Q 10: Quantum Gases (Bosons) I

Time: Monday 10:30–12:30 Location: K 2.020

Q 10.1 Mon 10:30 K 2.020

Microscopy of many-body localization in one dimension — •Julian Léonard, Alexander Lukin, Matthew Rispoli, Robert Schittko, Eric Tai, and Markus Greiner — Harvard University, Cambridge, MA, USA

Many-body localization (MBL) challenges our understanding of thermalization in quantum systems. While non-equilibrium systems usually relax and approach thermal equilibrium, MBL systems remain in a state far from equilibrium.

We study this behaviour in a Bose-Hubbard chain that is subject to a controlled disorder potential. We start with a system at unity filling and prepare it in an out-of-equilibrium state by quenching the tunneling rate from zero a to a finite value. By performing site-resolved full counting statistics, we are able to locally measure the atom number distribution, determine the degree of thermalization, and extract the on-site entropy. We observe a breakdown of thermalization at high disorders, locally suppressed thermalization at the boundaries and map out the MBL transition.

Q 10.2 Mon 10:45 K 2.020

Quantum thermalization in isolated ultracold gases — •Marvin Lenk[1], Anna Posazhennikova[2], Tim Lappe[1], and Johann Kroha[1] — [1]Physikalisches Institut, Universität Bonn, Germany — [2]Department of Physics, Royal Holloway University of London, UK

Quantum thermalization, i.e., how an isolated quantum system with unitary time evolution can ever reach thermal equilibrium behavior, is a long-standing problem of quantum statistics. It has moved in the focus of attention due to realizations in ultracold gas systems. The eigenstate thermalization hypothesis (ETH) poses that, under certain restrictive conditions, a microcanonical average is indistinguishable from the expectation value w.r.t. a typical eigenstate. By contrast, thermal behavior is reached quite generally in a non-integrable quantum many-body system alone due to the vast size of the Hilbert space dimension D. In any realistic experiment, only a small subset of the quantum numbers defining a pure state can be measured, if D is sufficiently large. The Hilbert space spanned by the undetermined quantum numbers is traced over and, thus, forms a grand canonical bath [Ann. Phys. 1700124 (2017)]. We show that this mechanism is valid for a generic system of N interacting bosons in M single-particle levels by computing numerically exactly the time evolution of the reduced densitiy matrix, the entanglement entropy as well as expectation values and fluctuations for the observed subsystem. The thermalizing quantities are, thus, defined by the measurement itself and not restricted to local observables. For $N \approx 25$ and $M \approx 5$, D is already large enough for thermalization to occur. We also analyze the validity of ETH.

Q 10.3 Mon 11:00 K 2.020

Observation of universal dynamics in an isolated quantum system — •Maximilian Prüfer[1], Philipp Kunkel[1], Christian-Marcel Schmied[1], Daniel Linnemann[1], Stefan Lannig[1], Helmut Strobel[1], Jürgen Berges[2], Thomas Gasenzer[1], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg

After a quench a non-integrable many-particle system will eventually relax to its thermal state. However, on the route to thermalisation universal dynamics characterised by temporal rescaling of spatial correlation functions may be encountered, a phenomenon known as a non-thermal fixed point. We access and study this regime both experimentally and theoretically for a Bose-Einstein condensate of ^{87}Rb in the $F = 1$ hyperfine manifold with ferromagnetic interactions. We prepare our system in the polar phase and quench into the easy-plane ferromagnetic phase. After a build-up of excitations in the transversal spin we observe self-similar evolution, which is due to the non-linear redistribution of excitations among different momenta. We determine the emerging scaling form for the structure factor of the transversal spin and extract the set of corresponding scaling exponents. Our results give access to universal properties of the transient dynamics towards thermal equilibrium.

Q 10.4 Mon 11:15 K 2.020

Damping of BEC Josephson oscillations by dynamical fluctuation excitation — •Tim Lappe[1], Anna Posazhennikova[2], and Johann Kroha[1] — [1]Physikalisches Institut and Bethe Center for Theoretical Physics, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Department of Physics, Royal Holloway, University of London, Egham, Surrey TW20 0EX, UK

The nonequilibrium dynamics of Bose-Josephson junctions can be investigated with Bose-Einstein condensates (BEC) of cold atoms in double-well traps. These systems are perfectly isolated, yet the experiments manifest an intriguing divergence: While some exhibit dissipation-free Josephson oscillations, others show strong damping. Some of us have demonstrated before how inelastic collisions of incoherent excitations can lead to damping and eventual thermalization [PRL 116, 225304 (2016)]. Here we scrutinize the generation of such excitations in realistic traps and their effect on damping. This cannot be achieved on the usual Gross-Pitaevskii (GP) level. Using a Keldysh path-integral formalism, we develop a time-dependent, multimode description beyond the GP equation, including quadratic fluctuations. We find an excess of fluctuations when their renormalized excitation energy, $\tilde{\varepsilon}$, is near the renormalized Josephson frequency, $\tilde{\omega}_J$. Both $\tilde{\varepsilon}$ and $\tilde{\omega}_J$ are strongly renormalized by interactions. Calculating the system parameters and coupling constants quantitatively, we show that these renormalizations can explain the apparently contradictory damping behavior of two well-known experiments. This sheds light on the unresolved origin of damping observed in these isolated systems.

