Q 16: Bosonic Quantum Gases III (joint session Q/A)

Time: Tuesday 11:00–13:00 Location: Aula

Q 16.1 Tue 11:00 Aula

Sub-unity superfluid fraction of a supersolid from self-induced Josephson effect — •Nicolò Antolini[1,2], Giulio Biagioni[2,3], Beatrice Donelli[1,2,4,5], Luca Pezzè[1,2,4], Augusto Smerzi[1,2,4], Marco Fattori[1,2,3], Andrea Fioretti[2], Carlo Gabbanini[2], Massimo Inguscio[1,6], Luca Tanzi[1,2], and Giovanni Modugno[1,2,3] — [1]LENS, University of Florence — [2]CNR-INO — [3]Department of Physics and Astronomy, University of Florence — [4]QSTAR — [5]Università degli Studi di Napoli — [6]Università Campus Bio-Medico di Roma

Many quantum materials in various systems feature a spatially modulated macroscopic wavefunction resulting from spontaneous breaking of gauge and translational symmetries. Their connection with supersolids has only been traced in a few cases since a universal property able to quantify the differences between supersolids, superfluids/superconductors, and crystals has not been established. A key property is the superfluid fraction, measuring the reduction in superfluid stiffness due to spatial modulations, leading to the non-standard superfluid dynamics of supersolids. We employ the Josephson effect to locally measure the superfluid fraction in a supersolid. Even without a physical barrier, the Josephson effect arises spontaneously in a supersolid, and single lattice cells act as self-induced Josephson junctions. We studied a cold-atom dipolar supersolid, revealing a significant sub-unity superfluid fraction. Our results point to new research directions, like the study of partially quantized vortices and supercurrents, and have an impact on the understanding of other supersolid-like systems.

Q 16.2 Tue 11:15 Aula

Supersolidity in a driven quantum gas — •Nikolas Liebster[1], Marius Sparn[1], Elinor Kath[1], Keisuke Fujii[2], Sarah Görlitz[2], Tilman Enss[2], Helmut Strobel[1], and Markus Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 19, 69120 Heidelberg, Germany

Driven systems are of fundamental scientific interest, as they can display properties that are radically different from similar systems at equilibrium. However, systems out of equilibrium are difficult to describe theoretically, as they are inherently time-dependent and deeply nonlinear. This makes the study of such systems an ideal task for quantum field simulators, in which complex dynamics emerge naturally and can be probed experimentally. Here, we demonstrate the emergence of supersolidity in a driven, two-dimensional superfluid, that only has contact interactions. The self-stabilized system is characterized by simultaneously broken translational and U(1) gauge symmetry, and emerges as a result of large occupations of phononic modes due to driving. We characterize the state by observing collective modes of the lattice as well as lattice phonon propagation. We also show that the system maintains phase rigidity, a key property of superfluidity. This work introduces a novel type of supersolid that is readily experimentally accessible, and establishes a conceptual framework for describing elementary excitations of driven systems.

Q 16.3 Tue 11:30 Aula

Strong-coupling expansion for disordered Bose-Hubbard model — •Renan da Silva Souza[1], Axel Pelster[2], and Francisco Ednilson Alves dos Santos[3] — [1]Goethe-Universität, Institut für Theoretische Physik, Frankfurt am Main, Germany — [2]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [3]Departamento de Física, Universidade Federal de São Carlos, Brazil

We identified the different ground states corresponding to the disordered Bose-Hubbard model at zero and finite temperatures and for small tunneling energies. Employing a field-theoretical approach, we constructed a strong-coupling expansion. By utilizing the Poincaré-Lindstedt method, we calculated a renormalized expression for the local density of states, providing clear differentiation between the Mott-insulator and Bose-glass phases. Applying a resummation technique, we computed the expression for the disorder ensemble average of the spectral function. Its analysis shows that disorder leads to an increase in the effective mass of both quasi-particle and -hole excitations of the Mott phase. And it yields the emergence of damped states, which exponentially decay during propagation in space and dominate the whole band when disorder becomes comparable to interactions. We argue that such damped-localized states correspond to single-particle excitations of the Bose-glass phase. Our results for the phase boundary compare well against stochastic and local mean-field numerical predictions.

[1] New J. Phys. **23**, 083007 (2021) and **25**, 063015 (2023)

Q 16.4 Tue 11:45 Aula

Dynamical analysis of the chaotic phase in the Bose-Hubbard model — Óscar Dueñas Sánchez[1] and •Alberto Rodríguez[1,2] — [1]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain — [2]Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, E-37008 Salamanca, Spain

We study the dynamical manifestation of the Bose-Hubbard model's chaotic phase [1] by analysing the temporal behaviour of connected two-point density correlations on experimentally accessible time scales up to a few hundred tunneling times. The exact time evolution of initial states with unit density reveals that the chaotic phase can be unambiguously identified from the 'early' time fluctuations of the considered observable around its equilibrium value [2]. The emergence of the chaotic phase is also seen to leave an imprint in the initial growth of the time signals. Specifically, the short time evolution in systems with $L \gtrsim 40$ is scrutinized to investigate the potentially diffusive spreading of density correlations within the chaotic phase.

