23/02/2015 — Monday

- **Peter Hänggi — EPJ Lecture**

Quantum fluctuation relations

Fluctuation Relations connect the probabilities for quantities like work that is applied to a system by external forces, and heat or particle numbers that are exchanged with a reservoir to those which are observed in a time-reversed set-up of the original experimental situation. For the fluctuation relations to hold, both the forward and the backward processes have to start out in thermal equilibrium but subsequently may drive the system into arbitrarily far-from-equilibrium situations.

Such Fluctuation Relations are not restricted to the linear response regime but rather establish exact relations between non-equilibrium fluctuations of the forward and backward processes with equilibrium quantities of the according equilibrium states. Taken to the quantum realm, fluctuation relations underwent rapid progress in recent years in providing a new avenue to characterize nonlinear transport of work, energy, heat or charge for quantum devices and engines.

Apart from stating what we know, in this talk I will focus on subtle issues relating to the notion of work and particularly of heat, plus yet still further unresolved issues when it comes to the role of finite-to-strong interactions between System-and-Bath(s), as well as subtleties that arise in case that the quantum measurements on the *system* are not strictly projective but of a generalized nature.

The material for this talk is based on joint collaborations with Peter Talkner and Michele Campisi.

For feature articles, talks and ref. materials see "(Quantum)-Fluctuation Theorems" http://www.physik.uni-augsburg.de/theo1/hanggi/Fluctuation.html

Some comprehensive references are:

[1] M. Campisi, P. Hänggi and P. Talkner. Colloquium: Quantum fluctuation relations: Foundations and applications. Rev. Mod. Phys. **83**, 771 (2011); M. Campisi, P. Hänggi and P. Talkner. Addendum and Erratum: Quantum fluctuation relations: Foundations and applications. Rev. Mod. Phys. **83**, 1653 (2011).

[2] P. Hänggi and P. Talkner, Perspective Insight: The other QFT. Nature Physics **11**, 108 (2015).

Workshop on Quantum Information and Thermodynamics

- ## Massimiliano Esposito

Quantum thermodynamics with strong coupling

I will present a formulation of quantum thermodynamics within the framework of nonequilibrium Green's functions which can treat strong system-reservoir interactions. The first and second law will be derived and used to characterize transport in steady-state as well as in driven devices.

- ## Mauro Paternostro

A many-body perspective to quantum thermodynamics

We consider the non-equilibrium dynamics of a simple system consisting of interacting spin-1/2 particles subjected to a collective damping. The model is close to situations that can be engineered in hybrid electro/opto-mechanical settings. Making use of large-deviation theory, we find a Gallavotti-Cohen symmetry in the dynamics of the system as well as evidence for the coexistence of two dynamical phases with different activity levels. We show that additional damping processes smoothen out this behavior. Our analytical results are backed up by Monte Carlo simulations that reveal the nature of the trajectories contributing to the different dynamical phases.

- ## Adolfo del Campo

Shortcuts to adiabaticity in many-body systems

The nonadiabatic dynamics of a many-body system driven through a quantum critical point can be controlled using counterdiabatic driving, where the formation of excitations is suppressed by assisting the dynamics with auxiliary multiple-body nonlocal interactions. We propose an alternative scheme which circumvents practical challenges to realize shortcuts to adiabaticity in mesoscopic systems by tailoring the functional form of the auxiliary counterdiabatic interactions. A driving scheme resorting on few-body short-range interactions is shown to generate an effectively adiabatic dynamics. Quantum thermodynamic cycles and engines assisted by these shortcuts will be discussed.

- ## Varun Narasimhachar

Towards a complete theory of thermodynamics with quantum coherence

We find an elegant characterization of the low-temperature limit of the "thermal operations" model of thermodynamics. We call the resulting model "cooling processes". We derive necessary and sufficient conditions for the feasibility of state transitions under cooling

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processes. We also rigorously confirm the intuitive robustness of quantum coherence against low-temperature thermal noise. Additionally, we develop the low-temperature "Gibbs-preserving" model, and by comparing our results on the two models, we argue that the latter is a poor approximation to physical processes. While other recent works have provided important insights into the workings of quantum coherence in thermodynamics, our treatment incorporates coherence completely (i.e., yielding necessary and sufficient conditions) in the low-temperature regime. Combining the spirit of our approach with that of the other works could pave the way towards a more complete treatment of coherent thermodynamics at general temperatures.

