Nonequilibrium Physics – Current Trends and Future Perspectives

793. WE-Heraeus-Seminar

28 August - 01 September 2023

at the Physikzentrum Bad Honnef, Germany

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 793. WE-Heraeus-Seminar:

The main focus of this WE-Heraeus Seminar will be on the question of how the characteristic dynamical and statistical properties of macroscopically large as well as relatively "small" systems can be deduced and understood from first principles, i.e., directly from the basic microscopic laws of physics. Within this general context, particular emphasis will be laid on the following three major current research directions.

- Firstly, there is the long-standing problem whether and how isolated many-body systems approach thermal equilibrium.
- Secondly, for small (sub-)systems the question emerges how to describe random fluctuations in an adequate manner, and how to utilize them deliberately.
- Thirdly, many-body systems driven out of equilibrium by time-periodic forcing may adopt unusual nonequilibrium steady states; the challenge is to "engineer" such states with specific, often topologically motivated properties.

The objective of this WE-Heraeus Seminar is to bring together leading experts with complementary views on these fundamental questions from a variety of different disciplines, such as statistical physics, solid state physics, mathematical stochastics, numerical computing, and quantum information theory.

This seminar has grown out of the scientific activities of the research group FOR 2692.

Scientific Organizers:

Prof. Dr. Martin Holthaus — Universität Oldenburg, Germany
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Prof. Dr. Peter Reimann — Universität Bielefeld, Germany
E-mail: reimann@physik.uni-bielefeld.de

Introduction

Administrative Organization:

Dr. Stefan Jorda
Elisabeth Nowotka

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Registration:

Elisabeth Nowotka (WE Heraeus Foundation)
at the Physikzentrum, reception office
Sunday (17:00 h – 21:00 h) and Monday morning

Program

Program

Sunday, 27 August 2023

17:00 – 20:00	Registration
18:00	*BUFFET SUPPER and informal get-together*

Monday, 28 August 2023

08:00	*BREAKFAST*	
08:45 – 09:00	Scientific organizers	**Welcome words**
09:00 – 09:50	Masahito Ueda	**Eigenstate thermalization hypothesis: locality and range of interactions**
09:50 – 10:40	Michael Kastner	**Equilibration timescales of isolated quantum systems: the role of locality**
10:40 – 11:10	*COFFEE BREAK*	
11:10 – 11:40	Karen Hovhannisyan	**Long-time equilibration can determine transient thermality**
11:40 – 12:10	Jiaozi Wang	**Impact of decoherence on the route to equilibrium**
12:10 – 12:40	Cornelia Vogel	**Canonical typicality for other ensembles than micro-canonical**
12:40	*LUNCH*	

Program

Monday, 28 August 2023

14:10 – 15:00	Tony Short	**Equilibration in discrete time**
15:00 – 15:50	Lev Vidmar	**Scale invariant quantum dynamics at eigenstate transitions**
15:50 – 16:20	Christopher Wächtler	**Topological synchronization of classical and quantum systems**
16:20 – 16:50	*COFFEE BREAK*	
16:50 – 17:05	Stefan Jorda	**About the WE-Heraeus-Foundation**
17:05 – 17:55	Roland Ketzmerick	**Structure of resonance states in open chaotic systems**
17:55 – 18:45	Sebastian Eggert	**Resonances in many-body Floquet systems**
18:45	*DINNER*	

Program

Tuesday, 29 August 2023

08:00	*BREAKFAST*	
09:00 – 09:50	Roderich Moessner	**Dynamical fractal and anomalous noise in a clean magnetic crystal**
09:50 – 10:40	Fabian Essler	**Statistics of matrix elements in integrable models**
10:40 – 11:10	*COFFEE BREAK*	
11:10 – 11:40	Christian Eidecker-Dunkel	**Allosteric impurity effects in long spin chains**
11:40 – 12:10	Roopayan Ghosh	**Relaxation of imbalance in a disordered XX model with on-site dephasing**
12:10 – 12:40	Dominik Weis	**Understanding intrinsic ratchets microscopically and phenomenologically**
12:40	*LUNCH*	
14:10 – 16:00	**Poster flash**	
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 18:30	**Poster session**	
18:30	*DINNER*	

Program

Wednesday, 30 August 2023

08:00	*BREAKFAST*	
09:00 – 09:50	Lennart Dabelow	**Stalled response near thermal equilibrium in periodically driven systems**
09:50 – 10:40	Jesko Sirker	**Many-body localization?**
10:40 – 11:10	*COFFEE BREAK*	
11:10 – 12:00	Keiji Saito	**Information propagation and thermalization in bosonic systems**
12:00 – 12:30	Maximilian Prüfer	**Squeezing oscillations and information extraction in one-dimensional BECs**
12:30 – 12:40	**Conference Photo** (in the front of the lecture hall)	
12:40	*LUNCH*	
14:00	**Excursion** *(planned is an optional walking tour of either about 2 or 3.5 hours duration plus a coffee break of about 1 hour)*	
18:30	*HERAEUS DINNER* *(social event with cold & warm buffet with complimentary drinks)*	

Program

Thursday, 31 August 2023

08:00	*BREAKFAST*	
09:00 – 09:50	Konrad Viebahn	**Many-body Floquet engineering with optical lattices**
09:50 – 10:40	André Eckardt	**Floquet engineering of open quantum systems**
10:40 – 11:10	*COFFEE BREAK*	
11:10 – 11:40	Karel Proesmans	**Precision-dissipation trade-off for driven stochastic systems**
11:40 – 12:10	Hans Keßler	**From a continuous to a discrete time crystal in a driven atom-cavity system**
12:10 – 12:40	Krzysztof Ptaszyński	**System-bath entanglement in nonequilibrium fermionic systems**
12:40	*LUNCH*	

Program

Thursday, 31 August 2023

14:10 – 15:00	Jorge Kurchan	**Eigenstate thermalization, quantum designs and free probability**
15:00 – 15:50	Takashi Mori	**Liouvillian gap analysis in the weak dissipation limit**
15:50 – 16:20	Dirk Schuricht	**Long-lived circulating currents in strongly correlated nanorings**
16:20 – 16:50	*COFFEE BREAK*	
16:50 – 17:40	Markus Schmitt	**Simulating non-equlibrium dynamics of Rydberg atom arrays**
17:40 -18:30	Alvaro Alhambra	**The law of large numbers in quantum non-equilibrium dynamics**
18:30	*DINNER*	

Program

Friday, 01 September 2023

08:00	*BREAKFAST*	
09:00 – 09:50	Artur Widera	**Quantum-engine cycles in ultracold gases**
09:50 – 10:40	Luca Asteria	**Real space studies of ultracold atomic systems out of equilibrium with quantum gas magnification**
10:40 – 11:10	*COFFEE BREAK*	
11:10 – 11:40	Jonas Glatthard	**Lamb shift, potential renormalisation and mean-force Gibbs state: to shift or not to shift?**
11:40– 12:10	Zahra Shomali	**Thermal investigation of newly proposed field effect transistors using non-equilibrium Monte Carlo simulation of phonon Boltzmann equation**
12:10 – 12:40	Ryotaro Suzuki	**Quantum complexity phase transitions in monitored random circuits**
12:40 – 12:50	Scientific organizers	**Closing words**
12:50	*LUNCH*	

