Q 26: Ultracold atoms, ions, and BEC IV (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: f303

Invited Talk Q 26.1 Wed 11:00 f303

Fate of the Amplitude Mode in a Trapped Supersolid — •Jens Hertkorn[1], Fabian Böttcher[1], Mingyang Guo[1], Jan-Niklas Schmidt[1], Tim Langen[1], Hans Peter Büchler[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

Bose-Einstein condensates (BECs) with strong magnetic dipolar interactions have an excitation spectrum that can feature a minimum known as roton minimum. In a certain interaction parameter range, the roton can induce an instability to the ground state leading to the formation of quantum droplets purely stabilized by quantum fluctuations. These droplets have been shown to realize a counter-intuitive phase of matter called supersolid, which combines the frictionless flow of a superfluid with the crystalline order of a solid.

We theoretically investigate the spectrum of elementary excitations of a trapped dipolar quantum gas across the BEC-supersolid phase transition. The energetically low-lying excitations and the relation between the spectrum of the BEC and the supersolid reveal the existence of distinct Higgs amplitude and Nambu-Goldstone modes that emerge from the softening roton modes at the phase transition point [1].

[1] J. Hertkorn et al., Phys. Rev. Lett. **123**, 193002 (2019)

Q 26.2 Wed 11:30 f303

The low-energy Goldstone mode in a trapped dipolar supersolid — •Mingyang Guo[1], Fabian Böttcher[1], Jens Hertkorn[1], Jan-Niklas Schmidt[1], Matthias Wenzel[1], Hans Peter Büchler[2], Tim Langen[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany — [2]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany

A supersolid is a counter-intuitive state of matter that combines the frictionless flow of a superfluid with the crystal-like periodic density modulation of a solid, simultaneously breaking the global gauge symmetry and translational symmetry. Although predicted more than 50 years ago, it is only recently that its defining properties are observed in ultracold quantum gases.

In this talk, I will focus on the realization of a supersolid state with a self-organized array of dipolar quantum droplets, where the crystallization arises owing to intrinsic interactions within the Dysprosium atoms. Besides the periodic density modulation and global phase coherence, the low-energy Goldstone mode, associated directly to the two broken symmetries, is observed. The dynamics of this mode features an out-of-phase oscillation of the crystal array and the superfluid density while keeping the center-of-mass constant. This mode exists only as a result of the phase rigidity of the state, and therefore confirms the superfluidity of the realized supersolid.

Q 26.3 Wed 11:45 f303

Strongly correlated Bose-Einstein Condensates with spin-orbit coupling of the Rashba-Dresselhaus type — •Clemens Staudinger and Robert E. Zillich — Institute for Theoretical Physics, Johannes Kepler University Linz, Austria

In a Bose-Einstein condensate (BEC) it is possible to couple two internal states (pseudospin up and down) in a way that the resulting Hamiltonian contains a coupling between the linear momentum and the pseudospin (Rashba-Dresselhaus coupling). Experimentally this has been achieved by irradiating the BEC with lasers of different frequencies. Such BECs have been treated extensively within mean-field theories [1]. Instead, we propose a new variational Hyper-Netted-Chain method, which accounts for correlations nonperturbatively, but is orders of magnitude faster than quantum Monte-Carlo simulations [2]. With our method we a able to accurately calculate properties of the ground-state of the BEC such as the pair-distribution function, the structure factor and other thermodynamic quantities such as the energy or the chemical potential.

[1] Y.-J. Lin, K. Jiménez-García and I. B. Spielman, Nature 471, 83 (2011).

[2] A. Ambrosetti, P. L. Silvestrelli, F. Toigo, L. Mitas, and F. Pederiva, Phys. Rev. B 85, 045115 (2012).

Q 26.4 Wed 12:00 f303

Probing the role of long-range coherence for superfluid dynamics by disorder quenches — •Jennifer Koch[1], Benjamin Nagler[1,2], Sian Barbosa[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

Quantum fluids exhibit a well-defined phase, which can be interferometrically measured. The direct connection of long-range coherence with superfluid transport and expansion dynnamics is, however, challenging to access experimentally. I report on experimentally revealing the role of long-range coherence for superfluid flow in an interacting gas of ^{6}Li atoms, quenched into and out of optical disorder. I will discuss our investigations about the density and superfluid-expansion response of a molecular Bose-Einstein condensate after quenching. We measure the breakdown and reoccurrence of superfluid hydrodynamics. We track the response times on which the system relaxes to a new equilibrium and relate the time scales to fundamental energy scales of the system. Our results shed light onto the importance of long-range phase coherence for superfluid flow, and also suggest a possible route of studying complex phase dynamics in superfluids by imprinting disordered phases.

