UNIVERSITÄT OSNABRÜCK

International Workshop of
DFG Research Unit FOR 2692

# Out-Of-Equilibrum Dynamics in Many-Body Systems

24. – 26. September 2018
Universität Osnabrück


Fachbereich Physik
www.**for2692**.de

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## Venue on Monday and Tuesday

Universität Osnabrück · Botanic Garden
Bohnenkamphaus
Albrechtstr. 29 · 49076 Osnabrück

## Venue on Wednesday

Universität Osnabrück · Fachbereich Physik
Room 32/102
Barbarastr. 7 · 49076 Osnabrück

## Lunch from Monday to Wednesday

Universität Osnabrück · Canteen
Barbarastr. 20 · 49076 Osnabrück

Please show your authorization card at the cash desk.

## **Excursion on Tuesday** (18:15)

Rathaus Osnabrück
Markt 30 · 49074 Osnabrück

## **Conference Dinner on Tuesday** (20:00)

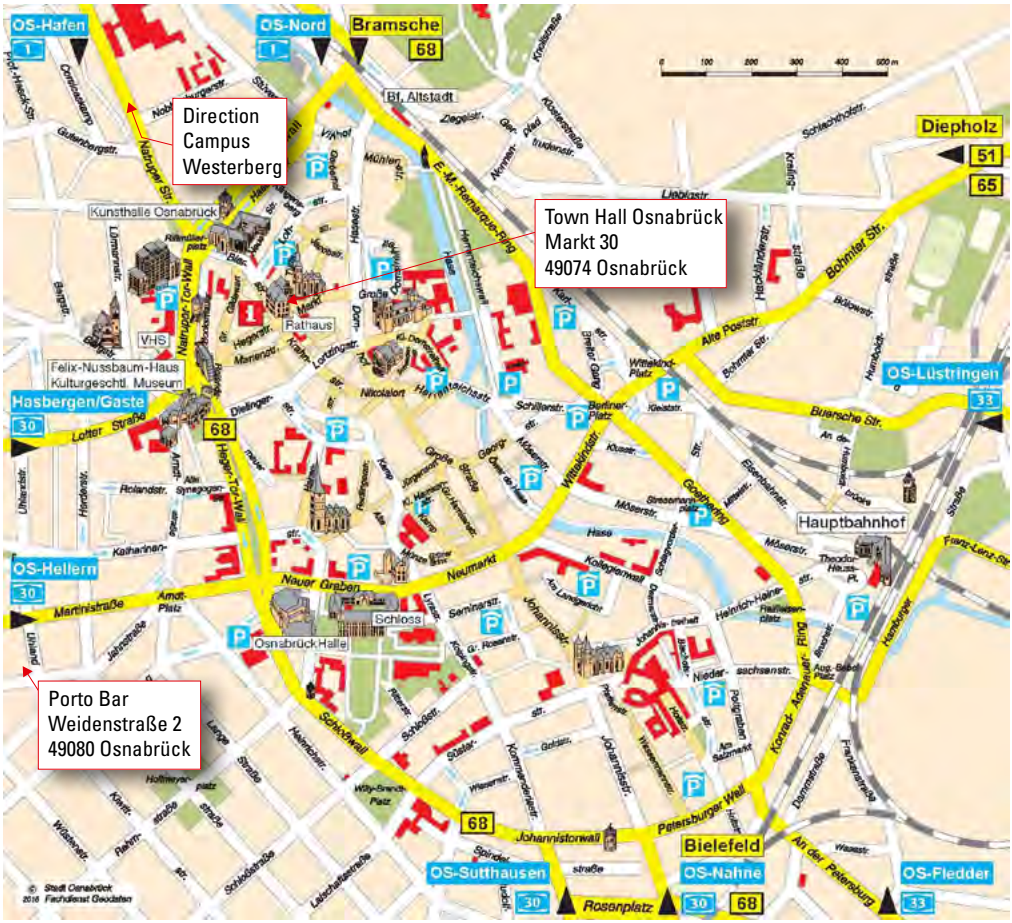
Portobar
Weidenstr. 2 · 49080 Osnabrück

### Internet

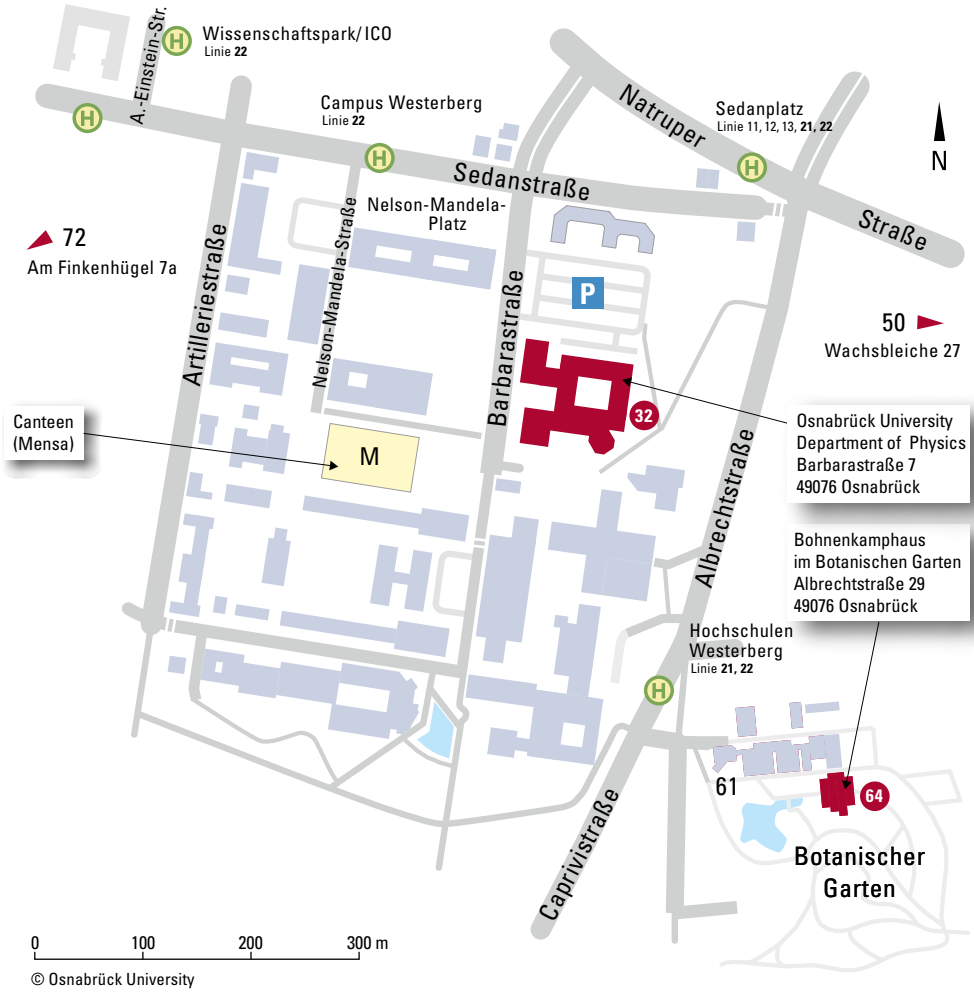
WLAN via eduroam
User: for2692
Password: Osnabrueck_9

# Maps

# Downtown Osnabrück



# Campus Westerberg



# Program

# Program

## Monday, 24. September 2018

13:30 – 13:35 · **Welcome**

13:35 – 14:20
Quench, hydro, and Floquet dynamics in integrable systems
Jean-Sébastian Caux

14:20 – 15:05
