FOR 5522 PhD School on Nonergodic Quantum Dynamics

Monday, 23 September 2024 - Friday, 27 September 2024

Faculty of Physics

List of Posters

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A novel method to classify continuous phase transitions in isolated quantum spin systems

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Co-authors: Daniel Rubin [1]; Margeaux Cartier [1]; Gerhard Zürn [1]; Matthias Weidemüller [1]

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Phase transitions play an important role in all branches of physics, from cosmology to the quark-gluon plasma, as they allow to study the structure of different systems. An important subclass are continuous phase transitions, which are usually related to symmetries and critical phenomena, and allow to classify different systems into universality classes. Each class is characterized by a set of critical exponents, which can be obtained for example by exploiting the Kibble-Zurek mechanism (KZM). However, the KZM relies on the ability to prepare the ground state of one phase and measure topological defects in a different phase. For complex and highly correlated magnetic systems, typically it is hard to experimentally prepare the ground state, and the form of the defects is not known. We present a novel technique that overcomes these limitations, possibly for arbitrary quantum spin systems, where the KZM critical exponent can be extracted by preparing a fully spin polarized state and the measurement of global magnetization. Analytically, we show that the method gives the correct KZM exponent for the 1D transverse field nearest-neighbour Ising model, and numerically for the disordered 1D transverse field nearest neighbour Ising model. We will also discuss a possible implementation using a Rydberg quantum simulator for disordered spin systems as realized in our lab.

References:

An internal clock perspective of the dynamics of disordered quantum many body systems

Authors: Ferdinand Evers[1]; Soumya Bera[2]

Co-authors: Ishita Modak [2]; Roderich Moessner [3]

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[2] *Indian Institute of Technology Bombay*

[3] *Max Planck Institute for the Physics of Complex Systems*

Generically isolated quantum many-body systems reach a thermal equilibrium state upon unitary time evolution, which is explained by the Eigenstate thermalization hypothesis. But, when disorder is added to these systems, the dynamics becomes extremely slow. These systems are believed to evade thermalization even after very long time evolution. Our work sheds light on the slow dynamics of these systems from a very different perspective, namely the internal clock perspective. Considering the entanglement entropy as an internal clock, we get an idea about the fate of these disordered systems (simulation done for an XXZ chain) which can not be predicted from the real time simulation. We extend this idea in a disordered floquet model where we study the relaxation dynamics of local (inverse-) temperature. The broad distribution of relaxation time of the local (inverse-) temperature even in the ergodic regime, suggests us a striking similarity of this system with classical glasses which also show an inhomogeneous relaxation dynamics. However, a unified perspective emerges when considering the system's diagonal entropy as an internal clock, revealing an underlying homogeneity in the temperature dynamics for a broad range of disorder strengths.

References:

1) Internal clock of many-body delocalization, Phys. Rev. B 108, 134204, Ferdinand Evers, Ishita Modak, and Soumya Bera. 2) Inhomogeneous Floquet thermalization, Phys. Rev. B 109, 224206, Soumya Bera, Ishita Modak, and Roderich Moessner,

Can prethermal quantum machines beat thermal ones?

Authors: Alberto Brollo[1]; Alvise Bastianello[2]

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[2] *Technical University Munich*

Quantum heat engines operate through quasistatic transformations, and a common assumption is that the working medium is in instantaneous thermal equilibrium. However, several many-body systems offer long-lived prethermal states: can we use them to operate quantum engines with enhanced efficiency? This work considers the quantum Otto cycle, which consists of two adiabatic strokes and two thermalizations with a reservoir. The adiabatic strokes are performed in isolation from the environment, so prethermal systems move along generalized Gibbs states rather than canonical equilibrium states. We provide how to construct prethermal cycles, and we build a comparison with the standard thermal case. We present analytical results on infinitesimal cycles and numerical results on cycles over finite regions in the parameter space. We found temperature as the crucial parameter: the prethermal cycle displays advantage for negative temperature, regardless of the model and the initial data. Negative temperature can be realized in models with bounded energy, like spin chains. Hence, we focused on the integrable XXZ chain displaying prethermal states.

References:

Characterizing the Entanglement of Mixed States in Anyonic Systems

Author: Nico Kirchner[1]

Co-authors: Wonjune Choi [1]; Frank Pollmann [1]

[1] *Technische Universität München*

Entanglement of mixed quantum states can be quantified using the partial transpose and its corresponding entanglement measure, the logarithmic negativity. Recently, the notion of partial transpose has been extended to systems of anyons, which are exotic quasiparticles whose exchange statistics go beyond the bosonic and fermionic case. Studying the fundamental properties of this anyonic partial transpose, we first reveal that when applied to the special case of fermionic systems, it can be reduced to the fermionic partial transpose or its twisted variant depending on whether or not a boundary Majorana fermion is present. Focusing on ground state properties, we find that the anyonic partial transpose captures both the correct entanglement scaling for gapless systems, as predicted by conformal field theory, and the phase transition between a topologically trivial and a nontrivial phase. For non-abelian anyons and the bipartition geometry, we find a rich multiplet structure in the eigenvalues of the partial transpose, the so-called negativity spectrum, and reveal the possibility of defining both a charge- and an imbalance-resolved negativity.