End of the seminar and departure

NO DINNER for participants leaving on Saturday; however, a self-service breakfast will be provided on Saturday morning

Posters

Posters

Alexander Antonov Philipp Maass	**Soliton-mediated transport in periodic structures**
Mirko Daumann Thomas Dahm	**Interacting flat band systems: anomalous transport and prethermalization**
Francesca De Franco	**Out-of-equilibrium finite-size scaling in generalized Kibble-Zurek protocols crossing quantum phase transitions in the presence of symmetry-breaking perturbations**
Jannis Eckseler	**Unitary non-ergodic dynamics of the quantum spin delta chain**
Merlin Füllgraf	**Novel techniques to improve the results of DMRG-X**
Jan Mathis Giesen	**Low frequency resonances in periodically driven magnon systems**
Fengping Jin	**Quantum annealing: Sampling efficiency for 2-SAT problems with multiple solutions**
Wladislaw Krinitsin	**Quantum many-body dynamics in two dimensions using tree tensor networks**
Jia Grace Lu	**Weyl semimetal integrated 3-unit polarimeters**
George Moethrath	**Universal conductance fluctuations and phase-coherent transport in GeTe nanowires**
Madhumita Sarkar	**Manipulating exciton binding by floquet engineering in Fermi Hubbard ladder**
Jürgen Schnack	**Non-equilibration and synchronization in isotropic Heisenberg models**
Kunal Vyas	**Investigating various possibilities to solve the Fermi-Hubbard model using the kinetic energy part for quantum annealing**

Abstracts of Talks

(in alphabetical order)

The law of large numbers in quantum non-equilibrium dynamics

J. Riddell[1] Nathan Pagliaroli[2], and A.M. Alhambra[3]

[1]University of Nottingham – UK
[2]University of Western Ontario, London, Canada
[3] Instituto de Fisica Teorica UAM/CSIC

We explain the various ways in which elementary results in probability theory, and in particular statements about concentration around the mean, become useful when study many-body quantum dynamics. First, we will explain how the energy distribution of many-body systems concentrates around the mean in a normal fashion, and how this impacts dynamics. Then, we will show how the dynamics of generic quantum systems concentrate around their “average” equilibrium value when measuring at arbitrary times. This means that the probability of finding such values away from that equilibrium is exponentially suppressed, with a decay rate given by the effective dimension.

References

[1] J. Riddell, N. Pagliaroli, A.M. Alhambra , arXiv:2206.07541 [quant-ph]

[2] Hartmann, M., Mahler, G. & Hess, O. Gaussian Quantum Fluctuations in Interacting Many Particle Systems. Letters in Mathematical Physics 68, 103–112 (2004).

Real space studies of ultracold atomic systems out of equilibrium with quantum gas magnification

Luca Asteria[1,2], Henrik P. Zahn[1], Marcel N. Kosch[1,2], Vijay Singh[2,3], Lukas Freystatzki[2,3], Ludwig Mathey[1,2,3], Klaus Sengstock[1,2,3], Christof Weitenberg[1,2]

[1]Institute for Laserphysics, Hamburg, Germany

[2] The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

[3]Center for optical quantum technologies, Hamburg, Germany

In this talk I will present results obtained using quantum gas magnification as a microscopy tool for ultracold atoms in optical lattices.

We developed a matter wave optics protocol which magnifies the atomic density distribution by almost two orders of magnitude [1], allowing to image the magnified cloud in a single-shot and with sub-lattice resolution by using standard optical imaging techniques. Importantly, this approach works in regimes where high-resolution real-space access with conventional techniques is not possible, namely 3D systems with many particles per lattice site.

This technique allows direct access to thermodynamic quantities like the temperature of the cloud in the lattice but also to prepare states out of equilibrium with magnetic resonance techniques for local addressing of individual lattice sites.

I will report on the observation of a novel phenomenon, namely the spontaneous formation a density wave which breaks the symmetry of the lattice, which appears when introducing a strong force into the system in the regime of many particles per lattice site [2]. Single-particle tunneling becomes here an off-resonant process, leaving the correlated tunneling of pairs of atoms the relevant dynamical process. This density wave can be directly seen via quantum gas magnification.

Finally, I will report on a novel method for generating optical lattices with dynamically tunable geometry [3]. I will report on experimental results where the geometry parameter is varied as a function of time and discuss generalization of this scheme to 3D non-separable optical lattices and quasicrystal lattices.

References

[1] L. Asteria et al., **Nature** 599, 571–575 (2021)
[2] H. P. Zahn et al., **PRX** 12, 021014 (2022)
[3] M. N. Kosch et al., **PRR 4,** 043083 (2022)

Stalled response near thermal equilibrium in periodically driven systems

L. Dabelow

RIKEN Center for Emergent Matter Science, Wako, Saitama 351-0198, Japan

We consider isolated many-body quantum systems which either start out far from equilibrium and then thermalize or find themselves near thermal equilibrium from the outset. How does the observable behavior change in response to time-periodic perturbations of moderate strength in the sense that they do not heat up the system too quickly? Our main discovery consists in the astonishing phenomenon of stalled response: While the driving usually causes quite considerable reactions for systems far from thermal equilibrium, its effects become extremely weak whenever the unperturbed system is close to thermal equilibrium. Numerical results are complemented by a quantitatively accurate analytical description and by simple heuristic arguments.

Floquet engineering of open quantum systems

André Eckardt

TU Berlin, Institut für Theoretische Physik, Berlin, Germany

Open Floquet systems, for instance periodically driven quantum systems in contact with a thermal bath, approach non-equilibrium (quasi) steady states (NESS), having a periodic time dependence. Different from equilibrium states of non-driven systems, which depend on the environment only via its temperature, these NESS depend on the details of the environment and how it couples to the system. This offers the opportunities to engineering the properties of a system by controlling the interplay between driving and dissipation. I will present two examples of our recent work, where this approach is employed for the design of schemes for the robust preparation and stabilization of target states. The first one concerns the driving-induced non-equilibrium Bose condensation in a scar-like Floquet mode at high bath temperatures [1]. The second example is about generalizing the idea of reservoir engineering, as it has been employed successfully for cooling systems of superconducting circuits, for the preparation of effective ground states of Floquet systems [2].

References

[1] A. Schnell. L.-N. Wu, A. Widera, A. Eckardt, *Floquet heating induced Bose condensation in a scar-like mode of an open driven optical-lattice system*, Phys. Rev. A **107**, L021301 (2023).

[2] F. Petiziol, A. Eckardt, *Cavity-Based Reservoir Engineering for Floquet-Engineered Superconducting Circuits*, Phys. Rev. Lett. **129**, 233601 (2022).

Resonances in many-body Floquet systems

Sebastian Eggert

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67663 Kaiserslautern, Germany

Time periodic driving has proven to be a useful tool for Floquet engineering artificial gauge fields and new phases of matter. However, the description of driven strongly interacting systems with resonances remains a challenge. As we show here, analytical progress can be made using a Floquet-Bogoliubov rotation to obtain the Floquet eigenstates exactly and predict resonance behavior in a number of different strongly correlated systems with time periodic driving, such as the Lieb-Liniger model, spin-chains, long-range interacting magnons, and interacting bose condensates. We also discuss possible numerical approaches, which still pose a number of open problems.

