# TT 69: Nonequilibrium Quantum Systems II (joint session TT/DY)

Time: Thursday 9:30–13:00 Location: H 3025

TT 69.1 Thu 9:30 H 3025

**Nontrivial damping of quantum many-body dynamics in the spin-1/2 XXZ chain** — •Mariel Kempa and Robin Steinigeweg — U Osnabrück, Germany

Understanding how the dynamics of a given quantum system with many degrees of freedom is altered by the presence of a generic perturbation is a notoriously difficult question. Recent works predict that, in the overwhelming majority of cases, the unperturbed dynamics is just damped by a simple function, e.g., exponentially as expected from Fermi's golden rule. While these predictions rely on random-matrix arguments and typicality, they can only be verified for a specific physical situation. It also remains unclear how frequent and under which conditions counterexamples to the typical behavior occur. We address this question from the perspective of projection-operator techniques, where exponential damping of a density matrix occurs in the interaction picture but not necessarily in the Schrödinger picture. We show that a nontrivial damping in the Schrödinger picture can emerge if the dynamics in the unperturbed system possesses rich features, for instance due to the presence of strong interactions. We substantiate our theoretical arguments by large-scale numerical simulations of spin transport in a perturbed spin-1/2 XXZ chain.

[1] T. Heitmann et al., Phys. Rev. E 104 (2021) 054145
[2] M. Kempa et al., in preparation

TT 69.2 Thu 9:45 H 3025

**Cluster Truncated Wigner Approximation: Long-range bond disordered interacting spin-1/2 models** — Adrian Braemer[1], •Javad Vahedi[1,2], and Martin Gärttner[1,2] — [1]Physikalisches Institut, Heidelberg, Germany — [2]Friedrich-Schiller-University, Jena, Germany

Phase-space methods, like Truncated Wigner Approximation (TWA), effectively simulate quantum system dynamics near classical limits by simplifying complexity and preserving initial noise information. However, TWA has limitations in finite times and classical/non-interacting scenarios. For strongly interacting systems far from the classical limit, conventional methods may provide unreliable approximations. The Cluster Truncated Wigner Approximation (cTWA) is an alternative approach introducing additional degrees of freedom to represent correlations independently, using classical equations of motion with initial conditions sampled from Gaussian distributions [1].

Our investigation focuses on quench dynamics in a spin chain with long-range interactions and disordered couplings[2]. Initializing the system in a Néel state, we compute dynamical observables, such as the staggered magnetization and Renyi entropy S_2 for a two-spin subsystem, using cTWA with different choices for the clustering and compare these to results from exact diagonalization. We find that a clustering strategy inspired by real-space renormalisation group argument matches the exact dynamics almost perfectly for a wide range of both interaction range and disorder strength.

TT 69.3 Thu 10:00 H 3025

**Current-Voltage Characteristics of the Normal Metal-Insulator-PT-Symmetric Non-Hermitian Superconductor Junction as a Probe of Non-Hermitian Formalisms** — •Viktoriia Kornich — Universität Würzburg

We study theoretically a junction consisting of a normal metal, PT-symmetric non-Hermitian superconductor, and an insulating thin layer between them. We calculate current-voltage characteristics for this junction using left-right and right-right bases and compare the results. We find that in the left-right basis, the Andreev-scattered particles move in the opposite direction compared with the right-right basis and conventional Andreev scattering. This leads to profound differences in current-voltage characteristics. Based on this and other signatures, we argue that the left-right basis is not applicable in this case. Remarkably, we find that the growth and decay with time of the states with imaginary energies in the right-right basis are equilibrated.

