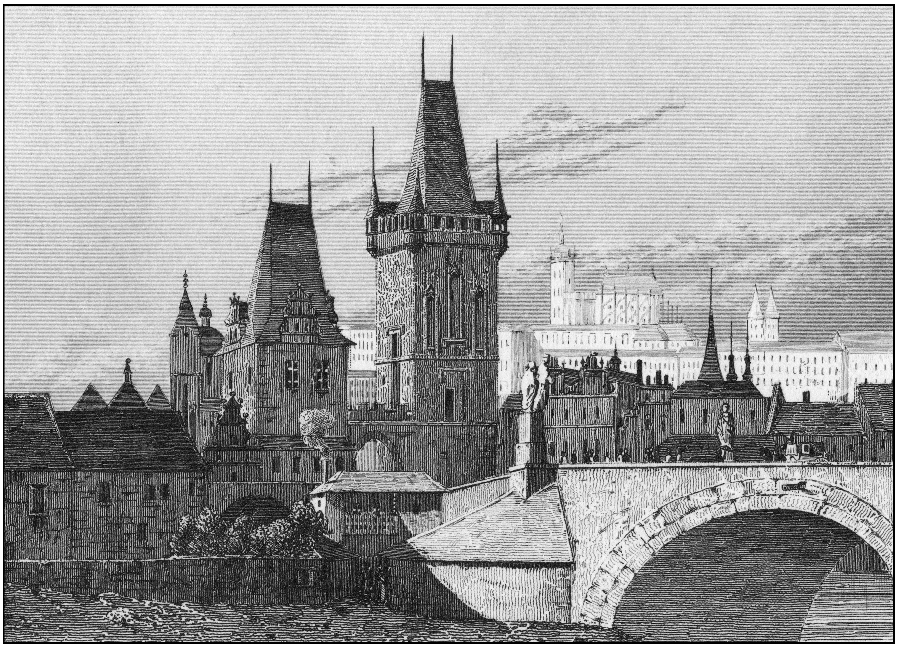
Frontiers of Quantum and Mesoscopic Thermodynamics

9 - 15 July 2017, Prague, Czech Republic



Under the auspicies of

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President of the Czech Republic

Milan Štěch
President of the Senate of the Parliament of the Czech Republic

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- Institute for Theoretical Physics, University of Amsterdam, The Netherlands
- Department of Physics, Texas A&M University, USA
- College of Engineering and Science, University of Detroit Mercy, USA
- Institut de Physique Théorique, CEA/CNRS Saclay, France

Topics

- Non-equilibrium statistical physics
- Quantum many body physics, quantum field theory
- Foundations of quantum physics
- Quantum thermodynamics
- Quantum optics
- Photonics, plasmonics, atomtronics
- Quantum simulations
- Physics of quantum information and computing
- Cosmology, gravitation and astrophysics
- Quantum measurement, entanglement and coherence
- Dissipation, dephasing, noise and decoherence
- Topological states of quantum matter, quantum phase transitions
- Macroscopic quantum behavior
- Cold atoms and molecules, Bose-Einstein condensates
- Mesoscopic, nano-electromechanical and nano-optical systems
- Biological systems, molecular motors and quantum biology

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Organized by

- Institute of Physics, the Czech Academy of Sciences
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Preface

Recent advances in technologies have led to enormous improvements of measurement, imaging and observation techniques at microscopic, mesoscopic and macroscopic scales. At the same time, various methods allow us to investigate not only equilibrium features, but also time evolution of classical and quantum systems (which are in general far from equilibrium) at different time scales. This increasing ability to study subtle details of the dynamics of systems yields new versions of old questions and creates new challenges in many fields of physics.

Various systems, of natural and artificial origin, can exhibit mesoscopic features depending on inner parameters of these systems and interactions with their environment. Typical mesoscopic systems can be of nanoscale size, composed from atoms (molecules). Nanoscale structures include not only very small physical structures, but also structures occurring in living cells, as for example complex molecules, proteins and molecular motors. At the same time, nanoscale technologies enable the preparation of well-defined artificial structures composed of between a few and hundreds of atoms (molecules) to create an enormous diversity of systems with well-defined inner parameters and external fields which can influence them. They can be studied by methods of condensed matter physics and quantum optics in such detail that affords a deeper understanding of quantum physics, as represented by quantum interferences, entanglement, the uncertainty principle, quantum measurement and what is often termed “non-locality”. At the same time, studies of these artificial structures can help us on our way to improve our knowledge of the processes in living cells.

The FQMT’17 conference will be thus focused on conceptual and experimental challenges of quantum many body physics, non-equilibrium statistical physics, foundations of quantum mechanics, quantum field theory, and quantum thermodynamics. Further development of all these fields is needed to deal with an increasing requirement for more detailed understanding and use of such phenomena as quantum correlations, entanglement and their dynamics; decoherence and dissipation; light-matter interactions; behavior of closed and open quantum systems far from equilibrium; equilibration and thermalization of systems; roles of initial and boundary conditions; influences of environment, reservoirs and external fields on the time evolution of systems; quantum to classical transitions; dynamics of quantum phase transitions; and topological states of systems. As for systems which enable study of various related questions, the conference will deal mainly with mesoscopic systems.

FQMT’17 is a follow-up to the five previous, successful Prague conferences “Frontiers of Quantum and Mesoscopic Thermodynamics” (FQMT’04, FQMT’08, FQMT’11, FQMT’13, and FQMT’15). For the details of their programs and the history of the FQMT conferences see the www pages https://fqmt.fzu.cz/. The contributions from the previous conferences have been published in Physica E (vol. 29, issues 1-2, 2005, and vol. 42, issue 3, 2010), Physica Scripta (vol. T151, 2012), and Fortschritte der Physik (Progress of Physics, vol. 65, issue 6-8, 2017).

As in the foregoing FQMT conferences, the aim of FQMT’17 is to create a bridge between the fields of non-equilibrium statistical physics, quantum many body physics, foundations of quantum physics, quantum thermodynamics, quantum optics, physics of quantum information, astrophysics, condensed matter physics, physics of mesoscopic systems, chemical physics and biophysics. Following the tradition of the FQMT conferences, FQMT'17 will again bring together a unique combination of both young and experienced scientists across a disciplinary spectrum covering the above mentioned topics. The interdisciplinary character of the conference will be supported by the choice of key speakers who, apart from their specializations, are not only able to report specific results within their fields, but are also able to discuss the state of the art of their fields from the standpoint of a broader perspective of overlap with other fields. It is an objective to gather important scientists from overlapping branches of physics who can mutually benefit from the exchange of different views and ideas, experiences from studies of many different systems and various theoretical and experimental approaches to the study of current problems in physics. It is intended that this arrangement of the scientific program of the conference will again significantly contribute to the formulation of challenging questions and problems, as well as their related answers that are nowadays essential to improve the understanding of the foundations of quantum physics, many body physics, quantum statistical physics of systems far from equilibrium, the physics of nanoscale and biological systems, and further, will motivate new collaboration and intensive discussions between experts from differing fields of physics, chemistry, and biology.

To this end, the organizers have endeavored to create a program which is encompassing while simultaneously achieves an "equilibrium" between theoretically and experimentally orientated talks to stimulate the discussion between the experimentalists and the theorists as much as possible.

In keeping with the multidisciplinary character of the scientific program, the cultural richness of the City of Prague and the tradition of the previous FQMT conferences, the FQMT'17 program will feature four concerts of classical music performed by world-class musicians, held at outstanding venues of the city. Both the scientific program and the musical program are intended as a complement to one another, where scientists and musicians are encouraged to mingle and share their knowledge and experience.

Dear colleague, we welcome you to the FQMT'17 conference and we hope you will enjoy your stay in Prague.

On behalf of the organizers

Václav Špička, Peter D. Keefe, and Theo M. Nieuwenhuizen

Contents

Abstracts are sorted alphabetically according to the family names of the presenting author.

Important Information

Contact address

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Emergency phone numbers (free calls):

Police: 158
Ambulance: 155
Fire Department: 150
Unified Emergency Call: 112

Conference sites

The FQMT'17 conference will take place at the following site:

Pyramida Hotel
address: Bělohorská 24, Praha 6, phone: +420 233 102 111

Conference welcome party will take place at:
Wallenstein Palace Garden
address: Valdštejnské náměstí 4, Praha 1

First public lecture and concert will take place at:
Mayakovsky Hall of National House of Vinohrady
address: Náměstí Míru 9, Praha 2 - Vinohrady

Second public lecture and concert will take place at:
Dvořák's Hall of Rudolfinum
address: Náměstí Jana Palacha 79/1, Praha 1 - Staré Město

Concert will take place at:
St. Vitus Cathedral
address: Prague Castle, Praha 1 - Hradčany

Conference dinner and concert will take place at:
Břevnov Monastery
address: Markétská 28/1, Praha 6 - Břevnov

Limitations related to the Wallenstein Palace

There are some limitations related to the Wallenstein Palace due to the two facts:
1. the Wallenstein Palace is the seat of the Senate of the Czech Republic
2. the Wallenstein Palace is a historical building
Please, read carefully the following text to know about these limitations:

The entrance to the Wallenstein Palace: it is a little more complicated than in recent conferences because of the security reasons (the Palace is the seat of the Senate of the Czech Republic). There is a possibility that all participants will have to pass the metal detection frame and their things have to be screened by x-rays similarly as at airports.
Important: Participants are, therefore, kindly asked to come to the Wallenstein Palace not at the last moment just before the beginning of guided tours/welcome party.

Very important: When entering and moving inside the Wallenstein Palace, all participants are requested to have with them their **conference badges and passports**; both documents can be asked to be shown by the security guards in the Wallenstein palace. Please note that **forgetting a passport could be an admission problem**.

Limitations related to the Prague Castle (St. Vitus Cathedral)

There are some limitations related to the Prague Castle due to the fact that the Prague Castle is the seat of the President of the Czech Republic.
Please, read carefully the following text to know about these limitations:

The entrance to the Prague Castle: it is a little more complicated than in the previous years because of the newly introduced security measures. All visitors of the Prague Castle area have to pass the security check and possibly metal detection frame and their things have to be screened by x-rays similarly as at airports.
Important: Participants are, therefore, kindly asked to come to the Prague Castle not at the last moment before the beginning of the concert in the St. Vitus Cathedral.

Very important: When entering and moving inside the Prague Castle area, all participants are requested to have with them their **conference badges and passports**; both documents can be asked to be shown by the Prague Castle security guards. Please note that **forgetting a passport could be an admission problem**.

Rooms and facilities available for the participants

Pyramida Hotel

- Lecture Hall (ground floor): Most talks will be presented there. During the parallel session program, the Hall will be split into two smaller rooms.

- Conference Room 3 (first floor) will also be used for parallel sessions.

- Lobby of the Lecture Hall (ground floor): it will serve as a coffee room; tea and coffee will be available there all time.

- Several other rooms will be available for the FQMT'17 participants, e.g. study and computer rooms on the first floor.

Posters

Poster session will be held on Thursday (July 13). Posters can be fixed already from 7:30 a.m. on Tuesday on the first floor (corridors) of the Pyramida Hotel and can be exhibited till Friday 11 a.m.

Social events

- Tour of the Wallenstein Palace: Wallenstein Palace, Monday July 10
- Welcome party: Wallenstein Palace Garden, Monday July 10
- First public lecture: National House of Vinohrady, Tuesday July 11
  This evening lecture will be given by Anton Zeilinger.
- Classical music concert: Mayakovsky Hall of National House of Vinohrady, Tuesday July 11
- Second public lecture: Dvořák's Hall of Rudolfinum, Wednesday July 12
  This evening lecture will be given by John Pendry.
- Classical music concert: Dvořák's Hall of Rudolfinum, Wednesday July 12
- Classical music concert: St. Vitus Cathedral, Thursday July 13
- Tour of Břevnov Monastery: Břevnov Monastery, Friday July 14
- Conference dinner: Břevnov Monastery, Friday July 14
- Classical music concert: St. Margaret Church of Břevnov Monastery, Friday July 14

Exact times of the events can be found in the conference program.

Food

Lunches:

All participants can use either:

- a possibility to buy during their registration on Sunday or Monday tickets for lunches in the restaurant just in the Pyramida Hotel.
  The price of one lunch will be 15 EUR.

  or

- to go for lunch to restaurants which are situated in the vicinity of the Pyramida Hotel.

Dinners:

- **Monday:** Welcome party in the **Wallenstein Palace Garden**.
- **Tuesday:** There will be enough time to go for dinner before the public lecture of Anton Zeilinger, either in the **Pyramida Hotel** or to various restaurants in the vicinity of the Pyramida Hotel. It is also possible to go for dinner to numerous restaurants in the Vinohrady area (near the National House of Vinohrady).
- **Wednesday:** There will be enough time to go for dinner before the public lecture of John Pendry, either in the **Pyramida Hotel** or to various restaurants in the vicinity of the Pyramida Hotel. It is also possible to go for dinner to numerous restaurants in the Old Town area (near the Rudolfinum).
- **Thursday:** Buffet during the poster session in the **Pyramida Hotel**.
- **Friday:** Conference dinner in **Břevnov Monastery**.
  Price: 60 EUR per person - tickets for this dinner will be available during the registration.

PROGRAM

Sunday, 9 July 2017

17:00 – 21:00 Registration and welcome refreshment

Location: Pyramida Hotel - lobby

Monday, 10 July 2017

08:00 – 08:30 **Opening addresses**

Location: Pyramida Hotel Lecture Hall
(chairperson: Václav Špička)

08:30 – 10:00 **1 session: Quantum thermodynamics**

Location: Pyramida Hotel Lecture Hall
(chairperson: Christopher Jarzynski)

08:30 – 09:00	Marlan Scully:	*Quantum entropy*
09:00 – 09:30	Amir Ordacgi Caldeira:	*Statistical entropy of open quantum systems*
09:30 – 10:00	Peter Hänggi:	*(Quantum) - Thermodynamics at strong coupling and its implications for Stochastic Thermodynamics*

10:00 – 10:20 Coffee break

10:20 – 12:10 **2 session: Foundations of quantum physics**

Location: Pyramida Hotel Lecture Hall
(chairperson: Ana Maria Cetto)

10:20 – 10:50	Philippe Grangier:	*Recovering the quantum formalism from physically realist axioms*
10:50 – 11:20	Howard J Carmichael:	*Monitored quantum jumps do not "jump": A proposed experimental demonstration in superconducting circuits*
11:20 – 11:50	Alexia Auffèves:	*Rebuilding quantum thermodynamics on quantum measurement*
11:50 – 12:10	Sebastian Deffner:	*Foundations of statistical mechanics from symmetries of entanglement*

12:10 – 13:00 Lunch

13:00 – 15:00	**3 session: Nonequilibrium statistical physics**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Pawel Danielewicz)	
13:00 – 13:30	Jens Eisert:	*Quantum systems out of equilibrium, quantum simulation and the quest for quantum supremacy*
13:30 – 14:00	David Jennings:	*Irreversibility and symmetry principles in quantum theory*
14:00 – 14:30	Wei-Min Zhang:	*General non-Markovian dynamics in open quantum systems*
14:30 – 15:00	Howard Mark Wiseman:	*What is quantum Markovianity?*
15:00 – 15:20	Coffee break	
15:20 – 16:50	**4 session: Quantum transport**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Michael Thorwart)	
15:20 – 15:50	Jianshu Cao:	*Quantum coherence and thermodynamics in non-equilibrium transport*
15:50 – 16:20	Shmuel Gurvitz:	*Closed quantum Master equations for energy transfer in Light-Harvesting complex and multi-exciton dynamics*
16:20 – 16:50	Daniel Esteve:	*When quantum transport meets quantum optics*
16:50 – 17:00	Free time	
17:00 – 18:20	**Round table discussion**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Václav Špička)	
17:00 – 18:20	Quantum thermodynamics, measurement and systems out of equilibrium	
18:20 – 19:30	Free time and transfer to Wallenstein Palace	
19:30 – 22:30	**Welcome party**	
	Location: Wallenstein Palace and its Garden	
19:30 – 20:00	Opening	
20:00 – 22:30	Welcome party in the Wallenstein Palace Garden	

Tuesday, 11 July 2017

08:00 – 10:00	**1 session: Cold atoms**	

Location: Pyramida Hotel Lecture Hall
(chairperson: Linda Reichl)

08:00 – 08:30	Yoram Alhassid:	*The nature of superfluidity in the cold atomic unitary Fermi gas*
08:30 – 09:00	Tilman Esslinger:	*Supersolid phases in quantum gases*
09:00 – 09:30	Frédéric Chevy:	*From ultraslow to ultrafast. Analog simulation of Weyl fermions using ultracold atoms*
09:30 – 10:00	Christophe Salomon:	*Bose-Fermi dual superfluids*
10:00 – 10:20	Coffee break	

10:20 – 12:10	**2 session: Plasmonics, biophysics**	

Location: Pyramida Hotel Lecture Hall
(chairperson: Marlan Scully)

10:20 – 10:50	Norbert Kroo:	*Some novelties in nonlinear plasmonics*
10:50 – 11:20	Tamar Seideman:	*Current-driven phenomena in surface nanoscience*
11:20 – 11:50	Reinhard Lipowsky:	*From curvature elasticity to synthetic biology*
11:50 – 12:10	Stefan Klumpp:	*Life in crowded conditions*
12:10 – 13:00	Lunch	

13:00 – 15:00	**3 session - A parallel: Cold atoms, biophysics**	

Location: Pyramida Hotel Lecture Hall A
(chairperson: Yoram Alhassid)

13:00 – 13:30	Sylvain Nascimbene:	*Ultracold dysprosium gases: A complex system from radiative trapping to many-body physics*
13:30 – 14:00	Nir Navon:	*Tuning the dissipation scale of a quantum-gas turbulent cascade*
14:00 – 14:20	Fernando Sols:	*Synthetic magnetic fields in cold atom systems*

14:20	–	14:40	Francesco Scazza:	*From N+1 to N+N: Exploring repulsive many-body states with ultracold spin mixtures*
14:40	–	15:00	Lawrence S. Schulman:	*Model of horizontal gene transfer, and another power law mystery*

13:00 – 15:00 **3 session - B parallel: Quantum transport, thermodynamics**

Location: Pyramida Hotel Lecture Hall B

(chairperson: James Freericks)

13:00	–	13:30	Klaus Ensslin:	*Spin-orbit interaction on the level of individual electrons*
13:30	–	14:00	Hyunggyu Park:	*Carnot efficiency in an irreversible process*
14:00	–	14:20	Martin Leijnse:	*A quantum-dot heat engine operated near its theoretical efficiency limits*
14:20	–	14:40	Mauro Antezza:	*Excitation injector in an atomic chain: Long-ranged transport and efficiency amplification*
14:40	–	15:00	Jakub Spiechowicz:	*Nonmonotonic temperature dependence of diffusion in driven periodic systems*

13:00 – 15:00 **3 session - C parallel: Quantum phase transitions**

Location: Pyramida Hotel Conference Room 3

(chairperson: Alexander Shnirman)

13:00	–	13:30	Efrat Shimshoni:	*Classical and quantum buckling transitions in cold ion crystals*
13:30	–	14:00	Ralf Schuetzhold:	*Avalanche of entanglement and correlations at quantum phase transitions*
14:00	–	14:20	Thomas Vojta:	*Fate of the amplitude (Higgs) mode at a disordered quantum phase transition*
14:20	–	14:40	Yuval Oreg:	*Topological phases in superconducting lattices*
14:40	–	15:00	Roland E Allen:	*Ultrafast phase transitions in advanced materials, including light-induced superconductivity*

15:00 – 15:20 Coffee break

15:20	–	17:00	**4 session - A parallel: Quantum optics**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: Marlan Scully)	
15:20	–	15:50	Edward Strauss Fry:	*Integrating cavities and ultra-sensitive absorption spectroscopy*
15:50	–	16:20	Jean Etesse:	*Multiplexed quantum correlated photons generated with a tunable delay in a solid-state ensemble*
16:20	–	16:40	Janne Ruostekoski:	*Cooperative atom response to light and giant subradiant correlations in arrays of atoms*
16:40	–	17:00	Radim Filip:	*Non-Gaussian quantum optics and optomechanics*

15:20	–	17:00	**4 session - B parallel: Majorana fermions**	
			Location: Pyramida Hotel Lecture Hall B	
			(chairperson: Thomas Vojta)	
15:20	–	15:50	Alexander Shnirman:	*Emulating Majorana fermions and their braiding by Ising spin chains*
15:50	–	16:20	Pascal Simon:	*Topological superconductivity and Majorana bound states in 2D superconductors*
16:20	–	16:40	Llorenç Serra:	*Current distributions and conductance oscillations in stripe Majorana junctions*
16:40	–	17:00	Kyrylo Snizhko:	*Measurement and control of Coulomb-blockaded parafermion box*

15:20	–	17:00	**4 session - C parallel: Cosmology, quantum physics**	
			Location: Pyramida Hotel Conference Room 3	
			(chairperson: Arkady Plotnitsky)	
15:20	–	15:50	Andrei Khrennikov:	*Quantum-like models: From information laser to color revolutions, Brexit and Donald Trump*
15:50	–	16:20	Pavel Kroupa:	*Galaxy formation in Milgromian gravitation*
16:20	–	16:40	Theo M. Nieuwenhuizen:	*Subjecting theories of dark matter to the cluster test*
16:40	–	17:00	Y. Jack Ng:	*Gravitational thermodynamics and modified dark matter*
17:00	–	19:00	Free time and transfer to National House	

19:00	–	22:30	**Evening session: Public lecture of Anton Zeilinger and concert**	

Location: National House of Vinohrady - Mayakovsky Hall

(chairperson: Václav Špička, Peter Keefe)

19:00	–	19:15	Music introduction and opening address	
19:15	–	20:30	Public lecture	
19:15	–	20:15	**Anton Zeilinger:**	***From quantum puzzles to quantum information technology***
20:15	–	20:30	Discussion after the lecture of Anton Zeilinger	
20:30	–	20:45	Break	
20:45	–	22:00	**Concert of classical music**	

Wednesday, 12 July 2017

08:00 – 10:00	**1 session: Molecular machines, quantum engines**	

Location: Pyramida Hotel Lecture Hall
(chairperson: Saar Rahav)

08:00 – 08:30	Ronnie Kosloff:	*Dynamical view of quantum thermodynamics*
08:30 – 09:00	Gershon Kurizki:	*Universal thermodynamic bound on quantum engine efficiency*
09:00 – 09:30	Stefan Nimmrichter:	*Quantum rotor engines and absorption fridges*
09:30 – 10:00	Ortwin Hess:	*Quantum theory of room temperature single quantum-dot strong-coupling with plasmonic nanoresonators*

10:00 – 10:20 Coffee break

10:20 – 12:10	**2 session - A parallel: Molecular Junctions**	

Location: Pyramida Hotel Lecture Hall A
(chairperson: Ferdinand Evers)

10:20 – 10:50	Abraham Nitzan:	*Electron transfer across thermal gradients*
10:50 – 11:20	Ora Entin-Wohlman:	*Enhanced performance of three-terminal thermoelectric devices*
11:20 – 11:50	Uri Peskin:	*Field-induced inversion of resonant tunneling currents through single molecule junctions and the directional photo-electric effect*
11:50 – 12:10	Oren Tal:	*Magneto-conductance and spin related shot noise properties of half-metallic molecular junctions*

10:20 – 12:10	**2 session - B parallel: Cold atoms, transport**	

Location: Pyramida Hotel Lecture Hall B
(chairperson: Yoram Alhassid)

10:20 – 10:50	Thomas Gasenzer:	*Strongly anomalous non-thermal fixed point in a quenched Bose gas*

10:50	–	11:20	Linda E. Reichl:	*Microscopic hydrodynamic modes in a hard sphere binary mixture*
11:20	–	11:50	Gergely Zarand:	*A semi-semiclassical approach to quantum quenches*
11:50	–	12:10	Marcos Cesar de Oliveira:	*Staggered quantum walks with superconducting microwave resonators*

10:20 – 12:10 **2 session - C parallel: Physics of information**

Location: Pyramida Hotel Conference Room 3

(chairperson: William Wooters)

10:20	–	10:50	Elisabetta Paladino:	*Quantum control of non-Gaussian noise in hybrid quantum networks*
10:50	–	11:20	Giuseppe Falci:	*Probing ultrastrong coupling by coherent amplification of population transfer*
11:20	–	11:50	Austin Peter Lund:	*Boson sampling and continuous variables*
11:50	–	12:10	Masanao Ozawa:	*Quantum root mean square error and universally valid uncertainty relations*
12:10	–	13:00	Lunch	

13:00 – 15:00 **3 session - A parallel: Quantum Thermodynamics, transport**

Location: Pyramida Hotel Lecture Hall A

(chairperson: James Freericks)

13:00	–	13:30	Andreas Wacker:	*Violation of Onsager's theorem in approximate master equation approaches*
13:30	–	14:00	Ferdinand Evers:	*Propagation of charge and energy density in disordered interacting quantum wires - ergodic phases with subdiffusive dynamics?*
14:00	–	14:20	Gilles Montambaux:	*The generalized Stefan-Boltzmann law*
14:20	–	14:40	Rudolf Hilfer:	*Thermodynamics in the presence of anomalous flows*
14:40	–	15:00	Haim Beidenkopf:	*One dimensional hot electrons regain coherence in semiconducting nanowires*

13:00	–	15:00	**3 session - B parallel: General physics, biophysics**	
			Location: Pyramida Hotel Lecture Hall B	
			(chairperson: Stefan Klumpp)	
13:00	–	13:30	Denys Bondar:	*Measurement inspired modeling of dynamical systems*
13:30	–	14:00	Philip Hemmer:	*Organic nanodiamonds*
14:00	–	14:20	Marcelo Lozada-Cassou:	*Long range correlation in complex fluids*
14:20	–	14:40	Boris V. Fine:	*Lyapunov exponents in many-body systems from Loschmidt echoes*
14:40	–	15:00	Jiří J. Mareš:	*Possible role of quantum diffusion in ontogenesis of nervous tissue*

13:00	–	15:00	**3 session - C parallel: Foundations of quantum physics**	
			Location: Pyramida Hotel Conference Room 3	
			(chairperson: Theo Nieuwenhuizen)	
13:00	–	13:30	Ana María Cetto:	*A physical explanation for the connection between the electron spin and statistics*
13:30	–	14:00	Joan A Vaccaro:	*Physical signatures of the quantum nature of time*
14:00	–	14:20	Luis de la Peña:	*Classical explanation of the quantum problem of the particle in a well: Role of the zero-point radiation field*
14:20	–	14:40	Carlos Baladrón:	*Bell inequality violation in the framework of a Darwinian approach to quantum mechanics*
14:40	–	15:00	Arkady Plotnitsky:	*"Human, All Too Human:" On the concept of quantum state, from Bohr's atom to quantum automata*

15:00	–	15:20	Coffee break

15:20	–	17:00	**4 session - A parallel: Superconducting junctions**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: Oren Tal)	
15:20	–	15:50	Mikko Möttönen:	*Experiments on temporally controllable dissipation in superconducting quantum circuits*
15:50	–	16:20	Andrei D. Zaikin:	*Andreev levels as a quantum dissipative environment for superconducting nanojunctions*

16:20 – 16:40	Liliana Arrachea:	*Josephson current in time-reversal invariant topological superconductors*
16:40 – 17:00	Thibaut Jonckheere:	*Hanbury Brown and Twiss noise correlations in a topological superconductor beam splitter*

15:20 – 17:00 **4 session - B parallel: Fluctuations**

Location: Pyramida Hotel Lecture Hall B
(chairperson: Yasuhiro Utsumi)

15:20 – 15:50	Anne Anthore:	*Controlling charge quantization with quantum fluctuations*
15:50 – 16:20	Kensuke Kobayashi:	*Fluctuations along symmetry crossover in a Kondo-correlated quantum dot*
16:20 – 16:40	David Sanchez:	*Cotunneling drag effect in double quantum dots*
16:40 – 17:00	Marti Perarnau-Llobet:	*No-go theorem for the characterisation of work fluctuations in coherent quantum systems*

15:20 – 17:00 **4 Session - C parallel: Graphene, Casimir forces**

Location: Pyramida Hotel Conference Room 3
(chairperson: Giles Montambaux)

15:20 – 15:50	Eric Akkermans:	*Quantum symmetry breaking: Observation of scale anomaly in graphene*
15:50 – 16:20	J. Miguel Rubi:	*Casimir forces out of equilibrium*
16:20 – 16:40	Alessandro De Martino:	*Chiral interface states in pn junctions in graphene*
16:40 – 17:00	Sense Jan van der Molen:	*Probing the electronic coupling between atomically thin layers in van der Waals systems*

17:00 – 19:00 Free time and transfer to Rudolfinum

19:00 – 22:30	**Evening session: Public lecture of John Pendry and concert**		

Location: Rudolfinum Dvořák's Hall
(chairperson: Václav Špička, Peter Keefe)

19:00 – 19:15	Music introduction and opening address	
19:15 – 20:30	Public lecture	
19:15 – 20:30	**John Pendry:**	***Metamaterials and the science of invisibility***
20:15 – 20:30	Discussion after the lecture of John Pendry	
20:30 – 20:45	Break	
20:45 – 22:00	**Concert of classical music**	

Thursday, 13 July 2017

08:00 – 10:00	**1 session: Physics of mesoscopic systems**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Ora Entin-Wohlman)	
08:00 – 08:30	Yigal Meir:	*How can one measure the entropy of a mesoscopic system?*
08:30 – 09:00	Hermann Grabert:	*Input-output theory for AC driven tunnel junctions*
09:00 – 09:30	Amnon Aharony:	*Spin orbit interactions, time reversal symmetry and spin filtering*
09:30 – 10:00	Michael Pollak:	*A new look at an old controversy: Interacting electrons in Anderson-Mott insulators*
10:00 – 10:20	Coffee break	
10:20 – 12:10	**2 session: Optomechanics**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Warwick Bowen)	
10:20 – 10:50	Markus Aspelmeyer:	*New frontiers in quantum optomechanics: From levitation to gravitation*
10:50 – 11:20	Andreas Nunnenkamp:	*Non-reciprocity and directional amplification with cavity optomechanics*
11:20 – 11:50	Joachim Ankerhold:	*Multiple-period Floquet states and time-translation symmetry breaking in quantum oscillators*
11:50 – 12:10	Christoph Bruder:	*Quantum synchronization*
12:10 – 13:00	Lunch	
13:00 – 14:40	**3 session - A parallel: Nonequilibrium statistical physics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Jurgen Stockburger)	
13:00 – 13:30	Michael Thoss:	*Simulation of quantum transport in molecular junctions using multiconfiguration wavefunction and reduced density matrix methods*

13:30	–	14:00	Francesco Petruccione:	*A repeated interaction approach to open quantum walks and open quantum Brownian motion*
14:00	–	14:20	Eric Lutz:	*Irreversibility and the arrow of time in a quenched quantum system*
14:20	–	14:40	Peter Schmitteckert:	*A discrete energy space induced fermion parity breaking fixed point of the Kondo model*

13:00 – 14:40 **3 session - B parallel: Thermodynamics**

Location: Pyramida Hotel Lecture Hall B
(chairperson: Ronnie Kosloff)

13:00	–	13:30	Shin-ichi Sasa:	*Thermodynamic entropy as a Noether invariant*
13:30	–	14:00	Saar Rahav:	*The copying fidelity of a polymerase facing an obstacle*
14:00	–	14:20	Thomas L. Schmidt:	*Quantum thermodynamics in strongly coupled quantum dots*
14:20	–	14:40	Roberto M. Serra:	*Experimental rectification of entropy production by a Maxwell's demon in a quantum system*

13:00 – 14:40 **3 session - C parallel: General physics**

Location: Pyramida Hotel Conference Room 3
(chairperson: Peter Keefe)

13:00	–	13:30	Nicolas Roch:	*Quantum simulation of the spin-boson model: Monitoring the bath*
13:30	–	14:00	Bryan J Dalton:	*EPR steering, Bell non-locality and entanglement in systems of identical massive bosons*
14:00	–	14:20	Michael Guidry:	*A multidisciplinary approach to the theory of emergent states*
14:20	–	14:40	Suzy Lidström:	*Life, the universe, and everything – the emerging Renaissance of physics and astronomy*

14:40 – 15:00 Coffee break

15:00	–	16:00	**4 session - A parallel: Quantum transport**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: Peter Schmitteckert)	
15:00	–	15:20	Gianluca Rastelli:	*Ground state cooling of a nanomechanical resonator by electron transport*
15:20	–	15:40	Rafael Sánchez:	*All-thermal transistor based on stochastic switching*
15:40	–	16:00	Miguel Ortuno:	*Many-body localization from displacement transformations*

15:00	–	16:00	**4 session - B parallel: Stochastic thermodynamics**	
			Location: Pyramida Hotel Lecture Hall B	
			(chairperson: Eric Lutz)	
15:00	–	15:20	Haitao Quan:	*Stochastic thermodynamics of a particle in a box*
15:20	–	15:40	Édgar Roldán:	*Negative records of entropy production: The infimum law*
15:40	–	16:00	Izaak Neri:	*Universal statistics of entropy production in Langevin processes*

15:00	–	16:00	**4 session - C parallel: Superconductivity**	
			Location: Pyramida Hotel Conference Room 3	
			(chairperson: Liliana Arrachea)	
15:00	–	15:20	Peter D. Keefe:	*Proposed experimental investigation into relaxation phenomena in the adiabatic phase transition of Type I superconductor particles*
15:20	–	15:40	Dragos-Victor Anghel:	*New phenomenology from an old theory – the BCS theory of superconductivity revisited*
15:40	–	16:00	Michele Governale:	*Unconventional superconductivity from magnetism in transition metal dichalcogenides*
16:00	–	16:20	Free time	

16:20 – 17:00	**Special talk**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Václav Špička)	
16:20 – 17:00	Emmanuel Fort:	*Hydrodynamic analog of wave-particle duality*
17:00 – 18:50	**Poster session and refreshment**	
	Location: Pyramida Hotel - first floor	
18:50 – 20:00	Transfer to St. Vitus Cathedral	
20:00 – 21:10	**Concert of classical music**	
	Location: Prague Castle - St. Vitus Cathedral	

Friday, 14 July 2017

08:00 – 10:00	**1 session: Nonequilibrium statistical physics**	

Location: Pyramida Hotel Lecture Hall
(chairperson: Michael Thorwart)

08:00 – 08:30	Jan van Ruitenbeek:	*High current-bias effects in atomic and molecular junctions*
08:30 – 09:00	Rémi Avriller:	*Time-dependent quantum transport in molecular junctions: Some effects of electron-phonon interactions*
09:00 – 09:30	James Freericks:	*Relaxation of populations in nonequilibrium many-body physics: Breakdown of Mathiessen's rule*
09:30 – 10:00	Pawel Danielewicz:	*Quantum dynamics of nuclear slabs: Mean field and short-range correlations*
10:00 – 10:20	Coffee break	

10:20 – 12:10	**2 session - A parallel: Quantum transport**	

Location: Pyramida Hotel Lecture Hall A
(chairperson: Pawel Danielewicz)

10:20 – 10:50	Emanuel Gull:	*Monte Carlo for real-time diagrammatics on the Keldysh contour – results from inchworm quantum Monte Carlo*
10:50 – 11:20	Branislav K. Nikolić:	*Diagrammatic and resummation algorithms for electron-magnon and electron-phonon interacting systems in nanojunctions far from equilibrium*
11:20 – 11:50	Claudio Verdozzi:	*Green's function and (TD)DFT descriptions of lattice models out of equilibrium*
11:50 – 12:10	Michael Galperin:	*Hubbard nonequilibrium Green functions*

10:20 – 12:10	**2 session - B parallel: Quantum heat engines**	

Location: Pyramida Hotel Lecture Hall B
(chairperson: Saar Rahav)

10:20 – 10:50	Ahsan Nazir:	*Performance of a quantum heat engine at strong reservoir coupling*

10:50 – 11:20	Fabio Taddei:	*Thermoelectric properties of an interacting QD-based heat engine*
11:20 – 11:50	Konstantin Dorfman:	*Quantum heat engine enhanced by coherence: Efficiency at maximum power and Chambadal-Novikov-Curzon-Ahlborn limit*
11:50 – 12:10	Thomas Fogarty:	*Shortcuts to adiabaticity in the Feshbach engine*

10:20 – 12:10 **2 session - C parallel: Physics and information**

Location: Pyramida Hotel Conference Room 3
(chairperson: Austin Lund)

10:20 – 10:50	Lea F Santos:	*Static and dynamical properties of isolated many-body quantum systems*
10:50 – 11:20	Yasuhiro Utsumi:	*Full-counting statistics of information content*
11:20 – 11:50	Ofer Biham:	*Analytical results for the distribution of shortest path lengths in random networks*
11:50 – 12:10	Eytan Katzav:	*The distribution of last hitting times of self avoiding walks on random networks*

12:10 – 13:00 Lunch

13:00 – 15:00 **3 Session: Optomechanics**

Location: Pyramida Hotel Lecture Hall
(chairperson: Warwick Bowen)

13:00 – 13:30	Dirk Bouwmeester:	*Entangling mechanical resonators*
13:30 – 14:00	Yaroslav M. Blanter:	*Light scattering in cavity optomagnonics*
14:00 – 14:30	Andrew Armour:	*First-order non-equilibrium noise transition in a superconducting circuit*
14:30 – 15:00	Marco Gramegna:	*Measuring non-commuting observables of a single photon via sequential weak values evaluation*

15:00 – 15:20 Coffee break

15:20 – 16:50	**4 Session: Physics of quantum information**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: William Wooters)	
15:20 – 15:50	Steven Mark Girvin:	*Quantum bath engineering and quantum error correction in circuit QED*
15:50 – 16:20	Florian Fröwis:	*Experimental certification of millions of genuinely entangled atoms in a solid*
16:20 – 16:50	Mario Krenn:	*On computer-designed quantum experiments*

16:50 – 18:00 Free time and transfer to Břevnov Monastery

18:00 – 23:00	**Conference dinner and concert**
	Location: Břevnov Monastery
18:00 – 18:20	Welcome
18:20 – 19:30	Guided tour through Břevnov Monastery
19:30 – 21:00	First part of the conference dinner
21:00 – 22:00	**Concert of classical music in the St. Margaret Church**
22:00 – 23:00	Second part of the conference dinner

Saturday, 15 July 2017

08:00 – 10:00	**1 session: Foundations of quantum physics**	

Location: Pyramida Hotel Lecture Hall
(chairperson: Steven Girvin)

08:00 – 08:30	D. Christian Glattli:	*Levitons, minimal excitation states for single electron sources in electron quantum optics*
08:30 – 09:00	Marc Cheneau:	*A two-particle, four-mode interferometer for atoms*
09:00 – 09:30	Sebastien Gleyzes:	*A sensitive electrometer based on a Rydberg atom in a Schrodinger-cat state*
09:30 – 10:00	Johannes Handsteiner:	*Cosmic Bell test: Measurement settings from Milky Way stars*

10:00 – 10:20 Coffee break

10:20 – 11:50	**2 session: Quantum transport**	

Location: Pyramida Hotel Lecture Hall
(chairperson: James Freericks)

10:20 – 10:50	Michael Thorwart:	*Quantum coherence in the dynamics of biomolecular excitons - revisited*
10:50 – 11:20	Wolfgang Belzig:	*Quantum entanglement detection in quantum transport*
11:20 – 11:50	Warwick P. Bowen:	*Single molecule biosensing at the quantum limit*

11:50 – 13:00 Lunch

13:00 – 15:00	**3 session: Foundations of quantum physics**	

Location: Pyramida Hotel Lecture Hall
(chairperson: Marc Cheneau)

13:00 – 13:30	Yuval Gefen:	*Bell non-local correlations from Majorana end-points*
13:30 – 14:00	Christopher Jarzynski:	*A classical route to quantum control*
14:00 – 14:30	William Wootters:	*The Boltzmann distribution and the quantum-classical correspondence*

14:30	–	15:00	Alexander Pechen:	*Use of a non-equilibrium environment for controlling open quantum systems*
15:00	–	15:20	Coffee break	

15:20 – 16:00 **4 session: Nonequilibrium statistical physics**

Location: Pyramida Hotel Lecture Hall

(chairperson: Branislav Nikolic)

15:20	–	15:40	Jürgen T. Stockburger:	*Mutual information: A key concept for irreversibility and mesoscopic thermodynamics*
15:40	–	16:00	Václav Špička:	*Relation between full NEGF, Non-Markovian and Markovian transport equations*

16:00 – 16:30 **Closing and refreshment**

Public Lectures

Metamaterials and the science of invisibility

John Pendry

Imperial College London, Prince COnsort Road, London SW7 2AZ, United Kingdom

In the last decade a new area of research has emerged as a result of our ability to produce materials with entirely novel electromagnetic properties. Known as metamaterials because they take us beyond the properties of conventional materials, they display remarkable effects not found in nature, such as negative refraction.

Spurred on by these new opportunities, theorists have produced exotic concepts that exploit the new materials: we can now specify how to make a lens whose resolution is limited not by the laws of nature but only by our ability to build to the stated specifications; we can guide radiation along a trajectory, avoiding objects and causing them to appear invisible; we can design and manufacture materials that are active magnetically in the optical range.

There has been a truly amazing amount of innovation but more is yet to come. The field of metamaterials is developing into a highly disruptive technology for a plethora of applications where control over light (or more generally electromagnetic radiation) is crucial, amongst them telecommunications, solar energy harvesting, stealth, biological imaging and sensing, and medical diagnostics.

From quantum puzzles to quantum information technology

Anton Zeilinger

VCQ, Faculty of Physics, University of Vienna
Institute of Quantum Optics and Quantum Information IQOQI,
Austrian Academy of Sciences

What are Schrödinger's cat, Einstein's "spooky action at a distance" and his comment that God does not play dice with the Universe all about? Such puzzles led to many experiments which gave rise to world-wide activities to develop quantum information technologies.

The question raised by Schrödinger's cat is how large quantum systems can be. It will be argued that this is a practical question for experimental development in the future with currently no limit in sight.

Einstein's "spooky action at a distance" epitomizes the importance of quantum entanglement. The discussion began by Einstein, Podolsky, and Rosen in 1935 has led to Bell's Theorem. Most recently, experiments have been realized closing more loopholes in such test of local realistic ("classical") views than ever before. In the most recent "Cosmic Bell Experiment", the source of randomness came from distant stars.