- ## Marcus V. S. Bonança

Optimal driving of isothermal processes close to equilibrium

We investigate how to minimize the work dissipated during nonequilibrium processes. To this end, we employ methods from linear response theory to describe slowly varying processes, i.e., processes operating within the linear regime around quasistatic driving. As a main result we find that the irreversible work can be written as a functional that depends only on the correlation time and the fluctuations of the generalized force conjugated to the driving parameter. To deepen the physical insight of our approach we discuss various self-consistent expressions for the response function, and derive the correlation time in closed form. Our findings are illustrated with several analytically solvable examples.

- ## Lea Santos

Relaxation and thermalization in isolated interacting quantum systems

We consider one-dimensional isolated interacting quantum systems that are taken out of equilibrium instantaneously. Three aspects are addressed: (i) the relaxation process, (ii) the size of the temporal fluctuations after relaxation, (iii) the conditions to reach thermal equilibrium. The relaxation process and the size of the fluctuations depend on the interplay between the initial state and the Hamiltonian after the perturbation, rather than on the regime of the system. They may be very similar for both chaotic and integrable systems. The general picture associating chaos with the onset of thermalization is also further elaborated. It is argued that thermalization may not occur in the chaotic regime if the energy of the initial state is close to the edges of the spectrum, and it may occur in integrable systems provided the initial state is sufficiently delocalized.

- **George Ruppeiner**

Three ways to thermodynamic curvature

The thermodynamic Ricci curvature scalar R is an inevitable element of thermodynamics. R emerges naturally on representing thermodynamic fluctuation theory with a Riemannian thermodynamic information metric. Thermodynamic fluctuation theory extends macroscopic thermodynamics to the mesoscopic regime, and R reflects the organizing effects of interatomic interactions. R is positive if repulsive interatomic interactions dominate, and negative if attractive interactions dominate. The absolute value —R— gives the characteristic size scale of the mesoscopic fluctuations, the correlation length ξ. In this talk I demonstrate three methods of calculating R: 1) from statistical mechanics, 2) from thermodynamics, and 3) from symmetry, analyticity, and limiting properties alone. For method 1, I show several fluid and magnetic spin models, including some recent results. For method 2, I show a few examples based on black hole thermodynamics. For method 3, I show two examples, the critical point and strongly interacting Fermi systems, both with strong interactions and universal properties. Applications where R is calculated for cases where the microscopic properties are either too hard to calculate, or entirely unknown have particular promise.

- **Philip Walther**

Tunable Boson Sampling and superimposing quantum gates for quantum computes

The advantages of the photons makes optical quantum system ideally suited for fundamental quantum physics experiments and a variety of applications in quantum information processing. Here I will discuss new experimental insights into resource-efficient intermediate quantum computing utilizing the Bosonic nature of photons as well as new quantum computational concepts that superimpose the order of quantum gates.

- **Jens Eisert**

Local quantum thermodynamics

Quantum thermodynamics aims at identifying the ultimate limits of notions of work extraction and thermodynamic state transformations in the quantum regime. Resource theories provide a quantum information-inspired mathematical framework capturing the most general reasonably allowed operations in this context, reminding of resource theories of entanglement in composite quantum systems. In this work, we introduce the notion of local thermodynamics, bringing together ideas of quantum thermodynamics with the study of local interactions and multi-partite quantum systems, and identify significant limitations that arise in this setting. Specifically, we prove that without additional assumptions there are situations where no work can be extracted using thermalising processes while a finite amount of work can be extracted using Gibbs-preserving maps if constraints on locality are imposed. This is in strong contrast to the setting where no constraints are imposed and where thermalising porcesses are universal with respect to work extraction in the sense that the same amount of work can be extracted as with more general Gibbs-preserving maps. In a more abstract setting, these results can be seen as a step to an understanding of the intersection thermodynamics with different resource theories, such as entanglement. Furthermore, we argue that state-spaces and operations of general resource theories are not most conveniently modelled as spaces of quantum states and CPT-maps, but by more general objects in a language of category theory, and briefly discuss the application of this idea to the resource theory of asymmetry.

