Invited Talks

Emergent integrability in Heisenberg spin models with disordered couplings

Adrian Braemer, Universität Heidelberg, Germany

Abstract: Disordered quantum many-body systems can show striking phenomena such as slow relaxation or many-body localization. Quantum simulation experiments have proven a useful tool for understanding the dynamics of such non-integrable systems beyond system sizes accessible to numerical methods. In this talk, I present recent results from theory and experiment concerning the dynamics of spatially disordered Heisenberg-type models with power-law interactions. Concretely, we used a cold gas of Rydberg atoms to realize Ising, XXZ and XX models and found the relaxation dynamics of the global magnetization to be universal with respect to a typical timescale. The origin of this universal behavior lies within the disordered couplings which lead to the formation of strongly interacting pairs of spins that constitute quasi-conserved quantities for long periods of time. Higher order perturbation theory reveals a strong renormalization group flow towards an effective Ising model of clusters of spins.

Converting entanglement into mixture: a new algorithm for long-time dynamics with tensor networks

Mari Carmen Bañuls, MPQ Garching, Germany

In out-of-equilibrium quench scenarios, fast degrees of freedom contribute to long-range entanglement that hinders their simulation with tensor networks. Local observables, on the other hand, are not sensitive to such long-range correlations, but only to their contribution to the reduced state at the level of the local subsystem. We present a tensor network method that identifies long-range entanglement structures in the time-evolved quantum many-body state and efficiently transforms them into mixture. In this way, we obtain an effective description of the time-evolved state as a density matrix that captures the long-time behavior of local properties for systems in which quasiparticles (exact or not) are responsible for the entanglement spreading.

Time-dependent correlations in fermionic many-body systems

Iva Brezinova, TU Vienna, Austria.

Solving the time-dependent Schrödinger equation with sufficient accuracy for strongly non-equilibrium or strongly driven quantum many-body systems remains a major challenge to date. In my talk, I will review our recently developed method, which uses the time-dependent two-particle reduced density matrix (TD2RDM) as the fundamental variable. The TD2RDM method entails reconstruction functionals of the three-particle reduced density matrix, employing the assumption that three-particle correlations can be sufficiently well approximated by two-particle correlations even in a time-dependent setting. Using the Fermi-Hubbard model as a model system, I will show that this assumption is valid for a large range of parameter regimes of interaction strengths and quench fields. By avoiding the wavefunction, the method has a favorable scaling and allows the treatment of systems with many sites over large time intervals independent of the spatial dimensionality. As an application of the method, I will demonstrate the dynamical build-up and decay of fermionic condensation in the Fermi-Hubbard model.

Scale invariant mid-time dynamics at eigenstate transitions

Miroslav Hopjan, Josef Stefan Institute, Ljubljana, Slovenia

Understanding quantum phase transitions in highly excited Hamiltonian eigenstates is currently far from being complete. It is particularly important to establish tools for their characterization in time domain. Here we argue that dynamics of the spectral form factor and scaled survival probability, where time is measured in units of a typical Heisenberg time, exhibits a scale invariant mid-time behaviour at eigenstate transitions. We demonstrate this property in quadratic models as well as in an interacting model [1]. This establishes an intriguing similarity between localization transition in quadratic systems and ergodicity breaking phase transition in interacting systems and opens new possibilities to characterize and detect ergodicity breaking phenomena.

[1] M.Hopjan and L. Vidmar, Phys. Rev. Lett. 131, 060404 (2023).

Iterative construction of conserved quantities in dissipative nearly integrable systems
Zala Lenarčič, Josef Stefan Institute, Ljubljana, Slovenia

Integrable systems are a rare example of a solvable many-body problem in the quantum world. Due to the fine-tuned structure, their realization in nature and experiment is never completely accurate, therefore effects of integrability are observed only transiently. One way to surpass that is to couple nearly integrable systems to baths and driving: these will stabilize integrable effects, encoded in the time dependent, and eventually, the stationary state of form of a generalized Gibbs ensemble, up to arbitrary time. However, the description of such driven dissipative nearly integrable models is challenging and no exact analytical methods have been proposed so far. I will introduce an iterative scheme in which integrability breaking perturbations (baths) determine the most necessary conservation laws to be added into a truncated generalized Gibbs ensemble description. Our scheme significantly reduces the complexity of the problem, paving the way for thermodynamic results.

