
Ettore Majorana

ETTORE MAJORANA FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE

TO PAY A PERMANENT TRIBUTE TO ARCHIMEDES AND GALILEO GALILEI, FOUNDERS OF MODERN SCIENCE AND TO ENRICO FERMI, THE "ITALIAN NAVIGATOR", FATHER OF THE WEAK FORCES

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15th Course of the

INTERNATIONAL SCHOOL OF STATISTICAL PHYSICS

New Trends in Nonequilibrium Statistical Mechanics: Classical and Quantum Systems

(nesmcq18)

Directors of the School: P. Hänggi, F. Marchesoni

Chair: B. Spagnolo

co-Chair: D. Valenti

July 25-31 2018

The nonlinear relaxation process in many condensed matter systems proceeds through metastable states, giving rise to long-lived states. Stochastic many-body systems, classical and quantum, often display a complex and slow relaxation towards a stationary state. A common phenomenon in the dynamics of out of equilibrium systems is the ***metastability***, and the problem of the lifetime of metastable states involves fundamental aspects of ***nonequilibrium*** statistical mechanics. In spite of such ubiquity, the microscopic understanding of metastability and related out of equilibrium dynamics still raise fundamental questions.

The aim of this meeting is to bring together scientists interested in the challenging problems connected with dynamics of out of equilibrium classical and quantum physical systems from both theoretical and experimental point of view, within an ***interdisciplinary*** context. Specifically, three main areas of out-of-equilibrium statistical mechanics will be covered: ***long range interactions*** and ***multistability***, ***anomalous diffusion***, and ***quantum systems***. Moreover, the conference will be a discussion forum to promote new ideas in this fertile research field, and in particular new trends such as ***quantum thermodynamics*** and novel types of ***quantum phase transitions*** occurring in ***non-equilibrium steady states***, and ***topological phase transitions***.

INVITED SPEAKERS

E. Barkai, Ramat Gan, IL
A. Braggio, NEST, Pisa, IT
M. Campisi, Firenze, IT
A. Carollo, Palermo, IT
F. Ciccarello, Palermo, IT
A. Cuccoli, Firenze, IT
G. Falci, Catania, IT
R. Fazio, ICTP, Trieste, IT
A. Gambassi, SISSA, Trieste, IT
C. Guarcello, NEST, Pisa, IT
S. Iubini, CNR, Firenze, IT
M. Kastner*, NITheP, ZA
A. Lanzara, Berkeley, USA
R. Livi, Firenze, IT
N. Lo Gullo, Turku, FI
L. Magazzù, Regensburg, DE
V. Marinari, Rome, IT
J. Marino, Cambridge, USA
R. Meltzer*, Postdam, DE
M. Paternostro, Belfast, UK
E. Paladino, Catania, IT
J. P. Pekola, Aalto, FI
P. Politi, Firenze, IT
F. Ritort, Barcelona, ES
M. Rubi, Barcelona, ES
S. Ruffo, SISSA, Trieste, IT
S. Saveliev, Loughborough, UK
U. Seifert, Stuttgart, DE
A. Silva, SISSA, Trieste, IT
S. Vishveshwara, Illinois, USA

*EPS Invited Speaker

New Trends in Nonequilibrium Statistical Mechanics: Classical and Quantum Systems

Erice (Italy), 25-31 Jul 2018

REGIONE SICILIANA
Assessorato Regionale
Dell'Istruzione e della Formazione Professionale

UNIVERSITÀ DEGLI STUDI DI PALERMO

LOBACHEVSKY UNIVERSITY

IUPAP International Union of Pure and Applied Physics

Thursday 26/7

	Speaker	Talk
09:00 – 09:45	Paternostro	*Irreversible entropy production in non-equilibrium quantum processes*
09:45 – 10:30	Campisi	*Quantum Measurement Cooling*
10:30 – 11:00		**Coffee Break**
11:00 – 11:45	Metzler	*Anomalous Diffusion in Membranes and Cytoplasm of biological cells*
11:45 – 12:20	Hilfer	*Anomalous Bochner-Levy-Riesz Diffusion*
12:20 – 12:55	Radons	*Anti-Persistent Random Walks and Anomalous Deterministic Diffusion of Dissipative Solitons*
12:55 – 14:30		**Lunch**
14:30 – 15:15	Saveliev	*Modelling diffusive memristors for emulation neural dynamics and neuromorphic computer applications*
15:15 – 15:50	Rohwer	*Non-equilibrium forces following temperature quenches in classical fluids: the role of fluctuations and conservation laws*
15:50 – 16:25	Politi	*One dimensional phase ordering with long-range interactions*
16:25 – 16:55		**Coffee Break**
16:55 – 17:40	Rubi	*How environmental fluctuations affect the population behavior?*
17:40 – 18:00	Fiasconaro	*Modelling the DNA/RNA G-quadruplex mechanical unfolding*
18:00 – 18:20	Kabakcioglu	*Role of helicity in DNA hairpin folding dynamics*
18:20 – 18:40	Maynar	*Understanding confined systems with kinetic theory*
18:40 – 19:00	Rogers	*Maximum Entropy Closure for Nonequilibrium Statistical Mechanics*
19:00 – 19:45		**Project Multistability Round Table**

Friday 27/7

	Speaker	Talk
09:00 – 09:45	Ruffo	*Statistical physics of the Kuramoto model*
09:45 – 10:30	Ritort	*Q-stat thermodynamics: a new perspective on nonequilibrium phenomena*
10:30 – 11:00		**Coffee Break**
11:00 – 11:45	Fazio	*Boundary time crystals*
11:45 – 12:30	Lanzara	*Switching quantum materials properties with light*
12:30 – 13:05	Falci	*Probing Ultrastrong Coupling by Coherent Amplification of Population Transfer*
13:05 – 14:30		**Lunch**
14:30 – 15:15	Marino	*Orthogonality Catastrophe from dissipative impurities?*
15:15 – 16:00	Pekola	*Superconducting qubits as quantum refrigerators and heat switches*
16:00 – 16:30		**Poster Session 1st Oral**
16:30 – 17:00		**Coffee Break**
17:00 – 17:40		**Poster Session 2nd Oral**
17:40 – 19:30		**Poster Session 3rd Discussion**

Saturday 28/7

	Speaker	Talk
09:00 – 09:45	Livi	*Heat transport in low dimensions*
09:45 – 10:30	Seifert	*Stochastic thermodynamics: From principles to the cost of precision*
10:30 – 11:00		**Coffee Break**
11:00 – 11:35	Cuccoli	*Dynamics of Hybrid Quantum Systems*
11:35 – 11:55	Settino	*Dynamical properties of impenetrable bosons in optical lattices.*

Sunday 29/7

	Speaker	Talk
09:00 – 09:45	Vishveshwara	*Quantum quench dynamics in topological systems*
09:45 – 10:30	Kastner	*Speed limits in classical and quantum lattice models*
10:30 – 11:00		**Coffee Break**
11:00 – 11:45	Marinari	*The power spectrum for Fractional Brownian Motion: much information from few time trajectories.*
11:45 – 12:20	Barkai	*Quantum first detection problem*
12:20 – 12:55	Corberi	*Development of a large fluctuation in a statistical system.*
12:55 – 14:30		**Lunch**
14:30 – 15:10	Carollo	*Uhlmann curvature in dissipative phase transitions*
15:10 – 15:50	Braggio	*Majorana states in hybrid 2D Josephson junctions with ferromagnetic insulators*
15:50 – 16:30	Magazzù	*The driven spin-boson dynamics in a superconducting quantum circuit and the onset of resonant activation in the spin-boson model at strong dissipation*
16:25 – 16:55		**Coffee Break**
17:00 – 17:20	Leonforte	*Topological properties of fermionic systems at finite temperature*
17:20 – 17:40	Kopec	*Quantum glass of interacting bosons with off-diagonal disorder*
17:40 – 18:00	Bascone	*Kitaev's honeycomb model at finite temperature: topological properties*
18:00 – 18:20	Mathey	*Fluctuation Induced First Order Phase Transitions in Open Floquet Systems*
18:20 – 16:55	Paladino	*1/f critical current noise in short ballistic graphene Josephson junctions*
16:55 – 19:15	Dell'Anna	*Supercritical entanglement, violation of cluster decomposition and anomalous dynamics in local quantum spin chains*

Monday 30/7

	Speaker	Talk
09:00 – 09:45	**Gambassi**	*Dynamical transitions, universality, and chaos in prethermal states*
09:45 – 10:30	**Silva**	*Quantum many-body Kapitza phases of periodically driven spin systems*
10:30 – 11:00		**Coffee Break**
11:00 – 11:35	**Lo Gullo**	*A self-consistent non-equilibrium Green's functions approach to interacting many-body quantum systems*
11:35 – 12:10	**Jussiau**	*Abrupt change in thermoelectric transport due to a quantum dot's bound state*
12:10 – 12:45	**Ciccarello**	*Collision Models in Quantum Thermodynamics*
12:45 – 13:05	**Novotný**	*Analytical calculation of phase bistability switching rates in dissipative Jaynes-Cummings model*
13:05 – 14:30		**Lunch**
14:30 – 15:00	**Spiechowicz**	*Quantum law for equipartition of energy*
15:00– 15:20	**Hovhannisyan**	*Autonomous thermal rotor in the quantum regime*
15:20 – 15:40	**Ha**	*Role of Localized Defect in 1D Driven Diffusive Flow*
15:40 – 16:00	**Iubini**	*Coupled transport phenomena in chains of oscillators*
16:00 – 16:30	**Mulugeta**	*A spin-half system as a working substance of a heat engine: exploring its finite-time thermodynamic quantities*
16:30 – 17:00		**Coffee Break**
17:00 – 17:35	**Grassberger**	*Self-trapping self-repelling random walks*
17:35 – 18:10	**Guarcello**	*Soliton-based coherent caloritronics in long Josephson tunnel junctions*
18:00 – 19:30		**Closing Remarks Free Discussion**

- Out of Equilibrium Anomalous Diffusion
- Out of Equilibrium Classical Systems
- Out of Equilibrium Quantum Systems

Poster Session

Posters will be exposed in the hall from Friday 08:30 to Friday 19:30
Poster discussion will be held in Friday from 17:40 – 19:30.
Poster session will be preceded by a brief oral presentation, 3 slides in 3 minutes, in which each participant will briefly show the focus and the main results of his poster, inviting listeners to view his poster.

