DY 4: Nonequilibrium Quantum Many-Body Systems 1 (joint session TT/DY)

Time: Monday 9:30–12:45 Location: H22

DY 4.1 Mon 9:30 H22

Quantum Loschmidt echo in quenched Hubbard model — •Nikodem Szpak[1] and Ralf Schützhold[2,3] — [1]Fakultät für Physik, Universität Duisburg-Essen — [2]Helmholtz-Zentrum Dresden-Rossendorf — [3]Institut für Theoretische Physik, Technische Universität Dresden

A quantum Loschmidt echo (also referred to as quantum time mirror) corresponds to an effective time inversion after which the quantum wave function reverses its previous time evolution and eventually reaches its initial distribution again. We consider a Hubbard model describing free dispersion in a lattice and impose a sudden pulse-like perturbation (pi-pulse) which reverses the sign of all quasi-momenta simultaneously. After equal period of time, we observe the rebuild of the initial state. We generalize previous results obtained in this field and propose a comparably simple protocol for ultra-cold atoms in optical lattices which should be easier to realize experimentally than previous proposals.

DY 4.2 Mon 9:45 H22

Ion Impact induced Doublon Creation in Strongly Correlated Finite Hubbard Systems — •Maximilian Rodriguez Rasmussen, Karsten Balzer, Niclas Schlünzen, Jan-Philip Joost, and Michael Bonitz — CAU Kiel, Germany

Under certain conditions strongly correlated fermions in lattice systems are known to form doublons - quasi-particles consisting of two electrons on the same site. Due to the interesting resulting electronic properties doublon formation processes have been the subject of various studies. Here a new mechanism of doublon production due the impact of energetic ions is presented. The processes leading to doublon creation are described and verified by numerical results [1, 2] obtained by exact diagonalization for small systems and non-equilibrium Green functions approach [3] for larger systems.

[1] K. Balzer, M.R. Rasmussen, N. Schlünzen, J.-P. Joost, M. Bonitz, submitted to Phys. Rev. Lett., arXiv:1801.05267
[2] M. Bonitz, K. Balzer, N. Schlünzen, M.R. Rasmussen, J.-P. Joost, Phys. Stat. Sol. (b) (2018), arXiv:1808.07868
[3] K. Balzer and M. Bonitz, "Nonequilibrium Green's Functions Approach to Inhomogeneous Systems", Springer 2013

DY 4.3 Mon 10:00 H22

Hidden phases in the photodoped two-band Hubbard model — •Jiajun Li and Martin Eckstein — University of Erlangen-Nuremberg, Erlangen, Germany

Recent years have witnessed intense interest in controlling materials through non-equilibrium protocols. In particular, a strong electric pulse can drastically disturb a Mott insulator, giving rise to a transient photo-doped state featuring charge excitations across the insulating gap. This protocol of photo-doping can yield non-trivial physical consequences, such as non-thermal melting of symmetry-breaking phases and the formation of hidden states with entangled spin-orbital ordering which are inaccessible in equilibrium. We demonstrate the scenarios in a two-band Hubbard model using non-equilibirum Dynamical Mean-Field Theory. Furthermore, controlled studies of the photo-doped state are often prone to the limited time range that is numerically accessible. Thus, we adopt a non-equilibrium steady-state formulation of Dynamical Mean-Field Theory to describe a longlived photo-doped system, which is constantly perturbed to maintain a stationary state containing charge excitations across the gap. The perturbation can be adjusted to control the excitation density continuously. Using this method, we study a photo-doped two-band Hubbard model. We find the photo-doping drives the system to a hidden phase, which exhibits non-thermal ordering essentially distinct from an equilibrium or Floquet engineered system.

DY 4.4 Mon 10:15 H22

Non-equilibrium optical conductivity for the antiferromagnetic single-band Hubbard model: Time-dependent Gutzwiller analysis — •Christian Martens[1], Jörg Bünemann[2], and Götz Seibold[1] — [1]Institut für Physik, BTU Cottbus-Senftenberg, Postfach 101344, 03013 Cottbus, Germany — [2]Fakultät Physik, TU Dortmund, 44227 Dortmund, Germany

Based on the time-dependent Gutzwiller approximation (TDGA) for the Hubbard model we analyze the optical conductivity $\sigma(\omega)$ in an out-of equilibrium situation for underlying antiferromagnetic ground states. The equilibrium state is perturbed by an instant quench of the local Coulomb interaction parameter U or by an electric field $E(t)$. We analyze various shapes for the applied electric field and discuss our results with regard to the optical conductivity determination from pump-probe experiments. In the linear response regime, RPA corrections to the TDGA vanish, so that the optical response is determined by the bare current-current correlation function. In contrast, far from the linear response regime the out-of equilibrium case shows a more interesting behavior and in particular mixes double occupancy fluctuations to the current response.