Quantum reaction-diffusion systems
Igor Lesanovsky, Universität Tübingen

Ongoing progress in the control of cold atomic gases continuously offers new opportunities for creating and probing quantum matter. In this talk I will discuss how these advances put us into position to investigate the impact of quantum effects on collective behavior and the long-time dynamics of many-body systems out of equilibrium. I will focus mainly on two instances: the contact process [1], which is a simple model for epidemic spreading, and lattice gases featuring two-body annihilation [2]. In both settings the introduction of non-classical effects, such as coherence, appears to alter emergent dynamical behavior. This manifests in a change of static and dynamical critical exponents, which can in principle be probed on lattice quantum simulators with Rydberg and ground state atoms. The particular challenge is (also for theory) that an unambiguous identification of these signatures requires the study of large quantum many-body systems at long times.

[1] F. Carollo, E. Gillman, H. Weimer and I. Lesanovsky, Critical behavior of the quantum contact process in one dimension, Physical Review Letters 123, 100604 (2019)
[2] G. Perfetto, F. Carollo, J.P. Garrahan and I. Lesanovsky, Reaction-limited quantum reaction-diffusion dynamics, Physical Review Letters 130, 210402 (2023)

Quantum-chaotic quadratic Hamiltonians: Weak eigenstate thermalization and equilibration of many-body observables
Patrycja Łydżba, Wroclaw University of Science and Technology, Poland

Quantum-chaotic quadratic (QCQ) models are quadratic models that exhibit the single-particle quantum chaos [1]. Specifically, their single-particle energies agree with the random-matrix-like level statistics, while matrix elements of observables in single-particle energy eigenstates satisfy the eigenstate thermalization hyphothesis (ETH). Paradigmatic examples of local QCQ models are the three-dimensional Anderson model [2,3] in the delocalized regime and chaotic tight-binding billiards [4]. We argue that the QCQ models comply with the weak version of the ETH ansatz. Specifically, the eigenstate-to-eigenstate fluctuations and variances of diagonal matrix elements of nonextensive observables decrease polynomially with the system size. Additionally, we demonstrate that there are exponentially many maximal outliers. Finally, we prove that observables equilibrate in the many-body states of QCQ models [5]. We show that the vanishing of temporal fluctuations in the thermodynamic limit can be established without any assumption on the initial state or the details of nonequlibrium dynamics.

[1] P. Łydżba, M. Rigol, and L. Vidmar, Phys. Rev. B 103, 104206 (2021).
[2] P. Łydżba, Y. Zhang, M. Rigol, and L. Vidmar, Phys. Rev. B 104, 214203 (2021).
[3] J. Šuntajs, T. Prosen, and L. Vidmar, Annals of Physics 168469 (2021).
[4] I. Iris Ulčakar and L. Vidmar, Phys. Rev. E 106, 034118 (2022).
[5] P. Łydżba, M. Mierzejewski, M. Rigol and L. Vidmar, accepted in Phys. Rev. Lett., (2023).

Strongly disordered Anderson insulator chains with generic two-body interaction
Marcin Mierzejewski, Wroclaw University of Science and Technology, Poland

We consider a chain of interacting fermions with random disorder that was intensively studied in the context of many-body localization. We show that only a small fraction of the two-body interaction represents a true local perturbation to the Anderson insulator. While this true perturbation is nonzero at any finite disorder strength W, it decreases with increasing W. Then, the interpretation of finite-size numerical calculations at large W is very challenging since finite integrable systems with small perturbations are hardly distinguishable from strictly integrable systems. Therefore, we study also other forms of the two-body interaction for which the strength of the true perturbation is of the same order of magnitude as the bare two-body interaction. Focusing on the strong interaction regime, numerical results for the level statistics and the eigenstate thermalization hypothesis are consistent with emergence of ergodicity at arbitrary strong disorder.

