Non-equilibrium physics
of driven-dissipative many-body systems
Palm Dune
21-25 September 2015

Monday, 21 September

Mini-School on "An introduction to tensor network methods for many-body quantum systems"

$09^{30} - 10^{00}$ Tea/Coffee

$10^{00} - 12^{00}$ Ryan Sweke (UKZN, South Africa), An introduction to tensor network methods for many-body quantum systems (lecture 1).

$13^{00} - 14^{00}$ Lunch

$14^{40} - 15^{00}$ Tea/Coffee

$15^{00} - 17^{00}$ Ryan Sweke (UKZN, South Africa), An introduction to tensor network methods for many-body quantum systems (lecture 2).

$18^{30} - 21^{00}$ Welcome Reception

Tuesday, 22 September

Session Chair: Francesco Petruccione

$09^{30} - 10^{00}$ Tea/Coffee

$10^{00} - 12^{00}$ Hakan E. Tureci (Princeton University, USA), Cavity QED Lattices: A platform to study many-body physics with photons.

$12^{00} - 13^{00}$ Discussion

$13^{00} - 14^{00}$ Lunch

$14^{00} - 14^{20}$ Daniel Uken (UKZN, South Africa), Quantum dynamics of a plasmonic metamolecule with a time dependent driving.

$14^{20} - 14^{40}$ Filip Wudarski (UKZN, South Africa), Admissible memory kernels for random unitary qubit evolution.

$14^{40} - 15^{00}$ Tea/Coffee

$15^{00} - 17^{00}$ Peter Kirton (University of St Andrews, UK), Modelling Photon Condensation.

$17^{00} - 18^{00}$ Discussion

$19^{00} - 21^{00}$ Dinner (wine tasting)

Wednesday, 23 September

Session Chair: Jens Koch

$09^{30} - 10^{00}$ Tea/Coffee

$10^{00} - 12^{00}$ Igor Lesanovsky (University of Nottingham, UK), Kinetic constraints in strongly interacting gases of Rydberg atoms.

$12^{00} - 13^{00}$ Discussion

$13^{00} - 14^{00}$ Lunch

$14^{00} - 14^{20}$ Camille Lombard Latune (UKZN, South Africa), Quantum Metrology and the Noise.

$14^{20} - 14^{40}$ Ilya Sinayskiy (UKZN, South Africa), Open Quantum Brownian Motion.

$14^{40} - 15^{00}$ Tea/Coffee

$15^{00} - 17^{00}$ Hendrik Weimer (University of Hannover, Germany), Variational principle for dissipative quantum systems.

$17^{00} - 18^{00}$ Discussion

$19^{00} - 21^{00}$ Dinner

Thursday, 24 September

Session Chair: Ilya Sinayskiy

$09^{30} - 10^{00}$ Tea/Coffee

$10^{00} - 12^{00}$ Davide Rossini (Scuola Normale Superiore, Pisa, Italy), Many-body simulations of open quantum systems.

$12^{00} - 12^{30}$ Analabha Roy (NITheP Stellenbosch, South Africa), Persistent Many-Body Freezing in Periodically Driven Spins: From simple quantum magnets to disordered, non-integrable and long range models.

$12^{30} - 13^{00}$ Discussion

$13^{00} - 14^{00}$ Lunch

$14^{00} - 14^{20}$ Konstantin G. Zloshchastiev (DUT, South Africa), Quantum entropy of systems with sinks or sources described by non-Hermitian Hamiltonians.

$14^{20} - 14^{40}$ Vitalii Semin (UKZN, South Africa), Description of non-equilibrium quantum systems with the help of projection operators.

$14^{40} - 15^{00}$ Tea/Coffee

$15^{00} - 17^{00}$ Jens Koch (Northwestern University, USA), Validating Open Quantum Simulators by Lindblad Resummation Techniques.

