DY 35: Poster: Quantum Dynamics and Many-body Systems

Time: Wednesday 15:00–18:00 Location: Poster D

DY 35.1 Wed 15:00 Poster D

Krylov Complexity in generic and flat band spinsystems — •Max Pieper, Jannis Eckseler, and Jürgen Schnack — Universität Bielefeld

Krylov Complexity [1] is a measure of the operator growth in quantum many-body-systems. It describes how an initial operator spreads in the Krylov-space under unitary Heisenberg time evolution. The behavior of Krylov complexity has been linked to a difference between integrability and chaos [2]. We are investigating the evolution of the Krylov complexity in generic and flat-band-systems.

[1] Daniel E. Parker et. al. Phys. Rev. X 9, 041017 (2019)

[2] E. Rabinovici et. al. JHEP07(2022)151

DY 35.2 Wed 15:00 Poster D

Impact of noise on localized solutions in the discrete nonlinear Schrödinger equation — •Mahdieh Ebrahimi[1], Wolfram Just[2], and Barbara Drossel[1] — [1]Institute of Condensed Matter Physics, Technical University of Darmstadt, Hochschulstr. 6, 64289 Darmstadt, Germany — [2]Institute of Mathematics, University of Rostock, D-18057 Rostock Germany

The Discrete Nonlinear Schrodinger equation (DNLS) serves as a prominent model across various scientific domains, ranging from physics and chemistry to biology. Within the realm of Hamiltonian systems, the nonlinear Schrodinger equation emerges as a fundamental representation for pattern formation, with a particular focus on examining localized solutions known as breather states. Understanding the underlying processes of the discrete systems is important for many physical phenomena such as excitations in crystal lattices and molecular chains, the light propagation in waveguide arrays, and the dynamics of Bose-condensate droplets. Here, we consider the DNLS as an effective macroscopic equation for a quantum mechanical many-particle system. We explore how localized solutions are affected by adding damping and noise to the Hamiltonian equations of motion.

DY 35.3 Wed 15:00 Poster D

Probing many-body localization via compression of Floquet random circuits — •Francesca De Franco[1,6], David J. Luitz[2], Dante M. Kennes[3,4], Matteo Rizzi[1,5], and Markus Schmitt[1,6] — [1]FZ Jülich, Institute of Quantum Control (PGI-8), Jülich, Germany — [2]University of Bonn, Bonn, Germany — [3]RWTH Aachen University, Aachen, Germany — [4]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [5]University of Cologne, Cologne, Germany — [6]University of Regensburg, Regensburg, Germany

We investigate many-body localization (MBL) in Floquet random circuits and methods for their compression into shallow circuits. In particular, we address the question how the different characteristics of entanglement spreading in the localized and ergodic regimes affect the compressibility of the circuits. Besides serving as a possible probe for localization, compressed Floquet random circuits might open a practical route to observe dynamical signatures of localization in digital quantum simulations on near-term quantum processors.

DY 35.4 Wed 15:00 Poster D

Allosteric impurity effects in long spin chains — •Christian Eidecker-Dunkel and Peter Reimann — Faculty of Physics, Bielefeld University, 33615 Bielefeld, Germany

Allosterism traditionally refers to local changes in an extended object, for instance the binding of a ligand to a macromolecule, leading to a localized response at some other, possibly quite remote position. Here, we show that such fascinating effects may already occur in very simple and common quantum many-body systems, such as an anisotropic Heisenberg spin chain: Introducing an impurity at one end of a sufficiently long chain may lead to quite significant changes of the observable behavior near the other end, but not in the much larger region in between. Specifically, spin autocorrelation functions at thermal equilibrium are found to exhibit a pronounced allosterism of this type.

DY 35.5 Wed 15:00 Poster D

Aspects of the dynamics of the Kagome Heisenberg Antiferromagnet in the one magnon space — •Henrik Schlüter, Jannis Eckseler, and Jürgen Schnack — Bielefeld University. Bielefeld, Germany

We present aspects of the one-magnon dynamics of the antiferromagnetic kagome lattice as an example of flat-band-dynamics, extending the work of [1] to two dimensional systems. We illustrate how localized eigenstates also called localized magnons influence the dynamics of excitations and possibly prevent the system from thermalization.

