DY 5: Many-Body Quantum Dynamics 1 (joint session DY/TT)

Time: Monday 10:00–12:45 Location: H20

DY 5.1 Mon 10:00 H20

Squeezed-field path integral method for fermionic superfluid systems — •Dapeng Li — Luruper Chaussee 149, Gebäude 69 22761 Hamburg

We develop a squeezed field path integral method for fermionic superfluid systems including BCS superconductors and unconventional superfluid systems. In this method, the squeezing parameters of the Bogoliubov transformation for fermions become dynamical variables representing bosonic collective excitations on superfluid systems. Using this method, we analyze the spectral function of the single particle excitations for BCS superconductors. We demonstrate that, as a main consequence of the method, a bosonic branch corresponding to the Higgs mode appears as a sideband branch, in addition to the single particle excitation branches obtained from the BCS mean-field approximation. Moreover, we show that our framework can also be applied to low-energy excitations of systems with unconventional orders.

DY 5.2 Mon 10:15 H20

Suppression of inter-band heating for random driving — •Hongzheng Zhao[1,2], Johannes Knolle[2,3,4], Roderich Moessner[1], and Florian Mintert[2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Imperial College London, London, United Kingdom — [3]Technical University of Munich, Munich, Germany — [4]Munich Center for Quantum Science and Technology, Munich, Germany

Heating to high-lying states strongly limits the experimental observation of driving induced non-equilibrium phenomena, particularly when the drive has a broad spectrum. Here we show that, for entire families of structured random drives known as random multipolar drives, particle excitation to higher bands can be well controlled even away from a high-frequency driving regime. This opens a window for observing drive-induced phenomena in a long-lived prethermal regime in the lowest band. Reference: arXiv:2201.08130

DY 5.3 Mon 10:30 H20

Anomalous hydrodynamics and exact quantum scars in frustration-free Hamiltonians — •Jonas Richter and Arijeet Pal — University College London, UK

We study the interplay between quantum scarring and weak Hilbert-space fragmentation in a class of one-dimensional spin-1 frustration-free projector Hamiltonians, known as deformed Motzkin chain. We show that the particular form of the projectors causes the emergence of disjoint Krylov subspaces, with an exact quantum scar being embedded in each subspace, leading to slow growth of entanglement and localized dynamics for specific out-of-equilibrium initial states. Focusing on infinite temperature, we unveil that spin transport is subdiffusive, which we corroborate by simulations of constrained stochastic cellular automaton circuits. Compared to dipole moment conserving systems, the deformed Motzkin chain belongs to a different universality class with distinct dynamical transport exponent and only polynomially many Krylov subspaces. Based on J. Richter and A. Pal, Phys. Rev. Research 4, L012003 (2022).

DY 5.4 Mon 10:45 H20

Influence functional of quantum many-body systems — •Alessio Lerose, Michael Sonner, Julian Thoenniss, and Dmitry Abanin — University of Geneva, Switzerland

Feynman-Vernon influence functional (IF) was originally introduced to describe the effect of a quantum environment on the dynamics of an open quantum system. We apply the IF approach to describe quantum many-body dynamics in isolated spin systems, viewing the system as an environment for its local subsystems. While the IF can be computed exactly only in certain many-body models, it generally satisfies a self-consistency equation, provided the system, or an ensemble of systems, are translationally invariant. We view the IF as a fictitious wavefunction in the temporal domain, and approximate it using matrix-product states (MPS). This approach is efficient provided the temporal entanglement of the IF is sufficiently low. We illustrate the versatility of the IF approach by analyzing several models that exhibit a range of dynamical behaviors, from thermalizing to many-body localized, in both Floquet and Hamiltonian settings. The IF approach offers a new lens on many-body non-equilibrium phenomena, both in ergodic and non-ergodic regimes, connecting the theory of open quantum systems theory to quantum statistical physics.

DY 5.5 Mon 11:00 H20

Transition from localized to uniform scrambling in locally hyperbolic systems — •Mathias Steinhuber, Juan-Diego Urbina, and Klaus Richter — University of Regensburg, Regensburg, Germany

A major signature of Quantum Chaos is the fast scrambling of quantum correlations, quantified by the exponential initial (pre-Ehrenfest time) growth of out-of-time-order correlators (OTOCs) and by their later saturation. As previously shown by [1] and [2], there is a significant difference in the short time dynamics of the OTOCs in integrable systems around hyperbolic fixed points depending on the initial state being localized or uniform (high-temperature). In these cases, the exponential regime is given respectively by twice the instability-exponent 2λ or only once the stability-exponent λ of the hyperbolic fixed point. We show that a local wave-packet can have a clear *dynamical* transition between these two reported exponential-regions within the pre-Ehrenfest-time regime. Thus, the question arises on how to decide, based on the properties of the hyperbolic fixed point which of the two scenarios applies in each particular situation.

1 Hummel, Q., Geiger, B., Urbina, J. D. & Richter, K. Reversible Quantum Information Spreading in Many-Body Systems near Criticality. Phys. Rev. Lett. 123, 160401 (2019).

