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

Time: Friday 10:30–12:15 Location: A-H1

Invited Talk A 31.1 Fri 10:30 A-H1

Cavity-enhanced optical lattices for scaling neutral atom quantum technologies — •Jan Trautmann[1,2], Annie J. Park[1,2], Valentin Klüsener[1,2], Dimitry Yankelev[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2] — [1]MPQ, 85748 Garching, Germany — [2]MCQST, 80799 München, Germany — [3]LMU, 80799 München, Germany

We present a solution to scale up optical lattice experiments with ultracold atoms by an order of magnitude compared to the state-of-the-art. We utilize power enhancement in optical cavities to create two-dimensional optical lattices with large mode waists using low input power. We test our system using high-resolution clock spectroscopy on ultracold Strontium atoms trapped in the lattice. The observed spectral features can be used to locally measure the lattice potential envelope and the sample temperature with a spatial resolution limited only by the optical resolution of the imaging system. The measured lattice mode waist is 489(8) μm and the trap lifetime is 59(2) s. We observe a long-term stable lattice frequency and trap depth on the MHz level and the 0.1% level. Our results demonstrate that large, deep, and stable two-dimensional cavity-enhanced lattices can be created at any wavelength and can be used to scale up neutral-atom-based quantum simulators, quantum computers, sensors, and optical lattice clocks.

[1] A. J. Park, J. Trautmann, N. Šantić, V. Klüsener, A. Heinz, I.Bloch, and S. Blatt. Cavity-enhanced optical lattices for scaling neutral atom quantum technologies, arXiv:2110.08073, (2021).

A 31.2 Fri 11:00 A-H1

Ionic Polarons in a Bose-Einstein condensate — •Luis Ardila — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

The versatility and control of ultracold quantum gases opened up a plethora of theoretical predictions on polaronic physics using ultracold quantum gases, resulting in several experimental realizations. In his talk, we will discuss ionic polarons created as a result of charged particles interacting with a Bose-Einstein condensate. Here we show that even in a comparatively simple setup consisting of a charged impurity in a weakly interacting bosonic medium with tunable atom-ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state. Using quantum Monte Carlo simulations, we unravel its vastly different polaronic properties compared to neutral quantum impurities. Moreover, we identify a transition between the regime amenable to conventional perturbative treatment in the limit of weak atom-ion interactions and a many-body bound state with vanishing quasi-particle residue composed of hundreds of atoms. Recent experiments on ionic impurities in quantum gases are promising platforms to study ionic polarons. Our work paves the way to understand how ions coupled a quantum gas which may be important for future applications in quantum technologies.

A 31.3 Fri 11:15 A-H1

An Artificial Bosonic Atom in One Spatial Dimension — •Fabian Brauneis[1], Timothy Backert[1], Simeon Mistakidis[2], Mikhail Lemeshko[3], Hans-Werner Hammer[1,4], and Artem Volosniev[3] — [1]Technische Universität Darmstadt, Department of Physics, Institut für Kernphysik, 64289 Darmstadt, Germany — [2]ITAMP, Center for Astrophysics | Harvard & Smithsonian, Cambridge, MA 02138 USA — [3]Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria — [4]ExtreMe Matter Institute EMMI and Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

We study an analogue of an atom realized by a one-dimensional Bose gas. Repelling bosons (“electrons”) are attracted to an impurity, the “nucleus”. The interplay between the attractive impurity-boson and repulsive boson-boson interaction leads to a crossover between different states of the system when the parameters are varied. For a non-interacting Bose gas, an arbitrary number of bosons can be bound to the impurity. In contrast, if they are impenetrable, the bosons fermionize and only one boson is bound. This observation implies that there is a critical number of bosons that can be bound to the impurity for finite values of the boson-boson interaction strength. We discuss the three resulting states of the system - bound, transition and scattering - within the mean-field approximation. In particular, we calculate the critical particle number supporting a bound state. To validate our mean-field results, we use the flow equation approach.

A 31.4 Fri 11:30 A-H1

Pattern formation and symmetry breaking in a periodically driven 2D BEC — •Nikolas Liebster, Celia Viermann, Maurus Hans, Marius Sparn, Elinor Kath, Helmut Strobel, and Markus Oberthaler — Kirchhoff Institut für Physik, Heidelberg, Deutschland

Dynamical pattern formation is a ubiquitous phenomenon in nature, and has relevance in many fields in physics. The emergence of these patterns, as well as how symmetries are broken, remains an open field of research in quantum physical systems. By periodically driving the scattering length in a 2D potassium-39 Bose-Einstein condensate, we use parametric resonance to non-linearly populate specific momentum modes of trapped condensates. We show the emergence of randomly oriented standing waves with D4 symmetry and investigate these structures in real and momentum space, showing the growth of both primary and secondary momentum modes. Finally, we investigate the effects of trapping geometries on the formation of patterns on the condensate.

A 31.5 Fri 11:45 A-H1

Quantum gas magnifier for sub-lattice-resolved imaging of 3D quantum systems — Luca Asteria, Henrik P. Zahn, •Marcel N. Kosch, Klaus Sengstock, and Christof Weitenberg — Universität Hamburg, Hamburg, Deutschland

Imaging is central for gaining microscopic insight into physical systems, but direct imaging of ultracold atoms in optical lattices as modern quantum simulation platform suffers from the diffraction limit as well as high optical density and small depth of focus. We introduce a novel approach to imaging of quantum many-body systems using matter wave optics to magnify the density distribution prior to optical imaging, allowing sub-lattice spacing resolution in three-dimensional systems. Combining the site-resolved imaging with magnetic resonance techniques for local addressing of individual lattice sites, we demonstrate full accessibility to local information and local manipulation in three-dimensional optical lattice systems. The method opens the path for spatially resolved studies of new quantum many-body regimes including exotic lattice geometries.

A 31.6 Fri 12:00 A-H1

Resetting many-body quantum systems — •Gabriele Perfetto, Federico Carollo, Matteo Magoni, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We consider closed quantum many-body systems subject to stochastic resetting. This means that their unitary time evolution is interrupted by resets at randomly selected times. The study of the non-equilibrium stationary state that emerges from the combination of stochastic resetting and coherent quantum dynamics has recently raised significant interest. The connection between this non-equilibrium stationary state, an effective open dynamics and non-equilibrium signatures of quantum phase transitions is, however, not fully understood.

In the talk we provide a unified understanding of these phenomena by combining techniques from quantum quenches in closed systems and semi-Markov processes. We discuss as an application the paradigmatic quantum Ising chain. We show that signatures of its ground-state quantum phase transition are visible in the steady state of the reset dynamics as a sharp crossover.

Our findings show that stochastic resetting can be exploited to generate many-body quantum stationary states where incoherent effects, such as heating, can be hindered. These stationary states can be then used in quantum simulator platforms for sensing applications.

[1] G.Perfetto *et al.*, Phys. Rev. B **104**, L180302 (2021)