Spin and charge dynamics in disordered chains with many-body interactions
Marcin Mierzejewski

15:05 – 16:45 · **Posters, snacks, and photo**

16:45 – 17:30
Renyi entropy of a nonequilibrium stationary state
Martin Evans

17:30 – 18:00
Brownian asymmetric simple exclusion process
Dominik Lips

18:00 · **Free evening**

## Tuesday, 25. September 2018

9:30 – 10:15
Nonequilibrium steady state of the dissipative Heisenberg quantum spin chain
Gunter Schütz

10:15 – 11:00
Energy dissipation in strongly correlated materials driven out of equilibrium
Uwe Bovensiepen

11:00 – 11:30 · **Break and coffee**

11:30 – 12:15
Thermalization and spin dynamics of individual impurities coupled to an ultracold bath
Artur Widera

12:15 – 13:00
Optimizing the cooling of a dilute atomic gas
Eric Lutz

13:00 – 14:30 · **Lunch at canteen**

14:30 – 15:15
Irreversibility in closed quantum many-body systems
Stefan Kehrein

15:15 – 16:00
Quantum simulators probing out of equilibrium dynamics
Jens Eisert

16:00 – 16:30 · **Break and coffee**

16:30 – 17:15
Thouless and relaxation time scales in many-body quantum systems
Lea Santos

17:15 – 17:45
Transportless equilibration in isolated many-body quantum systems
Peter Reimann