Likewise, the randomness of individual quantum events is now considered a fundamental constituent of our understanding of Nature. Its most recent application is the NIST randomness beacon.

A most interesting and rather visual work horse have become orbital angular momentum (OAM) states, "screws of light". These can be used to carry much more information than one bit per photon, and they can be entangled in very high dimensions. These features open up new possibilities, also relevant for fundamental questions. Realizations include 3-dimensional, 3-particle GHZ states.

To date, the fundamental concepts, demonstrated by these puzzles, became the basis for the emerging quantum information technology. It includes quantum teleportation, and quantum computation.

I expect that a future quantum internet will combine these ideas. It will consist of quantum computers connected by quantum links carrying photons. I will shortly introduce these fields. From a fundamental point of view, some of the technical realizations have helped to sharpen our basic questions about the nature of quantum systems.

Invited Talks

Spin orbit interactions, time reversal symmetry and spin filtering

Amnon Aharony

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Tel Aviv University, School of Physics and Astronomy, Tel Aviv, Israel

Quantum computing requires the ability to write and read quantum information on the spinors of electrons. Here we discuss writing information on mobile electrons, which move through mesoscopic (or molecular) quantum wire networks. When such a network is connected to one source and one drain then time-reversal symmetry and unitarity imply no spin polarization. Tunable spin filtering can be achieved by adding a magnetic field, which breaks time-reversal symmetry, or by leakage, which breaks unitarity. Alternatively, filtering is also achieved with more than one drain. Specific examples include transport through a mesoscopic Aharonov-Bohm interferometer and through a helical molecule.

Filtering can also be achieved for a single one-dimensional wire which has spin-orbit interactions, when the chain vibrates in the transverse direction. Such a single wire can also change the Josephson current between two superconductors.

Work with S. Matityahu, O. Entin-Wohlman, C. Baseiro and Y. Utsumi.

Quantum symmetry breaking: Observation of scale anomaly in graphene

Eric Akkermans[1], Omrie Ovdat[1], Eva Andrei[2], and Jinhai Mao[2]

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[2]*Department of Physics, Rutgers University, USA*

Scale invariance is a common property of our everyday environment. Its breaking gives rise to less common but beautiful structures like fractals. At the quantum level, breaking of continuous scale invariance is a remarkable exemple of quantum phase transition also known as scale anomaly. The general features of this transition will be presented at an elementary quantum mechanics level. Then, we will show recent experimental evidence of this transition in graphene.

[1] Observing a Scale Anomaly in Graphene: A Universal Quantum Phase Transition, O. Ovdat, J. Mao, Y. Jiang, E. Y. Andrei, and E. Akkermans, under review in Nature Comm. (2017)

The nature of superfluidity in the cold atomic unitary Fermi gas

Yoram Alhassid

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The two-species cold atomic Fermi gas system provides a well-defined and clean system for which the interaction strength can be tuned experimentally to describe a crossover between a Bose-Einstein condensate (BEC) and the Bardeen-Cooper-Schrieffer (BCS) regime. Of particular interest is the unitary limit for which the interaction is strongest and characterized by an infinite scattering length.

The nature of superfluidity in the unitary gas remains incompletely understood. In particular, a pseudogap phase, in which the gap is non-zero above the critical temperature, was proposed but its existence is still debated both theoretically and experimentally. We implemented finite-temperature auxiliary-field quantum Monte Carlo (AFMC) methods for the canonical ensemble to study the nature of superfluidity of the unitary gas in both a harmonic trap and in a periodic box (describing a homogeneous gas).

(i) *Superfluidity in the finite-size trapped unitary gas.* We used AFMC methods in the framework of the configuration-interaction (CI) shell model [1] to study the thermodynamics of the finite-size cold atom condensate [2]. We performed the first ab initio calculations of the energy-staggering pairing gap, the condensate fraction and the heat capacity in a trapped cold atom system. We observed clear signatures of the superfluid phase transition in these quantities. However, we found no signatures of a pseudogap effect in the energy-staggering pairing gap.

(ii) *Superfluidity in the homogenous unitary gas.* We have used AFMC methods on a spatial lattice to study the cold atom Fermi gas at unitarity [3]. We present the first quantum Monte Carlo calculation of the heat capacity as a function of temperature and compare it with the recently measured lambda peak. We have also calculated the condensate fraction, pairing gap, and the spin susceptibility as a function of temperature. We find no evidence of a pseudogap phase above the critical temperature for superfluidity.

[1] For a recent review of AFMC, see Y. Alhassid, Ch. 9 in a review book *Emergent Phenomena in Atomic Nuclei from Large-Scale Modeling: a Symmetry-Guided Perspective*, edited by K.D. Launey, World Scientific (2017), arXiv:1607.01870.

[2] C.N. Gilbreth and Y. Alhassid, Phys. Rev. A **88**, 063643 (2013).

[3] S. Jensen, C.N. Gilbreth and Y. Alhassid, in preparation (2017).

Ultrafast phase transitions in advanced materials, including light-induced superconductivity

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We begin by reviewing some experimental studies of advanced materials responding to femtosecond-scale laser pulses, with an emphasis on ultrafast phase transitions. One motivation for the experiments, and for the theoretical approaches described below, is that the dynamical response can help to discriminate among possible mechanisms for an observed phase transition. A paradigm is the metal-insulator transition in VO_2; if it is primarily an electronic Mott-Hubbard transition, rather than a structural Peierls transition, the time scale may be roughly two orders of magnitude shorter – femtoseconds rather than hundreds of femtoseconds. The dynamics of phase transitions in the cuprates and iron-based high-Tc materials may provide information on the mechanism of superconductivity, which is still an unsolved problem despite the claims of success for various different theoretical models. In particular, we will discuss the apparent observations of light-induced superconductivity in cuprates and doped fullerenes. In one set of experiments [1], the interpretation is that stripe ordering is a competing phase, and "melting" of the stripes permits the emergence of 3-dimensional superconductivity.

We introduce a new method for treating ultrafast phase transitions, such as those involving superconductivity, magnetism, charge density waves, and spin density waves. This method is made possible by the fact that the density-functional-based technique emphasized here (and also standard density-functional approaches and other first-principles techniques, as long as they include nuclear motion) can yield a true electronic temperature [2]. Illustrative results will be presented for a simple model, with the electronic temperature immediately after the laser pulse calculated as a function of the fluence. In addition, we describe two other complementary approaches. In the first of these, phenomenological Landau-Ginzburg-like order parameters are coupled to one another and to the vector potential of the laser pulse. In the third and most ambitious approach, a self-energy is included in the time domain.

[1] D. Fausti, R. I. Tobey, N. Dean, S. Kaiser, A. Dienst, M. C. Hoffmann, S. Pyon, T. Takayama, H. Takagi, and A. Cavalleri, Light-Induced Superconductivity in a Stripe-Ordered Cuprate, Science 331, 189 (2011).

[2] Zhibin Lin and Roland E. Allen, Ultrafast equilibration of excited electrons in dynamical simulations, J. Phys. Condens. Matter 21, 485503 (2009).

New phenomenology from an old theory – the BCS theory of superconductivity revisited

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We revisit the Bardeen-Cooper-Schriefer (BCS) theory of superconductivity by studying the effect of the asymmetry of the attraction band with respect to the chemical potential on the physical properties of the superconductor. The attraction band is defined as the interval $I_V = [\mu - \hbar\omega_c, \mu + \hbar\omega_c]$ in which the pairing interaction is manifested. In the "standard" BCS formalism, μ, which is the center of the attraction band, is identified with the chemical potential. Nevertheless, this is not a physical requirement and in multiband superconductors the cutoff of the pairing interaction may be asymmetric with respect to the chemical potential in some of the conduction bands. Furthermore, the chemical potential and the attraction band may be influenced differently by the external conditions (e.g. pressure) or preparation methods (e.g. changing the conduction band by changing the chemical composition of the superconductor), so it is natural to assume that μ is not identical to the chemical potential.

We consider here single-band superconductors and we denote the chemical potential by μ_R to distinguish it from μ. We analyze the effect of the difference $\mu - \mu_R$ on the physical properties of the superconductor. We find that if $\mu \neq \mu_R$, the energy gap Δ and the temperature of the superconductor-normal metal phase transition T_{ph} change and there are two solutions for the energy gap equation; the ratio $\Delta(T = 0)/T_{ph}$ changes also with $\mu - \mu_R$. More dramatically, when $\mu \neq \mu_R$, a population imbalance appears in equilibrium and the superconductor-normal metal phase transition becomes of the first order in the grandcanonical ensemble. If $\mu - \mu_R$ varies monotonically with pressure or doping, then a feature like the superconducting dome appears when the temperature of the phase transition is plotted vs pressure or doping concentration (for details, see Refs. [1,2]).

[1] D. V. Anghel and G. A. Nemnes, Physica A 464, 74 (2016).

[2] D. V. Anghel, arXiv:1609.07931.

Multiple-period Floquet states and time-translation symmetry breaking in quantum oscillators

Yaxing Zhang[2], Jennifer Gosner[1], Björn Kubala[1], Steven M. Girvin[2], Mark Dykman[3], and Joachim Ankerhold[1]

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[2]*Department of Physics, Yale University, New Haven, CT 06511, USA*
[3]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*

Quantum nonlinear oscillators subject to periodic driving have received substantial attention in the last years, e.g., in the context of nano-mechanical, superconducting, and atomic systems. Their dynamics is described in terms of Floquet states based on the fact that a driven system has discrete time-translation symmetry with the period of the driving. Recently, the breaking of discrete time-translational symmetry has attracted much interest, known as "time crystallization". Nonlinear oscillators provide an ideal platform for studying this effect as they are intermediate between large closed systems and dissipative systems, which both display the symmetry breaking, but have qualitatively different dynamics. Here we show that this phenomenon may also occur in a quantum coherent regime and specifically discuss nonlinear quantum oscillators driven close to three times their eigenfrequencies [1]. This class of oscillators exhibits features which seem to be generic beyond linear and parametric driving. It turns out that time-translational symmetry breaking occurs due to crossings of quasi-energy levels originating from geometric phases. These phases depend on the driving strength and are directly determined by the topology of the corresponding quasi-energy fields. The role of dissipation is also addressed, where with varying detuning a reentrant kinetic transition appears between states of different time-translational symmetry. These findings can be experimentally explored particularly in circuit QED set-ups with voltage biased Josephson junctions [2-4].

[1] Yaxing Zhang, J. Gosner, S. M. Girvin, J. Ankerhold, and M. Dykman, arXiv: 1702.07931.

[2] M. Hofheinz, F. Portier, Q. Baudouin, P. Joyez, D. Vion, P. Bertet, P. Roche, and D. Esteve, Phys. Rev. Lett. 106, 217005 (2011).

[3] A. D. Armour, M. P. Blencowe, E. Brahimi, and A. J. Rimberg, Phys. Rev. Lett. 111, 247001 (2013).

[4] V. Gramich, B. Kubala, S. Meister, and J. Ankerhold, Phys. Rev. Lett. 111, 247002 (2013).

Excitation injector in an atomic chain: Long-ranged transport and efficiency amplification

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We investigate the transport of energy in a linear chain of two-level quantum emitters ("atoms") weakly coupled to a blackbody radiation bath [1]. We show that, simply by displacing one or more atoms from their regular-chain positions, the efficiency of the energy transport can be considerably amplified of at least one order of magnitude. Besides, in configurations providing an efficiency greater than 100% , the distance between the two last atoms of the chain can be up to 20 times larger than the one in the regular chain, thus achieving a much longer-range energy transport. By performing both a stationary and time-dependent analysis, we ascribe this effect to an elementary block of three atoms, playing the role of excitation injector from the blackbody bath to the extraction site. By considering chains with up to 7 atoms, we also show that the amplification is robust and can be further enhanced up to 1400%.

[1] P. Doyeux, R. Messina, B. Leggio, and M. Antezza, Phys. Rev. A 95, 012138 (2017).

Controlling charge quantization with quantum fluctuations

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On a simple piece of metal, charge is quantized. Yet, in most of the electronic circuits, despite the granularity of charge transfer, no hints of charge quantization remain. To observe and exploit charge quantization effects, people have realized metallic nodes weakly connected to the circuit through tunnel contacts, as, for example, in a single electron transistor. Beyond tunnel junctions, quantized charging effects can arise in circuits made of coherent conductors and strongly modify the electrical transport. So, what governs the crossover from quantized to continuous charge on a metallic node?

In this talk, I will present our experimental investigation of charge quantization in a node, when the coupling of the node to the circuit evolves from tunnel regime to ballistic regime [1]. A single electron transistor was realized where the two tunnel junctions were replaced by quantum conductors with electronic quantum channels of arbitrary transmission probabilities. The charge quantization is revealed by a periodic modulation of the circuit zero-bias conductance when sweeping the voltage applied to a gate capacitively coupled to the island, and is characterized by the visibility of conductance variations.

Theory predicts that charge quantization in the island is reduced by quantum fluctuations as the transmission probabilities τ increase, and that it is completely destroyed as soon as one conduction channel is ballistic [2]. In our experiment, we can quantitatively check this prediction by avoiding spurious direct coherence effect. It closes a long standing debate as regard charging effects in open quantum dots [3,4,5]. Finally, our data provide a blueprint for charge quantization versus transmission probabilities at larger temperature when thermal fluctuations take the lead on quantum fluctuations.

[1] S. Jezouin et al., Nature 536 (2016) 58

[2] A. Furusaki, K.A. Matveev, PRB 52 (1995) 16678

[3] L.P. Kouwenhoven et al., Z. Phys. B - Condensed Matter 85 (1991) 367

[4] C. Pasquier et al., Surface Science 263 (1992) 419

[5] C.-T. Liang et al., PRL 81 (1998) 3507

First-order non-equilibrium noise transition in a superconducting circuit

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In systems which combine high-quality superconducting cavities and mesoscopic conductors a large non-equilibrium photon population can build up which in turn acts back on the charge transport leading to potentially novel regimes where the dynamics of the charge and photons become strongly coupled. Considering a voltage-biased Josephson junction coupled to a microwave cavity, we explore the fluctuations in the Cooper-pair current and their relationship to the non-equilibrium photon population in the cavity. When quantum fluctuations in the cavity are weak the current noise in the system displays clear signatures of bifurcations in the underlying classical non-linear dynamics. These include a first-order transition in which the system switches abruptly from a very low current noise state (signifying strongly coherent charge transport) to one where the noise is large, as the Josephson energy of the junction is increased. When the quantum fluctuations are stronger the changes in the current noise are smoothed out.

Josephson current in time-reversal invariant topological superconductors

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Time reversal invariant topological superconducting (TRITOPS) wires are known to host a fractional spin $\hbar/4$ at their ends. We investigate how this fractional spin affects the Josephson current in a TRITOPS-quantum dot-TRITOPS Josephson junction, describing the wire in a model which can be tuned between a topological and a nontopological phase. We compute the equilibrium Josephson current of the full model by continuous-time Monte Carlo simulations and interpret the results within an effective low-energy theory. We show that in the topological phase, the 0-to-π transition is quenched via formation of a spin singlet from the quantum dot spin and the fractional spins associated with the two adjacent topological superconductors.

New frontiers in quantum optomechanics: From levitation to gravitation

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Quantum optics provides a high-precision toolbox to enter and to control the quantum regime of the motion of massive mechanical objects [1]. Levitation of solid-state objects is a unique approach to realise (nano- or micro-) mechanical devices with minimal mechanical losses [2]. Besides improved sensing capabilities such systems have the potential for significantly increased coherence time when operated in the quantum regime. This opens the door to a hitherto untested parameter regime of macroscopic quantum physics [3,4]. The availability of quantum superposition states involving increasingly massive objects could enable a completely new class of experiments, in which the source mass character of the quantum system starts to play a role. This addresses directly one of the outstanding questions at the interface between quantum physics and gravity, namely "how does a quantum system gravitate?". This is reminiscent of Feynman's proposal at the 1957 Chapel Hill Conference on the generation of entanglement through gravitational interaction [5]. I will discuss the feasibility of such experiments and the relevance of quantum controlling levitated mechanical systems [6-8].

[1] M. Aspelmeyer, F. Marquardt, T. Kippenberg, Rev. Mod. Phys. 86, 1391 (2014)

[2] V. Jain et al., Phys. Rev. Lett. 116, 243601 (2016)

[3] O. Romero-Isart et al., Phys. Rev. Lett. 107, 020405 (2011)

[4] H. Pinot et al., arxiv:1603.01553 [quant-ph] (2016)

[5] R. Feynman in: C. M. DeWitt & D. Rickles (Eds.), The Role of Gravitation in Physics. Report from the 1957 Chapel Hill Conference. Max Planck Research Library for the History and Development of Knowledge. pp. 250 ff.

[6] Chang et al., PNAS 107, 1005 (2010); Romero-Isart et al., N. J. Phys. 12, 033015 (2010)

[7] Romero-Isart et al., Phys. Rev. Lett. 109, 147205 (2012)

[8] N. Kiesel et al., PNAS 110, 14180 (2013)

Rebuilding quantum thermodynamics on quantum measurement

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Thermodynamics relies on randomness. In classical thermodynamics, the coupling to a thermal bath induces stochastic fluctuations on the system considered: Thermodynamic irreversibility stems from such fluctuations [1], which also provide the fuel of thermal engines. Quantum theory has revealed the existence of an ultimate source of randomness: Quantum measurement through the well-known measurement postulate [2]. In this talk I will present recent attempts to rebuild quantum thermodynamics on quantum measurement, from quantum irreversibility to quantum engines extracting work from quantum fluctuations [3,4].

[1] A. Auffèves, Viewpoint : Nuclear spin points out the arrow of time, Physics 8, 106 (2015)

[2] A. Auffèves, P. Grangier, Recovering the quantum formalism from physically realist axioms, Scientific Reports 43365 (2017)

[3] C. Elouard, D. Herrera-Marti, M. Clusel, A. Auffèves, The role of quantum measurement in stochastic thermodynamics, Nature Quantum Information, 10.1038/s41534-017-0008-4 (2017)

[4] C. Elouard, D. Herrera-Marti, B. Huard, A. Auffèves, Extracting work from quantum measurement in Maxwell's demon engines, arXiv:1702.01917, accepted in Physical Review Letters

Time-dependent quantum transport in molecular junctions: Some effects of electron-phonon interactions

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The study of time-dependent current fluctuations in nanoscale conductors is of great importance as it can provide informations on the interactions and quantum correlations between electrons [1]. While these studies have been traditionally restricted to the stationary regime, the advent of single-electron sources [2], has triggered a renewed interest in investigating the short-time behavior as well [3].

This presentation aims at reviewing some recent advances in this field of research. In particular, we develop a theoretical approach to study the transient dynamics and the time-dependent statistics of charge transfer for the Anderson-Holstein model in the regime of strong electron-phonon coupling [4]. The generating function for the time-dependent charge transfer probabilities is evaluated numerically by discretization of the Keldysh contour. The method allows us to analyze the system evolution to the steady state after a sudden connection of the dot to the leads, starting from different initial conditions.

It is shown that the transient dynamics is slowed down significantly upon increasing e-ph interactions, thus resulting in an apparent bistable behavior [4]. Simple analytical results are obtained in the regime of very short times which provide a simple unifying explanation for this polaronic « blocking-deblocking » dynamics based on an analogy between optics and nanoelectronics.

We finally analyze the waiting time distribution and charge transfer probabilities, showing that only a single electron transfer is responsible for the rich structure found in the short-time regime [4]. A universal scaling (independent of the model parameters) is found for the relative amplitude of the higher order current cumulants in the short-time regime [4], starting from an initially empty dot.

[1] Y. M. Blanter and M. Büttiker, Phys. Rep. 336, 1 (2000).

[2] G. Fève et al., Science 316, 1169 (2007).

[3] K. Thibault, J. Gabelli, Ch. Lupien, and B. Reulet, Phys. Rev. Lett. 114, 236604 (2015).

[4] R. Seoane Souto, R. Avriller, R. C. Monreal, A. Martin-Rodero and A. Levy Yeyati, Phys. Rev. B 92, 125435 (2015).

Bell inequality violation in the framework of a Darwinian approach to quantum mechanics

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A fundamental particle in physical space subject to conservation of momentum and energy, and characterized by its average mass and its position is methodologically supplemented with an information processor – a classical Turing machine – and a randomizer both defined on an information space. In this way the particle can be considered a generalized Darwinian system on which natural selection acts steering the evolution on the information space of the algorithm that governs the behaviour of the particle. Assuming as starting point for every system the blank state, i.e. no information, an initial random behaviour would plausibly give rise to an emergent quantum behaviour, as discussed in previous preliminary studies [1, 2]. This theory is applied to an EPR-Bohm experiment for electrons in order to analyze Bell inequality violation [3]. A model for the entanglement of two particles has been considered. The model includes shared randomness – by means of a randomizer shared by both particles – and the mutual transfer of their algorithms – sharing programs – that contain their respective anticipation modules. This fact enables every particle to anticipate not only the possible future configurations of its surrounding systems, but also those of the surrounding systems of its entangled particle, bringing about information nonlocality, but only in the information space. Thus, locality would be preserved in the physical space. The theory is realist in a minimalist sense, since the state of the particle includes its position at any time as part of its characterization, as in the de Broglie-Bohm theory. Finally, in this theory randomness is fundamental and irreducible, although the weight of randomness – versus causality – would presumably decrease with time as the complexity of the algorithm increased, up to reaching the quantum equilibrium.

[1] C. Baladrón, in Quantum Foundations and Open Quantum systems edited by T. Nieuwenhuizen et al. (World Scientific, Singapore, 2014), Chap.13.

[2] C. Baladrón and A. Khrennikov, BioSystems 150 (2016) 13.

[3] A. Khrennikov, Fortschr. Phys. doi:10.1002/prop.201600044 (2016).

One dimensional hot electrons regain coherence in semiconducting nanowires

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Electrons confined to one dimension exhibit various counter-intuitive phenomena such as charge fractionalization, spin-charge separation, and Majorana end modes induced at nanowires rendered topologically superconducting. We study the phase coherence of hot electrons in semiconducting InAs nanowires through scanning tunneling spectroscopic imaging. By maintaining the MBE grown nanowires under ultra-high vacuum we are able to atomically resolve their facets and spectroscopically investigate the quasi-one-dimensional electronic states in them. We visualize the confined nature of these states both through the Van Hove singularities in their spectrum as well as through direct mapping of the quantized channels via quasi-particle interference. We thus identify a new relaxation regime of electrons in one-dimension. Above a certain energy threshold the relaxation rate turns non-monotonic where the higher the injection energy of the hot electron is, the more stable it becomes against relaxation. We detect this behavior both in the decay length of the quasi-particle interference patterns at the nanowire end as well as via the finite life-time of the hot electrons within Fabry-Perot resonators formed by adjacent stacking faults. The origin of this unusual energy-evolution of coherence lies in the form of the Coulomb interaction in quasi-one-dimension as well as the non-linear dispersion over the energy scale probed.

[1] Jonathan Reiner, Abhay Kumar Nayak, Nurit Avraham, Binghai Yan, Yan Sun, Ion Cosma Fulga, Jung-Hyun Kang, Torsten Karzig, Hadas Shtrikman, and Haim Beidenkopf, Phys. Rev. X 7, 021016 (2017).

Quantum entanglement detection in quantum transport

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The creation and detection of entangled particle in a mesoscopic system constitutes an important field of research in both experiment and theory. While sources of spin-entangled electrons are readily available in the form for Cooper pairs in superconductors, to controllably separate the two electrons and detect the entanglement is still a challenge. Experimentally carbon nanotube quantum dots are promising systems to spatially separate Cooper pairs [1,2]. However the detection through current cross correlations presents a challenge, in particular to theory [3]. The reason is that usual schemes like violation of the Bell inequality are not applicable due to the continuous character of the current signal [4]. In this talk I will critically review proposals like entanglement detection through the measurement of current noise correlators, non-local conductances or so-called entanglement witnesses. They all have in common that they cannot exclude in general dephasing induced "detanglement", while still signalling entanglement. In the end I will propose how entanglement can be unambiguously detected and discuss novel schemes to detect controlled entanglement in a Cooper pair splitter pump.

[1] L. Hofstetter, S. Csonka, J. Nygård, and C. Schönenberger, Nature 461, 960 (2009).

[2] L. G. Herrmann, F. Portier, P. Roche, A. Levy Yeyati, T. Kontos, and C. Strunk, Phys. Rev. Lett. 104, 026801 (2010).

[3] W. Belzig and A. Bednorz, Phys. Status Solidi B 251, 1945 (2014).

[4] A. Bednorz and W. Belzig, Phys. Rev. B 83, 125304 (2011).

Analytical results for the distribution of shortest path lengths in random networks

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The increasing interest in network research in recent years is motivated by the realization that a large variety of systems and processes which involve interacting objects can be described by network models. In these models, the objects are represented by nodes and the interactions are expressed by edges. The interactions between non-adjacent pairs of nodes are facilitated by paths going through intermediate nodes and edges. The shortest paths between such pairs are of particular importance because they provide the strongest interactions and fastest response. Therefore, the distribution of shortest path lengths (DSPL) is of great relevance to many dynamical processes taking place on networks such as diffusive processes, first passage processes, traffic flow, communication and epidemic spreading. We argue that the DSPL is a natural quantity by which dynamical processes on networks should be formulated. In particular, it incorporates the statistical symmetries of the network in the dynamical equations, in analogy to the reduction of a partial differential equation in Euclidean space to an ordinary differential equation for the radial component, in the presence of a spherical symmetry, and hence of fundamental importance. While the average of the DSPL has been studied extensively, the analytical calculation of the entire distribution has remained an open problem. In this presentation a novel analytical approach for calculating the DSPL in random networks will be discussed. This approach is based on the cavity method, and applies to a large family of network types, which includes Erdos-Renyi networks [1], regular graphs and more generally, configuration model networks [2]. The results are found to be in agreement with numerical simulations for a broad range of networks, sizes and connectivities.

[1] E. Katzav, M. Nitzan, D. ben-Avraham, P. L. Krapivsky, R. Kuhn, N. Ross and O. Biham, Analytical results for the distribution of shortest path lengths in random networks, EPL 111, 26006 (2015).

[2] M. Nitzan, E. Katzav, R. Kuhn and O. Biham, Distance distribution in configuration model networks, Phys. Rev. E 93, 062309 (2016).

Light scattering in cavity optomagnonics

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Brillouin light scattering is an established technique to study magnons, the elementary excitations of a magnet. Its efficiency can potentially be enhanced by cavity effects that concentrates the light power in the magnet. Here, we study inelastic scattering of photons by a magnetic sphere that supports optical whispering gallery modes, in a configuration of light traveling perpendicular to the magnetization. We find light scattering in two regimes. For low angular momentum magnons, the light is scattered in the forward direction with a pronounced asymmetry in the Stokes and the anti-Stokes scattering probability, consistent with recent experiments. High angular momentum magnons back-scatter light into either the Stokes or anti-Stokes peaks. We further show that the light scattering in the latter regime permits mapping of the high angular momentum magnon dispersion.

Measurement inspired modeling of dynamical systems

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We will provide an answer to the question: "What kind of observations and assumptions are minimally needed to formulate a physical theory?" Our answer to this question leads to the new systematic approach of Operational Dynamical Modeling (ODM), which allows to deduce equations of motions from time evolution of observables. Using ODM, we are not only able to re-derive well-known physical theories (such as the Schrodinger and classical Liouville equations), but also infer novel physical dynamics (and solve open problems) in the realm of non-equilibrium quantum statistical mechanics.

Entangling mechanical resonators

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Hybrid quantum systems have been developed with various mechanical, optical and microwave harmonic oscillators. The coupling produces a rich library of interactions including two mode squeezing, swapping interactions, back-action evasion and thermal control. In a multimode mechanical system, coupling resonators of different scales (both in frequency and mass) leverages the advantages of each resonance. For example: a high frequency, easily manipulated resonator could be entangled with a low frequency massive object for tests of gravitational decoherence. We demonstrate coherent optomechanical state swapping between two spatially and frequency separated resonators with a mass ratio of 4. We find that, by using two laser beams far detuned from an optical cavity resonance, efficient state transfer is possible through a process very similar to STIRAP (Stimulated Raman Adiabatic Passage) in atomic physics. Although the demonstration is classical, the same technique can be used to generate entanglement between oscillators in the quantum regime.

Single molecule biosensing at the quantum limit

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Sensors that are able to detect and track single unlabelled biomolecules are an important tool both to understand biomolecular dynamics and interactions, and for medical diagnostics operating at their ultimate detection limits. Recently, exceptional sensitivity has been achieved using the strongly enhanced evanescent fields provided by optical microcavities and plasmonic resonators [1,2]. However, at high field intensities photodamage to the biological specimen becomes increasingly problematic [3]. Here, we introduce a new approach to evanescent biosensing that combines dark field illumination and heterodyne detection in an optical nanofibre-based platform [4]. This allows operation at the fundamental precision limit introduced by quantisation of light. We achieve state-of-the-art sensitivity with a four order-of-magnitude reduction in optical intensity. This enables quantum noise limited tracking of single biomolecules as small as 3.5 nm and surface-molecule interactions to be monitored over extended periods. This opens the door to study the nanoscale machinery of life in its native state, without requiring either labels or photointrusion, including motor molecules such as myosin, kinesin and ATPase. By achieving quantum noise limited precision, our approach provides a pathway towards quantum-enhanced single-molecule biosensors.

[1] M. D. Baaske, M. R. Foreman and F. Vollmer, Nature Nanotechnology 9 933-939 (2014).

[2] Y. Pang and R. Gordon, Nano Letters 12 402-406 (2012).

[3] See e.g. U. Mirsaidov, W. Timp, K. Timp, M. Mir, P. Matsudaira and G. Timp, Phys. Rev. E. 78 021910 (2008).

[4] N. P. Mauranyapin et al. arxiv:1609.05979 (2016).

Quantum synchronization

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Synchronization of self-oscillators is a universal phenomenon that is important both in fundamental studies and in technical applications. Recent experimental progress in optomechanical systems has motivated the study of synchronization in quantum systems. We have studied the synchronization of a van der Pol self-oscillator with Kerr anharmonicity to an external drive [1]. We have shown that this system exhibits genuine quantum signatures like multiple resonances in both phase locking and frequency entrainment not present in the corresponding classical system. Very recently, we have predicted a novel quantum phenomenon in synchronization which we called *quantum synchronization blockade* [2]. Classically, the tendency towards spontaneous synchronization is strongest if the natural frequencies of the self-oscillators are as close as possible. We have shown that this wisdom fails in the deep quantum regime, where the uncertainty of amplitude narrows down to the level of single quanta for a proposal of how to stabilize Fock states in superconducting circuits). Under these circumstances identical self-oscillators cannot synchronize and detuning their frequencies can actually *help* synchronization.

[1] N. Lörch, E. Amitai, A. Nunnenkamp, and C. Bruder, Phys. Rev. Lett. **117**, 073601 (2016).

[2] N. Lörch, S.E. Nigg, A. Nunnenkamp, R.P. Tiwari, and C. Bruder, arXiv:1703.04595; accepted for publication in Phys. Rev. Lett.

Statistical entropy of open quantum systems

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Dissipative quantum systems are frequently described within the framework of the so-called "system-plus-reservoir" approach. In this work we assign their description to the Maximum Entropy Formalism and compare the resulting thermodynamic properties with those of the well - established approaches. Due to the non-negligible coupling to the heat reservoir, these systems are non-extensive by nature, and the former task may require the use of non-extensive parameter dependent informational entropies. In doing so, we address the problem of choosing appropriate forms of those entropies in order to describe a consistent thermodynamics for dissipative quantum systems.

T24 Mon, 10 July, 15:20 - 15:50, 4 session

Quantum coherence and thermodynamics in non-equilibrium transport

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Transport in nano-scale systems often display intriguing quantum mechanical effects, which will be illustrated using examples such as the non-equilibrium spin-boson model, energy transfer networks, and three-level energy transfer systems. Using these examples, we hope to demonstrate non-trivial quantum effects: polaron-induced coherence, multiple steady-state solutions, and ballistic-diffusive transition. Our analysis will shed light on the coherent nature in quantum transport and will be relevant for the design and control of nano-scale quantum devices.

[1] Dynamical signatures of molecular symmetries in non-equilibrium quantum transport. J. Thingna, D. Manzano, and J. Cao, Sci. Rep. 6, 28027 (2016)

[2] Quantum transport in d-dimensional lattices. D. Manzano, C. Chuang, and J. Cao, New J. Phys. 18, 043044 (2016)

[3] Polaron effects on the performance of light-harvesting systems: A quantum heat engine perspective. D. Xu, C. Wang, Y. Zhao, and J. Cao, New J. Phys. 18, 023003 (2016)

[4] Nonequilibrium energy transfer at nanoscale: A unified theory from weak to strong coupling. C. Wang, R. Jie, and J. Cao, Sci. Rep. 5, 11787 (2015)

[5] Unifying quantum heat transfer in non-equilibrium spin-boson model with full counting statistics, C. Wang, J. Ren, and J. Cao, Phys. Rev. A 95, 023610 (2017)

Monitored quantum jumps do not "jump": A proposed experimental demonstration in superconducting circuits

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The evolving status of "jumps" in the lexicon of quantum physics is a tale that reaches back 100 years [1]. Beginning with the atomic model of Niels Bohr [2], jumps between quantized energy levels were a staple of the old quantum theory; they underpinned the relationship between the frequency of radiation—either emitted or absorbed—and the energy change of the atom. Continuing on, however, to Schrödinger's wave equation, an opposing position was introduced: discontinuity (the quantum jump) was banished in Schrödinger's thinking [3], to be replaced by continuously changing weights in a sum over a pair of proper modes of atomic oscillation (initial and final states). Moving ahead a further 60 years, in 1986 quantum jumps were observed in experiments with single trapped ions [4-6], evidenced by random telegraph noise—induced by the jumps—on the intensity of fluorescence driven on a strong (dipole allowed) optical transition, when the ion was simultaneously driven on a weak (metastable) transition sharing the same ground state. Numerous confirmations of the trapped-ion results have since been reported, including, most recently, in superconducting circuits [7]. We argue here that the jumps in effect (random telegraph noise) of the readout monitoring an open quantum system are not "jumps" in fact of the monitored system; indeed, transitions in the monitored system conform to Schrödinger's thinking, though follow a continuous path imposed by null-measurement backaction, not a path that Schrödinger would have envisaged. We propose, furthermore, that this path can be operationally mapped out in experiments based on superconducting circuits [8]. We outline an experimental design and present quantum trajectory simulations that show how the quantum "jump" can be caught mid-flight, i.e., conditioned appropriately on the measurement record, quantum tomography reconstructs a superposition state that tracks continuously in time from the initial to the final state.

[1] H. J. Carmichael, New Zealand Science Review 72, 31 (2015)

[2] N. Bohr, Philos. Mag. 26, 1, 476, 857 (1913)

[3] E. Schrödinger, Br. J. Philos. Sci., Vol. III, 109, 233 (1952)

[4] W. Nagourney, J. Sandberg, and H. Dehmelt, Phys. Rev. Lett. 56, 2797 (1986)

[5] T. Sauter, W. Neuhauser, R. Blatt, and P. Toschek, Phys. Rev. Lett. 57, 1696 (1986)

[6] J. Bergquist, R. Hulet, W. Itano, D. Wineland, Phys. Rev. Lett. 57, 1699 (1986)

[7] R. Vijay, D.H. Slichter, I. Siddiqi, Phys. Rev. Lett. 106, 110502 (2011)

[8] M. H. Devoret and R. J. Schoelkopf, Science 339, 1169 (2013)

A physical explanation for the connection between the electron spin and statistics

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Which is the physical agent behind the spin-statistics connection? Despite their enormous impact on the whole of physics, the antisymmetry of the electron wave function and the associated Pauli principle are commonly taken in quantum mechanics as empirical facts. The spin itself has been shown in stochastic electrodynamics (SED) to result from the coupling of the electron to circularly polarized modes of the electromagnetic vacuum, taken as a real fluctuating field. In this work, profiting from the fact that for a bipartite system the entangled state function as given by SED reproduces the quantum result but still contains information about the vacuum field mode that mediates between the particles, we show that the electrons couple in antiphase to the same field mode. This finding, encoded in the antisymmetry of the state vector, provides a physical rationale for the Pauli exclusion principle.

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A two-particle, four-mode interferometer for atoms

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The extraordinary character of entanglement stems from the fact that the many-body wave-function of entangled particles cannot be factorized in a product of single-particle wave-functions. When one insists on describing such wave-function in our ordinary space-time, one has to face the problem of non-locality. This is clearly evidenced by the violation of Bell's inequalities, which apply to any system that can be described in the spirit of the local realist world view of Einstein, in which physical reality lies in our ordinary space-time. While the violation of Bell's inequalities is a two-particle interference effect, the converse is not true: not all two-particle interferences can lead to a violation of Bell's inequalities, and thus be impossible to describe in a local realist point of view. This is for instance the case of the Hong–Ou–Mandel effect. The key difference between these effects is the number of modes that are made to interfere. While the Hong–Ou–Mandel effect involves only two modes for two particles, a test of Bell's inequalities requires four modes that can be made to interfere two by two at two different places. Experimental tests of Bell's inequalities always closer to the ideal configuration have been performed with low energy photons, or internal states of atoms. But we do not know of experiments on two-particle, four mode interferences involving the external degrees of freedom of massive particles (position or momentum), in a configuration permitting Bell's inequalities to be tested. Such tests involving mechanical observables are desirable, in particular because they may give access to the interface between quantum mechanics and gravitation. In this talk, we propose an experiment enabling the observation of a two-particle, four-mode interference with atoms entangled in momentum, and realize a test of Bell's inequalities. It is based on the experimental set-up used in our recent atomic Hong–Ou–Mandel experiment [1]. We also present preliminary data, recorded with a simplified version of the interferometer, that are are compatible with the existence of a quantum interference in this set-up.

[1] R. Lopes, A. Imanaliev, A. Aspect, M. Cheneau, D. Boiron, and C. I. Westbrook, Nature 520, 66 (2015)

From ultraslow to ultrafast. Analog simulation of Weyl fermions using ultracold atoms

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Weyl fermions are solutions of Dirac's Equation describing massless particles and as such they constitue one of the cornerstones of the Standard Model of particle physics. Using a unitary transformation, it is possible to map the dynamics of harmonically trapped Weyl particles onto that of atoms confined in a magnetic quadrupole potential [1]. We show that even in the absence of interparticle interactions, the non-linearity of the single-particle Hamiltonian leads to a quasi-thermalization of an ideal gas of Weyl fermions towards a non-Boltzmanian state that we characterize using simple arguments. Finally, we suggest possible experimental pathways towards the experimental study of the peculiar topological features of Weyl fermions.

[1] D. Suchet, M. Rabinovic, T. Reimann, N. Kretzschmar, F. Sievers, C. Salomon, J. Lau, O. Goulko, C. Lobo, and F. Chevy, Europhys. Lett. 114 (2016) 26005

EPR steering, Bell non-locality and entanglement in systems of identical massive bosons

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In previous work [1] quantum entanglement was treated for identical particle bipartite systems based on requiring the density operator to comply with the symmetrisation principle (SP) and with super-selection rules (SSR) prohibiting states with coherences between differing total particle numbers. The subsystems are distinguishable modes, the subsystem density operators for separable states also satisfying the SP and SSR for subsystem particle numbers. Spin squeezing in any spin component, two mode quadrature squeezing and a weak correlation test were shown to be new sufficiency tests for two mode entanglement with massive bosons. A test for the sum of Sx, Sy spin operator variances being less than half the mean boson number N [2] also applied.

Quantum states for composite systems are categorised as either separable or entangled, but states can also be divided differently into Bell local or Bell non-local states based on local hidden variable theory (LHVT) [3]. For Bell local states three cases occur depending on whether both, one of or neither of the LHVT subsystem probabilities are also given by a quantum probability involving sub-system density operators. Cases where one or both are given by a quantum probability are known as local hidden states (LHS) and such states are non-steerable [3]. All separable states are LHS, but some LHS are entangled.

Recently [4] we found that spin squeezing in any spin component, two mode quadrature squeezing and a weak correlation test show that the LHS model fails (including for the non-separable case) - hence the quantum state is steerable. A new spin variance test was also found for the sum of Sx, Sy spin operator variances, but now involving the means of both Sz and N.

In addition [4] we found a new test for Bell non-locality that applies when the measured quantities A, B have outcomes other than +1,-1 – such as for spin components.

[1] B. J. Dalton, L. Heaney, J. Goold, B. M. Garraway and Th. Busch, New J. Phys. 16 (2014) 013026; B. J. Dalton, J. Goold , B. M. Garraway and M. D. Reid, ArXiv Quant-ph, (2016) 1506.06906, 1506.06892; Phys. Scr. (2016) (in press).

[2] M. Hillery and M. S. Zubairy, Phys. Rev. Letts. 96 (2006) 050503.

[3] H. M. Wiseman, S. J. Jones and A. C. Doherty, Phys. Rev. Letts. 98 (2007) 140402; Phys. Rev. A 76 (2007) 052116; E. G. Cavalcanti, S. J. Jones, H. M. Wiseman and M. D. Reid, Phys. Rev. A 80 (2009) 032112.

[4] B. J. Dalton and M. D. Reid, (2017) (in preparation).

Quantum dynamics of nuclear slabs: Mean field and short-range correlations

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Computational difficulties aside, nonequilibrium Green's functions seem ideally suited for investigating the dynamics of central nuclear reactions. Many particles actively participate in those reactions. At the two energy extremes for the collisions, the limiting cases of the Green's function approach were successful: the time-dependent Hartree-Fock theory at low energy and Boltzmann equation at high. The strategy for computational adaptation of the Green's function to central reactions is discussed. The strategy involves, in particular, progressing through one and two dimensions to develop and assess approximations, rotation to relative and average coordinates, discarding of far-away function elements, local expansion in anisotropy and preparation of initial states for the reactions through adiabatic switching. At this stage we concentrate on inclusion of correlations in one dimension, where relatively few approximations are needed, and we carry out reference calculations that can benchmark approximations needed for more dimensions. We switch on short-range interactions generating the correlations adiabatically in the Kadanoff-Baym equations to arrive at correlated ground states for uniform matter. As the energy of the correlated matter does not quite match the expectations for nuclear matter we add mean field to arrive at the match in energy. From there on, we move to finite systems. In switching on the correlations we observe emergence of extended tails in momentum distributions and evolution of single particle occupations away from 1 and 0. Subsequently we study collective oscillations for nuclear slabs, that exhibit damping tied to the heating of slab interiors.