24/02/2015 — Tuesday

- ## Ronnie Kosloff

Dynamical viewpoint on quantum thermodynamics: towards the III-law

TBA.

- ## Andrea Gambassi

Irreversible work, large deviations, critical Casimir effect, and universality in quantum quenches

Recent experimental progresses in the physics of ultracold atomic gases have revived the interest in the behavior of thermally isolated quantum statistical systems, especially after sudden changes (quenches) of their control parameters. Considering the quench as a thermodynamic transformation, we focus on the probability distribution of the irreversible work done on the system. Large deviations, i.e., rare fluctuations of this intensive work are unexpectedly connected to the physics of a classical system confined in a film geometry. If the quench occurs close to a (quantum) critical point, the large deviations acquire universal features dictated by the critical Casimir effect in the corresponding classical system. The statistics of the work in bosonic systems may additionally display a transition which is analogous to the equilibrium Bose-Einstein condensation.

- ## Michele Campisi

Nonequilibrium fluctuations in quantum heat engines: Theory, example, and possible solid state experiments

We study the stochastic energetic exchanges in quantum heat engines. Due to microreversibility, these obey a fluctuation relation, called the heat engine fluctuation relation, which implies the Carnot bound: no machine can have an efficiency larger than Carnot's efficiency. The stochastic thermodynamics of a quantum heat engine (including the joint statistics of heat and work and the statistics of efficiency) is illustrated by means of an optimal two-qubit heat engine, where each qubit is coupled to a thermal bath and a two-qubit gate determines energy exchanges between the two qubits. We discuss possible solid state implementations with Cooper pair boxes and flux qubits, quantum gate operations, and fast calorimetric on-chip measurements of single stochastic events.

ACKNOWLEDGEMENTS: This talk presents a joint work with Prof. Rosario Fazio and Prof. Jukka Pekola. This research was supported by a Marie Curie Intra European Fellowship within the 7th European Community Framework Programme through the project NeQuFlux grant n. 623085 and by the COST action MP1209 "Thermodynamics in the quantum regime".

[1] Michele Campisi, J. Phys. A **47**, 245001 (2014).

[2] Michele Campisi, Jukka Pekola and Rosario Fazio, in press New J. Phys. (2015), arXiv:1411.2425.

- ## André Xuereb

Dynamical symmetries and crossovers in spin systems with collective dissipation

I discuss the non-equilibrium dynamics of a simple system consisting of interacting spin-1/2 particles subjected to a collective damping. The model is close to situations that can be engineered in hybrid electro/optomechanical settings. Making use of large-deviation theory, I explore symmetries in the dynamics of the system as give evidence for the coexistence of two dynamical phases with different activity levels. I show how additional damping processes affect this behaviour. Analytical results are backed up by Monte Carlo simulations that reveal the nature of the trajectories contributing to the different dynamical phases.

- ## Sai Vinjanampathy

Second law for quantum operations in presence of memory

The formulation of the second law thus far has relied on the Born-Markov approximation. I will talk about the extension of the second law of thermodynamics to quantum systems that share initial correlations with their environment, going beyond such an approximation. Such system dynamics are known to not be described well by CPTP description. Such initial correlations also make the discussion of entropy evolution subtle. I will resolve these issues and present a complete second law for evolution of such quantum systems.

- ## Roberto S. Sarthour

Experimental demonstration of information to energy conversion in a quantum system at the Landauer Limit

Landauer's principle sets fundamental thermodynamic constraints for classical and quantum information processing. Here we measure, for the first time, the heat dissipated in elementary quantum logic gates, at the Landauer limit, implemented in a Nuclear Magnetic Resonance system. This allows for the detailed study of irreversible entropy production in quantum information processors.

