TT 83: Correlated Electrons: Nonequilibrium Quantum Many-Body Systems I

Time: Thursday 9:30–13:00 Location: HSZ 03

Topical Talk TT 83.1 Thu 9:30 HSZ 03

Kinetic Theory for the Relaxation of Quantum Many-Body Systems — •Marcus Kollar — Theoretische Physik III, Zentrum für Elektronische Korrelationen und Magnetismus, Universit*ät Augsburg

After being forced out of equilibrium, an isolated quantum many-body system is expected to relax to thermal equilibrium, unless it is integrable and retains memory of the initial state due to a large number of constants of motion. For weak interactions a large number of *approximate* constants of motion leads to a short-time prethermalization regime [1], which we discuss for several interacting systems in high and low dimensions. We then use a weak-coupling kinetic theory [2] to describe both the initial prethermalization regime as well as the subequent crossover towards the thermal state.

[1] M. Kollar, F. A. Wolf, and M. Eckstein, PRB 84, 054304 (2011).
[2] M. Stark and M. Kollar, arXiv:1308.1610.

TT 83.2 Thu 10:00 HSZ 03

Quench Dynamics in a Model with Tuneable Integrability Breaking — Fabian H.L. Essler[1], Stefan Kehrein[2], •Salvatore R. Manmana[2], and Neil J. Robinson[1] — [1]The Rudolf Peierls Centre for Theoretical Physics, Oxford University, UK — [2]Institut für Theoretische Physik, Georg-August-Universität Göttingen, Germany

We consider quantum quenches in an integrable quantum chain with tuneable integrability breaking interactions. In the case where these interactions are weak, we demonstrate that at intermediate times after the quench local observables relax to a prethermalized regime, which can be described by a density matrix that can be viewed as a deformation of a generalized Gibbs ensemble. We present explicit expressions for the approximately conserved charges characterizing this ensemble. We do not find evidence for a crossover from the prethermalized to a thermalized regime on the time scales accessible to us. Increasing the integrability-breaking interactions leads to a behaviour that is compatible with eventual thermalization.

TT 83.3 Thu 10:15 HSZ 03

Finite-size scaling of eigenstate thermalization — •Wouter Beugeling, Roderich Moessner, and Masud Haque — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

According to the eigenstate thermalization hypothesis (ETH), even isolated quantum systems can thermalize because the eigenstate-to-eigenstate fluctuations of typical observables vanish in the limit of large systems. Since isolated systems are by nature finite, the finite-size scaling of such fluctuations is a central aspect of the ETH. We propose that for generic non-integrable systems these fluctuations scale with a universal power law in the dimension of the Hilbert space. We present extensive multiple-system numerical evidence for this scaling law and provide supporting arguments. We also show how the scaling changes when approaching integrability.

TT 83.4 Thu 10:30 HSZ 03

Entanglement propagation and typicality of measurements in a quantum version of the Kac ring — •Johannes M. Oberreuter, Ingo Homrighausen, and Stefan Kehrein — Institut für Theoretische Physik, Georg-August-Universität Göttingen, Germany

Time development in quantum many body systems poses serious challenges to our understanding of classical statistical mechanics. Exact results are very rare due to the large Hilbert spaces and the resulting complexity involved. We propose a pedagogical approach with a very tractable toy model, in which questions of entanglement creation, propagation and destruction between a system and an environment can be studied explicitly. Comparing this quantum model with its classical counterpart [1], we find an intriguing correspondence between the typical result of repeated measurements on a classical ensemble and the repeated measurements of a quantum system in an appropriate superposition.