Tba

Cristiane de Morais Smith, Utrecht Univerity, The Netherlands

Floquet Quantum East Circuit: Localization Transition in Thermodynamic Limit
Tomaz Prosen, University of Ljubljana, Slovenia

We define and study the Floquet Quantum East circuit model, a kinetically constrained quantum dynamics in discrete space-time, exhibiting a localization transition in infinite volume. The localization is established using perturbative arguments as well as convergent TEBD (time-evolving block decimation) method in real time.

Generalized hydrodynamics, local prethermalization, and hydrodynamization in ultracold 1D gases
Marcos Rigol, Penn State University, U.S.A.

Experiments with nearly-integrable ultracold 1D gases have probed dynamics involving large distances and long times, testing the recently proposed theory of generalized hydrodynamics [1]. Using "high-energy" quenches implemented via a Bragg scattering pulse, the experiments have also unveiled equilibration at the shortest available time scales, a process known as hydrodynamization in the context of relativistic heavy-ion collisions, which precedes local prethermalization [2]. I will discuss the experimental results as well as their theoretical understanding and modeling. For hydrodynamization, I'll argue that near-integrability provides a theoretical framework from which one can draw a general picture that applies to nonintegrable systems.

[1] N. Malvania, Y. Zhang, Y. Le, J. Dubail, MR, and D. S. Weiss, Generalized hydrodynamics in strongly interacting 1D Bose gases, Science 373, 1129 (2021).
[2] Y. Le, Y. Zhang, S. Gopalakrishnan, MR, and D. S. Weiss,Observation of hydrodynamization and local prethermalization in 1D Bose gases, Nature 618, 494 (2023).

Renormalization Group Analysis of the Anderson Model in infinite dimensions: 1/d expansion and many-body localization
Antonello Scardicchio, ICTP Trieste, Italy

I will discuss the work in https://arxiv.org/abs/2306.14965 and some more recent work, yet unpublished. I will show how to write a beta function for eigenstates and spectral observables of the Anderson model on RRG and how to use it as a starting point for the discussion of a 1/d expansion of the model in finite-dimensional lattices, and to analyse MBL and Floquet MBL.

Spectra and localization properties of master operators: glassy models on random graphs
Peter Sollich, Univsität Göttingen

In this talk, I discuss trap models as a generic model for glassy systems on random graphs. The essential properties of these models are encoded in a master operator, whose eigenvalues and eigenvectors correspond to the relaxation rates and modes of the system, respectively. Using techniques from the field of disordered systems, primarily the cavity method, we obtain the spectral density and are able to make statements on the localization properties of the corresponding eigenvectors by analogy with Anderson localization physics. The spectra show very rich behaviour as a function of network connectivity c and temperature T, and we trace this back to a crossover from entropic and energetic barriers in the glassy dynamics.

Constructing nonequilibrium steady states from equilibrium correlation functions
Robin Steinigeweg, Universität Osnabrück

Abstract: State-of-the-art approaches to extract transport coefficients of many-body quantum systems broadly fall into two categories: (i) they target the linear-response regime in terms of equilibrium correlation functions of the closed system; or (ii) they consider an open-system situation typically modeled by a Lindblad equation, where a nonequilibrium steady state emerges from driving the system at its boundaries. While quantitative agreement between (i) and (ii) has been found for selected model and parameter choices, also disagreement has been pointed out in the literature. Studying magnetization transport in the spin-1/2 XXZ chain, we here demonstrate that at weak driving, the nonequilibrium steady state in an open system, including its buildup in time, can remarkably be constructed just on the basis of correlation functions in the closed system. We numerically illustrate this direct correspondence of closed-system and open-system dynamics, and show that it allows the treatment of comparatively large open systems, usually only accessible to matrix product state simulations. We also point out potential pitfalls when extracting transport coefficients from nonequilibrium steady states in finite systems.