Allosteric impurity effects in long spin chains

C. Eidecker-Dunkel[1] and P. Reimann[1]

[1]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, which causes 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.

Statistics of matrix elements in integrable models

Fabian Essler

University of Oxford, Rudolf Peierls Centre for Theoretical Physics, Oxford, UK

I consider the statistics of matrix elements of local operators in the basis of energy eigenstates in a paradigmatic integrable many-particle quantum theory, the Lieb-Liniger model of bosons with repulsive delta-function interaction. Using methods of quantum integrability I determine the scaling of matrix elements with system size. As a consequence of the extensive number of conservation laws the structure of matrix elements is fundamentally different from, and much more intricate than, the predictions of the eigenstate thermalization hypothesis for generic models. I report an interesting connection between this structure for local operators in interacting integrable models, and the one for local operators that are not local with respect to the elementary excitations in free theories.

Relaxation of imbalance in a disordered XX model with on-site dephasing

R. Ghosh[1] and M Žnidarič[2]

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[2] Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, SI-1000 Ljubljana, Slovenia

The relaxation of observables to their nonequilibrium steady states in a disordered XX chain subjected to dephasing at every site has been intensely studied in recent years. We comprehensively analyze the relaxation of staggered magnetization, i.e., imbalance, in such a system, starting from the Néel initial state. We analytically predict emergence of several timescales in the system and extract results which match with large-system numerics without any extra fitting parameter until a universal timescale. An often reported stretched exponential decay is just one of the regimes which holds in a finite window of time and is therefore in fact not a true stretched exponential decay. Subsequently, the asymptotic decay of imbalance is governed by a power law irrespective of the disorder. We show that this emerges from the continuum limit of the low magnitude eigenspectrum of the Liouvillian. However, for finite systems, due to discreteness of the spectrum, the final phase of relaxation is governed by the relevant smallest Liouvillian gap

References

[1] R Ghosh, M Žnidarič, Physical Review B **107**, 184303 (2023).

Lamb Shift, Potential Renormalisation and Mean-force Gibbs State: to Shift or Not to Shift?

L. A. Correa[1,2] and J. Glatthard[2]

[1]Universidad de La Laguna, Spain
[2] University of Exeter, Exeter, UK

An open system, even if coupled weakly to a bath, can experience a non-negligible potential renormalisation, quantified by the 'reorganisation energy'. Often, the microscopic system–bath coupling gives rise to a counter term which adds to the bare Hamiltonian, exactly compensating for such potential distortion. On the other hand, when describing quantum dissipative dynamics with weak-coupling master equations, a number of 'Lamb-shift terms' appear which cannot, in general, be neglected. And yet, the practice of vanishing both the counter term and Lamb-shift contributions is almost universal; and, surprisingly, it gives excellent results. In this paper[1] we justify this practice in the 'adiabatic' limit using careful perturbation theory and illustrate the advantages of this procedure on the example of the damped quantum harmonic oscillator. We show that it yields an excellent approximation to the exact steady state and long-time dynamics. Those steps succeed at building the asymptotic mean-force Gibbs state—or rather, its classical limit—into the master equation. This noticeably increases its accuracy, especially at moderate-to-low temperatures and even up to intermediate coupling. More generally, this master equation succeed at predicting the steady state of arbitrary open systems at high enough temperature. In the adiabatic limit, they also capture the transient oscillation frequency. We thus shed light on an overlooked issue that becomes critical in the calculation of heat currents in quantum thermodynamics.

References

[1] L. A. Correa and J. Glatthard, arXiv preprint arXiv:2305.08941 (2023)

Long-time equilibration can determine transient thermality

K. V. Hovhannisyan[1], S. Nemati[1], C. Henkel[1], and J. Anders[1,2]

[1]University of Potsdam, Institute of Physics and Astronomy, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany

[2] Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, UK

When two initially thermal many-body systems start interacting strongly, their transient states quickly become non-Gibbsian, even if the systems eventually equilibrate. To see beyond this apparent lack of structure during the transient regime, we use a refined notion of thermality, which we call g-local. A system is g-locally thermal if the states of all its small subsystems are marginals of global thermal states. We numerically demonstrate for two harmonic lattices that whenever the total system equilibrates in the long run, each lattice remains g-locally thermal at all times, including the transient regime. This is true even when the lattices have long-range interactions within them. In all cases, we find that the equilibrium is described by the generalized Gibbs ensemble, with 3D lattices requiring special treatment due to their extended set of conserved charges. We compare our findings with the well-known two-temperature model. While its standard form is not valid beyond weak coupling, we show that at strong coupling it can be partially salvaged by adopting the concept of a g-local temperature.

Equilibration timescales of isolated quantum systems: the role of locality

Daniel Nickelsen[1] and Michael Kastner[2,3]

[1]Rechnerorientierte Statistik und Datenanalyse, Universität Augsburg, Germany
[2] Department of Physics, Stellenbosch University, South Africa
[3] Hanse-Wissenschaftskolleg, Delmenhost, Germany

Equilibration is one of the key concepts in thermodynamics, and there is a long-standing interest in deriving, or at least justifying, equilibration from an underlying microscopic theory. Over the past two decades, conditions under which a sufficiently complex isolated quantum system approaches equilibrium have been firmly established. However, in order to explain why equilibration is so ubiquitously observed in nature, one needs to show not only that equilibration takes place, but also that it happens on a physically realistic timescale, neither too long for equilibrium ever to be attained, nor too short for the equilibration process to be observed. Locality is believed to be an important ingredient for predicting physically realistic timescales. In this talk, I study equilibration of an isolated quantum system by mapping it onto a network of classical oscillators in Hilbert space. By choosing a suitable basis for this mapping, the degree of locality of the quantum system reflects in the sparseness of the network. I present a Lieb-Robinson bound on the speed of propagation across the classical network, from which an estimate of the equilibration time of the quantum system is obtained. The more local the Hamiltonian and observables, the longer the equilibration timescale predicted by the bound. The results are confirmed by exact diagonalisation for small systems, where estimated equilibration times are not only found to lower-bound the numerically obtained equilibration times, but also to qualitatively capture their functional dependencies.

References

[1] D. Nickelsen and M. Kastner, *Classical Lieb-Robinson bound for estimating equilibration timescales of isolated quantum systems*, Phys. Rev. Lett. **122**, 180602 (2019).

[2] D. Nickelsen and M. Kastner, *Modelling equilibration of local many-body quantum systems by random graph ensembles*, Quantum **4**, 273 (2020).

