Q 13: Ultracold Matter (Bosons) I (joint session Q/A)

Time: Monday 17:00–19:00 Location: HS I PI

Q 13.1 Mon 17:00 HS I PI

Quantum geometry of bosonic Bogoliubov quasiparticles — •Isaac Tesfaye and André Eckardt — Institut für Theoretische Physik, Technische Universität Berlin Hardenbergstraße 36, 10623 Berlin, Germany

Topological features arising bosonic Bogoliubov-de Gennes (BBdG) systems have mainly been studied by utilizing a generalized symplectic version of the Berry curvature and Chern number. However, the characterization of the geometrical features in BBdG systems is still lacking. Here, we propose a symplectic quantum geometric tensor (SQGT) whose imaginary part leads to the previously studied symplectic Berry curvature, while the real part gives rise to a symplectic quantum metric, providing a natural distance measure in the space of bosonic Bogoliubov modes. We show that all components of the SQGT are measurable by extracting excitation rates in response to periodic modulations of the systems' parameters. Moreover, we connect the symplectic Berry curvature to a generalized symplectic anomalous velocity term for Bogoliubov Bloch wave packets. We test our results for a bosonic Bogoliubov-Haldane model. Our results open new avenues for the quantum geometrical characterization of Bose condensed and parametrically driven photonic quantum systems.

[1] I. Tesfaye and A. Eckardt, arXiv:2406.12981.
[2] R. Shindou et al., Phys. Rev. B **87**, 174427 (2013).
[3] S. Furukawa and M. Ueda, New J. Phys. **17**, 115014 (2015).
[4] V. Peano et al., Nat Commun **7**, 10779 (2016).
[5] G. Engelhardt and T. Brandes, Phys. Rev. A **91**, 053621 (2015).

Q 13.2 Mon 17:15 HS I PI

Absence of gapless Majorana edge modes in few-leg bosonic flux ladders — •Felix A. Palm[1,2], Cécile Repellin[3], Nathan Goldman[2,4], and Fabian Grusdt[1] — [1]LMU Munich & MCQST, Munich, Germany — [2]Université Libre de Bruxelles, Brussels, Belgium — [3]Université Grenoble-Alpes, Grenoble, France — [4]Laboratoire Kastler Brossel, Collège de France, Paris, France

Non-Abelian phases of matter, such as certain fractional quantum Hall states, are a promising framework to realize exotic Majorana fermions. Quantum simulators provide unprecedented controllability and versatility to investigate such states, and developing experimentally feasible schemes to realize and identify them is of immediate relevance. Motivated by recent experiments, we consider bosons on coupled chains, subjected to a magnetic flux and experiencing Hubbard repulsion. At magnetic filling factor ν=1, similar systems on cylinders have been found to host the non-Abelian Moore-Read Pfaffian state in the bulk.

Here, we address the question whether more realistic few-leg ladders can host this exotic state and its chiral Majorana edge states. We perform extensive DMRG simulations and determine the central charge of the ground state. While we do not find any evidence of gapless Majorana edge modes in systems of up to six legs, exact diagonalization of small systems reveals evidence for the Pfaffian state in the entanglement structure. By systematically varying the number of legs and monitoring the appearance and disappearance of this signal, our work highlights the importance of finite-size effects for the realization of exotic states in experimentally realistic systems.

Q 13.3 Mon 17:30 HS I PI

Ghost fixed point dynamics of driven-dissipative BEC — •Moritz Janning[1] and Johann Kroha[1,2] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn — [2]University of St. Andrews, North Haugh

We investigate the driven-dissipative dynamics of an open photon BEC in a single-mode microcavity filled with dye molecules using the Lindblad master-equation approach. While one would expect a dephasing behaviour due to the driven-dissipative nature of the system a stationary condensate has been observed experimentally[1]. In recent theoretical investigations we were able to predict such a long lived stationary condensate which then dephases after a time farly outreaching the experimental observation. Interestingly, the quasi-stationary condensate is strongly influenced by the presence of a ghost fixed point, and its lifetime can be controlled by the driving parameters. This fixed point also enables a crossover to an oscillatory behavior that was experimentally observed as a non-hermitean phase transition[1]. The precise point of the non-hermitian phase transition can subsequently be understood as an exceptional point within the framework of nonlinear dynamics.

[1] F. E. Öztürk et al., Science, 372, 6537, pp. 88-91 (2021)

Q 13.4 Mon 17:45 HS I PI

Matter-wave vortex N00N states by resonant excitation — •Lars Arne Schäfer and Reinhold Walser — TU Darmstadt, Germany

We study a gas of few interacting bosons in a ring trap that is superimposed with a freely programmable periodic azimuthal potential [1]. This highly controllable quantum system has been proposed as a platform for quantum simulation and sensing [2]. In contrast to angular momentum transfer from Gauss-Laguerre laser beams [3], we describe techniques to use the time-dependent programmable lattice potential. This will induce resonant excitations between angular momentum Fock states in the ring trap. As a specific application, we discuss the creation of the entangled N00N state

$$|\psi\rangle = \frac{1}{\sqrt{2}} \left(|2_{-p}, 0_p\rangle + |0_{-p}, 2_p\rangle\right),$$

where the two modes are angular momentum eigenstates with $k_{\pm p}$.

