Q 26: Quantum Gases: Bosons III

Time: Wednesday 11:00–13:00 Location: E214

Q 26.1 Wed 11:00 E214

Emergence of damped-localized excitations in the Mott phase due to disorder — Renan Souza[1,2], •Axel Pelster[1], and Francisco dos Santos[2] — [1]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil

A key aspect of ultracold bosonic quantum gases in deep optical lattice potential wells is the realization of the strongly interacting Mott insulating phase. Many characteristics of this phase are well understood, however little is known about the effects of a random external potential on its gapped quasiparticle and quasihole low-energy excitations. In the present study we investigate the effect of disorder upon the excitations of the Mott insulating state at zero temperature described by the Bose-Hubbard model. Using a field-theoretical approach we obtain a resummed expression for the disorder ensemble average of the spectral function. Its analysis shows that disorder leads to an increase of the effective mass of both quasiparticle and quasihole excitations. Furthermore, 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 excitations of the Bose-glass phase.

Q 26.2 Wed 11:15 E214

Quantum Critical Behavior of Entanglement in Lattice Bosons with Cavity-Mediated Long-Range Interactions — •Simon B. Jäger[1,2], Shraddha Sharma[2,3], Rebecca Kraus[2], Tommaso Roscilde[4], and Giovanna Morigi[2] — [1]Physics Department, Technische Universität Kaiserslautern — [2]Theoretische Physik, Saarland University — [3]ICTP-The Abdus Salam International Center for Theoretical Physics — [4]Univ. Lyon, Ens de Lyon, CNRS, Laboratoire de Physique

We analyze the ground-state entanglement entropy of the extended Bose-Hubbard model with infinite-range interactions. This model describes the low-energy dynamics of ultracold bosons tightly bound to an optical lattice and dispersively coupled to a cavity mode. The competition between on-site repulsion and global cavity-induced interactions leads to a rich phase diagram, which exhibits superfluid, supersolid, and insulating phases. We use a slave-boson treatment of harmonic quantum fluctuations around the mean-field solution and calculate the entanglement entropy across the phase transitions. At commensurate filling, the insulator-superfluid transition is signaled by a singularity in the area-law scaling coefficient of the entanglement entropy, which is similar to the one reported for the standard Bose-Hubbard model. Remarkably, at the continuous $\mathbb{Z}_2$ superfluid-to-supersolid transition we find a critical logarithmic term, regardless of the filling. This behavior originates from the appearance of a roton mode in the excitation and entanglement spectrum, becoming gapless at the critical point, and it is characteristic of collective models.

Q 26.3 Wed 11:30 E214

Out of equilibrium dynamical properties of Bose-Einstein condensates in ramped up weak disorder — •Milan Radonjić[1,2], Rodrigo P. A. Lima[3,4], and Axel Pelster[4] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]GISC and GFTC, Instituto de Física, Universidade Federal de Alagoas, Maceió AL, Brazil — [4]Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Germany

We investigate theoretically how the superfluid and the condensate deformation of a weakly interacting ultracold Bose gas evolve during the ramping up of an external weak disorder potential. Both resulting deformations turn out to consist of two distinct contributions, namely a reversible equilibrium one [1,2], as well as a non-equilibrium dynamical one, whose magnitude depends on the details of the ramping protocol [3]. For the specific case of the exponential ramping up protocol, we are able to derive analytic time-dependent expressions for the aforementioned quantities. After sufficiently long time, the steady state emerges that is generically out of equilibrium. We make the first step in examining its properties by studying the relaxation dynamics into it. Also, we investigate the two-time correlation function and elucidate its relation to the equilibrium and the dynamical part of the condensate deformation. [1] K. Huang and H.-F. Meng, Phys. Rev. Lett. 69, 644 (1992). [2] B. Nagler, M. Radonjić, S. Barbosa, J. Koch, A. Pelster, and A. Widera, New J. Phys. 22, 033021 (2020). [3] M. Radonjić and A. Pelster, SciPost Phys. 10, 008 (2021)

Q 26.4 Wed 11:45 E214

Quantum phase transitions of excited states in spinor BECs — •Bernd Meyer-Hoppe[1], Fabian Anders[1], Polina Feldmann[2,3], Luis Santos[2], and Carsten Klempt[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [2]Leibniz Universität Hannover, Institut für Theoretische Physik, Appelstraße 2, 30167 Hannover, Germany — [3]Stewart Blusson Quantum Matter Institute, The University of British Columbia, 2355 East Mall, Vancouver BC V6T 1Z4, Canada

Depending on external control parameters, the physically realized states of a given system can be grouped into phases that are defined by a measurable order parameter. For ultracold systems, where quantum fluctuations dominate thermal ones, quantum phases arise, which are separated by quantum phase transitions (QPTs) with a vanishing energy gap between the ground state and the first excited state. Today, ultracold quantum many-body systems can also be prepared at non-zero energy without thermalization. For such systems, it is possible to define excited-state quantum phase transitions (ESQPTs) by an analogous divergence of the density of states.