18:15 – 19:15 · **Excursion: Town hall guide**

20:00 · **Conference dinner**

## Wednesday, 26. September 2018

9:30 – 10:15
Relaxation, thermalization, and Markovian dynamics of one and two spins coupled to a spin bath
Hans De Raedt

10:15 – 11:00
Eigenstate thermalization scaling for nonlocal and local operators
Masud Haque

11:00 – 11:30 · **Break and coffee**

11:30 – 12:15
Emergent eigenstate solution to quantum dynamics
Lev Vidmar

12:15 – 12:45
Impact of eigenstate thermalization on the route to equilibrium
Jonas Richter

12:45 – 12:50 · **Closing**

12:50 · **Lunch at canteen**

# Speakers and Participants

## Invited Speakers

| | |
|---|---|
| Bovensiepen, Uwe | Duisburg-Essen, Germany |
| Caux, Jean-Sébastian | Amsterdam, The Netherlands |
| De Raedt, Hans | Groningen, The Netherlands |
| Eisert, Jens | Berlin, Germany |
| Evans, Martin | Edinburgh, UK |
| Santos, Lea | New York, USA |
| Haque, Masud | Maynooth, Ireland |
| Kehrein, Stefan | Göttingen, Germany |
| Lutz, Eric | Stuttgart, Germany |
| Mierzejewski, Marcin | Wroclaw, Poland |
| Schütz, Gunter | Jülich, Germany |
| Vidmar, Lev | Ljubljana, Slovenia |
| Widera, Artur | Kaiserslautern, Germany |

## Speakers of the Research Unit FOR 2692

| | |
|---|---|
| Lips, Dominik | Osnabrück, Germany (Maass group) |
| Reimann, Peter | Bielefeld, Germany |
| Richter, Jonas | Osnabrück, Germany (Steinigeweg group) |

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# Abstracts

## Abstracts of the Talks

### Jean-Sébastian Caux

### Quench, hydro, and Floquet dynamics in integrable systems

(Monday, 13:35 – 14:20)

Many-body quantum systems in one dimension have many remarkable characteristics as compared to their higher-dimensional counterparts.
On the formal side, advanced nonperturbative methods such as integrability can be used to compute their physical properties, which are nowadays accessible in real experiments on magnetic systems and cold atoms. Moreover, their relaxation and equilibration behaviour cannot be simply described by traditional textbook methods, and can lead to long-lived non-thermal equilibrium states. This talk will provide an overview of current research in this area, and introduce recentlydiscovered methods to treat quenched and driven systems in various experimentally-relevant contexts.

### Marcin Mierzejewski

### Spin and charge dynamics in disordered chains with many-body interactions

(Monday, 14:20 – 15:05)

Experiments on many-body localization are performed on cold-fermion lattices where the relevant model is the Hubbard model with spin-1/2 fermions and the disorder enters only via a random charge potential. Recent numerical studies of such model reveal that even at strong disorder, localization and nonergodicity occurs only in the charge subsystem, unless one introduces also random magnetic field. We derive and study the effective spin model that explains the anomalous spin dynamics in the one-dimensional Hubbard model with strong potential disorder. Assuming that charges are localized, we show that spins are delocalized and their subdiffusive transport originates from a singular random distribution of spin exchange interactions. The exponent relevant for the subdiffusion is determined by the Anderson localization length and the density of electrons. While the analytical derivations are valid for low particle density, numerical results for the full Hubbard model reveal a qualitative agreement up to half-filling.

Martin Evans

## Renyi entropy of a nonequilibrium stationary state

(Monday, 16:45 – 17:30)

The Renyi entropy is a generalisation of the Gibbs-Shannon entropy. I will discuss its definition and status.

I will present results for the Renyi entropy of the stationary state of a paradigmatic nonequilibrium model - the totally asymmetric exclusion process (TASEP). To do so we calculate explicitly the sum of squares of configuration probabilities, using the matrix product formalism to map the problem to one involving a six direction lattice walk in the upper quarter plane with absorbing boundary conditions. We derive the generating function across the whole phase diagram, using an obstinate kernel method. This gives the leading behaviour of the Renyi entropy and corrections in all phases of the TASEP.

