Q 4: Quantum Gases (Bosons) I

Time: Monday 10:30–12:30 Location: S HS 037 Informatik

Group Report Q 4.1 Mon 10:30 S HS 037 Informatik

Quantum correlations across the many-body localization transition — •Julian Léonard, Matthew Rispoli, Alexander Lukin, Robert Schittko, Sooshin Kim, Joyce Kwan, and Markus Greiner — Harvard University, Cambridge, MA, USA

An interacting quantum system that is subject to disorder may cease to thermalize due to localization of its constituents, thereby marking the breakdown of thermodynamics. We realize such a many-body-localized system in a disordered Bose-Hubbard chain and characterize its entanglement properties through particle fluctuations and correlations.

We observe that the particles become localized, suppressing transport and preventing the thermalization of subsystems. Notably, we measure the development of non-local correlations, whose evolution is consistent with a logarithmic growth of entanglement entropy - the hallmark of many-body localization. These results experimentally establish many-body localization as a qualitatively distinct phenomenon from localization in non-interacting, disordered systems.

Furthermore, we characterize the entanglement properties at the many-body localization transition by their quantum correlations. In the quantum critical regime, we observe anomalous diffusive transport and the emergence of strong correlations in the system. The correlations form by a sparse network that spans the entire system and extends to high orders, signaling the presence of multi-particle entanglement. Our results describe the structure of the quantum critical many-body state, and they provide an essential step to understanding criticality and universality in non-equilibrium systems.

Q 4.2 Mon 11:00 S HS 037 Informatik

Rhombi-chain Bose-Hubbard model: Geometric frustration and interactions — Christine Cartwright[1], Gabriele De Chiara[1], and •Matteo Rizzi[2] — [1]Centre for Theoretical Atomic, Molecular and Optical Physics, Queen's University Belfast, Belfast BT7 1NN, United Kingdom — [2]Institut für Physik, Johannes Gutenberg Universität, Staudingerweg 7, 55099 Mainz, Germany

We explore the effects of geometric frustration within a one-dimensional Bose-Hubbard model using a chain of rhombi subject to a magnetic flux. The competition of tunneling, self-interaction, and magnetic flux gives rise to the emergence of a pair-superfluid (pair-Luttinger liquid) phase besides the more conventional Mott-insulator and superfluid (Luttinger liquid) phases. We compute the complete phase diagram of the model by identifying characteristic properties of the pair-Luttinger liquid phase such as pair correlation functions and structure factors and find that the pair-Luttinger liquid phase is very sensitive to changes away from perfect frustration (half-flux). We provide some proposals to make the model more resilient to variants away from perfect frustration. We also study the bipartite entanglement properties of the chain. We discover that, while the scaling of the block entropy pair-superfluid and of the single-particle superfluid leads to the same central charge, the properties of the low-lying entanglement spectrum levels reveal their fundamental difference.

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Q 4.3 Mon 11:15 S HS 037 Informatik

Localization in the two-dimensional Bose-Hubbard-model — •Andreas Geissler[1,2], Johannes Schachenmayer[1,3], and Guido Pupillo[1,3] — [1]ISIS, University of Strasbourg, Strasbourg, France — [2]Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, Germany — [3]IPCMS, University of Strasbourg, Strasbourg, France

Experiments in recent years (e.g. [1,2]) have shown signatures of many-body localization (MBL) for the bosonic Hubbard model realized as one and two dimensional systems in ultra cold atomic gas experiments. The theoretical investigation of these systems has so far proved to be very hard as a proper understanding of the MBL phenomenon depends on knowledge about the full eigenstate spectrum. Therefore, commonly used exact diagonalization, renormalization group and tensor network methods have been limited to small system sizes. Extending a recently developed beyond-Bogoliubov quasiparticle theory I present theoretical results for a recent experiment [2], showing comparable signatures of localization while suggesting that the observed localization also strongly depends on the confining potential. Furthermore, I present a detailed phase diagram as a function of disorder and interaction strength, obtained via various level statistical and wave function related measures for localization.