Charalambous	*Two distinguishable impurities in BEC: squeezing and entanglement of two Bose polarons*
Dima	*A spin-half system as a working substance of a heat engine: exploring its finite-time thermodynamic quantities*
García	*Enskog equation for confined systems*
Hasegawa	*Quantized pumping via a single-level quantum dot in coherent transport region*
Jo	*Non-equilibrium phase transitions in dissipative open quantum system with long-range interaction*
Jung	*Expansion dynamics of a self-avoiding chain under cylindrical confinement*
Kharcheva	*Time and probability characteristics of steady-state Lévy flights in bistable potential*
Klyuev	*Relation of macroscopic parameters fluctuations with microscopic dynamics of magnetic monopoles in spin ice*
Koriazhkina	*Statistical analysis of memristor response to complex electric activity*
Mitsokapas	*Peak-End Memory: An Extension to Asymmetric Choices*
Piccitto	*Out of equilibrium long range interacting Ising chain: a cluster meanfield approach.*
Puglia	*Phase-Coherent Thermal Router*
Razzitte	*Entropy in multifractal non equilibrium structures of dielectric breakdown*
Rubtsov	*The creation of an interdisciplinary laboratory of stochastic multistable systems in the UNN*
Ryabov	*Diffusing up the hill: Dynamics and equipartition in highly unstable systems*
Safonov	*Relaxation times of steady-state concentration of diffusing particles in memristive systems*
Sliusarenko	*Model for Anomalous Diffusion with Finite Moments in Complex Medium*
Spiechowicz	*Subdiffusion via dynamical localization induced by thermal equilibrium fluctuations*
Suñé	*Efficiency fluctuations in cyclic machines*
Timchenko	*Atomic Motion in Out-of-Equilibrium Radiation*
Yamamoto	*Heat transport in a two-state system coupled with bosonic reservoirs*

25/7	26/7	27/7	28/7	29/7	30/7
	9:00 AM Paternostro	9:00 AM Ruffo	9:00 AM Livi	9:00 AM Vishveshwara	9:00 AM Gambassi
	9:45 AM Campisi	9:45 AM Ritort	9:45 AM Seifert	9:45 AM Kastner **(EPS Lecture)**	9:45 AM Silva
	10:30 AM **Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**
	11:00 AM Metzler **(EPS Lecture)**	11:00 AM Fazio	11:00 AM Cuccoli	11:00 AM Marinari	11:00 AM Lo Gullo
	11:45 AM Hilfer	11:45 AM Lanzara	11:35 AM Settino	11:45 AM Barkai	11:35 AM Jussiau
	12:20 PM Radons	12:30 PM Falci	11:55 AM	12:20 PM Corberi	12:10 PM Ciccarello
	12:55 PM **Lunch**	1:05 PM **Lunch**	12:15 PM **Excursion**	12:55 PM **Lunch**	12:45 PM Novotný
	2:30 PM Saveliev	2:30 PM Marino		2:30 PM Carollo	1:05 PM **Lunch**
	3:15 PM Rohwer	3:15 PM Pekola		3:10 PM Braggio	2:30 PM Spiechowicz
	3:50 PM Politi	4:00 PM Poster Session 1st Oral		3:50 PM Magazzù	3:00 PM Hovhannisyan
	4:25 PM **Coffee Break**	4:30 PM **Coffee Break**		4:30 PM **Coffee Break**	3:20 PM Ha
					3:40 PM Iubini
					4:00 PM Mulugeta
					4:30 PM **Coffee Break**

5:00 PM Informal get-together at San Rocco's Cloister 8:00 PM DINNER	Coffee Break 4:55 PM Rubi 5:40 PM Fiasconaro 6:00 PM Kabakcioglu 6:20 PM Maynar 6:40 PM Rogers 7:00 PM Project Multistability Round Table 7:45 PM 8:00 PM DINNER	Coffee Break 5:00 PM Poster Session 2^{nd} Oral 5:40 PM Poster Session 3^{rd} Discussion 7:30 PM 8:00 PM DINNER	Excursion (with lunch box) and Conference Dinner	Coffee Break 5:00 PM Leonforte 5:20 PM Kopec 5:40 PM Bascone 6:00 PM Mathey 6:20 PM Paladino 6:55 PM Dell'Anna 7:15 PM 8:00 PM SOCIAL DINNER (ULISSE)	Coffee Break 5:00 PM Grassberger 5:35 PM Guarcello 6:10 PM Closing Remarks Free Discussion 7:30 PM 8:00 PM DINNER
10:00 PM Almonds Sweets and Marsala at Marsala room				10:00 PM Almonds Sweets and Marsala at Marsala room	

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Quantum first detection problem

Eli Barkai *† [1]

[1] Physics Dept., Bar-Ilan Univeristy – Phys. Dept., Bar-Ilan University, Ramat-Gan, Israel

We introduce the quantum first detection problem for a quantum walk using projective measurement postulates, discussing the quantum renewal equation. Its classical counter part is widely used to find statistics of first passage time for random walks and Brownian motion. Zeno limit, time operators, amplitude of first detection, revivals, relations between classical and quantum exponents, quantisation of averaged detection time related to the Grunbaum phase lead to rich physical behaviours, even for quantum walks on simple graphs.

Joint work with Harel Fridman, David Kessler, and Felix Thiel.
PRE 95, 032141 (2017). Editors' suggestion.

PRL 120, 040502 (2018)

Self-trapping self-repelling random walks

Peter Grassberger * [1]

[1] FZ Juelich – Germany

I will present a seemingly trivial modification of the 2-d "true self-avoiding walk" (TSAW) model of Amit, Peliti, and Parisi. In this generaiized model, the walker is not only repelled from previously visited sites, but (with some parameter epsilon > 0) also from neighboring sites. Surprisingly, it shows a completely different asymptotic behavior, if epsilon is larger than a critical value that depends on the lattice type, but not on the temperature of the TSAW model. For small times, the behavior is qualitatively the same as in the unmodified TSAW model, but after a charateristic time (that depends on epsilon) it becomes self-trapping: Walks are then subdiffusive, displacements are intermittent, and the residence probabilities for different sites become increasingly non-uniform.

*Speaker
†Corresponding author: barkaie@biu.ac.il
*Speaker

Kitaev's honeycomb model at finite temperature: topological properties

Francesco Bascone *† [1], Luca Leonforte [1], Davide Valenti [1], Bernardo Spagnolo [1], Angelo Carollo [1]

[1] Department of Physics and Chemistry, Group of Interdisciplinary Theoretical Physics and CNISM, University of Palermo – Italy

Topological phase transitions require a new paradigm since they cannot be identified by their pattern of symmetry breaking. Recently, much effort has been dedicated to the study of fault-tolerant quantum computation via topology. In this context the well known Kitaev honeycomb model, extensively studied only at zero temperature, shows a rich phase structure that allows for both Abelian and non-Abelian anyonic excitations.
We study finite temperature topological phase transitions of the Kitaev's spin honeycomb model in the vortex-free sector with the use of the recently introduced mean Uhlmann curvature. We employ an appropriate Fermionization procedure to study the system as a two-band p-wave superconductor described by a BdG Hamiltonian. This allows to study relevant quantities such as Berry and mean Uhlmann curvatures in a simple setting. More specifically, we consider the spin honeycomb in the presence of an external magnetic field breaking the time reversal symmetry. The introduction of such an external perturbation opens a gap in the phase of the system characterized by non-Abelian statistics, and makes the model to belong to a symmetry protected class, so that the Uhlmann number can be analyzed. We first consider the Berry curvature on a particular evolution line over the phase diagram. The Berry curvature behaviour signals the presence of the topological phase transition. The mean Uhlmann curvature and the Uhlmann number are then analyzed considering the system to be in a Gibbs state at finite temperature. Then, we show that the mean Uhlmann curvature describes a cross-over effect of the phases at high temperature and a smoothing of the eventual critical behaviour of the Berry curvature. We also find an interesting nonmonotonic behaviour of the Uhlmann number as a function of the temperature in the trivial phase, which is due to the partial filling of the conduction band around Dirac points.

*Speaker
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Quantum Measurement Cooling

Lorenzo Buffoni [1,2], Andrea Solfanelli [1], Paola Verrucchi [1,3,4], Alessandro Cuccoli [1,4], Michele Campisi [*† 1,4]

[1] Università di Firenze - Dipartimento di Fisica e Astronomia (UniFI) – Via Sansone, 1 50019 Sesto Fiorentino (FI), Italy
[2] Università di Firenze - Dipartimento di Ingegneria dell'informazione – via S. Marta 3, I-50139 Florence, Italy, Italy
[3] Istituto Sistemi Complessi del CNR (ISC) – c/o Dipartimento di Fisica e Astronomia - Via G. Sansone, 1 - 50019 Sesto Fiorentino, Italy
[4] Istituto Nazionale di Fisica Nucleare, Sezione di Firenze (INFN, Sezione di Firenze) – Via G. Sansone 1, I-50019 Sesto Fiorentino (FI), Italy

Invasiveness of quantum measurements is a genuinely quantum mechanical feature that is not necessarily detrimental: Here we show how quantum measurements can be used to fuel a cooling engine. We illustrate quantum measurement cooling (QMC) by means of a prototypical two-stroke two-qubit engine which interacts with a measurement apparatus and two heat reservoirs at different temperatures. Optimal cooling efficiency is reached when the post measurement state is not entangled. We quantify the probability that QMC occurs when the measurement basis is chosen randomly, and find that it can be very large as compared to the probability of extracting energy (heat engine operation), while remaining always smaller than the most useless operation, namely dumping heat in both baths. Besides shedding new light on many facets of the second law of thermodynamics, the results show that QMC can be very robust to experimental noise. A possible low-temperature solid-state implementation that integrates circuit QED tools with circuit QTD (quantum thermodynamics) elements and methods is presented.

[*] Speaker
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Uhlmann curvature in dissipative phase transitions

Angelo Carollo * [1], Bernardo Spagnolo [1], Davide Valenti [1]

[1] Department of Physics and Chemistry, Group of Interdisciplinary Theoretical Physics and CNISM, University of Palermo – Italy

A novel approach based on the Uhlmann curvature is introduced for the investigation of non-equilibrium steady-state quantum phase transitions (NESS-QPTs). Equilibrium phase transitions fall invariably into two markedly non-overlapping categories: classical phase transitions and quantum phase transitions. NESS-QPTs offer a unique arena where such a distinction fades off. We propose a method to reveal and quantitatively assess the quantum character of such critical phenomena. We apply this tool to a paradigmatic class of lattice fermion systems with local reservoirs, characterised by Gaussian non-equilibrium steady states. The relations between the behaviour of the Uhlmann curvature, the divergence of the correlation length, the character of the criticality and the dissipative gap are demonstrated. We argue that this tool can shade light upon the nature of non equilibrium steady state criticality in particular with regard to the role played by quantum vs classical fluctuations

Speed limits in classical and quantum lattice models

Michael Kastner * [1]

[1] National Institute for Theoretical Physics – Wallenberg Research Centre 10 Marais Street Stellenbosch 7600, South Africa

I review some recent results on the speed at which a variety of quantities (perturbations, correlations, information, entanglement, etc) can propagate through lattice systems. Lieb-Robinson bounds give rigorous estimates of this speed in quantum systems of arbitrary dimension, and similar techniques can be used to derive rigorous bounds on the maximum speed at which a perturbation of the initial state propagates in space and time in classical lattice models ("butterfly effect"). In the presence of long-range interactions the spatio-temporal propagation pattern changes qualitatively, to the point that the concept of a propagation velocity breaks down entirely when the interaction range exceeds a critical value. The theoretical results have been confirmed quantum simulation experiments, and they should be relevant for the understanding of equilibration and thermalisation timescales in lattice models as well as for other more complicated nonequilibrium phenomena.

*Speaker

*Speaker

Two distinguishable impurities in BEC: squeezing and entanglement of two Bose polarons

Christos Charalambous * [1], Miguel Angel Garcia-March [1], Aniello Lampo [1], Mohammad Mehboudi [1], Lewenstein Maciej [1]

[1] Institut de Ciencies Fotoniques [Castelldefels] (ICFO) – Parc Mediterrani de la Tecnologi, E-08860 Castelldefels (Barcelona), Spain

We apply the quantum open system formalism to describe the physics of two impurities immersed in a Bose-Einstein condensate. Here, the impurities are considered to be two quantum Brownian particles interacting with a bath of oscillators corresponding to the Bogoliubov modes of the condensate. We characterize the dynamics of the Brownian impurities with Langevin-like quantum stochastic equations carrying an account of memory effects. The Langevin equations are solved to evaluate the covariance matrix. We find that the presence of the bath induces an interaction between the impurities, which leads to entanglement among them. Whether or not the impurities are trapped in an external potential gives rise to different behaviours of such entanglement: (i) In the absence of external potential, we observe sudden death of entanglement, i.e., entanglement disappears at long enough times; (ii) In the presence of external harmonic potential, entanglement survives even at asymptotic time limit. Our study puts the behaviour of entanglement under scrutiny and captures its response to experimentally tunable parameters. Besides entanglement, we study the squeezing as well. Interestingly, we find that the mean-square-displacement is super-diffusive, which as we prove, is due to non-Markovianity of the dynamics. Further, a full analysis of squeezing is provided, which explains how experimentally tunable parameters create or destroy squeezing. We emphasize that all of our analysis is rigorously obtained from a realistic physical model; in particular, we avoid manipulating it by introducing artificial Hamiltonians, or by introducing arbitrary spectral densities.

