Q 9: Quantum Gases: Bosons I

Time: Monday 17:00–19:00 Location: A320

Invited Talk Q 9.1 Mon 17:00 A320

Compressibility and the equation of state of an optical quantum gas in a box — •Julian Schmitt — University of Bonn, Germany

Quantum gases of atoms, exciton-polaritons, and photons provide a test bed for many-body physics under both in- and out-of-equilibrium settings. Experimental control over their dimensionality, potential energy landscapes, or the coupling to reservoirs offers wide possibilities to explore phases of matter, for example, by probing susceptibilities, as the compressibility. For gases of material particles, such studies of the mechanical response are well established, in fields from classical thermodynamics to cold atomic quantum gases; for optical quantum gases, they have so far remained elusive. In my talk, I will discuss experimental work demonstrating a measurement of the compressibility of a two-dimensional quantum gas of photons in a box potential, from which we obtain the equation of state for the optical medium. The experiment is carried out in a nanostructured dye-filled optical microcavity. We observe signatures of Bose-Einstein condensation at large phase-space densities in the finite-size system. Upon entering the quantum degenerate regime, the density response to an external force sharply increases, hinting at the peculiar prediction of a highly compressible Bose gas. In other recent work, we have demonstrated a non-Hermitian phase transition of an open photon Bose-Einstein condensate, which is revealed by an exceptional point in the fluctuation dynamics.

Q 9.2 Mon 17:30 A320

Realization of a fractional quantum Hall state with ultracold atoms — •Julian Léonard[1,2], Sooshin Kim[1], Joyce Kwan[1], Perrin Segura[1], Fabian Grusdt[3,4], Cécile Repellin[5], Nathan Goldman[6], and Markus Greiner[1] — [1]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna, Austria — [3]Department of Physics and ASC, LMU München, Theresienstr. 37, München D-80333, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany — [5]Univ. Grenoble Alpes, CNRS, LPMMC, 38000 Grenoble, France — [6]CENOLI, Université Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium

Fractional quantum Hall states embody emblematic instances of strongly correlated topological matter, where the interplay of magnetic fields and interactions gives rise to exotic properties including fractionally charged quasi-particles, long-ranged entanglement, and anyonic exchange statistics. Here, we report on the realization of a fractional quantum Hall (FQH) state with ultra-cold atoms in an optical lattice. The state is a lattice version of a bosonic $\nu = 1/2$ Laughlin state with two particles on sixteen sites. We observe a suppression of two-body interactions, we find a distinctive vortex structure in the density correlations, and we measure a fractional Hall conductivity of $\sigma\mathrm{H}/\sigma 0 = 0.6(2)$ via the bulk response to a magnetic perturbation. Our work provides a starting point for exploring highly entangled topological matter with ultracold atoms.

Q 9.3 Mon 17:45 A320

Observation of a continous time crystal — •Hans Kessler[1], Phatthamon Kongkhambut[1], Jim Skulte[1], Evgenii Gadylshin[1], Ludwig Mathey[1], Jayson G. Cosme[2], and Andreas Hemmerich[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

Time crystals are classified as discrete or continuous depending on whether they spontaneously break discrete or continuous time translation symmetry. While discrete time crystals have been extensively studied in periodically driven systems since their recent discovery, the experimental realisation of a continuous time crystal [1] is still pending. We report the observation of a limit cycle phase in a continuously pumped dissipative atom-cavity system [2], which is characterized by emergent oscillations in the intracavity photon number. We observe that the phase of this oscillation is random for different realisations, and hence this dynamical many-body state breaks continuous time translation symmetry spontaneously. The observed robustness of the limit cycles against temporal perturbations confirms the realisation of a continuous time crystal.

[1] H. Keßler et al., Emergent limit cycles and time crystal dynamics in an atom-cavity system, PRA, 99(5), 053605 (2019)

[2] P. Kongkhambut et al., Observation of a continuous time crystal, Science 307, 6606, 670-673 (2022)

Q 9.4 Mon 18:00 A320

Dynamics of Stripe Patterns in Supersolid Spin–Orbit-Coupled Bose Gases — •Kevin T. Geier[1,2], Giovanni I. Martone[3], Philipp Hauke[1,2], Wolfgang Ketterle[4,5], and Sandro Stringari[1] — [1]Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Università di Trento, I-38123 Trento, Italy — [2]INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, Trento, Italy — [3]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-PSL Research University, Collège de France; 4 Place Jussieu, 75005 Paris, France — [4]MIT-Harvard Center for Ultracold Atoms, Cambridge, Massachusetts 02138, USA — [5]Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