Classical explanation of the quantum problem of the particle in a well: Role of the zero-point radiation field

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The problem of a quantum particle confined in an infinite square-well potential is approached from a novel point of view that helps to throw light on the physics behind its known solution. Our approach consists in the study of an ensemble of charged particles (typically electrons) confined inside the well, described by classical physics and subject to the action of the stochastic zero-point radiation field. The high-frequency modes generate a jiggling motion and give rise to the de Broglie wave that accompanies the particle along its mean trajectory. This endows de Broglie's wave with an electromagnetic nature. The associated Lorentz force is responsible for the odd distribution of particles inside the well. Though the calculation, being strictly classical, leads to an approximate result, it serves to disclose the key role played by the field in producing the counterintuitive quantum behavior.

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Chiral interface states in pn junctions in graphene

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We present a theoretical study of unidirectional interface states which form near pn junctions in a graphene monolayer subject to a homogeneous magnetic field. The semiclassical limit of these states corresponds to trajectories propagating along the pn interface by a combined skipping-snaking motion. Studying the two-dimensional Dirac equation with a magnetic field and an electrostatic potential step, we provide and discuss the exact and essentially analytical solution of the quantum-mechanical eigenproblem for both a straight and a circularly shaped junction. The spectrum consists of localized Landau-like and unidirectional snaking-skipping interface states, where we always find at least one chiral interface state. For a straight junction and at energies near the Dirac point, when increasing the potential step height, the group velocity of this state interpolates in an oscillatory manner between the classical drift velocity in a crossed electromagnetic field and the semiclassical value expected for a purely snaking motion. Away from the Dirac point, chiral interface states instead resemble the conventional skipping (edge-type) motion found also in the corresponding Schrödinger case. We also investigate the circular geometry, where chiral interface states are predicted to induce sizeable equilibrium ring currents.

Staggered quantum walks with superconducting microwave resonators

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Quantum walks form the building blocks in designing quantum search algorithms [1]. In one-dimensional (1D) discrete-time quantum walks (DTQWs) [2], a two-level quantum system plays the role of a quantum coin, which is able to exist in a superposition of states, leading to a ballistic spreading of the walker encoded in a set of discrete states. In continuous-time quantum walks (CTQWs) [3], the excitation exchange between the neighboring sites, in a lattice, directly works as a walker with no need of a coin. Recently we have proposed the staggered quantum walk (SQW with Hamiltonians) [4], which employs graph tessellations to define local Hamiltonians. This model has two general advantages - Firstly, it is quite general and includes several quantum quantum walk model as particular cases. Secondly, the SQW with Hamiltonians is highly fitted for implementation through bosonic nearest neighbor interactions, similarly to the CTQW [5], with the advantage of being able to outperform classical search algorithms at lower dimensional lattice structures [6]. The intrinsic difficulty is the required ability to have a high control over interactions required. Here we present a discussion on the SQW with Hamiltonians model and on the requirements for it to be implemented. We specifically propose an implementation employing microwave resonators coupled through SQUIDs [7]. The implementation is a prototype to describe any general dynamics on triangle-free graphs. In that class of graphs, which includes N-dimensional square lattices and trees, the resonators interact in a pairwise way in each element of the tessellation. In the proposal the lattice dynamics is coherently controlled through external electromagnetic pulses.

[1] R. Portugal, Quantum Walks and Search Algorithms, (Springer, New York, 2013).

[2] Y. Aharonov, L. Davidovich, and N. Zagury, Phys. Rev. A 48, 1687 (1993).

[3] E. Farhi and S. Gutmann, Phys. Rev. A 58, 915 (1998).

[4] R. Portugal, M. C. Oliveira, and J. K. Moqadam, Phys. Rev. A 95, 012328 (2017).

[5] J. Lozada-Vera, A. Carrillo, O. P. S. Neto, J. K. Moqadam, M. D. LaHaye, and M. C. Oliveira, EPJ Quantum Technology 3, 1 (2016).

[6] T. D. Fernandes and R. Portugal, "Quantum search on the two-dimensional lattice using the staggered model with Hamiltonians", arXiv:1701.01468 (2017).

[7] J. K. Moqadam, M. C. Oliveira, and R. Portugal, "Staggered quantum walks with superconducting microwave resonators", To appear in Phys. Rev. B (2017); arXiv:1609.09844.

Foundations of statistical mechanics from symmetries of entanglement

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Quantum entanglement is among the most fundamental, yet from classical intuition also most surprising properties of the fully quantum nature of physical reality. Envariance—entanglement assisted invariance—is a recently discovered symmetry of composite quantum systems. We show that thermodynamic equilibrium states are fully characterized by their envariance. In particular, the microcanonical equilibrium of a system S with Hamiltonian H_S is a fully energetically degenerate quantum state envariant under every unitary transformation. The representation of the canonical equilibrium then follows from simply counting degenerate energy states. Our conceptually novel approach is free of mathematically ambiguous notions such as ensemble, randomness, etc., and, while it does not even rely on probability, it helps to understand its role in the quantum world. In addition, we report several experiments performed on IBM's Quantum Experience demonstrating envariance as a pedagogical illustration of these novel concepts. These very easily reproducible and freely accessible experiments on Quantum Experience provide simple tools to study the properties of envariance, and we illustrate this for several cases with "quantum universes" consisting of up to five qubits.

[1] S. Deffner and W. H. Zurek, New J. Phys. 18 (2016) 063013

[2] S. Deffner, arXiv:1609.07459

Quantum heat engine enhanced by coherence: Efficiency at maximum power and Chambadal-Novikov-Curzon-Ahlborn limit

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Various quantum effects have been observed in the thermodynamic of small systems. For instance understanding the microscopic origin of the quantum coherence and its role in the energy and charge transfer processes along with thermodynamics characteristics of the small systems is a key problem in both thermodynamics and quantum mechanics. We had investigated the possible role of quantum coherence and interference on steady state and transient behavior of the quantum heat engines (QHE), e.g lasers, photovoltaic cells, photosynthetic reaction centers, and nanoplasmonic devices. We showed that the maximum power of a QHE that converts incoherent thermal energy into coherent cavity photons could be enhanced by manipulating quantum coherences. We demonstrated that in both artificial (solar cells) and natural (photosynthesis) light harvesting coherence affects the same population–coherence coupling term which is induced by bath (e.g. phonons), does not require coherent light, and will therefore work for incoherent excitation under natural conditions of solar excitation. We further investigate a novel model of the three-level laser QHE where lasing occurs between two closely spaced metastable states and the ground stated. Engine operates by transferring energy from hot bath to cold bath via nonequilibrium coherence assisted process. Coherence has two sources: first is due to quantum interference generated via hot bath and second is due to the lasing field coupled to both metastable states. The resulting efficiency at maximum power may be improved due to interplay between these two coherence contributions. Various parameter regimes are considered.

[1] M.O. Scully, K. Chapin, K.E. Dorfman, M. Kim, and A.A. Svidzinsky, PNAS 108, pp. 15097-15100, (2011).

[2] K.E. Dorfman, D.V. Voronine, S. Mukamel, and M.O. Scully, PNAS, 110, 2746 (2013).

[3] K.E. Dorfman, P.K. Jha, D.V. Voronine, P. Genevet, F. Capasso, and M.O. Scully, Phys. Rev. Lett. 111, 043601 (2013).

[4] D. Xu, C. Wang, Y. Zhao, and J. Cao, New J. Phys. 18, 023003 (2016).

[5] D. Xu and J. Cao, Front. Phys. 11, 1 (2016).

[6] K.E. Dorfman, D. Xu, and J. Cao, in preparation (2017).

T36 Mon, 10 July, 13:00 - 13:30, 3 session

Quantum systems out of equilibrium, quantum simulation and the quest for quantum supremacy

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Dynamical analogue quantum simulators allow to probe a plethora of physical phenomena related to the physics of quantum systems out of equilibrium. In this talk, we will consider questions of equilibration, Gaussification, the dynamics of quantum phase transitions and the absence of thermalization - present in disordered interacting models that show features of the multi-faceted phenomenon of many-body localization. We discuss both new theoretical results, as well as tools used in collaborations with experimentalists working with cold atoms in optical lattices and on atom chips.

In the last part of the talk, we will have a look at work in progress on conceptual questions that seem to be key to the idea of a quantum simulator: This in on the one hand one of how to devise quantum simulators that have the potential of computationally outperforming classical devices, discussing variants of IQP circuits. On the other hand, it the question of the certification of quantum simulators for which no classical simulation algorithm is known.

Spin-orbit interaction on the level of individual electrons

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Single electron charge detection in AlGaAs/GaAS heterostructures allows for a precise determination of the tunneling rates into and out of the quantum dot. This leads to a measurement of the level degeneracy of a state, which depends on its occulation and it can be changed by magnetic fields. We furthermore show that charge fluctuations in and out of equilibrium can be measured by implementing feedback loops into the detection setup. For double dots with a well-defined orientation of electron tunneling the strength of spin-orbit interaction can be investigated and tuned on the level of individual electrons.

Enhanced performance of three-terminal thermoelectric devices

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A three-terminal device, comprising two electronic terminals and a thermal one (e.g., a boson bath), is discussed. In the first part, we investigate the coefficient of performance for the joint operation of cooling one of the electronic terminals and producing electric power. Surprisingly enough, the coefficient of performance can be enhanced as compared to the case where that electronic terminal is cooled by investing thermal power (from the thermal bath) and electric power (from voltage applied across the electronic junction). We next examine the efficiency of an effective two-terminal thermoelectric device under a broken time-reversal symmetry which is derived from the three-terminal thermoelectric device. We find that breaking time-reversal symmetry can enhance the figure of merit for delivering electric power by supplying heat from a phonon bath beyond the one for producing the electric power by investing thermal power from the electronic baths. We also show that although such a device can approach very close to the the Carnot efficiency, it cannot reach this efficiency while generating a finite power, contrary to a recent claim.

Work with K. Yamamoto, A. Aharony and N. Hatano.

Supersolid phases in quantum gases

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The concept of a supersolid state is paradoxical. It combines the crystallization of a many-body system with dissipationless flow of the atoms it is built of. This quantum phase requires the breaking of two symmetries, the phase invariance of a superfluid and the translational invariance to form the crystal. We experimentally studied two forms of supersolids: i) a lattice supersolid, breaking a discrete translational symmetry. This bosonic lattice model features competing short- and long-range interactions, and we observed the appearance of four distinct quantum phases—a superfluid, a supersolid, a Mott insulator and a charge density wave. The system is based on an atomic quantum gas trapped in an optical lattice inside a single high-finesse optical cavity [1]. ii) Most recently, we succeeded in realizing a supersolid breaking a continuous translational symmetry. This symmetry emerges from two discrete spatial ones by symmetrically coupling a Bose-Einstein condensate to the modes of two optical cavities [2].

[1] R. Landig, L. Hruby, N. Dogra, M. Landini, R. Mottl, T. Donner, T. Esslinger, Nature 532, 476 (2016).

[2] J. Léonard, A. Morales, P. Zupancic, T. Esslinger, T. Donner, Nature 543, 87 (2017).

When quantum transport meets quantum optics

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Transport of elementary charge carriers across a dc voltage biased circuit usually does not couple to the electromagnetic modes embedded in the circuit. We consider here an opposite situation where these modes strongly couple to charge transfer: a voltage biased Josephson junction in series with a high impedance microwave resonator [1]. In this very simple quantum electrodynamics open system, the effective coupling constant that replaces the fine structure constant of QED is the ratio between the resonator characteristic impedance and the relevant resistance quantum Hofheinz et al., $R_Q = h/4e^2 \simeq 6.5\ \mathrm{k}\Omega$. At coupling constant approaching one, the transfer of single Cooper pairs strongly couples to the resonator whose quantum state can be probed externally. We show that, in this strong coupling regime, the transfer of a single Cooper pair only occurs when its energy 2 eV can be transformed in $1, 2...n$ photonic excitations of the resonator. We also identify a recently predicted regime for which the presence of a single photon blocks the creation of a second one, which forces the resonator to emit a single photon in the external circuit before another Cooper pair can pass and re-excite it. Using a two-mode resonator circuit with different frequencies, we demonstrate a regime in which the transfer of a single Cooper pair simultaneously excites a single photonic excitation in each mode [2]. We find that the quantum state of the resonator violates a Cauchy inequality, which demonstrates its non-classical character.

[1] Hofheinz et al., Phys. Rev. Lett. 106, 217005 (2011)

[2] Westig et al., arXiv 1703.05009

Multiplexed quantum correlated photons generated with a tunable delay in a solid-state ensemble

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The quantum repeater [1] is a device that would help to distribute entanglement at high distances. A possible way of implementing this device is to use the DLCZ protocol [2], in order to store entangled excitations in spatially separated media and thus distribute the entanglement. We show here the first implementation of the DLCZ protocol in a rare-earth ion doped crystal, which allowed us to store correlated pairs of photons for 1 ms. As the electric dipole of these material is very weak, the control pulses (write and read pulses) must be applied on resonnance, so that the write photons (Stokes photons) are spontaneously emitted from the excited state of the lambda system. Due to the very large inhomogeneous linewidth of the optical transition, we use a technique initially designed for quantum memories application in order to rephase the atoms after the emission of this Stokes photon: the atomic frequency comb (AFC) technique [3,4]. In this method, the inhomogeneous profile is shaped with a comb-like structure with teeth spacing Δ, so that any photon absorbed on the tailored structure creates a coherence that rephases after a time $1/\Delta$. In the DLCZ experiment, this relates to the fact that the anti-Stokes photon (read photon) is emitted at a very precise instant, when the atomic coherence is rephased. In addition, this protocol allows for the emission of the anti-Stokes photon on demand, as the optical coherence is frozen in a spin transition, like in the spin-wave storage protocol [5].

We implemented this experiment in an isotopically pure $^{151}Eu^{3+}:Y_2SiO_5$ crystal, on the visible transition at 580.04 nm. The nuclear quadratic hyperfine splitting of the ground state is used to define the two ground states of the lambda system. By using an AFC time of $1/\Delta = 20\,\mu$s and a spin storage time of 1 ms, we could retrieve photons with a Cauchy-Schwarz violation of $R = 2.88 > 1$, proving the non-classical correlations between the two temporally separated photons. In addition, the photons have a temporal width of 400 ns and are detected on a temporal gate of 10 μs, which means that the temporal multimode capacity of our protocol is of more than 10 modes.

[1] N. Sangouard, C. Simon, H. de Riedmatten and N. Gisin, Rev. Mod. Phys. 83 (2011) 33

[2] L.-M. Duan, M.D. Lukin, J.I. Cirac and P. Zollze, Nature 414 (2001) 413

[3] M. Afzelius, C. Simon, H. de Riedmatten and N. Gisin, Phys. Rev. A 79 (2009) 052329

[4] P. Sekatski, N. Sangouard, N. Gisin, H. de Riedmatten and M. Afzelius, Phys. Rev. A (2011) 053840

[5] P. Jobez, C. Laplane, N. Timoney, N. Gisin, A. Ferrier, P. Goldner and M. Afzelius, Phys. Rev. Lett. 114 (2015) 230502

Propagation of charge and energy density in disordered interacting quantum wires - ergodic phases with subdiffusive dynamics?

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We investigate charge relaxation in the spin-less disordered fermionic Hubbard chain (t-V model). Our observable is the time-dependent density propagator, $\Pi_\varepsilon(x,t)$, calculated in windows of different energy density, ε, of the many-body Hamiltonian.

The width $\Delta x_\varepsilon(t)$ of $\Pi_\varepsilon : (x,t)$ exhibits a behavior that is best described by an effective exponent: $\beta_\varepsilon(t){=}d\ln\Delta x_\varepsilon(t)/d\ln t$. While for diffusive dynamics the exponent equals $1/2$, an impressive body of numerical data has been accumulated that currently is interpreted as suggesting a subdiffusive behavior $\beta_\varepsilon(t){\lesssim}1/2$ in large regions of phase space.

Our numerical work does not lend support to this interpretation, because we observe that β_ε depends strongly on the system size L at all investigated parameter combinations. Specifically, we do not find a region in phase space that exhibits subdiffusive dynamics in the sense that $\beta{<}1/2$ in the thermodynamic limit. Instead, subdiffusion may well be transient, giving way eventually to conventional diffusive behavior, $\beta{=}1/2$.

Interestingly, (transient) subdiffusion $0{<}\beta_\varepsilon(t) \lesssim 1/2$, coexists with an enhanced probability for returning to the origin, $\Pi_\varepsilon(0,t)$, decaying much slower than $1/\Delta x_\varepsilon(t)$. Correspondingly, the spatial decay of $\Pi_\varepsilon(x,t)$ is far from Gaussian, i.e. exponential or even slower.

[1] https://arxiv.org/abs/1610.03085

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 unexplored 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 $\sim$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 found that requirements are met by persistent current qubits, already fabricated within present technology, driven in 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].

[1] T. Niemczyk, F. Deppe, et al., Nat. Phys. 6, 772 (2010).

[2] G. Falci, P.G. Di Stefano, A. Ridolfo, A. D'Arrigo, G.S. Paraoanu and E. Paladino, Fort. Phys. online 18 NOV 2016; DOI: 10.1002/prop.201600077, arxiv:1704.00581.

[3] G. Falci, A.A. Ridolfo, P.G. Di Stefano and E. Paladino, preprint (2017).

[4] R. Stassi, A. Ridolfo, O. Di Stefano, M.J. Hartmann, and S. Savasta, Phys. Rev. Lett. 110, 243601 (2013).

[5] N.V. Vitanov, A.A. Rangelov, B.W. Shore, and K. Bergmann, Rev. Mod. Phys. 89, 015006 (2017).

Non-Gaussian quantum optics and optomechanics

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The talk will present resent achievements in quantum optics with non-Gaussian states of light and their applications in quantum communication and quantum optomechanics: (i) novel hierarchy of criteria of quantum non-Gaussianity for multiphoton states of light, (ii) first experimental verification of this criteria using parametric down conversion source, (iii) analysis of quantum non-Gaussian states of photons transferred to phonons and back to photons in optomechanical and electromechanical oscillators. We will conclude by recent theory and experimental achievements in decoherence control of non-Gaussian states of light and mechanical oscillators and their applications in construction of nonlinear quantum operations.

Lyapunov exponents in many-body systems from Loschmidt echoes

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Experimental verification of the chaotic character of dynamics in many-particle systems remains one of the outstanding challenges for the foundations of statistical physics. It was shown recently [1], that, for a lattice of interacting classical spins, the primary characteristics of chaos, namely, the largest positive Lyapunov exponent can be extracted from the initial exponential regime of Loschmidt echoes (defined as response of the system to imperfect reversal of system's dynamics). At the same time, it was shown that lattices of quantum spins would exhibit exponential regime only if the value of quantum spin is sufficiently large [2]. We have recently extended the above investigations to Loschmidt echoes for coupled Bose-Einstein condensates in optical lattices. We have demonstrated numerically that, to the extent that the above system is describable by the discrete Gross-Pitaevskii equation, the value of its largest Lyapunov exponent can, indeed, be extracted from a Loschmidt echo. We have also proposed an experimental implementation of the above procedure.

[1] B. V. Fine, T. A. Elsayed, C. M. Kropf, and A. S. de Wijn, Phys. Rev. E 89, 012923 (2014)
[2] T. A. Elsayed and B. V. Fine, Phys. Scr. 2015, 014011 (2015)

Shortcuts to adiabaticity in the Feshbach engine

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In this work we focus on a trapped Bose-Einstein condensate (BEC) and use the framework of non-equilibrium thermodynamics to study compression and expansion strokes in a theoretical quantum heat engine. By taking advantage of Feshbach resonances to control the nonlinear interactions in the trapped BEC, compression of the gas can be achieved by increasing the attractive nonlinear interaction, while expansion can be implemented using the reverse process. Non-adiabatic ramps of the interaction strength can create excitations in the system which leads to the creation of irreversible work. This irreversible work is analogous to friction and thereby reduces the efficiency of the engine. I will show that by exploiting shortcuts to adiabaticity these out-of-equilibrium excitations can be reduced resulting in a more efficient process on short timescales, and that large nonlinear interactions can improve the robustness of the shortcut allowing for faster stroke times which improves the power output of the engine [1,2]. Finally, I show that these shortcuts cannot result in infinitesimally small stroke durations as the energetic cost associated with implementing the shortcuts results in growing inefficiencies, and that these are heavily dependent on the strength of the nonlinear interaction in this system.

[1] Jing Li, Kun Sun & Xi Chen, Scientific Reports 6, 38258 (2016)

[2] Obinna Abah and Eric Lutz, arXiv:1611.09045 (2016)

Hydrodynamic analog of wave-particle duality

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We have recently discovered a macroscopic object composed of a material particle dynamically coupled to a wave packet. The particle is a droplet bouncing on the surface of a vertically vibrated liquid bath; its pilot-wave is the result of the superposition of the surface waves it excites. Above an excitation threshold, this symbiotic object, designated as a “walker” becomes self-propelled. Such a walker exhibits several features previously thought to be specific to the microscopic realm. The unexpected appearance of both uncertainty and quantization behaviors at the macroscopic scale lies in the essence of its “classical” duality. The dynamics of the droplet depends on previously visited spots along its trajectory through the surface waves emitted during each bounce. This path memory dynamics gives a walker an intrinsic spatio-temporal non-locality. I will discuss the characteristics of these objects that encode a wave memory. In particular, I will introduce the concept of time mirror to interpret the characteristics of the driving wave packet.

Relaxation of populations in nonequilibrium many-body physics: Breakdown of Mathiessen's rule

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The lifetime of a quasiparticle of an equilibrium many-body system is determined by Mathiessen's rule, where the total scattering rate is given by the sum of the scattering rate for all different scattering processes. The relaxation time is then represented by 1/[-2Im $\Sigma(\omega)$], which determines both the lifetime of the quasiparticle spectral function and the linear-response dc resistivity. In a pump/probe experiment, a high intensity pump excites electrons into a nonequilibrium distribution, and those excited populations decay and relax back towards a new equilibrium, with a characteristic relaxation time, that depends on the energy of the excitation above the Fermi energy. It turns out that this relaxation time is often significantly different from the equilibrium relaxation time. In this talk, I will describe what determines this nonequilibrium relaxation time. It does not satisfy Mathiessen's rule, but instead depends in a complicated fashion on how energy is exchanged from electrons to phonons, as the populations relax. It also is often not given by the equilibrium relaxation time. One consequence of this analysis, is an explicit proof that a simple hot electron model is inconsistent with the exact equations of motion of a many-body system. We end with a discussion of some experiments that illustrate this behavior and some open challenges that remain in fully understanding nonequilibrium relaxation.

[1] Alexander Kemper and James Freericks, Relationship between Population Dynamics and the Self-Energy in Driven Non-Equilibrium Systems, Entropy 18, 180 (2016).

[2] A. F. Kemper, H. R. Krishnamurthy, and J. K. Freericks, The role of average time dependence on the relaxation of excited electron populations in nonequilibrium many-body physics,to appear in Fortschritte der Physik (2016).

Experimental certification of millions of genuinely entangled atoms in a solid

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Quantum theory predicts that entanglement –the paradigmatical quantum effect, now routinely observed in microscopic experiments– can also persist in macroscopic physical systems, albeit difficulties to demonstrate it experimentally remain. Beyond the fundamental interest, these large-scale quantum systems could also serve applications in quantum technologies. Recently, significant progress has been achieved with new theoretical concepts leading to the experimental demonstration of genuine entanglement between up to 2900 atoms (McConnell et al., Nature 2015). Going to larger groups of entangled particles is challenging due to unavoidable noise, decoherence and the lack of robust entanglement witnesses. Here we demonstrate 16 million genuinely entangled atoms in a solid-state quantum memory prepared by the absorption of a single photon. We develop an entanglement witness for quantifying the number of genuinely entangled particles based on the collective effect of directed emission combined with the nonclassical nature of the emitted light. The method is applicable to a wide range of physical systems and is effective even in situations with significant losses. Our results clarify the role of multipartite entanglement in ensemble-based quantum memories as a necessary prerequisite to achieve a high single-photon process fidelity crucial for future quantum networks. On a more fundamental level, our results reveal the robustness of certain classes of multipartite entangled states, contrary to, e.g., Schrödinger-cat states, and that the depth of entanglement can be experimentally certified at unprecedented scales.

Integrating cavities and ultra-sensitive absorption spectroscopy

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Spectroscopy using an integrating cavity with diffuse reflecting walls is a highly sensitive technique for weak absorption measurements. Since the diffuse reflecting walls of the cavity produce an isotropic illumination of the sample, absorption measurements are not affected by scattering in the sample. Due to multiple reflections of the light from the cavity walls, the light makes many transits through the sample, i.e. the effective path length through the sample far exceeds the dimensions of the sample; the result is a high sensitivity to very weak absorption. We have used this approach to measure the optical absorption of pure water and have just recently obtained the first reliable measurements down to 250 nm.

Another approach to high sensitivity absorption spectroscopy is cavity ring down spectroscopy (CRDS), a very different but well-known technique. It also provides a very long effective path length through the sample and is consequently an extremely sensitive technique for weak absorption measurements. But, since it cannot distinguish scattering from absorption, this powerful technique is only useful when scattering is negligible.

However, combining these two absorption spectroscopy techniques (integrating cavity and CRDS) would provide an extremely powerful and useful new technology - Integrating Cavity Ring-Down Spectroscopy (ICRDS). But, ICRDS has not previously been exploited because the diffuse reflectivity of all known materials was not high enough to do ring-down spectroscopy. Our newly developed diffuse reflecting material does have the required high diffuse reflectivity (e.g. 0.9992 at 532 nm) and is opening new research vistas by providing very sensitive and accurate direct spectral absorption measurements of both a sample and any particulates suspended in it while being unaffected by the scattering in the sample. An important example would be the capability to measure (for the first time) the very weak spectral absorption in highly scattering biological samples.

Hubbard nonequilibrium Green functions

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We introduce diagrammatic technique for Hubbard nonequilibrium Green functions. The formulation is an extension of equilibrium considerations for strongly correlated lattice models to description of current carrying molecular junctions. Within the technique intra-system interactions are taken into account exactly, while molecular coupling to contacts is used as a small parameter in perturbative expansion.

Progress in experimental techniques at nanoscale made measurements of noise in molecular junctions possible. These data are important source of information not accessible through average flux measurements. Emergence of optoelectronics, recently shown possibility of strong light-matter couplings, and developments in the field of quantum thermodynamics are making counting statistics measurements of even higher importance. Theoretical methods for noise evaluation in first principles simulations can be roughly divided into approaches applicable in the case of weak intra-system interactions, and those treating strong interactions for systems weakly coupled to baths. We argue that due to structure of its diagrammatic expansion and the fact of utilizing many-body states as a basis of its formulation recently introduced nonequilibrium Hubbard Green functions formulation is a relatively inexpensive method suitable for evaluation of noise characteristics in first principles simulations over wide range of parameters.

We demonstrate the viability of the approach with numerical simulations of current, noise, and noise spectrum for a generic junction model of quantum dot coupled to two electron reservoirs in non-, weakly and strongly interacting regimes. Results of the simulations are compared to exact data (where available) and to simulations performed within approaches best suited for each of the three parameter regimes.

[1] F. Chen, M. A. Ochoa, and M. Galperin, J. Chem. Phys. 146 (2017) 092301

[2] M. Galperin, Chem. Soc. Rev. Advance Article (2017) doi: 10.1039/C7CS00067G

[3] K. Miwa, F. Chen, and M. Galperin, to be published

Strongly anomalous non-thermal fixed point in a quenched Bose gas

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Non-equilibrated quantum many-body systems show much richer characteristics than those in equilibrium. There is the possibility for universal dynamics, showing up with the same properties in very different systems irrespective of their concrete building blocks. Prominent examples are the phenomenon of prethermalisation and the development of Generalised Gibbs Ensembles [1]. Superfluid turbulence in an ultracold atomic gas has the potential to show universal aspects shared by dynamics which occurred after the inflationary period of the early universe [2]. Non-thermal fixed points have been proposed in this context which lead beyond standard equilibrium universality. Turbulent dynamics in one- and two-dimensional bosonic matter-wave systems will be discussed which are characterized by universal scaling behavior in space and time, with strong anomalous effects caused by conservation laws and non-dissipative dynamics [3]. This exhibits a close relation between quantum turbulence, the dynamics of topological defects, as well as magnetic and charge ordering phenomena.

[1] T. Langen, T. Gasenzer, and J. Schmiedmayer, JSTAT 064009 (2016). arXiv:1603.09385 [cond-mat.quant-gas].

[2] B. Nowak, S. Erne, M. Karl, J. Schole, D. Sexty, and T. Gasenzer, arXiv:1302.1448 [cond-mat.quant-gas], in *Strongly Interacting Quantum Systems out of Equilibrium*, edited by T. Giamarchi, et al. (Oxford University Press, 2016).

[3] M. Karl and T. Gasenzer, arXiv:1611.01163 (2016).

Bell non-local correlations from Majorana end-points

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Entanglement in quantum mechanics contradicts local realism and is a manifestation of quantum non-locality. Its presence can be detected through the violation of Bell, or the Clauser-Horne-Shimony-Holt (CHSH) inequalities. Paradigmatic quantum systems provide examples of both non-entangled and entangled states. Here we consider a minimal complexity setup consisting of 6 Majorana bound states. We find that any allowed state in the degenerate Majorana space is non-locally entangled. We show how to measure the CHSH-violating correlations in a semiconductor-wire based setup.

T54 Fri, 14 July, 15:20 - 15:50, 4 Session

Quantum bath engineering and quantum error correction in circuit QED

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Recent remarkable experimental progress in 'circuit QED' has dramatically extended the phase coherence times of superconducting qubits and now allows realization of extremely strong dispersive coupling between these qubits and microwave photons in resonators. This together with the ability to do quantum bath (reservoir) engineering yields a 'quantum toolbox' that permits universal control (unitary and dissipative) of qubit and resonator states, the ability to perform quantum many-body simulations, and the ability to test new error correction codes which extend the lifetime of quantum information stored in the collective system beyond the time it could be stored in the best individual component of the system. Paradoxically, some of these successful codes are based on Schrödinger cat states, normally thought to be extremely fragile holders of quantum information. These 'cat codes' are members of a general class of quantum error correction codes which store quantum information in coherent superpositions of photon Fock states and which can survive various errors including photon loss, gain and dephasing.

Levitons, minimal excitation states for single electron sources in electron quantum optics

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A simple approach to realize an on-demand electron source is to apply a voltage pulse on a contact of a mesoscopic conductor such that the resulting current pulse injects a single charge in the conductor. At first sight, the idea seems too naive to produce something useful. However this procedure actually works [1]. More surprisingly it contains a rich physics: the generation of a new type of excitation carrying a single particle: a leviton. This minimal excitation state has been theoretically predicted 20 years ago by L. Levitov and collaborators [2] who found that a voltage pulse with Lorentzian shape produces a noiseless state. In this talk, I will present experimental generation of levitons and report electron quantum optics applications: a two-leviton quantum interference experiment, the electrical analog of the photonic Hong Ou Mandel experiment revealing perfect electron coherence. With single electron sources (SES), electron quantum tomography is accessible and a complete picture of the Leviton wave-function can be experimentally given [3]. Finally, I will extend the periodic SES approach to the pseudo-random binary injection of levitons for future electronic flying qubits [4].

[1] J. Dubois et al, Nature 502, 659-663 (2013)

[2] Levitov et al., J. Math. Phys. 37, 4845-4856 (1996)

[3] T. Jullien et al., Nature 514, 603-607 (2014)

[4] D.C. Glattli and P. Roulleau, arXiv:1702.00499

A sensitive electrometer based on a Rydberg atom in a Schrodinger-cat state

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The projection noise that is intrinsic to quantum measurement limit the precision of metrology experiment. In particular, metrology methods based on the measurement of small rotation of a large angular momentum are usually limited by the quantum fluctuations that constrain the precision with which one can determine the direction of the angular momentum. When the measurement is perfomed using classical states, like the coherent spin states, the precision cannot exceed the standard quantum limit (SQL), that scales like $1/J^{1/2}$. To beat the SQL, one need to implement a quantum method that make use of non-classical states.

In our experiment [1], instead of looking at the classical direction of the angular momentum, we prepare the system in a Schrodinger cat state and measure the quantum phase accumulated by the angular momentum during its rotation. Our system is a Rydberg atom with a large quantum principal number n = 51. Using a radio frequency field with a well-defined sigma + polarization, we restrict the evolution of the atom to a subspace of the Stark manifold where the system behaves like a large spin J = (n-1)/2. We have then used this effective spin to perform a quantum enabled measurement of the static electric field. We show that the achieved precision exceeds the SQL and approaches the fundamental Heisenberg limit (HL) in this context. The single-shot sensitivity reaches 1.2 mV/cm for a 100 ns interaction time, (30 microvolt/cm/$Hz^{1/2}$ at a 3 kHz repetition rate). This highly sensitive, non-invasive space- and time-resolved field measurement extends the realm of electrometric techniques and could have important applications.

[1] A. Facon, et al, "A sensitive electrometer based on a Rydberg atom in a Schrodinger-cat state", Nature 535, 262-265 (2016)

Unconventional superconductivity from magnetism in transition metal dichalcogenides

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Understanding possible mechanisms for the coexistence and interplay of superconductivity with magnetism has been one of the most long-standing and intensely studied questions in condensed-matter physics [1]. We investigate proximity-induced superconductivity in monolayers of transition metal dichalcogenides (TMDs) that are tunnel-coupled to a conventional singlet s-wave superconductor and subject to an external exchange field generated by a ferromagnetic substrate or an applied magnetic field [2]. A variety of superconducting order parameters is found to emerge from the interplay of magnetism and superconductivity, covering the entire spectrum of possibilities to be symmetric or antisymmetric with respect to the valley and spin degrees of freedom, as well as even or odd in frequency. As a key finding, we reveal the existence of an exotic even-frequency triplet pairing between equal-spin electrons from different valleys, which arises whenever the spin orientations in the two valleys are noncollinear. The opposite-spin-pairing component of this exotic superconducting correlation is a realization of the previously discussed phenomenon of Ising superconductivity. Among the different order parameters, we also identify the existence of induced intra-valley pairings, which are particular instances of the generic pair-density-wave order associated with Cooper pairing at finite momentum. Finally, all types of induced superconducting order parameters turn out to be tunable via manipulations of the external exchange field.

[1] L. N. Bulaevskii, A. I. Buzdin, M. L. Kulić, and S. V. Panjukov, Adv. Phys. **34**, 175 (1985).

[2] M. A. Rahimi, A. G. Moghaddam, C. Dykstra, M. Governale, and U. Zülicke, Phys. Rev. B **95**, 104515 (2017).

Input-output theory for AC driven tunnel junctions

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Based on previous studies [1-3], we examine the response of a tunnel junction embedded in an electromagnetic environment to driving by DC and AC voltages. The voltage input is supplied via a transmission line, which also serves to monitor the output of the device. The Hamiltonian model of the device includes the dynamics of the transmission line and allows for a detailed study of the radiation scattered by the junction.

[1] H. Grabert, Phys. Rev. B92 (2015) 245433

[2] M. Frey and H. Grabert, Phys. Rev. B94 (2016) 045429

[3] M. Frey and H. Grabert, Progr. Phys. DOI: 10.1002/prop.201600055

Measuring non-commuting observables of a single photon via sequential weak values evaluation

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This communication reports on the first experimental verification of the peculiar predictions regarding single and sequential weak values on a unique quantum particle, and to be specific related to the simultaneous measure of non-compatible polarization observable of a single photon [1]. This experimental evidence could result at odd with "one of the canonical dicta of quantum mechanics" [2]: the impossibility of measuring two non-commuting observable at the same time because of the wave function collapse. Nevertheless, in the framework of weak measurements (WMs) this impossibility can be partially smoothed if sequential or joint weak values evaluation is taken into account [2–5]. In fact, operating within this quantum measurement paradigm, weak values are obtained extracting only a small amount of information from a single measurement, preventing the collapse of the initial quantum state. Up to now only WMs on a unique observable (eventually followed by a strong measurement) or joint WMs performed on commuting observable and on different particles (or optical modes), have been realized in laboratories [6–9]. On the contrary, sequential weak measurements, which present features very sensitive to the systems dynamics and whose time order plays a primary role, have not been performed yet. The main experimental results of this research will be presented, showing a remarkable agreement with the theoretical simulations. The most paradoxical situations, typical of weak values behavior, will be put in evidence.

[1] F. Piacentini, et al., Phys. Rev. Lett. 117, 170402 (2016).
[2] G. Mitchison, R. Jozsa, and S. Popescu, Phys. Rev. A 76, 062105 (2007).
[3] K. J. Resch, et al., Phys. Rev. Lett. 92, 130402 (2004).
[4] Y. Aharonov, D. Z. Albert & L. Vaidman, Phys. Rev. Lett. 60, 1351-1354 (1988).
[5] A. G. Kofman, S. Ashhab & F. Nori, Phys. Rep. 520, 43-133 (2012).
[6] O. Hosten & P. Kwiat, Science 319, 787-790 (2008).
[7] D. J. Ressel, et al., Rev. Mod. Phys. 86, 307-316 (2014).
[8] K. J. Resch, Science 319, 733 (2008).
[9] G. J. Pryde, et al., Phys. Rev. Lett. 94, 220405 (2005).

Recovering the quantum formalism from physically realist axioms

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We present a heuristic derivation of Born's rule and unitary transforms in Quantum Mechanics, from a simple set of axioms built upon a physical phenomenology of quantization [1, 2]. This approach naturally leads to the usual quantum formalism, within a new realistic conceptual framework that is discussed in details. Physically, the structure of Quantum Mechanics appears as a result of the interplay between the quantized number of "modalities" accessible to a quantum system, and the continuum of "contexts" that are required to define these modalities. Mathematically, the Hilbert space structure appears as a consequence of a specific "extra-contextuality" of modalities, closely related to the hypothesis of Gleason's theorem, and consistent with its conclusions.

[1] A. Auffeves and P. Grangier, Found. Phys. 46, 121 (2016); eprint arXiv:1409.2120 [quant-ph] (2014).

[2] A. Auffeves and P. Grangier, Sci. Rep. 7, 43365 (2017); eprint arXiv:1610.06164 [quant-ph] (2016).

A multidisciplinary approach to the theory of emergent states

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Our physics textbooks are dominated by examples of simple, weakly-interacting microscopic states. But the actual physical states of our world are often most effectively described as emergent, meaning that they are strongly-correlated and dominated by properties that emerge as a consequence of interactions and are not part of the description of the corresponding weakly-interacting system. Such states often have a phenomenologically description but no clear microscopic connection to the simple states described in our textbooks. This talk proposes a microscopic connection of weakly-interacting states and emergent states through dynamical symmetries that imply unique truncations of the full Hilbert space to a collective subspace where emergence lives. Much as Einstein used the equivalence principle to argue that gravity must be a property of spacetime and not of specific objects in spacetime, it will be proposed that emergence is in essence a property of a symmetry-truncated Hilbert space and not of specific microscopic systems whose wavefunctions may reside in that space. Thus emergent properties achieve a universality largely independent of underlying microscopic details, as is observed for many physical systems. As a concrete example of applying these ideas it will be shown that atomic nuclei, high-temperature cuprate and iron-based superconductors, and monolayer graphene in a strong magnetic field – which have little in common microscopically – exhibit a remarkable universality in emergent behavior that is described quantitatively by the ideas presented above.

Monte Carlo for real-time diagrammatics on the Keldysh contour – results from inchworm quantum Monte Carlo

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We present a general introduction to Monte Carlo algorithms for solving impurity problems exposed to strong time-dependent variation of their parameters. We will show several numerical approaches to Keldysh diagrammatics and present results for voltage quenches, interaction quenches, time-dependent quenches, and non-equilibrium dynamical mean field theory.

Closed quantum Master equations for energy transfer in Light-Harvesting complex and multi-exciton dynamics

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Usually the study of energy-transfer in the Light Harvesting Complex is limited by a single-exciton motion along the antenna. Starting from the many-body Schrodinger equation, we derived the Lindblad-type Master equations describing the cyclic exciton-electron dynamics of the Light Harvesting Complex, due to charge-restoration of a donor 1]. These equations, which resemble the Master equations for electric current in mesoscopic systems [2], go beyond the single-exciton description by accounting the multi-exciton states accumulated in the antenna, as well as the charge-separation, fluorescence and initial photo-absorption. Although these effects take place on very different time-scales, we demonstrate that their account is necessary for consistent description of the exciton dynamics. We applied our results for evaluation of the energy (exiton) current and the (damaging) fluorescent current as a function of light-intensity.

[1] Shmuel Gurvitz, Gennady P. Berman and Richard T. Sayre, arXiv:1706.01958.

[2] Shmuel Gurvitz, Front. Phys. 12 (2017) 120303.

Cosmic Bell test: Measurement settings from Milky Way stars

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Bell's theorem states that some predictions of quantum mechanics cannot be reproduced by a local-realist theory. That conflict is expressed by Bell's inequality, which is usually derived under the assumption that there are no statistical correlations between the choices of measurement settings and anything else that can causally affect the measurement outcomes. In previous experiments, this "freedom of choice" was addressed by ensuring that selection of measurement settings via conventional "quantum random number generators" was space-like separated from the entangled particle creation. This, however, left open the possibility that an unknown cause affected both the setting choices and measurement outcomes as recently as mere microseconds before each experimental trial. Here we report on a new experimental test of Bell's inequality that, for the first time, uses distant astronomical sources as "cosmic setting generators." In our tests with polarization-entangled photons, measurement settings were chosen using real-time observations of Milky Way stars while simultaneously ensuring locality. Assuming fair sampling for all detected photons, and that each stellar photon's color was set at emission, we observe statistically significant $\gtrsim 7.31\sigma$ and $\gtrsim 11.93\sigma$ violations of Bell's inequality with estimated p-values of $\lesssim 1.8 \times 10^{-13}$ and $\lesssim 4.0 \times 0^{-33}$, respectively, thereby pushing back by $\sim$600 years the most recent time by which any local-realist influences could have engineered the observed Bell violation.