DY 4.5 Mon 10:30 H22

Time-dependent wave functions with multiple correlators for the Hubbard model in nonequilibrium — •Patricia Mayer[1], Masud Haque[2], and Marcus Kollar[1] — [1]Theoretische Physik III, Universität Augsburg — [2]Department of Theoretical Physics, Maynooth University, Ireland

For the solvable $1/r$-Hubbard chain [1], the double occupation relaxes to nonthermal values after an interaction quench [2]. We apply time-dependent variational wave functions to this problem to assess their descriptive capabilities. We find that the Gutzwiller wave function, which acts on the Fermi sea with the exponentiated double occupation as correlator, can describe the time evolution accurately only for short times and then keeps oscillating with a single frequency, similar to the infinite-dimensional case [3]. On the other hand, in the Gutzwiller-Baeriswyl wave function the exponentiated kinetic energy is applied in turn to the Gutzwiller wave function [4], which leads to accurate expectation values up to longer times followed by a more complicated oscillating pattern. We conclude that multiple variational correlators substantially improve the description of Hubbard models in nonequilibrium.

[1] F. Gebhard and A.E. Ruckenstein, Phys. Rev. Lett. **68**, 244 (1992)
[2] M. Kollar and M. Eckstein, Phys. Rev. A **78**, 013626 (2008)
[3] M. Schiró and M. Fabrizio, Phys. Rev. Lett. **105**, 076401 (2010)
[4] M. Dzierzawa et al., Phys. Rev. B **51**, 1993 (1995)

DY 4.6 Mon 10:45 H22

Dynamics of densities and currents in spin ladders — •Jonas Richter[1], Fengping Jin[2], Lars Knipschild[1], Jacek Herbrych[3], Hans De Raedt[4], Kristel Michielsen[2], Jochen Gemmer[1], and Robin Steinigeweg[1] — [1]University of Osnabrück, Germany — [2]Forschungszentrum Jülich, Germany — [3]The University of Tennessee, USA — [4]University of Groningen, The Netherlands

The impact of integrability or nonintegrability on the dynamics of isolated quantum systems is a longstanding issue. For integrable models, a macroscopic set of (quasi)local conservation laws can lead to partially conserved currents and ballistic transport. In generic situations, however, integrability is lifted due to various perturbations and currents are expected to decay. Still, since the dynamics of interacting quantum many-body systems poses a formidable challenge to theory and numerics, it remains open whether nonintegrability as such already implies the emergence of diffusion. In this context, we study the dynamics of spin and energy in the two-leg spin-1/2 ladder with up to 40 lattice sites, using an efficient pure-state approach based on the concept of typicality. We discuss correlation functions in real and momentum space, and in the time and frequency domain, providing a comprehensive picture of high-temperature dynamics in this archetypal nonintegrable quantum model. Particularly, we unveil the occurence of diffusion for both spin and energy.

[1] J. Richter *et al.*, Phys. Rev. B **97**, 174430 (2018)
[2] J. Richter *et al.*, arXiv:1811.02806

15 min. break.

DY 4.7 Mon 11:15 H22

Inhomogeneous quench on the Bethe lattice — •Marc Alexander and Marcus Kollar — Theoretische Physik III, Universität Augsburg

An abrupt change of the on-site energy for a single site in a one-dimensional non-interacting tight-binding model generates dynamical

Friedel oscillations of the disturbed Fermi sea [1]. In order to study this phenomenon in higher dimensions we obtain exact time evolution for such an inhomogeneous quench for a Bethe lattice with arbitrary coordination number. We use the exact eigenstates of finite Cayley trees without [2,3] or with an impurity at the central site. For the Bethe lattice with infinite coordination number we observe dynamical Friedel oscillations with two qualitative different long-time limits depending on the strength of the impurity potential.