Dominik Lips

## Brownian asymmetric simple exclusion process

(Monday, 17:30 – 18:00)

We present a model of a Brownian asymmetric simple exclusion process (BASEP) with overdamped Brownian dynamics that resembles properties of the asymmetric simple exclusion process (ASEP) on a lattice. In this BASEP, particles of size $\sigma$ with hardcore interaction are driven by a constant drag force through a one-dimensional cosine potential with period $\lambda$. The amplitude of the cosine potential is much larger than the thermal energy, leading to an effective hopping motion of the particles between potential wells. Under periodic boundary conditions, the system reaches a non-equilibrium steady state (NESS) with a constant particle current. In general, the character of the NESS is strikingly different from that in the ASEP. Compared to the particle current in a system of non-interacting particles, we observe an enhancement for small $\sigma/\lambda$ ratios, caused by a barrier reduction effect arising from multi-occupation of potential wells. Larger $\sigma/\lambda$ ratios lead to a suppression of the current because of blocking effects. Surprisingly, an exchange-symmetry effect causes the current-density relation to be identical to that of non-interacting particles for commensurable lengths $\sigma=\lambda$. A current-density relation similar to the ASEP is obtained only for a limited parameter regime. The rich behavior of the current-density relation leads to phase diagrams of NESS in open systems with up to five different phases. The topology of these phase diagrams changes with varying $\sigma/\lambda$ ratio.

## Gunter Schütz

### Nonequilibrium steady state of the dissipative Heisenberg quantum spin chain

(Tuesday, 9:30 – 10:15)

We demonstrate that the exact nonequilibrium steady state of the one-dimensional Heisenberg XXZ spin chain driven by boundary Lindblad operators can be constructed explicitly with a matrix product ansatz for the nonequilibrium density matrix.

For the isotropic Heisenberg chain, polarized at the boundaries in different directions with a non-zero twist angle, we calculate the exact magnetization profiles and magnetization currents. The in-plane steady-state magnetization profiles are harmonic functions with a frequency proportional to the twist angle.

In-plane steady-state magnetization currents are subdiffusive and vanish as the boundary coupling strength increases, while the transverse current is diffusive and saturates as the coupling strength becomes large. For the anisotropic chain we find a current resonance where the transverse current is independent of system size, even for non-integrable higher-spin chains. In the Zeno-limit of strong coupling, the relaxation towards stationarity is shown to be given by a classical master equation.

## Uwe Bovensiepen

### Energy dissipation in strongly correlated materials driven out of equilibrium

(Tuesday, 10:15 – 11:00)

Thermodynamics provides excellent means to describe broken symmetry ground states of condensed matter in thermal equilibrium because the temperature determines the population of excited states and the resulting overall energy minimization leads to, e.g., structural transitions, magnetic order, or superconductivity. However, identification of the microscopic interactions, which generate such symmetry breaking, is far from trivial due to cooperation or competition of various interactions.

Experiments in the time domain provide additional insights in this regard because they operate on the characteristic time scales of such interactions. In particular, femtosecond laser based pump-probe experiments address these time scales for elementary processes. Recent results from the fields of surface science [1], strongly correlated materials [2,3,4], and magnetism [4] will be discussed.

[1] Frigge *et al.*, Nature **544**, 207 (2017).

[2] Rameau *et al.*, Nature Commun. **7**, 13761 (2016).

[3] Ligges *et al.*, Phys. Rev. Lett. **120**, 166401 (2018).

[4] Konstantinova *et al.*, Science Adv. **4**, eaap7427 (2018).

[5] Razdolski *et al.*, Nature Commun. **8**, 15007 (2017).

Artur Widera

## Thermalization and spin dynamics of individual impurities coupled to an ultracold bath

(Tuesday, 11:30 – 12:15)

Ultracold gases of atoms have become a powerful platform to precisely investigate details of quantum many-body systems. While global properties of such systems are routinely accessible experimentally, novel insights about complex dynamics can be expected by local probes.

I will present our experimental approach to immerse individual Cesium atoms as tighly-controlled atomic impurities into an ultracold Rubidium cloud, being either a thermal gas or a Bose-Einstein condensate. We study the interaction between impurity and gas, where all relevant parameters, including interaction strength between impurity and gas atoms, can be experimentally controlled. We have implemented a range of methods to retrieve precise information about motional or thermal as well as internal (spin) states of the impurity, reflecting a snapshot of the local state of the many-body system. I will present the current state of the project, aiming on local, non-destructive probing of the relaxation dynamics of a quantum gas out of equilibrium.

Eric Lutz

## Optimizing the cooling of a dilute atomic gas

(Tuesday, 12:15 – 13:00)

We optimize the Raman cooling of a noninteracting gas of cold atoms using tools of nonequilibrium thermodynamics. We determine an optimal cooling protocol, in particular the optimal Raman pulse separation, by minimizing the entropy production. We obtain excellent agreement between theoretical simulations and experimental data.