$17^{00} - 18^{00}$ Discussion

$19^{00} - 21^{00}$ Beach barbeque - conference dinner

Friday, 25 September

$09^{30} - 10^{00}$ Tea/Coffee

$10^{00} - 13^{00}$ Discussion

$13^{00} - 14^{00}$ Lunch

$14^{00} - \ldots$ Departure of delegates

List of Abstracts

Monday, 21 September

An introduction to tensor network methods for many-body quantum systems

Ryan Sweke

Fairly recently it has been realised that locality of interactions in quantum many-body systems has profound consequences for the entanglement and correlation structure of certain states within these systems. A tensor network representation of a many-body quantum state is a representation in which this correlation structure is made explicit, and over the last twenty years such representations have proven to be powerful tools for both the theoretical and numerical study of many-body quantum systems. In these lectures I will provide a motivation for tensor networks, an introduction to the formalism of tensor network diagrams and a brief description of some standard tensor network based numerical methods for both open and closed one-dimensional systems.

Tuesday, 22 September

Cavity QED Lattices: A platform to study many-body physics with photons

Hakan E. Tureci

Quantum matter coupled to enhanced optical fields in confined geometries such as resonators and waveguides offer a promising platform to study emergent phenomena far-from-equilibrium [1]. In my talk I will discuss our recent efforts [2,3,4] at understanding what a quantum phase transition of photons may look like in a lattice of Cavity Quantum Electrodynamics systems, where photons become itinerant. Surprisingly this has lead us back to the very origin of Quantum Electrodynamics and the Quantum Theory, namely to Planck and Einstein's theory of thermal cavity radiation. We find a modification to the Planck-Einstein theory due to the backaction from (material) oscillators and show that a Cavity QED network displays an instability towards a ferroelectric phase when light-matter coupling is sufficiently increased. The true potential of coupled light-matter systems is however unleashed in driven Cavity QED networks. I will discuss a general method to use photon-mediated interactions between qubits to drive them to a long-distance entangled state with an arbitrarily long lifetime [5]. We find that photon-mediated interactions provide a highly versatile toolbox to engineer the unitary and dissipative dynamics of spatially separated qubits, with important implications for an infinitely long-lived distributed quantum memory [6].

1 A. Houck, H. E. Tureci, J. Koch, Nature Physics 8, 292 (2012).

2 M. Schiro, M. Bordyuh, B. Oztop, H. E. Tureci, Phys. Rev. Lett. 109, 053601 (2012).

3 M. Schiro, M. Bordyuh, B. Oztop, H. E. Tureci, J. Phys. B 46, 224021 (2013).

4 M. Schiro et al, arxiv:1503.04456

5 C. Aron, M. Kulkarni, H. E. Tureci, Phys. Rev. A 90, 062305 (2014).

6 C. Aron, M. Kulkarni, H. E. Tureci, arxiv:1412.8477

Quantum dynamics of a plasmonic metamolecule with a time dependent driving

Daniel Uken

We simulate the dynamics of a quantum dot coupled to the single resonating mode of a metal nano-particle. [D.A. Uken and A. Sergi, arXiv:1506.05664 (quant-ph)] Systems like this are known as metamolecules. In this talk, we consider a time-dependent driving field acting onto the metamolecule. We use the Heisenberg equations of motion for the entire system, while representing the resonating mode in Wigner phase space. A time-dependent basis is adopted for the quantum dot. We integrate the dynamics of the metamolecule for a range of coupling strengths between the quantum dot and the driving field, while restricting the coupling between the quantum dot and the resonant mode to weak values. By monitoring the average of the time variation of the energy of the metamolecule model, as well as the coherence and the population difference of the quantum dot, we observe distinct non-linear behavior in the case of strong coupling to the driving field.

Admissible memory kernels for random unitary qubit evolution

Filip Wudarski

We analyze random unitary evolution of a qubit within memory kernel approach. We provide sufficient conditions which quarantee that corresponding memory kernel generates physically legitimate dynamics. Interesitngly, we are able to recove several well-known examples and to generate new classes of non-trivial qubit evolution. Surprisingly, it turns out that a class of quantum evolutions with memory kernel generated by out approach give rise to the vanishing of a non-Markovianity measrue based on the distiguishability of quantum states.

Modelling Photon Condensation

Peter Kirton

Recent experiments [1] have shown a thermalised gas of weakly interacting photons which obeys the Bose-Einstein distribution, and undergoes a transition to a Bose condensed state above a critical density at room temperature. The photons are able to reach this state by repeated absorption and emission from dye molecules. While the results presented so far match closely the equilibrium Bose-Einstein distribution, it is not clear what exactly is the distinction between this system and regular laser.