*Speaker

Collision Models in Quantum Thermodynamics

Francesco Ciccarello *† [1]

[1] NEST, Istituto Nanoscienze-CNR and Dipartimento di Fisica e Chimica, Università degli Studi di Palermo – Palermo, Italy

A collision model (aka repeated interactions model) is a simple heoretical framework assuming a bath made out of a large collections of subunits ('ancillas') with which a system S 'collides' one at a time. The last few years are apparently witnessing a growing use of collision models (CMs) in the quantum thermodynamics literature [1,2,3]. Two major reasons can be given: (i) CMs allow to keep track of the environmental degrees of freedom (in most cases analytically); (ii) the bath ancillas can be used as a controllable thermal/work/information reservoir. The latter property mostly relies on the availability of setups such as micromasers whose discrete dynamics is explicitly described by a CM. The above might suggest to look at CMs as either environmental toy models or descriptions of just a specific class of engineered dynamics. In this talk, we illustrate instead that the occurrence of CMs is far more general: any environmental model featuring a "white" (i.e. frequency-independent) system-bath coupling typically leads to a CM. From such a broader perspective, a CM embodies an effective *picture* to describe the system-bath dynamics. This can be shown explicitly [4] for bosonic baths by resorting to the input-output formalism of quantum optics combined with the so called continuous-time tensor decomposition [5]. This way standard environmental microscopic models can be connected to CMs so as to benefit from the advantageous features of the latter such as the ability to work out *rates* of relevant thermodynamical quantities (like heat and entropy), this being a primary taskin the study of non-equilibrium quantum processes.

[1] J. Goold, M. Huber, A. Riera, L. del Rio, P. Skrzypczyk. J. Phys. A: Math. And Theor. 49, 143001 (2016).
[2] M. Campisi Campisi, P. Hänggi, and P. Talkner, Rev. Mod. Phys. 83, 771 (2011).
[3] P. Strasberg, G. Schaller, T. Brandes, and M. Esposito, Phys. Rev. X 7, 021003 (2017).
[4] F. Ciccarello, Quantum Meas. Quantum Metrol. 4,53 (2017).
[5] See e.g B. Baragiola, PhD Thesis, arXiv:1408.4447.

*Speaker
†Corresponding author: francesco.ciccarello@unipa.it

Development of a large fluctuation in a statistical system.

Federico Corberi * [1]

[1] University of Salerno (UNISA) – Università degli Studi di Salerno - Via Giovanni Paolo II, 132 - 84084 - Fisciano (SA), Italy

We consider the evolution leading to a large fluctuation in a Statistical Mechanical system by introduceing and studying analytically a simple model of many identically and independently distributed microscopic variables evolving by means of a master equation. We show that the process producing a non-typical fluctuation of a varibale N is slow and characterized by the power-law growth of the largest possible observable value of N at a given time. We discuss the analogy between such dynamical process and the slow kinetics observed in systems brought across a phase-transition.

Supercritical entanglement, violation of cluster decomposition and anomalous dynamics in local quantum spin chains

Luca Dell'anna * [1]

[1] Department of Physics and Astronomy, University of Padova – Italy

We compute exactly the correlation functions in two classes of integer and half-integer spin chains whose ground states can be expressed in terms of uniform superpositions of colored Motzkin and Dyck paths. We find that when long distance correlations occur, there is a square root deviation from the area law for the entanglement entropy and a light-cone profile in the propagation of excitations after a local quench is absent so that the system seems to feel the perturbation istantaneously.

*Speaker
*Speaker

Dynamics of Hybrid Quantum Systems

Alessandro Cuccoli * [1,2], Paola Verrucchi [1,2,3], Caterina Foti [1,2]

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We consider the dynamics of hybrid quantum systems, i.e. composite systems where one, or more, small quantum objects are accompanied by, and interact with, large, but still quantum, subsystems. The problem is related with the analysis of the quantum-to-classical crossover, quantum measurements and, more generally, the behaviour of open quantum systems, where the large subsystem can be thought as the environment. In our investigation we mainly focused our attention on: i) the preservation and possible exploitation of genuine quantum effects related with the presence of the large component; ii) the possibility to describe the action of one of the two subsystems onto the other one in terms of (generally time-dependent) effective classical field; iii) the role played by the symmetries of the large subsystems, or of their breaking in the proximity of a phase transition, on the dynamics of the system. In the specific systems we have considered, the small quantum object is either a single bosonic mode, or one or two qubits, while the large subsystem is modeled by a set of bosons or by one or more spin-S objects, with S constant and large; in the spin case, the actual calculation is made possible by a suitable approximation, valid in the large-S limit, which simplify the spin-algebra, so that we are able to keep track of the quantum correlations establishing between the small and large subsystems. A further trait of our approach is the judicious use of generalized coherent states (employed to describe the large component), which reveal to be a precious aid both in implementing the calculation and in improving our understanding of the role played by the residual quantumness of the almost classical subsystem. Several applications of the general framework have been considered so far: A quantum mechanical oscillator coupled to a spin environment has been investigated, showing that an insightful expression for the propagator of the whole system can be found, where we can identify an effective "back-action" term, i.e. an operator acting on the magnetic environment only, and yet missing in the absence of the quantum principal system, which behaves as an effective time-dependent magnetic anisotropy. We have also derived a set of sufficient conditions that allows one to describe the short-time dynamics of a bosonic system coupled to either a bosonic or a magnetic environment in terms of the effective interaction with a classical fluctuating field, also showing that this is generally possible whenever global symmetries lead to the definition of environmental operators that remain well defined when increasing the size, i.e., the number of dynamical variables, of the environment. The same scheme has been also applied to the general analysis of quantum measurement processes and to the study of the dynamics of large-S spin chains to be used as conveyors of quantum correlations, and we are currently employing it to investigate the possibility of increasing the coherence time of a qubit pair bringing its surrounding environment in the neighborhood of a critical point.

*Speaker

Simple optimized heat engines: exploring thermodynamic behavior of finite-time quantities

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In this work, a model heat engine, which operates between two reservoirs at two inverse negative absolute temperatures, is investigated. As a working substance of the engine, a system of two-level spin-half particles, in the thermodynamic limit, subjected to a time-dependent external magnetic field, is used because of its capability to demonstrate negative absolute temperatures. We investigate the heat engine under two schemes: the quasistatic and finite-time thermodynamic processes. Quasistatic process is a very slow process wherein, except for the adiabatic changes, the system and the reservoirs essentially remain in thermal equilibrium and exchange energy in the form of heat and work. As they link the isothermal processes, adiabatic changes are also basic components of the quasistatic processes. After properly setting the model, the expressions for the net work done, net heat absorbed and the efficiency of the model are analytically derived. For parameter values of energy level spacing, occupation probability in the excited state and inverse temperature, efficiency coincide with the Carnot efficiency. In the finite-time process, thermodynamic processes are described by three fundamental units of operations: adiabatic process, relaxation of the system-a process in which the system (detached from a reservoir) is left to relax to equilibrium (at constant external field) and a thermalization process in which the system (at constant external magnetic field) exchanges heat with the reservoir. In the adiabatic process, there is only work done on (by) the system; in the relaxation of the system to equilibrium, irreversible work and heat (assumed small in this case) can accompany the process. In the thermailization process, due to thermal interaction between the system and the reservoirs, there is heat exchange. Per cycle, we have find the expressions for the net work done, power and efficiency of the heat engines. In the model, power versus period initially (when period is shorter than τmp-period at the maximum power) shows a rapid increase with period; then it shows a maximum value at some non-zero finite period, τmp, and finally decrease as period becomes longer and longer. In the very long period limit, finite-time quantities, including power, approach to their corresponding quasistatic values. An optimum working condition for the heat engine is also sought by employing a unified criterion for energy converters. Using the criterion, the model engine is effectively optimized and found to yield optimum finite-time quantities. The optimized Quantities are of mixed advantages: efficiency-wise optimized efficiency is found to be better than efficiency at maximum power; however, power-wise, the optimized power is smaller than its maximum power. So figure of merit is suggested for the engine to estimate its performance as product of scaled optimized power and scaled optimized efficiency. Accordingly, the figure of merit of model I, ψI , plotted against the quaistaitic efficiency, increases from its 1.12 to about 1.3, as its quasistatic efficiency increases from zero to the maximum possible value. So, in the entire range of ηC, optimum working condition is an advantage for the model.

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A spin-half system as a working substance of a heat engine: exploring its finite-time thermodynamic quantities

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A model heat engine which operates between two reservoirs at inverse positive absolute temperatures is investigated. As its working substance, a system of two-level spin-half particles, in the thermodynamic limit subjected to a time dependent external magnetic field, is used. The heat engine is investigated under the quasistatic and finite-time working conditions.
Quasistatic process is a very slow process, wherein, except for the adiabatic changes, the system and the reservoirs essentially remain in thermal equilibrium and exchange energy in the form of heat and work. As they link the isothermal processes, adiabatic changes are also basic components of the quasistatic processes. After properly setting the model, the expressions for the net work done, net heat absorbed and the efficiency of the model are analytically derived. For parameter values of energy level spacing, occupation probability in the excited state and inverse temperature, the efficiencies coincide with the Carnot efficiency for the model.
In the finite-time process, thermodynamic processes are described by three fundamental units of operations: adiabatic (constant occupation probability) process, relaxation of the system-a process in which the system (detached from a reservoir) is left to relax to equilibrium (at constant external field) and a thermalization process in which the system (at constant external magnetic field) exchanges heat with the reservoirs. In the adiabatic process, there is only work done on (by) the system; in the relaxation of the system to equilibrium, irreversible work and heat (assumed small in this case) can accompany the process. In the thermailization process, due to thermal interaction between the system and the reservoirs, there is heat exchange. Per cycle, we have found the expressions for the net work done, power and efficiency of the heat engine. For the model engine, power versus period initially (when period is shorter than tmp -period at the maximum power) shows a rapid increase with period; then it shows a maximum value at some non-zero finite period, tmp, and finally decrease as period becomes longer and longer. In the very long period limit, finite-time quantities, including power, approach to their corresponding quasistatic values.
An optimum working condition for the heat engines is also sought by employing a unified criterion for energy converters. Using the criterion, the model engine is effectively optimized and found to yield optimum finite-time quantities with better performances as compared to quantities at maximum power.

*Speaker

Probing Ultrastrong Coupling by Coherent Amplification of Population Transfer

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The ability of manipulating multilevel coherence in solid-state architectures of artificial atoms would be a key issue for several achievements both in fundamental and in applied physics. Fabrication techniques have recently allowed to enter the regime of ultra-strong coupling (USC) between light and matter where unprecedently explored non-perturbative phenomena emerge [1]. While experiments so far provided spectroscopic evidence of USC, we propose the detection of a dynamical signature of USC in atom-cavity systems[2,3]. Indeed a new channel opens for photon-pair creation, whose detection is a smoking gun for the existence in Nature of this new ultra-strong regime of coherent coupling with the electromagnetic field[4]. We show how to coherently amplify this channel by inducing coherent population transfer via advanced control similar to STIRAP in atomic physics[5], which yields 100% detection efficiency. To this end we propose to operate a three level system where a selected transition is coupled in the USC regime to a cavity[2]. We then address implementation of the protocol in state of the art quantum hardware, and show that unambiguous detection of USC poses strong design constraints to the device. We have found that requirements are met by persistent current qubits, already fabricated within present technology, driven in the the Vee configuration. Alternatively systems of many artificial atoms strongly coupled to a cavity could be used [3]. Besides its fundamental importance, the proposed dynamical detection of the USC channel in state of the art superconducting architectures would be a benchmark for quantum control in distributed networks, in view of new ideas of using adiabatic protocols in this coupling regime[2,3].

