DY 32: Many-body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)

Time: Wednesday 9:30–12:45 Location: HÜL/S186

DY 32.1 Wed 9:30 HÜL/S186

Compression of Floquet random circuits — •Francesca De Franco[1,2], David Luitz[3], Dante Kennes[4], Matteo Rizzi[1,5], and Markus Schmitt[1,2] — [1]FZ Juelich, Institute of Quantum Control (PGI-8) — [2]University of Regensburg — [3]University of Bonn — [4]RWTH Aachen University — [5]University of Cologne

Current quantum computing hardware suffers from significant dissipation due to the coupling to the environment. This limits the depth of unitary quantum circuits which can be applied with high fidelity and hence the physical timescales reachable by digital quantum simulation. Here, we show that the reachable timescale in practice depends strongly on the physics of the many-body system under investigation: For systems deep in a many-body localized phase, we can find shallow circuit representations of the evolution operator U to late times, while in a chaotic regime this is not possible. The associated compressibility of the late time evolution operator is hence associated with the accessibility of long times on noisy quantum hardware. Moreover, we compare the performance of these compressed, variationally obtained circuits to tensor-network simulations, which allow us to compute quantum-information-spreading diagnostics such as entanglement entropy and out-of-time-ordered correlators.

DY 32.2 Wed 9:45 HÜL/S186

Spectral pairing statistics in Floquet time crystals — Alexander-Georg Penner[1], •Harald Schmid[1,2,3], Leonid I. Glazman[4], and Felix von Oppen[1] — [1]Dahlem Center for Complex Quantum and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [4]Department of Physics, Yale University, New Haven, Connecticut 06520, USA

Floquet time crystals are characterized by the subharmonic behavior of temporal correlation functions. Studying the paradigmatic time crystal based on the disordered Floquet quantum Ising model, we show that its temporal spin correlations are directly related to spectral characteristics and that this relation provides analytical expressions for the correlation function of finite chains, which compare favorably with numerical simulations. Specifically, we show that the disorder-averaged temporal spin correlations are proportional to the Fourier transform of the splitting distribution of the pairs of eigenvalues of the Floquet operator, which differ by pi to exponential accuracy in the chain length. We find that the splittings are well described by a log-normal distribution, implying that the temporal spin correlations are characterized by two parameters. We discuss possible implications for the phase diagram of Floquet time crystals.

DY 32.3 Wed 10:00 HÜL/S186

Spin-Spin Correlations and Multifractality in 1D disordered $SU(2)$-Invariant Heisenberg Spin Chains — •Debasmita Giri, Julian Siegl, and John Schliemann — Institute for Theoretical Physics, University of Regensburg, Regensburg, Germany

Disorder and interactions in one-dimensional quantum spin chains give rise to rich non-ergodic phenomena that lie beyond the conventional eigenstate thermalization hypothesis (ETH). In the presence of sufficiently strong quenched disorder, many-body localization (MBL) can emerge: transport is frozen, entanglement growth is logarithmically slow, and local operators retain memory of their initial conditions even at infinite temperature. On the contrary, studies on models with non-Abelian symmetries have demonstrated that continuous symmetries, such as $SU(2)$, can obstruct the construction of local integrals of motion and thus hinder full localization. We investigate spin correlations in one-dimensional $SU(2)$-invariant Heisenberg chains with exchange disorder for spin lengths $S = 1/2$ and $S = 1$. In the weak-disorder regime, the eigenmodes of the spin-spin correlation matrix are delocalized, consistent with ergodic behavior. Under strong disorder, the system enters a quasi-localized multifractal phase characterized by exponentially decaying, dimer-like spin correlations. Finite-size scaling of the inverse participation ratios of the correlation-matrix eigenmodes yields a correlation dimension, $D_2 \approx 0.37 - 0.39$, confirming the presence of a multifractal regime that is distinct from both the ergodic limit ($D_2 = 1$) and the fully localized limit ($D_2 = 0$).

DY 32.4 Wed 10:15 HÜL/S186

Timescales for Deep and Full Thermalization — •Tabea Herrmann[1], Felix Fritzsch[2], and Arnd Bäcker[1] — [1]TU Dresden, Institut für Theoretische Physik, Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Isolated quantum systems typically approach thermal equilibrium as described by the Eigenstate Thermalization Hypothesis (ETH). Going beyond this involves either higher order correlators (full ETH) or the approach of moments of the reduced density matrix towards thermal equilibrium (deep thermalization). In this talk we compare these two types of thermalization using extensive numerical studies within a paradigmatic model for chaotic many-body quantum dynamics. For this we find exponential relaxation for both types: For deep thermalization all moments relax with the same rate, which approximately equals the relaxation rate of two-point correlation functions within full ETH. In contrast, all higher order correlation functions approach equilibrium twice as fast.