Q 10.5 Mon 11:30 K 2.020

Spin dynamics of individual neutral impurities coupled to a Bose-Einstein condensate — •Felix Schmidt[1], Daniel Mayer[1], Daniel Adam[1], Quentin Bouton[1], Tobias Lausch[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

Individual spins immersed into a superfluid form a paradigm of quantum physics. It lies at the heart of many models exploiting the quantum nature of individual spin to understand quantum phenomena or to open novel routes to local probing and engineering of quantum many-body systems.

We report on the controlled immersion of individual localized neutral Caesium (Cs) atoms having total spin $F = 3$ into a Rubidium Bose-Einstein condensate (BEC) with total spin $F = 1$. We observe inelastic spin exchange as well as coherent dynamics of the Cs impurity's quasi-spins interacting with the BEC with high position and time resolution. Our work paves the way for local quantum probing of superfluids, and thus might shed light on the local state of nonequilibrium or correlated quantum many-body systems.

Q 10.6 Mon 11:45 K 2.020

Quantum Chaos of Cold Atoms in Optical Lattices: A Trajectory-Based Analysis of Out-Of-Time-Ordered Correlators in Many-Body Space — •Josef Rammensee, Juan Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

To address the question of how to measure many-body quantum chaos, i.e. the influence of classical chaos underlying a quantum many-particle system, so-called out-of-time-ordered correlators $\langle[\hat{V}, \hat{W}(t)]^\dagger[\hat{V}, \hat{W}(t)]\rangle$ have been identified to be highly suitable tools[1]. Contrary to already known indicators, their unusual time ordering of the operators is able to directly capture the hyperbolic nature of the classical counterpart, as one expects an exponential increase at short times with a rate related to classical Lyapunov exponents. Arguments based on a naive quantum-classical correspondence motivate this expectation. Numerical studies further indicate, without quantitative explanation, a later saturation after the time scale for the classical-to-quantum-crossover, known as Ehrenfest or scrambling time. Here we provide insight into the physical origin of the exponential growth and the saturation by using semiclassical methods based on the Van-Vleck-propagator for Bose-Hubbard systems[2]. We show that the notion of interfering classical mean-field trajectories is well suited to provide a quantitative picture for interacting bosonic systems. We explicitly discuss the emergence of the Lyapunov exponent and the relevant time scales.

[1] J. Maldacena *et al.*, J. High Energ. Phys. (2016) 2016:106.

[2] T. Engl, J. Dujardin, A. Argüelles *et al.*, PRL **112**, 140403 (2014)

Q 10.7 Mon 12:00 K 2.020

Off-resonant many-body quantum carpets in strongly tilted optical lattices — Manuel H. Muñoz-Arias, •Javier Madroñero, and Carlos A. Parra-Murillo — Physics Department, Universidad del Valle, Cali, Colombia

A unit filling Bose-Hubbard Hamiltonian embedded in a strong Stark field is studied in the off-resonant regime inhibiting single- and many-particle first-order tunnelling resonances. We investigate the occurrence of coherent dipole wavelike propagation along an optical lattice by means of an effective Hamiltonian accounting for second-order tunnelling processes. It is shown that dipole wave function evolution in the short-time limit is ballistic and that finite-size effects induce dynamical self-interference patterns known as quantum carpets.

Q 10.8 Mon 12:15 K 2.020

Reconstructing quantum states of cold atomic quantum simulators from non-equilibrium dynamics — •Marek Gluza[1], Thomas Schweigler[2], Bernhard Rauer[2], Christian Krumnow[1], Joerg Schmiedmayer[2], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria

Systems of ultra-cold atoms on atom chips provide an architecture to probe aspects of out-of-equilibrium quantum many-body physics including equilibration, thermalization and pre-thermalization. We present a novel tomographic reconstruction method for these quantum simulators allowing to access the expectation value of quadrature operators which are inaccessible from direct measurements but capture crucial characteristics of the elementary excitations of cold atomic systems. Specifically, we use interferometric data of non-equilibrium phase fluctuations to reconstruct the covariance matrix – including density fluctuations – of eigenmodes of the corresponding mean-field models. Experimentally, we observe quench dynamics in the non-interacting regime of particles in harmonic or box potentials. Formally, we use that one can efficiently keep track of the evolution and employ signal processing and semi-definite programming to perform a reliable reconstruction of covariance matrices. This method opens a new window into the study of dynamical quantum simulators – an insight that we exploit and discuss at the hand of several examples, including Gaussifying quantum many-body dynamics.