[1] Florian Johannesmann et al. Phys. Rev. B 108, 064304

DY 35.6 Wed 15:00 Poster D

Probing Many-Body Dynamics in Dense Nitrogen Vacancy Ensembles — •David O'Shea, Soham Pal, Toby Mitchell, and Helena Knowles — University of Cambridge

Dense ensembles of nitrogen-vacancy centres (NVs) in diamond offer a promising platform for investigating the intricate dynamics of disordered, strongly interacting spin systems and the interplay between different thermalizing processes in them. Floquet engineering can then be used to tune the interactions and on site disorder in the sample, allowing for exploration of predicted phenomena such as many-body-localisation and quantum many-body-scars.

The study of many-body phenomena in NV centres holds several advantages like (a) High Fidelity Control: NV centres provide a platform for global control of spins enabling manipulation of spin states and interactions, (b) Scalability: Dense NV ensembles offer a scalable platform for studying large-scale many-body systems, (c) Coupling to different spin baths: NV ensembles can be coupled to other spin baths, enabling exploration of non-equilibrium dynamics in open systems. Our research aims to elucidate the thermalization dynamics of these complex coupled systems by systematically tuning the disorder and dimensionality of the NV ensemble using a state-of-the-art home-build AFM setup integrated in a confocal setup.

DY 35.7 Wed 15:00 Poster D

revealing quantum effects in bosonic Josephson junctions: a multi-configuration atomic coherent state approach — •Yulong Qiao[1] and Frank Grossman[2] — [1]Institute for theoretical physics, TU Dresden, 01062 Dresden, Germany — [2]Institute for theoretical physics, TU Dresden, 01062 Dresden, Germany

The bosonic Josephson junction can be effectively described by a two-site Bose-Hubbard model. Many quantum phenomena in this model result from the dynamic interplay between the particle imbalance and the relative phase between two sites, which are treated as a pair of conjugated variables in mean-field theory. However, some nontrivial quantum effects such as the self-trapping effect and spontaneous symmetry breaking are described incorrectly by mean-field results [1].

We have developed a new variational approach utilizing a set of generalized coherent states to study the non-equilibrium dynamics of the Bose-Hubbard model [2]. Here, we apply this method to the bosonic Josephson junction and demonstrate that quantum effects beyond the mean-field approximation are easily uncovered by only a few basis functions [3]. Specifically, for the case of plasma oscillations, just two basis states already gives a good qualitative agreement with numerically exact quantum solutions. In order to correctly account for macroscopic quantum self-trapping, moderately more basis states are needed.

[1] Y. Qiao and F. Grossmann, Phys. Rev. A 103, 042209 (2021). [2] S. Wimberger, G Manganelli, A Brollo, L Salasnich, Phys. Rev. A 103, 023326 (2021) [3] Y. Qiao and F. Grossmann, Front. in Phys., 11:1221614 (2023)

DY 35.8 Wed 15:00 Poster D

Thermalization of locally perturbed many-body quantum systems — Peter Reimann[1], •Patrick Vorndamme[1], and Lennart Dabelow[2] — [1]Universität Bielefeld — [2]Queen Mary University, London

Deriving conditions under which a macroscopic system thermalizes directly from the underlying quantum many-body dynamics of its microscopic constituents is a long-standing challenge in theoretical physics. The well-known eigenstate thermalization hypothesis (ETH) is presumed to be a key mechanism, but has defied rigorous verification for generic systems thus far. A weaker variant (weak ETH), by contrast, is provably true for a large variety of systems, including even many integrable models, but its implications with respect to the problem of thermalization are still largely unexplored. Here we analytically demonstrate that systems satisfying the weak ETH exhibit thermalization for two very natural classes of far-from-equilibrium initial conditions: the overwhelming majority of all pure states with a preset nonequilibrium expectation value of some given local observable, and the Gibbs states of a Hamiltonian which subsequently is subject to a quantum quench in the form of a sudden change of some local system properties. As numerical example we show our findings for the (integrable) transverse-field Ising model (TFIM).