References:

arXiv:2403.12121, Phys. Rev. B 110, 085143 (2024)

Constrained dynamics in synthetic dimensions of ultracold polar molecules

Authors: Emil Reiter[1]; Fabian Heidrich-Meisner[2]; Suman Mondal[3]

[1] *UYST*

[2] *Georg-August-Universität Göttingen*

[3] *UPTP*

In this work, we explore nonequilibrium dynamics in the system of ultracold polar molecules with synthetic dimensions trapped in a 1D optical lattice. In the system, the excitation of rotational states of the molecule plays a role of a particle that can hop along the synthetic dimension, and two nearest neighbor molecules interact when the synthetic distance is one between them. We numerically calculate autocorrelation function and distance between molecules in the synthetic dimension to characterize the dynamical behavior of the system. In the case of strong interactions, the initial states with molecules at the nearest neighbor in the synthetic dimension stay at the nearest neighbor throughout the time evolution. We also find that the system exhibits strong Hilbert space fragmentation in the infinite interaction limit. The goal of the ongoing work is to further investigate dynamics of the system for strong interactions.

References:

Delocalization in a partially disordered interacting many-body system

Authors: Suman Mondal[1]; Fabian Heidrich-Meisner[1]

[1] *Georg-August-Universität Göttingen*

We study a partially disordered one-dimensional system with interacting particles. Concretely, we impose a disorder potential to only every other site, followed by a clean site. Our numerical analysis of eigenstate properties is based on the entanglement entropy. Most importantly, at large disorder, there exist eigenstates with large entanglement entropies and significant correlations between the clean sites. These states have volume-law scaling, embedded into a sea of area-law states, reminiscent of inverted quantum-scar states. These eigenstate features leave fingerprints in the nonequilibrium dynamics even in the large-disorder regime, with a strong initial-state dependence. We demonstrate that certain types of initial charge-density-wave states decay significantly, while others preserve their initial inhomogeneity, the latter being the typical behavior for many-body localized systems.

References:

Phys. Rev. B 109, 125127 (2024)

Dynamical screening in and Floquet theory for X-ray spectroscopies

Author: Eva Paprotzki[1]

Co-authors: Jose Mendez-Guerra [2]; Martin Eckstein [1]

[1] *UHH*

[2] *Temple University*

We develop a Floquet theory tailored for resonant inelastic X-ray scattering (RIXS) and present first results employing our formalism. In particular, there are two effects of a periodic driving: (i) the dipolar light-matter transition can be interpreted as a non-local operator, (ii) elastic-like resonances and orbital excitations in the RIXS signal show different selection rules on the Floquet side-bands.
Second, we investigate signatures of dynamical screening on charge-transfer insulators in X-ray absorption spectroscopy (XAS). One can observe a redshift of the excitonic main peak, as also seen in experiments [1,2], interpreted as Hubbard-band renormalization, and additional screening mode excitations. Their presence and amplitude depends on the nature of the screening (adiabatic to anti-adiabatic) and the lifetime of the final core-hole after absorption. We discuss these phenomena in the case of damped and undamped screening; latter is computed with a new, efficient impurity solver employing a complex-mode decomposition of the hybridization function (the screening propagator).

References:

[1] Lojewski et al., Photo-induced charge-transfer renormalization in NiO, arXiv:2305.10145v2
[2] Baykusheva et al., Ultrafast Renormalization of the On-Site Coulomb Repulsion in a Cuprate Superconductor, PRX 12, 011013

Entanglement dynamics and eigenstate correlations in strongly disordered quantum many-body systems

Authors: Bikram Pain[1]; Sthitadhi Roy[1]

[1] *International Centre for Theoretical Sciences, Bengaluru*

The many-body localised phase of quantum systems is an unusual dynamical phase wherein the system fails to thermalise and yet, entanglement grows unboundedly albeit very slowly in time. We present a microscopic theory of this ultraslow growth of entanglement in terms of dynamical eigenstate correlations of strongly disordered, interacting quantum systems in the many-body localised regime. These correlations involve sets of four or more eigenstates and hence, go beyond correlations involving pairs of eigenstates which are usually studied in the context of eigenstate thermalisation or lack thereof. We consider the minimal case, namely the second Rényi entropy of entanglement, of an initial product state as well as that of the time-evolution operator, wherein the correlations involve quartets of four eigenstates. We identify that the dynamics of the entanglement entropy is dominated by the spectral correlations within certain special quartets of eigenstates. We uncover the spatial structure of these special quartets and the ensuing statistics of the spectral correlations amongst the eigenstates therein, which reveals a hierarchy of timescales or equivalently, energyscales. We show that the hierarchy of these timescales along with their non-trivial distributions conspire to produce the logarithmic in time growth of entanglement, characteristic of the many-body localised regime. The underlying spatial structures in the set of special quartets also provides a microscopic understanding of the spacetime picture of the entanglement growth. The theory therefore provides a much richer perspective on entanglement growth in strongly disordered systems compared to the commonly employed phenomenological approach based on the ℓ-bit picture.

References:

Entanglement phases, localization and multifractality of monitored free fermions in 2D

Authors: Karim Chahine[1]; Michael Buchhold[1]

[1] *University of Cologne*

We investigate the entanglement structure and wave function characteristics of continuously monitored free fermions with $U(1)$-symmetry in 2D. Using exact numerical simulations, we establish the phenomenology of the entanglement transition and explore the similarities and differences with Anderson-type localization transitions. At weak monitoring, we observe characteristic $L\log(L)$ entanglement growth and multifractal dimension $D_q = 2$, resembling a metallic Fermi liquid. At strong monitoring, we find a phase transition into an area law, localized phase and a Poissonian distribution for the entanglement spectrum is seen. In between, we reveal another point in the low-measurement regime with indications of an emergent conformal invariance and strong multifractality. Furthermore, we find another witness of multifractality in the spectral form factor. Our results shape the understanding of a monitoring-induced metal-to-insulator transition in entanglement content. This establishes 2D monitored fermions as a unique platform to explore the connection between non-unitary quantum dynamics in D dimensions and quantum statistical mechanics in $D+1$ dimensions.