TT 69.4 Thu 10:15 H 3025

**A Conjecture Regarding Ground State Overlaps** — •Sarah Damerow and Stefan Kehrein — Institut für Theoretiche Physik, Friedrich-Hund-Platz 1, 37077 Göttingen, Georg-August Universität Göttingen, Germany

A conjectured extension of the adiabatic theorem to quantum quenches, i.e. non-adiabatic changes, is presented. Using Exact Diagonalisation and the Lanczos method, we study the Axial Next Nearest Neighbour Ising Model (ANNNI). We numerically test the following conjecture: A system is prepared in its ground state. Under adiabatic time evolution of the Hamiltonian this initial ground state evolves under the time-dependent Schrödinger equation. The overlap between the initial and the final ground state will be larger than any other overlap, if both states are in the same magnetic phase.

TT 69.5 Thu 10:30 H 3025

**Constructing nonequilibrium steady states from equilibrium correlation functions in generic nonintegrable systems** — •Markus Kraft[1], Jonas Richter[2,3], Fengping Jin[4], Sourav Nandy[5], Zala Lenarčič[5], Jacek Herbrych[6], Kristel Michielsen[4], Hans De Raedt[7], Jochen Gemmer[1], and Robin Steinigeweg[1] — [1]U Osnabrück — [2]U Stanford — [3]U Hannover — [4]FZ Jülich — [5]U Ljubljana — [6]U Wroclaw — [7]U Groningen

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.

[1] T. Heitmann et al., arXiv:2303.00430
[2] T. Heitmann et al., Phys. Rev. E 108 (2023) 024102
[3] M. Kraft et al., in preparation

TT 69.6 Thu 10:45 H 3025

**A Mixed Quantum-Classical Approach to Nonequilibrium Charge Transport in Strongly Interacting Molecular Junctions** — •Samuel Rudge, Christoph Kaspar, and Michael Thoss — University Freiburg, Freiburg im Breisgau, Deutschland

Electronic friction and Langevin dynamics (EF-LD) is a popular mixed quantum-classical approach to modeling the dynamics of molecules near metal surfaces [1]. We have recently shown that, using the numerically exact hierarchical equations of motion (HEOM) transport method, one can calculate the electronic friction of systems containing electron-electron correlations or high-frequency quantum vibrational modes [2].

In this contribution, we use, for the first time, the combined EF-LD and HEOM approach to explore nonequilibrium charge transport in molecular junctions containing strong interactions. The analysis is performed for a broad parameter regime and uncovers interesting transport behavior arising from the strong interactions. The method opens the door for the analysis of realistic multimode molecular models containing anharmonic vibrational modes and nonlinear electronic-vibrational interactions, which fully quantum methods currently struggle to treat [3].

[1] J. T. Lü *et al.*, Prog. Surf. Sci. **94** (2019) 21
[2] S. L. Rudge *et al.*, Phys. Rev. B **107**, (2023) 115416
[3] C. Schinabeck *et al.*, Phys. Rev. B **97**(2018) 235429

TT 69.7 Thu 11:00 H 3025

**Transport resonances in systems with time periodic impurities** — •Jan Mathis Giesen and Sebastian Eggert — Department of Physics and Research Center Optimas, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Periodically driven impurities in tight binding chains can lead to the complete breakdown of transport even at infinitesimal small driving amplitudes due to a Fano-like resonance [1]. We now go beyond the simple model to analyse effects of time-periodic impurities in general setups like electronic systems, magnons in thin ferromagnetic films, photonic waveguides and the scattering of cold atoms. More specifi-

cally we examine single particle transport resonances in models featuring long range coupling and generally more complicated band structures as well as multiple channels, modes or bands.
We extend the Floquet scattering ansatz using plane waves to include multiple modes and also apply a generalization in form of a Floquet-S-matrix scattering approach. We find that transport resonances are highly susceptible to changes in the band structure. Depending on the driving parameters and energy of incoming states new transport resonances can appear while others might become completely suppressed.
[1] S. A. Reyes *et al.*. New J. Phys. **19** (2017) 043029