[1] G. Gottwald and M. Oliver, Boltzmann's Dilemma : An Introduction to Statistical Mechanics via the Kac Ring, SIAM Rev. 51, 613 (2009)

TT 83.5 Thu 10:45 HSZ 03

Excited states above a non-equilibrium steady state (NESS) and approach to NESS — •Mariya Medvedyeva and Stefan Kehrein — Goettingen University

The simplest way to address the evolution of an open quantum system is the Lindblad equation, which describes a quantum system coupled to a classical environment. In the long-time time limit the system reaches a non-equilibrium steady state (NESS). The spectrum of the Liouvillian operator from the Lindblad equation determines the excited states with respect to the NESS. In general, the spectrum consists of complex numbers, whose real parts determine the relaxation speed while the imaginary parts lead to oscillations. The approach of a generic initial state to equilibrium is determined by the longest-living excited states which do not oscillate. If the density of such states shows a power law behavoir close to zero, then the approach to NESS also follows a power-law rather than an exponential behavior. We demonstrate this statement for the example of non-interacting fermions coupled to a Markovian bath, where the solution can be found exactly (up to numerical matrix diagonalization).

TT 83.6 Thu 11:00 HSZ 03

Analysis of the work distribution function after a quench in the transverse field Ising model — •Nils Abeling and Stefan Kehrein — Department of Physics, Georg-August-Universität, Göttingen, Germany

Non-analytic behaviour of the Loschmidt echo in non-equilibrium quantum many-body systems indicates a breakdown of the short time expansion. The analytically calculated work distribution function in the thermodynamic limit was shown to display such non-analytic behaviour at $T = 0$ in Ref. [1] indicating a dynamical phase transition. The result is generalized to non-zero temperature and a suggestive interpretation is given.

[1] M. Heyl, A. Polkovnikov, and S. Kehrein, Phys. Rev. Lett. 110, 135704 (2013)

15 min. break.

TT 83.7 Thu 11:30 HSZ 03

Thermalization timescales in a 1d Hubbard model with slightly broken integrability — •Fabian Biebl and Stefan Kehrein — Univ. Göttingen, Germany

Understanding relaxation in quantum systems is essential to determine whether an experimental setup can be described by equilibrium concepts. For example integrable systems do not thermalize, but develop into non-thermal steady states. By slightly breaking integrability, thermalization of such non-thermal (prethermalized) states becomes possible. An important question is to identify the corresponding timescale for thermalization due to the breaking of integrability.

We investigate this question for a fermionic Hubbard chain. The integrability breaking term is a small next to nearest neighbor hopping term [1,2]. The thermalization timescale is extracted from the quantum Boltzmann equation and depends strongly on temperature.

[1] M. L. R. Fuerst et al., Phys. Rev. E 86, 031122 (2012)
[2] M. L. R. Fuerst et al., Phys. Rev. E 88, 012108 (2013)

TT 83.8 Thu 11:45 HSZ 03

Nonequilibrium Dynamics beyond the Mean Field Approximation — •Ingo Homrighausen and Stefan Kehrein — Universität Göttingen

Mean field type approximations are one of the most accessible methods to study the complexity of quantum many body systems out of equilibrium. However, the validity of such approximations has to be examined in each case. Building on Ref. [1] we investigate three different quantum many particle models on finite fully connected lattices: the transverse field Ising model, the Bose-Hubbard model and the Jaynes Cummings model. In particular, we explore the nonequilibrium dynamics of the order parameter and its variance after a quantum quench. The most intriguing observation is that all three models exhibit the same universal behavior: For quenches within the ordered phase, the variance of the order parameter shows a quasiperiodic breathing behavior. The local maxima of this breathing increase in time whereas the local minima decrease. Applying a semiclassical expansion, we explain these findings and argue why the observations are generic. We also discuss the time scale of validity of our analysis by comparing to numerically exact data.

[1] B. Sciolla, G. Biroli, J. Stat. Mech. (2011) P11003

TT 83.9 Thu 12:00 HSZ 03

Is there Andreev-reflection in 1D Fermi-Hubbard systems? — •Mirco Marahrens[1], Salvatore R. Manmana[1], and Philippe Jacquod[2] — [1]University of Göttingen, Göttingen, Germany — [2]University of Arizona, Tucson, Arizona, USA

We investigate for the possibility of *directly* observing Andreev-reflection in the time evolution of an initial wave packet at a metal/superconductor junction in interacting one-dimensional Fermi-Hubbard systems. We apply the adaptive time-dependent density matrix renormalization group (t-DMRG) method to obtain the behaviour when the wave packet initially prepared in the metallic region (modelled by non-interacting electrons) hits the interface to the superconducting region which we model by an attractive Fermi-Hubbard model. Somewhat surprisingly, and at first sight in contradiction to the findings in [1,2], we do not obtain a clear signal for hole-reflection over a wide range of parameters. This appears to be different for bosonic systems, in which we identify hole-like reflection, in line with the findings of [2]. We discuss ongoing work on this issue and the different aspects of the results obtained so far.