DY 32.5 Wed 10:30 HÜL/S186

Free Cumulants and Full Eigenstate Thermalization from Boundary Scrambling — •Felix Fritzsch, Gabriel O. Alves, Michael A. Rampp, and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Out-of-time-order correlation functions (OTOCs) represent important probes of quantum information dynamics and scrambling. We introduce a solvable many-body quantum circuit model, which we term boundary scrambling, for which the full dynamics of OTOCs is analytically tractable. These dynamics support a decomposition into free cumulants and unify recent extensions of the eigenstate thermalization hypothesis (full ETH) with predictions from random quantum circuit models. We moreover obtain exact expressions for higher-order correlations between matrix elements as predicted by the full ETH. The solvability is enabled by the identification of a higher-order Markovian influence matrix, capturing the effect of the full system on a local subsystem.

DY 32.6 Wed 10:45 HÜL/S186

Mechanism of Eigenstate Thermalization Breakdown — •Rafał Świetek[1,2,3] and Lev Vidmar[2,3] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany — [2]Department of Theoretical Physics, J. Stefan Institute, SI-1000 Ljubljana, Slovenia — [3]Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, SI-1000 Ljubljana, Slovenia

Establishing a common framework for ergodicity-breaking transitions has many potential applications and provides insight into the nature of non-ergodic phases. In this work, we show that the softening of fluctuations within the recently established fading ergodicity framework can be derived directly from the emergence of the Fermi Golden Rule (FGR), ultimately classifying fading ergodicity as manifestation of FGR physics in quantum many-body systems. We show that this framework identifies the width of the local density of states and the fractal nature of eigenstates in the unperturbed basis as building blocks for fading ergodicity. Furthermore, we argue that our theory can be also applied to integrability-breaking transitions, where the critical point drifts exponentially with system size to a singular point, providing a common framework for ergodicity breaking in RMT models and integrability-breaking in local Hamiltonians.

15 min. break

DY 32.7 Wed 11:15 HÜL/S186

Entanglement in bipartite systems with symmetry: coupled chaotic kicked Bose-Hubbard systems — •Jan Himmelsbach[1], Maximilian F.I. Kieler[1,2], and Arnd Bäcker[1] — [1]TU Dresden, Institut für Theoretische Physik, Dresden, Germany — [2]CESAM research unit, University of Liège, B-4000 Liège, Belgium

We study the eigenstate entanglement of a time-periodically driven Bose-Hubbard system in a bipartite setting with a tunable coupling between two subsystems. By incorporating the symmetry of the particle conservation and employing perturbation theory we find that the entanglement transition for varying coupling strength is described by a universal transition parameter. It turns out that the entanglement transition is governed by localization for the particle conservation symmetry and a thermalizing process between the subsystems.

DY 32.8 Wed 11:30 HÜL/S186

Dynamical Pictures for Growth of Entanglement and Decay of Correlators in U(1) Conserving Random Circuits — •Marco Lastres[1,2], Olexei I. Motrunich[3], and Sanjay Moudgalya[1,2] — [1]Technical University of Munich, School of Natural Sciences, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Department of Physics, Caltech, Pasadena, CA, USA

We study the dynamics of random circuit models with a global $U(1)$ charge conservation law. Prior work showed that systems without conservation laws exhibit linear growth of entanglement, linked to domain wall dynamics in an effective ferromagnetic model. In contrast, rigorous upper bounds for $U(1)$-conserving systems indicate that diffusive charge transport constrains Rényi entropies to grow only diffusively as $\sqrt{t}$. We study the second Rényi entropy in $U(1)$-conserving random circuits by mapping its dynamics onto the low-energy physics of an effective interacting Hamiltonian. This approach explicitly demonstrates the microscopic mechanism which produces diffusive growth of entanglement in the effective replica model. We also show that the same effective model naturally captures the recently discovered subexponential decay of non-hydrodynamic correlations through a closely related mechanism. Further, we demonstrate that in a different regime this model can also describe the dynamics of entanglement in noisy free-fermion systems, which also exhibit diffusive entanglement growth, but through a different mechanism. Finally, we discuss extensions to other continuous symmetries and to higher Rényi entropies.