Coexistence of localisation and transport in many-body two-dimensional quasi-periodic models
Antonio Štrkalj, University of Cambridge, U.K.

Many-body localisation (MBL) provides a mechanism to avoid thermalisation in interacting systems. It is well understood that the MBL phase can exist in closed one-dimensional systems subjected to random disorder, quasiperiodic modulations, or homogeneous electric fields. However, the fate of MBL in higher dimensions remains unclear. Although some experiments on randomly disordered two-dimensional (2D) systems observe a stable MBL phase on intermediate time scales, recent theoretical works show that the phenomenon cannot persist forever and in a thermodynamic limit due to the rare regions and the avalanche instability. On the other hand, quasiperiodic systems do not host rare regions, and avalanche instability is avoided; yet, the existence of an MBL phase in these systems remains to date largely unexplored. Using the numerical method of the time-dependent variational principle, we investigate the localisation properties of the many-body 2D Aubry-André quasiperiodic model by studying its out-of-equilibrium dynamics. We find a long-lived MBL phase that is stable upon scaling the system size, in contrast to random disorder. Surprisingly, we also observe large-scale transport along deterministic lines of weak potential, which appear in the investigated quasiperiodic models. Our results demonstrate that quasiperiodic many-body systems have the remarkable and counter-intuitive capability of exhibiting coexisting localisation and transport properties – a phenomenon reminiscent of the behaviour of supersolids. Our findings are of direct experimental relevance and can be tested using state-of-the-art cold atomic systems.

A. Štrkalj, E.V.H. Doggen, C. Castelnovo, Phys. Rev. B **106**, 184209 (2022)

Microscopic observation of spin superdiffusion in Heisenberg chains

David Wei, MPQ Garching

Spin transport in the 1D quantum Heisenberg model has been predicted to exhibit anomalous hydrodynamics, following the space-time scaling function of the Kardar-Parisi-Zhang universality class. In our experiment, we employ a cold-atom quantum simulator to study this conjecture by characterizing the relaxation of domain walls. We find that spin transport is superdiffusive and indeed obeys the characteristic KPZ space-time scaling with dynamical exponent z=3/2. We observe that superdiffusion breaks down when probing dynamics both in the 2D model and in the net-magnetized 1D model, which supports the notion that integrability and the non-abelian SU(2) symmetry of the 1D Heisenberg model give rise to its superdiffusive dynamics. Finally, we leverage the single-spin-sensitive detection enabled by our quantum-gas microscope to measure the full spin-transport counting statistics. We find signatures that the underlying transport dynamics is nonlinear and discuss their relation to the KPZ universality class.

Contributed Talks

Quantum simulation and out-of-equilibrium dynamics of Sachdev-Ye-Kitaev (SYK) model
Soumik Bandyopadhyay, University of Trento, Italy

The quest for a quantum theory of gravity has led to the discovery of quantum many-body systems that are dual to gravitational models with quantum characteristics. Amongst these the Sachdev-Ye-Kitaev (SYK) model has received tremendous research interest in recent years. The model features maximal scrambling of quantum information, and opens a potential inroad to experimentally investigating aspects of quantum gravity. A scalable laboratory realisation of this model, however, remains outstanding. In this talk, we shall be discussing a possible implementation of the SYK model in cavity quantum electrodynamics platforms. Our detailed analytical and numerical analysis reveals that a cloud of fermionic atoms trapped in a multi-mode optical cavity subjected to a spatially disordered AC-Stark shift retrieves the physics of the SYK model, with random all-to-all interactions and fast scrambling. Furthermore, our work demonstrates that for local observables the out-of-equilibrium dynamics of the model is universal with respect to generic initial conditions. To reveal this, we develop a general open quantum system frame-work for the disorder averaged closed evolution, and reveal the universality through the spectral characteristics of the corresponding Liouvillian. Our works provide a blueprint for realising the SYK model in a scalable system, with the prospect of studying holographic quantum matter in the laboratory, and shed light on challenging questions for systems far from equilibrium, such as, thermalization of closed and disordered quantum systems.