From a continuous to a discrete time crystal in a driven atom-cavity system

H. Keßler[1], P. Kongkhambut[1], J. Skulte[1], L. Mathey[1,2], J. G. Cosme[3], and A. Hemmerich[1,2]

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[2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany
[3]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines

We are experimentally exploring the non-equilibrium physics of a strongly coupled atom-cavity system pumped with a transversal standing wave light field. The unique feature of our system, is the small field decay rate of the cavity, which is comparable to the recoil frequency for the rubidium atoms. As a consequence of the recoil resolution, the cavity-mediated infinite-range interaction acquires a relevant degree of retardation, which leads to a qualitatively unique dynamical character. For pump light blue-detuned with respect to the atomic resonance, we observed a limit cycles phase, which is characterised by periodic oscillations of the intracavity photon number, while the atomic density cycling through recurring pattern [1]. Since the system is pumped time independent the time phase of the oscillations takes random values between 0 and 2π, as expected for a spontaneously broken continuous symmetry. If we modulate the pump strength periodically in time with a frequency close to twice the intrinsic limit cycle frequency, the system's response locks to the sub-harmonic of the drive and the time phase of the oscillation pins to one of the two values 0 or π, as for a discrete time crystalline phase [2,3].

References

[1] P. Kongkhambut, J. Skulte, L. Mathey, J. G. Cosme, A. Hemmerich, and H. Keßler,
Observation of a continuous time crystal,**Science 377**, 6606 (2022)

[2] H. Keßler, J. G. Cosme, C. Georges, L. Mathey, ans A. Hemmerich,
From a continuous to a discrete time crystal in a dissipative atom-cavity system, **New J. Phys. 22** 085002

[3] P. Kongkhambut, J. Skulte, L. Mathey, J. G. Cosme, A. Hemmerich, and H. Keßler,
Seeding a time crystalline phase (manuscript in preparation)

Structure of resonance states in open chaotic systems

R. Ketzmerick[1]

[1]*TU Dresden, Institut für Theoretische Physik, Dresden, Germany*

Quantum systems that are open due to the escape of particles or probability are described by resonance states. The structure of the resonance states in real space and phase space is very different from closed quantum systems, even in the simple setting of a system where the underlying classical dynamics is fully chaotic.

We conjecture that resonance states can be described by a product of a multifractal pattern of classical origin and universal, exponentially distributed fluctuations. This is demonstrated numerically by resonance states with unprecedented small wave lengths, i.e. far in the semiclassical limit. We study paradigmatic examples of quantum chaotic scattering, like the 3-disk scattering system [1], optical microcavities [2], and time-periodically kicked open systems [3]. The multifractal factor is determined quantum mechanically by averaging resonance states with similar lifetime and is compared to a conditionally-invariant measure with this lifetime from classical dynamics [4, 5]. A new type of scarring along ray segments dominates every resonance state in the semiclassical limit. It is unrelated to periodic-orbit scarring and has been overlooked for 30 years.

References

[1] J.R. Schmidt and R. Ketzmerick, to be published

[2] R. Ketzmerick, K. Clauß, F. Fritzsch, and A. Bäcker, Phys. Rev. Lett. **129**, 193901 (2022)

[3] K. Clauß, F. Kunzmann, A. Bäcker, and R. Ketzmerick, Phys. E **103**, 042204 (2021)

[4] K. Clauß, E.G. Altmann, A. Bäcker, and R. Ketzmerick, Phys. Rev. E **100**, 052205 (2019)

[5] K. Clauß, M.J. Körber, A. Bäcker, and R. Ketzmerick, Phys. Rev. Lett. **121**, 074101 (2018)

Eigenstate thermalization, quantum designs and free probability

Jorge Kurchan

Ecole Normale Superieure, lpens, Paris, France

The Eigenstate Thermalization Hypothesis needs to be completed to take into account higher correlators, for example to compute out of time order operators (OTOCs). Once this is done, a Pandora's box of contributions is opened. As it turns out, the instrument for organizing this has been around for a few decades: it is the technique of Free Probability. Once Free Probability is taken on board, one finds an immediate connection with Spherical Designs, a construction of a set of unitary matrices that can be taken as a proxy for the whole unitary group, a subject that has attracted considerable interest in quantum information.

Dynamical fractal and anomalous noise in a clean magnetic crystal

R. Moessner

MPI-PKS Dresden

Fractals -- objects with non-integer dimensions -- occur in manifold settings and length scales in nature, ranging from snowflakes and lightning strikes to natural coastlines. Much effort has been expended to generate fractals for use in many-body physics. Here, we identify an emergent dynamical fractal in a disorder-free, stoichiometric three-dimensional magnetic crystal in thermodynamic equilibrium. The phenomenon is born from constraints on the dynamics of the magnetic monopole excitations in spin ice, which restrict them to move on the fractal. This observation explains the anomalous exponent found in magnetic noise experiments in the spin ice compound Dy2Ti2O7, and it resolves a long-standing puzzle about its rapidly diverging relaxation time. The capacity of spin ice to exhibit such striking phenomena holds promise of further surprising discoveries in the cooperative dynamics of even simple topological many-body systems.

References

[1] J. Hallen, S. Grigera, A. Tennant, C. Castelnovo, R. Moessner, Science 378, 1218 (2022)

Liouvillian gap analysis in the weak dissipation limit

T. Mori

Riken Center for Emergent Matter Science, Japan

Recent experimental advance in cold-atomic physics enables us to implement well-controlled dissipation in quantum many-body systems. It is therefore a fascinating problem to explore generic phenomena arising from the interplay between interactions in many-body systems and dissipation.

Theoretically, the time evolution of a Markovian open quantum system is generated by the Liouvillian of the Lindblad form, whose spectral properties (e.g., the relation between the spectral gap and the relaxation time [1-4]) have been intensively studied up to now. In this talk, I focus on the spectral gap of the Liouvillian (the Liouvillian gap) *in the weak dissipation limit*. I argue that the Liouvillian gap under a weak bulk dissipation often exhibits a singularity in the thermodynamic limit, which is closely related with the irreversible relaxation that is observed in the chaotic quantum many-body system completely isolated from the environment.

References

[1] M. Žnidarič, Phys. Rev. E **92**, 042143 (2015)
[2] T. Mori and T. Shirai, Phys. Rev. Lett. **125**, 230604 (2020)
[3] T. Haga, M. Nakagawa, R. Hamazaki, and M. Ueda, Phys. Rev. Lett. **127**, 070402 (2021)
[4] T. Mori and T. Shirai, Phys. Rev. Lett. **130**, 230404 (2023)

Precision-dissipation trade-off for driven stochastic systems

K. Proesmans

Copenhagen University, Copenhagen, Denmark

In this talk, I will discuss how precisely a meso-scaled stochastic system can follow a pre-defined trajectory, while keeping its dissipation below a fixed limit. In the high-precision limit, the total dissipation is inversely proportional to the expected deviation from the pre-defined trajectory. I will also discuss several general properties for the optimal protocol and show how it can be applied to bit-erasure and to electronic networks

References

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Squeezing Oscillations and information extraction in one-dimensional BECs

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The key ingredient for studying the dynamics of quantum many-body systems is the ability to prepare and manipulate quantum states and eventually perform an efficient readout of the available information. In this talk, I present our experimental studies using one-dimensional Bose-Einstein condensates on an atomchip combined with spatially resolved measurements.

We prepare quantum-correlated states of two tunnel-coupled superfluids and track the dynamical evolution of the relative atom number squeezing [1]. The observed dynamics are governed by the interplay of on-site interactions and tunneling; we show further how to drive the tunneling actively by exciting transversal dynamics. Utilizing the control over the dynamics, we prepare optimized spin-squeezed states prolonging the phase coherence of the system.