References:

K. Chahine, M. Buchhold , "Entanglement phases, localization and multifractality of monitored free fermions in two dimensions", arXiv:2309.12391 (2023)

Entanglement transitions in unitary circuit games with free fermions

Author: Raul Morral Yepes[1]

Co-authors: Adam Smith [2]; Barbara Kraus [1]; Frank Pollmann [1]; Marc Langer [1]

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[2] *University of Nottingham*

In the recently introduced unitary circuit games, a competition between two unitary parties, an "entangler" and a "disentangler," can lead to an entanglement phase transition, with a behavior that differes from measurement-induced transitions. In this work, we study unitary circuit games within the framework of free fermion (matchgate) dynamics. First, we examine the game for braiding dynamics, where gates are selected from the intersection of Clifford and matchgates. In this scenario, we find that the disentangler can always control the growth of entanglement, resulting in no volume law phase except for a disentangling probability $p = 0$. For generic matchgates, we determine that the optimal strategy for disentangling a state is to choose the unitary that minimizes the Rényi-0 entanglement entropy. We propose an algorithm to identify the optimal disentangling unitary based on the state's correlation matrix. Finally, we employ the Rényi-0 disentangler to compete against random matchgate dynamics in the unitary circuit game.

References:

Entanglement-based approaches in studying highly correlated 1D spin systems using DMRG

Authors: Clio Agrapidis[1]; Jędrzej Wardyn[1]; Miłosz Panfil[1]; Satoshi Nishimoto[2]

[1] *Faculty of Physics, University of Warsaw*

[2] *IFW Dresden*

For my poster I would like to show recent works:

First part shows joined work [1] with Clio Agrapidis and Satoshi Nishimoto we investigate the low-energy properties of the dimerized frustrated ferromagnetic (FM) $J_1 - J_1' - J_2$ model with the density

matrix renormalization group method. We show the ground state phase diagram spanned by a wide range of J_1'/J_1 and $J_2/|J_1|$features ferromagnetic phase and valence bond solid (VBS) phases that are continuations from the J_1'/J_1 limits of the model. In the limit J_1'/J_1=1 we recover FM $J_1 - J_2$ model hosting $\mathcal{D}_3$-VBS state where valence bonds form between third-neighbor spins. The other VBS phase named mixed-VBS features both second- and third neighboring spins that continue from the J_1'/J_1=0 limit. We show that both phases feature hidden antiferromagnetic order and twofold degeneracy in the entanglement spectrum characterizing them as Haldane states. Remarkably, we encounter a nontrivial quantum phase transition between two topological VBS states, where at the boundary of phases VBS stability is enhanced.
We discuss results in the context of other spin chain models and edge-sharing cuprate materials.

Second part shows current cooperative work with Miłosz Panfil. We study the q-deformed Majumdar-Ghosh (qMG) [2] model. Beside magnetisation, energy gap or dimer order parameter we look how entanglement observables like von Neumann entropy, entanglement gap, central charge change under the influence of magnetic field. These measurements gave different perspectives on an unique system where commutation relations are broken by design and offer a bridge between: transverse field Ising (integrable model) and Majumdar- Ghosh model (Heisenberg system projected from spin-3/2 to spin 1/2).

For now both models do not have established dynamics, however we intend to look for them later motivated by results from [3] Phys. Rev. B 98, 235156 (2018) and [4] Phys. Rev. B 98, 235155 (2018), where the latter discusses strong ETH hypothesis.

References:

[1] https://doi.org/10.1103/PhysRevB.108.205111
[2] https://doi.org/10.1142/S021797929400155X
[3] https://doi.org/10.1103/PhysRevB.98.235155
[4] https://doi.org/10.1103/PhysRevB.98.235156

Erbium-Lithium: towards a new quantum mixture experiment

Authors: Christian Groß[1]; De Martino Alexandre[1]; Florian Kiesel[1]; Jonas Auch[None]; Kirill Karpov[1]

[1] *University of Tübingen*

In this Erbium-Lithium mixture experiment, we want to realize a quantum gas mixture of erbium and lithium. Remarkably for this mixture is the heavy mass imbalance with a factor of 28, where thermalisation properties will be interesting to observe.

As an additional constrain, we want to trap erbium in a shallow trap at 1064 nm, whereas lithium shall be in a narrow trap at 841 nm, where a tuneout wavelength of erbium is expected.

Besides this thermalisation aspect, the combination of erbium and lithium enables polaron physics, with heavy dopants of erbium in an lithium environment.

Currently, we have loaded erbium and lithium in a dipole trap, whereas the measurement of the tuneout wavelength and the transport of both species into a glass cell are ungoing.

