DY 20: Many-body Quantum Dynamics II (joint session DY/TT)

Time: Wednesday 9:30–13:00 Location: H37

DY 20.1 Wed 9:30 H37

The Sound of Entanglement — •Benjamin Orthner[1], Clemens Wenger[5], Johannes Kofler[2], Richard Küng[2], Enar de Dios Rodríguez[3], Martin Ringbauer[4], Alexander Ploier[2], and Philipp Haslinger[1] — [1]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna, Austria — [2]Johannes Kepler University Linz, Austria — [3]Internationale Forschungszentrum Kulturwissenschaften, Kunstuniversität Linz, Austria — [4]University of Innsbruck, Austria — [5]Universität für Musik und darstellende Kunst Graz, Austria

This contribution presents *The Sound of Entanglement*, a project at the intersection of quantum physics, music, and visual art. At its core lies a Bell experiment setup, where polarization-entangled photon pairs are generated through spontaneous parametric down-conversion in a β-BBO crystal. The experiment acts as a quantum conductor, utilizing the quantum correlations between the photons to coordinate and influence the choices of live musicians in real-time, creating a performance guided by principles beyond classical physics.

This work seeks to make these abstract concepts more accessible and engaging to broader audiences by transforming them into tangible, sensory experiences. By combining live music with a dynamic light show, both controlled by the experiment, this project illustrates how advancements in technology, like those shaping the second quantum revolution, can redefine artistic expression and bridge the gap between science and art.

DY 20.2 Wed 9:45 H37

A Solvable Model for Full Eigenstate Thermalization — •Felix Fritzsch and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The Full Eigenstate Thermalization Hypothesis (Full ETH) aims to characterize thermalization in many-body quantum systems in terms of the dynamics of higher-order spatiotemporal correlation functions, going beyond the current standard ETH paradigm. In this talk, we introduce a solvable random matrix model for many-body quantum dynamics in which the asymptotic dynamics of generalized out-of-time-order correlation functions can be exactly obtained in the thermodynamic limit. The dynamics of this model naturally maps to dynamics on the lattice of non-crossing partitions, combinatorial structures underlying the mathematics of Free Probability and Full ETH. We demonstrate how local observables approach asymptotic freeness at late times and explicitly characterize all relevant time scales. We confirm our analytical results with numerical simulations performed directly in the thermodynamic limit.

DY 20.3 Wed 10:00 H37

Scrutinizing the Mori memory function for transport scenarios — •Scott Daniel Linz, Jiaozi Wang, Robin Steinigeweg, and Jochen Gemmer — Department of Mathematics/Computer Science/Physics, University of Osnabrück, D-49076 Osnabrück, Germany

Diffusion is a phenomenological hydrodynamic transport behavior that holds over a wide range of materials. Within condensed matter physics there is the opinion that as long as the area under the current-current correlation function converges in time, one has a criterion for diffusive behavior of the corresponding spatiotemporal density dynamics. Attempts to derive this statement are notoriously challenging. We will first demonstrate that it is possible to construct correlation functions of some local density, where the area under a current-current correlation function converges, but the system is not diffusive. After this is demonstrated, we shall introduce a method based on the recursion method and the Mori memory formalism, that yields insight into whether or not a process is truly diffusive. The only disadvantage of this strategy is that one would have to know the behavior infinitely many Lanczos coefficients, whereas in practice one can only calculate a finite number of them in most cases. In the cases examined in this talk, however, the convergence or lack thereof becomes apparent to the naked eye with the finite amount of coefficients that were calculated.

DY 20.4 Wed 10:15 H37

Long-time Freeness in the Kicked Top — •Elisa Vallini and Silvia Pappalardi — University of Cologne, Köln, Germany

Recent work highlighted the importance of higher-order correlations in quantum dynamics for a deeper understanding of quantum chaos and thermalization. The full Eigenstate Thermalization Hypothesis, the framework encompassing correlations, can be formalized using the language of Free Probability theory. In this context, chaotic dynamics at long times are proposed to lead to free independence or "freeness" of observables. We investigate these issues in a paradigmatic semiclassical model - the kicked top - which exhibits a transition from integrability to chaos. Despite its simplicity, we identify several non-trivial features. By numerically studying 2n-point out-of-time-order correlators, we show that in the fully chaotic regime, long-time freeness is reached exponentially fast. These considerations lead us to introduce a large deviation theory for freeness that enables us to define and analyze the associated time scale. The numerical results confirm the existence of a hierarchy of different time scales, indicating a multifractal approach to freeness in this model. Our findings provide novel insights into the long-time behavior of chaotic dynamics and may have broader implications for the study of many-body quantum dynamics.