We present our first experimental results concerning the implementation of weak probes for the simultaneous readout of number imbalance and phase to study mean-field dynamics and quantum correlations in this system with previously inaccessible observables.

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System-bath entanglement in nonequilibrium fermionic systems

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System-bath entanglement is often believed to be related to the strong system-environment coupling. Based on the Born approximation, it has been argued that it is absent in weak coupling regime, when the reduced dynamics of the system is Markovian. Here we demonstrate, instead, that entanglement between a fermionic impurity and the reservoir can be generated for an arbitrarily weak system-bath coupling when the system is driven out of equilibrium. First, we show the presence of a transient system-environment entanglement during a relaxation of a fermionic impurity to the thermal state [1]. This entanglement vanishes at long times, but is preserved at timescales comparable to the relaxation time. Its magnitude depends only weakly on the system-bath coupling but instead strongly on the purity of the initial state of the system. Secondly, we demonstrate the presence of steady state entanglement in voltage-driven fermionic junctions above a certain threshold voltage [2]. The magnitude on this entanglement is maximized for a high particle-hole and tunnel coupling symmetry of the system. Our work thus demonstrates the potential of nonequilibrium dynamics for generation and preservation of genuine quantum correlations.

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Information propagation and thermalization in bosonic systems

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The speed limit of information propagation is one of the most fundamental features in non-equilibrium physics. The region of information propagation by finite-time dynamics is approximately restricted inside the effective light cone that is formulated by the Lieb-Robinson bound. To date, extensive studies have been conducted to identify the shape of effective light cones in most experimentally relevant many-body systems. However, the Lieb-Robinson bound in the interacting boson systems, one of the most ubiquitous quantum systems in nature, has remained a critical open problem. This study reveals an optimal light cone to limit the information propagation in interacting bosons, where the shape of the effective light cone depends on the spatial dimension. To achieve it, we prove that the speed for bosons to clump together is finite, which in turn leads to the error guarantee of the boson number truncation at each site.

With the information propagation, thermalization under the periodic driving is also considered. We discuss several interesting properties arising from the bosonic nature of particles.

Simulating non-equlibrium dynamics of Rydberg atom arrays

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Experiments with Rydberg atom arrays open up new possibilities to investigate two-dimensional interacting quantum systems away from equilibrium and call for us to push also numerical simulations in this regime. In a first part, I will discuss how combining the time-dependent variational principle with two families of ansatz for the variational wave function — artificial neural networks and tree tensor networks — allows us to overcome some of the current limitations. As an application I will address quantum phase transition dynamics and the fate of initially prepared domain walls in two spatial dimensions of a model that is experimentally realized in Rydberg quantum simulators.

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Long-lived circulating currents in strongly correlated nanorings

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We study the time-evolving currents flowing in an interacting ring-shaped nanostructure after a bias voltage has been switched on. The source-to-drain current exhibits the expected relaxation towards its quasistatic equilibrium value at a rate Γ_0 reflecting the lead-induced broadening of the ring states. In contrast, the current circulating within the ring decays with a different rate Γ, which is a rapidly decaying function of the interaction strength and thus can take values orders of magnitude below Γ_0. This implies the existence of a regime in which the nanostructure is far from equilibrium even though the transmitted current is already stationary. We discuss experimental setups to observe the long-lived ring transients.

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Thermal investigation of newly proposed field effect transistors using non-equilibrium Monte Carlo simulation of phonon Boltzmann equation

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In nano-electronics, the overall reliability is determined by the temperature of the hottest zone on the die. Hence, the selection of materials and also the heat spreader design, as a thermal management solution for managing the temperature of the spots known as hotspots, are proposed. Beside the attempts to find the proper methods for heat removal, finding the low-dimensional silicon replacement candidates, with the lowest maximum temperature, is the most proper and perfect choice for the nano-electronics industry. Accordingly, the transistor with a lower maximum temperature can be easier kept under the threshold temperature. Consequently, it is necessary to study the thermal behavior of the electrically-efficient FETs, to make sure that they also present energy efficiency for better cooling and operation. In this research, first, the formalism for investigation of thermal behavior in common 3-D silicon transistors is developed [1,2]. The non-Fourier thermal attitudes are studied using the non-equilibrium Monte-Carlo simulation of the phonon Boltzmann equation. Then, the formalism is used to study well-known two- dimensional replacements for silicon channels such as graphene, blue phosphorene, germanene, silicene, MoS_2 [3] and recently, the two-dimensional complex MA_2Z_4 structures. Specifically, two materials of $MoSi_2N_4$ and WSi_2N_4 due to their proper electrical and thermal characteristics are investigated. Our calculations establish that $MoSi_2N_4$ and WSi_2N_4 present lower peak temperature rise. In fact, the phonon analysis shows that the competition between the dominant heat carrier velocity, and its related frequency determines the maximum temperature value. Particularly, the material WSi_2N_4 with much more phonons in TA mode, with almost high velocity and relatively low-frequency, has adequate thermal condition, and its peak temperature is very low [4].

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Equilibration in discrete time

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It has been shown that a small quantum system interacting with a large environment will equilibrate under very general conditions, reaching a static equilibrium state and remaining close to it for the vast majority of the time [1,2]. Similar results can be shown for closed quantum systems with realistic measurement capabilities [3]. Here we extend these results from continuous time-evolution to discrete time-evolution, such as may arise in a quantum cellular automaton [4], or if space and time are fundamentally discrete at the Planck scale. An interesting aspect of this scenario is that it includes classical reversible cellular automata as a special case, highlighting key differences between classical and quantum equilibration. We will also briefly discuss some problems with thermalization in discrete time, due to energies essentially lying on a circle rather than a line.

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Many-body Localization?

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I will consider the question whether or not the spin-1/2 Heisenberg chain with quenched disorder has a many-body localized phase. While this question appeared to have been settled in many publications in the years 2006-2019 in favour of such a phase, it has become clear since then that the interpretation offered in these papers is false. There is no numerical evidence for localization in this model. I will discuss, in particular, evidence for slow ongoing magnetization transport even at strong disorder based on the symmetry-resolved entanglement entropy and, if time permits, will also discuss very recent results on operator growth in this model.

Quantum complexity phase transitions in monitored random circuits

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Recently, the dynamics of quantum systems that involve both unitary evolution and quantum measurements have attracted attention due to the exotic phenomenon of measurement-induced phase transitions[1,2]. The latter refers to a sudden change in a property of a state of n qubits, such as its entanglement entropy, depending on the rate at which individual qubits are measured. At the same time, quantum complexity emerged as a key quantity for the identification of complex behaviour in quantum many-body dynamics[3]. In this work, we investigate the dynamics of the quantum state complexity in monitored random circuits, where n qubits evolve according to a random unitary circuit and are individually measured with a fixed probability at each time step. We find that the evolution of the exact quantum state complexity undergoes a phase transition when changing the measurement rate. Below a critical measurement rate, the complexity grows at least linearly in time until saturating to a value exponential in n. Above, the complexity does not exceed $\mathrm{poly}(n)$. In our proof, we make use of percolation theory to find paths along which an exponentially long quantum computation can be run below the critical rate, and to identify events where the state complexity is reset to zero above the critical rate. We lower bound the exact state complexity in the former regime using recently developed techniques from algebraic geometry[4]. Our results combine quantum complexity growth, phase transitions, and computation with measurements to help understand the behavior of monitored random circuits and to make progress towards determining the computational power of measurements in many-body systems.