- ## Ivan S. Oliveira

The Fantastic two-qubit Quantum Computer

For the past twenty years the search for a large scale quantum computer, containing hundreds or may be thousands of qubits, has been the holy grail for different groups, systems and techniques. However, it has been on the side of very basic and fundamental physics where exciting results have appeared, in systems containing only a few qubits. Actually, in many interesting situations it is undesirable to have more than two qubits. Here is where Nuclear Magnetic Resonance (NMR), as a quantum information processing (QIP) technique, appears as one of the main experimental techniques for testing fundamental principles and ideas. On this talk I will review some of the basic NMR aspects for QIP, and present two rather distinct two-qubit NMR quantum processors. I'll show some examples of studies on quantum simulation and quantum thermodynamics, including a proof-of-principle of a two-qubit quantum thermometer which uses a scattering circuit, and never thermalizes with the system it reads the temperature. All the selected experiments were performed by the NMR Group, in various collaborations, at the Brazilian Center for Research in Physics, in Rio de Janeiro, CBPF (www.cbpf.br).

- **Artur Malabarba**

Autonomous Quantum Thermal Machines

We consider a completely isolated autonomous quantum thermal machine, where an explicit quantum clock is responsible for implementing all transformations on a system, bath, and work storage device. In a general context, we show this is enough to perform any unitary on the system, with no external control. In the context of thermodynamic work extraction, this new framework obbeys the first and second laws of thermodynamics, and optimal work extraction and state transformations are possible (extracting work as close as desired to the change in free energy of the system). Finally, we shown that these autonomous machines suffer no intrinsic thermodynamic cost compared to externally controlled ones.

- **Jan Gieseler**

Microscopic thermodynamics with levitated nanoparticles

Micsospheres trapped in liquid by so called optical tweezers have been established as useful tools to study microscopic thermodynamics. Since the sphere is in direct contact with the liquid, it is strongly coupled to the thermal bath and its dynamics is dominated by thermal fluctuations. In contrast, here we use an optically trapped nanoparticle in vacuum to study fluctuations of a system that is coupled only weakly to the thermal bath. The weak coupling allows us to resolve the ballistic dynamics and to control its motion, thereby preparing it in a non-equilibrium state. We demonstrate experimentally the validity of a fluctuation theorem for the relative entropy change occurring during relaxation from such a non-equilibrium steady state. In addition, by using a nanoparticle trapped in a bi-stable potential we experimentally measure the nanoparticle's transition rates for variable damping and directly resolve the Kramers' turnover.

Workshop on Quantum Information and Thermodynamics

- **Kurt Jacobs**

The minimum energy cost of controlling high-Q mesoscopic systems

The energy cost of controlling mesoscopic systems is important in many contexts: it provides the equivalent for mesoscopic systems of the fundamental cost of refrigeration; it tells us the minimum power consumption required by mesoscopic devices maintained in nonequilibrium states; and it allows us to determine the efficiency of any control method, thereby providing insight into the design of efficient control mechanisms. I will present recent results that answer the question of the energy cost of control for all weakly-coupled, or "high-Q", mesoscopic systems.

25/02/2015 — Wednesday

- **Masahito Ueda**

Absolute irreversibility in nonequilibrium processes under feedback control

We generalize nonequilibrium integral equalities to situations involving absolutely irreversible processes for which the forward-path probability vanishes and the entropy production diverges, rendering conventional integral fluctuation theorems inapplicable. We identify the mathematical origins of absolute irreversibility as the singularity of probability measure, and demonstrate the validity of the obtained equalities in simple examples.