DY 32.9 Wed 11:45 HÜL/S186

Correspondence principle, dissipation, and Ginibre ensemble — •David Villaseñor, Hua Yan, Matic Orel, and Marko Robnik — CAMTP - Center for Applied Mathematics and Theoretical Physics, University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia, European Union

The correspondence between quantum and classical behavior has been essential since the advent of quantum mechanics. This principle serves as a cornerstone for understanding quantum chaos, which has garnered increased attention due to its strong impact in various theoretical and experimental fields. When dissipation is considered, quantum chaos takes concepts from isolated quantum chaos to link classical chaotic motion with spectral correlations of Ginibre ensembles. This correspondence was first identified in periodically kicked systems with damping, but it has been shown to break down in dissipative atom-photon systems [Phys. Rev. Lett. 133, 240404 (2024)]. In this contribution, we revisit the original kicked model and perform a systematic exploration across a broad parameter space, reaching a genuine semiclassical limit. Our results demonstrate that the correspondence principle, as defined through this spectral connection, fails even in this prototypical system. These findings provide conclusive evidence that Ginibre spectral correlations are neither a robust nor a universal diagnostic of dissipative quantum chaos.

DY 32.10 Wed 12:00 HÜL/S186

Quantum Mpemba effect from Stark localization — •Nico Albert[1], Masudul Haque[1], and Shovan Dutta[2] — [1]TU Dresden, Dresden, Germany — [2]Raman Research Institute, Bangalore, India

In the Mpemba effect a system prepared at a higher temperature cools down faster to a target equilibrium state than the same system prepared at a lower temperature. We investigate how quantum effects can influence the occurence of such an effect. As an example we consider a bosonic chain subject to a suitable onsite potential that is dissipatively cooled to its ground state, and find that Stark localization significantly enhances the Mpemba effect compared to analogous classical systems.

DY 32.11 Wed 12:15 HÜL/S186

Robustness of interference-caged QMBS under real-space local perturbations: analysis through the Fock-space local interference pattern — •Tao-Lin Tan[1] and Yi-Ping Huang[1,2,3] — [1]Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan — [2]Physics Division, National Center for Theoretical Sciences, Taipei 10617, Taiwan — [3]Institute of Physics, Academia Sinica, Taipei 115, Taiwan

Quantum many-body scars (QMBS) represent a notable violation of the eigenstate thermalization hypothesis (ETH), hosting non-thermal eigenstates embedded in an otherwise thermal spectrum. Despite recent progress, a systematic understanding of their stability under real-space local (r-local) perturbations remains lacking. Building on recent insights of interference-caged quantum many-body scars (ICQMBS), protected by exact many-body destructive interference on Fock-space graphs, we develop an interference-based diagnostic to assess the robustness of ICQMBS in various lattice Hamiltonians. Applying this framework to quantum link models (QLM) and quantum dimer models (QDM), we analyze how r-local perturbations deform the underlying Fock-space local (f-local) interference structure, thereby identifying heuristic mechanisms that stabilize or destabilize ICQMBS. Our results broaden the applicability of the interference-based perspective beyond previously studied models and provide practical criteria for evaluating the persistence of ICQMBS in experimentally relevant Hamiltonians.

DY 32.12 Wed 12:30 HÜL/S186

Scrambling and Scarring in Topological Materials — •Nicholas Sedlmayr, Dominik Szpara, and Szczepan Głodzik — Institute of Physics, M. Curie-Skłodowska University, 20-031 Lublin, Poland

Topological insulators and superconductors have recently attracted considerable attention, and many different theoretical tools have been used to gain insight into their properties. Here we investigate how perturbations can spread through exemplary one-dimensional topological insulators and superconductors using out-of-time ordered correlators. Out-of-time ordered correlators are often used to consider how information becomes scrambled during quantum dynamics. The wavefront of the out-of-time ordered correlator can be ballistic regardless of the underlying system dynamics, and here we confirm that for topological free fermion systems the wavefront spreads linearly at a characteristic butterfly velocity. We pay special attention to the topologically protected edge states, finding that information can become trapped in the edge states and essentially decoupled from the bulk, surviving for relatively long times - a form of scarring. We further investigate what happens due to the chiral and helical edge modes of two dimensional topological models. The information travels around the edge, carried by the edge mode, but again is not scrambled over very long time scales.