Q 26.5 Wed 12:15 f303

Tracking Rydberg atoms with Bose-Einstein Condensates — •Shiva Kant Tiwari and Sebastian Wüster — Indian Institute of Science Education and Research (IISER) Bhopal Bhopal Bypass Road, Bhauri Bhopal - 462066, M.P. India

We propose to track the position and velocity of mobile Rydberg excited impurity atoms through the elastic interactions of the Rydberg electron with a host condensate [1]. Tracks first occur in the condensate phase, but are then naturally converted to features in the condensate density or momentum distribution. The condensate thus acts analogously to the cloud or bubble chambers in the early days of elementary particle physics. The technique will be useful for exploring Rydberg-Rydberg scattering, rare inelastic processes involving the Rydberg impurities, coherence in Rydberg motion, and forces exerted by the condensate on the impurities [2]. Our simulations show that resolvable tracks can be generated within the immersed Rydberg lifetime and condensate heating is under control. Finally, we demonstrate the utility of this Rydberg tracking technique to study ionizing Rydberg collisions or angular momentum changing interactions with the condensate [3].

References: [1] R. Mukherjee, et al. Phys. Rev. Lett. 115, 040401 (2015). [2] G. E. Astrakharchik, et al. Phys. Rev. A 70, 013608 (2004). [3] M. Schlagmüller, et al. Phys. Rev. X 6, 031020 (2016).

Q 26.6 Wed 12:30 f303

Rotons and Maxons in a Rydberg-Dressed Bose-Einstein Condensate — •Gary McCormack[1], Rejish Nath[2], and Weibin Li[1] — [1]School of Physics and Astronomy, and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, Nottingham, UK — [2]Indian Institute of Science Education and Research, Pune, India

We investigate a three-dimensional Bose-Einstein condensate with a long-range soft-core two-body interaction. This interaction is induced by laser coupling the condensed atom to a highly excited Rydberg state off-resonantly. We show that the long-range interaction drastically alters the dispersion relation, giving rise to both roton and maxon modes. While rotons are typically responsible for density modulations throughout the system, maxons are normally unstable and hence decay quickly once excited, as predicted in dipolar condensates. We show that maxon modes in the Rydberg-dressed condensate, on the contrary, is stable in the dynamics. We provide a scheme to trigger the maxon mode through a quench, i.e. suddenly activation of the strong soft-core interaction. The emergence of the maxon is accompanied by persistent, high frequency oscillations in the quantum depletion, while rotons cause much slower oscillations. Through a self-consistent Bogoliubov approach, we identify the dependence of maxon modes on the soft-core interaction. We also reveal how the maxons will modify the dynamics of density-density correlations and number fluctuations of the condensate. Our study paves a new route to probe exotic quasiparticles in ultracold Bose gases with Rydberg-dressed long-range interactions.

Q 26.7 Wed 12:45 f303

Studies of circular Rydberg states in an ultracold atomic gas
— •Christian Hölzl, Thomas Dieterle, Moritz Berngruber, Felix Engel, Robert Löw, Tilman Pfau, and Florian Meinert — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

Hybrid systems of ions immersed in ultracold atomic gases provide appealing means for studies comprising cold collisions, ultracold chemistry, or strongly interacting impurities. Recently, we have demonstrated a new approach for embedding a single ionic impurity into a Bose-Einstein condensate exploiting a highly excited Rydberg atom [1,2]. Here, the Rydberg core acts as a sub-μK cold ion while the Rydberg electron protects the ion from detrimental stray electric fields. In this context, circular Rydberg states are appealing candidates to improve on lifetimes of the impurity. We will present the status of our work to access circular Rydberg states from an ultracold Rubidium sample.

[1] K. S. Kleinbach, F. Engel, T. Dieterle, R. Löw, T. Pfau, and F. Meinert, Phys. Rev. Lett. 120, 193401 (2018)
[2] F. Engel, T. Dieterle, T. Schmid, C. Tomschitz, C. Veit, N. Zuber, R. Löw, T. Pfau, and F. Meinert, Phys. Rev. Lett. 121, 193401 (2018).