**15 min. break**

TT 69.8 Thu 11:30 H 3025

**Numerically exact simulation of photo-doped Mott insulators** — •Fabian Künzel[1], André Erpenbeck[2], Daniel Werner[3], Enrico Arrigoni[3], Emanuel Gull[2], Guy Cohen[4], and Martin Eckstein[1] — [1]University of Hamburg, 20355 Hamburg, Germany — [2]University of Michigan, Ann Arbor, Michigan 48109, USA — [3]Graz University of Technology, 8010 Graz, Austria — [4]Tel Aviv University, Tel Aviv 6997801, Israel

A description of long-lived photo-doped states in Mott insulators is challenging, as it needs to address exponentially separated timescales. These photo-doped states simultaneously host strongly correlated electron-like and hole-like carriers and can show instabilities into various non-thermal orders. In our recent work (arXiv:2311.13933 [cond-mat.str-el]) we demonstrate how properties of such quasi-steady states can be accessed using numerically exact techniques, in particular the steady state Quantum Monte Carlo inchworm framework, by establishing a time-local ansatz for the distribution function with separate Fermi functions for the electron and hole quasiparticles. We compare the results to non-perturbative steady state solvers and validate the consistency of this approach upon comparison with real-time simulations in a quenched Hubbard model. The simulations show that the Mott gap remains robust to large photo-doping, and the photo-doped state has hole and electron quasiparticles with strongly renormalized properties. By combining the steady state ansatz with Quantum Boltzmann Equation schemes, they open up new avenues for characterizing the slow dynamics of Mott insulators.

TT 69.9 Thu 11:45 H 3025

**Fractonic Dynamics in Breathing Quantum-Spin Ice** — •Gloria Isbrandt[1,2], Frank Pollmann[1,2], and Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany

Fracton quantum matter is characterized by excitations with constrained mobility. It remains an open challenge to identify suitable material candidates for such systems. Recently, breathing pyrochlore lattices have been argued as potential candidates for realizing fractonic constraints. Here, we study the dynamics of excitations in such a breathing pyrochlore lattice. We derive an effective Hamiltonian for excitations in the fractonic ground state manifold, by resorting to the rank-2 U(1) gauge theory formulation and the rank-2 Gauss law of fractons. We show both by analytical considerations and by numerical simulations based on cellular automaton circuit dynamics, that excitations in these systems are confined to two-dimensional planes within the three-dimensional breathing pyrochlore lattice. We derive a height-field theory for the effective two-dimensional dynamics, which exhibits diffusive dynamics with slow modes at finite momenta, resulting from effective subsystem symmetries. Coined as "Fractonic Quantum-Spin Ice," this system offers a physically realizable platform for fractonic excitations predicted by higher-rank gauge theories

TT 69.10 Thu 12:00 H 3025

**Dynamical Spectral Response of Fractonic Quantum Matter** — •Philip Zechmann[1,2], Julian Boesl[1,2], Johannes Feldmeier[3], and Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Department of Physics, Harvard University, Cambridge, MA 02138, USA

Quantum many-body systems with fractonic excitations can realize fascinating phases of matter. Here, we study the low-energy excitations of a constrained Bose-Hubbard model in one dimension, which conserves the center of mass or, equivalently, the dipole moment in addition to the particle number. This model is known to realize fractonic phases, including a dipole Mott insulator, a dipole Luttinger liquid, and a metastable dipole supersolid. We use tensor network methods to compute spectral functions from the dynamical response of the system and verify predictions from low-energy field theories of the corresponding ground state phases. We demonstrate the existence of gapped excitations compatible with strong coupling results in a dipole Mott insulator, linear sound modes characteristic of a Luttinger liquid of dipoles, and soft quadratic modes at both zero and finite momenta in a supersolid state with charge density wave order and phase coherence at non-integer filling.