[1] M. R. Sturm, M. Schlosser, R. Walser, and G. Birkl, Quantum simulators by design: Many-body physics in reconfigurable arrays of tunnel-coupled traps, Phys. Rev. A **95**, 063625 (2017).

[2] L. Amico et al., Quantum Many Particle Systems in Ring-Shaped Optical Lattices, Phys. Rev. Lett. **95**, 063201 (2005).

[3] G. Nandi, R. Walser, and W. P. Schleich, Vortex creation in a trapped Bose-Einstein condensate by stimulated Raman adiabatic passage, Phys. Rev. A **69**, 063606 (2004).

Q 13.5 Mon 18:00 HS I PI

Temporal Bistability in the Dissipative Dicke-Bose-Hubbard System — Tianyi Wu[1], Fredrik Vermeulen[1], •Sayak Ray[1], and Johann Kroha[1,2] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews, KY16 9SS, United Kingdom

We consider a driven-dissipative system consisting of an atomic Bose-Einstein condensate loaded into a two-dimensional Hubbard lattice and coupled to a single mode of an optical cavity. Due to the interplay between strong, repulsive atomic interaction and the atom-cavity coupling, the system exhibits several phases of atoms and photons including the atomic superfluid (SF) and supersolid (SS). We investigate the dynamical behaviour of the system, where we include dissipation by means of the Lindblad master-equation formalism. Due to the discontinuous nature of the Dicke transition for strong atomic repulsion, we find a extended co-existence region of different phases. Such a co-existence, in the limit of vanishing dissipation, is further investigated from the underlying Ginzburg-Landau free energy landscape. We study the resulting, temporal switching dynamics, particularly between the coexisting SF and SS phases, which eventually become damped due to the dissipation.

Reference: Tianyi Wu, Sayak Ray and Johann Kroha, Annalen der Physik, **536**, 2300505 (2024).

Q 13.6 Mon 18:15 HS I PI

Correlation functions of the anyon-Hubbard model from Bogoliubov theory — •Binhan Tang[1], Axel Pelster[1], and Martin Bonkhoff[2] — [1]Physics Department and Research Center Optimas, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]I. Institut für Theoretische Physik, Universität Hamburg, 22607 Hamburg, Germany

Applying a modified Bogoliubov theory to the bosonic representation of the anyon-Hubbard model faithfully describes its characteristic low-energy properties. These are manifested by an asymmetric dispersion of the Bogoliubov particles, which arises due to the breaking of parity and time reversal symmetry. Furthermore, statistical interactions cause a depletion of both the condensate and the superfluid densities even in the absence of any Hubbard interaction. On the basis of this Bogoliubov theory we determine then characteristic correlation functions as, for instance, density-density correlations, which are experimentally accessible via quantum gas microscopes. In view of recent experimental progress, we re-investigate a quantity previously declared as unobservable, the anyonic quasi-momentum distribution.

Q 13.7 Mon 18:30 HS I PI

Localization/delocalization-phase transition of quantum impurities in 1D Bose gases — •Dennis Breu, Eric Vidal Marcos, Martin Will, and Michael Fleischhauer — University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

We investigate the dynamics of a single finite-mass impurity in a 1D Bose gas in a box potential using Tensor Network simulations. This algorithm makes it possible to theoretically probe Bose polarons in the regime of strong bose-bose interactions for the entire range of the Tonks parameter γ. We observe a transition between a delocalized impurity and an impurity localized at the system boundaries, as a function of Impurity-Bose interaction strength. While this transition can reasonably be predicted by a mean-field ansatz based on coupled Gross-Pitaevski-Schrödinger equations, the mean-field ansatz also suggests the existence of a self-localized polaron solution. We show that the self-localization is an artifact of the underlying decoupling approximation. This shows that even for weak bose-bose interactions, where mean-field approaches are expected to work well, Impurity-Bose correlations are important for representing the true behavior of a system. By comparing energy estimations of the phases, we also calculate the critical Bose-Bose interactions strength of the phase transition.

Q 13.8 Mon 18:45 HS I PI

Driven-dissipative fermionized topological phases of strongly interacting bosons — •Arkajyoti Maity[1], Bimalendu Deb[2], and Jan-Michael Rost[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]Indian Association for the Cultivation of Science, Kolkata

We study the optical response of a one-dimensional array of strongly nonlinear optical microcavities with alternating tunnel transmissivities, mimicking the paradigmatic Su-Schriefer Heeger model. We show that the non-equilibrium steady state of the bosonic system contains clear signatures of fermionization when the intra-cavity Kerr nonlinearity is stronger than both losses and inter-site tunnel coupling. Furthermore, changing the experimentally controllable parameters detuning and driving strength, in a topologically non-trivial phase, one can selectively excite either the bulk or edge modes or both modes, revealing interesting topological properties in a non-equilibrium system.