References:

Evidence for simple "arrow of time functions" in closed quantum systems

Author: Merlin Füllgraf[1]

Co-authors: Jiaozi Wang ; Jochen Gemmer

[1] *Universität Osnabrück*

Through an explicit construction, we assign to any infinite temperature autocorrelation function $C(t)$ a function $\alpha^R(t)$, called "arrow of time function". The construction of $\alpha^R(t)$ from $C(t)$ requires the first $2R$ temporal derivatives of $C(t)$ at times 0 and t. For correlation functions of few body observables we numerically observe the following: There is a overall tendency of the $\alpha^R(t)$ to become more monotonously decreasing with increasing R. However, while this tendency may by weak or absent in nonchaotic models, it is rather pronounced in chaotic regimes. The R at which the $\alpha^R(t)$ become essentially monotonous may exceed 100 in nonchaotic models, but we always find this monotonicity at lower two digit R in the chaotic regime. All $\alpha^R(t)$ put upper bounds to the respective autocorrelation functions, i.e. $\alpha^R(t) \geq C^2(t)$. Hence $\alpha^R(t)$ may be interpreted as a distance from equilibrium. Thus the above construction is called an arrow of time since it states that a meaningful distance from equilibrium can (almost) only decrease, a statement similar in spirit to that of the H-theorem. We furthermore argue that finding may to some extend be traced back to the operator growth hypothesis. This argument is laid out in the framework of the so called recursion method.

References:

Fading Ergodicity

Author: Rafał Świętek[1]

[1] *Institute Jozef Stefan*

Eigenstate thermalization hypothesis (ETH) represents a breakthrough in many-body physics since it allows to link thermalization of physical observables with the applicability of random matrix theory (RMT). Recent years were also extremely fruitful in exploring possible counterexamples to thermalization, ranging, among others, from integrability, single-particle chaos, many-body localization, many-body scars, to Hilbert-space fragmentation. In all these cases the conventional ETH is violated. However, it remains elusive how the conventional ETH breaks down when one approaches the boundaries of ergodicity, and whether the range of validity of the conventional ETH coincides with the validity of RMT-like spectral statistics. Here we bridge this gap and we introduce a scenario of the ETH breakdown in many-body quantum systems, dubbed fading ergodicity regime, which establishes a link between the conventional ETH and non-ergodic behavior. We conjecture this scenario to be relevant for the description of finite many-body systems at the boundaries of ergodicity, and we provide numerical and analytical arguments for its validity in the quantum sun model of ergodicity breaking phase transition. For the latter, we provide evidence that the breakdown of the conventional ETH is not associated with the breakdown of the RMT-like spectral statistics.

References:

Fractionalized Prethermalization in the hole doped Hubbard model

Authors: Anton Romen[1]; Johannes Knolle[1]; Michael Knap[1]

[1] *TUM*

Prethermalization phenomena in driven systems are generally understood via a local Floquet Hamiltonian obtained from a high frequency expansion. It turns out that this picture is insufficient for systems with emergent fractionalized excitations. A first example is a driven Kitaev spin liquid which realizes a quasistationary state with vastly different Temperatures of the matter and flux sectors –a phenomenon dubbed fractionalized prethermalization [1]. In our work we argue that similar heating dynamics also occur in driven 1D tJ-models. In the weak doping limit of this model, the electron fractionalizes into quasiparticles carrying charge and spin. We show that the nonequilibrium heating dynamics of this model feature a quasistationary state characterized by a low spin and high charge temperature. We argue that the lifetime of this quasistationary state is determined by two competing processes depending on the specific drive chosen: A Fermi Golden Rule that describes the lifetime of the quasiparticles and the exponential lifetime of a Floquet prethermal plateau. Using a time dependent variant of the Schrieffer-Wolff transformation we systematically analyze the different classes of drives emerging from the respective Hubbard model. Lastly, we discuss potential ways towards an experimental realization in cold atom experiments.

References:

[1] PRL 130, 226701, 2023

Fractonic dynamics in breathing pyrochlore

Author: Gloria Isbrandt[1]

Co-authors: Frank Pollmann [1]; Michael Knap [2]

[1] *TUM*

[2] *Technical University of Munich*

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 a toy model on such a breathing pyrochlore lattice. We show, both by analytical considerations and by numerical simulations based on cellular automaton circuit dynamics, that excitations in this model 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. This model, therefore, offers a potential physically realizable platform for fractonic excitations.

References:

Highly-entangled stationary states from strong symmetries

Authors: Frank Pollmann[1]; Nicholas Read[2]; Pablo Sala[3]; Yahui Li[4]

[1] *Technical University of Munich*

[2] *Yale University*

[3] *California Institute of Technology*

[4] *Technische Universität München*

We find that the presence of strong non-Abelian conserved quantities can lead to highly entangled stationary states even for unital quantum channels. We derive exact expressions for the bipartite logarithmic negativity, Rényi negativities, and operator space entanglement for stationary states restricted to one symmetric subspace, with focus on the trivial subspace. As Abelian examples, we show that strong U(1) symmetries and classical fragmentation lead to separable stationary states in any symmetric subspace. In contrast, for non-Abelian SU(N) symmetries, both logarithmic and Rényi negativities scale logarithmically with system size. We prove that the method apply to open quantum evolutions with a broad class of symmetries.

References:

https://arxiv.org/abs/2406.08567

Imaging dynamics of the confinement transition in a lattice gauge theory

Author: Bernhard Jobst[1]

Co-authors: Abe Asfaw [2]; Adam Gammon-Smith [3]; Eliott Rosenberg [2]; Frank Pollmann [1]; Melissa Will [1]; Michael Knap [1]; Pedram Roushan [2]; Tyler Cochran [2]; Yuri Lensky [2]

[1] *Technical University of Munich*

[2] *Google Quantum AI*

[3] *University of Nottingham*

Lattice models can be employed to understand a wide range of phenomena, from elementary particles in high energy physics to effective descriptions of many-body interactions in materials. In these models, studying the emergent phases and their dynamical properties can be extremely challenging as it requires solving many-body problems that are generally beyond the perturbative limit.Using a 2D lattice of superconducting qubits, we study dynamics of local excitations in a $\mathbb{Z}_2$ lattice gauge theory (LGT). Implementing a simple variational ansatz allows us to design circuits to prepare low-energy quantum states with large overlap with the groundstate of the model via continuous variation of a single parameter. Particles can then be created using local gate operations and their dynamics simulated via a discretized time evolution. As the effective magnetic field strength is increased, measurements show clear signatures of transitioning from a deconfined to a confined phase. In the confined phase, tuning the effective magnetic field induces tension in the string connecting the charge excitations, which we observe with two-time correlation functions. Our LGT implementation on a quantum processor highlights a novel approach for studying dynamics of interacting elementary excitations.