(Quantum) - Thermodynamics at strong coupling and its implications for Stochastic Thermodynamics

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The case of strong system-environment coupling plays an increasingly important role when it comes to describe systems of small size which are in contact with an environment. The commonly known textbook situation refers solely to a weak coupling situation for which the equilibrium state of the system is described by a Gibbs state. This situation changes drastically, however, when strong coupling is at work; then, the interaction energy can be of the order of the (sub)-system energy of interest [1]. Let us consider first an overall thermal equilibrium of a total setup composed of a system Hamiltonian H_S, coupling Hamiltonian H_{int} and a bath Hamiltonian H_B.

Based on an explicit knowledge of the so termed *Hamiltonian of mean force* [2], the classical statistical mechanics and, as well, the quantum thermodynamics of open systems which are in contact with a thermal environment – at arbitrary strong interaction strength – can be formulated. Yet, even though the Hamiltonian of mean force uniquely determines the thermal phase space probability density (or the density operator, respectively) of a strongly coupled open system, the knowledge of this quantity alone is *insufficient* to determine the Hamiltonian of mean force itself; the latter must be known for constructing an underlying Stochastic Thermodynamics. This fact presents a major stumbling block for any classical Stochastic Thermodynamics scenario which solely builds upon the knowledge of (observed or calculated) open system trajectories. – In the classical case we demonstrate that under the assumption that the Hamiltonian of mean force is known explicitly, an extension of thermodynamic structures from the level of averaged quantities to *fluctuating* objects (such as internal fluctuating energy, heat, entropy, or free energy); i.e., a Stochastic Thermodynamics, is possible. However, such a construction is by far not unique but involves a vast ambiguity.

Generally, however, the situation becomes a No-Go if we consider initial non-equilibrium where even the concept of a Hamiltonian of mean force does not exist [1, 3].

[1] P. Talkner and P. Hänggi, Open system trajectories specify fluctuating work but not heat, Phys. Rev. E 94, 022143 (2016).

[2] M. Campisi, P. Talkner, and P. Hänggi, Fluctuation theorem for arbitrary open quantum systems, Phys. Rev. Lett. 102, 210401 (2009).

[3] H. Grabert, P. Talkner, and P. Hänggi, Microdynamics and Time-Evolution of Macroscopic Non-Markovian System, Z. Physik B 26, 389–395 (1977).

Organic nanodiamonds

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I discuss recent progress on the growth of nanodiamonds in the presence of stable diamond-like organic seed molecules. Briefly the goal is to grow diamonds around specially designed seed molecules that have the dopant atoms needed for specific color centers. It can be seen that this approach can give unprecedented control over the number and placement of color centers. Complete, scalable, quantum registers might also be fabricated by this technique, for example a nitrogen-vacancy and a 13C atom with a well-defined separation surrounded by only 12C diamond. Other benefits to this approach include near-deterministic number and placement of color centers, so that nanodiamonds no matter how small can be designed to have at least one bright and photostable fluorescent emitter. Given the low-toxicity of diamond and the demonstrated small size (1.6 nm) for photostable fluorescent nanodiamonds this could lead to new generation of non-bleaching fluorescent bio-markers that are smaller than many existing dye molecules.

Quantum theory of room temperature single quantum-dot strong-coupling with plasmonic nanoresonators

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Plasmonic nanomaterials and nanophotonics have the unique ability to confine light in extremely sub-wavelength volumes and massively enhance electromagnetic fields. Fundamentally, such high-field enhancement can alter the local density of states of a photoactive molecule to unprecedented degrees and control its exchange of energy with light. For high enough field enhancement, one enters the strong-coupling regime, where the energy exchange between the excited states of molecules/materials and plasmons is faster than the de-coherence processes of the system. As a result, the excitonic state of the molecule becomes entangled with the photonic mode, forming hybrid excitonic-photonic states. These hybrid-states are part light, part matter and allow for the characteristic Rabi oscillations of the atomic excitations to be observed. Until recently, the conditions for achieving strong-coupling were most commonly met at low temperatures, where de-coherence processes are suppressed. As a major step forward, we have recently demonstrated room-temperature strong coupling of single molecules in a plasmonic nano-cavity [1] achieved using a host-guest chemistry technique, controlling matter at the molecular level.

Here, linking nano-spectroscopy of quantum emitters with strong coupling allows to lithographically realise a strong-coupling set-up that couples dark plasmonic modes and quantum dots. A quantum nanophotonic model which incorporates a non-degenerated multi-level emitter strongly coupled with a broadband resonator explains and quantifies this boost of coupling strength due to collective coupling to band-edge states. Our combined theoretical and experimental findings [2] pave the road for a wide range of ultrafast quantum optics experiments and quantum technologies at ambient conditions. Moreover, the pronounced position-dependent spectral changes may lead to new types of quantum sensors and near-field quantum imaging modalities.

[1] R. Chikkaraddy, B. de Nijs, F. Benz, S. J. Barrow, O. A. Scherman, E. Rosta, A. Demetriadou, P. Fox, O. Hess and J. J. Baumberg, Nature 535 (2016), 127.

[2] H. Gross, J. M. Hamm, T. Tuffarelli, O. Hess and B. Hecht, (2017), submitted.

Thermodynamics in the presence of anomalous flows

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Thermodynamic states of quantum many body systems often exhibit slow variation of their macroscopic parameters with time. The long time limits of systems with infinitely many degrees of freedom give rise to anomalous flows of almost invariant and macroscopically indistinguishable states after scaling. Mathematically the results are related to stable convolution semigroups and based on properties of functions with bounded mean oscillation [1,2]. The infinitesimal generator of anomalous flows are operators that are nonlocal in time. The results are applied to irreversibility and experiment.

[1] R. Hilfer, Mathematics 3 (2015), 623–643.

[2] R. Hilfer, Analysis 36 (2016), 49–64.

A classical route to quantum control

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Quantum "shortcuts to adiabaticity" are strategies for quickly achieving a result that would ordinarily require a long, slow process. The basic goal is to guide a system to evolve from an eigenstate of an initial Hamiltonian H_0 to the same eigenstate of a final Hamiltonian H_1, without having to vary the Hamiltonian slowly (adiabatically) with time. Although formal solutions to this problem exist, they are often difficult to translate into laboratory settings. I will argue that classical mechanics can help to achieve this goal.

The classical version of the quantum problem can be formulated precisely and solved exactly for a generic one-dimensional Hamiltonian that varies rapidly with time. Specifically, for a Hamiltonian H(q,p,t), and for an arbitrary choice of action I_0, I will show how to construct a "fast-forward" potential energy function V_{FF}(q,t) that deftly guides all trajectories with initial action I_0 to end with the same value of action. The solution is surprising simple, relying only on elementary manipulations of Hamilton's equations [1]. When this classical solution is applied to the quantum Hamiltonian, the result is a quantum shortcut to adiabaticity, which guides a wavefunction to the desired final energy eigenstate with high accuracy.

[1] C. Jarzynski, S. Deffner, A. Patra and Y. Subasi, "Fast forward to the classical adiabatic invariant", Phys Rev E **95**, 032122 (2017)

Irreversibility and symmetry principles in quantum theory

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The concept of irreversibility lies at the heart of physics and can often be a subtle thing to pin down. In recent years it has acquired new guises that are motivated by information-theoretic aims. For example, in the theory of entanglement intrinsically quantum-mechanical correlations may be utilised to achieve tasks such as quantum teleportation. The use of this entanglement results in its consumption, and a form of irreversibility that can be quantified and studied in a precise manner. Symmetry principles are powerful and unifying concepts in modern quantum physics, however they are normally associated with the conservation of quantities, for example via Noether's theorem. Here I will discuss a novel framework that is motivated by the theory of entanglement. This general framework allows us to study irreversibility in the quantum degrees of freedom of a multipartite system constrained by local or global symmetry principles. The approach leads to a range of results, including a novel information-theoretic perspective on gauge theories, and connections with recent work on quantum thermodynamics. In particular I will present a framework for quantum thermodynamics based on simple physical principles of stability and symmetry, and which admits a complete entropic description.

Hanbury Brown and Twiss noise correlations in a topological superconductor beam splitter

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We study Hanbury-Brown and Twiss current cross-correlations in a three-terminal junction where a central topological superconductor (TS) nanowire, bearing Majorana bound states at its ends, is connected to two normal leads.

Relying on a non-perturbative Green function formalism, our calculations allow us to provide analytical expressions for the currents and their correlations at subgap voltages, while also giving exact numerical results valid for arbitrary external bias. We show that when the normal leads are biased at voltages V_1 and V_2 smaller than the gap, the sign of the current cross-correlations is given by -sgn(V1, V2). In particular, this leads to positive cross-correlations for opposite voltages, a behavior in stark contrast with the one of a standard superconductor, which provides a direct evidence of the presence of the Majorana zero-mode at the edge of the TS.

We further extend our results, varying the length of the TS (leading to an overlap of the Majorana bound states) as well as its chemical potential (driving it away from half-filling), generalizing the boundary TS Green function to those cases. In the case of opposite bias voltages, sgn(V1, V2)=-1, driving the TS wire through the topological transition leads to a sign change of the current cross-correlations, providing yet another signature of the physics of the Majorana bound state.

[1] T. Jonckheere, J. Rech, A. Zazunov, R. Egger, and T. Martin, Phys. Rev. B 95, 054514 (2017)

The distribution of last hitting times of self avoiding walks on random networks

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Analytical results will be presented for the paths of self avoiding walks (SAWs) on random networks. Since these walks do not retrace their paths, they effectively delete the nodes they visit, together with their links, thus pruning the network. The walkers hop between neighboring nodes, until they reach a dead-end node (on the yet-unvisited sub-network) from which they cannot proceed.

Focusing on Erdos-Renyi networks we show that the pruned networks maintain a Poisson degree distribution with an average degree that decreases linearly in time. We enumerate the SAW paths of any given length and find that the number of paths increases dramatically as a function of their length. We also obtain analytical results for the distribution of the SAW path lengths for those paths which are actually pursued starting from a random initial node. This length is actually also the time at which the SAW inevitably hits its past trajectory and stops. We therefore refer to this time as the last hitting time - being the latest time at which a random walk can actually avoid itself. It turns out that it follows the Gompertz distribution, which means that the termination probability of an SAW path increases exponentially with its length. The implications of these results to various physical processes and their generalization to a broader class of networks will be discussed.

[1] I. Tishby, O. Biham and E. Katzav, The distribution of path lengths of self avoiding walks on Erdos-Renyi networks, J. Phys. A: Math. Theor. 49 (2016) 285002.

Proposed experimental investigation into relaxation phenomena in the adiabatic phase transition of Type I superconductor particles

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The first order phase transition of a Type I superconductor involves thermal and electrodynamic relaxation processes of the control variables for which the time of the electrodynamic relaxation is three orders of magnitude faster than the thermal relaxation. [1-6]

In the first order adiabatic phase transition of macroscopic specimens, collective averaging renders relaxation time differences of the control variables unobservable and the phase transition isentropic. In the first order adiabatic phase transition of mesoscopic particles, coherence renders time differences of the control variables observable and the phase transition non-isentropic.

An experimental approach to the relaxation processes of the control variables for first order adiabatic phase transitions in both the macroscopic and mesoscopic size regimes will be discussed.

[1] P.D. Keefe, The second law of thermodynamics and quantum heat engines: Is the law strictly enforced?, Physica E: Low-dimensional Systems and Nanostructures, Vol. 42, Issue 3, Jan. 2010, Pgs 461-465.

[2] P.D. Keefe, Quantum limit to the second law by magneto-caloric effect, adiabatic phase transition of mesoscopic-size Type I superconductor particles, Physica E, Vol. 29, Oct. 2005, Pgs 104-110.

[3] P.D. Keefe, Second Law Implications of a Magnetocaloric Effect Adiabatic Phase Transition of Type I Superconductor Particles, Journal of Modern Optics, V. 51, No. 16-18, pp 2727-2730, 10-12/2004.

[4] P.D. Keefe, Second Law Violation By Magneto-Caloric Effect Adiabatic Phase Transition of Type I Superconductor Particles, Entropy, V. 6, pp. 116-127, 03/2004.

[5] P.D. Keefe, Coherent Magneto-Caloric Effect Superconductive Heat Engine Process Cycle, Journal of Modern Optics, V. 50, No. 15-17, pp 2443-2454, 10-11/2003.

[6] P.D. Keefe, Coherent-Magneto-Caloric Effect Heat Engine Process Cycle, 1st International Conference on Quantum Limits to the Second Law, AIP Conference Proceedings No. 643, pp. 213-218, 09/2002.

Quantum-like models: From information laser to color revolutions, Brexit and Donald Trump

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The recent quantum information revolution has tremendous consequences not only for development of novel physical technologies, but even social ones. We know well about successes in quantum physical technologies related to quantum computing, cryptography, teleportation, and recently quantum stimulator: from philosophizing (Einstein-Podolsky-Rosen paradox, 1933) to real quantum technological projects (the recent EU call for 1 billion Euro). We want to point out to similar success in development of novel social technologies based, in fact, on quantum informational principles. These technologies exhibited they power in a series of color revolutions and recently in Brexit and the election of Donald Trump as the USA president.

The main consequence of the quantum information revolution is that nowadays quantum systems are treated as carriers and processors of information. Nowadays quantum mechanics has a few purely information and probabilistic interpretations (Zeilinger and Bruckner, D'Ariano et al., Fuchs et al. - QBism, Khrennikov - the Växjö interpretation). In a series of works , see, e.g., the monograph [1] the author demonstrated that, in fact, the essence of quantum information processing is in sensitivity of systems to changes of surrounding contexts, adaptivity to environment. These studies led to formulation of the Quantum-like Paradigm (Khrennikov [1]): "The mathematical formalism of quantum information and probability theories can be used to model behavior not only of genuine quantum systems, but all context-sensitive systems, e.g., humans."

Starting with the quantum-like paradigm on application of quantum information and probability outside of physics we proceed to the information laser model describing Stimulated Amplification of Social Actions (SASA). The basic components of social laser are the quantum information field carrying information excitations and the human gain medium. The aim of this note is to analyze constraints on these components making possible SASA. The information laser model can be used to explain the recent wave of color revolutions as well as such "unpredictable events"as Brexit and election of Donald Trump as the president of the United States of America. The presented quantum-like model is not only descriptive. We shall list explicitly conditions for creation of "social laser" [2].

[1] A. Khrennikov, Ubiquitous quantum structure: from psychology to finances, Springer, Berlin-Heidelberg-New York, 2010.

[2] A. Khrennikov, Entropy 17 (2015) 6969.

Life in crowded conditions

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The interior of cells is densely packed with macromolecules. These crowded conditions affect the fundamental proecesses of life in a variety of ways, some of which are specific to certain molecules and some of whcih are generic. The generic effects of crowding are a slowing of diffusion and a shift of binding equilibria towards the bound states. In combination, these effects can already result in rather complex phenomona. As examples, I will discuss the search of DNA-binding proteins such as transcription factors for their binding sites on the genome and the folding of proteins. Beyond excluded volume, crowding in cells may also involve nonspecific attractive interactions and interactions with active processes, increasing the complexity further. These effects will also be discussed. The latter type of scenario, where processes occur in a dense suspension of active particles can also describe phenomena on a larger scale, such as dense systems of cells in tissues and biofilms.

Fluctuations along symmetry crossover in a Kondo-correlated quantum dot

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Understanding the emergence of universal properties in entangled many-body states is a major task in various branches of physics. The key challenge is to unveil how they are governed by quantum fluctuations. The Kondo effect is one of the paradigms for such many-body states, arising from entanglement of a localized electron with conduction electrons that screen its magnetic moment. It plays an important role in transport through quantum dots, where the dot and conducting electrons are entangled in a singlet ground state with SU(2) symmetry to screen the localized spin S=1/2. Interestingly, when several degrees of freedom including orbital magnetic moment as well as spins are combined in a highly degenerate internal moment, more peculiar Kondo many-body states are formed with different symmetries because of the resulting rich spin-orbital configurations. At the heart of these phenomena are the quantum fluctuations between different configurations reflecting quantum uncertainty. However, the evolution of fluctuations between different symmetries of the Kondo states remains unexplored.

Here, by tuning the Kondo state in a carbon nanotube (CNT) with a magnetic field, we change the quantum fluctuations to directly measure their influence on the many-body properties. Non-equilibrium current noise measurements along the crossover between SU(4) and SU(2) symmetry of the ground state quantitatively demonstrate how fluctuations affect the residual interaction between quasiparticles to enhance the Kondo resonance. This work provides a new way to measure quantum fluctuations via the effective charge e* in the non-linear noise, which can be used to unveil their critical role in quantum phase transitions [1].

I would like to thank my collaborators for this work, namely, M. Ferrier, T. Arakawa, T. Hata, R. Fujiwara, R. Delagrange, R. Deblock, Y. Teratani, R. Sakano, and A. Oguri.

[1] M. Ferrier, T. Arakawa, T. Hata, R. Fujiwara, R. Delagrange, R. Deblock, Y. Teratani, R. Sakano, A. Oguri and K. Kobayashi, Phys. Rev. Lett. 118, 196803 (2017).

Dynamical view of quantum thermodynamics

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Quantum thermodynamics addresses the emergence of thermodynamical laws from quantum mechanics. The viewpoint advocated is based on the intimate connection of quantum thermodynamics with the theory of open quantum systems. Quantum mechanics inserts dynamics into thermodynamics giving a sound foundation to finite-time-thermodynamics. The emergence of the 0-law I-law II-law and III-law of thermodynamics from quantum considerations will be presented through examples. I will show that the 3-level laser is equivalent to Carnot engine. I will reverse the engine and obtain a quantum refrigerator. Different models of quantum refrigerators and their optimization will be discussed. A heat-driven refrigerator (absorption refrigerator) is compared to a power-driven refrigerator related to laser cooling. This will lead to a dynamical version of the III-law of thermodynamics limiting the rate of cooling when the absolute zero is approached. The thermodynamically equivalence of quantum engines in the quantum limit of small action will be discussed. I will address the question why we need heat exchangers and flywheels in quantum engines. I will present a molecular model of a heat rectifier and a heat pump in a non-Markovian and strong coupling regime.

[1] K. Hoffmann, P. Salamon, Y. Rezek, and R. Kosloff, Time-optimal controls for frictionless cooling in harmonic traps. EPL (Europhysics Letters) 96, 60015 (2011)

[2] A. Levy, R. Alicki, and R. Kosloff, Quantum refrigerators and the third law of thermodynamics, Physical Review E 85, 061126 (2012)

[3] R. Kosloff, Quantum Thermodynamics: A dynamical Viewpoint, Entropy 15, 2100 (2013)

[4] R. Kosloff and A. Levy, Quantum heat engines and refrigerators: continuous devices, Annual Review of Physical Chemistry 65, 365 (2014)

[5] R. Uzdin and R. Kosloff, The multilevel four-stroke swap engine and its environment, New Journal of Physics 16, 095003 (2014)

[6] R. Uzdin, A. Levy, and R. Kosloff, Equivalence of Quantum Heat Machines, and Quantum-Thermodynamic Signature, Phys. Rev. X 5, 031044 (2015)

[7] R. Uzdin, A. Levy, and R. Kosloff, Quantum Heat Machines Equivalence, Work Extraction beyond Markovianity, and Strong Coupling via Heat Exchangers, Entropy 18, 124 (2016)

[8] G. Katz and R. Kosloff, Quantum Thermodynamics in Strong Coupling: Heat Transport and Refrigeration, Entropy 18, 186 (2016)

[9] A. Levy, L. Diosi, and R. Kosloff, Quantum flywheel, Phys. Rev. A 93, 052119 (2016)

On computer-designed quantum experiments

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Designing experimental setups for high-dimensional multipartite entangled states is a notoriously difficult feat. For that reason, we have developed the computer algorithm Melvin which is able to find new experimental implementations for the creation and manipulation of complex quantum states [1]. The discovered experiments extensively use unfamiliar and asymmetric techniques which are challenging to understand intuitively. Melvin autonomously learns from solutions for simpler systems, which significantly speeds up the discovery rate of more complex experiments. Several of the computer-designed experiments have already been successfully implemented in our laboratories [2-4].

By analysing Melvin's experimental proposal for an unexpectedly high-dimensional quantum state, we discovered a novel technique which allows for very well controlled generation of entanglement based on a technique introduced by the group of Leonard Mandel in 1991 [5]. Surprisingly, this technique only uses elements which were available already for 25 years, but it has been discovered only now by a computer algorithm. This shows that computer designed quantum experiments can be inspirations for new techniques [6].

[1] M. Krenn, M. Malik, R. Fickler, R. Lapkiewicz and A. Zeilinger, Automated search for new quantum experiments. *Physical Review Letters* **116**, 090405 (2016).

[2] M. Malik, M. Erhard, M. Huber, M. Krenn, R. Fickler and A. Zeilinger, Multi-photon entanglement in high dimensions. *Nature Photonics* **10**, 248-252 (2016).

[3] F. Schlederer, M. Krenn, R. Fickler, M. Malik and A. Zeilinger, Cyclic transformation of orbital angular momentum modes. *New Journal of Physics* **18**, 043019 (2016).

[4] A. Babazadeh, M. Erhard, F. Wang, M. Malik, R. Nouroozi, M. Krenn and A. Zeilinger, High-Dimensional Single-Photon Quantum Gates: Concepts and Experiments. *arXiv: 1702.07299* (2017).

[5] X. Zou, L. Wang and L. Mandel, Induced coherence and indistinguishability in optical interference. *Physical Review Letters* **67**, 318 (1991).

[6] M. Krenn, A. Hochrainer, M. Lahiri and A. Zeilinger, Entanglement by Path Identity. *Physical Review Letters* **118**, 080401 (2017).

Some novelties in nonlinear plasmonics

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Surface plasmons (SPP) are extensively studied, due to their interesting physical properties and a wide range of their potential applications. They can be excited in metallic films by lasers in the so-called Kretchmann geometry. The electromagnetic near field of SPP-s is significantly enhanced, compared to the field of the exciting laser. In so-called localized hot-spots the enhancement is even higher. This phenomenon is the source of numerous applications. This lecture deals with some nonlinear SPP phenomena, by describing properties of SPP assisted electron emission. Analysis of time-of-flight spectra of emitted electrons and of the response of a Surface Plasmon Near Field Scanning Tunneling Microscope (STM) to SPP excitation by high power femtosecond lasers is presented. In addition to electron pairing and some magnetic anomalies, results of plasmonic dynamical screening of conduction electrons in metal films, the dependence of the maximal energy of emitted electrons on the nanostructure of the (gold) surface is also analized. Hysteresis anomalies in the STM measurements, attributed to the multiple image charge effect on the metal film – STM tip current are also presented Both experimental findings and their brief theoretical interpretation is discussed.

Galaxy formation in Milgromian gravitation

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We now have the computer programme to study the formation and evolution of galaxies in MOND (i.e. Milgromian dynamics and without dark matter) and I will present our first results. These appear to be very encouraging indeed in that galaxies emerge as they are observed to be.

Universal thermodynamic bound on quantum engine efficiency

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The efficiency of heat engines is limited by the Carnot bound, attained when the engine cycle is reversible. Quantum engines fuelled by non-thermal (e.g., squeezed-thermal) baths have been shown to surpass this bound. Yet, their maximum efficiency cannot be determined by the reversibility condition, which may yield an unachievable efficiency bound above 1. This prompts the question: What does really limit the efficiency? We identify the fraction of the exchanged energy between a quantum system and a bath that necessarily causes an entropy change and derive a new inequality for the latter. This formulation reveals a universal efficiency bound for quantum engines which is invariably attained for the least dissipation over the engine cycle but does not imply reversibility, unless the baths are thermal. This bound thus cannot be solely deduced from the laws of thermodynamics. We illustrate these results for the practically-relevant Carnot- and Otto cycles energised by non-thermal baths, which are both shown to be restricted by our new efficiency bound.

[1] https://arxiv.org/abs/1703.02911

A quantum-dot heat engine operated near its theoretical efficiency limits

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In my talk, I will discuss recent progress in theoretical and experimental research on thermoelectric effects in nanoscale systems, with a particular focus on quantum dots defined in semiconductor nanowires. I will briefly discuss how thermoelectric measurements can provide additional spectroscopic information about the devices compared with standard conductance measurements. The main focus, however, will be on an experimental realization of a quantum dot-based thermoelectric generator, where a heat gradient gives rise to a current across a resistor, thereby generating electric power. The experimental data are in excellent agreement with theoretical calculations. Based on the experimentally measured output power and the theoretically calculated heat currents, we estimate that the heat engine operates close to the theoretical efficiency limits, in particular in the regime of large output power.

Life, the universe, and everything – the emerging Renaissance of physics and astronomy

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There is currently a remarkable mix of clarity and confusion in fundamental physics and astronomy. The situation in the early 21st century is, in fact, similar to what it was in the late 19th century. Then most physicists were generally satisfied with the successful paradigm of classical mechanics and electrodynamics, but there were some conflicting experimental data and theoretical puzzles. Now most physicists are generally satisfied with the successful paradigm of quantum fields and gauge theories (plus Einstein gravity), but there are again mysteries that suggest the need for a deeper theory. Most recently, the particle discovered by the ATLAS and CMS collaborations at the LHC is now known to be a Higgs boson. A naive conclusion is that the Standard Model of particle physics is now complete. But the more profound interpretation is that the discovery of a scalar boson immediately points to physics beyond the Standard Model. Another major advance has been the discovery and exploration of neutrino masses, which appear to open the door to a more fundamental understanding of forces and matter via grand unification. There are many other mysteries and gaps in fundamental understanding. For example, the discovery and exploration of cosmic acceleration has suggested the need for truly revolutionary new physics. The extremely sophisticated and varied array of current experimental efforts – including the recent birth of gravitational wave astronomy – provides hope that many of the most fundamental mysteries [1-4] will be resolved in the foreseeable future. As one example, we mention the experiments to observe dark matter through direct detection in terrestrial facilities, indirect detection in satellite observatories, particle creation in accelerator laboratories, and new phenomena in astronomy and cosmology [4]. All these capabilities are nearing the regimes of exploration where potential success is expected. In the fairly near future one therefore expects an exciting new era for young researchers – a long-awaited Renaissance in physics and astronomy.

[1] E.g., C. Patrignani et al. (Particle Data Group), Chinese Physics C 40, 100001 (2016)), updated at http://www-pdg.lbl.gov/.

[2] Roland E. Allen and Suzy Lidström, “Life, the universe, and everything – 42 fundamental questions”, Physica Scripta 92, 012501 (2017).

[3] Roland E Allen and Suzy Lidström, “21st Century frontiers—a series of articles on current challenges and future opportunities”, Physica Scripta 92, 010302 (2017) .

[4] Katherine Freese, "Status of Dark Matter in the Universe", Proceedings of 14th Marcel Grossman Meeting, Rome, July 2015; arXiv:1701.01840 [astro-ph.CO].

From curvature elasticity to synthetic biology

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The spatial architecture of biological cells is based on fluid membranes that separate space into separate compartments. These membrane compartments, which can be studied in a quantitative manner using model systems such as giant vesicles, are flexible and adjust to their enviroment by changes in their morphology and local composition. Prominent examples for morphological transformations are budding and tubulation of vesicles [1,2], membrane engulfment of nanoparticles [3,4], as well as interfacial phase transitions of droplet-vesicle systems [2]. All of these transformations can by coupled to patterns of intramembrane domains. [5] This multiresponsive behavior arises from the interplay of curvature elasticity, membrane adhesion, lipid demixing, and aqueous phase separation. One intriguing aspect of this interplay is the formation of membrane necks that provide narrow connections between different membrane compartments. The formation of these necks is a crucial step in many biological processes such as cellular uptake and secretion as well as cell division. In all cases, the formation and stability of these necks is governed by local stability conditions that are linear in the membrane curvature. [3,6] Another aspect are curvature-induced forces that push vesicle-bound nanoparticles towards curvature minima or maxima. [4] Recently, a new experimental method has been developed to produce giant vesicles using microfluidic pico-injection. [7] Combining this method with our quantitative understanding of the membrane behavior enables us to construct multiresponsive microcompartments for synthetic biology.

[1] R. Lipowsky: Spontaneous Tubulation of Membranes and Vesicles Reveals Membrane Tension Generated by Spontaneous Curvature. Faraday Discuss. 161 (2013) 305

[2] Y. Liu, ... and R. Lipowsky: Patterns of Flexible Nanotubes Formed by Liquid-ordered and Liquid-disordered Membranes. ACS Nano 10 (2016) 463

[3] J. Agudo-Canalejo and R. Lipowsky: Critical Particle Sizes for the Engulfment of Nanoparticles by Membranes and Vesicles with Bilayer Asymmetry. ACS Nano 9 (2015) 3704

[4] J. Agudo-Canalejo and R. Lipowsky: Uniform and Janus-like Nanoparticles in Contact with Vesicles: Energy Landscapes and Curvature-induced Forces. Soft Matter (2017) 13 (2017) 2155

[5] R. Lipowsky: Remodeling of membrane compartments: Some consequences of Membrane Fluidity. Biol. Chem. 395 (2014) 253

[6] J. Agudo-Canalejo and R. Lipowsky: Stabilization of Membrane Necks by Adhesive Particles, Substrate Surfaces, and Constriction Forces. Soft Matter 12 (2016) 8155

[7] M. Weiss, ... and J. P. Spatz: Sequential Bottom-Up Assembly of Synthetic Cells, Nature Materials (2017) under review

Long range correlation in complex fluids

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As early as in 1983 a coexistence of an ordered and disordered distribution of charged colloidal dispersions [1,2], as well as the formation of void structures [3,4] were reported. These phenomena imply that there are long range repulsive and attractive potentials, of the order of thousands or even tens of thounsands of Angstroms. However, molecular interaction potentials are relativelly short range [5]. Even for charged fluids, at low concentration, the particles correlation is at most a few hundreds of Angstroms. The nature of these long range correlation is up to now not clear [6].

In the past we have proposed and solved a Modified Collidal Primitive Model (MCPM), to study charged colloidal particles at finite volume fraction, where a long range colloidal correlation is reported [7]. In this presentation we extend our calculation and present, to the best of our knowledge, a new counterintuitive effect of long range overcharging, which may be of relevance in transport studies of charged nano-particles, colloids and/or proteins under the action of an external electrical field, and in other macroions phenomena, as those point out above.

[1] N. Ise, T. Okubo, M. Sugimura, K. Ito, and H. J. Nolte, J. Chem. Phys. 78 (1983) 536.

[2] N. Ise, T. Konishi, and B. V. R. Tata, Langmuir 15 (1999) 4176.

[3] K. Ito, H. Yoshida, N. Ise, Science 263 (1994) 66.

[4] H. Yoshida, N. Ise and T. Hashimoto, J. Chem. Phys. 103 (1995) 10146.

[5] Y. Min, M. Akbulut, K. Kristiansen, Y. Golan, and J. Israelachvili, Nature Materials 7 (2008) 527.

[6] K. S. Schmitz, Phys. Rev. E 65 (2002) 061402.

[7] H. M. Manzanilla-Granados and M. Lozada-Cassou, J. Phys. Chem. B 117 (2013) 11812.

Boson sampling and continuous variables

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The seemingly straightforward task of simulating random samples from the measurement of linearly scattered bosons has been shown by Aaronson and Arkipov to be an inefficient problem for a classical computer [1]. Naturally this task is straight forward to implement efficiently on a quantum computer, or if universality is not required, directly implemented using linear optics, single photon sources and detectors. This result has generated a lot of interest in achieving a near-term demonstration of the power of quantum computing over classical computing without the need to construct a universal quantum computer.

In this work we study boson sampling problems involving Gaussian states and operations. For Gaussian states and measurements efficient simulation is possible using classical resources for evolutions under any linear network [2]. More recently a scheme using Gaussian input states but with Fock basis detection can reproduce the result of Aaronson and Arkipov [3]. In this work we reverse the sources and detectors and study Gaussian measurements from the output of linear network fed with Fock basis states. As the detection outputs are continuous the computational complexity of probability *densities* must be considered.

The measurement we propose to use is a 50:50 beam-splitter between a prepared Fock 0 or 1 state and the output network mode. After mixing the modes are detected in a squeezed state basis. The continuous variable measurement results are then binned into "success" if both detectors produce results near the origin and "failures" otherwise. This converts the probability densities to true probabilities. Does sampling from the outputs of this scheme admit a classical computational hardness proof?

Following [1] there are two types of sampling algorithms considered. Exact sampling where the algorithm produces samples from a distribution exactly that of the desired task. This is a physically implausible requirement but can be useful in proofs. Approximate sampling allows sampling from a distribution close to that of the desired task. It is possible for exact sampling to be inefficient whilst approximate sampling is efficient. As shown in [1] both exact and approximate sampling are hard when using Fock basis inputs and detections. We find that in our scheme exact sampling hardness still holds with some additional caveats. In the more realistic case of approximate sampling, we find that there are a number of issues that conspire to render the quantum speed-up unable to be definitively shown.

[1] S. Aaronson and A. Arkhipov, Theory Comput. 9, 143 (2013).

[2] S. D. Bartlett, et al., Phys. Rev. Lett. 88, 097904 (2002).

[3] A. P. Lund, et al., Phys. Rev. Lett. 113, 100502 (2014).

Irreversibility and the arrow of time in a quenched quantum system

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Irreversibility is one of the most intriguing concepts in physics. While microscopic physical laws are perfectly reversible, macroscopic average behavior has a preferred direction of time. According to the second law of thermodynamics, this arrow of time is associated with a positive mean entropy production. Using a nuclear magnetic resonance setup, we measured the nonequilibrium entropy produced in an isolated spin-1/2 system following fast quenches of an external magnetic field. We experimentally demonstrated that it is equal to the entropic distance, expressed by the Kullback-Leibler divergence, between a microscopic process and its time reversal.

[1] T. B. Batalhao, A. M. Souza, R. S. Sarthour, I. S. Oliveira, M. Paternostro, E. Lutz, and R. M. Serra, Phys. Rev. Lett. 115, 190601 (2015).

Possible role of quantum diffusion in ontogenesis of nervous tissue

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A complete neglect of one fundamental feature of charge transport through any conductor, namely, the existence of temporary charged layer on its boundary accompanied by external electric field, led in the particular case of transfer of electric signals via nervous fibres to a rather bizarre but generally accepted theory. For example, for the description of transfer of electric signals by nerves, the non-adequate concept of "conduction velocity" is used, for myelinated axons with Ranvier's nodes an obscure idea of "saltatory propagation of action potential" through the surrounding tissue appears (e.g. [1]). Reconsidering this theory and relevant experimental data, we have concluded that the transfer of electric signals by nerve fibres has an overall character of diffusion. We further have shown that the build-up of charged boundary layer necessary for the electric transport through axon is very likely locally controlled by quantum diffusion of Na^+ and K^+ ions with Fürth's limiting diffusion constant $D_Q = h/2M$ (h is Planck's constant, M ionic mass) [2]. Finally, we have formulated a hypothesis that the ontogenesis of Ranvier's nodes interrupting myelin coat of nerve fibres is triggered by periodic self-organised reactions promoted just by the above mentioned ionic quantum diffusion.

[1] B. Hille: Ion Channels of Excitable Membranes. Sinauer Associtess Inc., Sunderland MA, 2001.

[2] J.J. Mareš, J. Stávek, J. Šesták: Quantum aspects of self-organized periodic chemical reactions. J. Chem. Phys. 121 (2004) 1499-1503.

How can one measure the entropy of a mesoscopic system?

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The additional entropy resulting from coupling a thermodynamic reservoir to a mesoscopic system is a measure of the number of possible microscopic states of that system in thermodynamic equilibrium. This quantity has been a key theoretical tool in determining the properties of the ground state and low lying excited states of the system at low temperatures (e.g. the difference between the ground states of the single- and two-channel Kondo impurity). In bulk systems, the entropy can only be determined by measuring thermodynamic quantities, such as the equation of state or the heat capacity as a function of temperature. However, so far there has been no experimental procedure to measure the entropy in mesoscopic systems.

In this work we demonstrate how transport measurements can be combined into determining the entropy change as additional electrons occupy the mesoscopic system, by carefully analyzing the deviation of the thermopower from the Mott formula. We present analytical derivation of this procedure for a quantum dot with arbitrary SU(N) symmetry, which is valid at high temperatures. Numerical renormalization group calculations, both for a direct determination of the entropy, and using our suggested procedure, show excellent agreement also at low temperatures. Lastly, we apply our formalism to experimental data for quantum dots and demonstrate how the formalism can allow the determination of the ground state degeneracy in each Coulomb valley.

The generalized Stefan-Boltzmann law

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We reconsider the thermodynamic derivation by L. Boltzmann of the Stefan law and we generalize it for various different physical systems *whose chemical potential vanishes*. Being only based on classical arguments, therefore independent of the quantum statistics, this derivation applies as well to the saturated Bose gas in various geometries as to "compensated" Fermi gas near a neutrality point, such as a gas of Weyl Fermions. It unifies in the same framework the thermodynamics of many different bosonic or fermionic non-interacting gases which were until now described in completely different contexts.

Experiments on temporally controllable dissipation in superconducting quantum circuits

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Quantum technology promises revolutionizing applications in information processing, communications, sensing, and modelling. However, efficient on-demand cooling of the functional quantum degrees of freedom remains a major challenge in many solid-state implementations, such as superconducting circuits. Here, we demonstrate direct cooling of a superconducting resonator mode using voltage-controllable photon-assisted tunneling of electrons [1]. The experimental results are in good quantitative agreement with our theoretical model which suggests that this kind of a quantum-circuit refrigerator is a very powerful tool in providing on-demand dissipation to a large class of quantum electric devices. For the superconducting quantum computer, for example, it may offer an efficient way of initializing the quantum bits.

At high bias voltages across the tunnel junctions of the quantum-circuit refrigerator, we observe direct heating of the resonator mode instead of cooling. Our experimental observations [2] of the power spectral density of the generated radiation reveal that the resonator mode can be at as high temperature as 2.5 K although the phonon and electron reservoirs are well below a kelvin. Consequently, the device may also be used as an incoherent photon source with voltage controllable output power exceeding those of the previous cryogenic sources based on single-charge tunneling. Finally, we measure the reflection co-efficient of the resonator as a function of the refrigerator operation voltage and observe that the voltage exponentially changes the dissipation rate inside the resonator. These experiments further support the validity of our theoretical model and our conclusions based on the first experiments in Ref. [1].

In summary, the quantum-circuit refrigerator is a promising component for initializing quantum electric devices and studying open quantum systems in general.

[1] K. Y. Tan, M. Partanen, R. E. Lake, J. Govenius, S. Masuda, and M. Möttönen, arXiv: 1606.04728 (2016)

[2] S. Masuda, K. Y. Tan, M. Partanen, R. E. Lake, J. Govenius, M. Silveri, H. Grabert, and M. Möttönen, arXiv:1612.06822 (2016)

Ultracold dysprosium gases: A complex system from radiative trapping to many-body physics

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Atomic dysprosium features a complex electronic structure, which leads to several interesting properties in the context of atomic physics: a large electronic angular momentum, a large magnetic moment, many narrow optical transitions. Those characteristics imply specific physical behaviors, from the radiative cooling and trapping to the design of novel schemes for quantum many-body physics.

We will first present a detailed study of the magneto-optical trapping (MOT) of ultracold dysprosium [1]. We will show that the MOT can be operated in several regimes, with either all or a single Zeeman components involved. Due to the weak radiative forces obtained with a narrow optical transition, gravity plays an major role, and tends to polarize the atomic sample. We will also discuss light-induced inelastic collisions.

The second part of the talk will address the prospects of our experiment, which aims at realizing topological superfluids with ultracold dysprosium. We will show that the structure of optical transitions is well suited for realizing light-induced gauge fields, the basic ingredient for realizing a topological superfluid. We will also present several schemes to reveal the presence of Majorana fermions at the edges of the topological superfluid.

[1] D. Dreon, L. A. Sidorenkov, C. Bouazza, W. Maineult, J. Dalibard, S. Nascimbene, Optical cooling and trapping highly magnetic atoms: The benefits of a spontaneous spin polarization, arXiv:1610.02284 (2016)

Tuning the dissipation scale of a quantum-gas turbulent cascade

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Many turbulent flows form so-called cascades, where excitations injected at large length scales, are transported to gradually smaller scales until they reach a dissipation scale. We initiate a turbulent cascade in a dilute Bose fluid by pumping energy at the container scale of an optical box trap using an oscillating magnetic force [1,2]. In contrast to classical fluids where the dissipation scale is set by the viscosity of the fluid, the turbulent cascade of our quantum gas finishes when the particles kinetic energy exceeds the laser-trap depth. This mechanism thus allows us to effectively tune the dissipation scale where particles (and energy) are lost, and measure the particle flux in the cascade at the dissipation scale. We observe a unit power-law decay of the particle-dissipation rate with trap depth, which validates the prediction that in a wave-turbulent direct energy cascade, the particle flux vanishes in the limit where the dissipation length scale tends to zero.

[1] A.L. Gaunt, T.F. Schmidutz, I. Gotlibovych, R.P. Smith, Z. Hadzibabic, Phys. Rev. Lett. 110, 20406 (2013)

[2] N. Navon, A.L. Gaunt, R.P. Smith, Z. Hadzibabic, Nature 539, 72 (2016)

Performance of a quantum heat engine at strong reservoir coupling

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We study a quantum heat engine at strong coupling between the system and the thermal reservoirs [1]. Exploiting a collective coordinate mapping [2], we incorporate system-reservoir correlations into a consistent thermodynamic analysis, thus circumventing the usual restriction to weak coupling and vanishing correlations. We apply our formalism to the example of a quantum Otto cycle, demonstrating that the performance of the engine is diminished in the strong coupling regime with respect to its weakly coupled counterpart, producing a reduced net work output and operating at a lower energy conversion efficiency. We identify costs imposed by sudden decoupling of the system and reservoirs around the cycle as being primarily responsible for the diminished performance, and define an alternative operational procedure which can partially recover the work output and efficiency. More generally, the collective coordinate mapping holds considerable promise for wider studies of thermodynamic systems beyond weak reservoir coupling, and we shall also discuss the potential for strong reservoir coupling effects to enhance power output in finite time engine cycles.