DY 35.9 Wed 15:00 Poster D

perfect solitary waves in flat band systems — •Jannis Eckseler and Jürgen Schnack — Bielefeld University

Solitary waves appear in many-body systems if the initial state is a superposition of eigenstates of the Hamiltonian and the translation operator which fulfill a generalised linear dispersion relation [1]. In general a system only has approximate solitary waves, due to the finite size and discreteness of the energy spectrum which does not allow for an exact linear dispersion relation. However, in flat band systems, such as the delta-chain, an exact linear dispersion relation can be fulfilled. We investigate such perfect solitary waves in the delta chain and their robustness to small perturbations.

[1] Jürgen Schnack et al. Journal of Magnetism and Magnetic Materials 306 (2006), 79-84

DY 35.10 Wed 15:00 Poster D

Nonequilibrium Green functions simulations of 2D hexagonal monolayers with the G1-G2 scheme — •Tim Kalsberger, Christopher Makait, Jan-Philip Joost, and Michael Bonitz — CAU Kiel, Germany

Since their discovery, 2D quantum materials such as graphene and TMDCs have been of great importance in solid state physics due to their unique properties. However, the numerical treatment of these quantum systems with satisfactory accuracy has been severely limited due to their complexity. Previous methods, for instance, utilize density matrix formalism to describe the behavior of electrons in nonequilibrium conditions [1]. Nonequilibrium Green functions (NEGF) provide an alternative method capable of capturing electronic correlations within the material. However, the scaling of NEGF is highly unfavorable due to its two-time nature. The G1-G2 scheme [2] has facilitated significant improvements in this scaling and was already successfully applied to finite graphene systems [3]. Now, this approach is extended to macroscopic systems and we present first results for the electronic relaxation following optical excitations.

[1] T. Winzer *et al.*, *Nano letters*, 10(12), 4839-4843 (2010)
[2] N. Schlünzen *et al.*, *Phys. Rev. Lett.*, 124, 076601 (2020)
[3] Anna Niggas *et al.*, *Phys. Rev. Lett.*, 129, 086802 (2022)

DY 35.11 Wed 15:00 Poster D

Disorder-Averaged Effective Time Evolution — •Mirco Erpelding[1], Adrian Braemer[1], and Martin Gärttner[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany

In his seminal work, Anderson demonstrated that a disordered quantum system may localize, i.e. escape thermalization, thereby initiating a whole new area of research. More recently, localization has also been studied for quantum many-body systems. Here information is usually gathered via the exact solution of many disorder realizations making the studies computationally very expensive. In this work, we approach this challenge by taking the disorder average first and explore what can be learned from the resulting effective description. Often additional symmetries arise in the average picture: For example while disorder typically breaks spatial symmetries within each shot, most of the time every site/spin experiences the same disorder distribution restoring the symmetry in the averaged time-evolution.

Concretely, we derive an effective Lindbladian for disordered Ising models with independent couplings, such as the Sherrington-Kirkpatrick model. Subsequently, we compare our findings to interacting models sharing the same effective symmetries, aiming for a simplified description.

DY 35.12 Wed 15:00 Poster D

Quantum engineering for compactly localized states in disordered Lieb lattices — Carlo Danieli[1], Jie Lie[2,3], and •Rudolf A. Römer[2,4] — [1]Institute for Complex Systems, CNR, Rome, Italy — [2]School of Physics and Optoelectronics, Xiangtan University, Xiangtan, China — [3]Institute of Mathematics and Physics, Central South University of Forestry and Technology, Changsha, China — [4]Department of Physics, University of Warwick, Coventry, UK