- **Mikko Möttönen**

Fluctuation relations in single-electron devices

Being a robust solid-state device, a single-electron box offers a convenient platform to study fluctuation relations. Typically hundreds of thousands of stochastic trajectories can be readily recorded giving rise to high precision in the resulting probability distributions. In this talk, I will present results from the first two experiments [1,2] on classical fluctuation relations carried out with driven single-electron boxes. In these experiments, we measured the integral and detailed fluctuation relations for dissipated work and entropy production and found that they closely follow the expected theoretical behavior with a large dynamic range. For the entropy, we considered separately two different entropy productions we refer to as stochastic and thermodynamic. They yield different distributions but both obey the fluctuation relations. I will also briefly discuss our latest results on quantum fluctuation relations of work, namely, the effect of (i) a quantum-mechanical drive [3] and (ii) an adiabatic classical drive [4].

[1] O.-P. Saira, Y. Yoon, T. Tanttu, M. Möttönen, D. V. Averin, and J. P. Pekola, Phys. Rev. Lett. **109**, 180601 (2012).
[2] J. V. Koski, T. Sagawa, O-P. Saira, Y. Yoon, A. Kutvonen, P. Solinas, M. Möttönen, T. Ala-Nissila, and J. P. Pekola, Nature Phys. **9**, 644 (2013).
[3] J. Salmilehto, P. Solinas, and M. Möttönen, Phys. Rev. E **89**, 052128 (2014).
[4]S. Suomela, J. Salmilehto, I. G. Savenko, T. Ala-Nissilä, and M. Möttönen, arXiv:1411.4805 (2014).

Workshop on Quantum Information and Thermodynamics

- **Bernhard Rauer**

Does an isolated quantum many-body system relax?

The connection between the non-equilibrium dynamics of isolated quantum many-body systems and statistical mechanics is a fundamental open question. In general it is conjectured that the unitary quantum evolution of a sufficiently complex system leads to an apparent maximum-entropy state that can be described by thermodynamical ensembles. Conventional ensembles fail to describe the large class of systems that exhibit non-trivial conserved quantities and generalized ensembles have been predicted to maximize entropy in these systems. We study relaxation dynamics in an isolated many-body system of interacting 1d Bosons by investigating the evolution of coherence between two 1d systems created from splitting a single system. In our experiments we explicitly show that the system relaxes to a pre-thermalized state [1], that the thermal-like properties emerge locally propagating through the system in a light-cone-like evolution [2] and that the pre-thermalized state can be described by a generalized Gibbs ensemble [3]. This is verified through a detailed study of the phase correlations between the two systems. The applicability of the generalized ensemble description for isolated quantum many-body systems points to a natural emergence of classical statistical properties from the microscopic unitary quantum evolution.

[1] M. Gring et al., Science **337**, 1318 (2012); D. Adu Smith et al.

NJP **15**, 075011 (2013). [2] T. Langen et al. Nature Physics **9**, 640 (2013). [3] T. Langen et al. arXiv:1411.7185 (2014).

- ## Alexia Auffeves

Information Thermodynamics in a hybrid optomechanical system

Information thermodynamics is a recent field that investigates the links between information and energy. Its most famous "Gedanken-experiments" are Landauer erasure and Szilard engine, that describe the reversible conversion of a single bit of information into an elementary amount of work between a system and a battery. So far, direct evidences of such reversible work exchanges by measuring the battery's energy has remained elusive. In this article, we show that a hybrid opto-mechanical transducer is a proper platform to monitor these conversions. Such devices consist in an optically active quantum emitter, playing the role of the bit, coupled to a mechanical resonator, playing the role of the battery. Heat is exchanged with the electromagnetic reservoir. Within a mechanical oscillation, we connect the entropy variations of the quantum emitter with the mechanical energy variations, that are identified with work exchanges. These results pave the road towards experimental investigation of quantum information thermodynamics.

- ## Jochen Gemmer

Relevance of the eigenstate thermalization hypothesis for thermal relaxation

In this Letter we study the validity of the eigenstate thermalization hypothesis (ETH) and its role for the occurrence of initial-state independent (ISI) equilibration in closed quantum many-body systems. Using the concept of dynamical typicality, we present an extensive numerical analysis of energy exchange in integrable and nonintegrable spin-1/2 systems of large size outside the range of exact diagonalization. In case of nonintegrable systems, our finite-size scaling shows that the ETH becomes valid in the thermodynamic limit and can serve as the underlying mechanism for ISI equilibration. In case of integrable systems, however, we observe ISI equilibration despite the violation of the ETH. We establish a connection between this observation and the need of choosing a proper parameter within the ETH.