[1] C. D'Errico et al., PRL 113, 095301 (2014)
[2] J.-y. Choi et al., Science 352, 1547 (2016)

Q 4.4 Mon 11:30 S HS 037 Informatik

Out-of-equilibrium dynamics of ultracold bosons in time-dependent random potentials — •Milan Radonjić and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

We investigate perturbatively the impact of time-dependent random potentials on a weakly interacting Bose gas at zero temperature. Generically, a random potential yields, on the ensemble average, a depletion of the condensate. It stems from the localization of bosons in the respective minima of the disordered landscape and is usually quantified by a Bose-glass order parameter [1] in close analogy to the well-known Edwards-Anderson order parameter for spin-glasses [2]. A time dependence of the random potential leads in addition to an out-of-equilibrium dynamics of the condensate depletion.

Here we study a smooth quench of a spatially delta-correlated disordered potential from an initial disorder-free state of a uniform Bose gas. Depending on the quench rise time we focus on two limiting cases: adiabatic and sudden quench. In the long-time limit the former scenario reproduces the static disorder equilibrium case [3], while the latter leads to the formation of a non-equilibrium steady state, which turns out to have an even larger condensate depletion.

[1] R. Graham and A. Pelster, Int. J. Bif. Chaos **19**, 2745 (2009)
[2] S. F. Edwards and P. W. Anderson, J. Phys. F **5**, 965 (1975)
[3] K. Huang and H.-F. Meng, Phys. Rev. Lett. **69**, 644 (1992)

Q 4.5 Mon 11:45 S HS 037 Informatik

Partial fermionization—spectral universality in interacting quantum gases — •Quirin Hummel, Juan Diego Urbina, and Klaus Richter — Universität Regensburg, Germany

We study the smoothed density of excited many-body levels in interacting quantum many-body systems. The paramount importance of this object stems from the fact that a large number of degrees of freedom leads to very dense spectra of interacting many-body levels, so that fluctuations become less important. Here we focus on continuous models with interactions of short-range character that are of special importance, but not restricted, to the broad field of cold atom gases. We introduce a novel approach based on cluster expansions that allows accurate analytic predictions for entire interacting spectra at the smooth level, embracing both, integrable as well as non-integrable cases. Most notably, it uncovers so far unrecognized universal features that uniquely relate spectra of systems with very few up to many particles.

Q 4.6 Mon 12:00 S HS 037 Informatik

Quantum transport between two equilibrating reservoirs — •Giulio Amato[1,2,3], Alberto Rodríguez[1], Sandro Wimberger[2,3], Heinz-Peter Breuer[1], and Andreas Buchleitner[1] — [1]Albert-Ludwigs-Universität Freiburg — [2]Universitá degli Studi di Parma — [3]Istituto Nazionale di Fisica Nucleare

We study quantum transport across an open quantum system connecting two finite reservoirs initially prepared with a finite particle number imbalance. The equilibration process of the reservoirs leads to a non-stationary current which vanishes once a global equilibrium condition is reached. This behaviour has been experimentally observed in quantum transport setups of fermionic ultracold atoms, with tunable interparticle interactions [1]. We devise a theoretical model based on a set of coupled quantum-classical master equations, describing the evolution of the system together with the temporal variation of the particle number in the reservoirs. We apply this formalism to investigate nonstationary bosonic currents across a one dimensional Bose-Hubbard lattice.

[1] S. Krinner, T. Esslinger and J.-P. Brantut, J. Phys.: Condens. Matter 29, 343003 (2017)

Q 4.7 Mon 12:15 S HS 037 Informatik

Measuring Dynamical Properties of Quantum Many-Body Systems Using Engineered Dissipation — •Kevin Geier[1,2] and Philipp Hauke[1,2] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

Dynamic correlation functions of observables at unequal times encode many fundamental properties of quantum many-body systems such as transport coefficients or excitation spectra. However, an experimental measurement of such correlations is challenging due to the quantum mechanical collapse of the wave function. We propose a novel, general technique of probing correlations in a system by coupling to an ancilla system exposed to classical noise. In the limit of large noise, back action from the ancilla on the system is minimized owed to a quantum Zeno effect, while the dissipative dynamics gives access to a hierarchy of correlation functions. We demonstrate the scheme for the measurement of current-current correlations in bosonic lattice systems by means of numerical simulations. Possible applications of the technique include the study of thermalization in quantum many-body systems far from equilibrium by experimentally testing fluctuation-dissipation relations.