We address this question [2] starting from a laser-like model and developing a full out-of-equilibrium treatment of the system. We use the model to look at how the thermal distribution arises and what mechanisms cause the state to cross-over to that more typical of a standard dye laser [3]. The behaviour in the presence of a spatially non-uniform pump is also examined and we show how this can lead to gain saturation and multimode condensation.

1 Klaers et al, Nature, 468, 545 (2010)

2 Kirton and Keeling, PRL, 111, 100404 (2013)

3 Kirton and Keeling, PRA, 91 033826 (2015)

Wednesday, 23 September

Kinetic constraints in strongly interacting gases of Rydberg atoms
Igor Lesanovsky

In the presence of dissipation the dynamics of gases in which atoms are laser-excited to high-lying Rydberg states is governed by so-called kinetic constraints. This means that the relaxation rate of a given atom is dictated in a very specific way by the precise state of its neighbourhood. These constraints lead to a remarkable rich out-of-equilibrium dynamics although the final stationary state might be entirely trivial. In the context of soft-condensed matter physics such kinetic constraints are believed to play a central role in the emergence of glassy behaviour. However, it is often difficult to establish the precise pathways that lead to their emergence.

In Rydberg gases kinetic constraints can be derived explicitly from first principles and lead to a remarkably complex dynamics. When driven on resonance these gases feature a self-similar evolution. When driven off-resonantly one can identify non-equilibrium features such as nucleation, clustering and growth and the emergence of a non-equilibrium phase transitions in the directed percolation universality class, whose experimental realisation in one and three dimensions so far has been elusive. I will discuss recent experimental and theoretical results which suggest that strongly interacting atomic Rydberg gases indeed enable new possibilities for the observation of correlated many-body effects that are typically studied in the context of soft-matter physics.

Quantum Metrology and the Noise
Camille Lombard Latune

We give a general introduction to Quantum Metrology, present the basic concepts and explain where limitations on parameter estimation precision come from for both classical and quantum systems, emphasizing their fundamental difference. The limitations due to the structure of quantum mechanics can be partially circumvent using genuine quantum properties (entanglement, squeezing, ...). The main problem in Quantum Metrology comes from the noise, stemming from the unavoidable interaction with some external system. Firstly the noise destroys quantum properties, and by the way our attempt to increase the precision using genuine quantum properties. Second problem, while the parameter estimation under unitary process is quite well understood, the non-unitary one is still widely unsolved. We introduce those problematics and give some partial solutions.

Open Quantum Brownian Motion

Ilya Sinayskiy

The microscopic derivation of Open Quantum Brownian Motion (OQBM) is presented. The quantum master equation for OQBM is derived for a weakly driven system interacting with the decoherent environment. The connection between dynamical and non-equilibrium thermodynamical aspects of the walk will be discussed. Examples of the dynamics for initial Gaussian and non-Gaussian distributions are presented.

Variational principle for dissipative quantum systems

Hendrik Weimer

Dissipative quantum many-body systems are extremely challenging to analyze, as most theoretical tools developed for equilibrium systems cannot be applied. I will present the first steps towards a deeper understanding of these systems by introducing a variational principle for the non-equilibrium steady states of the quantum master equation describing the dynamics. I will apply this approach to a dissipative extension of the Ising model, which is of importance to ongoing experiments on ultracold Rydberg atoms. Finally, I will present an extension of the variational principle that allows to investigate the full time evolution of open quantum many-body systems.

Thursday, 24 September

Many-body simulations of open quantum systems

Davide Rossini

Understanding the physics of dissipative strongly correlated quantum systems is a formidable task. Most of the results obtained so far are at the mean-field level, while little is known beyond that limit. To overcome this restriction, we propose a combination of numerical methods based on matrix product operators, quantum trajectories and cluster expansions.