Topological pumping in quasiperiodic optical lattices
Emmanuel Gottlob, University of Cambridge, U.K.

A Villain-like in-gap mode in a periodically driven charge density wave insulator
Salvatore Manmana, Universität Göttingen, Germany

Tuning the phase diagram of the Rosenzweig-Porter model
Madhumita Sarkar, Jozef Stefan Institute, Ljubljana

Posters

A Conjecture Regarding the Overlap of Different Ground States within the Same Phase
Sarah Damerow, Universität Göttingen, Germany

Novel techniques to improve the results of DMRG-X
Merlin Füllgraf, Universität Osnabrück, Germany

Quench dynamics of a free-fermionic lattice system in d>1 spatial dimensions
Molly Gibbins, University of Nottingham

Mathematical study of Gaussian fermionic operators with linear part
Arash Jafarizadeh, University of Nottingham

Temporal dynamics of inhomogeneous initial states in disordered quantum systems
Simon Jiricek, Universität Göttingen, Germany

Hilbert space fragmentation in open quantum systems
Yahui Li, TU Munich, Germany

Relaxation dynamics of quantum many-body systems with phonon degrees of freedom using the multitrajectory Ehrenfest method
Heiko Menzler, Universität Göttingen, Germany

Existence of extended states in periodically disordered systems
Suman Mondal, Universität Göttingen, Germany
Random disorder potentials localize all the eigenstates of a non-interacting system, known as Anderson localization. In one dimension, any finite disorder strength leads to the Anderson localization. Here we investigate a one-dimensional system where instead of considering random disorder potential at every site, we introduce random disorder potential periodically, leaving disorder-less sites in between. We find that there are special eigenstates that are not affected by the disorder-potentials and remain extended even in the presence of enormous disorder strength. We explore different disorder patterns and analyze the existence of these unique states in the spectrum. Finally, we investigate the system for the interacting particles.

Non-Hermitian Isospectral Reductions
Anouar Moustaj, Utrecht University

Long-lived circulating currents in strongly correlated nanorings
Dirk Schuricht, Utrecht University
We study the time-evolving currents flowing in an interacting ring-shaped nanostructure after a bias voltage has been switched on. The source-to-drain current exhibits the expected relaxation towards its quasistatic equilibrium value at a rate Γ0 reflecting the lead-induced broadening of the ring states. In contrast, the current circulating within the ring decays with a different rate Γ, which is a rapidly decaying function of the interaction strength and thus can take values orders of magnitude below Γ0. This implies the existence of a regime in which the nanostructure is far from equilibrium even though the transmitted current is already stationary. We discuss experimental setups to observe the long-lived ring transients. B. M. Schoenauer, N. M. Gergs, P. Schmitteckert, F. Evers, and D. Schuricht, Phys. Rev. Res. 1, 022006(R) (2019)

Measurement induced phase transition with an extended log-law phase in an integrability-broken transverse field Ising model
Monalisa Singh Roy, Bar-Ilan University

Average entanglement entropy of midspectrum eigenstates of quantum-chaotic interacting Hamiltonians
Rafal Swietek, Josef Stefan Institute, Ljubljana, Slovenia

Probes for localization on the sparse Barrat--Mézard trap model
Diego Tapias, Universität Göttingen
In this poster, I show the outcome of probes for localization applied to specific modes of the spectrum of the sparse Barrat-Mézard trap model. These modes are interesting because they exhibit full localization at zero temperature (strongly disordered phase) and non-trivial spectral properties at finite temperatures. In particular, they are characterized by a divergent spectral density and a power-law tail in the resolvent distribution that differs from the universal shape for Anderson localized states.

Hilbert space fragmentation in a tilted, two-dimensional Bose Hubbard model
Melissa Will, TU Munich, Germany