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Modelling the DNA/RNA G-quadruplex mechanical unfolding

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The G-quadruplexes (G4) are non-canonical secondary DNA and RNA structures composed of four guanine basis bonded each other in quartets forming planes eventually piled in two, three or four layers. They are present both in vivo and in vitro cultures, and have important role in telomere end-protection, chromosome stability, aging control. Their folding patterns and structures are also found in eukaryotic promoter regions of oncogenes, making them increasingly recognized among chemists and biologists due to their potential applications in Nanomedicine as therapeutic targets in cancer treatments. In the last years, single-molecule techniques have attracted much attention between the scientific community and a number of groups have extensively used them to analyze the mechano-chemical behavior of DNA and RNA chains. Optical and magnetic tweezers, as well as Atomic Force Microscopies, are employed to characterize not only the mechanical stability and unfolding dynamics of G-quadruplexes, but also to unveil structural intermediates not accessible by the means of ensemble-average techniques due to their relatively low occurrence. The stability of the G-quadruplex structure is related, among the others, to the specific G-quadruplex conformation, and the presence of a cation between each of the G4 planes. Although an increasing number experiments have been conducted with the purpose to finely analyze rupture profiles in single force-extension curves, the theoretical predictions remain difficult, due essentially to the long computational time required by atomistic simulations, which, moreover, use parameter values – specifically the velocity at which one extreme of the quadruplex is pulled to induce the rupture – orders of magnitude far away from the experimental values. With the aim to bridge the gap between experiment and theoretical expectations, we build a mesoscopic model of the G-quadruplex structure with a reduced number of degrees of freedom and a few effective potentials that permits to study the mechanical unfolding in a wider interval of time scales than those allowed in all-atom simulations, in particular under different pulling velocities. The subsequent analysis on the light of the most recent stochastic theories for rupture force – as those of Bell-Evans-Richie, Evans-Hummer-Szabo, and Friddle-Noy-DeYoreo – permit the estimations of the potential barriers and positions that characterize the energy landscape of the unfolding process.

In this comunication the model will be presented together with its validation against the results of an unfolding experiment on RNA G-quadruplex pulled by an optical tweezer.

*Speaker

Dynamical transitions, universality, and chaos in prethermal states

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Recent experimental progresses in the physics of ultracold atomic gases have revived the interest in the dynamics of thermally isolated quantum statistical systems after a sudden change (quench) of their control parameters, which provides access to novel non-equilibrium quantum states of matter and to long-lived pre-thermal states.
Analogously to phase transitions in equilibrium, collective non-equilibrium behaviours may emerge in these states, with an associated dynamical critical point characterised by scale invariance and universality. In addition to scaling at short times and aging with universal exponents, systems quenched close to such a dynamical critical point may display a chaotic behaviour induced by non-equilibrium fluctuations.

Enskog equation for confined systems

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An Enskog like equation is formulated for a system of hard spheres confined with a hard wall of arbitrary shape. The difference with the usual Enskog equation is that, closed to the walls, the possible collisions are restricted due to the geometrical constraints induced by the walls. Remarkably, the equation admits an H-theorem and, in the long time limit, the distribution function tends to a Maxwellian distribution with the density profile predicted by equilibrium Statistical Mechanics.

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Soliton-based coherent caloritronics in long Josephson tunnel junctions

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Although all electric and magnetic features concerning Josephson vortices, i.e., solitons, in long Josephson tunnel junctions were comprehensively hitherto explored, little is known about the coherent thermal transport through a temperature-biased junction in the presence of solitons. In fact, as a temperature gradient is imposed across the device, namely, as the electrodes forming the junction reside at different temperatures, we demonstrate that a heat current depending on the configurations of solitons flows through the device [1-3]. The phase dependent heat current was recently studied theoretically and experimentally in both Josephson junctions [4] and superconducting quantum-interference devices (SQUIDs) [5]. This phenomenon is the core of the emerging field of phase-coherent caloritronics, from which fascinating devices, such as heat diodes, thermal transistors, solid-state memories, microwave refrigerators, thermal engines, thermal routers, and heat amplifier, were conceived [6]. Additionally, we report the first endeavour to combine the phase-coherent caloritronics and the physics of solitons in one single solid-state quantum structure. Our results can have immediate impact, and open the avenue to the implementation of a novel generation of topologically-protected solitonic devices for caloritronics, such as a soliton-based thermal router[1], in which the thermal transport can be locally mastered by controlling the soliton eventually set along the system, or a magnetically-controlled Josephson heat oscillator [2].

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Role of Localized Defect in 1D Driven Diffusive Flow

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We study asymptotic properties in the totally asymmetric simple exclusion process (TASEP) with a localized defect, where we focus on the universal nature of nonequilibrium steady states of the TASEP, related to the Kardar-Parisi-Zhang (KPZ) universality class. It is mathematically and physically a quite interesting question whether the localized defect, namely slow-bond (SB), is always relevant to the KPZ universality or not. However, it is so far very unclear to answer the existence of the non-queued SB phase in the weak SB strength limit. Based on extensive numerical simulations and finite-size scaling tests, we present a comprehensive view of the non-queue SB phase, in the context of jamming and condensation in the modified SB problem and passive tracer dynamics in the KPZ-type growing interface. Finally, our results provide positive evidence that the previously reported nonzero threshold of the non-queued SB phase might be an artifact of a crossover phenomenon which logarithmically converges to zero as the system size goes to infinity [1-3].

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Quantized pumping via a single-level quantum dot in coherent transport region

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Until it was firstly proposed by Thouless[1], adiabatic charge pumping has been studied in decades. In the field of mesoscopic physics, adiabatic charge pumping via a quantum dot system has been discussed in many works[2]. By driving the strength of potential barriers surrounding a quantum dot periodically, one electron can be pumped in one cycle operation. This pumping was reported by Kouwenhoven[3] and many other researchers[2]. The interesting point of this pumping is that, as long as driving is chosen properly, the amount of pumped charge is quantized in one cycle. This quantization property is explained by the loading/unloading process picture[4]. However, this picture is applicable only for the incoherent transport region, where a quantum dot weakly couples to electron reservoirs. For the coherent transport region, where the system couples strongly to the reservoirs, it is necessary to improve the loading/unloading process picture. In order to improve the loading/unloading process picture, we study the adiabatic pumping induced by reservoir-system coupling driving via a single-level quantum dot system in coherent transport region. For simplicity, we assume a non-interacting system. We employ Keldysh Green's function approach and derive the Berry connection and curvature which describe the adiabatic charge pumping. Based on our calculation, we found that the amount of pumped charge is also quantized, which is similar to the previous result in incoherent transport region. However, we point out that, additional to the loading/unloading process, an extra charge moving process is necessary to explain this quantization in coherent transport region. We also discuss a critical slowing down effect on the adiabatic pumping. In the present system, the quantum dot has a quasi-bound state, which emerges due to quantum mixture of electrons in the quantum dot and the reservoirs. When reservoir-system coupling becomes stronger than a critical value, the energy level of this quasi-bound state becomes lower than the band-edge of the reservoirs, the quasi-bound state becomes true-bound state and it is never thermalized. This causes a critical slowing down, diverges the relaxation time of the system, and breaks down the adiabatic approximation. This indicates any adiabatic operation can not be realized around this critical point.

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Anomalous Bochner-Levy-Riesz Diffusion

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Anomalous Bochner-Levy-Riesz diffusion arises from ordinary diffusion by replacing the Laplacean with a noninteger power of itself. Bochner-Levy-Riesz diffusion as a mathematical model leads to nonlocal boundary value problems. As a model for nonequilibrium transport processes it seems to predict phenomena that have yet to be observed in experiment.

Autonomous thermal rotor in the quantum regime

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Setting a system in ordered motion using thermal energy requires more than a temperature gradient. Breaking of a certain spatial symmetry is indispensable in order to trigger the motion. We study a minimalistic autonomous thermal rotor consisting of two interacting particles, each moving on a ring consisting of three sites. Each particle is weakly coupled to a thermal bath, and the rotation is enabled whenever a generalized particle exchange symmetry is broken. When both tunnelling between sites and intra-particle interaction are non-negligible, the dynamics of the rotor is described by a "global" master equation, rendering the standard approach used in quantum transport theory fail to describe local particle current. By adopting an operational approach, we introduce a novel definition of particle current, based on direct observation of the current through time-separated on-site measurements. For a "local" master equation, the current obtained by our approach coincides with the standard definition. Therefore, our measurement-based definition can be thought of as an extension of the standard definition to the domain of strong interactions. We are thus able to describe the operation of the rotor deep in the quantum regime, which not only allows us to rigorously connect the occurrence of transport and symmetry breaking in the model, but also uncover two purely quantum features of the machine. First, current can change sign as the tunnelling rate is varied. Second, powered by thermal gradient and tunnelling, our machine is capable of evolving uncorrelated states into entangled steady states.

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Non-equilibrium phase transitions in dissipative open quantum system with long-range interaction

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We investigate a nonequilibrium absorbing transition in open quantum system with long-range interaction using the semi-classical field theory for the quantum Langevin equation. In previous works, it was revealed that the Rydberg atoms with strong dephasing noise realize the universal behavior of ordinary directed percolation (DP). However, when the Rydberg atoms are excited in d-state, we need to take into account of the dipole-dipole interaction between those atoms. This leads to the DP model with long-range interaction. Here, we extend the dissipatively driven Rydberg atoms with the long-range interaction to the quantum spin system manifesting the contact process, where not only classical interactions mediated by heat bathes, but also quantum coherent interaction are comprised. We derive the Heisenberg equations from the total Hamiltonian consisting of the system, bathes, and their interaction. We use the semi-classical approach to build a phase diagram composed of active and absorbing states. Several non-trivial fixed points are obtained and their physical states are realized.

Expansion dynamics of a self-avoiding chain under cylindrical confinement

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Inspired by recent bacterial chromosome experiments in narrow channels, we simulate the expansion dynamics of a self-avoiding polymer under cylindrical confinement. Our results suggest that the chain initially expands like a concentrated hard-sphere system, enters a subdiffusive regime at an intermediate time, and eventually relaxes globally to its equilibrium size. Using our results, we test a few theoretical models.

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Abrupt change in thermoelectric transport due to a quantum dot's bound state

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We study a quantum thermoelectric made up of a single-level quantum dot coupled to two leads that can be described by the exactly solvable Fano-Anderson Hamiltonian. We consider the case of a power-law spectral density with a band edge. In this configuration, one may distinguish two regimes depending on the strength of the coupling between the dot and the reservoirs: If the coupling parameter is higher than a critical value, a bound state outside of the continuum and thus with infinite lifetime appears. We analyze the influence of the latter on the steady state of the system and show that the reduced dynamics of the dot explicitly depends on the existence of the bound state. We show that there is an abrupt change in the thermoelectric transport properties at the critical point. Typically, the thermoelectric efficiency grows as the coupling approaches its critical value, but then drops sharply at the critical point.