TT 69.11 Thu 12:15 H 3025

**Deconfinement Dynamics of Fractons in Tilted Bose-Hubbard Chains** — •Julian Boesl[1,2], Philip Zechmann[1,2], Johannes Feldmeier[3], and Michael Knap[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Department of Physics, Harvard University, Cambridge, MA 02138, USA

Fractonic constraints can lead to exotic properties of quantum many-body systems. Here, we investigate the dynamics of fracton excitations on top of the ground states of a one-dimensional, dipole-conserving Bose- Hubbard model. We show that nearby fractons undergo a collective motion mediated by exchanging virtual dipole excitations, which provides a powerful dynamical tool to characterize the underlying ground state phases. We find that in the gapped Mott insulating phase, fractons are confined to each other as motion requires the exchange of massive dipoles. When crossing the phase transition into a gapless Luttinger liquid of dipoles, fractons deconfine. Their transient deconfinement dynamics scales diffusively and exhibits strong but subleading contributions described by a quantum Lifshitz model. We examine prospects for the experimental realization in tilted Bose-Hubbard chains by numerically simulating the adiabatic state preparation and subsequent time evolution, and find clear signatures of the low-energy fracton dynamics.

TT 69.12 Thu 12:30 H 3025

**Current-induced excitonic condensation in bilayer systems** — •Alexander Osterkorn and Denis Golež — Institut "Jožef Stefan", Jamova cesta 39, 1000 Ljubljana, Slovenia

Excitons are correlated electron-hole pairs in multi-band electron systems, which can condense and form ordered phases of matter called excitonic insulators. These are expected to display novel and interesting features like superfluid energy transport and perfect Coulomb drag. While it is experimentally challenging to identify real materials hosting equilibrium excitonic order, out-of-equilibrium protocols open up an independent route to stabilize excitonic condensates. Ma et.al. [1] proposed a gated semiconductor bilayer architecture, in which an applied voltage bias allows for the continuous creation of interlayer excitons by means of an induced electrical current. We model the setup starting from the quasi-stationary situation [2] within the Hartree-Fock and second order Born approximations and discuss the strong impact of dimensionality on the formation of the excitonic state. In order to go beyond the static picture, we demonstrate the dynamical formation of a steady-state subsequent to a switch-on of the voltage bias within real-time DMFT. We discuss how the formation of an excitonic condensate depends on steady-state temperature and doped carrier concentration.
[1] L. Ma et al., Nature 598 (2021) 585
[2] M. Xie, A.H. MacDonald, Phys. Rev. Lett. 121 (2018) 067702

TT 69.13 Thu 12:45 H 3025

**Semi-classical analysis of HHG in pseudo-relativistic materials** — •Wolfgang Hogger[1], Vanessa Junk[1], Alexander Riedel[1], Cosimo Gorini[2], Angelika Knothe[1], Juan-Diego Urbina[1], and Klaus Richter[1] — [1]Institute for theoretical physics, University of Regensburg, Germany — [2]Université Paris-Saclay, CEA, CNRS, SPEC, 91191, Gif-sur-Yvette, France

The study of high-order harmonic generation (HHG) in solids by virtue of intense laser pulses provides a fascinating platform to study ultrafast electron dynamics as well as material properties. We theoretically investigate HHG on the basis of massive Dirac Fermions, serving as a prototypical model for topologically non-trivial matter and other systems with pseudo-relativistic dispersion. A successful and intuitive picture for HHG in gases is the three-step model[1], which was also generalized and brought to the realm of semiconductors and 2D materials[2]. We study the emergence of this semi-classical model from a LZS-transfer-matrix method[3] which can account for the characteristic transition dynamics of Dirac Fermions and thus may provide a way to understand the physical mechanism of HHG in these systems.

[1] M. Lewenstein, P. Balcou, M. Y. Ivanov, A. L. Huillier, P. B. Corkum, Phys. Rev. A 49 (1994) 2117
[2] G. Vampa, C. R. Mcdonald, G. Orlando, D. D. Klug, P. B. Corkum, T. Brabec, Phys. Rev. Lett. 113 (2014) 073901
[3] S. N. Shevchenko, S. Ashhab, F. Nori, Phys. Rep. 492 (2010) 1