Stefan Kehrein

## Irreversibility in closed quantum many-body systems

(Tuesday, 14:30 – 15:15)

The question of how one can reconcile the second law of thermodynamics with microscopic time-reversal invariance goes back to the very beginning of statistical mechanics and the dispute between Boltzmann and Loschmidt. While the answer to this question is nowadays very well understood for classical systems, its quantum mechanical version has until recently hardly been explored. Besides its importance for the foundations of quantum statistical mechanics, the understanding of reversibility and irreversibility in quantum systems also plays an important role for example in spin echo experiments. In my talk I will give an overview of recent progress on this topic.

## Jens Eisert

### Quantum simulators probing out of equilibrium dynamics

(Tuesday, 15:15 – 16:00)

Quantum systems out of equilibrium pose some of the most intriguing problems of the study of interacting quantum matter. In this talk, we will start from discussing foundational aspects of quench dynamics, related to equilibration - how it can actually be derived from volume laws of energy eigenstates and notions of entanglement ergodicity - and general instances of Gaussification. We will then take a pragmatic stance and explore to what extent those questions can be probed with cold atomic systems that constitute quantum simulators. Specifically, we will discuss new results on equilibration, experimental Gaussification, a new tomographic procedure for cold atomic simulators, offering a new window into quantum simulators. Only if time allows, the talk will be ended with an elaboration on how cold atomic quantum simulators may be an excellent platform to show a much sought after quantum advantage, in a way that the advantage can be certified.

## Lea Santos

### Thouless and relaxation time scales in many-body quantum systems

(Tuesday, 16:30 – 17:15)

Using physical observables, we study numerically and analytically the Thouless time and the relaxation time of realistic interacting many-body quantum systems. The Thouless time refers to the point beyond which the dynamics acquires universal features and becomes purely quantum. Relaxation happens when the evolution reaches a stationary state. These two time scales are not necessarily equal. For chaotic systems, the Thouless time is much smaller than the relaxation time, while for systems approaching a many-body localized phase, they merge together. Both times increase exponentially with system size and are significantly larger than the characteristic time for the fast initial depletion of the initial state. Our results are compared with those for random matrices, which corroborates their generality. These studies are relevant to experiments with cold atoms and ion traps, where the unitary dynamics of isolated interacting many-body quantum systems is becoming accessible for an ever longer time.

## Peter Reimann

### Transportless equilibration in isolated many-body quantum systems

(Tuesday, 17:15 – 17:45)

A general analytical theory of temporal relaxation processes in isolated quantum systems with many degrees of freedom is elaborated, which unifies and substantially generalizes several previous approximations. The main prerequisite is the absence of

any notable transport currents, caused for instance by some initially unbalanced local densities of particles, energy, and so on. In particular, such a transportless relaxation scenario naturally arises when both the system Hamiltonian and the initial non-equilibrium state do not exhibit any spatial inhomogeneities on macroscopic scales.

Hans De Raedt

## Relaxation, thermalization, and Markovian dynamics of one and two spins coupled to a spin bath

(Wednesday, 9:30 – 10:15)

Computer simulation can be viewed as a metaphor for perfected laboratory experiments and offers unique possibilities to confront man-made concepts and theories with actual facts, i.e. real perfect experiments [1]. In this talk, the metaphor is used to study the relaxation, thermalization, decoherence and the relation with Markovian dynamics of one and two spins coupled to a spin bath. I start by briefly reviewing of the features of a massively parallel quantum dynamics simulator which can simulate universal quantum computers with up to 48 qubits (using the largest supercomputers that are available to us [3]) and, when used to simulate quantum spin systems, allows us to compute the density of states, the time evolution of the reduced density matrix of a subsystem, Kubo formulas for spin transport, etc. for systems containing up to 43 spins (at the time of writing). In this talk, I focus on how well Markovian dynamics can describe the time evolution of one or two spins coupled to a spin bath [4,5]. It is shown that by fitting a Markovian quantum master equation to the numerical solution of the time-dependent Schrödinger equation the former captures the dynamics of the one- or two-spin system rather well. The fitting procedure that yields this Markovian quantum master equation accounts for all non-Markovian effects in as much the general structure of this equation allows and yields a description that is incompatible with the Lindblad equation.

[1] De Raedt, Michielsen, and Hess, »The digital computer as a metaphor for the perfect laboratory experiment: Loophole-free Bell experiments«, Comp. Phys. Comm. **209**, 42 (2016).

[2] De Raedt and Michielsen, »Computational Methods for Simulating Quantum Computers«, Handbook of Theoretical and Computational Nanotechnology, American Scientific Publisher, Los Angeles (2006).

[3] De Raedt, Jin, Willsch, Nocon, Yoshioka, Ito, Yuan and Michielsen. »Massively parallel quantum computer simulator, eleven years later«, arXiv:1805.04708.