[1] J. M. Zhang and Y. Liu, Phys. Rev. B. **97**, 075151 (2018)
[2] M. van den Berg et al., J. Stat. Phys. **69**, 307 (1992)
[3] G. D. Mahan, Phys. Rev. B **63**, 155110 (2001)

DY 4.8 Mon 11:30 H22

Steady-state charge transport through Falicov-Kimball system connected to metallic leads — Martin Žonda and •Michael Thoss — Institute of Physics, Albert-Ludwig University of Freiburg, Hermann-Herder-Strasse 3, 791 04 Freiburg, Germany

We study steady-state nonequilibrium charge transport in a model heterostructure, where a two-dimensional spin-less Falicov-Kimball system is coupled to two noninteracting leads, using a combination of a sign-problem-free Monte Carlo approach and nonequilibrium Green's function techniques. We show that the transport characteristic depends sensitively on the electrostatic potential in the system and exhibits different properties for different phases of the Falicov-Kimball model. In particular, pronounced step-like changes of the current and transmission are observed at the phase boundaries, evident even on a logarithmic scale. Analyzing finite size effects, we find that with the method used a relatively small system can be utilized to address specific thermodynamic limits.

DY 4.9 Mon 11:45 H22

Heating Dynamics in a Periodically Driven SYK-Model — •Clemens Kuhlenkamp, Simon Weidinger, and Michael Knap — Technische Universität München

Periodically driven quantum matter can realize exotic dynamical phases that do not even exist in equilibrium. In order to understand how ubiquitous and robust these phases are, it is important to understand the heating dynamics of generic interacting quantum systems. We study the thermalization and heating dynamics in a generalized SYK-model subjected to a periodic drive, which realize a Fermi-Liquid (FL) to Non-FL crossover at a certain energy scale. Using an exact field theoretic approach we determine two regimes in the heating dynamics. Only at energies above this crossover scale the system is efficiently thermalizing and heats up exponentially. The crossover in the heating dynamics may be experimentally studied by measuring the absorption of THz laser light that impinges on an irregularly shaped graphene flake in a strong magnetic field, which has been proposed to realize exotic SYK physics.

DY 4.10 Mon 12:00 H22

Periodically Driven Manybody System: a Density Matrix Renormalization Group Study — Shaon Sahoo, •Imke Schneider, and Sebastian Eggert — Department of Physics and Research Center OPTIMAS, Technical University of Kaiserslautern

Driving a quantum system periodically in time can profoundly alter its long-time dynamics and trigger exotic quantum states of matter. We propose a new DMRG method which directly deals with the Fourier components of the eigenstates of a periodically driven system using Floquet theory. With this new method we can go beyond effective Hamiltonians and take into account higher Floquet modes. Numerical results are presented for the isotropic Heisenberg antiferromagnetic spin-1/2 chain under both local (edge) and global driving for energies, spin-spin correlation and temporal fluctuations. As the frequency is lowered, the spin system enters into a Floquet regime with coherent excitations of a large number of Floquet modes, which shows characteristic quantum correlations that cannot be described by any effective static model.

DY 4.11 Mon 12:15 H22

Matrix Product Operator Algorithm for Quantum Hydrodynamics — •Tibor Rakovszky[1], Curt von Keyserlingk[2], Ehud Altman[3], and Frank Pollmann[1] — [1]Department of Physics, T42, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany — [2]University of Birmingham, School of Physics & Astronomy, B15 2TT, UK — [3]Department of Physics, University of California, Berkeley, California 94720, USA

Motivated by recent understanding of the Heisenberg picture evolution of operators in many-body systems, and the growth of quantum entanglement in systems subject to weak measurements, we propose a novel numerical algorithm for extracting the long-time hydrodynamic transport properties of strongly interacting spin chains. Our algorithm is based on time evolving local operators corresponding to conserved densities, making use of the so-called matrix product operator representation, and adding an artificial dissipative term that reduces the weight of large, un-physical operators that do not contribute to the physically relevant few-point correlations. The dissipation leads to a significant reduction in the number of parameters needed to represent the operator and allows us to compute the aforementioned correlation functions up to much longer times then would otherwise be possible. Using this we extract the diffusion constants of several model Hamiltonians and benchmark them against existing results in the literature.

DY 4.12 Mon 12:30 H22

Diffusion and operator spreading in matrix product operators — •Johannes Hauschild and Frank Pollmann — Department of Physics, Technische Universität München, Garching, Germany

Matrix product states (MPS) became one of the standard tools for the simulation of real time dynamics in quantum many-body systems in one dimensional systems. The fast growth of entanglement during a real time evolution usually restricts the evolution of pure MPS to short to intermediate times. In certain cases, the operator entanglement entropy of a single-site operator evolved in the Heisenberg picture grows much slower. We discuss advantages and disadvantages of the different methods in the context of extracting diffusion constants and the study of operator spreading in disordered systems. Starting from a model which displays diffusion already after short times, we study the transition to a many-body localized phase and perform a careful convergence analysis in the bond dimension.