Q 2: Quantum Gases (Bosons) I

Time: Monday 14:00–16:00 Location: Q-H10

Invited Talk Q 2.1 Mon 14:00 Q-H10

Matter-wave microscope for sub-lattice-resolved imaging of 3D quantum systems — •Christof Weitenberg — Institut für Laserphysik, Luruper Chaussee 149, 22761 Hamburg

Imaging is central to gaining microscopic insight into physical systems, and new microscopy methods have always led to the discovery of new phenomena and a deeper understanding of them. Ultracold atoms in optical lattices provide a quantum simulation platform, featuring a variety of advanced detection tools including direct optical imaging while pinning the atoms in the lattice. However, this approach suffers from the diffraction limit, high optical density and small depth of focus, limiting it to two-dimensional (2D) systems.

In this talk, I will present our new imaging approach where matter-wave optics magnifies the density distribution before optical imaging, allowing 2D sub-lattice-spacing resolution in three-dimensional (3D) systems. The method opens the path for spatially resolved studies of new quantum many-body regimes and paves the way for single-atom-resolved imaging of atomic species, where efficient laser cooling or deep optical traps are not available, but which substantially enrich the toolbox of quantum simulation of many-body systems.

Q 2.2 Mon 14:30 Q-H10

Observation of a dissipative time crystal — •Hans Kessler[1], Phatthamon Kongkhambut[1], Jim Skulte[1], Ludwig Mathey[1,2], Jayson G. Cosme[3], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Center for Ultrafast Imaging — [3]National Institute of Physics, University of the Philippines

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the small field decay rate ($\kappa/2\pi$=4.5kHz), which is in the order of the recoil frequency (ωrec/2π=3.6kHz). This leads to a unique situation where cavity field evolves with the same timescale as the atomic distribution. If the system is pumped transversally with a steady state light field, red detuned with respect to the atomic resonance, the Hepp-Lieb superradiant phase transition of the open Dicke is realized. Starting in this self-ordered density wave phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetrybroken states [1]. For a blue-detuned pump light with respect to the atomic resonance, we propose an experimental realization of limit cycles. Since the model describing the system is time-independent, the emergence of a limit cycle phase heralds the breaking of continuous time-translation symmetry [2]. References [1] H. Keßler et al., PRL 127, 043602 (2021). [2] H. Keßler et al., PRA 99, 053605 (2019).

Q 2.3 Mon 14:45 Q-H10

Realization of a periodically driven open three-level Dicke model — •Phatthamon Kongkhambut[1], Hans Kessler[1], Jim Skulte[1,2], Ludwig Mathey[1,2], Jayson G. Cosme[3], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Center for Ultrafast Imaging — [3]National Institute of Physics, University of the Philippines

A periodically driven open three-level Dicke model is realized by resonantly shaking the pump* field in an atom-cavity system. As an unambiguous signature, we demonstrate the emergence of a dynamical phase, in which the atoms periodically localize between the antinodes of the pump lattice, associated with an oscillating net momentum along the pump axis. We observe this dynamical phase through the periodic switching of the relative phase between the pump and cavity fields at a small fraction of the driving frequency, suggesting that it exhibits a time crystalline character.

[1] P. Kongkhambut et al., arXiv:2108.11113 (2021). [2] J. Skulte et al., arXiv:2108.10877 (2021).

Q 2.4 Mon 15:00 Q-H10

Extended Bose-Hubbard models with Rydberg macrodimer dressing — •Mathieu Barbier[1], Simon Hollerith[2], and Walter Hofstetter[1] — [1]Institut für theoretische Physik, Goethe Universität, 60438 Frankfurt am Main — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

We propose dressing bosonic quantum gases dressed with macrodimer states - molecular bound states in Rydberg interaction potentials - as a promising approach for experimental observation of novel quantum phases such as supersolids. We investigate the scaling laws of the dressed interaction strength and the scattering rate with respect to the effective principal quantum number and trapping frequency of the ground state atoms for the molecular potentials of Rubidium and Potassium. Additionally, we propose a two-color excitation scheme which significantly increases the dressed interaction and cancels otherwise limiting AC Stark shifts. Furthermore, we study the corresponding extended Bose-Hubbard model within the Cluster Gutzwiller approach and compute the equilibrium phase diagram. By means of time-evolution simulations in the presence of realistic dissipation we investigate the possible preparation of supersolid phases and suggest a parameter regime for which, through ramping up to coupling to the macrodimer states, supersolid phases could be experimentally observable.