Role of helicity in DNA hairpin folding dynamics

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We study hairpin folding dynamics by means of extensive computer simulations, with particular attention paid to the influence of helicity on the folding time τ. We find that the dynamical exponent α of the anomalous scaling $\tau \sim N^{\alpha}$ for a hairpin with length N changes from $1.6(\simeq 1+\nu)$ to $1.2(\simeq 2\nu)$ in three dimensions, when duplex helicity is removed. The relation $\alpha = 2\nu$ in rotationless hairpin folding is further verified in two dimensions ($\nu = 0.75$), and for a ghost-chain ($\nu = 0.5$). This, to our knowledge, is the first observation of the theoretical lower bound on α, which was predicted earlier on the basis of energy conservation for polymer translocation through a pore. Our findings suggest that the folding dynamics in long helical chains is governed by the duplex dynamics, contrasting the earlier understanding based on the stem-flower picture of unpaired segments. We propose a scaling argument for $\alpha = 1+\nu$ in helical chains, assuming that duplex relaxation required for orientational positioning of the next pair of bases is the rate-limiting process.

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Time and probability characteristics of steady-state Lévy flights in bistable potential

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Anomalous diffusion in the form of Lévy flights is of permanent interest due to wide applications in different areas of science [1–4]. The related dynamics is investigated through a Langevin equation with Lévy noise and the corresponding fractional Fokker–Planck equation with non-trivial conditions on absorbing and reflecting boundaries. As a result, steady-state probability distributions of the particle coordinate can be found only for some simple potential profiles [1–3]. The correlation time of the steady-state Lévy flights in the symmetric bistable quartic potential was explored in [5], finding an interesting power-law dependence with exponent 4/3 of the correlation time on the positions of the potential wells. The steady-state correlation characteristics of superdiffusion in one-dimensional confinement potential profiles were investigated both theoretically and numerically in [6]. However, the analytical investigation of correlation and spectral properties of steady-state Lévy flights in confinement potentials remains an open problem. In this study we report the results for temporal and probability characteristics of Lévy flights in asymmetric bistable quartic potential as a generalization of the previous results obtained in Refs. [2-6]. Specifically, we analyze the steady-state probability distribution and the average lifetime of the excited state.

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Relation of macroscopic parameters fluctuations with microscopic dynamics of magnetic monopoles in spin ice

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In the last time there was a lot of works, due to a great interest in the study of spin ice. Such an interest was caused by the theoretical prediction of unusual magnetic defects in spin ice, which were called as emergent magnetic monopoles.
Originally, the term spin ice was applied to the compounds such as Ho2Ti2O7. Magnetic ions in them are located at the vertices of regular tetrahedra linked into three dimensional pyrochlore lattice. The ground state of the spin system is characterized by the ice rule: two spins of each tetrahedron are directed toward its center and two other ones away from its center. This corresponds to a distribution of electrical dipole moments hydrogen bonds in hexagonal ice, solid phase of water in natural conditions, that justifies the term "spin ice".

The flipping of an arbitrary spin in ground state configuration, which takes place at finite temperatures, breaks the ice rule in two neighboring tetrahedra. One tetrahedron has three spins directed "in", and one – "out", while its neighbor has one "in" and three – "out". These tetrahedra can be considered as positive and negative emergent magnetic monopoles respectively. The flipping of any of three identical magnetic spins of the defect is equivalent to the defect movement to another site. Monopoles play the role of classical quasiparticles, which movement through the lattice change the spin configuration on all the distance traveled, resulting in the formation of a "spin spaghetti" and creating a memory effect. This effect make possible to developing an analogue of perspective memristive structures, based on spin ice.
The purpose of our article is the investigation of the fluctuations in the number of magnetic monopoles. To implement this we derive the Langevin equation for these fluctuations by the Einstein – Fokker – Planck equation method. That allows us to calculate the spectrum of relative fluctuations in the number of magnetic monopoles. Then we discuss a possible relation of fluctuations in the number of pairs of magnetic monopoles with measurable characteristic of spin ice and an experimental display of obtained results.

*Speaker

Statistical analysis of memristor response to complex electric activity

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Memristors [1] or memristive nanomaterials (devices) are the basis for new-generation memory devices (Resistive Random Access Memory) and neuromorphic systems, the operation of which relies on switching between the different resistive states of a material at various applied bias [2]. However, there is a serious fundamental problem, without the solution of which it is impossible to commercialize memristive devices in electronics industry for mass production. This problem consists in a pronounced stochastic nature of the resistive switching phenomenon. Experimental studies suggest that, at each switching (rewriting) cycle, a new resistive state corresponds to a new configuration of atoms in the local switching region, which is modified or destroyed by the next switching (rewriting) event [3]. In the present work, the metal-oxide memristive devices on the basis of yttria stabilized zirconia revealing bipolar resistive switching of anionic type have been investigated. To demonstrate the stochastic nature of resistive switching, the device was influenced by a complex and noisy bioelectric activity recorded in the culture of hippocampal cells. As a result of experiment, the resistance distribution of memristive device was obtained. If we assume that a memristive system is in a quasi-stationary equilibrium state, then it is possible to obtain the energy profile using the Boltzmann distribution. It is shown that such profile allows predicting and tailoring the resistive state of memristive device by using the well developed stochastic resonance theory.

Acknowledgements

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Switching quantum materials properties with light

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The recent advancements in laser technology have dramatically expanded the applications of lasers to table top experiments in condensed matter physics. Femtosecond time-resolved spectroscopy techniques are emerging tools in the study of quantum materials, offering new paths to disentangle coexisting phases with similar energy scale, selectively tune a specific phase across a quantum critical point and create hidden states that do not exist in equilibrium, to name a few. In this talk I will present some of our recent work where ultrafast light is used to manipulate electron charges, spin and lattice to reveal underlying properties in quantum materials, to drive metal insulator transition, to destroy superconductivity and to control spin texture in topological insulators. Future direction in the field will be discussed.

Heat transport in low dimensions

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We overview the hydrodynamic description of heat transport in lattice and fluid models in 1 and 2 space dimensions. We focus on the main difficulties encountered in describing these kind of phenomena by refined theories and also on the crucial role of finte size and time effects. While the former have led us to conjecture a unified framework with a few universilaty classes depending on the main symmetries (i.e. conservation laws), the latter may exhibit sensible deviations from theoretical expectations. Far from being just an academic problem, this complex scenario is certainly of interest for nanosystems, where the limited numebr of elementary components could demand a second order hydrodynamic approach, dealing with finite size corrections as a crucial ingredient.

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Topological properties of fermionic systems at finite temperature

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The topological ordered phases of matter are a new research field which recently attracted an increasing interest among physicist. An interesting aspect is that transitions between topological different phases do not respect the paradigm of the Landau theory of phase transitions. Different topological phases can be classified, and eventually defined through topological invariants.
In this work we consider only classes which at zero temperature, that is in their ground state, are characterized by the Chern number. These classes are composed by 2D translational invariant fermionic systems such as Topological Insulator and Topological Superconductors.
Here, we define the Uhlmann number as an extension of the Chern number, and we use this quantity to describe the topology of these systems at finite temperature, where the system is in a mixed state. We consider two paradigmatic systems which belong to the above mentioned classes, and we study, at finite temperature, the evolution of their topology thanks to the Uhlmann number. At low temperature we find the topological phase transition predicted by the Chern number, but at higher temperature we find a cross-over behaviour, without any criticalities. Then, we find a general relation between the mean Uhlmann curvature and the dynamical susceptibility, that gives a hint on how to measure the mean Uhlmann curvature. We also link the Uhlmann number to the dynamical conductivity of topological insulators and superconductors, which extends the Thouless, Kohmoto, Nightingale, den Nijs formula to finite temperature, showing a natural way to measure the Uhlmann number. Finally, we relate the mean Uhlmann curvature over the electric field parameter space to the Uhlmann number, whose relation shows how the topology affects the system at finite temperature.

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The driven spin-boson dynamics in a superconducting quantum circuit and the onset of resonant activation in the spin-boson model at strong dissipation

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The key features of open quantum systems are captured by the paradigmatic spin-boson model which describes a two-state system interacting with an environment formed of harmonic oscillators. In the strong coupling regime, this model provides an accurate representation of a variety of physical and chemical situations [1].
The impact of a time-dependent driving on the Ohmic spin-boson model is investigated [2] by means of a superconducting qubit setup subject to a monochromatic field of tunable parameters. The qubit's response to the drive is analyzed with a non-perturbative path-integral approach, suited to describe the strong qubit-environment coupling attained in the experiment.

The same approach to the spin-boson dynamics is also used to explore [3] the onset of a resonant activation regime [4,5] under deterministic and stochastic driving with variable intensity and characteristic frequency.

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*Speaker

The power spectrum for Fractional Brownian Motion: much information from few time trajectories.

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Time-dependent processes are often analysed using the power spectral density (PSD), calculated by taking an appropriate Fourier transform of individual trajectories and finding the associated ensemble-average. Frequently, the available experimental data sets are too small for such ensemble averages, and hence it is of immense conceptual and practical importance to understand to which extent relevant information can be gained from S(f; T), the PSD of a single trajectory. Here we focus on the behaviour of this random, realisation-dependent variable, parametrised by frequency f and observation-time T, for a broad family of anomalous diusions—fractional Brownian motion (fBm) with Hurst-index H—and derive exactly its probability-density-function. We show that S(f; T) is proportional (up to a random numerical factor whose universal distribution we determine) to the ensemble-averaged PSD.

Orthogonality Catastrophe from dissipative impurities?

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We present an analog of the phenomenon of orthogonality catastrophe in quantum many body systems subject to a local dissipative impurity. We show that the fidelity, giving a measure for distance of the time-evolved state from the initial state, displays a universal scaling form when the state of the system supports long range correlations, in a fashion reminiscent of traditional instances of orthogonality catastrophe in condensed matter. This picture is derived within a second order cumulant expansion suited for Liouvillian dynamics, and substantiated for the one-dimensional transverse field quantum Ising model subject to a local dephasing jump operator, as well as for XY and XX quantum spin chains, and for the two dimensional Bose gas deep in the super fluid phase with local particle heating.

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Fluctuation Induced First Order Phase Transitions in Open Floquet Systems

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We investigate phase transitions in rapidly periodically driven, open quantum systems within a complex bosonic order parameter model with phase rotation symmetric drive. The infinitely rapidly driven limit is effectively stationary and exhibits a second order phase transition. Based on a Floquet renormalization group analysis, we reveal a universal mechanism showing that fluctuations associated to the first rotating wave correction mask the critical physics linked to the equilibrium fixed point. This mechanism is brought about by an additional relevant coupling that emerges as a result of he breaking of time-translation invariance inherent to Floquet systems. The system parameters must be fine-tuned to their critical values as well as to equilibrium for criticality to be fully visible. The critical exponents of the infinitely rapidly driven fixed point can however be probed upon smoothly approaching it, in some analogy to the opposite limit of slowly driven systems within the Kibble-Zurek mechanism.

Analytical calculation of phase bistability switching rates in dissipative Jaynes-Cummings model

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We study the dynamics of a dissipative Jaynes-Cummings model subject to a strong resonant drive. Above a certain drive threshold there appear two metastable states in the stationary state with roughly the same field amplitude but different phases which are well captured by the bifurcation in the neo-classical approach. Their appearance is associated with the splitting of the spectrum of the corresponding Liouvillean heralding the quantum bistability. We focus on the analytical evaluation of the switching rates between the two metastable states which we achieve by a generalized Fermi-golden-rule-like method based on a precise estimate of the character of the metastable states. We find simple analytical expression for the rate surprisingly of non-exponential (i.e., non-Arrhenius) form, which nevertheless matches nearly perfectly the numerical results.