Blending ordering within an uncorrelated disorder potential in families of 3D Lieb lattices preserves the macroscopic degeneracy of compact localized states and yields unconventional combinations of localized and delocalized phases. We proceed to reintroduce translation invariance in the system by further ordering the disorder. We discuss the spectral structure and eigenstates features of the resulting perturbed lattices. We restore order in steps by first (i) rendering the disorder binary, i.e. yielding a randomized checkerboard potential, then (ii) reordering the randomized checkerboard into an ordered one, and at last (iii) realigning all the checkerboard values yielding a constant potential shift, but only on a sub-lattice. Along this path, we test the influence of additional random impurities on the order restoration. We find that in each of these steps, sub-families of states are projected upon the location of the degenerate compact states, while the complementary ones are localized in the perturbed sites with energy determined by the strength of the checkerboard. This highlights order restoration as an experimental pathway to engineer features in disordered lattice structures in the pursuit of quantum storage and memory applications.

DY 35.13 Wed 15:00 Poster D

Non-abelian invariants in periodically-driven quantum rotors — •Volker Karle, Areg Ghazaryan, and Mikhail Lemeshko — Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg

This poster explores the role of topological invariants in the nonequilibrium dynamics of periodically-driven quantum rotors, inspired by experiments on closed-shell diatomic molecules driven by periodic, far-off-resonant laser pulses. This approach uncovers a complex phase space with both localized and delocalized Floquet states. We demonstrate that the localized states are topological in nature, originating from Dirac cones protected by reflection and time-reversal symmetry. These states can be modified through laser strength adjustments, making them observable in current experiments through molecular alignment and observation of rotational level populations. Notably, in scenarios involving higher-order quantum resonances leading to multiple Floquet bands, the topological charges become non-Abelian. This results in the remarkable finding that the exchange of Dirac cones across different bands is non-commutative, enabling non-Abelian braiding, paving the way for the study of controllable multi-band topological physics in gas-phase experiments with small molecules, as well as for classifying dynamical molecular states by their topological invariants.

DY 35.14 Wed 15:00 Poster D

Semiclassical structure of resonance states of the three-disk scattering system — Roland Ketzmerick, Florian Lorenz, and •Jan Robert Schmidt — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

For the paradigmatic three-disk scattering system, the structure of resonance states in the semiclassical limit is investigated. We introduce a classical multifractal measure that describes resonance states with decay rate γ in this limit. This measure (i) maximizes an entropy-like quantity and (ii) is conditionally invariant with the same decay rate γ. It is derived from a local random vector model and replaces previous approximate approaches. This supports the recently proposed factorization conjecture, that resonance states are a product of a classical measure and universal fluctuations [1, 2]. Here, these results are applied to the three-disk scattering system. Furthermore, we confirm the fractal Weyl law, counting the number of states, over an unprecedented large range.

[1] R. Ketzmerick, K. Clauß, F. Fritzsch, and A. Bäcker,
Chaotic resonance modes in dielectric cavities: Product of conditionally invariant measure and universal fluctuations,
Phys. Rev. Lett. **129**, 193901 (2022).

[2] J. R. Schmidt and R. Ketzmerick,
Resonance states of the three-disk scattering system,
arXiv:2308.12783 (2023).

DY 35.15 Wed 15:00 Poster D

Ray-segment scars in the random wave model — •Jakob Lindermeir, Jan Robert Schmidt, and Roland Ketzmerick — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

A new type of scars along ray segments, unrelated to periodic-orbit scars, was recently observed in optical microcavities [1] and in the 3-disk scattering system. We introduce a method for their numerical analysis and apply it, as a first step, to the random wave model. This method involves calculating a new representation of the wave function that distinctly highlights scars. Subsequent steps enable the determination of length, width, and wavenumber of these scars. We compare the result of the numerical analysis to analytical predictions.

[1] R. Ketzmerick, K. Clauß, F. Fritzsch, and A. Bäcker, Chaotic resonance modes in dielectric cavities: Product of conditionally invariant measure and universal fluctuations, Phys. Rev. Lett. **129**, 193901 (2022).