DY 20.5 Wed 10:30 H37

Periodically and aperiodically Thue-Morse driven long-range systems: from dynamical localization to slow dynamics — •VATSANA TIWARI — Indian Institute of Science Education and Research Bhopal, Bhopal, India

In this talk, I will discuss the impact of time-periodic and aperiodic field on power-law random banded matrix (PLRBM) model where variation in the power-law exponent yields a delocalization-to-localization phase transition. We investigate the periodically driven PLRBM model with the help of the static measures such as level spacing ratio and generalized inverse participation ratio and report the drive-induced multifractal to localization transition. The transport study of the periodically driven system demonstrates the transition from diffusive to logarithmically slow relaxation at dynamical localization point. Extending our analysis to the aperiodic Thue-Morse driving, we find that specific driving parameters leads to the *exact dynamical localization* in a disordered-free long-range model regardless of the long-range parameter. In the disordered case, the localized phase exhibits a long prethermal plateau followed by diffusion to an infinite temperature state, while the delocalized phase shows immediate diffusion. Additionally, we compare this with a quasi-periodic model that also undergoes a localization-delocalization transition, noting that, unlike the delocalized side of the disordered long-range model, it features a prolonged plateau followed by diffusion to the infinite temperature state.

DY 20.6 Wed 10:45 H37

Symmetry-Resolved Out-of-Time-Order Correlators with Projected Matrix Product Operators — •Martina Gisti, David Luitz, and Maxime Debertolis — Institute of Physics, University of Bonn, Nußallee 12, 53115 Bonn, Germany

Out-of-Time-Order Correlators (OTOCs) are key measures of quantum many-body chaos and information spreading. We systematically analyse OTOCs as a function of particle number for interacting spinless fermions in one dimension. With the concept of generalized operator charge, we develop a formalism for the time evolution of symmetry-projected matrix product operators, which we use to resolve the scrambling behaviour by particle number sector. Our results reveal a crossover from ballistic to diffusive dynamics at early times and a saturation regime at late times.

DY 20.7 Wed 11:00 H37

Revealing ultrafast phonon mediated inter-valley scattering through transient absorption and high harmonic spectroscopies — •Kevin Lively[1], Shunsuke Sato[2,3], Guillermo Albareda[2,4], Angel Rubio[2], and Aaron Kelly[2] — [1]Deutsches Zentrum für Luft- und Raumfahrt — [2]Max Planck Institute for the Structure and Dynamics of Matter — [3]University of Tsukuba — [4]Ideaded

Processes involving ultrafast laser driven electron-phonon dynamics play a fundamental role in the response of quantum systems in a growing number of situations of interest, as evinced by phenomena such as strongly driven phase transitions and light driven engineering of material properties. To show how these processes can be captured from a computational perspective, we simulate the transient absorption spectra and high-harmonic generation signals associated with valley selective excitation and intraband charge-carrier relaxation in monolayer hexagonal boron nitride. We show that the multitrajectory Ehrenfest dynamics approach, implemented in combination with real-time time-dependent density-functional theory and tight-binding models, offers a simple, accurate, and efficient method to study ultrafast electron-phonon coupled phenomena in solids under diverse pump-probe regimes which can be easily incorporated into the majority of real-time ab initio software packages.

15 min. break

DY 20.8 Wed 11:30 H37

Chiral basis for qubits and decay of spin-helix states — •Frank Göhmann — Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, 42097 Wuppertal, Germany

In a recent cold-atom experiment by the Ketterle group at MIT one-dimensional spin-helix states could be prepared and their time evolution induced by the XXZ Hamiltonian could be observed. The experiment allows to adjust the anisotropy parameter of the latter. For the special case of the XX model we describe the spatio-temporal decay of a transversal spin helix explicitly. The helix pattern stays stable in space, but has a non-trivial time-dependent decay amplitude which is of scaling form and is governed by a universal function that can be represented as a semi-infinite determinant related to the discrete Bessel kernel. This representation is valid for all times, is numerically utterly efficient and allows us to obtain the long-time asymptotics of the function. Our work is a rare example of a quench that has been experimentally realized and for which the full time dependence could be calculated exactly.

V. Popkov, X. Zhang, F. Göhmann and A. Klümper, *Chiral basis for qubits and spin helix decay*, Phys. Rev. Lett. **132** (2024) 220404 (5pp)

DY 20.9 Wed 11:45 H37

Towards the chaotic melting at low energies in large systems — •Mathias Steinhuber[1], Jonas Rigo[2], Juan Diego Urbina[1], Klaus Richter[1], and Markus Schmitt[1,2] — [1]University of Regensburg, Regensburg, Germany — [2]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), Jülich, Germany

Thinking in a classical phase space picture, a many-body ground state should be localized around the minimum of the classical mean-field energy landscape with stable integrable features. But here, we investigate many-body ground states on chaotic features, as the phase space picture is actually fragile if we increase the system size and keep the quantum scale (the effective Plank constant $\hbar_{\text{eff}}$) fixed. With the new degrees of freedom, we disturb the energy landscape in the classical limit more and more such that classical chaos is present even for low energies. We show this phenomenon, called 'chaotic melting' [1,2], is indeed happening in the Bose-Hubbard system with disorder. By using neural quantum states we can push quantum calculations for ground states to large systems and find signatures of chaos at the ground state. An intriguing application for these large systems is that the Bose-Hubbard Hamiltonian with disorder is an effective model for transmon arrays which are a prime candidate for quantum computer hardware. Therefore we also gain access to quantum states describing a possible quantum computer with chaotic features.