We first employ our techniques to study an array of QED cavities coupled by nonlinear elements in the presence of photon leakage and driven by a coherent source. We address the steady-state phase diagram and the photon transport through a one-dimensional setup. Later we consider a dissipative array of spin-1/2 quantum systems interacting through an XYZ Heisenberg Hamiltonian, and subjected to incoherent spin flips. We focus on the emergence of a Z_2-symmetry breaking phase transition, which has been predicted to appear with mean field. We show that significant differences are found if the interactions are treated carefully; such discrepancies become more pronounced in a reduced dimensionality.

Persistent Many-Body Freezing in Periodically Driven Spins: From simple quantum magnets to disordered, non-integrable and long range models

Analabha Roy

Dynamical freezing is one of the most startling manifestations of quantum interference, where the evolution of a simple system is arrested with infinite hysteresis under a finite but suitably tuned coherent periodic drive. Freezing can be seen as a many body generalization of Coherent Destruction of Tunneling (CDT), where single particle quantum systems can be localized in space as the ratio of the drive frequency ω and amplitude h_0 tends to certain specific values (the freezing condition). I will demonstrate the onset of freezing in periodically driven Ising spins with nearest neighbour interactions, and then discuss our investigations of the fate of freezing in more complex quantum many body systems. These include BCS superfluids, which can be mapped (when in equilibrium) to the Ising model, as well as spin systems without the simplifying symmetries of the n.n. Ising model. In the latter cases, I first focus on destroying translational invariance through disorder. I will demonstrate that, although random interactions kill freezing eventually, spectacular remnants survive even with strong disorder. During the time evolution of such an system without a drive, the transverse magnetization relaxes exponentially with time with a decay time-scale τ. Under external periodic drive at the freezing condition, this relaxation slows down (τ shoots up) by orders of magnitude, although it remains finite. I will demonstrate the persistence of this freezing remnant using Floquet Theory and asymptotic renormalization group techniques, as well as confirm our findings with exact numerical simulations. Finally, I will report findings from our ongoing works on nonintegrable spin systems with long range interactions. These involve the exploration of novel numerical techniques, such as the quantum BBGKY hierarchy, and the Discrete Truncated Wigner Approximation, that provide approximate dynamics of correlations and entanglement witnesses.

Relevant Publications:

- A. Roy and A. Das, "Fate of dynamical many-body localization in the presence of disorder", arXiv:1405.3966, Phys. Rev. B, 91, 121106(R) (2015).
- A. Roy, "Nonequilibrium dynamics of Ultracold Fermi superfluids", Invited mini-review, arXiv:1211.6936 , Eur. Phys. J. ST, 222 (3-4), 975-993 (2013).

Quantum entropy of systems with sinks or sources described by non-Hermitian Hamiltonians

Konstantin G. Zloshchastiev

We study the quantum entropy of systems that are described by non-Hermitian Hamiltonians, which can model the effects of sinks or sources. We generalize the von Neumann entropy to the non-Hermitian case and find that one needs both the normalized and non-normalized density operators in order to properly describe irreversible processes. Such a generalization captures the expected behavior of the entropy as a measure of disorder in quantum dissipative systems

Description of non-equilibrium quantum systems with the help of projection operators

Vitalii Semin

In this work we study different form of projection operators and their application to describing of quantum systems out of equilibrium. We show that projection operators give a convenient way to build majority of known master equations, which are equivalent to each other in this approach. This equivalency can be use to extract some additional information about the quantum systems just switching the form of projection operators. The main features of the projection operator technique are described by an example of a dissipative XX spin chain.

Validating Open Quantum Simulators by Lindblad Resummation Techniques

Jens Koch

Lattice models of fermions, bosons, and spins have long served to elucidate the physics of quantum phase transitions in a variety of systems. Generalizing such models to incorporating driving and dissipation has opened new vistas to investigate nonequilibrium phenomena and dissipative phase transitions in interacting many-body systems. As the first circuit-QED based quantum simulators realizing such models are currently being studied experimentally, it is timely to consider the theoretical validation of new devices in accessible asymptotic regimes. For this purpose, I will present a resummation scheme for the Lindblad perturbation series applicable to general open quantum lattices. Employing a convenient diagrammatic representation, we can utilize this method to investigate open Jaynes-Cummings lattices in specific limits and reliably predict observables for such lattices with different lattice geometries.