2 Xu, T., Scaffidi, T. & Cao, X. Does Scrambling Equal Chaos? Phys. Rev. Lett. 124, 140602 (2020).

15 min. break

DY 5.6 Mon 11:30 H20

Optimal route to quantum chaos in the Bose-Hubbard model — Lukas Pausch[1,2], Edoardo Carnio[1,2], Andreas Buchleitner[1,2], and •Alberto Rodríguez[3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [3]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain

The dependence of the chaotic phase of the Bose-Hubbard Hamiltonian [1,2] on particle number N, system size L and particle density is investigated in terms of spectral and eigenstate features. We analyze the development of the chaotic phase as the limit of infinite Hilbert space dimension is approached along different directions, and show that the fastest route to chaos is the path at fixed density $n \lesssim 1$ [3]. The limit $N \to \infty$ at constant L leads to a slower convergence of the chaotic phase towards the random matrix theory benchmarks. In this case, from the distribution of the eigenstate generalized fractal dimensions, the ergodic phase becomes more distinguishable from random matrix theory for larger N, in a similar way as along trajectories at fixed density.

[1] L. Pausch *et al.*, Phys. Rev. Lett. 126, 150601 (2021)
[2] L. Pausch *et al.*, New J. Phys. 23, 123036 (2021)
[3] L. Pausch *et al.*, arxiv:2205.04209

DY 5.7 Mon 11:45 H20

Observation of phase synchronization and alignment during free induction decay of quantum spins with Heisenberg interactions — •Jürgen Schnack[1], Heinz-Jürgen Schmidt[2], Christian Schröder[3], and Patrick Vorndamme[1] — [1]Universität Bielefeld — [2]Universität Osnabrück — [3]Fachhochschule Bielefeld

Equilibration of observables in closed quantum systems that are described by a unitary time evolution is a meanwhile well-established phenomenon apart from a few equally well-established exceptions. Here we report the surprising theoretical observation that integrable as well as non-integrable spin rings with nearest-neighbor or long-range isotropic Heisenberg interaction not only equilibrate but moreover also synchronize the directions of the expectation values of the individual spins (New J. Phys. 23 (2021) 083038). We highlight that this differs from spontaneous synchronization in quantum dissipative systems. In our numerical simulations, we investigate the free induction decay (FID) of an ensemble of up to N = 25 quantum spins with s = 1/2 each by solving the time-dependent Schrödinger equation numerically exactly. Our findings are related to, but not fully explained by conservation laws of the system. The phenomenon very robust against for instance random fluctuations of the Heisenberg couplings. Synchronization is not observed with strong enough symmetry-breaking interactions such as the dipolar interaction and is also not observed in closed-system classical spin dynamics.

DY 5.8 Mon 12:00 H20

Long-lived coherence in driven spin systems: from two to infinite spatial dimensions — •Walter Hahn[1,2,3] and Viatcheslav Dobrovitski[2,4] — [1]Fraunhofer IAF, Fraunhofer Institute for Applied Solid State Physics, Freiburg, Germany — [2]QuTech, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands — [3]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Innsbruck, Austria — [4]Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands

Long-lived coherences, emerging under periodic pulse driving in the disordered ensembles of strongly interacting spins, offer immense advantages for future quantum technologies but the physical origin and the key properties of this phenomenon remain poorly understood. We theoretically investigate this effect in ensembles of different spatial dimensionality, and predict existence of the long-lived coherences in all such systems, from two-dimensional to infinite-dimensional, which are of particular importance for quantum sensing and quantum information processing. We explore the transition from two to infinite dimensions and show that the long-time coherence dynamics in all dimensionalities is qualitatively similar, although the short-time behavior is drastically different exhibiting dimensionality-dependent singularity

DY 5.9 Mon 12:15 H20

A Flow Equation Approach to Many-Body Localisation — •Steven Thomson — Dahlem Centre for Complex Quantum Systems, Freie Universität Berlin

Many-body localisation is a fascinating example of a scenario in which interacting quantum systems isolated from their environments can fail to thermalise, usually due to some form of disorder. Key to our understanding of this enigmatic phase of matter are emergent conserved quantities known as local integrals of motion (LIOMs, or l-bits), which prevent thermalisation from occurring. In this talk, I will present a powerful new numerical method known as the tensor flow equation technique ideally suited for computing LIOMs.

I will demonstrate how this method can be used to compute the integrals of motion in a variety of different systems, including disorder-free potentials and models of spinful fermions. I will show how this method gives an insight into the nature of many-body localisation in these different models, with LIOMs that retain a strong 'fingerprint' of the underlying potential, and will show that in some cases the method can also predict the onset of a delocalised phase. I will end by outlining promising future applications of the method, including to periodically driven and dissipative systems.

DY 5.10 Mon 12:30 H20

Towards a dictionary between JT gravity and periodic orbit theory — •Torsten Weber, Fabian Haneder, Juan-Diego Urbina, and Klaus Richter — University of Regensburg, Germany

Periodic orbit theory is a far reaching development of the semiclassical methods where the most fundamental signatures of the quantum nature of closed systems, like the discreteness of their energy spectrum, emerges from interference between amplitudes constructed from the classical properties of periodic solutions [1]. This conceptual basis, leading to the celebrated Gutzwiller trace formula, has provided impressive achievements from quantum transport to atomic physics and multi-particle scattering. In particular, together with the necessary existence of periodic orbit bunching in ergodic systems, it has lead to an understading of the emergence of universal spectral correlations in chaotic systems, the BGS conjecture [2].
We report our progress in studying how a loss of information (characterized by a coarse graining of classical bunches of orbits) at the level of the trace formula implies the emergence of genus-like expansions with formally the same structure as the solution of JT quantum gravity found in [3]. Our work thus gives convincing hints toward a possible dictionary between quantum-gravitational and periodic orbit objects and concepts.

[1] See e.g. F. Haake, Quantum Signatures of Chaos, Springer, 2000
[3] S. Müller et al., Phys. Rev. E 72, 046207 (2005)
[3] P. Saad, S. Shenker, D. Stanford, arXiv:1903.11115