The supersolid phase of matter combines superfluid properties with a crystalline spatial structure, arising as a consequence of the spontaneous breaking of both phase and translational symmetry. In spin–orbit-coupled Bose–Einstein condensates, supersolidity has been predicted and observed in the form of stripes in the density profile, but up to now it has been unclear whether the stripe pattern features the typical excitations of a crystal. In this talk, I will explain based on analytical and numerical results how spin perturbations can induce the translational, compressional, as well as rotational motion of the stripes. Our findings expose the rich hybridization of density and spin degrees of freedom and show that this system is indeed a paradigmatic supersolid with a fully dynamic crystalline structure.

Q 9.5 Mon 18:15 A320

Observation of many-body scarring in a Bose-Hubbard quantum simulator — Guo-Xian Su[1], Hui Sun[1], •Ana Hudomal[2], Jean-Yves Desaules[3], Zhao-Yu Zhou[1], Bing Yang[4], Jad C. Halimeh[5], Zhen-Sheng Yuan[6], Zlatko Papić[3], and Jian-Wei Pan[6] — [1]Heidelberg University, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]University of Leeds, UK — [4]Southern University of Science and Technology, China — [5]LMU Munich, Germany — [6]University of Science and Technology of China

Quantum many-body scarring has recently opened a window into novel mechanisms for delaying the onset of thermalization by preparing the system in special initial states, such as the $\mathbb{Z}_2$ state in a Rydberg atom system. Here we realize many-body scarring in a Bose-Hubbard quantum simulator from previously unknown initial conditions such as the unit-filling state [1]. Our measurements of entanglement entropy illustrate that scarring traps the many-body system in a low-entropy subspace. Further, we develop a quantum interference protocol to probe unequal-time correlations, and demonstrate the system's return to the vicinity of the initial state by measuring single-site fidelity. Our work makes the resource of scarring accessible to a broad class of ultracold-atom experiments.

[1] G.-X. Su et al., arXiv:2201.00821 (2022).

Q 9.6 Mon 18:30 A320

Quantum Gas Microscopy of Cesium Atoms in Optical Superlattices — Julian Wienand[1,2,3], Alexander Impertro[1,2,3], Simon Karch[1,2,3], Hendrik von Raven[1,2,3], •Scott Hubele[1,2,3], Sophie Häfele[1,2,3], Ignacio Pérez[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Schellingstr. 4, D-80799 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80333 Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, D-85748 Garching, Germany

Ultracold cesium atoms provide a promising experimental platform for quantum simulation of interacting quantum many-body phases. This is due to a convenient control of the scattering length via a broad low-field Feshbach resonance and the possibility to engineer state-dependent lattices with minimal heating. In this talk we present recent progress on our cesium quantum gas microscope, where we have implemented 2d optical superlattices, a digital mirror device (DMD) for potential shaping, and an active magnetic field stabilization. This paves the way for quantum simulation of a large variety of different Hamiltonians ranging from tunable spin models to topological lattices. In order to enhance the nearest-neighbor tunnel coupling, we work with rather short-spaced optical lattices prohibiting the direct resolution of neighboring lattice sites. To overcome this challenge we have developed a novel deep-learning assisted single-site reconstruction algorithm, which provides access to local observables.

Q 9.7 Mon 18:45 A320

Phase Diagram Detection via Gaussian Fitting of Number Probability Distribution — Daniele Contessi[1,2,3], Alessio Recati[1], and •Matteo Rizzi[2,3] — [1]Università di Trento & INO-CNR Pitaevskii BEC Center, Povo, Italy — [2]Peter-Grünberg-Institut 8, FZ Jülich, Germany — [3]Institute for Theoretical Physics, University of Cologne, Germany

In recent years, methods for automatic recognition of phase diagrams of quantum systems have gained large interest in the community: Among others, machine learning analysis of the entanglement spectrum has proven to be a promising route. Here, we discuss the possibility of using an experimentally readily accessible proxy, namely the number probability distribution that characterizes sub-portions of a quantum many-body system with globally conserved number of particles. We put forward a linear fitting protocol capable of mapping out the ground-state phase diagram of the rich one-dimensional extended Bose-Hubbard model: The results are quantitatively comparable with more sophisticated traditional numerical and machine learning techniques. We argue that the studied quantity should be considered among the most informative and accessible bipartite properties.

D. Contessi, A. Recati, M. Rizzi, https://arxiv.org/abs/2207.01478