[1] L. Pausch *et al.*, Phys. Rev. Lett. 126, 150601 (2021)
[2] D. Peña Murillo, MSc Thesis, Universidad de Salamanca (2022)

Q 16.5 Tue 12:00 Aula

Emergence of fluctuating hydrodynamics in chaotic quantum systems — •Julian Wienand[1,2,3], Simon Karch[1,2,3], Alexander Impertro[1,2,3], Christian Schweizer[1,2,3], Ewan McCulloch[4], Romain Vasseur[4], Sarang Gopalakrishnan[5], Monika Aidelsburger[1,2,3], and Immanuel Bloch[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [4]Department of Physics, University of Massachusetts, Amherst, MA 01003, USA — [5]Department of Electrical and Computer Engineering, Princeton University, Princeton, NJ 08544, USA

A fundamental principle of chaotic quantum dynamics is that local subsystems eventually approach a thermal equilibrium state. Large subsystems thermalise slower: their approach to equilibrium is limited by the hydrodynamic build-up of fluctuations on extended length scales. We perform large-scale quantum simulations that monitor particle-number fluctuations in tunable ladders of hard-core bosons and explore how the build-up of fluctuations changes as the system crosses over from ballistic to chaotic dynamics. Our results indicate that the growth of large-scale fluctuations in chaotic far-from-equilibrium systems is even quantitatively determined by equilibrium transport coefficients, in agreement with the predictions of fluctuating hydrodynamics. This emergent hydrodynamic behaviour of fluctuations provides a novel test of fluctuation-dissipation relations far from equilibrium.

Q 16.6 Tue 12:15 Aula

Extreme wave events and spacetime defects in a spinor Bose-Einstein condensate — •Yannick Deller, Ido Siovitz, Alexander Schmutz, Felix Klein, Helmut Strobel, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Ruprecht-Karls Universität Heidelberg, Deutschland

Many-body systems far from equilibrium can exhibit self-similar dynamics characterized by universal exponents. Numerical studies of a quenched ferromagnetic spinor BEC have revealed the appearance of extreme wave events on the way to the universal regime [1]. Furthermore, as a result of these caustics, real-time instanton defects are generated, which take on the form of space-time vortices in the transversal spin order parameter. However, the random appearance of real-time instantons in space and time makes it experimentally challenging to study these excitations in a controlled way. Thus we aim for deterministic preparation of a single instanton event. We employ local spin-dependent phase imprints, which lead to excitations in the transversal spin length. We probe their time evolution and characterize their structure with spatially resolved detection of all relevant spin observables.

[1] Siovitz et. al. , PRL 131, 183402 (2023)

Q 16.7 Tue 12:30 Aula

Entrainment of a continuous time crystal

— Anton Bölian[1], •Phatthamon Kongkhambut[1], Jim Skulte[1], Ludwig Mathey[1], Jayson G. Cosme[3], Hans Kessler[2], and Andreas Hemmerich[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Quantenphysik, Universität Hamburg, Germany. — [2]Physikalisches Institut der Universität Bonn, Germany. — [3]National Institute of Physics, University of the Philippines, Diliman, Quezon City, Philippines.

Discrete and continuous time crystals are novel dynamical many-body states, that are characterized by robust self-sustained oscillations, emerging via spontaneous breaking of discrete or continuous time translation symmetry. Here, we demonstrate dynamical control of a continuous time crystal by driving it into a discrete time crystalline state. This transition is related to subharmonic entrainment of classical limit cycles, which arises here on the level of many-body quantum systems. Specifically, we prepare a continuous time crystal in a pumped atom-cavity system oscillating at a frequency $\omega_{\rm CTC}$ and subsequently modulate the continuous pump intensity with a frequency $\omega_{\rm dr}$ close to $2\,\omega_{\rm CTC}$. For sufficiently large modulation strengths, the emission frequency switches from $\omega_{\rm CTC}$ to $\omega_{\rm CTC} = \omega_{\rm dr}/2$, which demonstrates the phase transition to a discrete time crystal.

Q 16.8 Tue 12:45 Aula

Effects of quantum depletion and gradient corrections on the critical atom number of dipolar droplets

— Milan Radonjić[1,2], Axel Pelster[3], and •Antun Balaž[2] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

The first experimental realization of quantum droplets in dipolar condensates [1] has highlighted the importance of quantum fluctuations [2], which were later shown to be the main source of system's stability against the dipolar collapse. The droplets were predicted and shown to be self-bound beyond the critical atom number even without the trap. However, there is a systematic difference in theoretical estimates of the critical atom number and experimental results [3]. Here we use an approach based on the extended Gross-Pitaevskii equation, which includes quantum depletion and beyond-LDA gradient corrections, to numerically and variationally study their effects on the critical atom number.

[1] H. Kadau et al., Nature **530**, 194 (2016).

[2] A. R. P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011); Phys. Rev. A **86**, 063609 (2012).

[3] F. Böttcher et al., Phys. Rev. Research **1**, 033088 (2019).