26/02/2015 — Thursday

- ## Antonio Acín

Work and correlations

We generalize nonequilibrium integral equalities to situations involving absolutely irreversible processes for which the forward-path probability vanishes and the entropy production diverges, rendering conventional integral fluctuation theorems inapplicable. We identify the mathematical origins of absolute irreversibility as the singularity of probability measure, and demonstrate the validity of the obtained equalities in simple examples.

- ## Sebastian Deffner

Quantum fluctuation theorems in open systems

For isolated quantum systems fluctuation theorems are commonly derived within the two-time energy measurement approach. After summarizing recent result on more general measurements we turn to an experimentally relevant class of systems. In particular, we show that the quantum Jarzynski equality generalizes to PT-symmetric quantum mechanics with unbroken PT-symmetry. In the regime of broken PT-symmetry the Jarzynski equality does not hold as also the CPT-norm is not preserved during the dynamics. These findings are illustrated for an experimentally relevant system – two coupled optical waveguides. It turns out that for these systems the phase transition between the regimes of unbroken and broken PT-symmetry is thermodynamically inhibited as the irreversible work diverges at the critical point.

- ## Yariv Kafri

Pressure in non-equilibrium (active) systems

Pressure is the mechanical force per unit area that a confined system exerts on its container. In thermal equilibrium, the pressure depends only on bulk properties (density, temperature, etc.) through an equation of state. The talk will show that in active systems containing self-propelled particles, the pressure instead can depend on the precise interactions between the system's contents and its confining walls. This implies that generic active systems have no equation of state. Other anomalous attributes of pressure will also be discussed. Finally, it will be shown that in certain fine tuned cases an equation of state can be recovered. The physics behind the equation of state in a specific example will be discussed.

- **Lídia del Rio**

A generalized resource theory for thermodynamics

We introduce a general framework for resource theories, and discuss applications to thermodynamics. This framework allows us to analyse different aspects of thermodynamics independently, and helps understand the origin of familiar features of the theory. For instance, what impact does it have to change the structure of the state space from classical to quantum mechanics, or even box world? How do the laws of thermodynamics look if, instead of energy conservation, we impose other physical constraints on the allowed transformations? We also model the knowledge of an agent acting on a system explicitly, and see how it affects the work gain or cost of a state transformation in different settings.

- **Martí Perarnau-Llobet**

The most energetic passive state

Passive states are defined as those states that do not allow for work extraction in a cyclic (unitary) process. Within the set of passive states, thermal states are the most stable ones: they maximize the entropy for a given entropy, and similarly they minimize the energy for a given entropy. We find the passive states lying in the other extreme, i.e., those states that maximize the energy for a given entropy, which we show also minimize the entropy when the energy is fixed. These extremal properties make these states useful to obtain fundamental bounds for the thermodynamics of finite dimensional quantum systems, which we show in several different scenarios. Furthermore, we find that this family of states is directly connected to the microcanonical state, thus building a new connection between the two most fundamental distributions in statistical physics.

- **Marcelo França Santos**

Non universality of entanglement convertibility

Recently, it has been suggested that operational properties connected to quantum computation can be alternative indicators of quantum phase transitions. In this work we systematically study these operational properties in 1D systems that present phase transitions of different orders. For this purpose, we evaluate the local convertibility between bipartite ground states. Our results suggest that the operational properties, related to non-analyticities of the entanglement spectrum, are good detectors of explicit symmetries of the model, but not necessarily of phase transitions. We also show that thermodynamically equivalent phases, such as Luttinger liquids, may display different convertibility properties depending on the underlying microscopic model.