References:

Interacting Quantum Hard Disks

Authors: Fabian Ballar Trigueros[1]; Vighnesh Dattatraya Naik[2]

Co-author: Markus Heyl

[1] *Theoretical Physics III, University of Augsburg*

[2] *GNOI*

The study of quantum matter with extended volume restrictions has revealed intriguing dynamical properties. In our recent investigation, we discovered that the two-dimensional quantum hard disk model exhibits Hilbert space fragmentation and quantum many-body scars. This phenomenon results in non-thermal behavior in the dynamics for specific initial conditions. In this work, we extend this model by introducing next-to-nearest neighbor interactions. We find that although many quantum many-body scars are absent in the interacting case, some persist. Furthermore, initial states with high overlap with these scars still exhibit non-thermal behavior. Other configurations that showed

non-thermal behavior in the interaction-free case display long plateaus before eventually thermalizing. We also present arguments suggesting that even extensive defects can maintain non-thermal behavior in the thermodynamic limit.

References:

V. D. Naik, F. B. Trigueros, and M. Heyl, Quantum hard disks on a lattice (2024), arXiv:2311.16240

Krylov locallization as a probe of ergodicity-breaking

Authors: Heiko Georg Menzler[1]; Rishabh Jha[1]

[1] *Georg-August-Universität Göttingen*

Krylov complexity has recently gained attention where the growth of operator complexity in time is measured in terms of the off-diagonal operator Lanczos coefficients. The operator Lanczos algorithm reduces the problem of complexity growth to a single-particle semi-infinite tight-binding chain (known as the Krylov chain). Employing the phenomenon of Anderson localization, we propose the inverse localization length on the Krylov chain as a probe to detect weak ergodicity-breaking. On the Krylov chain we find delocalization in an ergodic regime, as we show for the SYK model, and localization in case of a weakly ergodicity-broken regime. Considering the dynamics beyond scrambling, we find a collapse across different system sizes at the point of weak ergodicity-breaking leading to a quantitative prediction. We further show universal traits of different operators in the ergodic regime beyond the scrambling dynamics. We test for two settings: (1) the coupled SYK model, and (2) the quantum East model. Our findings open avenues for mapping ergodicity/weak ergodicity-breaking transitions to delocalization/localization phenomenology on the Krylov chain.

References:

https://doi.org/10.48550/arXiv.2403.14384

Lindblad dynamics from spatio-temporal correlation functions in nonintegrable spin-1/2 chains with different boundary conditions

Author: Markus Kraft[1]

Co-authors: Fengping Jin [2]; Hans De Raedt [3]; Jacek Herbrych [4]; Jochen Gemmer [5]; Jonas Richter [6]; Kristel Michielsen [2]; Robin Steinigeweg [5]; Sourav Nandy [7]

[1] *NOVW*

[2] *Forschungszentrum Jülich*

[3] *University of Groningen*

[4] *Wrocław University of Science and Technology*

[5] *University of Osnabrück*

[6] *Stanford University*

[7] *Jožef Stefan Institute*

We investigate the Lindblad equation in the context of boundary-driven magnetization transport in spin-1/2 chains. Our central question is whether the nonequilibrium steady state of the open system, including its buildup in time, can be described on the basis of the dynamics in the closed system. To this end, we rely on a previous study [Heitmann et al., Phys. Rev. B 108, L201119 (2023)],

in which a description in terms of spatio-temporal correlation functions was suggested in the case of weak driving and small system-bath coupling. Because this work focused on integrable systems and periodic boundary conditions, we here extend the analysis in three directions: (1) We consider nonintegrable systems, (2) we take into account open boundary conditions and other bath-coupling geometries, and (3) we provide a comparison to time-evolving block decimation. While we find that nonintegrability plays a minor role, the choice of the specific boundary conditions can be crucial due to potentially nondecaying edge modes. Our large-scale numerical simulations suggest that a description based on closed-system correlation functions is a useful alternative to already existing state-of-the-art approaches.

References:

[1] M. Kraft et al., Phys. Rev. Res. 6, 023251 (2024).
[2] T. Heitmann et al,. Phys. Rev. B 108, L201119 (2023)
[3] T. Heitmann et al., Phys. Rev. E 108, 024102 (2023)

Long-living prethermalization in nearly integrable spin ladders

Authors: Jacek Herbrych[1]; Jakub Pawłowski[1]; Marcin Mierzejewski[1]; Miłosz Panfil[2]

[1] *Wroclaw University of Science and Technology*

[2] *University of Warsaw*

Relaxation rates in nearly integrable systems usually increase quadratically with the strength of the perturbation that breaks integrability. We show that the relaxation rates can be significantly smaller in systems that are integrable along two intersecting lines in the parameter space. In the vicinity of the intersection point, the relaxation rates of certain observables increase with the fourth power of the distance from this point, whereas for other observables one observes standard quadratic dependence on the perturbation. As a result, one obtains exceedingly long-living prethermalization but with a reduced number of the nearly conserved operators. We show also that such a scenario can be realized in spin ladders.