[4] Zhao, De Raedt, Miyashita, Jin, and Michielsen, »Dynamics of open quantum spin systems: An assessment of the quantum master equation approach«, Phys. Rev. E **94**, 022126 (2016).

[5] De Raedt, Jin, Katsnelson, and Michielsen, »Relaxation, thermalization, and Markovian dynamics of two spins coupled to a spin bath«, Phys. Rev. E **96**, 053306 (2017)

## Masud Haque

### Eigenstate thermalization scaling for nonlocal and local operators

(Wednesday, 10:15 – 11:00)

The eigenstate thermalization hypothesis (ETH) is a cornerstone in our understanding of quantum statistical mechanics. The extent to which ETH holds for nonlocal operators (observables) is an open question. I will address this question using an analogy with random matrix theory. The starting point will be the construction of extremely nonlocal operators, which we call Behemoth operators. The Behemoths turn out to be building blocks for all physical operators. This construction allow us to derive scalings for both local operators and different kinds of nonlocal operators.

## Lev Vidmar

### Emergent eigenstate solution to quantum dynamics

(Wednesday, 11:30 – 12:15)

An exciting direction of current research is to establish tools for efficient manipulation of quantum many-body states. I am going to introduce the emergent eigenstate solution to quantum dynamics [1], which provides a new step in this direction.

The cornerstone of the emergent eigenstate solution is the construction of an explicitly time dependent operator in the Schrödinger picture, called an emergent local Hamiltonian, of which time-evolving pure states are eigenstates. The crucial property of the emergent Hamiltonian, which is not present in generic nonequilibrium situations, is locality. I am going to present experimentally relevant examples of quantum quenches in two families of one-dimensional lattice models (quadratic fermionic models including hard-core bosons, and the anisotropic Heisenberg spin-1/2 model), where the emergent local Hamiltonian can be constructed [1,2]. I am also going to present a nonequilibrium protocol, which suggests that the emergent eigenstate solution can be used as a tool to achieve shortcuts to adiabaticity [3].

[1] Vidmar, Iyer, and Rigol, PRX **7**, 021012 (2017).

[2] Vidmar, Xu, and Rigol, PRA **96**, 013608 (2017).

[3] Modak, Vidmar, and Rigol, PRE **96**, 042155 (2017).

Jonas Richter

## Impact of eigenstate thermalization on the route to equilibrium

(Wednesday, 12:15 – 12:45)

The eigenstate thermalization hypothesis (ETH) and the theory of linear response (LRT) are celebrated cornerstones of our understanding of the physics of many-body quantum systems out of equilibrium. While the ETH provides a generic mechanism of thermalization for states arbitrarily far from equilibrium, LRT extends the successful concepts of statistical mechanics to situations close to equilibrium. In our work, we connect these cornerstones to shed light on the route to equilibrium for a class of properly prepared states. We unveil that, if the off-diagonal part of the ETH applies, then the relaxation process can become independent of whether or not a state is close to equilibrium. Moreover, in this case, the dynamics is generated by a single correlation function, i.e., the relaxation function in the context of LRT. Our analytical arguments are illustrated by numerical results for idealized models of random-matrix type and more realistic models of interacting spins on a lattice. Remarkably, our arguments also apply to integrable quantum systems where the diagonal part of the ETH may break down.

[1] Richter, Gemmer, and Steinigeweg, arXiv:1805.11625.

[2] Richter and Steinigeweg, arXiv:1711.00672.

## Abstracts of the Posters
(Monday, 15:05 – 16:45)

### P 1: Onno Diermann

#### Heating of ultracold atoms in unconventional quasienergy bands

Optical lattices subjected to both static and time-periodic resonant forcing support unusual quasienergy bands which do not lend themselves to the commonly employed tight-binding approximation, but are strongly coupled to Gordon-Volkov-like above-barrier states. This coupling inevitably leads to the heating of ultracold atoms initially trapped in such a lattice configuration, and their ultimate escape.

We provide the first numerical computations of the strongly ragged dispersion relations of these unconventional bands, and suggest that the so-called box stabilization method, which is often used for calculating resonance energies and decay widths of metastable states, can be adapted for estimating the heating times. The numerical predictions obtained in this manner could be verified in current laboratory experiments.

### P 2: Mattes Heerwagen

#### Work in classical and quantum non-equilibrium systems

When extending the laws of thermodynamics to nanoscopic systems, two major challenges have to be met.