[1] D. Newman, F. Mintert, and A. Nazir, Phys. Rev. E 95, 032139 (2017)

[2] J. Iles-Smith, N. Lambert, and A. Nazir, Phys. Rev. A 90, 032114 (2014)

Universal statistics of entropy production in Langevin processes

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Fluctuations of the stochastic entropy production of nonequilibrium processes obey universal relations - these universal relations govern the fluctuations of active molecular processes. Here, we discuss stochastic entropy production of Langevin processes. We show that a stochastic time transformation renders fluctuations of the stochastic entropy production universal. The recently derived infimum laws, first-passage-time fluctuation theorems, and the martingale property of the exponentiated negative entropy production [1], follow from the stochastic time transformation. Additionally, we derive universal relations for entropy-production suprema and level crossings. In summary, we derive a simple equation for stochastic entropy production of Langevin processes that reveals its universal features.

[1] I. Neri, E. Roldán and F. Jülicher, Phys. Rev. X 7 (2017) 011019

Gravitational thermodynamics and modified dark matter

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Modified dark matter (MDM) is a phenomenological model of dark matter, inspired by quantum gravity. We review its construction based on gravitational thermodynamics / entropic gravity arguments. For an accelerating Universe with positive cosmological constant (Λ) such as ours, such considerations lead to the emergence of a critical acceleration parameter related to Λ. We show how modified Newtonian dynamics (MOND) is a phenomenological manifestation of MDM which, we further demonstrate, passes observational tests at both the galactic and cluster scales. Guided by our understanding of quantum gravity, we speculate on the extended nature of the quanta of MDM (obeying infinite statistics, aka quantum Boltzmann statistics) which appears to connect dark matter to such global aspects of spacetime as Λ and the Hubble parameter, and to lead to possible novel particle phenomenology for their interactions, which may explain why, so far, dark matter detection experiments have failed to definitively detect dark matter.

Subjecting theories of dark matter to the cluster test

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Galaxy clusters, such as the "cosmic train wreck" Abell 520 and the well relaxed, nearly spherical cluster Abell 1689, provide stringent tests for various theories of dark matter. Non-Newtonian gravities like MOND (MOdified Newtonian Dynamics), EG (Emergent Gravity), f(R) theories and MOG (MOdified Gravity) are seen to fail, unless additional massive neutrinos or axions are assumed. Primordial Black Holes and light axions appear to be under severe stress. New constraints appear for particle dark matter such as WIMPs, thermal axions and thermal neutrinos. The NFW profile does not perform well, but the isothermal profile can take its place. Thermal axions are possible. However, the best option remains thermal neutrinos with a mass of 1.85 eV and having a Dirac nature, that is, having also right handed "sterile" partners. The case will be tested later this year in the KATRIN experiment.

Diagrammatic and resummation algorithms for electron-magnon and electron-phonon interacting systems in nanojunctions far from equilibrium

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The nanoelectronic and spintronic devices based on single-molecule or magnetic tunnel junctions are typically operated by finite bias voltage which can lead to highly nonequilibrium states of electrons and bosons (such as phonons or magnons). While nonequilibrium Green function (NEGF) formalism offers a rigorous theoretical and computational framework to describe the effect of their mutual interaction on charge and spin currents underlying the device functionality, the computational complexity of standard self-consistent diagrammatic many-body perturbation scheme for NEGFs has restricted simulations to very small junctions (containing few tens of atomic orbitals). Furthermore, magnons have small bandwidth meaning that weak interactions felt by electrons turns out to be strongly coupled regime for magnons, thereby requiring higher order diagrams in the expansion of magnonic NEGF. On the other hand, as the interactions strength increases, self-consistent diagrammatic series often converges to the unphysical branch. This talk will overview our recent NEGF-based approach [1] to nonequilibrium electron-magnon systems in magnetic tunnel junctions, where magnons become quasiparticles dressed by the cloud of virtual electron-hole pairs while electrons scattering of low frequency magnons experience anomaly in their current-voltage characteristics at small bias voltage. I will then use an example of a single molecule nanojunction [2] to show how self-consistent diagrammatic series for NEGFs describing electron-phonon (or electron-magnon) inelastic scattering can be evaded by evaluating only fourth-order bare diagrams [3] and subsequently performing very recently proposed [4] hypergeometric resummation of perturbative series for physical observables that preserves conservation laws and can make possible simulations of electron-boson coupled systems in devices containing very large number of atoms.

[1] F. Mahfouzi and B. K. Nikolić, Phys. Rev. B 90, 045115 (2014).

[2] K. K. Saha, B. K. Nikolić, V. Meunier, W. Lu, and J. Bernholc, Phys. Rev. Lett. 105, 236803 (2010).

[3] H. Mera. T. G. Pedersen, and B. K. Nikolić, Phys. Rev. Lett. 115, 143001 (2015).

[4] H. Mera, T. G. Pedersen, and B. K. Nikolić, Phys. Rev. B 94, 165429 (2016).

Quantum rotor engines and absorption fridges

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In this talk, I will present the recent work of our group on quantum models of thermal machines and the impact of quantum features on their performance. I will present our bottom-up approach to realistic autonomous heat engines using a rotor degree of freedom as the system 'clock' and drawing inspiration from actual piston engines. Then I will discuss a recent experiment realizing an absorption refrigerator with three harmonic modes of trapped ions.

The triumph of heat engines is their ability to convert the disordered energy of thermal sources into useful mechanical motion. In recent years, much effort has been devoted to generalizing thermodynamic notions to the quantum regime, partly motivated by the promise of surpassing classical heat engines. For a fair quantum-classical comparison and as a testbed for quantum effects, we introduce an autonomous rotor heat engine model. It consists of a rotor playing the role of the piston, a harmonic working mode driving the piston, and piston-synchronized coupling to two thermal reservoirs. Our model can be studied in both a quantum and classical framework and is built from standard closed-system Hamiltonians and weak bath coupling terms. I will present a thermodynamic analysis of the engine's behaviour for several parameter regimes, using the classical model as a benchmark. An implementation of the engine model is not restricted to mechanical rotors, but can also be envisaged in the form of Josephson phase variables in superconducting circuits.

Another system for quantum-classical benchmarking is the absorption refrigerator model based on the resonant exchange coupling between three harmonic modes [1]. I will present a recent experiment with trapped ions implementing this model. In particular, I will discuss the experimental results on quantum coherence-assisted single-shot cooling below the steady state, as recently predicted by Mitchison et al [2].

[1] A. Levy and R. Kosloff, Phys. Rev. Lett. 108, 070604 (2012)

[2] M.T. Mitchison, M.P. Woods, J. Prior, and M. Huber, New J. Phys. 17, 115013 (2015)

Electron transfer across thermal gradients

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Recent advances in observing and manipulating charge and heat transport at the nanoscale, and recently developed techniques for monitoring temperature at high temporal and spatial resolution, imply the need for considering electron transfer across thermal gradients. Here, a theory is developed for the rate of electron transfer and the associated heat transport between donor-acceptor pairs located at sites of different temperatures. The electron transfer rate is obtained as a Marcus-type expression with an effective temperature in which the temperatures of the two sites are weighted by the corresponding reorganization (or small polaron formation) energies. The energy transferred per electron transfer event is calculated and the resulting contribution to the heat conductivity in a system where electronic transport is dominated by electron hopping between polaronic sites is evaluated. Furthermore in a system with three or more sites this kinetics is shown to lead to thermal transistor effects and to steady states characterized by circular electronic currents.

Non-reciprocity and directional amplification with cavity optomechanics

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Cavity optomechanics is a rapidly-growing field in which mechanical degrees of freedom are coupled to modes of the electromagnetic field inside optical or microwave resonators. Adapting laser-cooling techniques from atomic physics several experiments have recently observed mechanical motion close to the quantum ground-state. This paves the way to exploit these systems for the engineering of phonon and photons at the nanoscale with exciting, novel applications for science and technology [Rev. Mod. Phys. 86, 1391 (2014)].

Along this line of thought, I will give an overview of recent highlights. First, I will report on the realization of a dissipative quantum reservoir for microwave light based on the reversed dissipation regime of cavity optomechanics [PRL 113, 023604 (2014)] in which dissipation of the mechanical oscillator is faster than that of the electromagnetic modes. We have exploited the engineered dissipation to implement a large gain phase-preserving microwave amplifier operating 0.87 quanta above the limit imposed by quantum mechanics [arXiv:1602.05180, to appear in Nature Physics]. Second, I will discuss the demonstration of nonreciprocal transmission between two microwave modes with optomechanical interactions only in an electromechanical circuit [arXiv:1612.08223]. Finally, I will present an implementation for phase-preserving and phase-sensitive directional amplifier in setup of two microwave cavities and two mechanical resonators [arXiv:1705.00436].

T102 Tue, 11 July, 14:20 - 14:40, 3 session - C parallel

Topological phases in superconducting lattices

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We study superconducting lattices in which the superconductor is deposited periodically on a one- or two-dimensional sample. We suggest that a superconducting lattice is a practical realization platform for a variety of topological superconducting phases, which overcomes the challenge of controlling the position of the chemical potential. We show how zero-energy Majorana modes emerge at the ends of a one-dimensional system proximity coupled to a one-dimensional superconducting lattice, and continue to present realizations of two-dimensional topological phases based on superconducting lattice.

Many-body localization from displacement transformations

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The phenomenon of many-body localization (MBL) can be understood in terms of the existence of localized integrals of motion (IOMs). However, the actual computation of these IOMs throughout the phase diagram still is a daunting task. Recently we developed a method to calculate IOMs, based on sequential displacement transformations. We present data on the structure of the IOMs themselves, such as overlaps with original operators, as well as on the effective interactions between the IOMs. Finally, we present yet another way of computing IOMs using few-particle exact diagonalization and we will discuss possible future variations of the displacement transformation method.

Quantum root mean square error and universally valid uncertainty relations

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Recently, the problem of extending the classical notion of root mean square (rms) error, originally introduced by Gauss [1], to quantum measurements has attracted considerable attention [2,3]. To set a theoretical basis for this problem, here, we introduce the following basic requirements to be satisfied by any useful quantum generalizations of the classical rms error: (i) device-independent definability, (ii) correspondence principle (requiring coincidence with the classical notion in the commutative case), (iii) soundness (requiring to take zero for precise measurements [4]). We show that the root mean square of the noise operator, a notion having been used for a long time, satisfies all the above requirements, whereas the recently proposed [3] error notion based on distance between probability measures does not satisfy the correspondence principle. We show a simple method to strengthen the noise-operator based rms error to satisfy (iv) completeness (requiring to take zero only for precise measurements) in addition to the above three requirements. Recently obtained universally valid measurement uncertainty relations [5,6,7,8,9,10] are maintained with the same forms by this completion of the noise-operator based rms error. This clears a recent claim [3] that the state-dependent formulation of measurement uncertainty relations is not tenable.

[1] C. F. Gauss, Commentationes Societatis Regiae Scientiarum Gottingensis Recentiores V (Classis Mathematicae), 33 (1819–1822).

[2] P. Busch, T. Heinonen, and P. Lahti, Phys. Lett. A 320, 261 (2004).

[3] P. Busch, P. Lahti, and R. F. Werner, Rev. Mod. Phys. 86, 1261 (2014).

[4] M. Ozawa, Phys. Lett. A 335, 11 (2005); Ann. Physics 321, 744 (2006).

[5] M. Ozawa, Phys. Rev. A 67, 042105 (2003); Ann. Physics 311, 350 (2004).

[6] M. Ozawa, Int. J. Quant. Inf. 1, 569 (2003); Phys. Lett. A 320, 367 (2004).

[7] M. J. W. Hall, Phys. Rev. A 69, 052113 (2004).

[8] J. Erhart, S. Sponar, G. Sulyok, G. Badurek, M. Ozawa, and Y. Hasegawa, Nat. Phys. 8, 185 (2012).

[9] C. Branciard, Proc. Natl. Acad. Sci. USA 110, 6742 (2013).

[10] M. Ozawa, arXiv:1404.3388 [quant-ph]; B. Demirel, S. Sponar, G. Sulyok, M. Ozawa, and Y. Hasegawa, Phys. Rev. Lett. 117, 140402 (2016).

Quantum control of non-Gaussian noise in hybrid quantum networks

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The design of quantum control of non-Gaussian noise became a key requirement in the newly perspective of hybrid distributed architectures made of natural/artificial atoms and photons. In this presentation I will review our recent works on entanglement protection of non-Gaussian and 1/f noise via dynamical decoupling during both universal two-qubit gates and distribution through noisy communication channels.

First I will present the integration of dynamical decoupling into a universal two-qubit gate in the presence of 1/f noise [1] acting locally on each of the qubits forming the entangling gate. Both the case of pure dephasing and of depolarizing [2] noise will be addressed investigating the gate efficiency under periodic, Carr-Purcell, and Uhrig dynamical decoupling sequences. For local pure dephasing, dynamical control allows for quantum sensing of 1/f noise. We find an analytic expression of entanglement fidelity in terms of noise filter functions allowing to single out the sequence-specific capability to bypass cumulants of the underlying non Gaussian processes [3].

Finally, I will report two all-optical experiments demonstrating that purely local control also allows for on-demand entanglement restoration during distribution through noisy communication channels in the presence of non-Markovian dynamics [4]. The restored entanglement being a manifestation of "hidden" quantum correlations resumed by the local control [5].

[1] E. Paladino, Y. Galperin, G. Falci, and B. Altshuler, Rev. Mod. Phys. 86, 361 (2014).

[2] A. D'Arrigo, G. Falci and E. Paladino, Phys. Rev. A 94, 022303 (2016).

[3] A. D'Arrigo, G. Falci and E. Paladino, in peparation (2017).

[4] A. Orieux, A. D'Arrigo, G. Ferranti, R. Lo Franco, G. Benenti, E. Paladino, G. Falci, F. Sciarrino and P. Mataloni, Sci. Rep. 5, 8575 (2015).

[5] A. D'Arrigo, R. Lo Franco, G. Benenti, E. Paladino and G. Falci, Annals of Physics 350, 211 (2014).

Carnot efficiency in an irreversible process

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In thermodynamics, there exists a conventional belief that "the Carnot efficiency is reachable only when a process is reversible." However, there is no theorem proving that the Carnot efficiency is unattainable in an irreversible process. Here, we show that the Carnot efficiency is reachable in an irreversible process through investigation of the Feynman-Smoluchowski ratchet (FSR). Our result opens a new possibility of designing an efficient heat engine even in a highly irreversible process and also answers the long-standing question of whether the FSR can operate with the Carnot efficiency.

[1] Jae Sung Lee and Hyunggyu Park, arXiv:1611.07665

Use of a non-equilibrium environment for controlling open quantum systems

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Control of atomic and molecular scale quantum systems attracts interest due to various existing and prospective applications for quantum technologies including laser-assisted control of chemical reactions, quantum cryptography, quantum information, quantum metrology, quantum optics, etc. Often quantum systems subject to control interact with their environment, i.e., they are open quantum systems. This circumstance requires the analysis of abilities to control open quantum systems. We will discuss ab initio description of dynamical equations for open quantum systems interacting with their environment, including ab initio derivation of non-Markovian master equation for quantum systems weakly interacting with reservoir. Then we will discuss use of the environment for preparation of arbitrary density matrices of finite-level quantum systems, as well as for manipulation of quantum systems with infinite number of states. In this approach the system dynamics is adjusted by using (a) suitably tailored generally non-equilibrium state (i.e., spectral distribution function) of incoherent environment surrounding the systems and (b) coherent laser pulse with tailored time dependent profile. Such combination allows for approximate generation of arbitrary mixed density matrices of a wide class of quantum systems. Thus it allows to achieve the strongest degree of state control for quantum systems, namely, controlled transfer of arbitrary initial state into arbitrary predefined target state. This strongest degree of controllability might be used for quantum information and computing with mixed states and non-unitary quantum gates.

No-go theorem for the characterisation of work fluctuations in coherent quantum systems

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In this talk I will describe a recent no-go result that essentially shows that a notion of stochastic work can not exist for quantum processes in which the initial state is found in a quantum superposition of different energy states [1]. More precisely, we show that there exists no measurement scheme to estimate work fluctuations which satisfies that (i) the work statistics agree with standard results, as given by the two-point-measurement scheme [2], for initial non-coherent states, and at the same time that (ii) the average measured work corresponds to the difference of average energy for closed quantum systems. The implications of this result in several proposals to measure fluctuations of work in quantum systems [2-5] will be discussed, as well as a measurement scheme to approximately describe work fluctuations in coherent processes using two copies of the state [1].

[1] M. Perarnau-Llobet et al, Phys. Rev. Lett. 118, 070601 (2017).
[2] P. Talkner, E. Lutz, and P. Hänggi, Phys. Rev. E 75, 050102 (2007).
[3] A.E. Allahverdyan, Phys. Rev. E 90, 032137 (2014).
[4] P. Solinas and S. Gasparinetti, Phys. Rev. E 92, 042150 (2015).
[5] H.J.D. Miller and J. Anders, arXiv:1610.04285 (2016).

Field-induced inversion of resonant tunneling currents through single molecule junctions and the directional photo-electric effect

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It has been known for several decades that the electric current through tunneling junctions is affected by irradiation of the external leads. In particular, photon-assisted currents was demonstrated and studied extensively in tunneling junctions of different compositions, and for different radiation wavelengths. In this work this phenomenon is revisited in the context of single molecule junctions. Restricting the theoretical discussion to adiabatic periodic driving of the leads within a non-interacting electron formulation, the main features of specific molecules are encoded in the discrete electronic energy levels. The detailed level structure of the molecule is shown to yield new effects in the presence of asymmetric driving. In particular, when the field-free tunneling process is dominated by a single electronic level, the electric current can flow against the direction of an applied static bias. In the presence of a second electronic level, a directional photo-electric effect is predicted, where not only the magnitude but also the direction of the steady state electric current through the tunneling junction can be changed by a monotonous increase of the field intensity. These effects are analyzed and explained by outlying the relevant theory, using analytic expressions in the wide-band limit, as well as numerical simulations beyond this limit.

A repeated interaction approach to open quantum walks and open quantum Brownian motion

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Open quantum walks are discrete time random walks completely driven by dissipation. It is quite natural to derive them by reduction from a microscopic Hamiltonian for a walker-environment system in a repeated interaction scheme. Open quantum Brownian motion, on the other hand, is known to be a particular continuum limit of open quantum walks. Here we extend the repeated interaction perspective to the open quantum Brownian motion case. We show that a unified repeated interaction approach to both open quantum walks and open quantum Brownian motion is possible. We propose and discuss a quantum optical implementation of open quantum Brownian motion.

"Human, All Too Human:" On the concept of quantum state, from Bohr's atom to quantum automata

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Bohr's 1913 atomic theory is well known for several radical ideas, at the time even more radical than those, quite radical already, of his main predecessors, Planck and Einstein. One of these ideas, arguably most radical conceptually, is often overlooked or underappreciated. This idea could be sketched as follows, in part courtesy of Laurent Freidel's argument. The classical electron theory of H. Lorentz and his followers considered the probability of finding a moving electron in a given state, under the underlying realist assumptions, in particular that of (causally) representing the motion of electrons in terms of oscillators. Bohr's theory was instead concerned with the probabilities of transitions between stationary states, thus essentially defining quantum discreteness, without assuming the possibility of representing these transitions and, as a result, abandoning causality as well. This change of attention toward transition probabilities between quantum states was central to Einstein's remarkable 1916 treatment, using Bohr's theory, of spontaneous and induced emission and absorption of radiation, and then to Heisenberg's discovery of quantum mechanics, which abandoned any attempt at a mechanical (orbital) representation of even stationary states, as well as of transitions between them. As he wrote to R. Kronig, "What I really like in this scheme is that one can really reduce all interactions between atoms and the external world ... to transition probabilities [between states]." Note that one no longer thinks so much in terms of discrete quantum objects, such as electrons, but rather of discrete states of these objects, object that are no longer physically described, and probabilities of predicting these states. It follows that there is not, or in any event there may no longer be, either any underlying continuity or any underlying causality of quantum processes left, the probabilities of transitions between allowed stationary states, or by implications quantum states in general.

Taking this concept, which I assume to be crucial for all quantum theory, as a point of departure, this paper considers the concept of quantum state, both physical, to which and only to which the preceding description referred, and mathematical, as a vector (for which the name state may well be misleading) in the Hilbert-space formalism of quantum mechanics and then quantum field theory, and the relationships between both. I then argue that both concepts and the relationships between them underwent another revolutionary change with quantum electrodynamics and quantum field theory. The nature and implications of this change, specifically for the concept, physical and mathematical, of quantum field are far from fully explored and even understood even now, nearly a century since the theory was introduced by Dirac. I close by considering the implications of this situation for quantum information theory and, in part, via quantum information theory, quantum gravity.

A new look at an old controversy: Interacting electrons in Anderson-Mott insulators

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Mott-Anderson insulators are disordered solids on the insulating side of the Mott and of the Anderson quantum phase transitions. Electron localization on the insulating side makes screening inefficient, so electron-electron interactions become important. They have a profound effect on physical properties. The interaction makes the one-particle density of states (DOS) develop a gap (called Coulomb gap) around the Fermi level. The form of the Coulomb gap has been under dispute for several decades as were its role in determining physical properties; this talk focuses on transport and on relaxation.

Based on the requirement that any transition from the ground state must have a positive energy, two forms were proposed for the DOS. A "soft" gap DOS, $N(E) \sim |E-E_F|^{d-1}$ was derived for a so called "pseudo-ground" state stable to one-electron excitations and (approximately) a "harder" DOS $\ln N(E) \sim (-E_g/E)^{1/2}$ for the true ground state, stable to many-electron excitations. In something of a puzzle, it is the pseudo-ground gap that is believed to govern the DOS because of support by experimental results and by computer simulations. On this basis a one-particle transport theory was derived and has been widely used in the literature. This poses a number of questions, e.g. why would particles in an interacting system move independently of each other?

The talk will show that, on closer examination, the experiments and the simulations that are thought to favor the "soft" DOS do not truly support it. It will be further shown that the one-particle DOS is irrelevant to transport measurements in the linear response regime. Many-body transport theories that do not invoke the DOS and do agree with transport and relaxation experiments will be outlined.

In summary, the "hard" DOS should not be disputed but is not involved in transport.

Stochastic thermodynamics of a particle in a box

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The piston system (particles in a box) is the simplest paradigmatic model in traditional thermodynamics. However, the recently established framework of stochastic thermodynamics (ST) fails to apply to this model system due to the embedded singularity in the potential. We study the ST of a particle in a box by adopting a novel coordinate transformation technique. Through comparing with the exact solution of a breathing harmonic oscillator, we obtain analytical results of work distribution for an arbitrary protocol in the linear response regime and verify various predictions of the fluctuation-dissipation relation. When applying to the Brownian Szilard engine model, we obtain the optimal protocol $\lambda_t = \lambda_0\ 2^t$ for a given sufficiently long total time τ. Our study not only establishes a paradigm for studying ST of a particle in a box but also bridges the long-standing gap in the development of ST [1].

[1] Z. Gong, Y. Lan, H. T. Quan, Phys. Rev. Lett. 117 (2016) 180603.

The copying fidelity of a polymerase facing an obstacle

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The connections between information and thermodynamics have been fascinating scientists ever since Maxwell envisioned his famous demon. One of the extensively studied problems in this field is the copying fidelity of molecular machines. This fidelity can be increased using an out-of-equilibrium mechanism called kinetic discrimination. Kinetic discrimination results in higher fidelity when the system is driven further away from equilibrium, while at the same time the copying velocity increases. What will happen to the copying fidelity when such a machine encounter an obstacle and slows down?

We investigate a simple model of a polymerase that copies a template and at the same time must open a single- to double-stranded junction to progress along its track. We find that the kinetics of the bond opening and closing in the junction affect the fidelity of copying. Surprisingly, the copying fidelity turns out not to depend on the form of the elastic interaction between the polymerase and the junction. Both passive and active interactions lead to the same mean rate of copying errors. Our results suggest that the copying fidelity can not be used as a tool to investigate the properties of the motor-junction interaction.

Ground state cooling of a nanomechanical resonator by electron transport

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Nano-electro-mechanics pave the way to the formidable task of observing quantum effects in large mechanical systems formed by millions of atoms. To achieve such a goal, a crucial requirement is cooling the mechanical resonator to very low temperature. So far ground-state cooling has not been reported for NEMS using purely electron transport. I discuss two proposals to achieve the ground-state cooling for the mechanical vibration of a nanotube suspended between: (i) spin-polarised contacts [1,2] or (ii) a normal metal and a superconducting contact [3]. Assuming a suitable coupling between the vibrational modes and the charge or spin of the quantum dot formed on the nanotube itself, I show that ground-state cooling of the mechanical oscillator can be achieved for many of the oscillator's modes simultaneously as well as selectively for single modes. The range of parameters for ground-state cooling is within the reach of the state of the art for the suspended carbon nanotube devices. Finally, I will discuss how to detect the resonator's non-equilibrium state by analysing the current-voltage characteristic.

[1] P. Stadler, W. Belzig and G. Rastelli, Phys. Rev. Lett. 113 (2014), 047201.

[2] P. Stadler, W. Belzig and G. Rastelli, Phys. Rev. B 91 (2015), 085432.

[3] P. Stadler, W. Belzig and G. Rastelli, Phys. Rev. Lett. 117 (2016), 197202.

T116 Wed, 12 July, 10:50 - 11:20, 2 session - B parallel

Microscopic hydrodynamic modes in a hard sphere binary mixture

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The transport properties of binary gas mixtures provide a paradigm for understanding the transport properties of more complex gas mixtures. The detailed behavior of microscopic hydrodynamic modes in complex gas mixtures is sensitive to the structure of the kinetic equations used to describe the microscopic behavior of the gas. We use a method that has been applied successfully to monatomic quantum gases [1,2,3] and Bose-Einstein condensates [4,5]. We show that it is possible to derive analytic microscopic expressions for the shear viscosity, the speed of sound, and the decay rates of the hydrodynamic modes in a hard sphere binary gas mixture directly from the spectral properties of coupled Boltzmann equations. We show that the analytic expressions give good agreement with experimental viscosity data and to the results of light scattering experiments on noble gas binary mixtures.

[1] E.D. Gust and L.E. Reichl, “Molecular dynamics simulation of collision operator eigenvalues,” Phys. Rev. E, 79 (2009) 031202.

[2] E.D. Gust and L.E. Reichl, “Transport coefficients from the boson Uehling-Uhlenbeck equation,” Phys. Rev. E, 87 (2013) 042109.

[3] L.E. Reichl and E.D. Gust, “Transport theory for a dilute Bose-Einstein condensate,” Phys. Rev. A, 88 (2013) 053603.

[4] E.D. Gust and L.E. Reichl, “Decay of hydrodynamic modes in dilute Bose-Einstein condensates,” Phys. Rev. A, 90 (2014) 043615.

[5] L.E. Reichl and E.D. Gust, “Microscopic hydrodynamic modes in a binary hard sphere mixture,” J. Stat. Phys. (2017) DOI 10.1007/s10955-017-1798-7.

Quantum simulation of the spin-boson model: Monitoring the bath

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The spin-boson model occupies a central position in condensed matter physics. It describes the interaction between a two-level system and a collection of harmonic oscillators or dissipative bath. It was originally developed as a general, fully quantum-mechanical, framework to account for the dissipation inherent to any quantum system [1]. This formalism was successfully applied to various physical systems weakly coupled to a bosonic bath (mesoscopic circuits, amorphous solids…). However only a few experiments [2,3] explored its more challenging limit -when the quantum system is strongly coupled to the many degrees of freedom of the bath - despite numerous theoretical predictions. In this regime the ground state of the whole system is non-trivial: the spin is highly entangled with the bath, forming a many-body system.

I will present a new architecture based on superconducting circuits to tackle this challenging problem. It offers two main advantages: first it allows to reach the ultra-strong coupling between the quantum system and its bath; second one can experimentally monitor the qubit and its bath at the same time, and thus reveal the many-body correlations which are building up when all the degrees of freedom become entangled.

Our approach consists in coupling a superconducting artificial atom (namely a transmon qubit) to a meta-material made of thousands of SQUIDs. The latter sustains many photonic modes and shows characteristic impedance close to the quantum of resistance. As a direct application, we use this circuit to explore quantum optics in the ultrastrong coupling regime, where new phenomena arise [4–7].

[1] Leggett A. et al., Rev. Mod. Phys. 59(1), 1 (1987).
[2] Forn-Díaz P. et al., Nat. Phys. AOP (2016).
[3] Haeberlein M. et al., arXiv: 1506.09114 (2015).
[4] Le Hur K., Phys. Rev. B 85, 140506(R) (2012).
[5] Goldstein M. et al., Phys. Rev. Lett. 110, 017002 (2013).
[6] Gheeraert N. et al., arXiv :1601.01545 (2015).
[7] Yoshihara F. et al., Nat. Phys. AOP (2016).

Negative records of entropy production: The infimum law

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Little is known beyond the second law about the statistics of entropy-production fluctuations in the mesoscopic world. The best insights, so far, in fluctuations of entropy production are provided by fluctuation theorems. In addition to fluctuation theorems, an important question is to understand the extreme-value statistics of entropy production. What are the statistics of records of negative entropy production (also known as infima) during a given time interval?

We derive universal equalities and inequalities on the statistics of entropy-production infima [1]. We show that the mean of the finite-time infimum of the stochastic entropy production is bounded from below by minus the Boltzmann constant. We also show that the distribution of the global infimum of entropy production is exponential with mean equal to minus the Boltzmann constant. Key to our work is the connection between entropy production and martingales, which represent fair games and are widely studied in quantitative finance. The use of mathematical concepts from martingale theory for entropy production statistics bestows our results a universal character.

These results have interesting implications for stochastic processes that can be discussed in simple colloidal systems and in active molecular processes. The timing and statistics of discrete chemical transitions of molecular processes, such as the steps of molecular motors, are governed by the statistics of entropy production. We also show that the extreme-value statistics of active molecular processes are governed by entropy production; for example, we derive a relation between the maximal excursion of a molecular motor against the direction of an external force and the infimum of the corresponding entropy-production fluctuations. Using this relation, we make predictions for the distribution of the maximum backtrack depth of RNA polymerases, which follow from our universal results for entropy-production infima.

[1] I. Neri, É. Roldán, and F. Jülicher, Physical Review X 7 , 011019 (2017).

Casimir forces out of equilibrium

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We analyze both the attractive and repulsive Casimir-Lifshitz forces recently reported in experimental investigations. By using a kinetic approach, we obtain the Casimir forces from the power absorbed by the materials. We consider collective material excitations through a set of relaxation times distributed in frequency according to a log-normal function. A generalized expression for these forces for arbitrary values of temperature is obtained [1]. We compare our results with experimental measurements and conclude that the model goes beyond the proximity-force approximation.

[1] L. C. Lapas, A. Pérez-Madrid, and J. Miguel Rubi, Phys. Rev. Lett., 116, 110601 (2016)

T120 Tue, 11 July, 16:20 - 16:40, 4 session - A parallel

Cooperative atom response to light and giant subradiant correlations in arrays of atoms

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We demonstrate how cold dense atomic ensembles can respond to light differently from thermal atoms. In cold samples strong light-mediated resonant dipole-dipole interactions between atoms can be utilized in a control and storage of light. The method is based on a high-fidelity preparation of a collective atomic excitation in a single correlated subradiant eigenmode in a lattice. We demonstrate how a simple phenomenological model captures the qualitative features of the dynamics and sharp transmission resonances that may find applications in sensing.

[1] Storing Light with Subradiant Correlations in Arrays of Atoms, PRL 117, 243601 (2016)

Bose-Fermi dual superfluids

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We will report on the production and study of a mixture of Bose and Fermi superfluids. Such a mixture has long been sought in liquid helium where superfluidity was achieved separately in bosonic 4He and fermionic 3He. However due to strong interactions between isotopes, phase separation occurs when the 3He concentration exceeds 6%, which, so far, has prevented reaching simultaneous superfluidity for both species. Using dilute quantum gases where interactions can be tuned, we have produced a Bose-Fermi mixture where both species are superfluid [1]. By exciting center of mass oscillations of the mixture we probe the collective dynamics of the system. Coherent energy exchange between the Bose and Fermi gas is observed with very small damping below a certain critical velocity. We compare this critical velocity for superfluid counterflow to a recent theoretical prediction [2,3]. Finally raising the temperature of the system slightly above the superfluid transition reveals an unexpected phase-locking of the oscillations induced by dissipation.

[1] Igor Ferrier-Barbut, Marion Delehaye, Sebastien Laurent, Andrew T. Grier, Matthieu Pierce, Benno S. Rem, Frédéric Chevy, Christophe Salomon, A Mixture of Bose and Fermi Superfluids, Science 345, 1035 (2014)

[2] Y. Castin, I. Ferrier-Barbut, and C. Salomon, The Landau critical velocity for a particle in a Fermi superfluid, Comptes Rendus Physique 16, 241 (2015)

[3] M. Delehaye, S. Laurent, I. Ferrier-Barbut, S. Jin, F. Chevy, and C. Salomon, Critical Velocity and Dissipation of an ultracold Bose-Fermi Counterflow, Phys. Rev. Lett. 115, 265303 (2015)

Cotunneling drag effect in double quantum dots

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A key ingredient in quantum information processing is the measurement of the quantum state of a system. Unlike classical systems, backaction effects are unavoidable in the quantum realm. A relevant backaction phenomenon between Coulomb coupled conductors is the drag effect. In this effect, a current flowing in one conductor can induce a voltage across an adjacent conductor via the Coulomb interaction. The mechanisms yielding drag effects are not always understood, even though drag effects are sufficiently general to be seen in many low-dimensional systems. I will discuss the experimental observation for the Coulomb drag in a Coulomb-coupled double quantum dot and the theoretical arguments to explain it [1]. I will explain how cotunneling processes are the essential transport mechanism to obtain a correct qualitative understanding of the drag behavior in the experiments. This can be illustrated with a minimal model that leads to a purely quantum coherent drag effect and advances the possibility of engineering drag currents using band tailoring [2].

[1] A. J. Keller, J. S. Lim, D. Sanchez, R. Lopez, S. Amasha, J. A. Katine, H. Shtrikman, and D. Goldhaber-Gordon, Phys. Rev. Lett. 117, 066602 (2016).

[2] J. S. Lim, R. Lopez, and D. Sanchez, arXiv:1612.06627.

All-thermal transistor based on stochastic switching

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Fluctuations are strong in mesoscopic systems and have to be taken into account for the description of transport. We show that they can even be used as a resource for the operation of a system as a device. We use the physics of single-electron tunneling to propose a bipartite device [1,2] working as a thermal transistor [3]. Charge and heat currents in a two terminal conductor can be gated by thermal fluctuations from a third terminal to which it is capacitively coupled. The gate system can act as a switch that injects neither charge nor energy into the conductor hence achieving huge amplification factors. Non-thermal properties of the tunneling electrons can be exploited to operate the device with no energy consumption.

[1] R. Sánchez, M. Büttiker, Phys. Rev. B 83, 085428 (2011).

[2] H. Thierschmann et al., Nature Nanotech. 10, 854 (2015).

[3] R. Sánchez, H. Thierschmann, L. W. Molenkamp, Phys. Rev. B 95, 241401(R) (2017).

Static and dynamical properties of isolated many-body quantum systems

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We study static and dynamical properties of isolated many-body quantum systems and compare them with the results for full random matrices. In doing so, we link concepts from quantum information theory with those from quantum chaos. We argue that similar information about the system can be obtained either with the von Neumann entanglement entropy or with the Shannon information entropy, the latter being computationally less expensive. We also analyze the evolution of the survival probability. It reveals details about the system that the two entropies cannot capture. These include the correlation hole, which is a way to directly detect level repulsion from dynamics, and a slower evolution at long times caused by the unavoidable energy bounds of the spectrum.

Thermodynamic entropy as a Noether invariant

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Entropy is a fundamental concept in physics. It appears in thermodynamics, statistical mechanics, information theory, computation theory, and thermodynamics of black holes. Recently, the inter-relation between different types of entropy has been discovered. By synthesizing various aspects of entropy, we thus obtain a deeper understanding of fundamental laws in physics. Now, there is a paper [1], which claims that black hole entropy is obtained as the Noether charge associated with the horizon Killing field. We are then naturally led to ask whether thermodynamic entropy of standard materials is also characterized by a Noether invariant. In my talk, we first study a classical many-particle system with an external control represented by a time dependent parameter in a Lagrangian. We show that thermodynamic entropy of the system is uniquely characterized as the Noether invariant associated with a symmetry for an infinitesimal non-uniform time translation, where trajectories in the phase space are restricted to those consistent with quasi-static processes in thermodynamics [2]. The most remarkable result of our theory is the emergence of a universal constant of the action dimension, while our theory stands on classical mechanics, classical statistical mechanics, and thermodynamics. Next, we study a thermally isolated quantum many-body system with an external control represented by a time-dependent parameter. By formulating a path integral in terms of thermal pure states, we derive an effective action for trajectories in a thermodynamic state space, where the entropy appears with its conjugate variable. In particular, when operations are quasi-static, the symmetry for the uniform translation of the conjugate variable emerges in the path integral. This leads to the entropy as a Noether invariant [3].

[1] R. M. Wald, Phys. Rev. D 48, R3427 (1993)

[2] S. Sasa and Y. Yokokura, Phys. Rev. Lett. 116, 140601 (2016)

[3] S. Sasa, S. Sugiura, and Y. Yokokura, arXiv: 1611.07268

From N+1 to N+N: Exploring repulsive many-body states with ultracold spin mixtures

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Repulsive interactions lie at the heart of a variety of strong-correlation phenomena in condensed matter. In particular, strong repulsion between itinerant fermions fosters the emergence of ferromagnetism. We investigate many-body repulsive states within the minimal framework offered by ultracold Fermi gases with tunable short-range repulsive interactions and tunable spin polarization.

I will first report on a recent experimental study of repulsive Fermi polarons in the universal case of a mass-balanced mixture in the vicinity of a broad Feshbach resonance [1]. Understanding the properties of an impurity immersed in a degenerate quantum medium represents a fundamental problem in many-body physics. In particular, the Fermi polaron problem is centrally important for the description and the stability of correlated phases arising from repulsive interactions. We report on the observation of well-defined repulsive quasiparticles up to unitarity-limited interactions [1]. We characterize the many-body system via radio-frequency spectroscopy, extracting the elastic and inelastic properties of repulsive Fermi polarons: the energy E_+, the effective mass m^*, the residue Z and the decay rate Γ. Above a critical interaction, we find E_+ to exceed the Fermi energy of the bath, while m^* diverges and even turns negative, revealing an instability of the repulsive Fermi liquid.

In a different experiment, we probe the stability of a ferromagnetic domain wall by observing the collective spin dynamics of an initially fully magnetized spin mixture in a harmonic trap [2]. We find the spin susceptibility of the gas to significantly increase with the repulsion strength, while the two spin domains remain temporarily immiscible for critical interactions and temperatures, suggesting the presence of a Stoner-like ferromagnetic instability. Relatedly, in ongoing experiments, we investigate the evolution of the interaction energy and of the spin correlations in a balanced spin mixture after a rapid radio-frequency quench to the strongly repulsive regime.

[1] F. Scazza et al., Phys. Rev. Lett. 118, 083602 (2017)

[2] G. Valtolina et al., Nature Physics (Advance Online Publication, 24 April 2017)

Quantum thermodynamics in strongly coupled quantum dots

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It has emerged over the past years that it is not straightforward to find consistent definitions of thermodynamic quantities, such as heat and entropy, in driven quantum systems which are strongly coupled to reservoirs. In order to shed light on this question, we have investigated the simplest prototypical model, namely a noninteracting resonant level model coupled to fermionic reservoirs. Using an exact solution of the fully driven quantum mechanical model, we show how to define observable thermodynamical quantities which allow the derivation of a first and second law of thermodynamics.

A discrete energy space induced fermion parity breaking fixed point of the Kondo model

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One of the most striking features of quantum mechanics is the non-locality of entanglement. Taking this concept to its ultimate limit every particle should be able to explore the complete universe, even currently unknown parts of the universe possibly containing new physics. At least we can not rule out such an entanglement. In return we should treat every particle as a particle in a box, namely the universe, which leads us to the conclusion, that there is a discrete space–time at very low energies. Such an hypothesis opens the possibility for rather unconventional, speculative scenarios.

Here we combine the well established Kondo problem with the more speculative field of a discrete space time. We show that a discrete energy space induces a flow towards a new fix point by breaking the conservation of charge and spin and lifting the fermion parity. This parity lifting fixed point appears on a scale set by the discretization of energy space. In contrast to the Planck scale the associated energy scale is at very low energy scales, possibly given by the inverse size of the universe. We note that we one can not provide a term in a the Hamiltonian of a typical lattice model that breaks the fermion parity as it would consist of products of odd numbers of annihilation and creation operators.

Avalanche of entanglement and correlations at quantum phase transitions

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We study the ground-state entanglement in the quantum Ising model with nearest neighbor ferromagnetic coupling J and find a sequential increase of entanglement depth with growing J. This entanglement avalanche starts with two-point entanglement, as measured by the concurrence, and continues via the three-tangle and four-tangle, until finally, deep in the ferromagnetic phase arriving at a pure L-partite (GHZ type) entanglement of all L spins. Comparison with the two, three, and four-point correlations reveals a similar sequence and shows strong ties to the above entanglement measures for small J. However, we also find a partial inversion of the hierarchy, where the four-point correlation exceeds the three- and two-point correlations, well before the critical point is reached. Qualitatively similar behavior is also found for the Bose-Hubbard model, suggesting that this is a general feature of a quantum phase transition. This should be taken into account in the approximations starting from a mean-field limit.

Model of horizontal gene transfer, and another power law mystery

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Bacteria develop resistance to antibiotics either because of mutation (including the existing presence of a mutant, resistant strain in the population) or through a process known as horizontal gene transfer (HGT). There is a model of evolution and ecology known as the Tangled Nature model (TNM) that reproduces many natural features of both evolution and ecology and allows mutation. It is due to H. J. Jensen and collaborators. I have extended the model to describe the promiscuous process of HGT in which bacteria simply incorporate entire chunks of genome either from other bacteria or from the environment. I plan to review the TNM, the extensions for HGT and some results.