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Eigenstate thermalization hypothesis: locality and rage of interactions

Masahito Ueda

I will discuss the eigenstate thermalization hypothesis (ETH) on the basis of locality of observables and the range of interactions. First, we verify that the ETH holds universally for locally interacting quantum many-body systems. By introducing random matrix ensembles with interactions, we demonstrate that an overwhelming majority of pairs of local Hamiltonians and observables satisfy the ETH with exponentially small fluctuations. Second, we test the strong ETH for systems with power-law interactions ~ 1/r^α. We numerically demonstrate that the strong ETH typically holds, at least for systems with $\alpha \geq 0.6$, which include Coulomb, monopole-dipole, and dipole-dipole interactions. We find that Srednicki's ansatz breaks down for $\alpha \lesssim 1.0$, at least for relatively large system sizes. Finally, we identify rigorous upper and lower bounds on the m-body observables such that all m-body operators with $m < m^*$ satisfy the ETH in fully chaotic systems. Thermalization of typical systems for any few-body operators is thus rigorously proved.

Scale invariant quantum dynamics at eigenstate transitions

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Quantum phase transition in highly-excited Hamiltonian eigenstates (shortly, eigenstate transitions) can be seen as a generalization of ground-state quantum phase transitions. They are often characterized by an abrupt change of certain wavefunction properties such as participation ratios or entanglement entropies.

It is particularly important to establish tools for their characterization in time domain. We argue that a scaled survival probability, where time is measured in units of a typical Heisenberg time, exhibits a scale invariant behavior at eigenstate transitions [1]. We first demonstrate this property in two paradigmatic quadratic models, the one-dimensional Aubry-Andre model and three-dimensional Anderson model. Surprisingly, we then show that similar phenomenology emerges in the interacting avalanche model of ergodicity breaking phase transitions [2]. This establishes an intriguing similarity between localization transition in quadratic systems and ergodicity breaking phase transition in interacting systems.

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Many-body Floquet engineering with optical lattices

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Periodic 'Floquet' driving constitutes a ubiquitous method in the quest of designing functional quantum matter. In this talk I will present recent experimental progress in realising novel Floquet driving techniques with strongly interacting ultracold atoms in optical lattices. On the one hand, we investigate two fast drives with frequencies ω and 2ω. This combination of Floquet drives allows for two-path quantum interference within the Floquet spectrum, enabling several interesting phenomena, such as suppression of unwanted heating in driven many-body systems [1], as well as topological pumping in a simple sine-lattice [2]. On the other hand, we study topological pumping in the Fermi-Hubbard regime. Here, the adiabatic modulation of system parameters can be regarded as the 'slow drive' limit of periodic Floquet driving, in which the topological pump represents a bulk quantum Hall effect. Interestingly, we find that topological pumping remains robust against weak and moderate Hubbard interactions, while the pump breaks down for strong interactions [4]. By leveraging the long coherence time of our quantised Hall drifts within confining potentials, we demonstrate the emergence of topological edge modes. These edge states give rise to novel reflection phenomena at non-interacting and interacting topological boundaries [5].

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Canonical Typicality For Other Ensembles Than Micro-Canonical

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Canonical typicality is the known fact in quantum statistical mechanics that for most wave functions ψ from the unit sphere in a high-dimensional subspace $\mathcal{H}_R$ (such as a micro-canonical subspace) of the Hilbert space $\mathcal{H}_S = \mathcal{H}_a \otimes \mathcal{H}_b$ of a macroscopic quantum system S consisting of two subsystems a and b, the reduced density matrix $\rho_a^\psi := \mathrm{tr}_b |\psi\rangle\langle\psi|$ is close to $\mathrm{tr}_b \rho_R$ and thus nearly deterministic, provided that a is not too large. Here ρ_R is the projection to $\mathcal{H}_R$ normalized to trace 1 and the word "most" refers to the uniform distribution over the unit sphere in $\mathcal{H}_R$, which for a micro-canonical subspace can be regarded as an analog of the micro-canonical ensemble in classical statistical mechanics. In this talk, we generalize canonical typicality to other ensembles, in particular to an analog of the canonical ensemble, so it expresses a kind of equivalence of ensembles. For a general density matrix ρ, the measure over the unit sphere that forms the analog of the uniform measure but has density matrix ρ is known as GAP(ρ). We show that for any density matrix ρ on $\mathcal{H}_S$ with small eigenvalues, most wave functions ψ according to GAP(ρ) are such that ρ_a^ψ is close to $\mathrm{tr}_b \rho$. Our proof is based on a generalization of Lévy's lemma (concentration of measure) to GAP(ρ).

Topological synchronization of classical and quantum systems

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For many quantum mechanical applications dissipation is often regarded as an undesirable yet unavoidable consequence because it potentially degrades quantum coherences and renders the system classical. However, interactions with the environment can also be considered a fundamental resource for striking collective effects typically impossible in Hamiltonian systems. A hallmark of such collective behavior in nonequilibrium systems is the phenomenon of synchronization: in the complete absence of any time-dependent forcing from the outside, a group of oscillators adjusts their frequencies such that they spontaneously oscillate in unison. With the recent developments in quantum technology which allow one to exquisitely tailor both the system and environmental properties, synchronization has emerged in the quantum domain with various different examples ranging from nonlinear oscillators to spin-1 systems, superconducting qubits and optomechanics. However, to observe synchronization in large networks of classical or quantum systems demands both excellent control of the interactions between nodes and accurate preparation of the initial conditions due to the involved nonlinearities and dissipation. This limits its applicability for future devices. We present a potential route towards significantly enhancing the robustness of synchronized behavior in open nonlinear systems that utilizes the power of topological insulators, which exhibit an insulating bulk but conducting surface states, known as topological edge states. These edge states display a surprising immunity to a wide range of local deformations and even circumvent localization in the presence of disorder. By combining nontrivial topological lattices with nonlinear oscillators, we show that synchronized motion emerges at the lattice boundaries in the classical mean field as well as the quantum regime. Furthermore, the synchronized edge modes inherit the topological protection known from closed systems with remarkably robust dynamics against local disorder and even random initial conditions. Our work demonstrates a general advantage of topological lattices in the design of potential experiments and devices as fabrication errors and longterm degradation are circumvented in this way. This is especially important in networks where specific nodes need special protection.

Impact of decoherence on the route to equilibrium

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We study the time evolution of a single qubit in contact with a bath, within the framework of projection operator methods. Employing the so-called modified Redfield theory which also treats energy conserving interactions non-perturbatively, we are able to study the regime beyond the scope of the ordinary approach. Reduced equation of motion for the diagonal elements of the qubit is derived. In a idealistic system where both the bath and system-bath interactions are modeled by Gaussian distributed random matrices, energy conserving interactions are found to slow down the relaxation process, which leads to a zeno freezing if they are sufficiently strong. While in a more realistic system, where the qubit is coupled to a Ising chain, very different results are found.