- ## Daniel Alonso

Quantum refrigerator and their performance

In this lecture I shall present results on quantum continuous refrigerators, either absorption or driven, and their efficiency, define *a la* Carnot. The whole set up, working material and heat baths may reach an stationary state, if so, and stationary energy flux, $\dot{\mathcal{Q}}_c$ from the system to be cooled to the working material is obtained as well as stationary energy flux, $\dot{\mathcal{Q}}_w$ from the work bath to the working material. The ratio of those two fluxes defines the Carnot efficiency of the fridge as

$$\epsilon_C = \frac{\dot{\mathcal{Q}}_c}{\dot{\mathcal{Q}}_w},$$

Which is the object of our study. We shall look at simple systems operating in a thermodynamic cycle and address their optimal efficiency when operating as quantum refrigerators. One of our results shows that the cooling performance at maximum cooling power depends on the details of the systems-thermal baths interaction.

- ## Frederico Brito

Testing time reversal symmetry in artificial atoms

Over the past several decades, a rich series of experiments has repeatedly verified the quantum nature of superconducting devices, leading some of these systems to be regarded as artificial atoms. In addition to their application in quantum information processing, these ‘atoms’ provide a test bed for studying quantum mechanics in macroscopic limits. Regarding the last point, we present here a feasible protocol for directly testing time reversal symmetry through the verification of the microreversibility principle in a superconducting artificial atom. Time reversal symmetry is a fundamental property of quantum mechanics and is expected to hold if the dynamics of the artificial atom strictly follow the Schrödinger equation. However, this property has yet to be tested in any macroscopic quantum system. In the end, as an application of this work, we outline how the successful implementation of the protocol would provide the first verification of the quantum work fluctuation theorems with superconducting systems.

- **Stephen P. Walborn**

Detection of quantum entanglement: Experiments with spatially entangled photon pairs

The twin photons produced by spontaneous parametric down-conversion have been an exceptional tool for the study of entanglement and quantum information. The spatial correlation of these photons was one of the first properties to be studied. Nevertheless, the convenient and efficient detection of quantum entanglement in the spatial variables is still an active area of research, with possible applications in quantum cryptography and communication. Here we present several experiments performed at the Quantum Optics Laboratory at the Instituto de Física, Universidade Federal do Rio de Janeiro. We present several novel experimental methods to detect the entanglement in the transverse spatial variables of photon pairs. Both methods use spatial light modulators to imprint an appropriate phase profile on the down-converted photons. Our first method uses this phase profile to measure the spatial correlation functions directly. With these, we can evaluate known entanglement witnesses in a more efficient fashion, without the need for a position-dependent detection system. Our second method uses complementary masks to discretize the detection system, again allowing for a more efficient identification of entanglement via a novel entanglement witness.

- **Lea Kraemer**

An Axiomatic Relation between Information Theoretic and Thermodynamic Entropies

The notion of entropy is central in understanding the processes that can be performed, or that can occur, in thermodynamics as well as in information theory. However, the definitions employed in the two cases are conceptually very different, and in particular on the microscopic scale their connection is still not well understood. In this work, we show how the two notions of entropy can actually be brought onto the same conceptual footing: to do this, we use an axiomatic approach to entropy in thermodynamics by Lieb and Yngvason. We establish that this framework can be made more general than its derivation of standard thermodynamics, and study its application to microscopic information-theoretic scenarios. By adapting Lieb and Yngvson's results from the macroscopic thermodynamic setting to the context of quantum systems, we can show that the resulting entropy function, based now on the same conceptual foundation as thermodynamic entropy, is precisely the von Neumann entropy. Moreover, this approach can classify states which are out of thermal equilibrium. We show that, applied to our setting, this treatment naturally yields the same quantities as those developed in the smooth entropy framework, namely the min- and max-entropy, defined to characterise information theory beyond the i.i.d. regime. Furthermore, similar applications yield expressions for other thermodynamic potentials such as the free energy and their single shot variants.