As far as I know there are no known – yet – clinical applications.

There is also a mysterious power law that shows up. The modified TNM was allowed to run and statistics gathered in which genomes survived under the rules for TNM, namely the demand for compatibility during a long metastable period. It was found that the resulting genome distribution varied widely, so widely that it gave indications that it did not have a second moment, i.e., it was Levy distributed.

Two questions immediately come to mind: Does this occur in nature or is it only a property of the TNM? and why does it occur in the first place?

Quantum entropy

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The entropy concept is both a useful engineering tool and a philosopher's lodestone. We will review the way that Planck was led to the quantum of action by studying the entropy of thermal light and Einstein was led to the photon concept following Planck's studies. A century later we are still fascinated by (quantum) thermodynamics; For example, the quantum heat engine [1] and the entropy of laser light [2,3] will be discussed. Application of these ideas to a Bose condensate (a.k.a. atom laser) [4] will also be presented.

[1] Scovil Schulz-DuBois, PRL, 1955: "The Maser as a Heat Engine"
[2] M. Scully and W. Lamb, PRL, 1965: "The Quantum Theory of the Laser"
[3] M. Scully, T.B.P.: "The Entropy of Laser Light"
[4] M. Scully, PRL, 1999: "The Quantum Theory of a Bose Condensate"

Current-driven phenomena in surface nanoscience

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Resonance conductance, ubiquitous in molecular hetero-junctions and in STM surface experiments, is often inelastic; in the course of the tunneling event, electron energy is channeled into vibrational modes and triggers molecular dynamics. The qualitative physics underlying current-driven, resonance-mediated dynamics in molecular electronics is simple and general. Equilibrium displacement between the initial and resonant states produces a nonstationary superposition in the nuclear subspace that evolves during the resonance lifetime. Upon electronic relaxation the system is internally excited and interesting dynamics is likely to ensue.

While the physics underlying resonant inelastic current is very general, the single-molecule STM and molecular hetero-junction environments open unique and fascinating opportunities. The former introduces the possibility of determining dynamical properties through the combination of observations with a quantum mechanical theory. The latter introduces the possibility of developing individually-driven molecular machines, and new means of manipulating the conductivity of molecular scale devices.

In the talk I will discuss the qualitative physics underlying current-driven surface phenomena, mention the theory we developed to explore these dynamics, and describe the results of recent and ongoing research, focusing on a series of surprising observations of STM-triggered phenomena on silicon and graphene surfaces. Before concluding, I will sketch several of our favorite dreams in these areas.

Current distributions and conductance oscillations in stripe Majorana junctions

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We address the physics of Majorana states in hybrid semiconductor-superconductor nanowires of 2D geometry. Specifically, we describe current and density distributions in stripe (2D planar) junctions between normal and Majorana nanowires having a finite (y) transverse length. In presence of a magnetic field with vertical and in-plane components, the y-symmetry of the charge current distribution in the normal lead changes strongly across the Majorana phase transition. Our analysis is based on the spin, quasi-particle and charge distributions of density and current. The Majorana mode causes opposite spin accumulations on the transverse sides of the junction and the emergence of a spin current.

The usual magnetoconductance oscillations of a 2D NS nanowire junctions in perpendicular magnetic fields are completely suppressed when the superconductor side enters a topological phase. This suppression can be explained by the modification of the vortex structure of local currents at the junction caused by the topological transition of the superconductor. In practice, the two regimes (with and without oscillations) could be seen with an L-shaped junction in a uniform magnetic field, properly choosing the nanowire width. We predict similar oscillations and suppression as a function of the Rashba coupling (as tuned by an external potential gate). The oscillation suppression is robust against potential biases and against lateral phase differences of the superconductor.

[1] J. Osca, L. Serra, "Topological suppression of magnetoconductance oscillations in NS junctions", arXiv:1701.03082.

[2] J. Osca, L. Serra, "Current distributions in stripe Majorana junctions", Eur. Phys. J. B 90, 28 (2017).

[3] J. Osca, L. Serra, "Majorana states and magnetic orbital motion in planar hybrid nanowires", Phys. Rev. B 91, 235417 (2015).

Experimental rectification of entropy production by a Maxwell's demon in a quantum system

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Maxwell's demon explores the role of information in physical processes. Employing information about microscopic degrees of freedom, this "intelligent observer" is capable of compensating entropy production (or extracting work), apparently challenging the second law of thermodynamics. In a modern standpoint, it is regarded as a feedback control mechanism and the limits of thermodynamics are recast incorporating information-to-energy conversion.

Theoretical endeavours to incorporate information into thermodynamics acquire a pragmatic applicability within the recent technological progress, where information just started to be manipulated at the micro- and nanoscale. A modern framework for these endeavours has been provided by explicitly taking into account the change, introduced in the statistical description of the system, due to the assessment of its microscopic information. This outlines an illuminating paradigm for Maxwell's demon, where the information-to-energy conversion is governed by fluctuation theorems, which hold for small systems arbitrarily far from equilibrium.

We derive a trade-off relation between information-theoretic quantities empowering the design of an efficient Maxwell's demon in a quantum system. Supported by this trade-off relation and employing Nuclear Magnetic Resonance (NMR) techniques. The demon is experimentally implemented as a spin-1/2 quantum memory that acquires information, and employs it to control the dynamics of another spin-1/2 system, through a natural interaction. Noise and imperfections in this protocol are investigated by the assessment of its effectiveness. This realisation provides experimental evidence that the irreversibility in a nonequilibrium dynamics can be mitigated by assessing microscopic information and applying a feed-forward strategy at the quantum scale [1,2].

[1] P. A. Camati, J. P. S. Peterson, T. B. Batalhao, K. Micadei, A. M. Souza, R. S. Sarthour, I. S. Oliveira, and R. M. Serra, Experimental Rectification of Entropy Production by Maxwell's Demon in a Quantum System, Phys. Rev. Lett. 117, 240502 (2016).

[2] J. Goold, Maxwell's Demon Meets Nonequilibrium Quantum Thermodynamics, Physics 9, 136 (2016).

Classical and quantum buckling transitions in cold ion crystals

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Crystals of repulsively interacting cold ions in planar traps form hexagonal lattices, which undergo a buckling instability towards a multi-layer structure as the transverse trap frequency is reduced. The buckled structure is composed of three planes, whose separation increases continuously from zero. In this work [1], we study the effects of thermal and quantum fluctuations by mapping this structural instability to the six-state clock model. A prominent implication of this mapping is that at finite temperature T, fluctuations split the buckling instability into two thermal transitions, accompanied by the appearance of an intermediate critical phase. This phase is characterized by quasi-long-range order in the spatial tripartite pattern. It is manifested by broadened Bragg peaks at new wave vectors, whose line-shape provides a direct measurement of the temperature dependent exponent $\eta(T)$ characteristic of the power-law correlations in the critical phase. A quantum phase transition is found at the largest value of the critical transverse frequency, where the critical intermediate phase shrinks to zero. Moreover, within the ordered phase, we predict a crossover from classical to quantum behavior, signifying the emergence of an additional characteristic scale for clock order. We discuss experimental realizations with trapped ions and polarized dipolar gases, and propose that within accessible technology, such experiments can provide a direct probe of the rich phase diagram of the quantum clock model, not easily observable in condensed matter analogues. This highlights the potential for ionic and dipolar systems to serve as simulators of complex models in statistical mechanics and quantum field theory.

[1] Daniel Podolsky, Efrat Shimshoni, Giovanna Morigi and Shmuel Fishman, Phys. Rev. X 6, 031025 (2016).

Emulating Majorana fermions and their braiding by Ising spin chains

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We analyse the control of Majorana zero-energy states by mapping the fermionic system to a chain of Ising spins. Although the topological protection is lost for the Ising chain, the properties of this system provide insight into the nature of the quantum states. By controlling the local magnetic field the Ising chain can be separated into topological and non-topological parts. Specifically we propose – for a strictly one-dimensional geometry – a (topologically non-protected) scheme, which allows performing the braiding operation. It also allows for more general rotations. The proposed setup relies on an extra spin-1/2 coupler included as part of the chain, such that it controls one of the Ising links. Depending on the quantum state of the coupler this link can be either ferromagnetic or antiferromagnetic. The coupler can be manipulated once the topological parts of the chain hosting the Majorana fermions are moved far away. Our scheme overcomes limitations which are a consequence of the 1D character of the Jordan-Wigner transformation. We also propose an experimental implementation of our scheme using a chain of ux qubits with a design providing the needed control fields.

Topological superconductivity and Majorana bound states in 2D superconductors

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In recent years, a renewed interest in arrays of magnetic impurities in superconductors was driven by their potential to host Majorana fermions. I will first present recent results for a single classical magnetic impurity embedded in a two dimension (2D) superconductor and show that the spatial extent of the Shiba bound state is actually long-ranged compared to what was observed in 3D superconductors [1]. I will then report on the direct observation of dispersive in-gap states surrounding magnetic Co domains sandwiched between a single atomic layer of Pb and the substrate Si(111). The observed continuous dispersion across the superconducting gap is interpreted in terms of a spatial topological transition accompanied by a chiral Majorana edge mode and residual gaped helical edge states. I will finally show how a spectroscopic analysis of the spin dependence of the impurity-induced bund states in 2D superconductors can be used to extract important information on the nature of the host such as its order parameter, its degree of anomalous triplet pairing [3] or the amplitude of the spin-orbit coupling [4].

[1] G. Ménard et al., Nature Physics 11, 1013 (2015)

[2] G. Ménard et al., arXiv:1607.06353

[3] V. Kaladzhyan, C. Bena, P. Simon, Phys. Rev. B 93, 214514 (2016); J. Phys.: Condens. Matter 28, 485701 (2016)

[4] V. Kaladzhyan, P. Simon, C. Bena, Phys. Rev. B 94, 134511 (2016)

Measurement and control of Coulomb-blockaded parafermion box

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Parafermionic zero modes [1-3] are a fractional generalization of the well-known Majorana zero modes [4-6]. Similarly to Majoranas, a system of parafermions is predicted to have topologically protected ground state degeneracy, yet with a more intricate algebra of operators than that of Majoranas. Once implemented experimentally, both detecting parafermions and performing quantum manipulations with them would constitute an important challenge. In this talk I will discuss how employing Coulomb blockade effects in such a system allows one to design protocols for measurement and certain manipulations of the state of parafermions [7]. With these protocols, it is possible to confirm such crucial properties of the system as the dimension of the ground state subspace, degeneracy of the subspace, and the algebra of parafermionic operators.

[1] J. Alicea and P. Fendley, Annu. Rev. Condens. Matter Phys. 7 (2016) 119.

[2] N.H. Lindner, E. Berg, G. Refael, and A. Stern, Phys. Rev. X 2 (2012) 041002.

[3] D.J. Clarke, J. Alicea, and K. Shtengel, Nature Commun. 4 (2013) 1348.

[4] J. Alicea, Rep. Prog. Phys. 75 (2012) 076501.

[5] M. Leijnse and K. Flensberg, Semicond. Sci. Techn. 27 (2012) 124003.

[6] C. Beenakker, Annu. Rev. Condens. Matter Phys. 4 (2013) 113.

[7] K. Snizhko, R. Egger, and Y. Gefen, arXiv:1704.03241 (2017).

Synthetic magnetic fields in cold atom systems

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Cold atoms can be made to experience synthetic magnetic fields through suitable ac driving. Some methods rely on the properties of the atom internal structure. Shaking is a particular type of driving that couples only to the atom center of mass. By modulating the location of lattice sites periodically in time, shaking provides a powerful method to create effective magnetic fields in engineered quantum systems such as cold gases trapped in optical lattices. However, such schemes are typically associated with space-dependent effective masses (tunneling amplitudes) and non-uniform flux patterns. We compute the effective Hamiltonians and quasienergy spectra associated with several kinds of lattice-shaking protocols. Comparison is made with the method of moving lattices. This study allows the identification of novel shaking schemes, which simultaneously provide uniform effective mass and magnetic flux, with direct implications for cold-atom experiments and photonics.

[1] C E Creffield, F Sols, Europhys. Lett. 101 (2013) 40001. C E Creffield, F Sols, Phys. Rev. A90 (2014) 023636. C E Creffield, G Pieplow, F Sols, N Goldman, New J. Phys. 18 (2016) 093013.

Relation between full NEGF, Non-Markovian and Markovian transport equations

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This contribution addresses the problem of a proper description of electron dynamics of small open quantum systems out of equilibrium from a finite time initial state over the transient period to the long time asymptotics.

The standard tool, Non-Equilibrium Green's Functions (NEGF), can well be simplified, under some conditions, to Non-Markovian Generalized Master Equations (GME) for single particle density. The conventional approximation for this purpose, based on the causal Generalized Kadanoff-Baym Ansatz (GKBA), has been fairly succesful in practice, but exact criteria for its validity are missing so far.

This problem may be attacked for a variant of the generic molecular island model, an Anderson impurity linked between two bulk metallic leads by tunneling junctions: our electrodes are ferromagnetic, so that transient currents are spin polarized and the tunneling functions have a complex spectral structure. The transient studied is a free relaxation of an initial state created by suddenly switching on of both junctions.

In the first step, explicit conditions are obtained for the use of GKBA, permitting to delimit the range for reducing NEGF to a GME. In the second step, an asymptotic approximation for the vertex corrections to GKBA is proposed. This leads to a renormalized GME with a substantially extended applicability range. Implications for further reduction to a Markovian Master Equation are indicated.

Finally, the relation of the GME description to possible non-equilibrium generalizations of the Fluctuation-Dissipation Theorem (NE FDT) is shown, extended beyond the present model within the NEGF formalism and physically interpreted in terms of a simplified kinetic theory of non equilibrium electrons in open quantum systems.

Nonmonotonic temperature dependence of diffusion in driven periodic systems

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The spreading of a cloud of independent Brownian particles typically proceeds more effectively at higher temperatures, as it derives from the commonly known Sutherland–Einstein relation for systems in thermal equilibrium. Here, we report on a non-equilibrium situation in which the diffusion of a periodically driven Brownian particle moving in a periodic potential decreases with increasing temperature within a finite temperature window [1,2]. As the mechanism for this counterintuitive diffusive behaviour we propose the temperature dependence of transitions between certain regions in the phase space dynamics of the particle. The presented analysis is based on extensive numerical simulations of the corresponding Langevin equation describing the studied setup as well as on a simplified stochastic model formulated in terms of a three-state Markovian process.

[1] J. Spiechowicz, P. Talkner, P. Hanggi and J. Luczka, Non-monotonic temperature dependence of chaos-assisted diffusion in driven periodic systems, New J. Phys. 18, 123029 (2016)

[2] J. Spiechowicz, M. Kostur and J. Luczka, Brownian ratchets: How stronger thermal noise can reduce diffusion, in press in Chaos (2017)

Mutual information: A key concept for irreversibility and mesoscopic thermodynamics

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Mutual information is a key concept in both classical and quantum information theory. In the context of thermodynamics, it can be used to quantify correlations between subsystems, directly characterizing the state of a composite system rather then statistics of specific observables. In many cases, the question whether information theoretic and thermodynamic entropies are identical can be rephrased as "Can mutual information be coaxed back into observables?" Here the limitations of the spin temperature hypothesis are a good illustration of a more general question.

The "mystery of entropy production" can be reconciled with reversible microscopic dynamics using the link between global entropies, constituent entropies and mutual information: Entropy growth in a subsystem is compatible with reversible micro-dynamics if it is accompanied by an equal growth in mutual information. If this mutual information cannot be recovered by suitable probes, a process is irreversible. One might say, irreversibility is observed precisely because Maxwell's demon does not exist. Following Maxwell's philosophy of "avoiding all personal inquiries of molecules" about their past, I construct a very general effective dynamics of subsystems which "forgets" mutual information after a characteristic memory timescale. The resulting equation shares some broad features with the Boltzmann equation, which can be seen as a specific short-time limiting case of this dynamics.

The mutual information approach to irreversibility and equilibration is justified even if only *one* of the subsystems is large (and, in some broad sense, mixing): "Past" mutual information is then irrelevant and can be discarded. Equilibrium states of a *small* system interacting with a larger, reservoir-type system are thus well defined without reference to the notion of an ensemble. However, in the case of a small system, the applicable memory timescale is typically finite, i.e., mutual information in the stationary state is non-negligible. Similar results are found in in open-system dynamics beyond the Born approximation, and for the probability measure of the Gibbs ensemble of a strongly interacting composite system. Finally, taking mutual information into account leads to a natural understanding *perceived* anomalies such as negative contributions to entropy and/or heat capacity by interacting subsystems or systems strongly coupled to a reservoir.

Thermoelectric properties of an interacting QD-based heat engine

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We study the thermoelectric properties and heat-to-work conversion performance of an interacting, multi-level quantum dot (QD) weakly coupled to the leads. We focus on the sequential tunneling regime. The dynamics of the charge in the dot is studied by means of master equation for the probabilities of occupation. From here we compute the charge and heat currents in the linear response regime. Assuming a generic multi-terminal setup, and for low temperatures (quantum limit), we obtain analytical expressions for the transport coefficients which account for the interplay between interactions (charging energy) and level quantization. In the case of systems with two and three terminals we derive formulae for the power factor Q and the figure of merit ZT for a QD-based heat engine, identifying optimal working conditions which maximize output power and efficiency of heat-to-work conversion. Beyond the linear response we concentrate on the two-terminal setup. We first study the thermoelectric non-linear coefficients assessing the consequences of large temperature and voltage biases, focusing on the breakdown of the Onsager reciprocal relation between thermopower and Peltier coefficient. We then investigate the conditions which optimize the performance of a heat engine, finding that in the quantum limit output power and efficiency at maximum power can almost be simultaneously maximized by choosing appropriate values of electrochemical potential and bias voltage. At last we study how energy level degeneracy can increase the output power.

Magneto-conductance and spin related shot noise properties of half-metallic molecular junctions

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When the size of magnetic conductors is confined to several angstroms, novel magneto-transport properties can emerge. Here, we take advantage of the structural flexibility of magnetically active molecules to show that half-metallicity can be achieved at the level of a single molecule. Specifically, we use the break junction technique to demonstrate the effect in molecular junctions based on a single magnetic molecule embedded between two non-magnetic electrodes. The studied junction reveals surprising magneto-conductance and shot noise properties that will be discussed.

Quantum coherence in the dynamics of biomolecular excitons - revisited

Hong-Guang Duan[1,2,3], Valentyn I. Prokhorenko[2], Richard Cogdell[4], Khuram Ashraf[4], Amy L. Stevens[2,3,5], Michael Thorwart[1,3], and R.J. Dwayne Miller[2,3,5]

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I will show how quantum coherence of biomolecular excitons is influenced by environmental noise stemming from polarization fluctuations of the solvent under ambient conditions and from the vibrational motion of the molecular backbone [1-4]. In particular, I will report recent theoretical and experimental results [5] on optical 2D photon echo spectra of the Fenna-Mathews-Olson complex at ambient temperature in aqueous solution. They do not provide evidence of any long-lived electronic nor strong vibronic quantum coherence, but confirm the orthodox view of rapidly decaying quantum coherence on a time scale of 60 fs under ambient conditions. Corresponding calculations at low temoerature yield a dephasing time of 120 fs at a temperature of 77 K. Our results can be considered as generic and give no hint that electronic quantum coherence plays any biofunctional role in real photoactive biomolecular complexes. Since this natural energy transfer complex is rather small and has a structurally well defined protein with the distances between bacteriochlorophylls being comparable to other light-harvesting complexes, we anticipate that this finding is general and directly applies to even larger photoactive biomolecular complexes.

[1] P. Nalbach, C. A. Mujica-Martinez, and M. Thorwart, Phys. Rev. E91 (2015), 022706.

[2] C. Mujica-Martinez, P. Nalbach, and M. Thorwart, Phys. Rev. E88 (2013), 062719.

[3] P. Nalbach, D. Braun, and M. Thorwart, Phys. Rev. E84 (2011), 041926.

[4] H.-G. Duan, P. Nalbach, V. I. Prokhorenko, S. Mukamel, and M. Thorwart, New J. Phys. 17 (2015), 072002 (FTC).

[5] Hong-Guang Duan, Valentyn I. Prokhorenko, Richard Cogdell, Khuram Ashraf, Amy L. Stevens, Michael Thorwart, and R. J. Dwayne Miller, Nature does not rely on long-lived electronic quantum coherence for photosynthetic energy transfer, submitted (2016), arXiv:1610.08425

Simulation of quantum transport in molecular junctions using multiconfiguration wavefunction and reduced density matrix methods

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Nonequilibrium electron transport in molecular junctions often involves correlation effects due to electron-electron or electron-vibrational interaction. In this talk, methods are discussed, which allow an accurate description of correlated electron transport, including the hierarchical master equation approach [1] and the multilayer multiconfiguration time-dependent Hartree (ML-MCTDH) method [2]. Moreover, the combination of the ML-MCTDH method with reduced density matrix theory is outlined [3]. The performance of the methods is discussed based on models for vibrationally coupled electron transport in molecular junctions, including both time-dependent and steady-state transport.

[1] C. Schinabeck, A. Erpenbeck, R. Härtle, M. Thoss, Phys. Rev. B 94, 201407(R) (2016).

[2] H. Wang and M. Thoss, J. Chem. Phys. 131, 024114 (2009); 138, 134704 (2013); 145, 164105 (2016).

[3] E. Wilner, H. Wang, G. Cohen, M. Thoss, E. Rabani, Phys. Rev. B 88, 045137 (2013); 92, 195143 (2015).

Full-counting statistics of information content

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We consider a bipartite quantum conductor and discuss the joint probability distribution of particle number in a subsystem and the self-information associated to the reduced density matrix of the subsystem [1]. By extending the multi-contour Keldysh Green function technique [2], we calculate the Rényi entropy of a positive integer order M subjected to the particle number constraint, from which we derive the joint probability distribution. For energy independent transmission, the time dependence of the accessible entanglement entropy, or the conditional entropy, is derived. The properties of the joint probability for energy dependent transmission probability at the steady state are analyzed around the coherent resonant tunneling and the incoherent sequential tunneling conditions. We discuss the distribution of the efficiency, which measures the information content transfered by a single election.

[1] Y. Utsumi: "Full-counting statistics of information content in the presence of Coulomb interaction" Phys. Rev. B 92, 165312 (2015);"Full counting statistics of information content and particle number" arXiv:1704.02679

[2] Yu. V. Nazarov, Phys. Rev. B 84, 205437 (2011); M. H. Ansari and Yu. V. Nazarov, Phys. Rev. B 91, 104303 (2015); Phys. Rev. B 91, 174307 (2015); ZhETF 149, 453 (2016)

Physical signatures of the quantum nature of time

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I recently introduced [1,2] a new sum-over-paths formalism that accounts for the quantum nature of time. It treats time and space on the same footing at a fundamental level. The representation of the state of an object is given in terms of virtual quantum paths for which translations in time are generated by the Hamiltonian, and translations in space by the momentum operator. If the Hamiltonian respects time reversal symmetry then an object can be localised in both time and space. In this case there is no time evolution and no conservation laws. However, if the Hamiltonian violates time reversal symmetry (T violation), the same construction exhibits destructive interference in the paths over time, which results in time evolution that obeys conservation laws. The formalism is then analogous to the 5 dimensional "proper time" formalism introduced by Feynman [3] and extended by Nambu [4] in the 1950's and explored more recently as "parametrized relativistic quantum theories" [5].

The important point is that time evolution and conservation laws are not built into the formalism but rather they emerge *phenomenologically* from T violation. The formalism, therefore, potentially offers an explanation of the origin of dynamics and also new insight into the problem of the arrow of time.

Work has now progressed to checking for physical signatures of the new formalism. Local variations in T violation are found to induce corresponding variations in local clock time and this manifests as a quantum version of relativistic time dilation. Nuclear reactors provide sources of local variation in T violation and the prospect for detecting a predicted quantum time dilation in their vicinity will be discussed.

[1] J.A. Vaccaro, Quantum asymmetry between time and space, *Proc. R. Soc. A* **472** (2016) 20150670 http://bit.ly/QuantumTime

[2] J.A. Vaccaro, An anomaly in space and time and the origin of dynamics in *Space, Time and the Limits of Human Understanding* edited by S. Wuppuluri and G. Ghirardi (Springer International, 2016), 185-201 http://bit.ly/SpaceTimeAnomaly

[3] R. P. Feynman, Mathematical Formulation of the Quantum Theory of Electromagnetic Interaction, *Phys. Rev.* **80**, 440-457 (1950), Appendix A. http://dx.doi.org/10.1103/PhysRev.80.440

[4] Y. Nambu, The Use of the Proper Time in Quantum Electrodynamics I, *Prog. Theor. Phys.* **5**, 82 (1950). http://dx.doi.org/10.1143/ptp/5.1.82

[5] J. R. Fanchi, Review of invariant time formulations of relativistic quantum theories, *Found. Phys.* **23**, 487-548 (1993). http://dx.doi.org/10.1007/BF01883726

Probing the electronic coupling between atomically thin layers in van der Waals systems

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Many layered materials can be mechanically exfoliated, down to atomically thin sheets. This opens the possibility to stack different layers together to form systems with novel properties: the so-called van der Waals (vdW) materials. To create materials with custom-designed properties in the future, understanding the quantum overlap between the different layers is key. Here, we investigate interlayer interactions using a novel technique, focusing on graphene and hexagonal boron nitride (hBN).

Experimentally, the occupied bands can be routinely measured by ARPES (angle-resolved photo-emission spectroscopy). However, it has been remarkably difficult to characterize the (dispersion of the) empty part of the band structure. We have developed a method to do just that, based on low-energy electron microscopy (LEEM) [1]. The technique, coined angle-resolved reflected-electron spectroscopy (ARRES), relies on the dependence of the reflectivity of low-energy electrons on both their kinetic energy and their incident angle on the sample. It has a high cross-section and a spatial resolution of $\sim$10 nm, which is five orders of magnitude better than other techniques. The latter allows us to scrutinize even small flakes of vdW materials. Applying ARRES to flakes of few-layer graphene and hBN separately, we find quantization of the conduction band into well-defined interlayer states for both systems. These interlayer states have a similar dispersion and very similar energies for the two materials. Nevertheless, in a stack of graphene on hBN, we observe no coupling of the electronic systems of the two materials despite their intimate contact. This substantiates that hBN is an excellent substrate to isolate graphene from its environment over a wide energy range [2].

The possibility to perform both ARRES and local ARPES (angle-resolved photo-emission spectroscopy) will give us the opportunity to investigate band structure formation in a large range of vdW systems in the near future. Knowledge on this is crucial to tailor the properties of van der Waals crystals, stacked in a LEGO-like fashion.

[1] J. Jobst, et al., Nature Communications 6, 8926 (2015)

[2] J. Jobst, et al., Nature Communications 7, 13621 (2016)

High current-bias effects in atomic and molecular junctions

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Single-atom and single-molecule junctions survive surprisingly high currents. This fact is understood as being due to the ballistic character of the electron transport. The major part of the dissipation of energy takes place inside the leads, at a large distance from the junction. This permits the study of atomic and molecular wires under extreme non-equilibrium conditions. Under such conditions the fundamental processes of electron-electron and electron-ion scattering can be revealed and studied. For this study we employ break junction techniques and scanning tunneling microscopy. One of the tools revealing the statistics of electron scattering effects is the measurement of shot noise. We have extended the range of shot noise spectroscopy up to 10 MHz, which opens a new window on the scattering phenomena. By low-temperature STM experiments we can reveal single-ion diffusion and migration induced by the high current bias.

Green's function and (TD)DFT descriptions of lattice models out of equilibrium

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We use non-equilibrium Green's functions (NEGF) and time-dependent density-functional theory (TDDFT) to describe correlated lattice model systems out of equilibrium. Specifically, we consider charge transport in short wires and time-resolved dynamics at surfaces. The scope of perturbative treatments of correlations within NEGF and adiabatic approximations in TDDFT will be assessed, and possibilities offered by a hybrid TDDFT-NEGF scheme explored. Results from ongoing work will be presented.

Fate of the amplitude (Higgs) mode at a disordered quantum phase transition

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We investigate the amplitude (Higgs) mode of a diluted quantum rotor model in two dimensions close to the superfluid-Mott glass quantum phase transition. After mapping the Hamiltonian onto a classical (2+1)d XY model, the scalar susceptibility is calculated in imaginary time by means of large-scale Monte Carlo simulations. Analytic continuation of the imaginary time data is performed via maximum entropy methods and yields the real-frequency spectral function. The spectral peak associated with the Higgs mode is identified and its fate upon approaching the disordered quantum phase transition is determined.

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Violation of Onsager's theorem in approximate master equation approaches

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Onsager's theorem is an exact relation connecting the thermal and electrical transport within linear response. Its fulfillment is a strong test for the applicability of transport theories. Here we consider commonly used perturbative approaches, such as the Redfield and second-order von Neumann master equations, for thermoelectric transport through nanostructures. Studying a double quantum dot, which requires coherences between states for a correct description, we find that these perturbative approaches can provide results violating Onsager's theorem. We show that the deviations from the theorem scale with the lead-coupling strength in an order beyond the one considered systematically in the respective approach. Such comparisons provide a new way to study the reliability of perturbative approaches.[1]

[1] K. M. Seja et al, Phys. Rev. B 94 (2016) 165435.

What is quantum Markovianity?

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Markovianity versus non-Markovianity is a well-established distinction for classical systems. The same cannot be said for quantum systems. Different communities and individuals use "quantum Markovianity" to mean very different things. We argue that, to avoid confusion, it is best to avoid attributing that term any definite meaning at this stage. However, that does not mean that there is nothing to say about Markovianity for open quantum systens. We discuss a large number of concepts that have been, or could logically be, used to define quantum (non-)Markovianity, and prove hierarchical relations between them. Some are existing concepts, including "factorisation", "quantum regression formula", "divisibility", and "Lindblad". Others we introduce, including "past-future independence", and "composability". We also prove relations between these and other properties of interest for open quantum systems, such as the applicability of dynamical decoupling to preserve quantum information, the existence of (quantum) information backflow from the environment, and the physical reality of stochastic pure-state trajectories. Finally, we discuss in which concept the closest analogue of classical Markovianity lies.

The Boltzmann distribution and the quantum-classical correspondence

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Consider a one-dimensional quantum particle in a box, in thermal equilibrium with a large environment. Even for moderate temperatures, one finds that the probability distribution of the particle's position is remarkably uniform over most of the length of the box. This distribution function is a weighted average of the squares of the energy eigenfunctions, the weights being given by the Boltzmann distribution. In this talk, we begin by asking whether one can *deduce* the Boltzmann weights for this system – this would include deducing the energy eigenvalues – by insisting that the position distribution function be very flat. Numerical and analytic evidence suggests that the answer is yes. We then ask to what extent this observation might generalize to other physical systems.

Andreev levels as a quantum dissipative environment for superconducting nanojunctions

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Making use of the effective action theory [1,2] we demonstrate that at subgap energies quantum behaviour of highly transparent superconducting hybrid nanojunctions can be exactly described by an effective Hamiltonian for a Josephson particle in a quantum dissipative environment formed by a collection of harmonic oscillators with parameters directly related to those of subgap Andreev levels inside the junction. We investigate the problem of macroscopic quantum tunneling of the superconducting phase in such hybrid structures, evaluate both quantum and thermally activated supercurrent decay rates and identify the crossover conditions between these regimes. We also predict the possibility for non-monotonous dependence of the switching current distributions on temperature and elucidate the physics behind this non-trivial effect. In addition, we demonstrate that superconducting qubits fabricated with such highly transparent hybrid nanojunctions may be subjected to intrinsic dephasing caused by an effective dissipative environment formed by Andreev levels.

[1] A.V. Galaktionov and A.D. Zaikin. Phys. Rev. B 82, 184520 (2010).

[2] A.V. Galaktionov and A.D. Zaikin. Phys. Rev. B 92, 214511 (2015).

A semi-semiclassical approach to quantum quenches

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Recent years have witnessed an ever increasing interest in the out of equilibrium dynamics of quantum systems. The experimental techniques are developing rapidly and the present experiments call for the development of new analytical and numerical methods that are able to describe non-equilibrium dynamics in closed quantum systems. To give an example, interference experiments with low dimensional cold atomic condensates can be described in principle within a field theoretical framework. However, analytic or numerical methods for studying the dynamics of continuum systems are not in abundance.

We present a hybrid semiclassical method – that we dub semi-semiclassical – which combines a semiclassical description of quasiparticle propagation with a complete quantum-mechanical description of the internal degrees of freedom using a Time Evolving Block Decimation scheme. Our method is capable of describing the non-equilibrium dynamics of one-dimensional lattice and continuum systems up to time scales at which local thermalization occurs. It has all benefits of an intuitive semiclassical picture for the orbital degrees of freedom, while handling internal degrees of freedom completely quantum mechanically allows us to observe phenomena such as entanglement entropy production or phase diffusion.

As a proof of principle, we apply the method to the quench dynamics of a pair of tunnel coupled one dimensional Bose condensates described by the sine—Gordon model and currently studied in matter wave interference experiments. In the so-called universal limit, we are able to determine the complete time dependence of correlation functions analytically. Treating the collisions of quasiparticles quantum-mechanically and going beyond this universal limit by means of our semi-semiclassical method, we demonstrate the emergence of soliton-collision induced phase diffusion, soliton-entropy production and multistep thermalization. Our method can be applied to almost any gapped one-dimensional system, and can also be used to describe the dynamical properties and the formation of non-equilibrium steady states.

General non-Markovian dynamics in open quantum systems

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The foundations of statistical mechanics are based on two fundamental yet unsolved problems: (i) how does macroscopic irreversibility emerge from microscopic reversibility? (ii) how does the system relax in general to thermal equilibrium with its environment? The answers to these questions rely on a deep understanding of the dynamics of systems interacting with their environments. Recent results on environment-induced quantum decoherence [1-4] enable us to address these problems. Decoherence is also a main concern in developing quantum information technology. The current understanding of decoherence dynamics has provided answers to several fundamental issues, such as quantum measurement and the quantum-to-classical transition. In the past two decades, many theoretical and experimental investigations were devoted to this topic, most of these taking the memory-less (Markov) limit. However, experimental implementations of nanoscale solid-state quantum information processing makes strong non-Markovian memory effects unavoidable, thus rendering their study a pressing and vital issue. By exploring non-Markovian processes, we find that decoherence manifests unexpected complexities. Indeed, an arbitrary given initial quantum state, under the influence of different reservoirs, can evolve into four different steady states: thermal, thermal-like, qumemory (= quantum memory) and oscillating qumemory. The first two de facto provided a rigorous proof how the system relaxes in general to thermal equilibrium with its environment. The latter two steady states, with strong non-Markovian effects, will maintain the initial state information and not reach thermal equilibrium, which is beyond the conventional wisdom of statistical mechanics. Applications to various nanostructures and micro- and nano-photonic systems are demonstrated [5-8].

[1] W. M. Zhang, P. Y. Lo, H. N. Xiong, M. W. Y. Tu and F. Nori, Phys. Rev. Lett. 109, 170402 (2012).

[2] M. W. Y. Tu and W. M. Zhang, Phys. Rev. B 78, 235311 (2008).

[3] J. S. Jin, M. W. Y. Tu, W. M. Zhang, and Y. J. Yan, New. J. Phys. 12, 083013 (2010).

[4] P. Y. Yang and W. M. Zhang, Front. Phys. 12, 127204 (2017).

[5] M. W. Y. Tu, A. Aharony, W. M. Zhang, and O. Entin-Wohlman, Phys. Rev. B 90, 165422 (2014).

[6] H. N. Xiong, P. Y. Lo, W. M. Zhang, D. H. Feng and F. Nori, Sci. Rep. 5, 13353 (2015).

[7] Y. C. Lin, P. Y. Yang and W. M. Zhang, Sci. Rep. 6, 34804 (2016).

[8] Md. M. Ali and W. M. Zhang, Phys. Rev. A 95, 033830 (2017).

Invited Posters

Non-linear charge and energy dynamics of an adiabatically driven interacting quantum dot

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We formulate a general theory to study the time-dependent charge and energy transport of an adiabatically driven interacting quantum dot in contact to a reservoir for arbitrary amplitudes of the driving potential. We study within this framework the Anderson impurity model with a local ac gate voltage. We show that the exact adiabatic quantum dynamics of this system is fully determined by the behavior of the charge susceptibility of the frozen problem. At zero temperature, we evaluate the dynamic response functions with the numerical renormalization group (NRG). The time-resolved heat production exhibits a pronounced feature described by an instantaneous Joule law characterized by an universal Büttiker resistance quantum for each spin channel. We show that this law holds in non-interacting as well as in the interacting system and also when the system is spin-polarized. In addition, in the presence of a static magnetic field, the interplay between many-body interactions and spin polarization leads to a non-trivial energy exchange between electrons with different spin components. [1]

[1] Physical Review B 2017, arXiv: 1610.00308

I2

Quantum statistical forces via reservoir engineering

Shanon Vuglar[1], Dmitry Zhdanov[2], Renan Cabrera[1], Tamar Seideman[2], Christopher Jarzynski[3], Herschel Rabitz[1], and Denys Bondar[1]

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We show that, as in classical statistical physics, the effect of a dissipative environment on a quantum probe can be described by a quantum statistical force. Using Operational Dynamic Modeling, an environment is designed to exert a desired quantum statistical force on a quantum probe. In particular, we simulate an environment tailored to enhance quantum tunneling. We also provide a possible experimental implementation for this environment. These findings highlight the flexibility offered by non-equilibrium open quantum dynamics.

Noisy grin of the Cheshire Cat

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Even the subtle and apparently strange quantum effects can sometimes survive otherwise lethal influence of an omnipresent decoherence. We show that an archetypal quantum Cheshire Cat – a paradox of a separation between a position of a quantum particle, a photon, and its internal property, the polarization, in a two–path Mach–Zehnder setting – is robust to decoherence caused by a bosonic infinite bath locally coupled to the polarization of a photon. Decoherence affects either the cat or its grin depending which among the two paths is noisy. For a pure decoherence, in an absence of photon–environment energy exchange, we provide exact results for weak values of the photon position and polarization indicating that the information loss affects the quantum Cheshire Cat only qualitatively and the paradox survives. We show that it is also the case beyond the pure decoherence for a small rate of dissipation.

I4

Multipartite entanglement in Davies environment

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We analyse dynamics of genuinely multipartite entanglement of N–qubit states initially prepared in the form of X–matrices with one qubit coupled to a thermal environment modelled via rigorous Davies theory. We develop an analytical formulas for genuinely multipartite entanglement in terms of the concurrence of the investigated states as a function of time. We analyse the time evolution of entanglement both in a presence and in an absence of energy exchange between the system and its environment.

Interconversion between light and sound in tunable optomechanical Dirac materials

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Analyzing the scattering and conversion process between photons and phonons coupled via radiation pressure in a circular quantum dot region on a honeycomb array of optomechanical cells, we demonstrate the emergence of optomechanical Dirac physics. Specifically we prove the formation of polaritonic quasi bound states inside the dot, and angle-dependent Klein tunneling of light and emission of sound, depending on the energy of the incident photon, the photon-phonon interaction strength, and the radius of the dot. We furthermore demonstrate that forward scattering of light or sound can almost switched off by an optically tuned Fano resonance; thereby the system may act as an optomechanical switch or translator in a future photon-phonon based circuitry.

I6

Dynamical phase transitions in a Tonks-Girardeau gas

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We investigate the dynamics of the rate function and of local observables after a quench in models which exhibit phase transitions between a superfluid and an insulator in their ground states. Zeros of the return probability, corresponding to singularities of the rate functions, have been suggested to indicate the emergence of dynamical criticality [1] and we address the question of whether such zeros can be tied to the dynamics of physically relevant observables and hence order parameters in the systems. For this we first numerically analyse the dynamics of a hard-core boson gas in a one-dimensional waveguide when a quenched lattice potential is commensurate with the particle density [2]. Such a system can undergo a pinning transition to an insulating state and we find non-analytic behaviour in the evolution of the rate function which is indicative of dynamical phase transitions. In addition, we perform simulations of the time dependence of the momentum distribution and compare the periodicity of this collapse and revival cycle to that of the non-analyticities in the rate function: the two are found to be closely related only for deep quenches. We then confirm this observation by analytic calculations on a closely related discrete model of hard-core bosons in the presence of a staggered potential and find expressions for the rate function for the quenches. By extraction of the zeros of the Loschmidt amplitude we uncover a non-equilibrium timescale for the emergence of non-analyticities and discuss its relationship with the dynamics of the experimentally relevant parity operator.

[1] M. Heyl, A. Polkovnikov and S. Kehrein, Phys. Rev. Lett. 110, 135704 (2013)
[2] K. Lelas, T. Seva, H. Buljan and J. Goold, Phys. Rev. A 86, 033620 (2012)

Simultaneous measurement of noncommuting observables with quasi-minimal uncertainty

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We introduce the concept of macroscopic quantum measurement, that is, a quantum formalism describing the measurements we perform continuously in our everyday life; for example, when looking at a magnet. We idealize the problem by considering parallel spins whose direction has to be estimated. We present a physical measurement model weak enough to almost not disturb the quantum state, but strong enough to provide almost the maximal amount of information in a single shot. Interestingly an intermediate coupling strength between spin system and measurement apparatus achieves better results than a strong coupling.

I8

Ultraviolet (250–550 nm) absorption spectrum of pure water

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While the visible and infrared absorption spectrum of pure liquid water has been relatively well established (λ>400 nm), agreement on the absorption spectrum of water in the ultraviolet, as well as in portions of the blue, has yet to be achieved. The ultraviolet spectrum of water is impacted by many factors, such as organic content and dissolved oxygen, which are independent of the intrinsic optical properties of pure water. The most commonly accepted studies of the UV properties of pure water focused on the spectral region 180 nm to 320 nm. In these studies, the attenuation (i.e. scattering plus absorption) was measured. The absorption was then calculated by subtracting the molecular scattering (Rayleigh scattering) from the measured attenuation. The studies by Kröckel and Schmidt and by Quickenden and Irvin used the same differential attenuation experimental design. While the measured attenuation was nearly identical in both their studies, the scattering contributions used by Kröckel and Schmidt varied from the scattering contributions used by Quickenden and Irvin; they varied from a factor of 2.2 lower at 190 nm to 2.6 lower at 320 nm. The consequence was that the resulting absorption coefficients were quite different for the two studies. This is one example demonstrating the need for a scattering independent measurement.