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Understanding Intrinsic Ratchets Microscopically and Phenomenologically

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Intrinsic ratchets are Brownian motors in which the required asymmetry is a property of the Brownian particle itself. Given nonequilibrium conditions, they are able to generate directed motion fueled by thermal fluctuations. They have been described microscopically [1,2] and phenomenologically [3], but the link between these approaches has not been made completely clear.

In [3] it was shown phenomenologically and semi-quantitatively that a net energy flux from a gas to a Brownian particle (or vice versa) implies a deficit (or surplus) in the transferred momentum. They dubbed the phenomenon "momentum deficit due to dissipation" (MDD). The MDD force is in leading order proportional to the energy flux and therefore to the (kinetic) temperature difference between gas and particle. If the particle's motion is restricted to one translational or rotational degree of freedom and its left and right sides have different inclinations with respect to this direction of motion, the MDD forces on both sides don't cancel but result in a net MDD force which leads to directed motion.

Time-evolution equations for the moments of the velocity distribution of a Brownian particle can be derived microscopically: for general Hamiltonian dynamics with the projection operator technique [2], or for an ideal gas via the master equation [1]. The second moment appears in the equation for the first moment at the next order beyond the linear friction in an expansion in the mass ratio between gas particle and Brownian particle. Then, the first moment is coupled to the second and therefore has a non-zero steady state.

Within the kinetic theory of gases, we calculate the force of an ideal gas on such a Brownian particle as function of its velocity. We establish the link between the microscopic and phenomenological approaches by showing that the nonlinear term in the equation for the first moment is the MDD force. Thus, the coupling between first and second moment is the mathematical expression of the connection between the energy and momentum fluxes. In addition, we calculate the exact MDD force, explain its inclination dependence phenomenologically, and clarify the provenance and meaning of the two terms it consists of.

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Quantum-engine cycles in ultracold gases

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Excellent experimental control over quantum systems is increasingly bringing quantum techno-logical applications within reach. A central question of current research is how to realize, operate, and understand the smallest machines in the quantum world. In particular, it is interesting whether quantum effects can improve these machines somehow. I will discuss our recent progress in addressing such questions experimentally in two different ultracold-atom setups.

First, we have successfully introduced single Cs atoms as controlled impurities in an ultracold gas of Rb atoms. Spin-exchange collisions allow a very controlled transfer of energy quanta between bath and impurity. We use this transfer to operate the single atom as a machine in a magnetic field gradient, where the quasi-spin system of the impurity replaces the usually employed thermally populated states in an external trap [1]. I will show that the bound spectrum of the impurity's spin reduces the impact of fluctuations of the work output when population inversion is realized, offering high efficiency, high power, and low power fluctuations simultaneously [2].

Second, in another experimental setup, we address whether the significant energy difference between ensembles of different fermionic and bosonic quantum statistics, resulting from the Pauli exclusion principle, can be used as a novel form of energy to drive a quantum machine. To this end, we use a degenerate gas of fermionic Lithium atoms. We show that an Otto-inspired Pauli cycle can be operated by alternating strokes changing the trap frequency and the interaction-induced change of quantum statistics along the BEC-BCS crossover, outperforming comparable cycles relying on a change of interactions [3].

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Abstracts of Posters

(in alphabetical order)

Soliton-mediated transport in periodic structures

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Solitons are commonly known as waves that propagate without dispersion due to nonlinear effects in systems with inertia. We demonstrate that solitons can occur in the absence of inertia for fully overdamped Brownian dynamics of hard spheres in periodic potentials at high particle densities [1-2]. A generic model describing particle dynamics in such systems is the Brownian asymmetric simple exclusion process (BASEP). It describes the driven Brownian particle motion of hard spheres through a periodic structure under a constant drag force, which can be realized in experiments by driving suspended particles along an optical vortex [3]. The Brownian solitons manifest themselves as periodic sequences of different particle assemblies moving even in the zero-noise limit, where transport of single particles is not possible. To uncover the hard sphere dynamics at zero noise, a new simulation technique has been developed that can be applied for arbitrary external force fields [4]. At low temperatures, the solitons give rise to particle currents appearing in band-like structures around certain particle diameters. At high temperatures, currents occur for all particle diameters. The variation of the current magnitudes with particle diameter and driving force reflects the inherent soliton formation. The occurrence of the theoretically predicted Brownian soliton has recently been demonstrated in experiments, where colloidal particles are driven by a traveling wave [5].

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Interacting Flat Band Systems: Anomalous Transport and Prethermalization

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We study the broadening of initially localized wave packets in a quasi one-dimensional diamond ladder with interacting, spinless fermions. This lattice possesses a flat band which is a source of localization. We place special focus on the transition away from the flat band many-body localized case by adding weak dispersion. Propagation of the wave packet then happens on significantly different time scales which causes anomalous transport in the system. During the propagation process the system passes an interaction-induced, metastable equilibrium before thermalization. A physical picture of light and heavy modes for this prethermal behavior can be obtained within Born-Oppenheimer approximation via basis transformation of the original Hamiltonian. This reveals a detachment between light (symmetric) and heavy (anti-symmetric) states giving an explanation for the observed effects and links our flat band model to systems with different particle species.

Out-of-equilibrium finite-size scaling in generalized Kibble-Zurek protocols crossing quantum phase transitions in the presence of symmetry-breaking perturbations

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We study the effects of symmetry-breaking perturbations in the out-of-equilibrium quantum dynamics of many-body systems slowly driven by a time-dependent symmetry-preserving parameter, across the quantum critical regime associated with a continuous quantum transition (CQT). For this purpose, we analyze the out-of-equilibrium dynamics arising from generalized Kibble-Zurek (KZ) protocols, within a dynamic renormalization-group framework allowing for finite-size systems. We show that the time dependence of generic observables develops an out-of-equilibrium finite-size scaling (FSS) behavior, arising from the interplay between the timescale ts of the parameter variations in the KZ protocol, the size L of the system, and the strength h of the symmetry-breaking perturbation, in the limit of large ts and L. Moreover, scaling arguments based on the first-order adiabatic approximation of slow variations in quantum systems allow us to characterize the approach to the adiabatic regimes for some limits of the model parameters (for example, when we take ts $\to \infty$ before L $\to \infty$), predicting asymptotic power-law suppressions of the nonadiabatic behaviors in the adiabatic limits. This out-of-equilibrium FSS is supported by numerical analyses for the paradigmatic quantum Ising chain along generalized KZ protocols, with a time-dependent transverse field crossing its CQT, in the presence of a static longitudinal field breaking the Z2 symmetry.

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Unitary non-ergodic dynamics of the quantum spin delta chain

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We investigate the one-magnon dynamics of the antiferromagnetic delta chain as a paradigmatic example of tunable equilibration. Depending on the ratio of nearest and next-nearest exchange interactions the spin system exhibits a flat band in one magnon space [1] – in this case equilibration happens only partially, whereas it appears to be complete with dispersive bands as generally expected for generic Hamiltonians.