DY 35.16 Wed 15:00 Poster D

Phase-space representations of three-dimensional optical microcavities — •Tom Rodemund[1], Shilong Li[2], Síle Nic Chormaic[3], and Martina Hentschel[1] — [1]Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany — [2]College of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, China — [3]Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan

Analyzing the phase-space of a given dynamical system is a well-established and versatile tool towards their profound understanding. Prominent methods include the Poincaré surface of section for particle dynamics and the Husimi function for their wave counterpart. Often these are two-dimensional (2D) systems that allow for a convenient phase-space representation along a surface of section.

Three-dimensonal (3D) cavities such as bottles or microtoroids are typical samples investigated in mesoscopic optics. They are interesting objects of study, as they may behave qualitatively different to their 2D counterparts, e.g. due to Arnold diffusion. The existence of four phase-space coordinates hinders a compact representation of all their properties [1], making it impossible including all information in a single representation. Here we discuss possibilities and demonstrate how to extend the well-established concept of Husimi functions [2] to 3D optical microcavities of arbitrary shape, thereby focussing on experimentally accessible characterisitcs of 3D resonance modes.

[1] Firmbach et al., *Phys. Rev. E* **98** 022214 (2018)
[2] Hentschel et al., *Europhys. Lett.* **62** 636 (2003)

DY 35.17 Wed 15:00 Poster D

Analytical expressions for stationary solutions of the Lindblad equation — •Bernd Michael Fernengel — HIFMB, Oldenburg

The Lindblad equation is a quantum master equation describing the time evolution of quantum mechanical states. It is used to model open quantum systems. We give an analytical expressions of stationary solutions of the Lindblad equation in the case of a finite state space, using the concept of state transition networks of Markov chains. Our treatment is based on the so-called quantum-jump unravelling, which is an ensembles of stochastic quantum trajectories, compatible with the Lindblad equation. A single such trajectory is a piecewise deterministic process, which is interrupted by stochastic jumps. We discuss differences to the classical case and conditions, under which the Lindblad equation is asymptotically stable.

DY 35.18 Wed 15:00 Poster D

Topological phases in measurement-only quantum circuits and their transitions — •Pugazharasu Anancia Devaneyan[1,2], Michael Buchhold[2], and Kai Klocke[3] — [1]Department of Physics, Rheinische Friedrich-Wilhelms-Universität Bonn, D-53113 Bonn, Germany — [2]Institut für Theoretische Physik, Universität zu Köln, D-50937 Cologne, Germany — [3]Department of Physics, University of California, Berkeley, California 94720, USA

Random quantum circuits serve as a fertile domain for uncovering far from equillibrium phenomena, with measurements providing directionality to dynamics. Recent advances emphasize the utility of statistical mechanics of d-dimensional loop models as a framework for understanding specific classes of measurement-only random quantum circuits in $d+1$ dimensions. This work explores quantum phase transitions between different topological states in measurement-only random circuits, featuring a competition among several classes of non-commuting measurement operators precisely described by a loop model. Numerical simulations of the loop model yield information-theoretic observables entanglement entropy, mutual information, and the entanglement scaling pre-factor discerned from the distribution of loop lengths at the boundary. Our findings reveal a novel topological phase transition between well-defined winding number phases and those with fluctuating winding numbers, intricately linked to the annihilation of Majorana zero modes.

DY 35.19 Wed 15:00 Poster D

Scarred circuits - implementing integer subspaces within digital chaotic quantum dynamics — •Tobias Dörstel and Michael Buchhold — Institut für Theoretische Physik, Universität zu Köln, D-50937 Cologne, Germany

Weak ergodicity breaking describes scenarios where a subpart of the Hilbert space does not thermalise under generic time evolution. In Hamiltonian systems, this corresponds to so-called quantum many-body scar states, which are eigenstates of the Hamiltonian but disobey the eigenstate thermalisation hypothesis. Here, we extend the concept to chaotic quantum circuits by implementing conditioned unitary gates and measurements with feedback. The unitary gates implement the projector-based Shiraishi-Mori construction that leaves the scarred-subspace invariant. Measurements and feedback are designed such that they preserve this subspace and, in addition, guide the dynamics towards the scarred subspace. We study the robustness of the scarred subspace by categorizing the evolution into the scars and their stability against external perturbations. To do so, we combine efficient numerical simulations of so-called conditioned Haar random gates and feedback with analytical arguments.