[1] A.E. Feiguin, S.R. White, D.J. Scalapino, PRB 75, 024505 (2007)
[2] A.J. Daley, P. Zoller, B. Trauzettel, PRL 100, 110404 (2008).

TT 83.10 Thu 12:15 HSZ 03

A DMFT approach to dynamical quantum phase transitions. — •Elena Canovi and Martin Eckstein — Max Planck Research Department for Structural Dynamics, University of Hamburg (CFEL), Building 99, Luruper Chaussee 149, 22761 Hamburg, Germany

Recently, dynamical quantum phase transitions have been identified with non-analytic behavior of the Loschmidt echo in the thermodynamic limit (Heyl et al., Phys. Rev. Lett. 110 135704 (2013)), in analogy to non-analytic behavior of the free energy at a thermal phase transition. In this talk, we develop a formalism to obtain the Loschmidt echo within nonequilibrium dynamical mean-field theory, by mapping the lattice model to an impurity problem for which the time evolution is dictated by different Hamiltonians on the upper and lower real branches of the Keldysh contour. This opens the possibility of studying dynamical quantum phase transitions for the Hubbard model and related models in large dimensions.

TT 83.11 Thu 12:30 HSZ 03

Exact solution of polaron dynamics within nonequilibrium dynamical mean-field theory — •Sharareh Sayyad and Martin Eckstein — Max Planck Research Department for structural dynamics, University of Hamburg-CFEL, Hamburg, Germany

Ultra-fast pump-probe experiments have opened promising new avenues to control complex phases in correlated materials on femtosecond timescales. Of particular interest is an understanding of the combined electron lattice dynamics. In this talk we address the fundamental problem of a single electron interacting with the lattice, which is studied within the Holstein model. In equilibrium, this problem has been solved exactly using dynamical mean-field theory (DMFT) [1]. We have generalized this solution to non-equilibrium DMFT, which allows us to investigate the dynamics of photo-excited carriers in the presence of a strong electron-phonon interaction, and thus follow the formation of a polaron in real time.

[1] S. Ciuchi *et al.*, Phy. Rev. B **56**, 8 (1997)

TT 83.12 Thu 12:45 HSZ 03

Auxiliary Hamiltonian representation of the nonequilibrium Dyson equation — •Karsten Balzer and Martin Eckstein — Max Planck Research Department for Structural Dynamics, University of Hamburg (CFEL), Building 99, Luruper Chaussee 149, 22761 Hamburg, Germany

The nonequilibrium Dyson (or Kadanoff-Baym) equation, which is an equation of motion with long-range memory kernel for real-time Green functions, underlies many numerical approaches based on the Keldysh formalism. We show how the problem of solving the Dyson equation in real-time can be mapped onto a noninteracting auxiliary Hamiltonian with additional bath degrees of freedom [1]. The solution of the auxiliary model does not require the evaluation of a memory kernel and can thus be implemented in a very memory efficient way. The mapping is derived for a self-energy which is local in space and is thus directly applicable within nonequilibrium dynamical mean-field theory (DMFT) [2]. We apply the method to study the interaction quench in the Hubbard model for an optical lattice with a narrow confinement, using inhomogeneous DMFT in combination with second-order weak-coupling perturbation theory. We find that, although the quench excites pronounced density oscillations, signatures of the two-stage relaxation similar to the homogeneous system can be observed by looking at the time-dependent occupations of natural orbitals.

[1] C. Gramsch, K. Balzer, M. Eckstein and M. Kollar, Phys. Rev. B, accepted (2013) [arXiv:1306.6315]
[2] H. Aoki, N. Tsuji, M. Eckstein, M. Kollar, T. Oka and P. Werner (2013) [arXiv:1310.5329]