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Novel techniques to improve the results of DMRG-X

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The DMRG-X algorithm is a tensor network based method to find individual slightly entangled eigenstates [1]. It was introduced in the context of the study of many-body localized (MBL) systems where in the limit of large disorder it succeeds to determine the full spectrum whereas for low to intermediate disorder it typically shows non-injectivity which leads to parts of the spectrum being overlooked. In this work two novel methods are introduced to minimize this effect and are being discussed on the basis of the structure of the input they merge together, the influence of level crossings in the models and a possible low entanglement bias.

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Low frequency resonances in periodically driven magnon systems

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We establish a method based on Floquet theory to efficiently determine and examine instabilities of microscopic magnon systems such as thin films of ferro- or ferri-magnetic materials. A special feature of parameteric resonance is the possibility to excite magnons with higher energy than the driving frequency, which allows for new tuning possibilities. We examine regions of resonances for frequencies below the energy spectrum and predict different effects depending on the driving amplitude and frequency, like the vanishing of instabilities at high driving fields. We compare our results with phenomenological approaches to investigate the role damping plays in such systems and perform micromagnetic simulations in order to confirm our results.

Quantum annealing: Sampling efficiency for 2-SAT problems with multiple solutions

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The performance of quantum annealing has been studied well for solving optimization problems with a unique solution. One of the most common metrics of performance is the scaling of the success probability (the probability with which one finds the solution to the problem) or related quantities like time to solution (TTS) [1]. On the other hand, for problems with multiple solutions, another aspect of performance that becomes relevant is the fairness of quantum annealing in sampling the various solutions of the problem, i.e., whether or not it can sample all the solutions of the problem with comparable probabilities [2]. Using both simulations and the D-Wave Advantage_system5.1 (DWAdv) quantum annealer we study the sampling efficiency of the standard quantum annealing algorithm as well as the reverse annealing protocol, as implemented by the D-Wave systems, for solving 2-Satisfiability (SAT) problems with four satisfying assignments.
We find that while the numerically obtained sampling probabilities using the standard quantum annealing algorithm are not always fair, but in agreement with the perturbation theory in the long annealing time limit, the sampling probabilities of the four ground states from DWAdv are comparable for a majority of the problems, which indicates the presence of noise and temperature effects in the latter. On the other hand, we find that the sampling probabilities for the reverse annealing protocol depend greatly on the choice of annealing times, reversal distance, waiting time, and the initial state.

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Quantum many-body dynamics in two dimensions using tree tensor networks

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Many body systems out of equilibrium are notoriously difficult to solve due to the rapid growth of entanglement with time. In particular the rapidly expanding possibilities to address 2-dimensional systems in quantum simulation turn a spotlight on the lack of reliable numerical methods in this regime. We explore an approach to solve the time evolution of 2-dimensional systems by applying the time-dependent variational principle (TDVP) to Tree Tensor Networks (TTNs). More specifically, this method is used to study pre-thermal behavior in the quantum Ising model, leading to a slow relaxation of domain wall initial conditions.

Weyl Semimetal Integrated 3-Unit Polarimeters

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The unique topology of Weyl semimetals' band structure has been recently shown to lead to a host of novel optoelectronic properties. Among them is the prospect of polarization dependent photocurrents, most notably the circular photogalvanic effect arising from the spin-texture of the Weyl cones in the presence of symmetry breaking[1,2]. Here, we show that these helicity-dependent photocurrent processes can be employed to realize fully integrated polarimetric detection systems. In this respect, a TaAs based polarimeter is demonstrated involving three pixels that can uniquely map the polarization state of light on the Poincaré sphere. Our work could enable a new class of optoelectronic devices that directly respond to the polarization of incident light, while paving the way towards a better understating of light-matter interactions in Weyl semimetals.

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Universal conductance fluctuations and phase-coherent transport in GeTe nanowires

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Despite the fact that GeTe is known to be a promising material for applications in thermoelectrics and for phase-change memories, the knowledge on its low-temperature transport properties is quite limited. In this work, we have investigated the phase-coherent phenomena via the magnetotransport of GeTe nanowires. From universal conductance fluctuations measured on GeTe nanowires with Au contacts, a phase-coherence length of about 280 nm at 0.5 K is determined. Such distinct phase-coherence is confirmed by the observation of Aharonov–Bohm type oscillations for parallel magnetic fields. We interpret the occurrence of these magnetic flux-periodic oscillations by the formation of a tubular hole-accumulation layer. In the case of Nb/GeTe-nanowire/Nb Josephson junctions, we obtained a critical current of 0.2 μA at 0.4 K. By applying a perpendicular magnetic field, the critical current decreases monotonously with increasing field; and in contrast, in a parallel field, the critical current oscillates with a period of the magnetic flux quantum confirming the presence of a tubular hole-channel.

Manipulating exciton binding by floquet engineering in Fermi Hubbard ladder

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Strong excitations of correlated quantum materials give rise to various non-thermal phases which are not present in their equilibrium counterpart. Recently, it was shown that the one-dimensional Fermi Hubbard Model features charge density wave and η-pairing phases upon photo-doping.
In this study, we explore the non-equilibrium behaviour of the mix-D Fermi Hubbard model and employ the Schrieffer-Wolff transformation to map it to a simplified t-J-like model, providing an effective equilibrium description of the photo-doped states. Our investigation highlights the significance of an additional η-exchange coupling between exciton pairs in the presence of doublons. We find the dependence of binding energy of excitons on exchange couplings and show that the application of an electric field along the rung to the hopping term enhances exciton pairing. This floquet manipulation allows to increase the exchange coupling along the rung while keeping the magnitude of hopping constant. This is responsible for increasing the binding energy and in turn the critical temperature of superconductivity. To characterize the ground state of the system, we employ relevant correlators and make notable observations. We show that at strong anisotropy, the ground state encompasses a strongly bound doublon-hole pair along the rung, alongside inter-chain singlets. Additionally, we propose experimental setups to test the predictions put forth by our theory.

Non-equilibration and synchronization in isotropic Heisenberg models

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Heisenberg models in the presence of a homogeneous magnetic field are considered, including various integrable, non-integrable, as well as disordered examples, and not necessarily restricted to one dimension or short-range interactions. Taking for granted that the non-equilibrium initial condition and the spectrum of the field-free model satisfy some very weak requirements, expectation values of generic observables are analytically shown to exhibit permanent long-time oscillations [1], thus ruling out equilibration [2].

If the model (but not necessarily the initial condition) is translationally invariant, the long-time oscillations are moreover shown to exhibit synchronization in the long run, meaning that they are invariant under arbitrary translations of the observable.

Analogous long-time oscillations are also recovered for temporal correlation functions when the system is already at thermal equilibrium from the outset.

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Investigating various possibilities to solve the Fermi-Hubbard model using the kinetic energy part for quantum annealing

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Quantum annealing can help in finding the ground state of Hamiltonians describing many body systems. One such Hamiltonian is the Fermi-Hubbard Hamiltonian. We investigate the possibility of utilizing quantum phase estimation after the quantum annealing process carried out using the kinetic energy part of the Hubbard model as driving Hamiltonian for ground state calculations. We also try to exploit some symmetries in order to reduce size of the Hilbert space and study minimum gap for the same. We further outline our plan to study quantum annealing for a system described by the Hubbard Hamiltonian and coupled to a bath to investigate the effect of the environmental temperature and disorder on the ideal quantum annealing process for finding the ground state.

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