References:

Loss-induced quantum information jet in an infinite temperature Hubbard chain

Author: Patrik Penc[1]

[1] *Budapest University of Technology and Economics*

Information propagation in the one-dimensional infinite temperature Hubbard model with a dissipative particle sink at the end of a semi-infinite chain is studied. In the strongly interacting limit, the two-site mutual information and the operator entanglement entropy exhibit a rich structure with two propagating information fronts and superimposed interference fringes. A classical reversible cellular automaton model quantitatively captures the transport and the slow, classical part of the correlations, but fails to describe the rapidly propagating information jet. The fast quantum jet resembles coherent free particle propagation, with the accompanying long-ranged interference fringes that are exponentially damped by short-ranged spin correlations in the many-body background.

References:

https://arxiv.org/abs/2402.19390

Measurement-induced charge sharpening in 'Bayes non-optimal' U(1) circuits

Author: Sun Woo Kim[1]

Co-authors: Austen Lamacraft [2]; Curt von Keyserlingk [3]

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Ref. [1] introduced measurement-induced charge-sharpening in quantum circuits with qubits undergoing $U(1)$ dynamics alongside 'bath' qudits. Here the charge variance of the density matrix undergoes a (purportedly KT) transition before the entanglement transition. In the $d \to \infty$ limit, the transition can be described by stat-mech model of constrained hard-core walkers.

We show in this limit, the model can be framed as a Bayesian inference on a hidden Markov model, where a 'student' tries to infer state of the 'teacher' given noisy measurements. In this setting a concept of Bayes non-optimality can be invoked, referring to when the parameters (such as signal-to-noise ratio) assumed by the student differs from that of the teacher. The Bayes optimal case corresponds to equal student and teacher's parameters, and to the Born rule. In the spin-glass literature, it is also referred to as the Nishimori line. When the teacher supplies random noise but the student assumes some signal, this corresponds to the 'forced measurement' limit [2]. Measurement-free circuit in the quantum setting corresponds to the student assuming that there is zero information in the measurements.

References:

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Non-Equilibrium Quantum Lakes from Counter-Diabatic Driving

Author: Nik Gjonbalaj[1]

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One paradigmatic route to exploring states of matter in analog quantum simulators is to perform adiabatic parameter sweeps. However, the presence of small gaps along the sweep, either due to unavoidable quantum phase transitions or competing orders, generically poses an obstacle to preparing desired ground states. Recently, it was shown that the slightly non-equilibrium nature of dynamical sweeps can aid in the preparation of finite-size analogs of exotic states of matter (coined quantum puddles or lakes), even in the absence of a ground state with the desired order. Here, we show that going even further out of equilibrium can accelerate the preparation of these quantum lakes. In particular, we utilize insights from counter-diabatic driving to construct specific external drives that enable lake creation along systematically faster parameter sweeps. We give numerical evidence for these claims by simulating the preparation of $\mathbb{Z}_2$ quantum spin lakes both in a deformed toric code model and a model for Rydberg atoms. We conclude by exploring the construction of local Hamiltonians whose quench dynamics take product states to these quantum lakes, potentially eliminating limitations on the sweep rate and further accelerating state preparation.

References:

Polynomially filtered exact diagonalization in quantum many body systems

Author: Rok Pintar[1]

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The polynomially filtered exact diagonalization (POLFED) appeared (2020, Sierant) as an efficient method to extract eigenstates and eigenvalues at the middle of the spectrum for system sizes beyond exact diagonalization. The shift-and-invert method already provided those features but because of the filling-in phenomena can not reach as large system sizes as one would want. POLFED enables us to study ergodicity-breaking transitions in larger system sizes.

References:

https://doi.org/10.1103/PhysRevLett.125.156601

Quantum hard disks on a lattice

Authors: Vighnesh Dattatraya Naik[None]; Fabian Ballar Trigueros[None]

Co-author: Markus Heyl

We formulate a quantum version of the hard-disk problem on lattices, which exhibits a natural realization in systems of Rydberg atoms. We find that quantum hard disks exhibit unique dynamical quantum features. In 1D, the crystal melting process displays ballistic behavior as opposed to classical sub-diffusion. For 2D, crystal structures remain intact against most defects, whereas classically they are washed out completely. We link this peculiar quantum behavior to quantum many-body scars. Our study highlights the potential of constrained 2D quantum matter to display unique dynamical behaviors.

References:

V. D. Naik, F. B. Trigueros, and M. Heyl, Quantum hard disks
on a lattice, arXiv:2311.16240.

Quantum impurity coupled to the SYK bath

Authors: Anastasia Enckell[None]; Stefan Kehrein[None]

We study a non-equilibrium behavior of an impurity connected to the SYK bath. From the Kadanoff-Baym equations for a noninteracting impurity, we see that the only relevant property for the impurity occupation is a combination of hybridisation and density of states of the bath. These parameters can be adjusted in order to model the impurity connected to any bath of interest. Using this approach, we can study the impurity dynamics connected to an SYK bath by making suitable changes to the hybridisation in an impurity plus Fermi bath setting in the thermodynamic limit.