*Speaker

*Speaker

Understanding confined systems with kinetic theory

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In the last years, a granular system placed in a vertically vibrated quasi-two dimensional box has been widely studied [1]. For a wide range of the parameters the system reaches a homogeneous stationary state in which the energy lost in collisions is compensated by the energy injected by the wall. On the other hand, it is shown that by increasing the density and/or varying the way in which energy is injected, a dense cluster is developed surrounded by a hotter gas of grains. In order to understand this phenomenology, we have studied the simplest model with the same phenomenology. It is an ensemble of inelastic hard spheres confined between two parallel plates separated a distance smaller than two particle diameters. The system is vibrated from below with a sawtooth wall. By an extension of the previously studied elastic gas [2], an evolution equation for the one-particle distribution function is derived. It is a Boltzmann-like equation that incorporates the effect of the confinement on the particle collisions. The equation is exploited to derive evolution equations for the vertical and horizontal temperatures in the homogeneous regime. In the inhomogeneous case, the equations explain the instability. In effect, a stability analysis of the hydrodynamic equations around the homogeneous stationary state shows that, depending on the size of the system, the homogeneous stationary state is unstable. Moreover, we find excellent agreement with Molecular Dynamics, both in the stationary state and for the critical size for which the instability arises.

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*Speaker

Anomalous Diffusion in Membranes and Cytoplasm of biological cells

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A surging amount of experimental and simulations studies reveals persistent anomalous diffusion in both cellular membranes and the cytoplasm [1,2]. The anomalous diffusion is observed for micron-sized objects down to labelled single molecules such as green fluorescent proteins [3]. This talk will first present results from large scale computer simulations and stochastic analysis of the motion of lipids and embedded proteins in lipid bilayer model membranes [4], indicating that increased disorder longer and longer lasting anomalous diffusion. In particular, the motion of lipids and proteins can become non-Gaussian [4,5]. In the membranes of living cells anomalous diffusion of embedded protein channels can last over several hundreds of seconds [6]. In particular, this anomalous diffusion can become non-ergodic and exhibit ageing, two topics explained and discussed in this talk [7]. The findings of anomalous diffusion in membranes will be complemented by a brief summary of anomalous diffusion in the cellular cytoplasm, referring to both subdiffusion of passive tracers and superdiffusion due to active motion in cells.

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*Speaker

Peak-End Memory: An Extension to Asymmetric Choices

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The peak-end rule [1] (from behavioural economics) is a psychological heuris- tic which describes the way us humans tend to particularly remember extreme and recent experiences. Recent work [2] modelling this effect in a simple discrete- choice model (a random walker with extreme-value memory) revealed how this memory distortion could qualitatively affect the long-time behaviour. In this poster we report preliminary investigations, extending the framework to the case where the two possible choices have different distributions of experience (leading to an asymmetric random walk) with the interesting possibility that the agent becomes trapped in the rationally-less-good choice.

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1/f critical current noise in short ballistic graphene Josephson junctions

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Graphene Josephson Junctions in the regime of ballistic transport (bGJJ) where current is carried by discrete energy states of Andreev-reflected coherent electron-hole pairs have been recently demonstrated both in planar [1-3] and in vertical graphene heterostructures [4]. Due to the non-linear current-phase relation bGJJ can be used a sensitive probes of underlying microscopic noise sources. We investigate critical current fluctuations in bGJJ due to carrier density fluctuations. The noise spectrum, found in analytic form, displays a characteristic 1/f dependence for general doping (from the pristine case to the high doping limit) and temperature. Such fluctuations may represent a limiting factor to the phase coherent dynamics of graphene-based Josephson nanodevices, a critical requirement for quantum technologies.

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Irreversible entropy production in non-equilibrium quantum processes

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The characterization of irreversibility in general quantum processes is an open problem of increasing technological relevance.
Yet, the tools currently available to this aim are mostly limited to the assessment of dynamics induced by equilibrium environments, a situation that often does not match the reality of experiments at the microscopic and mesoscopic scale. In this talk I will propose a theory of irreversible entropy production that is suited for quantum systems exposed to general, non-equilibrium reservoirs.
I will illustrate the framework by addressing a set of physically relevant situations that clarify both the features and the potential of such an approach.

Superconducting qubits as quantum refrigerators and heat switches

Jukka Pekola * [1]

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I will first discuss thermodynamics of qubits coupled to classical heat baths. Then I describe how one can measure heat currents in them. As concrete examples I introduce a four-stroke quantum Otto refrigerator and a recent experiment on a quantum heat switch, based on flux-tunable superconducting qubits. This device shows qualitatively different behavior depending on how strongly the qubit is coupled to the heat bath: a theoretical model to describe the observations in the two regimes of the experiment will be presented. In the last part of the talk I describe our progress in developing a nano-calorimeter aiming to detect stochastic quantum trajectories by fast measurement of temperature.

Work done in collaboration with Bayan Karimi, Alberto Ronzani, Jorden Senior, Yu-Cheng Chang, Libin Wang, Klaara Viisanen, Michele Campisi, Rosario Fazio, Joonas Peltonen, Olli-Pentti Saira and Michael Roukes

*Speaker

*Speaker

Out of equilibrium long range interacting Ising chain: a cluster meanfield approach.

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We study the dynamics of a out of equilibrium Ising chain with dacaying power law interaction using a cluster menafield approach. Unlike other numerical approach, our cluster meanfield setup permits us to work in the thermodynamic limit and to overcome the problem of the finite size effects. The most important result that emerge from our analysis is that the esponent of the power law plays a crucial role in the phase properties of the system. The aim of this work is to study these properties and to characterize the criticalities of the model.

One dimensional phase ordering with long-range interactions

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The phase ordering process of a one dimensional Ising model displays a variety of interesting and unexpected features if the coupling J(r) decays either exponentially or as a power law: non trivial interplay between conservation laws and long-range, both convective and diffusive regimes, non universal dynamics, and the inability of continuum models to reproduce the whole dynamics.
The study of elementary configurations allows to capture the physics of phase ordering in a quantitative way.

*Speaker
*Speaker

Phase-Coherent Thermal Router

Claudio Puglia * [1,2], Giuliano Timossi [2], Antonio Fornieri [2], Federico Paolucci [2], Francesco Giazotto [2]

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In 1965, Maki & Griffin [1] predicted that the stationary heat current flowing through a thermally biased Superconductor-Superconductor tunnel junction (SIS) depends on the phase difference between the superconducting condensates. Recently, this prediction was proven experimentally [2], giving rise to a research field called coherent Caloritronics [3]. This field aims to achieve a control over heat currents in hybrid superconducting devices, similar to the one achieved for electron currents in electronics.
We show the experimental realization and characterization of a device able to control the spatial distribution of an incoming heat current, thus providing the possibility to tune the electronic temperatures of two output terminals, thus acting as a Phase-Coherent Thermal Router [4].
In the device, the steady heat currents is controlled by means of a direct current Superconducting Quantum Interference Device (dc-SQUID), which can tune the coherent component of the electronic heat currents flowing through its Josephson junctions.
In this case, the two parameters that allow us to tune the heat flow are the external magnetic flux over the SQUID and the bath temperature.

These results offer new opportunities for all microcircuits requiring an accurate energy management, including electronic coolers, quantum information architectures, and thermal logic components [2-5].

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[5] Paolucci, F., Marchegiani, G., Strambini, E., Giazotto, F., **arXiv:1709.08609** Phase-Tunable Thermal Logic: Computation with Heat

*Speaker

Anti-Persistent Random Walks and Anomalous Deterministic Diffusion of Dissipative Solitons

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Dissipative Solitons are well-known objects, observable, for instance, in nonlinear optics experiments with mode-locked lasers. Their dynamics can be well described by a simple, deterministic prototype model: the cubic-quintic complex Ginzburg-Landau equation. We demonstrate the occurrence of normal and anomalous diffusion of dissipative solitons in this deterministic prototypical partial differential equation in one and two spatial dimensions. In both cases repeated asymmetric explosions of solitons are responsible for random spatial shifts, leading to deterministic, chaotic diffusion. In one dimension we find normal diffusion, which can be well modelled by an anti-persistent random walk with increments correlated over hundreds of asymmetric explosions [1]. In contrast, in two spatial dimensions additional symmetric explosions cause long periods of sticking of the solitons. The distribution of these waiting times shows an approximate power law decay, which in some parameter regime causes a diverging mean waiting time. This, in connection with asymmetric explosions, leads to subdiffusive behavior, which can well be modelled by a continuous time random walk (CTRW) [2,3]. Correspondingly, these anomalously diffusing solitons show weak ergodicity breaking, i.e. an inequivalence of time- and ensemble averages as known from CTRWs, even in the distribution of diffusivities [3,4].

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*Speaker

Entropy in multifractal non equilibrium structures of dielectric breakdown

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In the present work we applied the Renyi entropy theory in the analysis of the multifractal structures due to the **Dielectric Breakdown (DB)** process. From the thermodynamic viewpoint all phenomena in nature have a tendency to reduce their energy, is the case of the propagation of electrical tree structure. As the tree channel front moves, the intense field near the front moves electrons and ions irreversibly in the region beyond the tree channel tips where electromechanical, thermal and chemical effects cause irreversible damage and from the non equilibrium thermodynamic viewpoint: entropy production. The maximal entropy approach then provide a passage between Renyi's information entropy and thermodynamics of multifractals. Non equilibrium growth results in structures which appear random and amorphous. The introduction of simple non equilibrium models and the utilization of fractal geometry has led to a good understanding of the morphology of such growth. The dielectric breakdown model DBM (Niemeyer, Pietronero, and Wiessman: NPW) [1] to explain the formation of fractal tree structures has been extended to incorporate non overlapping diagonal bonds modified by Vicente, Razzitte and Mola (VRM)[2].The used model is a two dimensional square lattice in which two opposite sides represent the two electrodes , is considered. The rules assumed for the growth of electrical tree are the following: The electrical trees grows stepwise. The discrete form of Laplace is solved with boundary conditions: $\Phi i,k=1/4(\Phi i+1,k+ \Phi i\text{-}1,k+ \Phi i,k\text{-}1+ \Phi i,k+1)$. A power law dependence with exponent η is assumed and the probability associated with points *I,k* at the structure and *I',k'* outside is given by : $P(I,k \text{ to } I',k')= (\Phi i',k')\eta \,/(\Sigma(j,l)(\Phi j,L)\eta$. The sum of denominator refer to the possible growth sites (J,l) adjacent to the electrical tree , where is the set of possible candidates to be incorporate into the electrical tree.Tools of the Thermodynamic formalism have proven to be extremely useful in the analysis and characterization of fractal objects. The results are related to thermodynamics and We obtain a relation between the Renyi entropy and fractal dimension for the tree growth structures [3], [4].

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*Speaker

• Q-stat thermodynamics: a new perspective on nonequilibrium phenomena

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Nonequilibrium pervades nature. From living cells to the expanding universe virtually all energy transformation processes in nature occur in nonequilibrium conditions [1]. In this regard thermodynamic equilibrium should be seen as an approximation to describe energy transformations in nature, certainly a very good one in many cases. Yet, how to leave the safe grounds of equilibrium thermodynamics adventuring the nonequilibrium realm by retaining universal features characteristic of equilibrium systems without loosing the predictive power of thermodynamics? In this talk I will introduce Q-stat thermodynamics as a new theoretical approach to characterize energy transformation processes in nonequilibrium systems [2,3]: when observed at two- different arbitrary times, nonequilibrium systems tend to partially equilibrate over the subspace of configurations with mutual two-times correlation equal to Q [3]. I will present theoretical calculations, simulations and experimental results in small systems [4,5], from single molecules to red blood cells, testing the validity and showing the power of Q-stat thermodynamics in physics and beyond.

