systems, few realisations were made in 2D systems and none in the 2D BEC-BCS crossover. Here, we will report on the deterministic creation and observation of vortices and their phase quantisation in homogeneous 2D ultracold Fermi gases.

We prepare the homogeneous 2D disk shaped systems by freezing out the vertical motion and imposing a circular outer radial barrier. The vortices are detected by ramping to a quasi-3D regime and subsequent time of flight imaging. This method allows us to reliably create and detect single vortex anti-vortex pairs as well as doubly charged vortices across the BEC-BCS crossover. We confirm that these vortices are quantised by observing the phase profile using matter wave interferometry. To this end, we let the central disk shaped region interfere with an annular outer gas as phase reference after ramping to

3D. Our observation of concentric rings and spirals with one or two arms when creating vortices with no, single or double charge confirms the quantisation of the phase of the vortex. Our measurements provide proof of phase coherence and strong evidence for superfluidity in these strongly interacting quantum fluids across the BEC-BCS crossover.

A 31.7 Thu 16:00 N 1

Extended Gross-Pitaevskii equation for quantum droplets in cavity BEC systems — •Leon Mixa[1,2,3], Laurenz Timmermann[1], Milan Radonjić[1,4], Axel Pelster[3], and Michael Thorwart[1,2] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Hamburg, Germany — [3]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany — [4]Institute of Physics Belgrade, University of Belgrade, Serbia

Quantum droplets are an exotic state of matter that characterizes a self-bound many-body system emerging from quantum fluctuation energy corrections to the ground state. Here, we present a theoretical framework for a new type of quantum droplet that emerges from a Bose-Einstein condensate in a cavity. Vacuum fluctuations in the cavity mediate an effective, long-range atom-atom interaction that, at the leading order, results in the formation of a distinct roton mode. The zero-point energy of the roton increases proportionally to the volume of the atom gas and thus competes with the repulsive s-wave contact interaction, facilitating the formation of the droplet [PRR 7, 033216; PRR 7, 023204 (2025)]. We present an extended Gross-Pitaevskii equation for the ground state incorporating the quantum fluctuation contribution. We analyze the impact of the roton mode correction term on the droplet wave function. Using a variational ansatz, we evaluate the stability, size, and density of the droplet, comparing it to the homogeneous density profile used in the original derivation.

A 31.8 Thu 16:15 N 1

Analytical approach to collisional decoherence in a BEC double-well accelerometer — •Kateryna Korshynska[1,2] and Sebastian Ulbricht[1,2] — [1]PTB Braunschweig — [2]TU Braunschweig

Modern quantum sensors provide a way to measure accelerations and gravitational fields to tremendous precision, surpassing their classical counterparts. One way to build such a quantum sensor is to exploit the process of quantum tunneling of a Bose-Einstein condensate (BEC), trapped in a double-well potential. This tunneling emerges as the collective oscillations of particles between the wells, which are usually referred to as Josephson oscillations. They rely on the coherence between the quantum states of each well, which can decrease due to collisional decoherence. For the weakly-interacting gas, we analytically describe this decoherence process with the density matrix approach and show how the Josephson oscillations decay with time. Further, we consider the BEC subject to external acceleration and find that the interplay between the acceleration and collisions leads to an additional shift of the oscillation frequency. Moreover, we study how this effect can be used as the basis of a BEC double-well accelerometer and estimate its expected sensitivity.