DY 35.20 Wed 15:00 Poster D

A margin of stability in the propagation of open quantum systems — •Malte Krug and Jürgen Stockburger — Institute for Complex Quantum Systems, Ulm University

The Hierarchical Equations of Motion (HEOM) method has become one of the cornerstones in the simulation of open quantum systems and their dynamics. It is a non-perturbative method, suitable also for strong coupling and sluggish environments with long-time correlations [1]. In spite of the wide range of successful applications of HEOM, there are certain instances where the necessary finite truncation of the hierarchy of auxiliary density operators leads to divergent solutions. We present results on the nature and causes of this type of critical error based on analytic results and numerical experiments [2]. Both the case of pure decoherence, where exact results are available for comparison, and divergences in certain parameter regions of the spin-boson model are investigated. We find that truncating the hierarchy to any finite size can be problematic for strong coupling to a dissipative reservoir, in particular when combined with an appreciable reservoir memory time.

[1] Xu, M., Yan, Y., Shi, Q., Ankerhold, J. and Stockburger, J.T. Taming quantum noise for efficient low temperature simulations of open quantum systems Phys. Rev. Lett. **129**, 230601 (2022). `https://doi.org/10.1103/PhysRevLett.129.230601`.
[2] Krug, M., Stockburger, J. On stability issues of the HEOM method. Eur. Phys. J. Spec. Top. (2023). `https://doi.org/10.1140/epjs/s11734-023-00972-9`.

DY 35.21 Wed 15:00 Poster D

Giant DC Residual Current Generated by Subcycle Laser Pulses — •Adrian Seith, Ferdinand Evers, and Jan Wilhelm — Institute of Theoretical Physics and Regensburg Center for Ultrafast Nanoscopy, University of Regensburg, 93053 Regensburg

On an ultrashort timescale, experimental indications have been reported suggesting that laser pulses can produce currents that survive long after the illumination has died out. Such residual currents (remnants) may have applications in petahertz logical gates. The amplitude of remnants strongly depends on the pulse shape. We develop an analytical formula that allows to optimize the pulse shape; we predict remnants that exceed the values observed so far by orders of magnitude. In fact, remnants can become almost as strong as the peak current under irradiation.

DY 35.22 Wed 15:00 Poster D

Attempts towards a quantum coherent extension of the "macroscopic fluctuation theory": Are there universal fluctuations of quantum coherences in noisy mesoscopic systems? — •Ludwig Hruza — Laboratoire de Physique de l'École Normale Supérieure, Université Paris Cité, 75005 Paris, France

The "macroscopic fluctuation theory" has been major achievement in the understanding of classical non-equilibrium over the past 20 years. Notably, it has been realized that the fluctuation of density and current profiles in classical current-carrying many-body systems with diffusive transport (e.g. a conductor between two reservoirs at different potentials) are non-local and universal, in the sense that they only depend on two system specific constants (the diffusion constant and the mobility) and the "macroscopic fluctuation theory" provides analytic formulae to compute these fluctuations. The question I will explore in this talk, is how one could incorporate quantum coherent effects into such a theory and why this would be an interesting thing to do? While experimentally, the measurement of coherences (and their fluctuations) between two points of a diffusive metallic conductor is still out of reach, the study of an analytically solvable toy model, the so-called QSSEP (Quantum Simple Symmetric Exclusion Principle), has provided us with first ideas for the mathematical structure of such a theory – with surprising connections to the free probability theory. I will also comment on our most recent finding, that the predictions of the QSSEP seems to agree with numerical simulations of the more realistic 3D Anderson model, which emphasizes the importance of QSSEP as a potential paradigmatic toy model in the study of the fluctuation of quantum coherences.

Reference: "Coherent Fluctuations in Noisy Mesoscopic Systems, the Open Quantum SSEP, and Free Probability", Ludwig Hruza and Denis Bernard, Phys. Rev. X 13, 011045, 2023.