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*Speaker

Maximum Entropy Closure for Nonequilibrium Statistical Mechanics

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The question of deriving general force/flux relationships that apply out of the linear response regime is a central topic of theories for nonequilibrium statistical mechanics. This work traces models for force/flux relations from early through modern theories of stochastic thermodynamics to show that the form of response theories in driven, nonequilibrium transient dynamics and their symmetries are essentially solved problems. A simple maximum entropy approach highlights key points of agreement with the projector-operator based fluctuation-dissipation theorem, the fluctuation theorem, large deviation theory and the chaotic hypothesis. This agreement requires the problem of force/flux relationships to be formulated in terms of transition distributions, rather than steady-state properties or trajectory distributions. Within this paradigm, it is actually simpler to work in the fully nonlinear regime without relying on any assumptions about the steady-state or long-time properties. Our comparison is illustrated by extensive numerical simulations of the periodic Lorentz gas (Galton board) and α-Fermi-Pasta-Ulam chains, two paradigmatic problems in nonequilibrium statistical mechanics. Although we simulate both starting from transient initial conditions, with evolution under constant external forcing, the maximum entropy structure of the transition distribution is clearly evident. I discuss a simple extension of this idea to quantum nonequilibrium dynamics which recovers the traditional Caldeira-Legett model with new insight into entropy and heat, along with an associated open problem on quantum-dynamical semigroups.

*Speaker

Non-equilibrium forces following temperature quenches in classical fluids: the role of fluctuations and conservation laws

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A rapid change of temperature ("quench") in a fluid can give rise to transient long-ranged correlations of density fluctuations when particle number is a conserved quantity of the system. These correlations, when confined by external objects, are predicted to lead to classical non-equilibrium fluctuation-induced forces (FIFs) between the objects (e.g., plates immersed in the fluid) [1]. In the presence of external potentials (e.g. those of immersed objects), temperature quenches also change the fluid's spatial mean density profile. The resulting diffusive density fronts emanating from immersed objects after a quench in turn give rise to a further type of non-equilibrium force, namely "density-induced forces" (DIFs) [2]. Our recent simulations show that both FIFs and DIFs appear in a fluid of interacting Brownian particles (BPs) after a quench [2]. For passive BPs, the quench is an actual change of temperature. For active BPs, this can be mimicked by *quenching the activity* (effective temperature) of the fluid particles. Importantly, the latter activity quench gives rise to qualitatively similar effects as the former, which suggest that rapidly changing the activity of an active medium could be used to realize both DIFs and FIFs experimentally. DIFs decay exponentially quickly in time, but the FIFs have algebraic long-time tails. This means that the fluctuation-effects dominate at long times after the quench. FIFs are also less dependent on the microscopic details of the system, and thus in a sense more generic. To good approximation, DIFs and FIFs, which can be described using coarse-graining methods [3], are additive and act independently. While both types of forces arise due to conservation of density (or density fluctuations) out of equilibrium, I will discuss their distinguishing features, as well as the physical conditions required for their appearance. Active matter systems, with their inherent tunability, are a promising candidate for experiments, and we propose several possible protocols to observe the discussed non-equilibrium forces.

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*Speaker

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How environmental fluctuations affect the population behavior?

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The way fluctuations shape the population behavior is an outstanding question of practical importance in ecology, microbiology and epidemiology. We present an analytical framework to examine the effects of external fluctuations in a wide variety of systems. Through this framework, we have obtained explicit conditions that determine to what extent fluctuations propagate to the variability of populations and how they affect fundamental properties of the system, including whether they promote or prevent proliferation and whether they stabilize or destabilize coexistence. The wide-ranging applicability of these general conditions has been extensively validated explicitly through computational experiments of single-species and multispecies dynamics, encompassing the three classical types of functional responses as well as exponential growth, growth with saturation, and logistic growth. We found that, in general, fluctuations can both positively and negatively impact population proliferation and coexistence, depending on their precise interplay with the linear and nonlinear terms of the system. Our results [J.M. Vilar, J.M. Rubi, Sci. Rep., 8, 887 (2018)] make it possible to informedly target the quantities and the fluctuation properties that best can be used to change the behavior of populations, thus opening an avenue for controlling populations through fluctuations in addition to just through average properties.

*Speaker

The creation of an interdisciplinary laboratory of stochastic multistable systems in the UNN

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Among the emerging memories, resistive switching memory (RRAM) based on memristive materials (metal oxides) raises strong interest. Memristor is an element of the electric circuit, able to change resistance depending on the applied electrical stimulation in the analog way. The main advantages of a memristor, realized on the basis of a thin firm technology are a simple structure and a small size (the change in electrical resistance at the application of voltage occurs in a local nanometer material area placed between two electrodes) and thus, the high switching rate and low energy consumption of memory device based on it. Despite the impressive range of promising applications of memristive nanomaterials and devices there is a serious fundamental problem, which must be overcome before successful implementation in industry. This problem consists in the fact that the phenomenon of resistive switching (memristive effect) has a pronounced stochastic nature. The experimental research provide the ground to conclude that, for each switching cycle, the new resistive state corresponds to a completely new atomic configuration in a local switching volume that is formed or destroyed whenever the state is switched. Therefore the memristor appears as multistable system, which switching dynamics occurs under action of strong noise, i.e. the noise with the intensity comparable to the height of energy barriers separating stable states of the system. The related variability of parameters, after setting the desired memristive state and their fluctuations over time, are very critical factors in terms of the use of memristive devices in combination with conventional digital circuits, when the unambiguous, programmed change in resistance of memristive device is required in response to the specified voltage levels. Nowadays there are many new results obtained in the theory of statistical analysis. It was shown that in the complex non-linear systems with coherent interaction of a significant number of components, the role of noise can be more essential than the simple deviation from the average and it can lead to transitions of the systems into new states or the formation of new non-linear structures. Currently the adequate analysis methods are developed for systems perturbed by noise of various statistical nature, . There have been identified a number of cases, in which the role of noise, in spite of classical common wisdom, has a constructive one, i.e. it improves some characteristics of the system as a whole. There were discovered such phenomena as stochastic resonance, noise enhanced stability, resonant activation, diffusion delay and acceleration, ratchet effect, transitional biomodality and multimodality. An interdisciplinary laboratory of stochastic multistable systems (StoLab) was established at the Lobachevsky University of Nizhny Novgorod (UNN) in 2018. The laboratory will combine and integrate activities research groups working in theoretical and experimental areas. Prof. B.Spagnolo will contribute to the effective governance of the laboratory and application of modern methods of statistical analysis described above for investigation of memristive systems. The researchers of UNN will provide the experimental study and, in particular, the verification of novel theoretical descriptions.

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Statistical physics of the Kuramoto model

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Spontaneous synchronization is a remarkable collective effect observed in nature, whereby a population of oscillating units, which have diverse natural frequencies and are in weak interaction with one another, evolves to spontaneously exhibit collective oscillations at a common frequency. The Kuramoto model provides the basic analytical framework to study spontaneous synchronization of phase oscillators. In this talk, I will summarize recent results on the study of a generalized Kuramoto model that includes inertial effects and stochastic noise. I will describe the dynamics from a different perspective, namely, that of long-range interacting systems driven out of equilibrium by quenched disordered external torques. Using tools of statistical physics, I will highlight the equilibrium and nonequilibrium aspects of the dynamics and uncover the rich and complex phase diagram that the model exhibits.

Relaxation times of steady-state concentration of diffusing particles in memristive systems

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We consider one-dimensional Brownian diffusion in the field of external force as a simple model for memristive system. The non-equilibrium steady-state concentration distributions that appear in the presence of source and sink of diffusive particles are obtained for virous external fields. Several approaches to calculate relaxation times to these steady-state distributions have been proposed to analyse the switching dynamics of memristor.

*Speaker

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Diffusing up the hill: Dynamics and equipartition in highly unstable systems

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Description and understanding of stochastic dynamics of a particle in highly unstable potentials is limited by its short lifetime. In such systems, stochastic trajectories quickly diverge leading to undefined statistical moments of the particle position. Instead of this standard and inapplicable statistical analysis, we propose a new approach that exploits advantages of the local characteristics of the most-likely particle motion. The new paradigmatic formalism is experimentally verified for a Brownian particle moving near an inflection in a cubic optical potential. The most likely position of the particle atypically shifts against the force despite the trajectories diverge in the opposite direction. The local uncertainty around the most-likely position saturates even for a strong thermal noise. Remarkably, the measured particle distribution quickly converges towards the quasi-stationary one, which is independent of the initial particle positions. The demonstrated experimental agreement with theoretical predictions approves the utility of local characteristics of the unstable dynamics. The theory can be further extended to describe thermodynamic processes in unstable systems.

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*Speaker

Modelling diffusive memristors for emulation neural dynamics and neuromorphic computer applications

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Recently fabricated volatile diffusive memristor [1,2] has demonstrated an ability to emulate neurons. In particular, it exhibits integrate-and-fire neural dynamics, depression effect after applying many voltage pulses, as well as can generate current-spikes if a DC voltage above resistive switching threshold is applied. A combination of diffusive memristors with capacitance and volatile shift memristors allowed to design and implement [3] a neuromorphic device enable unsupervised machine learning. Moreover, a stochastic resistance switching [2] of diffusive memristors allowed to use them as true random number generators [3]. In this talk, I will discuss modelling of diffusive memristors taking into account diffusion of Ag nanoclusters between memristor terminals for different electric circuits and thermal relaxation in these devices [1-4].

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*Speaker

Stochastic thermodynamics: From principles to the cost of precision

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For the macroscopic world, classical thermodynamics formulates the laws governing the transformation of various forms of energy into each other. Stochastic thermodynamics extends these concepts to micro- and nano-systems embedded or coupled to a heat bath where fluctuations play a dominant role. Examples are colloidal particles in time-dependent laser traps, single biomolecules manipulated by optical tweezers or AFM tips, and transport through quantum dots. For these systems, exact non-equilibrium relations like the Jarzynski relation, fluctuation theorems and, most recently, a thermodynamic uncertainty relation have been discovered. First, I will introduce the main principles and show a few representative experimental applications. In the second part, I will discuss the universal trade-off between the thermodynamic cost and the precision of any biomolecular, or, more generally, of any stationary non-equilibrium process. By applying this thermodynamic uncertainty relation to molecular motors, I will introduce the emerging field of "thermodynamic inference" where relations from stochastic thermodynamics are used to infer otherwise yet inaccessible properties of (bio)physical and (bio)chemical systems.

Quantum glass of interacting bosons with off-diagonal disorder

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We study disordered interacting bosons described by the Bose-Hubbard model with Gaussian-distributed random tunneling amplitudes. It is shown that the off-diagonal disorder induces a spin-glass-like ground state, characterized by randomly frozen quantum-mechanical U(1) phases of bosons. To access criticality, we employ the "n-replica trick", as in the spin-glass theory, and the Trotter-Suzuki method for decomposition of the statistical density operator, along with numerical calculations. The interplay between disorder, quantum and thermal fluctuations leads to phase diagrams exhibiting a glassy state of bosons, which are studied as a function of model parameters. The considered system may be relevant for quantum simulators of optical-lattice bosons, where the randomness can be introduced in a controlled way. The latter is supported by a proposition of experimental realization of the system in question.

*Speaker

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*Speaker

Dynamical properties of impenetrable bosons in optical lattices.

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The study of strongly correlated quantum systems is one of the most interesting and intriguing research field in physics. The framework of ultracold gases in optical lattices allows to explore equilibrium and non-equilibrium properties of such systems. One example is the Tonks-Girardeau (TG) gas, in which the infinite repulsive delta-like interaction mimics the Pauli exclusion principle and is reflected into the well known mapping to non-interacting fermions. While local quantities are identical to the fermionic case, all non local ones, like correlations or momentum distribution, are significally different.
We develop a powerful method to study the spectral function of the TG gas by using only single particle orbitals, and apply it to inspect the behaviour of ultracold gases in incommensurate, harmonic and hard-box potential. Moreover, the efficient implementation of the one body green's functions provide an instrument to investigate energy and mass transport in periodic media and quasicrystals via the scheme of non equilibrium green's functions.