Q 2.5 Mon 15:15 Q-H10

Supersolid phases of ultracold bosons trapped in optical lattices dressed with Rydberg *p*-states — •Mathieu Barbier, Henrik Lütjeharms, and Walter Hofstetter — Institut für theoretische Physik, Goethe Universität, 60438 Frankfurt am Main, Germany

In recent years Rydberg-excited bosonic quantum gases have emerged as a promising platform for realizing quantum phases with broken lattice translational symmetry, such as density wave and lattice supersolid phases. Although numerous theoretical works on trapped gases dressed with Rydberg *s*-states have predicted these phases, their experimental observation proves to be difficult due to challenges such as scattering processes and the limited experimentally achievable coupling strength. On the other hand, the less investigated case of Rydberg *p*-state dressing possesses advantages in this respect. We therefore study the quantum phases of an ultracold bosonic quantum gas trapped in a square optical lattice and dressed with Rydberg *p*-states, going both beyond the weak-dressing regime and the frozen regime. We consider an extended Bose-Hubbard model and compute its ground state phase diagram within Gutzwiller mean-field theory. We obtain Mott insulating, superfluid, density wave and supersolid regimes within the parameter space considered. Furthermore, through comparison with the ground state phases of bosons dressed with Rydberg *s*-states, we find the anisotropy of the long-range interaction to be beneficial for the coexistence of a condensate and spontaneously broken lattice translational symmetry, which is promising for realizing supersolid phases.

Q 2.6 Mon 15:30 Q-H10

Complex Langevin simulation of Bose-Einstein condensates — •Philipp Heinen and Thomas Gasenzer — Kirchhoff-Institut für Physik, Heidelberg

Complex Langevin (CL) is an approach to the solution of the sign problem, which arises when trying to numerically compute path integrals for complex-valued actions with standard Monte Carlo techniques. The idea behind the method is to rewrite the path integral as a stochastic Langevin equation. The latter can be straightforwardly generalized to the case of a complex action, leading to a stochastic evolution in a complexified field manifold. Whereas the application of CL has a long-standing tradition in high energy physics, in particular in the simulation of quantum chromodynamics at finite chemical potential, it is less established so far in the field of ultracold atomic gases. We present results of CL simulations for multi-component Bose-Einstein condensates.

Q 2.7 Mon 15:45 Q-H10

Spectroscopy of heteronuclear xenon-noble gas mixtures - Towards Bose-Einstein condensation of vacuum-ultraviolet photons — •Thilo vom Hövel, Eric Boltersdorf, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn

In the vacuum-ultraviolet regime (VUV, 100 - 200 nm), realizing lasers is difficult, as excited state lifetimes scale as $1/\omega^3$, resulting in the need of high pump powers to achieve population inversion in active media. We propose an experimental approach for the realization of a coherent light source in the VUV based on Bose-Einstein condensation of photons. In our group, Bose-Einstein condensation of visible photons is investigated using liquid dye solutions as thermalization media in wavelength-sized optical microcavities, the latter providing a non-trivial low-energy ground state the photons condense into.

Conveying these principles into the VUV, a suitable thermalization medium has to be found. For this, we here consider heteronuclear mixtures of xenon and another noble gas atom as a potential candidate, with absorption re-emission cycles on the transition from the atomic ground state ($5p^6$) to the lowest electronically excited state ($5p^5 6s$) and emission from a lightly bound heteronuclear excimer state for thermalization. We report on the results of current spectroscopic measurements, investigating VUV line profiles of samples containing xenon and different noble gases. Also, the data is tested for the validity of the Kennard-Stepanov relation, a fundamental prerequisite for the suitability of a medium as thermalization mediator in the scheme.