New measurements of pure water absorption that are scattering independent were made using an improved integrating cavity absorption meter (ICAM) that is based on our new quartz powder diffuse reflector; the latter maintains a high reflectivity down to a wavelength of 250 nm. The present study combined a state-of-the-art water purification system capable of producing semiconductor-grade water with this improved ICAM.

Nonexponential tunneling decay of ultracold atoms

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By using an exact analytical approach to the time evolution of decay we investigate the tunneling decay of ultracold single atoms to discuss the conditions for deviations of the exponential decay law. We find that R, given by the ratio of the energy of the decaying fragment to its corresponding width, is the relevant quantity in this study. The appropriate values of R may be obtained by a suitable design of the potential parameters and suggest that for values of R close to unity the experimental verification of nonexponential decay might be possible.

[1] Gastón García-Calderón and Roberto Romo, Phys. Rev. A 93, 022118 (2016).

I10

Fermion dynamical symmetries for collective states in graphene in a strong magnetic field

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A formalism is presented for treating strongly-correlated graphene quantum Hall states in terms of an SO(8) fermion dynamical symmetry that is isomorphic to an SO(8) algebra that has found broad application in nuclear physics, and exhibits a strong formal similarity to SU(4) symmetries that describe high-temperature superconductors. The well-known SU(4) symmetry of quantum Hall ferromagnetism for graphene is recovered as one subgroup of SO(8) but the dynamical symmetry structure associated with the full set of SO(8) subgroup chains allows analytical many-body solutions for a rich set of collective states exhibiting spontaneously-broken symmetry that may be important for the low-energy physics of graphene in strong magnetic fields. The SO(8) symmetry permits a natural definition of generalized coherent states that correspond to symmetry-constrained Hartree–Fock–Bogoliubov solutions exhibiting the interplay between competing spontaneously broken symmetries in determining the ground state.

Fluctuations in dissipative quantum phase transitions at finite size

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Traditionally, quantum phase transitions in driven optical systems are characterized by a sharp increase in photon number when some control parameter is changed, as exemplified by the laser and parametric oscillator thresholds [1], and the so-called spontaneous dressed state polarization [2]. Attention is increasingly drawn, however, to the strong-coupling regime [3], where changes at the one-photon level induce nonlinear effects; thus, behavior reminiscent of phase transitions is encountered with just a few photons present – i.e., at small system size. This departure from the thermodynamic limit is accompanied by smoothed out thresholds [4,5], where, in the absence of sharp discontinuities, a new way of characterizing transitions must be sought. In this work, we characterize the phases of two strongly coupled non-linear oscillators, where both oscillators are coherently driven and damped through their interaction with an external environment. The coupled system is shown to present three phases. Two of these phases exhibit high correlation between the cavities and are differentiated by their photon statistics. The third phase is characterized by a field localized in just one of the cavities. In order to characterize these phases, we begin from a mean-field treatment where the effects of fluctuations are neglected and a corresponding thermodynamic (large photon number) limit may be defined [6]. Steady-state solutions are found, and the steady-state photon-number imbalance and total photon number are used to define the phases of the system. The mean-field approach is then complemented by a quantum mechanical treatment, where the density matrix evolves under a Lindblad-type master equation. Departures from mean-field results are discussed, and a new way to characterize its different phases, through changes in the fluctuations, is proposed. A comparison between weak and strong coupling regimes is presented, which allows us to revisit the idea of a thermodynamic limit for dissipative quantum phase transitions of photons. The crucial role of quantum fluctuations is emphasized and quantified.

[1] H. J. Carmichael, Statistical Methods in Quantum Optics 1&2, Springer-Verlag, Berlin, Heidelberg, 1999 & 2008

[2] P. Alsing and H. J. Carmichael, Quantum Opt. 3, 13 (1991)

[3] M. Mabuchi and A. C. Doherty, Science 298, 1372 (2002)

[4] P. R. Rice and H. J. Carmichael, Phys. Rev. A 50, 4318 (1994)

[5] F. Dubin, C. Russo, H. G. Barros, A. Stute, C. Becher, P. O. Schmidt, and R. Blatt, Nature Physics 6, 350 (2010)

[6] H. J. Carmichael, Phys. Rev. X 5, 031028 (2015)

I12

Emergence of quantum mechanics from random field theory

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The scientific methodology based on two descriptive levels, ontic (reality as it is) and epistemic (observational), is briefly presented. Following Schrödinger, we point to the possible gap between these two descriptions. Our main aim is to show that, although ontic entities may be unaccessible for observations, they can be useful for clarification of the physical nature of operational epistemic entities. We illustrate this thesis by the concrete example: starting with the concrete ontic model preceding quantum mechanics (the latter is treated as an epistemic model), namely, prequantum classical statistical field theory (PCSFT) [1,2], we propose the natural physical interpretation for the basic quantum mechanical entity - the quantum state ("wave function"). The correspondence PCSFT to QM is not straightforward, it couples the covariance operators of classical (prequantum) random fields with the quantum density operators. We use this correspondence to clarify the physical meaning of the pure quantum state and the superposition principle - by using the formalism of classical field correlations.

[1] A. Khrennikov, Progress Theor. Phys. 128 (2012) 31.

[2] A. Khrennikov, Beyond Quantum. Pan Stanford Publ., Singapore, 2014.

Microwave bolometer with an ultralow noise equivalent power

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Microwave and terahertz nanobolometers can be used as ultrasensitive power meters in applications such as spectral mapping of extraterrestial low-energy electromagnetic radiation [1]. Bolometers are characterized by a quantity referred to as noise equivalent power (NEP), i.e., the noise spectral density in the bolometer readout with respect to the input power.

Intense development of nanobolometers has taken place for well more than a decade with the aim to reach NEP $= 10^{-20}$ W/$\sqrt{\mathrm{Hz}}$ which is required, for example, in efficient measurements of the terahertz spectrum in space [1]. Furthermore, bolometric observation of single photons at increasingly long wavelengths is a long-standing goal with the previous energy resolution falling above 10 zJ [2]. A single-photon microwave detector [3] has a multitude of applications in the emerging field of quantum technology. For example, it may enable wireless quantum-enhanced cryptography protocols.

We present a microwave nanobolometer based on superconductor–normal-metal–superconductor (SNS) Josephson junctions. Using positive electrothermal feedback, we show that we can achieve a single-shot detection fidelity of 0.56 for 1.1-zJ pulses of 8.4-GHz photons [4]. This is more than an order of magnitude improvement over the previous thermal detectors. Importantly, we observe that we can reach NEP $= 2 \times 10^{-20}$ W/$\sqrt{\mathrm{Hz}}$ with our detector in the linear mode. In the future, ultrasensitive bolometers and thermometers [5] are expected to play an important role also in quantum information processing and thermodynamics.

[1] B. S. Karasik, A. V. Sergeev, and D. E. Prober, IEEE Trans. Terahertz Sci. Technol. 1, 97 (2011).

[2] B. S. Karasik et al., Appl. Phys. Lett. 101, 052601 (2012).

[3] K. Inomata et al., Nat. Comm. 7, 12303 (2016).

[4] J. Govenius, R. E. Lake, K. Y. Tan, and M. Möttönen, Phys. Rev. Lett. 117, 030802 (2016).

[5] S. Gasparinetti et al., Phys. Rev. Appl. 3, 014007 (2015).

I14

On a test of optimality for decision making

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Engineered devices, living organisms, and humans have often to make reliable decision based on a continuous stream of scattered data. The task at hand is often to make a binary decision in a finite time. Is it possible to assess in how far these systems make optimal decisions? Here we provide a test for optimality of general black-box decision-making devices. Our test is based on the output of the decision device, and requires no knowledge about the inner workings of the decision device or the stream of input data. Our test has formal similarities with the first-passage time fluctuation theorems derived in the context of statistical physics [1]. We illustrate our test for optimality of decision making devices on some numerical examples.

[1] Izaak Neri, Édgar Roldán, and Frank Jülicher, Phys. Rev. X 7 (2017) 011019

Simultaneous measurement of two non-commuting quantum variables: Solution of a dynamical model

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The possibility of performing simultaneous measurements in quantum mechanics is investigated in the context of the Curie-Weiss model for a projective measurement. Concretely, we consider a spin–1/2 system simultaneously interacting with two magnets, which act as measuring apparatuses of two different spin components. We work out the dynamics of this process and determine the final state of the measuring apparatuses, from which we can find the probabilities of the four possible outcomes of the measurements. The measurement is found to be non-ideal, as (i) the joint statistics do not coincide with the one obtained by separately measuring each spin component, and (ii) the density matrix of the spin does not collapse in either of the measured observables. However, we give an operational interpretation of the process as a generalized quantum measurement, and show that it is fully informative: The expected value of the measured spin components can be found with arbitrary precision for sufficiently many runs of the experiment. This work is based on arXiv:1611.07937.

I16

Observational realism and spatial elements in quantum phenomenology

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The question of the continuity of material extensions was an important topic of discussion, before the development of the Euclidean geometry. It inspired the statement of the so called Archimedean Axiom, which was attributed to Eudoxus of Cnidus (390 - 337 BC). A version of this axiom was presented by Euclid, in definition 4, book 5 of 'The Elements' [1].

Recent reviews of this axiom, in the domain of mathematics, inspired the development of non-Euclidean geometries and also introduced the p-adic number system. And more recently Igor Volovich posed a deep question on the nature of the physical space around the Planck length, suggesting that a non-Archimedean approach based on p-adic analysis would be suitable for this physical domain [2]. Reviews on the mathematics of quantum mechanics were also suggested along these lines [3].

In the light of the epistemology of observational realism [4], we review again the Archimedean axiom and argue that the original question by Eudoxus was already posed outside the domain of Euclidean geometry, but had a later adaptation to it by Archimedes. We think that clarification of the original question is necessary, in order to fully understand the limitations of Euclidean geometry, which is usually considered as a basis of the physical space in the domain of quantum mechanics. And we emphasize that separation between observational and theoretical languages, in this theory, is a necessary step to investigate the question of the nature of the physical space in the quantum domain.

[1] Euclides, The thirteen books of Euclid's elements, edited and commented by T. L. Heath, Dover Publications, 1956.

[2] Igor Volovich, Number Theory as the Ultimate Physical Theory, p-Adic Numbers, Ultrametric Analysis and Applications, Vol. 2, No. 1, pp. 77-87, Pleiades Publishing, Ltd., 2010.

[3] Andrei Y. Khrennikov, Non-Archimedean Analysis: Quantum Paradoxes, Dynamical Systems and Biological Models, Springer, 1997.

[4] Claudia Pombo, Differentiation with Stratification: A Principle of Theoretical Physics in the Tradition of the Memory Art, Foundations of Physics, Volume 45, Issue 10, pp. 1301-1310, 2015.

Quantum fluctuations and density of states in superconducting nanowires

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Quantum fluctuations may strongly modify thermodynamic and trasport properties of superconducting nanowires as compared to bulk systems. One of the important features of such nanowires is the presence of sound-like collective plasma modes propagating along the wire. In this work we demonstrate that interaction between these modes and electrons inside the wire may strongly affect the electron density of states and yield total smearing of the BCS singularity in the vicinity of the superconducting gap. Treating fluctuations on a non-perturbative level, we derive an analytic expression for the superconducting density of states in different regimes and evaluate the tunneling current-voltage characteristics of superconducting nanowires which exhibit the power-law behavior in the low temperature limit. Our predictions can be directly tested in modern experiments with superconducting nanowires.

[1] K.Yu. Arutyunov, D.S. Golubev, and A.D. Zaikin, Phys. Rep. 464, 1 (2008)

[2] J.E. Mooij and G. Schön, Phys. Rev. Lett. 55, 114 (1985)

[3] A. van Otterlo, D.S. Golubev, A.D. Zaikin, and G. Blatter, Eur. Phys. J. B10, 131 (1999)

I18

Partition-free theory of time-dependent current noise in molecular junctions

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Working within the Nonequilibrium Green's Function (NEGF) formalism, a formula for the two-time current correlation function is derived for the case of transport through a nanojunction in response to an arbitrary time-dependent bias. The one-particle Hamiltonian and the Wide Band Limit Approximation (WBLA) are assumed, enabling us to extract all necessary Green's functions and self energies for the system, extending the analytic work presented previously [Ridley et al. Phys. Rev. B (2015)]. We show that our new expression for the two-time correlation function generalises the Buttiker theory of shot and thermal noise on the current through a nanojunction to the time-dependent bias case including the transient regime following the switch-on. Transient terms in the correlation function arise from an initial state that does not assume (as is usually done) that the system is initially uncoupled, i.e. our approach is partition-free. We show that when the bias loses its time-dependence, the long time-limit of the current correlation function depends on the time difference only, as in this case an ideal steady state is reached. This enables derivation of known results for the single frequency power spectrum and for the zero frequency limit of this power spectrum. In addition, we present a technique which for the first time facilitates fast calculations of the transient quantum noise, valid for arbitrary temperature, time and voltage scales. We then perform calculations on a molecular wire system for both DC and AC biases, and find a novel signature of the traversal time for electrons crossing the wire in the time-dependent cross-lead current correlations.

Decision making in the arrow of time

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Processes that take place far from thermodynamic equilibrium are in general irreversible and are associated with entropy production. Irreversibility implies that a sequence of events that takes place during a process occurs with different probability than the same sequence in time reversed order. Irreversibility and the thermodynamic arrow of time can be illustrated considering a movie displaying the evolution of a complex dynamic process. Such a movie can be run either forward in time or in reverse. For an irreversible process it is possible to decide whether the movie is run forward or in reverse defining the direction of the arrow of time by the direction in which entropy increases on average. For a system at thermodynamic equilibrium, however, even though all atoms or molecules move rapidly in all directions, it is impossible when watching a movie to tell whether it runs forward or in reverse. This raises the following question: Can the time needed to decide between two hypotheses (movie run forward or in reverse) be related quantitatively to the degree of irreversibility and the rate of entropy production?

In this work [1], we show that the steady-state entropy production rate of a stochastic process is inversely proportional to the minimal time needed to decide on the direction of the arrow of time. Here we apply Wald's sequential probability ratio test to optimally decide on the direction of time's arrow in stationary Markov processes. Furthermore, the steady-state entropy production rate can be estimated using mean first-passage times of suitable physical variables. We derive a first-passage time fluctuation theorem which implies that the decision time distributions for correct and wrong decisions are equal. Our results are illustrated by numerical simulations of two simple examples of nonequilibrium processes namely a colloidal particle moving in a ring and a minimal model of a molecular motor.

[1] É. Roldán, I. Neri, M. Dörpinghaus, H. Meyr, F. Jülicher, PRL 115 (25), 250602 (2015).

I20

Thermoelectricity without absorbing energy from the heat sources

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A thermocouple generates finite electrical power by coupling a part of an electrical conductor to an external heat source. Macroscopically, this part of the system equlibrates to an increased temperature that governs the thermoelectric performance. The generated power then depends on the heat current absorbed from the source. In a mesoscopic system, this is not necessarily the case. The coupling of a nanoscale system (e.g. a quantum dot) to a hot and a cold bath can be used to generate a finite power in the electrical conductor even in situations when it absorbed no heat. We show that this effect is possible in the presence of non-thermalized states [1]. We propose a configuration based on capacitively coupled quantum dots recently realized experimentally [2,3], but the effect does not rely on the presence of interactions.

[1] R. S. Whitney, R. Sánchez, F. Haupt, J. Splettstoesser, Physica E 75, 257 (2016)

[2] R. Sánchez, M. Büttiker, Phys. Rev. B 83, 085428 (2011)

[3] H. Thierschmann et al., Nature Nanotech. 10, 854 (2015)

Helical gaps in interacting Rashba wires

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A partially gapped spectrum due to the application of a magnetic field is one of the main probes of Rashba spin-orbit coupling in the nanowires used in the quest for Majorana fermions. I will present results about the helical gap with a particular focus on the interplay between Rashba spin-orbit coupling and electron-electron interactions.

In a quasi-one-dimensional wire, interactions can open a helical gap even without magnetic field [2,4,5], and indeed this prediction was recently verified experimentally [6]. To show how the two types of helical gaps, caused by magnetic fields or interactions, can be distinguished in experiments, we calculated dynamic response functions such as the spectral function, density of states and the structure factor [4]. Moreover, we showed that if a wire with such an interaction-induced helical gap is proximity-coupled to a superconductor it can host Z4-parafermions [2].

The helical gap typically occurs at low electron densities where the Coulomb energy dominates over the kinetic energy. To address this strongly correlated limit, we have also investigated Rashba wires using Wigner crystal theory [3,5].

[1] T. L. Schmidt, Phys. Rev. B, 88, 235429 (2013)

[2] C. J. Pedder, T. Meng, R. P. Tiwari, and T. L. Schmidt, arxiv/1507.08881 (2015)

[3] T. L. Schmidt and C. J. Pedder, Phys. Rev. B 94, 125420 (2016)

[4] C. J. Pedder, T. Meng, R. P. Tiwari, and T. L. Schmidt, Phys. Rev. B 94, 245414 (2016)

[5] V. Kornich, C. J. Pedder, T. L. Schmidt, Phys. Rev. B 95, 045413 (2017)

[6] S. Heedt et al., Nat. Phys. (2017), doi:10.1038/nphys4070

I22

Strong field enhancement and suppression of ionization with few cycle chirped laser pulses

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Selective excitation and suppression of atomic Rydberg level populations in sodium vapor (Na I) with intense laser pulses in the strong field limit is experimentally investigated. To demonstrate the coherent control of the atomic populations and related ionization channels we measure the variations of the above threshold ionization (ATI) spectra with intensity and chirp of Ti:sapphire 56fs pulses centered around 800nm. At low intensities where the AC Stark shift can be neglected, coherent control can be realized by tailoring relative phases of the laser pulse spectral components using resonances between energy states dressed by integer multiples of the photon energy. However, in the strong field limit with laser pulse intensities producing significant Stark shifts, the resonant conditions are dynamically fulfilled only for certain intervals in time and space during the laser pulse interaction with the medium. In the latter case we find that the ATI spectra and ionization channels are strongly influenced by dynamic Freeman resonances. By varying the laser intensity atomic excitation selectivity and high ionization yield can be simultaneously realized without the need to control the spectral phases. In particular, electron yields for ionization through 5p and 6p energy levels as a function of laser intensity shows qualitatively different behavior. The difference between the intensity responses of these energy states is explained by the fact that as intensity increases, the dynamic Stark effect shifts 5p towards a three-photon resonance relative to the ground state, while 6p shifts away from this resonance. The observed intensity dependencies are in qualitative agreement with simulations employing a simple dynamic model taking into account Freeman resonances. As an additional control mechanism, the chirp of the pulse determines the amount of time that each P state is in resonance and thus selectively controls the ionization rate of these states. This work was supported by the Robert A. Welch Foundation, grant No. A1546 and the Qatar Foundation, grant NPRP 8-735-1-154.

Sympathetic cooling of mixed ion Coulomb crystals

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We demonstrate the application of reliable methods to determine both the average micromotion energies and the number of sympathetically cooled ions (SCIs) embedded in mixed-ion Coulomb crystals in a linear Paul trap. The number of the SCIs and the micromotion energies for the observed mixed-ion crystals are determined by comparing experimentally obtained images with molecular-dynamics simulations, where the kinetic energies of SCIs trapped in rf fields are averaged in cold elastic collisions between the laser-cooled ions and virtual very light atoms. This combined method quickly achieves the quasiequilibrium state of large mixed Coulomb crystals with over 103 ions, regardless of the initial conditions, and shows that the previously used pseudopotential-based adiabatic approximations should be replaced by such molecular-dynamics simulations. In addition, a pattern-matching recognition procedure is introduced which objectively ascertains the number of ions. We also apply the presented characterization method for sympathetic cooling of highly charged ions by laser cooled singly charged ions. This work is financially supported in part by a Grant-in-Aid for Young Scientists from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Robert A. Welch Foundation under Grant No. A1546, and the Matsuo Foundation.

I24

Steady states of open quantum Brownian motion: Central limit theorem, Gaussian and non-Gaussian behavior

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Open Quantum Brownian Motion (OQBM) describes a Brownian particle with an additional internal quantum degree of freedom. Originally, it was introduced as a scaling limit of Open Quantum Walks (OQWs). Recently, it was noted, that for the model of free OQBM with a two-level system as an internal degree of freedom and decoherent coupling to a dissipative environment, one could use weak external driving of the internal degree of freedom to manipulate the steady-state position of the walker [Sinayskiy, I., and Petruccione, F. (2016). Fortschr. Phys.. doi:10.1002/prop.201600063]. This observation establishes a useful connection between controllable parameters of the OQBM, e.g. driving strengths and magnitude of detuning, and its steady state properties. Although OQWs satisfy a central limit theorem (CLT), it is known, that OQBM, in general, does not. The aim of this work is to derive steady states for some particular OQBMs and observe possible transitions from Gaussian to non-Gaussian behavior depending on the choice of quantum coin and as a function of diffusion coefficient and dissipation strength.

Non-local adiabatic pumping signatures of fractional quantum Hall effect parafermions

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Parafermionic zero modes [1] are a fractional generalization of the well-known Majorana zero modes [2-4]. Similarly to Majoranas, parafermions give rise to a topologically protected degeneracy of the system ground state. Parafermionic zero modes can be implemented in a number of ways [4]; in particular, using the fractional quantum Hall (FQH) edge states [5, 6].

We investigate adiabatic pumping of fractional quasiparticles in the system of FQH-based parafermions [7]. We discover an interference phenomenon of non-local pumping blockade, based on which we propose several pumping protocols. These protocols provide characteristic signatures of parafermions. In particular, they allow one to distinguish parafermions from Majorana fermions.

These protocols are applicable both to simple arrays of parafermions [5, 6] and to the Parafermionic Box setup [8] which features additional protection of the system quantum state from environmental influence due to electrostatic charging energy.

[1] J. Alicea and P. Fendley, Annu. Rev. Condens. Matter Phys. 7 (2016) 119.

[2] J. Alicea, Rep. Prog. Phys. 75 (2012) 076501.

[3] M. Leijnse and K. Flensberg, Semicond. Sci. Techn. 27 (2012) 124003.

[4] C. Beenakker, Annu. Rev. Condens. Matter Phys. 4 (2013) 113.

[5] N.H. Lindner, E. Berg, G. Refael, and A. Stern, Phys. Rev. X 2 (2012) 041002.

[6] D.J. Clarke, J. Alicea, and K. Shtengel, Nature Commun. 4 (2013) 1348.

[7] Y. Herasymenko, K. Snizhko, Y. Gefen, unpublished.

[8] K. Snizhko, R. Egger, and Y. Gefen, arXiv:1704.03241 (2017).

I26

Open quantum systems with memory friction: Efficient stochastic modelling

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In open quantum systems, fast driving or non-perturbative damping require mathematical approaches beyond simple master equations. The stochastic method of Stockburger and Grabert [1] addresses this case in considerable generality (arbitrary Hamiltonian, arbitrary Gaussian reservoir). In its original form, the numerical costs of this method increase rapidly when simulating dynamics over long time intervals. A recent modified simulation method [2] addresses this problem; requiring computational resources with much more benign, often linear, scaling with time. A sketch of the method and a few benchmark results are presented.

[1] J.T. Stockburger and H. Grabert, Exact c-Number Representation of Non-Markovian Quantum Dissipation, Phys. Rev. Lett. **88**, 170407 (2002)

[2] J.T. Stockburger, Exact propagation of open quantum systems in a system-reservoir context, EPL (Europhysics Letters) **115**, 40010 (2016)

Point information gain, multidimensional data analysis and the piecewise self-organised space

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We generalize the point information gain (PIG) and derived quantities, i.e., point information gain entropy (PIE) and point information gain entropy density (PIED), for the case of the Rényi entropy and simulate the behavior of PIG for typical distributions. We also use these methods for the analysis of multidimensional datasets. We demonstrate the main properties of PIE/PIED spectra for the real data with the examples on chemical self-organisation (the Belousov-Zhabotinsky reaction) and organisation of biological societies (fish school formation). The newly derived quantities may be very successfully used for representation and classification of the observed data. We propose a hypothesis that the phase space of self-organised systems is naturally and piecewise hierarchically nearly discrete. The leading, observably dynamic, process, may be analysed primarily on its own scale. The process at lower scale may, nevertheless, lead to qualitative differences of the outcomes of the leading process dynamics.

I28

Multipartite concurrence for identical-fermion systems

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A fundamental feature of quantum systems composed of N identical fermions is that their elementary (antisymmetric) pure state is a single Slater determinant. Such property has led to the notion of fermionic entanglement, associated with the quantum correlations exhibited on top of the Slater correlations. This opens the problem of constructing (fermionic) entanglement measures, that properly quantify the extra correlations beyond those due to the indistinguishability of the parties. Here we generalize previously existing fermionic entanglement criteria, and introduce a multipartite fermionic concurrence valid for pure states of N identical fermions, each one having a d-dimensional single-particle Hilbert space. It is shown that the proposed concurrence can be expressed as the mean value of an observable, provided two copies for the composite state are available. In addition, we find that the introduced entanglement measure is optimized for maximally entangled states of three identical fermions that play a role analogous to the usual (qubit) GHZ state.

[1] A. P. Majtey, P. A. Bouvrie, A. Valdés-Hernández and A. R. Plastino, Phys. Rev. A 93, 032335 (2016).

Posters

Thermodynamic uncertainty relation: Empirical verification

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In this work we found an experimental confirmation of thermodynamic uncertainty principle. In out work we used an installation consisting of two transistors 1×1 mm. Both transistors shared the same semiconductor crystal therefore formed a united semiconductor-device. One transistor served as a thermometer, the other was used to measure the parameters characterizing the energy of the system.

This approach allows to solve several inconsistencies arising during theoretical analysis. Experimental investigations were performed at different physical conditions: at equilibrium conditions and at conditions far from equilibrium. The total number of experiments was around 10 000. It should be noted that at thermodynamic equilibrium we were limited by the precision of measured parameters. Although in the most cases we prove the accuracy of thermodynamic uncertainty relation.

But, the analogy between thermodynamic and quantum-mechanic uncertainty relations is not so deep and has its boundaries.

P2

Local realism - case closed?

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Local realism in recent experiments [1-4] is excluded on condition of freedom of choice combined with no signaling between observers by implementations of simple quantum models. Both no-signaling and the underlying quantum model can be directly checked by analysis of experimental data [5]. For particular tests performed on the data, it is shown that two of these experiments give the probability for no-signaling at the level of 5%, accounting for look-elsewhere-effect, moderately suggesting that no-signaling is violated with 95% confidence. On the other hand the data from the two other experiments violate the assumption of the simple quantum model. Further experiments are necessary to clarify these issues and freedom of choice.

[1] B. Hensen, et al., Nature 526, 682 (2015)

[2] L.K. Shalm et al., Phys. Rev. Lett. 115, 250402 (2015)

[3] M. Giustina et al., Phys. Rev. Lett. 115, 250401 (2015)

[4] W. Rosenfeld et al., arXiv:1611.04604

[5] A. Bednorz, Phys. Rev. A 95, 042118 (2017)

Fully quantum second-law–like statements from the theory of statistical comparison

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I argue that the theory of statistical comparison – initiated in the late 1940s by works of Blackwell and developed later by Le Cam and Torgersen, among others – provides a nice framework to understand the statistical foundations of thermodynamics (in particular, the so-called "thermo-majorization" criterion) and other generalized resource theories. A major point in favor of this approach is that it can be extended to the non-commutative case, thus providing valuable insights in the fully quantum case, which is otherwise poorly understood in general.

[1] F. Buscemi: Fully quantum second-law–like statements from the theory of statistical comparisons. arXiv:1505.00535 [quant-ph]

[2] F. Buscemi and G. Gour: Quantum relative Lorenz curves. Physical Review A 95, 012110 (9 January 2017)

[3] F. Buscemi: Reverse data-processing theorems and computational second laws. arXiv: 1607.08335 [quant-ph]

P4

Reversibility vs invertibility: Information gain in general quantum measurements

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A new inequality relating the entropy change in quantum channels and the degree of reversibility is presented and applied to various situations of interest. Such inequality, which looks very similar to a fluctuation relation, has particularly nice implications when applied to quantum measurement processes, for which it provides a considerable strengthening of the second law formulated in Ref. [1]. Further connections with driven adiabatic processes and information-disturbance tradeoff relations for general quantum measurements are also discussed.

[1] K. Jacobs: Second law of thermodynamics and quantum feedback control. Physical Review A 80, 012322 (2009)

[2] F. Buscemi, S. Das, and M.M. Wilde: Approximate reversibility in the context of entropy gain, information gain, and complete positivity. Physical Review A 93, 062304 (2016)

[3] F. Buscemi and M. Rotondo: Invertibility, reversibility, and quantum information geometry (work in progress)

Electrical autonomous Brownian gyrator

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We report an experimental and theoretical investigation of an electrical version of an autonomous Brownian motor [1]. It is a Feynman-ratchet-like device which truly relies on real heat baths. The steady-state dynamics of an electrical system is studied, which features two resistor-capacitor (RC) circuits coupled through a third capacitor and the two resistors are subject to thermal noises of different temperatures [2,3]. The thermal voltage fluctuations across the resistors are analogous to a two-dimensional Brownian motion. This virtual Brownian particle exhibits an average gyrating motion around the potential minimum, identical to that of a Brownian gyrator proposed by R. Filliger and P. Reimann [4]. The gyrating probability flux also demonstrates the feature of detailed balance breaking in a nonequilibrium steady state caused by the temperature difference of the two thermal baths. We look into the details of the gyrating flux, its dependence on temperature difference and coupling strength, and the mechanism of heat transfer through this simple circuit with only two degrees of freedom. This work demonstrates that an autonomous Brownian motor can be realized in a simple linear system, and affirms the general principle and the possibility of a Brownian ratchet working near room temperature scale. This work is operated in the classical regime while its quantum version remains under exploration.

[1] K.-H. Chiang, C.-L. Lee, P.-Y. Lai, and Y.-F. Chen, arXiv:1703.10762

[2] S. Ciliberto, A. Imparato, A. Naert, and M. Tanase, Phys. Rev. Lett. 110, 180601 (2013)

[3] K.-H. Chiang, C.-L. Lee, P.-Y. Lai, and Y.-F. Chen, Phys. Rev. E 95, 012158 (2017)

[4] R. Filliger and P. Reimann, Phys. Rev. Lett. 99, 230602 (2007)

P6

Dissipation production: A measure of the failure of obversibility

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Understanding the nature of irreversibility has been a puzzle since the advent of thermodynamics. Irreversible behaviour is traditionally associated with open systems, and, in quantum systems, is usually quantified [1,2] with a change in the von Neumann entropy.

However, it is also possible to investigate the irreversibility at the level of the evolution of a single pure state rather than an ensemble. As an example, we might consider trajectories taken by a two level system on the Bloch sphere after a quantum measurement has been made.

Two measures of irreversibility can potentially be employed in this context. The first is stochastic entropy production, a measure of the failure of the mechanical reversibility of a trajectory. It is associated with the development of classical uncertainty in the pure state when it evolves under stochastic dynamics.

The second is dissipation production, a generalisation of an earlier quantity based on the dissipation function [3]. It measures the failure of the so-called obversibility of a trajectory [4]. It is an expression of the asymmetry in the probability distribution over system configuration (both classical and quantum) that leads to different likelihoods of exhibiting forward and the corresponding backward behaviour. It can be computed for deterministic as well as stochastic dynamics.

We here discuss the procedure needed to evaluate dissipation production in a simple, deterministic two level quantum system and provide numerical illustration. We consider cases which do, and do not satisfy a detailed fluctuation relation [5] for the dissipation production.

[1] Callens, Ilse, et al. "Quantum entropy production as a measure of irreversibility." Physica D: Nonlinear phenomena 187.1 (2004): 383-391.

[2] Henderson, Leah, and Vlatko Vedral. "Information, relative entropy of entanglement, and irreversibility." Physical Review Letters 84.10 (2000): 2263.

[3] Evans, Denis J., E. G. D. Cohen, and G. P. Morriss. "Probability of second law violations in shearing steady states." Physical Review Letters 71.15 (1993): 2401.

[4] Ford, Ian J. "Measures of thermodynamic irreversibility in deterministic and stochastic dynamics." New Journal of Physics 17.7 (2015): 075017.

[5] Evans, Denis J., and Debra J. Searles. "The fluctuation theorem." Advances in Physics 51.7 (2002): 1529-1585.

Applications of the stochastic Liouville-von Neumann (SLN) equation to quantum technology

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As nanoscale manipulations become increasingly feasible, a better understanding of quantum thermodynamics is required to improve our understanding of microscopic structures and subsequently increase the efficiency of operations on this scale. Various techniques currently exist to model the thermodynamic properties of quantum systems, but these generally rely on approximations. An exact method is the stochastic Liouville-von Neumann equation [1], based on unravelling Feynman-Vernon influence functionals [2]. We here extend its use from the one heat bath case [3] to consider the thermodynamic behaviour, including heat flow, of a system in a non-equilibrium stationary state brought about by coupling to more than one heat bath.

We develop this yet further to begin to consider using the SLN to model quantum systems, which could be used to experimentally realise quantum technologies such as heat engines and/or refrigerators. One scheme potentially amenable to modelling with the SLN equation is the recently proposed Otto refrigerator which used coupling of superconducting qubit to heat baths. Quantum thermodynamics experiments (such as electronic refrigeration) have been performed, so there is scope to ultimately compare SLN models with experimental data.

[1] Stockburger, J. T. (2004). Simulating spin-boson dynamics with stochastic Liouville–von Neumann equations. Chemical Physics, 296(2), 159-169.

[2] Feynman, R. P., & Vernon, F. L. (1963). The theory of a general quantum system interacting with a linear dissipative system. Annals of Physics, 24, 118-173.

[3] Schmidt, R., Carusela, M. F., Pekola, J. P., Suomela, S., & Ankerhold, J. (2015). Work and heat for two-level systems in dissipative environments: Strong driving and non-Markovian dynamics. Physical Review B, 91(22), 224303.

[4] Karimi, B., & Pekola, J. P. (2016). Otto refrigerator based on a superconducting qubit: Classical and quantum performance. Physical Review B, 94(18), 184503.

[5] Timofeev, A. V., Helle, M., Meschke, M., Möttönen, M., & Pekola, J. P. (2009). Electronic refrigeration at the quantum limit. Physical Review Letters, 102(20), 200801.

P8

Coherent and incoherent full counting statistics in linear triple quantum dots

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Arrays of coupled quantum dots have been shown to be tunable and controllable quantum systems suitable for the study of several quantum phenomena. Potential applications of arrays of quantum dots for quantum information processing and simulation architectures stress the importance of determining the coherence of such systems. I present here recent theoretical work on coherent and incoherent full counting statistics of a serially coupled triple quantum dot (TQD) and addressed the question on how to discern whether charge transport is due to quantum coherence or to incoherent processes.

By using a density matrix approach and a Pauli rate equation we analyzed the zero-frequency counting statistics for coherent and incoherent tunneling, respectively. Our findings reveal that the sensitivity to coherence shown by both shot noise and skewness, in particular in the limit of large coupling to a drain, can be used to unambiguously evidence the occurrence of coherent processes in charge transport across the TQD.

Stochastic laser cooling enabled by many body effects

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We describe a laser cooling mechanism based on many body effects. The mechanism is based on collective behaviour of particle and light media. It relies on stochastic occurrences giving a rise to an energy transfer between the two media, resulting in an increase of entropy of the EM field on account of the particles kinetic energy. The method can be generalized for different atoms and molecules by adding a further laser source inducing an AC stark effect. Simulations of phase space distributions where calculated comparing different the particle densities, trap potentials and external source intensity profile. The modelling shows efficient cooling rates up to 100 K/s for a dense ensemble of Rb 87 atoms, and cooling rates up to 600 K/s when adding an additional source.

[1] R. Dann, Phys.arXiv:1612.04294v2 (2016)

P10

Universal work fluctuations during shortcuts to adiabaticity

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Understanding the far-from-equilibrium dynamics of quantum systems is an open problem at the frontiers of physics. Yet, tailoring such dynamics is a necessity for the advancement of quantum technologies. This challenge is fully embodied within the field of quantum thermodynamics with potential applications in energy science. In any physical implementation, thermal machines such as quantum heat engines and refrigerators must operate in a finite time to achieve a nonvanishing output power. This motivates the study of finite-time thermodynamics that targets the optimization of the trade-off between efficiency and power. In this context, control techniques known as shortcuts to adiabaticity (STA) have appeared as a disruptive paradigm as they mimic the quantum adiabatic dynamics of the system and suppress excitations without the requirement of slow driving. In this work, we elucidate the thermodynamic cost of counterdiabatic driving by studying how work fluctuations are modified during the STA. We show that the mean work done by the counterdiabatic fields vanishes. However, we find that STA modifies the work probability distribution leading to an enhancement of work fluctuations. We have derived a fundamental inequality that constraints work fluctuations as a function of the time required to finish the protocol.

[1] Ken Funo, Jing-Ning Zhang, Cyril Chatou, Kihwan Kim, Masahito Ueda, and Adolfo del Campo Phys. Rev. Lett. 118, 100602 (2017).

Dissipative tunneling and the complex time method: I. Bath of oscillators with arbitrary spectral density function

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In Ref. [1], using a real-time formalism, a tunneling particle is described by complex traversal times of tunneling. Here we propose a broader real-time formalism that allows for a more natural introduction of complex values of time in the description of a tunneling particle interacting with the environment. This proposal is based on the well-known complex time method for the case of a tunneling particle with no interaction with the environment [2, 3].

Following [1], the particle environment is represented by a set, or heat bath, of harmonic oscillators which is characterized by a spectral density function. Using the Feynman path integrals method, we integrate out the coordinates of the bath oscillators and obtain an exact expression for the transmission spectrum of the particle for a bath temperature $T > 0$. Limiting ourselves to the simpler case $T = 0$, we study the case of dissipative tunneling.

Considering $\hbar$ a small parameter (semiclassical limit) we approximate the transmission spectrum of the particle by the contribution of the classical trajectories and its neighboring paths. In a variational problem for the duration times of the classical paths, according to the complex time method, and considering also the variation in the initial and final positions of these paths, we obtain the equations of motion for the so-called special classical paths.

The procedure followed in this work gives the appropriate coupling factor between the two paths describing the effective action of the particle and thus replaces the *ad hoc* procedure followed for this purpose in Ref. [1]. The complex time method also allows to obtain the difference term between the effective action of the particle and the tunneling exponent.

Considering terms up to first order in an external electric field and the particle interaction with the environment, we obtain general expressions for the tunneling exponent, transmission spectrum, total tunneling rate and traversal time of tunneling, valid for a bath of oscillators with an arbitrary spectral density function. We find that the particle interaction with a bath of oscillators with an *arbitrary* spectral density function decreases the total tunneling rate.

[1] M. Ueda, "Transmission spectrum of a tunneling particle interacting with dynamical fields: real-time functional-integral approach", Phys. Rev. B **54**, 8676 (1996).

[2] D. W. McLaughlin, "Complex time, contour independent path integrals, and barrier penetration", J. Math. Phys. **13**, 1099 (1972).

[3] B. R. Holstein and A. R. Swift, "Barrier penetration via path integrals", Am. J. Phys. **50**, 833 (1982).

P12

Dissipative tunneling and the complex time method: II. A bath of oscillators with a single frequency and an ohmic bath

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Besides the results obtained in part I by considering terms up to first order in an external electric field and the particle interaction with the environment, we also find that the interaction of the particle with the bath oscillators with frequencies $\omega_\alpha = \omega_c \approx 1.9\,T_0^{-1}$, where T_0 is the characteristic traversal time of tunneling when there is no interaction of the particle with the bath of oscillators nor electric field, does not affect the characteristic traversal time of tunneling. On the other hand, the interaction of the particle with the bath oscillators having frequencies $\omega_\alpha < \omega_c$ ($\omega_\alpha > \omega_c$) decreases (increases) the characteristic traversal time of tunneling.

In the case of a bath of oscillators with a single frequency ω and a coupling constant with the particle given by $C_\alpha = \widetilde{C}_\alpha(\omega T_0)^\sigma$, we identify five different behaviors depending on ω for the characteristic tunneling exponent and the characteristic traversal time of tunneling. These behaviors correspond to the values of $\sigma < 1$, $\sigma = 1$, $1 < \sigma < 2$, $\sigma = 2$ and $\sigma > 2$. In Ref. [1], it was only considered the characteristic tunneling exponent in the case $\sigma = 1$.

In the case of an ohmic bath of oscillators at zero temperature, as well as in the case of a bath of oscillators with a single frequency, we obtain that the transmission spectrum of the particle is zero for a final characteristic energy of the particle greater than the initial characteristic energy. This result corrects the corresponding result in Ref. [1] and allows for a more coherent derivation of the tunneling current between two metals separated by an insulating material at zero temperature. It is also obtained that the interaction of the particle with an ohmic bath of oscillators does not affect the characteristic traversal time of tunneling up to first order in that interaction.

[1] M. Ueda, "Transmission spectrum of a tunneling particle interacting with dynamical fields: real-time functional-integral approach", Phys. Rev. B 54, 8676 (1996).

Defects in quantum computers

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The shift of interest from general purpose quantum computers to devices based on adiabatic quantum computing or quantum annealing calls for a broadly applicable and easy to implement test to assess how quantum or adiabatic is a specific hardware. Here we propose such a test based on the exactly solvable many body system – the quantum Ising chain in transverse field – and discuss its implementation on the D-Wave chip.

P14

Information-disturbance measures in quantum measurements

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Within classical information theory, *information* itself is a well defined quantity (stemming from the uniqueness of entropy) which allows unambiguous statements of information flow or the acquisition of information using metrics such at mutual information. It is perhaps not surprising that in the quantum realm the situation is much more subtle and complex, in part due to the dual role of quantum measurements, prescribing how information is obtained, and having a back-action on the system being measured. Indeed there is a long history of attempts to quantifying the amount of information gained by a measurement, the size of the corresponding disturbance, and the relationship between the two. These include for example fidelity based measures [1,2] and entropic ones [3,4], with the result that in the literature many informational gain and disturbance relations have been proposed with no clear canonical pair of measures.