27/02/2015 — Friday

- **Anatoli Polkovnikov**

Quantum geometric tensor and it relation to non-adiabatic response

I will review the notion of the quantum geometric tensor and its relation to the gauge potentials generating unitary transformations. In particular, I will focus on transformations between ground states of a family of Hamiltonians connected by some smooth transformations of external parameters. The imaginary part of this tensor is the Berry curvature, while the real part defines the Fubini-Study metric tensor of the ground state manifold. The latter can be used to characterize geometry of the phases and phase transition via new invariants related to the Euler characteristic. I will demonstrate that this geometric tensor naturally emerges in the non-adiabatic response with the Berry curvature related to the Coriolis force and the Fubini-Study metric closely related to the mass tensor.

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- ## Juan Pablo Paz

A quantum algorithm to efficiently sample the work distribution and to estimate the free energy of quantum system

We present a new method to measure work and to efficiently sample its probability distribution with fixed precision. The method can be used to estimate free energies on a quantum computer. It is based on three facts: (i) The probability to detect work w in the state ρ is $P(w) = tr[\rho W(w)]$, where $W(w)$ are positive operators satisfying $\int dw W(w) = I$. As $W(w)$ define a POVM (positive operator valued measure), work measurement always reduces to a projective measurement performed at a single time on an enlarged system. (ii) Work can be estimated using a variant of the "phase estimation algorithm" which is such that work w is detected as the outcome of the single time measurement with probability $P(w)$. (iii) The efficient sampling of $P(w)$ can be combined with fluctuation theorems to estimate differences between the free energy of quantum states.

- ## Eric Lutz

The physics of information: from Maxwell's demon to Landauer

We discuss the intimate connection existing between information theory and thermodynamics. We focus on two complementary aspects: 1) the gain of information with Maxwell's famous demon and 2) the erasure of information with Landauer's principle. We further present a number recent experiments that have for the first time realized the above gedanken experiments in the lab.

- ## Raam Uzdin

High frequency equivalence of different quantum heat engines, and their quantum signature

Quantum heat engines are heat engines where the working substance is a single particle or a finite-level quantum system. We show that in the limit of very short cycle time, completely different machines like four-stroke engine, and two-stroke engine, behave exactly the same. Not only that they have the same power output, and the same efficiency, they also have the same dynamical behaviour (i.e. the same relaxation to steady state). We compare this to classical engines and show that the correction to the power in the equivalence regime scales differently with the cycle time compared to the quantum engine. In the equivalence regime the density matrix coherences are highly important. Their elimination leads to irreversibility that generates the classical scaling law. Furthermore, the power output of a "classical dephased engine" can be overwhelmingly smaller compared to the coherent quantum engine. Practical issues concerning implementation schemes will be discussed as well.

- **Thiago R. de Oliveira**

Pure State Thermodynamcs and Matrix Product States

We show how to approximate thermal states using pure states sampled from the class of Matrix Product States. In this approach thermodynamics properties are obtained without the use of ensembles but directly from a single pure state. This approach has conceptual and practical advantages: one does not need to justify the use of ensembles and one does not need to sample over many states pure states, decreasing the computational cost.

- **Roberto M. Serra**

Energy fluctuations, irreversibility, and arrow of time in an isolated quantum system

The inexorable entropy production imposes limits for general technological applications, information processing, parameter estimation (metrology), chemical reactions and biological processes. This phenomenon is even more provocative to our intuition about irreversibility in a far away from the equilibrium quantum scenario. In this case the observation of energy fluctuations is fundamental to the description of (quantum) thermodynamic quantities such as work, heat and entropy. Fluctuation relations and theorems (which were recently verified in quantum experiments) govern these quantities. We have developed an experimental platform, employing techniques of Nuclear Magnetic Resonance (NMR), where out of equilibrium quantum fluctuations can be observed, characterized and eventually manipulated. This platform allowed us to access the full statistics of work and entropy production on a quantum process. We will discuss advances in the direction of the establishment of the "experimental quantum thermodynamics". Besides the verification of fluctuation relations through the assessment of the non-equilibrium dynamics, we will provide a microscopic foundation of irreversibility beyond the linear response regime that both elucidates and quantifies the physical origin of the arrow of time in an isolated quantum system. We will also present an experimental implementation of quantum thermal machine.

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