Here we present the experimental determination of a quantum phase diagram in a spinor BEC, where the energy of the system is one of the control parameters. The quantum phases are detected by the measurement of an interferometric order parameter that abruptly changes at the ESQPTs. We identify three quantum phases and their transitions by varying two control parameters: the effective magnetic field and the excitation energy.

Q 26.5 Wed 12:00 E214

Hartree-Fock Analogue Theory for Thermo-Optic Interaction — •Enrico Stein und Axel Pelster — Physics Department and Research Centre OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger-Straße 46, 67663 Kaiserslautern

Photon Bose-Einstein condensates are created in a microcavity filled with a dye solution in which photons are trapped. The dye continually absorbs and re-emits these photons causing the photon gas to thermalise at room temperature and finally to form a Bose-Einstein condensate. Because of a non-ideal quantum efficiency, these cycles heat the dye solution, creating a medium in which effective photon-photon interaction takes place. However, a full Hamiltonian formulation of this process has yet to be derived.

In this talk, we focus on a Hamiltonian description of the effective photon-photon interaction that includes the thermal cloud and, thus, resembles a Hartree-Fock analogue theory for this kind of interaction. Using an exact diagonalisation approach, we work out how the effective photon-photon interaction modifies the spectrum of the photon gas and how it affects the condensate width. As a second case study, we apply our theory to the dimensional crossover from 2D to 1D. In this scenario, we focus on a comparison with a plain variational approach based on the Gross-Pitaevskii equation and explicitly work out the contribution of the thermal cloud.

Q 26.6 Wed 12:15 E214

Condensate formation in a dark state of a driven atom-cavity system — •Jim Skulte[1,2], Phatthamon Kongkhambut[1], Hans Kessler[1], Jayson G. Cosme[3], Andreas Hemmerich[1,2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany. — [3]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

An intriguing class of quantum states in light-matter systems are the so-called dark states. We demonstrate condensate formation in a dark state in an ultracold quantum gas coupled to a high-finesse cavity and pumped by a shaken optical lattice [1]. We show experimentally and theoretically that the atoms in the dark state display a strong suppression of the coupling to the cavity. On the theory side, this is supported by solving the dynamics of a minimal three-level model [2] and of the full atom-cavity system. The symmetry of the condensate wave function is anti-symmetric with respect to the potential minima of the pump lattice, and displays a staggered sign along the cavity direction. This symmetry decouples the dark state from the cavity, and is preserved when the pump intensity is switched off.

[1] J. Skulte et al., Condensate formation in a dark state of a driven atom-cavity system, arXiv:2209.03342 (2022)

[2] J. Skulte et al., Parametrically driven dissipative three-level Dicke model, PRA 127, 253601 (2021)

Q 26.7 Wed 12:30 E214

Real-Time Instantons and Self-Similar Scaling in a 1D Spin-1 Bose Gas Far from Equilibrium — •Ido Siovitz, Stefan Lannig, Yannick Deller, Helmut Storbel, Markus Oberthaler, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

A system driven far from equilibrium via a parameter quench can show universal dynamics, characterized by self-similar spatio-temporal scaling, associated with the approach to a non-thermal fixed point. The study of such universality classes may assist in a thorough investigation of many systems ranging from the post-inflationary evolution of the universe to low-energy dynamics in cold gases.

Topological excitations in the system are considered to be one of the driving mechanisms of coarsening dynamics in the system and are, as such, a point of interest in the study of far from equilibrium physics. We will discuss the infrared scaling phenomena of a one-dimensional spin-1 Bose gas quenched from the polar phase to the easy-plane phase and provide evidence of the existence of real-time instantons, appearing as vortices in space and time. The latter's contribution to the coarsening dynamics of the system will be shown, and an effective theory describing the mechanism of their appearance will be presented.

Q 26.8 Wed 12:45 E214

Condensation and Thermalization of an Easy-Plane Ferromagnet in a Spinor Bose Gas — Maximilian Prüfer[2], Daniel Spitz[3], •Stefan Lannig[1], Helmut Strobel[1], Jürgen Berges[3], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institute for Physics, Heidelberg, Germany — [2]Vienna Center for Quantum Science and Technology, Vienna, Austria — [3]Institute for Theoretical Physics, Heidelberg, Germany

Bose-Einstein condensates are ideally suited to investigate dynamical phenomena emerging in the many-body limit, such as the build-up of long-range coherence, superfluidity or spontaneous symmetry breaking. We study the thermalization dynamics of an easy-plane ferromagnet in a homogeneous one-dimensional spinor Bose gas of ^{87}Rb. This is demonstrated by the dynamic emergence of effective long-range coherence of the spin field. For a thermalized state we verify spin-superfluidity by experimentally testing Landau's criterion and reveal the structure of one massive and two massless modes, which are a consequence of explicit and spontaneous symmetry breaking, respectively. Our experiments allow us to observe the thermalization of an easy-plane ferromagnetic Bose gas. The relevant momentum-resolved observables are in agreement with a thermal prediction obtained from a microscopic model in the Bogoliubov approximation.

Prüfer et al., Nature Physics (2022), DOI: 10.1038/s41567-022-01779-6