Firstly, in systems with typical energy changes of the order of the average thermal energy per degree of freedom thermodynamic quantities like work, heat, andentropy fluctuate between identical repetitions of an experiment. This point can be dealt with using the framework of stochastic thermodynamics with the result that the full probability distributions of work, heat, and entropy need to be determined. As is well known, their large deviation tails carry important physical information.

Secondly, quantum effects may dominate the dynamics and have to incorporated these in a thermodynamic prescription. The definition of work in small quantum systems plays a pivotal role. Work is no state variable and classically depends on the complete trajectory of a system. However, in quantum mechanics work cannot be identified on a trajectory basis. A possible approach may be a measurement of the initial and final energy. Defining quantum work by a double measurement of energy has some virtues but also important drawbacks. In particular it is difficult to determine which quantum correlations are destroyed by the two projective measurements and which are retained. Accordingly, the proper definition of work in small quantum systems is still an open question.

We compare the definition of quantum work obtained from two projective energy measurements and the traditional notion of work used for classical systems. In [1] Jarzynski et al. calculated classical, quantum and semiclassical work distributions for

an anharmonic quartic oscillator, which gets linear compressed with time. We will discuss the main results coming from this linear compression and extend the system for other compressions.

[1] Jarzynski, Quan, and Rahav, »Quantum-Classical Correspndence Principle for Work Distributions«, Phys. Rev. X **5**, 031038 (2015).

## P 3: Fengping Jin

### Markovian dynamics of two spins coupled to a spin bath

It is shown that by fitting a Markovian quantum master equation to the numerical solution of the time-dependent Schrödinger equation of a system of two spin-1/2 particles interacting with a bath of up to 34 spin-1/2 particles, the former can describe the dynamics of the two-spin system rather well. The fitting procedure that yields this Markovian quantum master equation accounts for all non-Markovian effects in as much the general structure of this equation allows and yields a description that is incompatible with the Lindblad equation [1].

[1] De Raedt, Jin, Katsnelson, and Michielsen, Phys. Rev. E **96**, 053306 (2017).

## P 4: Stefan kleine Brüning

### Thermalization properties of a system with topological flat bands and impurities

Topological insulators are interesting materials, because they have protected edge states. Especially Bi2Se3 is theoretically interesting, because of its relatively simple Hamiltonian and it is known that under the influence of a Zeeman field there exist flat bands in thin stripes of this material [1]. In this work a 2D model with idealized parameters, which result in perfect flat bands, is considered.

Due to the zero group velocity of electrons in flat bands there is no thermalization for a localized initial state, at least if there is no disorder and interaction. The question arrises how this non-thermalization behaviour and the localization changes, if one introduces one of them. In this work we focus on disorder which is realized through random placed impurities, which are introduced as a change of the on-site energy of the lattice sites (lattice size: 1024x128x1).

The influence of the disorder is numercally investigated using time evolution. The observable of interest is a quantity which is related to the localization of the wavepacket. The behaviour of this observable under change of strength and number of impurities is then compared to a non-flat band. To illuminate the question of thermalization it is probed whether the Eigenstate Thermalization Hypothesis holds. To do this we employ a method suggested by Steinigeweg et al. [2]. This method uses random state vectors and scaling behaviour to decide this matter. First results on the thermalization question will be shown.

[1] Paananen and Dahm, »Magnetically robust topological edge states and flat bands«, Physical Review B **87**, 195447 (2013).

[2] Steinigeweg, Khodja, Niemeyer, Gogolin, and Gemmer, »Pushing the limits of the eigenstate thermalization hypothesis towards mesoscopic quantum systems«, Physical Review Letters **112**, 130403 (2014).

## P 5: Lars Knipschild

### Stability of quantum dynamics under constant Hamiltonian perturbations

Concepts like »typicality« and the »eigenstate thermalization hypothesis« aim at explaining the apparent equilibration of quantum systems, possibly after a very long time. However, these concepts are not concerned with the specific way in which this equilibrium is approached. Our point of departure is the (evident) observation that some forms of the approach to equilibrium, such as, e.g., exponential decay of observables, are much more common then others. We suggest to trace this dominance of certain decay dynamics back to a larger stability with respect to generic Hamiltonian perturbations.

A numerical study of a number of examples in which both, the unperturbed Hamiltonians as well as the perturbations are modeled by partially random matrices is presented. We furthermore develop a simple heuristic, mathematical scheme that describes the result of the numerical investigations remarkably well.

According to those investigations the exponential decay indeed appears to be most stable. Dynamics that are in a certain sense at odds with the arrow of time are found to be very unstable.