Quantum many-body Kapitza phases of periodically driven spin systems

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As realized by Kapitza long ago, a rigid pendulum can be stabilized upside down by periodically driving its suspension point with tuned amplitude and frequency. In this talk I will discuss a many-body analogue of this phenomenon: the stabilization by just driving periodically a single parameter of an otherwise unstable phase of matter against all possible fluctuations of its microscopic degrees of freedom. In particular, I will focus on the physics of quantum spin chains with long-range interactions, discussing in detail the non-equilibrium phase diagram in the presence of a periodic drive as a function of frequency and amplitude,

*Speaker
*Speaker

Model for Anomalous Diffusion with Finite Moments in Complex Medium

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Within our model, where the anomalous diffusion arises due to the permanent affect of a random environment on a single particle resulting in a population of different relaxation times and diffusion coefficients, we are able to reproduce a superdiffusive motion, which has both properties of Lévy flights (similar time and position scalings of the probability density functions (PDFs)) and that of Lévy walks (finite mean squared displacement and its scaling in time, shape of PDFs at large times). On the other hand, we found strong differences of our model from the mentioned ones. For example, the small times regimes have a different time scaling for the PDFs; the higher-order displacement moments are monoscaled and the motion does not exhibit a strong anomalous diffusion. An important feature of our model is that jumps in space are decoupled from waiting times.

We believe, our results will make an experimentalist more flexible in distinguishing between the available models of anomalous superdiffusion and choosing the most simple yet appropriate one.

*Speaker

Subdiffusion via dynamical localization induced by thermal equilibrium fluctuations

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We reveal the mechanism of subdiffusion which emerges in a straightforward, one dimensional classical nonequilibrium dynamics of a Brownian ratchet driven by both a time-periodic force and Gaussian white noise. In a tailored parameter set for which the deterministic counterpart is in a non-chaotic regime, subdiffusion is a long-living transient whose lifetime can be many, many orders of magnitude larger than characteristic time scales of the setup thus being amenable to experimental observations. As a reason for this subdiffusive behaviour in the coordinate space we identify thermal noise induced dynamical localization in the velocity (momentum) space. This novel idea is distinct from existing knowledge and has never been reported for any classical or quantum system. It suggests reconsideration of generally accepted opinion that subdiffusion is due to broad distributions or strong correlations which reflect disorder, trapping, viscoelasticity of the medium or geometrical constraints.

Atomic Motion in Out-of-Equilibrium Radiation

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The problem of a two-level atom interacting with equilibrium black-body radiation at temperature T was studied by Einstein in 1917. It served as a cornerstone for the study of light-atom interactions. Here, we study the non-equilibrium extension of this problem. To that purpose, we consider a system connected to two black-body radiation reservoirs at different temperatures. We characterize the non-equilibrium steady-state of the radiation, the energy flow throughout the system and its fluctuations by means of the large deviation function. Additionally, the interactions of a two-level atom with the non-equilibrium radiation are studied. A non-vanishing average force, proportional to the temperature difference, is found to be acting on the atom.

*Speaker
*Speaker

Quantum law for equipartition of energy

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One of the fundamental laws of classical statistical physics is the energy equipartition theorem which states that for each degree of freedom the average kinetic energy equals $E_k = k_B T/2$, where k_B is the Boltzmann constant and T is temperature of the system. Despite the fact that quantum mechanics has already been developed for more than 100 years still there is no quantum counterpart of this theorem. We attempt to fill this far-reaching gap and formulate the *quantum law for equipartition of energy* in the appealing form $E_k = \langle \mathcal{E}_k \rangle$, where $\mathcal{E}_k$ is thermal kinetic energy per one degree of freedom of the thermostat consisting of harmonic oscillators and $\langle ... \rangle$ denotes averaging over frequencies ω of those thermostat oscillators which contribute to E_k according to the probability distribution $\mathbb{P}(\omega)$. We derive it for two paradigmatic and exactly solvable models of quantum open systems: a free Brownian particle and a harmonic oscillator. We formulate conditions for validity of the relation $E_k = \langle \mathcal{E}_k \rangle$ for other quantum systems.

Efficiency fluctuations in cyclic machines

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We study the statistics of the efficiency in a class of isothermal cyclic machines with realistic coupling between the internal degrees of freedom. We derive, under fairly general assumptions, the probability distribution function for the efficiency. The macroscopic efficiency is always equal to the most likely efficiency. The machine achieves the maximal macroscopic efficiency in the limit of strong coupling, and such a maximum only depends on the input and output thermodynamic forces. The reversible efficiency is the least likely regardless of the coupling strength. Furthermore we find that the strong coupling limit is a necessary, yet not sufficient, condition for the engine to perform close to the reversible efficiency, even when the machine works in the far from equilibrium regime. By using a large deviation formalism we derive a fluctuation theorem for the efficiency, which holds for any number of internal degrees of freedom in the system.

*Speaker

*Speaker

A self-consistent non-equilibrium Green's functions approach to interacting many-body quantum systems

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In recent years there has been a growing interest in the study of the dynamics of many-body quantum systems. The reasons are manifold, ranging from purely theoretical interests in the behavior of complex quantum systems when brought out-of-equilibrium to the possibility of exploiting unusual quantum mechanical properties in technological applications. Together with new fascinating problems the need for techniques to deal with deam them became stronger and stronger. Non-equilibrium Green's functions theory provides a versatile approach to study out-of-equilibrium systemsin correlated matter starting from a microscopic description. The power of the method relies on the possibility to study a broad range of different phenomena: from time-dependent quantum transport in nanosystem, to post-quench dynamics in ultra-cold atomic gases, from driven quantum systems (e.g. heat engines) to dynamical phase transitions. Most importantly it allows to treat on equal footing b many-body interactions, external drivings and external reservoirs.
In my talk I will first give a brief general introduction to the technique moving then to describe the self-consisten approach we developed and its numerical implementation which solves the Dyson equation for the interacting single-particle Green's function. I will also discuss the choice of the proper self-energy and how to include into it the presence of external reservoirs. As an application of this technique I will discuss some examples, namely the Anderson model and the post-quench dynamics in an ultracold atomic gas in a bichromatic incommensurate potential.

*Speaker

Majorana states in hybrid 2D Josephson junctions with ferromagnetic insulators

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Majorana bound states (MBS)[1] have been proposed as a building block for solid-state topological quantum computation. Different setups, such as hybrid structures of proximized semiconducting nanowires, have been discussed theoretically[2] and explored experimentally[3]. Here we will discuss about more recent proposals based on proximised two-dimensional electron systems[4]. We propose[5] a Josephson junction consisting of superconductor/ferromagnetic insulator (S/FI) bilayers as electrodes which proximizes a nearby 2D electron gas (see Figure 1). By starting from a generic Josephson hybrid planar setup we present an exhaustive analysis of the the interplay between the superconducting and magnetic proximity effects and the conditions under which the structure undergoes transitions to a non-trivial topological phase. We approach the theoretical problem by developing an exact method that provides a systematic dimensional reduction procedure based on a continuum transfer matrix approach which in certain aspects is closely related to scattering theory. The effective 1D boundary Hamiltonian obtained provides access to the energy spectrum, the free energy, and the multiterminal Josephson currents in the setup. An analytically tractable 1D topological invariant also emerges in a natural manner. The approach also applies to 2DEG strongly coupled to superconductors via transparent interfaces, required for large topological energy gaps. As an example we consider a narrow channel coupled with multiple ferromagnetic superconducting fingers, and discuss how the Majorana bound states can be spatially controlled by tuning the superconducting phases. Our approach is quite general, not limited to any specific model or symmetry class, and can be extended to other 1D channel problems with continuum Hamiltonians that are polynomials in ky. Moreover, the model can be applied to investigate the properties of Josephson junctions in two and three-dimensional systems, for example surfaces of topological insulators or graphene junctions[6].

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Quantum quench dynamics in topological systems

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Can quench dynamics involving the dynamic tuning of a parameter in a system, such as a magnetic field, act as a probe of topological phases? Can the existence of topological order lead to a different realm in non-equilibrium dynamics? This talk addresses these two questions in the context of two hallmarks of topological phases – ground state degeneracies and the presence of edge modes. In the instance of quenching across a critical point separating a topological and a trivial phase, we show that under certain conditions, ground state degeneracies result in a 'topological blocking' phenomena. In such a situation, topological constraints force the system to completely occupy the excited spectrum of the final state and to have zero overlap with the final ground state. We then focus on the effect of edge modes on quenches in the paradigm Majorana wire system whose ends are expected to carry Majorana fermionic bound modes. Here, parity switches associated with the bound modes drastically affect non-equilibrium quench dynamics. In these contexts, we discuss possible influences of disorder on topologically constrained non-equilibrium dynamics. Finally, we propose that quantum Hall systems can behave as gravitational analogs and will explore possible simulation of black hole dynamics in these systems.

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Heat transport in a two-state system coupled with bosonic reservoirs

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Recent technological progress has enabled us to measure heat transport via a nanoscale object, where quantum properties of the system make transport process different from that in a macroscopic system. Among a number of models used to in study of heat transport via a microscopic system, the model of the two-state system coupled to heat baths (the spin-boson model) is the simplest one. In this model, properties of the heat baths are described by a spectral density function, which is proportional to the s-th power of the frequency. Recently, the Kondo-like effect has been discussed in low-temperature heat transport for the Ohmic case (s=1) [1]. However, heat transport has not been studied in detail for the sub-Ohmic (s< 1) and super-Ohmic case (s> 1) so far. Intriguingly, at zero temperature, a quantum phase transition occurs in the sub-Ohmic and Ohmic cases, but not in the super-Ohmic case.
In the present study [2], we consider heat transport via a two-state system for arbitrary exponent combining analytic and numerical methods. We first derive an asymptotically exact expression for the thermal conductance in the sufficiently low-temperature regime. This asymptotically exact formula for the thermal conductance predicts power-law temperature dependence at low temperatures. Second, we numerically investigate the thermal conductance using the continuous-time quantum Monte Carlo method [3] over the entire temperature regime for arbitrary heat bath. Our numerical calculations show that the noninteracting-blip approximation [4] quantitatively describes the thermal conductance in the incoherent tunneling regime. We also discuss the temperature dependences of the thermal conductance at a critical regime in the sub-Ohmic case.

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Boundary time crystals

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We introduce *boundary time-crystals wh*ere *continuous* time-translation symmetry breaking occurs at the boundary (or generically in a macroscopic portion) of a many-body quantum system. After introducing their definition and properties, we analyse in details a solvable model. We provide examples of other systems where boundary time crystalline phases can occur. The existence of the boundary time crystals is intimately connected to the emergence of time-periodic steady state in the thermodynamic limit of a many-body open quantum system. Connection to quantum synchronisation will be also discussed.

Coupled transport phenomena in chains of oscillators

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Coupled transport regimes occur when a system displays two or more species of irreversible flows that influence one another. Well known examples date back to the discoveries by Seebeck and Peltier of thermoelectricity in the first half of the XIX century and refer to the capacity of converting a temperature difference into a voltage (and vice-versa). From the point of view of statistical mechanics, the connection between microscopic interactions and macroscopic thermodynamic properties is still largely unexplored. In this talk, I will discuss how coupled transport effects arise in simple models of nonlinear interacting oscillators. Despite the simplicity of the microscopic particle-particle interaction, steady nonequilibrium states may be characterized by unusual complex features.

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