References:

Quantum many-body physics of MWIS-encoding gadgets

Authors: Lisa Bombieri[1]; Zhongda Zeng[1]

Co-authors: Hannes Pichler [1]; Roberto Tricarico [1]; Rui Lin [1]

[1] *University of Innsbruck*

We study the quantum dynamics of the encoding scheme proposed in [Nguyen et al., PRX Quantum 4, 010316 (2023)], which is designed to encode optimization problems on graphs with arbitrary connectivity into Rydberg atom arrays.
Here, a graph vertex is represented by a wire of atoms, and the (crossing) crossing-with-edge gadget is placed at the intersection of two wires to (de)couple the wire degrees of freedom, reproducing the graph connectivity. We consider the exemplified geometry of two wires intersecting via a single gadget and look at minimum gap scaling with system size along annealing protocols. We find that both polynomial and exponential scaling are possible and, by means of perturbation theory, we relate the exponential closure of the minimum gap to an unfavorable localization of the wavefunction. We then experimentally observe the occurrence of such localization and eventually propose possible strategies to circumvent it, leading to an exponential improvement of the annealing performance.

References:

Scaling theory of many-body ergodicity breaking

Author: Rafał Świętek[1]

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Scaling theory of localization in noninteracting systems established validity of one-parameter scaling hypothesis in the entire range from the ergodic to localized states.
It is expected that in the presence of interactions, the many-body ergodicity breaking transition gives rise to the breakdown of the one-parameter scaling.
Here, we argue that the one-parameter scaling hypothesis may still represent the relevant theoretical framework even in many-body systems.
Based on the insights from the quantum sun model of the avalanche theory for many-body ergodicity breaking, we introduce a theoretical framework that interpolates between the one-parameter scaling at the critical point and a nontrivial scaling in the vicinity of the ergodic fixed point.
In the latter, the irrelevant corrections amount to substitute the linear dimension L with $L - L_0$, in which L_0 is finite, and hence supporting the resilient one-parameter scaling at $L \gg L_0$.

References:

Scarred circuits - implementing integer subspaces within digital chaotic quantum dynamics

Author: Tobias Bernhard Dörstel[1]

Co-author: Michael Buchhold [2]

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[2] *University of Cologne*

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.

References:

Scattering theory of chiral edge modes in topological magnon insulators

Author: Stefan Birnkammer[1]

Co-authors: Alexander Mook [2]; Alvise Bastianello [1]; Johannes Knolle [1]; Michael Knap [1]

[1] *Technical University Munich*

[2] *Johannes Gutenberg Universität Mainz*

The well known Quantum Hall effect states that when a finite sample of a conductor is placed in a magnetic field, it develops stable chiral modes strongly localized at the edge. These emergent quasiparticles explore a system of an effective lower dimension: a great deal of attention has been devoted to single-mode properties, but interactions among edge modes are strong and further enhanced by the reduced dimensionality.
In this work, using a coupled array of interacting one-dimensional spin chains as a paradigmatic example, we characterize the scattering properties of edge modes. We numerically show that two edge modes do not scatter into the bulk but remain safely localized at the edge. Resonance with bulk modes can, however, heavily affect interactions and renormalize the scattering length. Our work is the first step towards a formulation of an effective truly many-body theory of chiral edge modes.

References:

Search For Quantum Many-Body Scars in Anyon-Models

Author: Ludwig Zweng[1]

Co-authors: Nico Kirchner [1]; Frank Pollmann [1]

[1] *Technical University of Munich*

Hilbert spaces of chains of non-Abelian anyons are constrained by their fusion rules. These constraints may restrict the dynamics and lead to nontrivial thermalization behavior for such systems. As an examplary anyonic model with restricted thermalization, we suggest a one dimensional Fibonacci anyonic chain where the topological charges can perform braid moves around each other. We identify subspaces in the fusion space of this model which are left invariant by certain braid moves and by fine-tuning an additional magnetic field, we find various dynamically disconnected sectors. These sectors stem from the destructive interference of different braid processes and we expect that this model displays weak Hilbert space fragmentation. Moreover, we show that in global

quenches certain initial states do not evolve to thermal states but display fidelity revivals up to late times.

References:

Space-time correlations in monitored kinetically constrained discrete-time quantum dynamics

Author: Marcel Cech[None]

State of the art quantum simulators permit local temporal control of interactions and midcircuit readout. These capabilities pave the way towards the exploration of intriguing non-equilibrium phenomena. We illustrate this by discussing a dissipative many-body model with kinetic constraints, which can for example be implemented on Rydberg quantum simulation platforms. The dynamics, which proceeds in discrete time, is generated by repeatedly entangling the system with an auxiliary environment that is measured and reset after each time-step. Despite featuring an uncorrelated infinite temperature average stationary state, the dynamics features a transition between a trivial a non-trivial phase. The latter is characterized by the coexistence of fast and slow space-time regions in stochastic realizations of the system state. The recorded measurements on the environment serve as natural probe of this transition, which we characterize using tools from large deviation theory. Our work establishes the large deviation framework for discrete-time open many-body systems as a means to characterize complex dynamical processes and collective phenomena in quantum processors and simulators.

References:

Temporal Entanglement Profiles in Dual-Unitary Clifford Circuits with Measurements

Authors: Jiangtian Yao[1]; Pieter Claeys[1]

[1] *MPI-PKS*

We study temporal entanglement in dual-unitary Clifford circuits with probabilistic measurements preserving spatial unitarity. We exactly characterize the temporal entanglement barrier in the measurement-free regime, exhibiting ballistic growth and decay and a volume-law peak. In the presence of measurements, we show that the initial ballistic growth of temporal entanglement with bath size is modified to diffusive, which can be understood through a mapping to a persistent random walk model. The peak value of the temporal entanglement barrier exhibits volume-law scaling for all measurement rates. Additionally, measurements modify the ballistic decay to the "perfect dephaser limit" with vanishing temporal entanglement to an exponential decay, which we describe through a spatial transfer matrix method. The spatial dynamics is shown to be described by a non-Hermitian hopping model, exhibiting a PT-breaking transition at a critical measurement rate p=1/2.