## P 6: Nils Krüger

### An iterative procedure for computing Floquet states in high-dimensional Hilbert spaces

The Floquet states of time-periodically forced Bose-Hubbard chains are investigated with the help of an iterative approach which enables one to compute individual Floquet states for large systems, for which the computation and diagonalization of the one-cycle evolution operator is no longer feasible. In particular, the Floquet state that evolves from the ground state of the undriven chain is traced through parameter space, allowing one to study the occurrence of the Mott insulator-to-superfluid transition in a periodically driven Bose-Hubbard system.

## P 7: Dominik Lips

### Counterintuitive asymmetry of transition times in the Brownian asymmetric simple exclusion process

Driven diffusion of hard spheres (rods) in a one-dimensional cosine potential under a static bias should reflect properties of the asymmetric simple exclusion process (ASEP) on a lattice, if the amplitude of the cosine potential is considered to be large compared to the particles' thermal energy. For this Brownian asymmetric exclusion process (BASEP), we study transition times of a tagged particle between potential wells against and along the bias direction in non-equilibrium steady states. These transition times exhibit a counterintuitive asymmetry: While one may expect that the mean transition time in bias direction is shorter, the opposite is true. We relate this surprising asymmetry to the collective motion of the particles. Differences in the distributions of the times in and against bias direction depend sensitively on the filling factor (number of particles per potential well) and the rod length. Our analysis sheds light on the transport behavior of the model, which, compared to the ASEP, shows richer properties due to the additional length scale given by the rod length.

## P 8: Jonas Richter

### Impact of eigenstate thermalization on the route to equilibrium

The eigenstate thermalization hypothesis (ETH) and the theory of linear response (LRT) are celebrated cornerstones of our understanding of the physics of many-body quantum systems out of equilibrium. While the ETH provides a generic mechanism of thermalization for states arbitrarily far from equilibrium, LRT extends the successful concepts of statistical mechanics to situations close to equilibrium. In our work, we connect these cornerstones to shed light on the route to equilibrium for a class of properly prepared states. We unveil that, if the off-diagonal part of the ETH applies, then the relaxation process can become independent of whether or not a state is close to equilibrium. Moreover, in this case, the dynamics is generated by a single correlation function, i.e., the relaxation function in the context of LRT. Our analytical arguments are illustrated by numerical results for idealized models of random-matrix type and more realistic models of interacting spins on a lattice. Remarkably, our arguments also apply to integrable quantum systems where the diagonal part of the ETH may break down.

[1] Richter, Gemmer, and Steinigeweg, arXiv:1805.11625.

[2] Richter and Steinigeweg, arXiv:1711.00672.

## P 9: Robin Steinigeweg

### Dynamics of typical pure states in integrable quantum many-body systems

The real-time broadening of density profiles starting from non-equilibrium states is at the center of transport in condensed-matter systems and dynamics in ultracold atomic gases. Initial profiles close to equilibrium are expected to evolve according to linear response, e.g., as given by the current correlator evaluated exactly at equilibrium. Significantly off equilibrium, linear response is expected to break down and even a description in terms of canonical ensembles is questionable.

In this poster, we show that single pure states with density profiles of maximum local amplitude yield a broadening in perfect agreement with linear response, if the structure of these states involves randomness in terms of decoherent off-diagonal density-matrix elements. While these states allow for spin diffusion in the XXZ spin-1/2 chain at large exchange anisotropies, coherences yield entirely different behavior [1]. In contrast, charge diffusion in the strongly interacting Hubbard chain turns out to be stable against varying such details of the initial conditions [2]. Non-integrable systems are briefly discussed as well [3].

[1] Steinigeweg, Jin, Schmidtke, De Raedt, Michielsen, and Gemmer, PRB **95**, 035155 (2017).

[2] Steinigeweg, Jin, De Raedt, Michielsen, and Gemmer, PRE **96**, 020105(R) (2017).

[3] Richter, Jin, De Raedt, Michielsen, Gemmer, and Steinigeweg, PRB **97**, 174430 (2018).

## P 10: Javad Vahedi

### to be announced

## P 11: Patrick Vorndamme

### Decoherence and relaxation in unitary time-developed quantum spin systems

Magnetic molecules are considered as promising constituents of quantum simulators or quantum computers. At low temperatures the magnetic levels of molecular nanomagnets enable the use as qubits. For such an application the investigation and understanding of decoherence and relaxation caused by external and internal effects is very important. Here we aim at a better understanding of the diverse aspects of decoherence by investigating experimentally relevant notions of decoherence in unitary time evolutions of finite-size closed systems of interacting electronic as well as nuclear spins. We examine the behavior of the qubits and related observables as a function of the considered interactions (SU(2) symmetric or dipolar) and the properties of the nuclear spin bath.

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