[1] S.-D. Börner, et al. Phys. Rev. Research 6, 033128 (2024)
[2] J. Chávez-Carlos, et al. arXiv: 2310.17698 (2024)

DY 20.10 Wed 12:00 H37

Period n-tupling in driven two level systems — •Dhruv Deshmukh and Joachim Ankerhold — Institute for complex quantum systems, Ulm University, Germany

This talk presents the necessary and sufficient conditions for realizing period n-tupling phenomena in periodically driven two-level systems. For the specific case of a two-level system driven linearly by a sinusoidal drive, we numerically identify the drive parameters that enable period n-tupling. Experimental results verifying period doubling in an NV centre driven by a microwave drive, are given. Further, we show that period quadrupling drives yield pulses which are much faster than the standard (Rabi) $\pi/2$ and π pulses built from weak drives. These stronger and faster pulses can be utilized for qubit manipulation, enabling faster gates and more efficient pulse sequences. Moreover, they inspire a new strategy for constructing efficient pulses using a Floquet theory approach to optimal control. Furthermore, the drive parameters could also be set to achieve period-1 (stroboscopic) dynamical freezing. The fragility of such phenomena can be exploited for sensing applications, as illustrated with an example in magnetometry.

DY 20.11 Wed 12:15 H37

Efficient computation of cumulant evolution and full counting statistics: application to infinite temperature quantum spin chains — •Angelo Valli[1,2], Cătălin Pascu Moca[2,3], Miklós Antal Werner[1,4], Márton Kormos[1,2], Žiga Krajnik[5], and Tomaž Prosen[6] — [1]Budapest University of Technology and Economics, Muegyetem rkp. 3., 1111 Budapest, Hungary — [2]HUN-REN BME Quantum Dynamics and Correlations Research Group — [3]University of Oradea, 410087, Oradea, Romania — [4]HUN-REN Wigner Research Centre for Physics, P.O. Box 49, 1525 Budapest, Hungary — [5]New York University, 726 Broadway, New York, NY 10003, USA — [6]University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia

We propose a numerical method to efficiently compute quantum generating functions (QGF) for a wide class of observables in one-dimensional quantum systems at high temperature. We obtain high-accuracy estimates for the cumulants and reconstruct full counting statistics from the QGF. We demonstrate its potential on spin S=1/2 anisotropic Heisenberg chain, where we can reach time scales hitherto inaccessible to state-of-the-art classical and quantum simulations. Our results are in excellent agreement with a recent Google Quantum AI experiment [2] and challenge the conjecture of the Kardar-Parisi-Zhang universality for isotropic integrable quantum spin chains.

[1] A. Valli et al. arXiv:2409.14442 (2024)
[2] E. Rozenberg et al. Science 384, 48-53 (2024)

DY 20.12 Wed 12:30 H37

Machine learning approach to study the properties of ground and excited states in the 1D Bose-Hubbard model — •Yilun Gao[1], Alberto Rodríguez González[2,3], and Rudolf A. Römer[1] — [1]Department of Physics, University of Warwick, Coventry, CV4 7AL — [2]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain — [3]Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, E-37008 Salamanca, Spain

Many-body quantum interacting systems continue to play a key role in theoretical developments of modern condensed matter physics. Various numerical techniques have been used to explore the features of these many-body systems. Exact diagonalization methods, which most results going beyond ground state properties are based on, can only deal with small system sizes $L \lesssim 15$ because the Hilbert dimensions grow exponentially in L. Recently, deep learning has emerged as a numerical technique that uses strategies of artificial intelligence to predict the physics of such systems. Here we focus on the Bose-Hubbard chain and use HubbardNet [1] to investigate the physics of ground and excited states. We show that the energies and wavefunctions predicted by HubbardNet agree well with the ones calculated by exact diagonalization over a broad range of interaction strengths. We investigate the properties of the eigenstates via their finite-size generalized fractal dimensions. [1] Ziyan Zhu, et al., HubbardNet: Efficient predictions of the Bose-Hubbard model spectrum with deep neural networks, Phys. Rev. Res., **5**, 043084 (2023)

DY 20.13 Wed 12:45 H37

Entanglement Transitions in Quantum Games through Reinforcement Learning — •Giovanni Cemin[1], Marin Bukov[1], and Markus Schmitt[2,3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]University of Regensburg, Regensburg, Germany — [3]Forschungszentrum Jülich, Institute of Quantum Control, Jülich, Germany

In this research, we investigate the dynamics of entanglement in Cliord circuits by employing a reinforcement learning (RL) algorithm in competition with a random agent. The RL agent is designed to strategically place gates that decrease entanglement, while the random agent aims to increase entanglement. This interaction between the two agents results in an entanglement transition, the nature of which is induced by the level of information accessible by the RL agent. By systematically varying the information provided to the RL agent, we analyze its impact on the transition characteristics. Our findings provide new insights into the interplay between entanglement manipulation and information constraints, shedding light on the fundamental mechanisms governing quantum circuit dynamics.