References:

https://arxiv.org/abs/2404.14374

Thouless time in a spin-1/2 XX ladder

Authors: Fabian Heidrich-Meisner[1]; Kadir Çeven[1]

[1] *Georg-August-Universität Göttingen*

In this study, we try to calculate the Thouless time by analyzing the spectral form factor, survival probability, and diffusion constant within the context of a spin-$1/2$ XX ladder model. We employ numerical methods to compare the Thouless time extracted from these different observables. However, our preliminary results indicate inconsistencies between the methods, prompting concerns about the consistency and reliability of the extracted Thouless time. We examine potential sources of these inconsistencies, including finite-size effects, numerical precision, and the choice of parameters. This ongoing investigation aims to distinguish whether the possible discrepancies are intrinsic to the model or arise from methodological limitations, ultimately contributing to a more accurate characterization of the time scales in closed quantum systems.

References:

Ultracold bosons in 2D quasicrystalline and Aubry-Andre systems

Authors: Bo Song[1]; David Gröters[2]; Emmanuel Gottlob[3]; Lee Reeve[3]; Qijun Wu[3]; Ulrich Schneider[3]; Zhuoxian Ou[3]

[1] *Peking University*

[2] *University of Cambridge –> MPQ*

[3] *University of Cambridge*

Ultracold atoms in optical lattices provide an ideal medium for studies of interacting lattice physics, thanks to their flexible, clean and widely tuneable nature. As such, applying this medium to the investigation of quasiperiodic systems, and the rich physics associated with them, presents a promising avenue to probing a range of physical phenomena, not least those related to localization. This poster presents an overview on our recent experiments studying such systems, in which we load ultracold bosons to both an eight-fold rotationally symmetric 2D optical quasicrystal, and a 2D Aubry-Andre lattice, observing signatures of superfluid, Bose glass, and Mott insulator phases and mapping out phase diagrams of both systems with variable interaction strength. We furthermore study the dynamics in the quasicrystal, looking into both sudden quenches between the superfluid and Bose glass regimes and discuss how the results relate to the underlying system and localization phenomena.
*European Union (ERC), EPSRC, EPSRC hub on Quantum Computing and Simulation

References:

Universal dynamics in disordered two-dimensional systems: semi-classical approach

Author: Łukasz Iwanek[1]

Co-authors: Adam Sajna [2]; Anatoli Polkovnikov [3]; Dries Sels [4]; Marcin Mierzejewski [2]

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[2] *Wroclaw University of Science and Technology*

[3] *Boston University*

[4] *New York University*

Understanding and predicting the temporal evolution of quantum systems is essential for the development of theoretical physics and modern quantum technologies. A significant group of models that have been intensively researched in recent years are non-ergodic systems of interacting particles. They open the way to future technological solutions such as quantum memories. In the relaxation process, these systems do not strive for thermal states, which means that the initial quantum information encoded in the initial conditions is not lost. Attempts to understand the physical mechanisms responsible for the above-mentioned anomalous quantum dynamics constitute an important research goal in the theory of non-equilibrium processes. They are extensively studied in condensed matter and high energy physics. Such systems have an experimental implementation on the so-called cold atoms on optical lattices [1-2]. Their great advantage is that they can be easily applied to various geometries. For this purpose, a semiclassical description of time evolution within the Wigner-Weyl representation will be used [3]. In my poster, I will demonstrate that a single-trajectory version of the fermionic truncated Wigner approximation (fTWA) gives unexpectedly accurate results for the dynamics of one-dimensional (1D) systems with moderate or strong disorders. At the same time, the computational complexity of calculations carried out within this approximation is small enough to enable studies of two-dimensional (2D) systems larger than standard fTWA. Using this method, we discuss the dynamics of interacting spinless fermions propagating on disordered 1D and 2D lattices. We find for both spatial dimensions that the imbalance exhibits a universal dependence on the rescaled time, where the time-scale follows a stretched-exponential dependence on the disorder strength.

References:

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[2] P. Bordia, H. Luschen, S. Scherg, S. Gopalakrishnan nad M. Knap, U. Schneider, and I. Bloch, Physical Review X,7 (2017)
[3] A. Polkovnikov, Annals of Physics 325, 1790 (2010)

What can we learn from time-dependent spectral functions?

Author: Salvatore R. Manmana[1]

[1] *UPTP*

The nonequilibrium dynamics of quantum many-body systems is a fascinating topic hosting a rich phenomenology. Going out of equilibrium, transient states can be realized, which are hard to obtain at equilibrium. One important tool for the investigation of such transient states is to examine the time evolution of spectral properties, like time-dependent band structures, single-electron spectral functions, or local densities of states. For example, periodically driven systems possess so-called Floquet side bands, and the band structure can be modified by the periodic driving such as to realize interesting states of matter, like topological phases ('Floquet engineering'). In this poster, I show some examples for the nonequilibrium dynamics of spectral properties of strongly correlated quantum systems when performing a global quantum quench [1], periodic driving [2], and a local perturbation [3].

References:

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[3] T. Blum, R.M. Noack, and SRM, Time evolution of the local density of states of strongly correlated fermions coupled to a nanoprobe, arXiv:2407.15609