We study several of these measures and their relationships, employing a family of generalized measurement instruments. This family has a well defined *a-priori* ordering in 'quality', in the sense that we start from an ideal measurement and deteriorate the apparatus using physically motivated mechanisms, making the measurement weaker and/or more inefficient. This provides an operational backdrop against which to test and compare the different measures of informational gain and disturbance. We find that entropic relations such as Buscemi et al. [3] intuitively capture the quality of this family.

[1] K. Banaszek, Phys. Rev. Lett. 86, 1366 (2001)

[2] C. A. Fuchs and K. Jacobs, Phys. Rev. A 63, 062305 (2001)

[3] F. Buscemi, M. Hayashi, and M. Horodecki, Phys. Rev. Lett. 100, 210504 (2008)

[4] S. Luo, Phys. Rev. A. 82, 052103 (2010)

[5] P. Mandayam and M. D. Srinivas, Phys. Rev. A 90, 062128 (2014)

Stability of quantum statistical ensembles with respect to local measurements

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We introduce a stability criterion for quantum statistical ensembles describing macroscopic systems. An ensemble is called "stable" when a small number of local measurements cannot significantly modify the probability distribution of the total energy of the system. We apply this criterion to lattices of spins-1/2, thereby showing that the canonical ensemble is nearly stable, whereas statistical ensembles with much broader energy distributions are not stable. In the context of the foundations of quantum statistical physics, this result justifies the use of statistical ensembles with narrow energy distributions such as canonical or microcanonical ensembles.

P16

Driven polaron quantum dots – from blockade to pumping

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Electron-vibron coupling in quantum dots can lead to a strong suppression of the average current in the sequential tunneling regime. This effect is known as Franck-Condon blockade and can be traced back to an overlap integral between composite electromechanical states ("polarons"), which becomes exponentially small for large electron-vibron coupling strength.

Using a non-equilibrium Green's function approach, we show [1] that the application of a time-dependent gate voltage lifts this blockade exponentially. Furthermore, we introduce a second time-dependence to the system, which enables us to model more involved driving schemes and pumping, thus turning the polaron quantum dot into a highly flexible and tunable piece of nanocircuitry.

[1] P. Haughian et al., Lifting the Franck-Condon blockade in driven quantum dots, Physical Review B 94, 205412 (2016)

Realistic model of a self-sustained quantum oscillator

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We study a quantum harmonic oscillator weakly coupled to two spin baths, and derive the quantum master equation for the oscillator. The oscillator can be shown to evolve according to the quantum van der Pol master equation under ideal conditions [1], but otherwise obtains corrections under more realistic conditions. We study and characterise the oscillator evolution and its sychronisation properties under a weak driving force in the quantum and classical regimes.

[1] S. Walter, A. Nunnenkamp, and C. Bruder, Phys. Rev. Lett 112(9) (2014) 094102.

P18

Order and symmetry-breaking in the fluctuations of driven systems

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Dynamic phase transitions (DPTs) in the space of trajectories are one of the most intriguing phenomena of nonequilibrium physics, but their nature in realistic high-dimensional systems remains puzzling. Here we observe for the first time a DPT in the current vector statistics of an archetypal two-dimensional (2d) driven diffusive system, and characterize its properties using macroscopic fluctuation theory. The complex interplay among the external field, anisotropy and vector currents in 2d leads to a rich phase diagram, with different symmetry-broken fluctuation phases separated by lines of first- and second-order DPTs. Remarkably, different types of 1d order in the form of jammed density waves emerge to hinder transport for low-current fluctuations, revealing a connection between rare events and self-organized structures which enhance their probability.

[1] N. Tizon-Escamilla, C. Perez-Espigares, P.L. Garrido, P.I. Hurtado, "Order and symmetry-breaking in the fluctuations of driven systems", arXiv:1606.07507

Scattering matrix approach to photon emission from a coherent conductor coupled to cavity modes

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Circuit QED systems based on conductors (quantum dot, point contacts, etc) coupled microwave cavity modes have demonstrated unprecedented control over the intrinsic electron-photon (e-p) interaction and the ability to manipulate the photon states by means electronic degrees of freedom. In this work, we explore the effect of many-body interactions on the photon emission from a biased quantum coherent conductor coupled to multiple cavity modes. In particular, we focus on quantum coherent higher-order e-p scattering processes in which multiple electron team up and thereby a able to excite "forbidden" cavity modes whose energy exceeds the energy given by the applied bias. For this purpose, we combine a scattering-matrix description of the conductor with a generalized Fermi's golden rule based on the T-matrix to calculate the photon emission and absorption rates due to higher-order processes, and determine the out-of-equilibrium state of the cavity photon modes. By studying the dependence on the conductance of the conductor, the above-mentioned excitation pathway for the "forbidden" cavity modes are demonstrated to show a unique scaling with the conductance, thereby allowing for their experimental identification. Via the fundamental link between the photon emission and the finite-frequency quantum shot noise of the conductor, such circuit QED systems provide a unique platform for the study of e-p induced many-body effects on the shot noise.

P20

Polaron states in two coupled self-assembled quantum dots

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Self assembled quantum dots (QDs) are continuously attracting attention in fundamental research. From the theoretical point of view, one of the most interesting aspect is related to carrier-phonon coupling. The coupling can lead to the formation of polarons. Systems composed of coupled QDs offer reacher physical properties than a single QDs. In particular, a double quantum dot (DQD) supports also spatially indirect states with different dipole moments, the energy of which can be tuned by applying an axial electric field. Experimental and theoretical work on QD polarons is crucial e.g. for carrier relaxation in self-assembled QD systems, where typical energy separations are comparable with the LO phonon energy.

We study polaron states in two vertically stacked QDs [1]. The electron and hole states are found by applying the 8-band kp model with strain distribution found within continuous elasticity approach. We calculate exciton states using the configuration interaction method, while polaron states are found by orthogonalization of the Fröhlich Hamiltonian in the basis of collective phonon modes [2]. We propose a numerically efficient mode orthogonalization scheme related to selection of effectively coupled modes. We investigate the dependence of polaron energy branches on axial electric field and also the dependence of the phonon-assisted tunnel coupling on the separation between dots.

In this presentation, we show that coupling between carriers and longitudinal optical phonons leads to the reconstruction of the optical spectra. In particular, we study resonances between the states belonging to different shells from different dots. We show that p-shell states are strongly coupled to the phonon replicas of s-shell states, while the direct s-p coupling is much weaker. We also show the exponential dependence of the strength of LO-phonon mediated coupling on the inter-dot distance.

[1] P. Karwat, K. Gawarecki, P. Machnikowski, arxiv: 1701.06613 (2017)

[2] T. Stauber, R. Zimmermann, H. Castella, Phys. Rev. B 62, 7336 (2000)

Thermal phonon lasing in nanoscopic quantum systems

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With the rapid progress in miniaturization many types of devices have reached the nanoscale where quantum effects become more prevalent, e.g., quantum lasers. On properly designed nanoscopic quantum systems a heat gradient can lead to inversion in parts of it, that could be utilized e.g. for the generation of phonons.

We study a theoretical concept of a nanoscopic quantum system representing the active medium of a thermal phonon emitter. Our model consists of a central three-level system (QS M) interacting with a two-level subunit at each side (QS L/R). Each two-level system is coupled to a heat bath. The different temperatures of the baths impose a heat gradient. The heat gradient leads to a flow of excitation from the hotter to the colder bath. For certain parameters, at the central quantum system, the flow could be accompanied by the emission of a phonon. Our description of the system kinetics is based on the Lindblad form of a Quantum Master Equation and the coupling to the lattice displacement field is described via a semiclassical equation.

In this presentation, we show that a positive inversion within the upper two levels of the central system takes place, which is a requirement to enable phonon lasing.

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Quantum mechanical oscillator governed by temperature dependent Hamiltonian

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We analyze a quantum mechanical oscillator coupled to a heat bath, while its oscillation frequency is determined by the temperature of the heat bath. We study processes in which the temperature is changed, directly affecting the dynamical and thermodynamic properties of the oscillator. Such situation can occur, e.g., if the effective description oscillator subsystem as the result of partial averaging over possible microstates of a larger equilibrium system.

Study of the equilibrium thermodynamic properties of such an oscillator is presented and, as well, the way how it approaches the equilibrium state. Assuming different temperature dependencies of the oscillator frequency, we observe, e.g., non-monotonic temperature dependence of the entropy. In the equilibrium situation we focus on the validity of relations between the basic thermodynamic variables and their temperature dependence. Namely, we study the behavior of entropy, internal energy, work and heat during quasi-reversible changes of the bath temperature.

Kondo chains on metallic surfaces: A possible route towards heavy fermions

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The heavy fermion behavior is a lattice analog of the single-impurity Kondo effect. We could think of it as assembling Kondo impurities, provided that magnetic interactions between impurities are suppressed. It is possible to realize the aforementioned strategy by atomic manipulation on surfaces facilitated by the scanning-tunneling microscope [1]. This was demonstrated in a recent experiment with Co ad-atoms on the surface of Ag [2,3]. Our many-body calculations show that the conductance maps manifest the presence of induced long-range hopping between impurities. Thus the inter-impurity cross-talk is inherently non-local in nature even in absence of magnetism.

[1] L. Zhang et al., Kondo effect in binuclear metal-organic complexes with weakly interacting spins, Phys. Rev. B 91, 195424 (2015)

[2] M. Moro Lageres, Doctoral thesis, University of Zaragoza

[3] M. Moro Lagares, R. Korytar, et al., Visualization of local moment deconfinement in atomic scale Kondo lattices, in preparation

P24

Kinetic field theory for non-linear cosmic structure formation

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We present a microscopic, non-equilibrium, statistical field theory for initially correlated canonical ensembles of classical microscopic particles obeying Hamiltonian dynamics to describe cosmic structure formation [1]. The conventional analytic treatment of cosmic density fluctuations via the hydrodynamical equations runs into severe problems even in a mildly non-linear regime. The non-linear regime of structure formation is so far only accessible through expensive numerical simulations. Our kinetic field theory avoids the difficulties of standard perturbation theory by construction and allows to proceed deeply into the non-linear regime of density fluctuations. We will show the non-linear power spectrum of cosmic structures obtained by fully analytical computations. We will also demonstrate how the complete hierarchy of initial momentum correlations is responsible for a characteristic deformation in the density-fluctuation power spectrum, caused by mode transport independent of the particle interaction [2]. Furthermore, we will give an outlook on how this analytic description of structure formation can provide insights into the origin of the NFW-density profile for Dark Matter halos.

[1] M. Bartelmann, F. Fabis, D. Berg, E. Kozlikin, R. Lilow and C. Viermann, New Journal of Physics 18 (2016) 4

[2] M. Bartelmann, F. Fabis, E. Kozlikin, R. Lilow, J. Dombrowski and J. Mildenberger (submitted to New Journal of Physics) arXiv:1611.09503

Thermoelectric transport of ultracold Fermi gases connected by a mesoscopic constriction

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Thermoelectricity describes the phenomenon by which a temperature gradient triggers the appearance of a chemical potential gradient and vice versa. It is of great technological importance for cooling materials (Peltier effect) or power generation (Seebeck effect), but it is also a fundamental probe of the physics of the medium in which the energy and particle currents are created. Thermoelectric effects have already been studied with cold atoms using a two-dimensional constriction [1].

We experimentally study those effects on our mesoscopic transport setup using ultracold fermionic Lithium atoms. These effects are affected by the properties of both the constriction and the reservoirs. First, we reduce the dimensionality of the constriction: two temperature imbalanced reservoirs are connected via a one to few mode channel, which is similar to the condensed matter quantum point contact systems. In addition, we can vary the interaction strength to reach the strongly interacting, unitary regime where the evolution of particle and energy currents are strongly modified compared to the weakly interacting case.

[1] J.-P. Brantut et al, Science 342, 713–715 (2013).

P26

Local control of transport in an atomic quantum wire: From one scanning gate to a finite size lattice

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Building on the holographic shaping of optical potentials and a high-resolution microscope, we demonstrate the local control of fermionic lithium atoms flowing through a one-dimensional structure [1]. We first image the transport through a quantum wire, in a way similar to the scanning gate technique applied to solid state devices [2]. By scanning the position of a sharp, repulsive optical gate over the wire and measuring the subsequent variations of conductance, we spatially map the transport at a resolution close to the transverse wavefunction inside the wire. The control of the gate at the scale of the Fermi wavelength makes it sensitive to quantum tunnelling. Furthermore, our knowledge of the optical potential allows a direct comparison of the experimental maps with a numerical and an analytical model for non-interacting particles .

The flexibility offered by our setup makes it relatively simple to imprint more complex structures. By projecting several consecutive scatterers, a lattice of variable length can be built inside the quantum wire. This opens the path to study metal-insulator physics with strong attractive interactions.

[1] S. Krinner, D. Stadler, D. Husmann, J.-P. Brantut, and T. Esslinger, Nature 517, 64–67 (2015)

[2] S. Häusler, S. Nakajima, M. Lebrat, D. Husmann, S. Krinner, T. Esslinger, and J.-P. Brantut, arXiv:1702.02135 [cond-mat] (2017)

Out-of-time-ordered correlator in time evolution from a prepared initial state in many-body localization

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We investigate the time evolution of out-of-time-ordered correlator (OTOC) in a disordered spin-1/2 XXZ Heisenberg chain. We find that a choice of initial state strongly affects the distributions of OTOC across the random disorder realizations. The distributions of OTOC show two types in their shape: one is very spiky and the other spreads widely over a possible range of OTOC. We analyze the distributions by using the inverse participation ratio (IPR) which gets smaller as the eigenstates more evenly are superposed in the initial state. We find that the initial state having the spiky distribution of OTOC shows a small IPR while the other having the broad distribution of OTOC shows a large IPR. We argue that a preparation of a optimal initial state can be relevant for the measurement of OTOC in a time evolution experiment with trapped ion [1].

[1] M. Gärttner, J. G. Bohnet, A. Safavi-Naini, M. L. Wall, J. J. Bollinger, and A. M. Rey, arXiv:1608.08938.

P28

Describing cosmic structure formation by resumming Hamiltonian particle dynamics

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Conventional analytic approaches to cosmic structure formation, like Eulerian and Lagrangian perturbation theory, have been very successful in predicting the linear and mildly nonlinear evolution of large-scale structures. Their incapability of describing crossing streams of dark matter particles, however, prevents them from advancing into the strongly nonlinear regime on smaller scales. In [1] we developed a new analytic description of structure formation which overcomes these problems by incorporating the full Hamiltonian dynamics of dark matter particles in a path integral formalism. The first perturbative results of this kinetic field theory already reproduced the nonlinear density contrast power spectrum found in numerical simulations well down to significantly smaller scales than what was possible before. On this poster we will demonstrate how this formalism can be resummed in terms of macroscopic fields without losing any of the underlying microscopic dynamics. This resummation makes a multitude of well-developed non-perturbative methods applicable to our theory and should thus allow us to extend even further into the nonlinear regime. We will show some first results and furthermore give an outlook on how this framework can be used to perform a consistent analysis of the scale-dependence of cosmic structure growth from the particle up to the Hubble scale.

[1] M. Bartelmann, F. Fabis, D. Berg, E. Kozlikin, R. Lilow and C. Viermann, New Journal of Physics 18 (2016) 043020.

Heating and thermoelectric transport in a molecular junction

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We consider the steady-state transport through a vibrating molecular quantum dot that is contacted by macroscopic leads. We investigate the impact of the formation of a local polaron on the thermoelectric properties of the junction. Our approach is based on a Lang-Firsov transformation and the solution of the equations of motion in the non-equilibrium Green function formalism. We calculate the thermoelectric current and voltage in the resonant and inelastic tunneling regimes. Thereby, we determine the effective dot temperature that is compatible with the steady state conditions for the heat flux.

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Phase diagram of the quantum dissipative rotor model with two competing baths

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We study a quantum dissipative rotor model in which each local phase-difference and each local momentum are uniformly coupled to two different baths. Such systems can represent e.g. a chain of resistively shunted Josephson junctions [1], capacitively coupled to a diffusive metal [2]. The first dissipative coupling quenches the quantum phase fluctuations favoring the long-range phase order (i.e. superconducting ground state) whereas the second one quenches momentum fluctuations destroying phase coherence (insulating ground state).

Using the Self-Consistent Harmonic Approximation [1], we calculate the zero-temperature phase diagram as determined by the two dissipative coupling constants and the bare zero point fluctuations. As an effect of the quantum frustration for the two canonical conjugate observables [3], we obtain an interesting phase diagram with a non-monotonic behavior: for instance, the ground state can pass from superconducting to insulating phase and back to superconducting phase by increasing the dissipation.

[1] S. Chakravarty et al., Phys. Rev. Lett. 56, 2303 (1986)
[2] A.M. Lobos, T. Giamarchi, Phys. Rev. B 84, 024523 (2011)
[3] G. Rastelli, New J. Phys. 18, 053033 (2016)

NEGF-Coulomb blockade methodology based on the two-particle Green's function applied to current through 1D nanostructure

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In this work we present a methodology describing Coulomb blockade into the Non Equilibrium Green Function formalism (NEGF) [1], which is based on the incorporation of the two-particle Green function (2pGF). Previous work [2] using the 2pGF in conjunction with NEGF assumed the central region of the nanostructure or the quantum dot as featureless and only describes it using the energy level and coupling constants. In standard NEGF, the potential energy on the electron is calculated in the mean field approximation. The 2pGF [2] incorporates the short-range electron-electron interaction [3]. Using a toy model structure we have carried out ballistic and dissipative (phonon scattering) calculations of the current. An increase of current is demonstrated. This is due to the shift and splitting of the energy levels caused by electron repulsion inside the structure. The short-range Coulomb energy is 100 meV. When the 2pGF is neglected, the ground state energy of the structure is lower than the source potential energy. In addition the next confined state energy is too high in energy to influence the current. In the upper panel the 2pGF is considered and as a consequence the ground state energy is lifted over the source potential entering into the bias bandwidth. This substantially enhances the current by more than 100% for a quasi-open nanostructure. Phonon scattering reduces the current substantially when the 2pGF is included. The method developed here can be extended to describe recent results [4] on charge transport in polymer semiconductors, where the presence of crystalline and amorphous domains leads to a confinement of charge carriers in nanometer scale crystallites [5]. It will open the possibility to bridge sequential tunnelling and coulomb blockade regimes in nanostructures.

[1] A. Svizhenko et al, J. Appl. Phys. 91, 2343 (2002)
[2] B. Song et al, Phys. Rev. B 76, 155430 (2007)
[3] J. Hubbard, Proc. Roy. Soc. A 276, 238 (1963)
[4] R. Di Pietro et al, Adv. Funct. Mater., accepted for publication (2016)
[5] R. Noriega et al, Nature Materials 12, 1038 (2013)

P32

Quantum phase transitions in the driven dissipative Jaynes-Cummings oscillator: From the dispersive regime to resonance

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The breakdown of the photon blockade in the driven dissipative Jaynes-Cummings (JC) model at resonance has revealed the significance of out-of-equilibrium quantum phase transitions, which have been recently studied theoretically [1] and demonstrated experimentally [2]. In our work we investigate the emergence of complex amplitude bistability in the strongly dispersive regime of the JC oscillator. We address the role of quantum fluctuations in the context of an effective Duffing nonlinearity [3] with one active quantum degree of freedom. We find that the development of joint bistability, in the drive region where the perturbative analysis is inadequate, is accompanied by an increasingly pronounced dark state with intense qubit fluctuations alongside significant qubit-cavity entanglement. We link our results to the solutions of the neoclassical equations of motion, and discuss the effect of a dispersive scale parameter associated with a weak-coupling "thermodynamic limit".

When the cavity mode, the qubit and the coherent drive field are all resonant, the neoclassical equations predict the existence of a threshold, above which the dressed states lie on the equatorial plane of the Bloch sphere, giving rise to a self-consistent cancellation [4]. To that end, we employ the von Neumann entanglement entropy in order to investigate the crossover between two dissipative quantum phase transitions, as the detuning between the qubit and cavity tends to zero: a first-order transition, without a pertinent threshold, and a second-order transition, with an associated phase bistability and the occurrence of spontaneous dressed-state polarization [1,4].

[1] H. J. Carmichael, Phys. Rev. X 5 (2015) 031028

[2] J. M. Fink et al., Phys. Rev. X 7 (2017) 011012

[3] P. D. Drummond and D. F. Walls, J. Phys. A 13 (1980) 725

[4] P. Alsing and H. J. Carmichael, Quantum Opt. 3 (1991) 13

Typical pure states and nonequilibrium processes for quantum many-body systems

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Recent advances on the manipulation of cold atomic systems motivate us to consider equilibration and nonequilibrium processes of isolated quantum systems. For isolated quantum many-body systems, a pure state typically well-reproduces the microcanonical ensemble average. A closely related intrinsic thermal nature of energyeigen states has been studied in the context of equilibration.

On the other hand, we can analyze the time-dependent and stationary nonequilibrium processes on the basis of a single pure state. In this poster, we address these issues by considering mesoscopic systems. First, we explore the energy absorpotion for time-dependent processes. In particlur, we calculate the work distribution by using a fixed pure state sampled from an energy shell with probability almost unity [1]. Then, we also construct a class of pure states expressing nonequilibrium steady states for quantum junctions [2], and explore the characteristic functions of an infinitely extended model [3]. Each pure nonequilibrium steady states correctly yields the grand canonical expectation values of operators such as the energy current.

[1] T. Monnai and A. Sugita, J. Phys. Soc. Jpn. 83, 9, 094001 (2014)

[2] T. Monnai and K. Yuasa, EPL 107, 40006 (2014)

[3] T. Monnai and K. Yuasa, Phys. Rev. E 94, 012146 (2016)

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Stochastic resonance in a proton pumping Complex I of mitochondria membranes

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One of the most important energy conversion mechanisms in nature are proton-pumping complexes of mitochondrial membranes. They enable to convert electronic energy into the more stable form of a proton gradient across a cellular membrane. One of them, Complex I, consists of an L-shaped assembly of a hydrophobic arm embedded in the lipid membrane and a hydrophilic peripheral arm, which protrudes into the mitochondrial matrix. Electron transfer occurs in the hydrophilic domain, while the actual proton pumps are located within the membrane. We propose that the energy transfer between electrons and protons is facilitated by mechanical or conformational changes, which we model as a charged piston. In the present work, we discuss a nanomechnical model, in which the electron subsystem has been replaced by a periodic external force acting on the piston. This system consists of three proton sites located between source and drain, and a charged piston located near the middle site. When the piston moves away from the proton sites, the energy of the center site is reduced and it can be populated from the left site. When the piston returns back, the energy of the middle site goes up and the proton can proceed to the right site and eventually to the right reservoir. Correspondingly, the protons are pumped, i.e. transferred to the reservoir with higher chemical potential. The equations of motion for the proton operators are derived and solved numerically jointly the phenomenological Langevin equation for the piston. We show that with an appropriate set of parameters, protons can be transferred against an applied voltage. We also show that the pumping disappears both at low noise levels and at small magnitude of the periodic force. Correspondingly, we conclude that only the joint action of the periodic modulation and the noise can lead to proton pumping in our model. This is a manifestation of stochastic resonance when the noise having a broad spectrum enhances the effect of the periodic driving. In our analysis, we have used the white noise with all the frequencies involved. The magnitude of this noise is quite large at the elevated physiological temperatures and even the moderate periodic driving force can be significantly amplified by means of the stochastic resonance.

Variational principles for quasi-steady states close to equilibrium

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We derive a McLennan (entropic) representation for quasi-steady distributions of slowly driven Markovian systems with weakly broken detailed balance condition. We apply it to show that these time-dependent distributions satisfy a non-standard version of the Minimum entropy production (MinEP) principle, the variational principle which can be used to determine the quasi-steady distributions without solving the corresponding dynamical equations. We demonstrate on several exactly solvable models how this MinEP principle can be used in practice.

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Simple model of a quantum heat engine: Can noise-induced coherence enhance output power and/or efficiency?

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Recently, it was shown on a simple model [1, 2] that noise-induced coherence can lead to an enhanced output power of heat engines. We revisit this model and investigate whether the obtained interesting results are not only artefacts of an oversimplified optical-master-equation description. First, we study the model in the basis where the steady state density matrix is diagonal and determine whether the non-zero steady state coherence are not just a product of wrong choice of the basis. Next, we consider also the situation where the model contains close, but non-degenerate energy levels and study whether the description using standard quantum optical master equation is appropriate in this situation.

[1] M. O. Scully, K. R. Chapin, K. E. Dorfman, M. B. Kim, and A. Svidzinsky, *Quantum heat engine power can be increased by noise-induced coherence*, Proceedings of the National Academy of Sciences **108**, 15097 (2011).

[2] K. E. Dorfman, D. V. Voronine, S. Mukamel, and M. O. Scully, *Photosynthetic reaction cen-ter as a quantum heat engine*, Proceedings of the National Academy of Sciences **110**, 2746 (2013).

Dissipative Floquet dynamics of a laser-driven quantum optical system

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We describe a laser-driven quantum system by a Dicke-Hamiltonian with periodic time-dependence beyond the rotating-wave approximation. In the regime of strong laser-excitation, the simultaneous consideration of this periodicity and also of the coupling to environmental degrees of freedom is necessary for the computation of the system dynamics. For weak system-environment coupling, the description is based on a Markovian master equation with time-dependent coefficients. To obtain a simpler differential equation with constant coefficients, we choose the Floquet states as the computational basis. We demonstrate this procedure for the example of few emitters strongly coupled to a cavity mode and driven by an external laser. As an evidence for the dynamic Stark effect, shifted peaks are observed in the emission spectra for different laser intensities. Analyzing the emission of nonclassical light with the Glauber function, we explain the additional features appearing for finite laser intensity in terms of the quasienergy spectrum of the driven emitter-cavity system. We further study the generation of entanglement among two emitters, and show that the laser-excitation leads to a decrease of entanglement. Finally, we project the system dynamics onto the emitter degrees of freedom and analyze the non-Markovianity of the resulting quantum process.

[1] D. Pagel, A. Alvermann, and H. Fehske, Phys. Rev. A 95 (2017) 013825.

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Autonomous quantum Maxwell's demon based on two exchange-coupled quantum dots

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Maxwell's demons, i.e. physical systems in which feedback control may lead to the negative entropy production, are one of the most shining examples of relation between thermodynamics and information theory. While in the original though experiment of Maxwell the principle of operation of the demon was based on applying the deterministic measurement-based feedback control protocol, it was recently shown both theoretically [1] and experimentally [2] that negative entropy production in one stochastic system may result also from the information exchange with an another stochastic system, which acts effectively as the feedback controller. Such systems are referred to as the autonomous Maxwell's demons [2,3]. Using the formalism of stochastic thermodynamics, Horowitz and Esposito [3] proposed, for a special class of bipartite systems, a way to describe the information flow between two subsystems quantitatively. This has enabled the consistent thermodynamic description of the autonomous Maxwell's demons. However, their proposal was confined to systems in which the quantum coherence between system states was not taken into account.

Here I propose a physical realization of the autonomous Maxwell's demon based on two exchange-coupled quantum dots, which act as spin qubits, each coupled to two separate spin-polarized leads. In the analyzed system the current in the one dot may flow against the bias, which leads to the negative entropy production, due to feedback control by the second spin qubit based on the operation of the quantum SWAP gate. Importantly, in the considered system the principle of operation is based on the nonvanishing quantum coherence between spin states. Due to this fact, the system has no clear bipartite structure, and therefore the formalism of Horowitz and Esposito cannot be directly applied. However, I propose the mapping procedure onto the thermodynamically-equivalent classical bipartite system which enables to describe the information transfer between spin qubits quantitatively. This paves a way to the consistent thermodynamic description of information exchange in quantum coherent systems.

This work has been supported by the National Science Centre, Poland, under the project 2016/21/B/ST3/02160.

[1] P. Strasberg, G. Schaller, T. Brandes, and M. Esposito, Phys. Rev. Lett. 110 (2013) 040601.

[2] J. V. Koski, A. Kutvonen, I. M. Khaymovich, T. Ala-Nissila, and J. P. Pekola, Phys. Rev. Lett. 115 (2015) 260602.

[3] J. M. Horowitz and M. Esposito, Phys. Rev. X 4 (2014) 031015.

Noise amplification in a one-dimensional topological quantum memory

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We prove a no-go theorem for simulating the Kitaev chain with a chain of superconducting qubits: we show that the noise strength for the topological qubit formed by the chain diverges as the square-root of the number of physical qubits. We find that, to minimize the rate of scaling, the chain must be operated as close as possible to the topological phase boundary. This phenomenon is universal in that it is independent of the bath spectral density.

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Thermodynamics of quantum coherences to control transport

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Quantum decoherence is seen as an undesired source of irreversibility that destroys quantum resources. Quantum coherences seem to be a property that vanishes at thermodynamic equilibrium. Away from equilibrium, quantum coherences challenge the classical notions of a thermodynamic bath in a Carnot engines, affect the efficiency of quantum transport, lead to violations of Fourier's law, and can be used to dynamically control the temperature of a state. However, the role of quantum coherence in thermodynamics is not fully understood. Here we show that the relative entropy of a state with quantum coherence with respect to its decohered state captures its deviation from thermodynamic equilibrium. As a result, changes in quantum coherence can lead to a heat flow with no associated temperature, and affect the entropy production rate. From this, we derive a quantum version of the Onsager reciprocal relations that shows that there is a reciprocal relation between thermodynamic forces from coherence and quantum transport. Quantum decoherence can be useful and offers new possibilities of thermodynamic control for quantum transport.

Using this, we demonstrate that in a standard thermo-electric nanodevice the current and heat flows are not only dictated by the temperature and potential gradient but also by the external action of a local quantum observer that controls the coherence of the device. Depending on how and where the observation takes place the direction of heat and particle currents can be independently controlled. In fact, we show that the current and heat flow can go against the natural temperature and voltage gradients. Dynamical quantum measurement offers new possibilities for the control of quantum transport far beyond classical thermal reservoirs.

Qubit-environment entanglement generation during pure dephasing

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The problem of detecting entanglement between a qubit and its environment is known to be complicated [1]. To simplify the issue, we study the class of Hamiltonians that describe a qubit interacting with its environment in such a way that the resulting evolution of the qubit alone is of pure dephasing type. Although this leads to some loss of generality, the pure dephasing Hamiltonian describes the dominant decohering mechanism for many types of qubits and is of fairly wide applicability. We define this situation by the requirement that the Hamiltonian of the qubit commutes with the qubit-environment interaction term. This relation means that the eigenstates of the qubit Hamiltonian form a preferred basis - they are pointer states [2] - selected by the form of the qubit-environment coupling. When both the qubit and the environment can initially be described by a (separable) wavefuntion (their state is pure throughout the evolution), an interaction between them that leads to a pure dephasing of the qubit always leads to the creation of entanglement between the two [3]. It is often assumed that a dephasing mechanism of this type must induce entanglement between the qubit and environment also when the environment is initially in a mixed state.

We show [4] that while the creation of qubit-environment entanglement in the pure dephasing case is possible when the environment is initially in a mixed state, the occurrence of this entanglement is by no means guaranteed. We give a simple necessary and sufficient condition on the initial density matrix of the environment together with the properties of the interaction, for appearance of qubit-environment entanglement (which is determined by the initial state of the environment and a relevant evolution operator which is derived from the Hamiltonian). Furthermore, we have shown [4] that restricting the class of studied initial environmental states to a certain class of states (which is very common in any realistic qubit-environment setup) enables the use of a very powerful tool to measure the entanglement, since the state of the environment will remain static throughout the evolution (the state of the environment is found by tracing out the qubit degrees of freedom). Hence, the detection of any change of the state of the environment is then equivalent to the detection of entanglement.

[1] B. Kraus, J. I. Cirac, S. Karnas, and M. Lewenstein, Phys. Rev. A 61 (2000) 062302.

[2] W. H. Żurek, Rev. Mod. Phys. 75 (2003) 715.

[3] R. Horodecki, P. Horodecki, M. Horodecki, and K. Horodecki, Rev. Mod. Phys. 81 (2009) 865.

[4] K. Roszak and Ł. Cywiński, Phys. Rev. A 92 (2015) 032310.

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Another look at the Schrödinger equation

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Our goal is to find another way to the Schrödinger equation based on natural probabilistic and physical assumptions. Essence of our approach has been developed by K. Košťál. We regard non-relativistic motion of a set of spinless quantum particles as doubly differentiable random process. We describe motion of the particles by evolution of the probability density and of the conditional mean velocity in the configuration space. Differentiability of this process implies validity of the continuity equation. The main part of our work is construction of the dynamical equation of this process for the case of noninteracting particles in vacuum. We suppose that its left side is the total time derivative of the conditional mean velocity and its right side is some polynomial in all variables (probability density and conditional mean velocity) and their space derivatives. By adding natural physical and probabilistic assumptions we significantly restrict the form of this polynomial and we obtain the Madelung form of the Schrödinger equation for free particles. Our assumptions include group of symmetry, scalability of probability density (consequence of the Bohmian measurement model), conservation of statistical independence of components of motion and non-negativity of probability density. In this approach, transition from classical to quantum dynamics is possible due to abandonment of the linearity of evolution of the probability density and its replacement with much weaker assumption arising from the Bohmian model of measurement. Description of entanglement is obtained due to weakening the assumption of independence of motions of classically noninteracting particles. Generalization of this dynamical equation to the case of classically interacting spinless quantum particles in classical external field is easy and straightforward. Connection with the Bialynicki-Birula and Mycielski nonlinear generalization of the Schrödinger equation is discussed.

A quantum diffusion law

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We analyze diffusion at low temperatures by bringing the fluctuation-dissipation theorem to bear on a response-function which, given current technology, can be realized in a laboratory with ultra cold atoms. As with our earlier analysis, the new response-function also leads to a logarithmic diffusion law in the quantum domain, indicating that this behavior is robust. The new response function has the additional advantage of yielding a positive mean square displacement even in the regime of ultrashort times, and more generally of complying with both "Wightman positivity" and "passivity", whose interrelationship we also discuss.

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Modeling of Wigner crystal response to external excitation

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We continued experimental studies of the earlier discovered effect of the sharp change in electron crystal conductivity under incomplete compensation of the holding potential. To understand this phenomenon the molecular dynamics studies were performed. It is shown that a most probable reason for the observed electron crystal response is not the variations in layer conductivity but rather features of the capacitive measurements of the two-dimensional electron system transport characteristics. These features are attributed to the limited size of the measured sample and the non-zero size of exciting electrode that lead to a specific distribution of the exciting field in the cell.

Thermoelectric noise – beyond thermal and shot noise

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Electronic current noise was proved to be a very useful tool for the study of electronic transport in nanoscale conductors. Up to now two fundamental types of current noise were identified: the electron thermal noise (Johnson–Nyquist noise) and shot noise (denoted as partition noise). The first is generated in equilibrium by finite temperature and the second by an applied voltage. Recently, we found indications for the generation of a new type of partition noise that is generated when a temperature gradient is applied across a nanoscale conductor. The temperature gradient breaks the symmetry of electronic transmission even in the absence of a voltage drop and has different properties in comparison to thermal or shot noise. While this "thermoelectric noise" is interesting from the fundamental point of view, it can serve as a useful temperature gradient probe, and should be taken into account when the size of electronic circuits approaches the miniaturization limit.

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A Casimir effect in a quantum mesoscopic system

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Fluctuation induced forces (FIF) are ubiquitous [1], and are caused by the confinement of long-range correlated fluctuations. They have first been predicted and measured using perfectly conducting plates immersed in the QED vacuum [2].

Here, we consider intensity fluctuations of classical light propagating through a scattering medium. In the multiple scattering regime, the average light intensity behaves diffusively. Its fluctuations are long-ranged as a result of underlying mesoscopic coherent effects [3]. The resulting FIF is described using an effective Langevin approach which properly incorporates coherent mesoscopic corrections. Its magnitude depends on the dimensionless conductance g. This Langevin description bears a strong similarity with corresponding FIF recently identified in non-equilibrium systems [4], as a result of long-ranged density fluctuations around the steady state density profile.

[1] M. Kardar, R. Golestanian. "The 'Friction' of Vacuum, and other Fluctuation-Induced Forces". Rev. Mod. Phys. 71 (1999) 4

[2] H. B. G. Casimir. "On the attraction between two perfectly conducting plates". Proc. Kon. Ned. Akad. Wet. B51 (1948) 793-795

[3] E. Akkermans, G. Montambaux. "Mesoscopic Physics of Electrons and Photons". Ed. Cambridge University Press (2007)

[4] M. Kardar, A. Aminov, Y. Kafri. "Fluctuation-Induced Forces in Nonequilibrium Diffusive Dynamics". Phys. Rev. Lett. 114 (2015) 230602

Optimal quantum interference thermoelectric heat engine with edge states

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We show theoretically that a thermoelectric heat engine, operating exclusively due to quantum-mechanical interference, can reach optimal linear-response performance. A chiral edge state implementation of a close-to-optimal heat engine is proposed in an electronic Mach-Zehnder interferometer with a mesoscopic capacitor coupled to one arm. We demonstrate that the maximum power and corresponding efficiency can reach 90% and 83%, respectively, of the theoretical maximum. The proposed heat engine can be realized with existing experimental techniques and has a performance robust against moderate dephasing.

[1] P. Samuelsson, S. Kheradsoud, and B. Sothmann, arXiv:1611.02997 (2016).

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Phase-space dynamics of quantum systems with dissipation

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The concept of a classical wavefunction in the phase space can be introduced on the basis of the Koopman-von Neumann theory. The squared modulus of the function gives the classical probability distribution function which satisfies the equation of motion in the Liouville form. The results which stem from the application of the theory to a simple but non-trivial system with dissipation term are presented, and illustrated with a careful dynamical analysis of the Wigner distribution function for the initially coherent state in the considered system. Finally, some dynamical characteristics of the system are determined within the presented approaches.

[1] D. Mauro, Int. J. Mod. Phys. A 17 (2002) 1301.

[2] W. P. Schleich, *Quantum Optics in Phase Space* (Wiley-VCH, Berlin, 2001).

[3] U. Kaczor, B. Klimas, D. Szydlowski M. Woloszyn, and B. J. Spisak, Open Phys. 14 (2016) 354.

[4] U. Weiss, *Quantum Dissipative Systems* (World Scientific Publishing Co. Pte. Ltd., Singapore, 2012).

Extracting Lyapunov exponent from echo dynamics of Bose-Einstein condensates on a lattice

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We propose theoretically an experimentally realizable method to demonstrate the Lyapunov instability and to extract the value of the largest Lyapunov exponent for a chaotic many-particle interacting system. The proposal focuses specifically on a lattice of coupled Bose-Einstein condensates in the classical regime describable by the discrete Gross-Pitaevskii equation. We suggest to use imperfect time-reversal of system's dynamics known as Loschmidt echo, which can be realized experimentally by reversing the sign of the Hamiltonian of the system. The routine involves tracking and then subtracting the noise of virtually any observable quantity before and after the time-reversal. We support the theoretical analysis by direct numerical simulations demonstrating that the largest Lyapunov exponent can indeed be extracted from the Loschmidt echo routine. We also discuss possible values of experimental parameters required for implementing this proposal.

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Strong non-linearity in high bias shot noise measurement over Au atomic contacts

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Since the work of Walter Schottky, it is known that the shot noise power for a completely uncorrelated set of electrons increases linearly with the time averaged current. At zero temperature and in the absence of inelastic scattering the linearity relation between noise power and average current still holds even for correlated electrons. By doing high bias shot noise measurement over single Au atom point contacts, that the noise power in high bias regime shows highly non-linear behaviour even leading to decrease in shot noise with voltage. We explain this non-linearity using a model based on quantum interference of electron waves with varying path difference due to scattering from randomly distributed defect sites in the leads, which makes the transmission probability for these electrons to cross the contact, both energy and voltage dependent.

Autonomous quantum heat engine using an electron shuttle

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In the last decades, quantum technologies became advanced, and physicists can now design, build and manipulate mesoscopic devices with few degrees of freedom and quantum coherence. On the other hand, classical thermodynamics is well understood only in the statistical picture by considering many degrees of freedom. Understanding the operation of thermodynamics in the mesoscopic will be crucial for the development of many quantum-based technologies. Recent theoretical works, such as [1,2], have shown how certain thermodynamic laws should be modified in quantum systems with a few degrees of freedom. However, these new laws of quantum thermodynamics are highly abstract and do not admit a clear, unambiguous physical interpretation consistent with our many intuitive notions from classical thermodynamics. This motivates the development of a quantum heat engine that can be used as a testbed to investigate these abstract ideas.

Heat engines are the heart of the thermodynamics. Different quantum heat engines have been proposed and built since 1980's (For examples looking at [3,4]). All of these engines use time-dependent, periodic Hamiltonian. Alternatively, we are interested in an autonomous quantum heat engine. Our proposed engine is a single-electron shuttle oscillating between two leads. This system was studied in [5] where it behaves as a mesoscopic electric motor driven by an external electrical bias. In contrast, our heat engine is a single-electron shuttle between two Fermi seas with the same chemical potentials but a temperature difference. Electrons can move from the high-temperature lead (source) to the low-temperature (drain) via the shuttle. The shuttle feels a force, when it carries an electron, due to the Jonson noise of the finite temperature lead. Since the average of the Johnson noise is zero; we need a rectifier to direct the force toward the drain. The rectification can be achieved by letting the shuttle oscillate in a half-harmonic potential. Moreover, we propose a quantum ratchet battery which can be charged by absorbing the phonons from the engine. Then we define the power output of the engine as the rate of the absorption by the battery.

[1] F. Brandao, M. Horodecki, N. Ng, J. Oppenheim, and S. Wehner, Proceedings of the National Academy of Sciences 112, 3275 (2015).

[2] M. Lostaglio, D. Jennings, and T. Rudolph, Nat. comm. 6 (2015).

[3] R. Kosloff, The Journal of chemical physics 80, 1625 (1984).

[4] J. Roßnagel, S. T. Dawkins, K. N. Tolazzi, O. Abah, E. Lutz, F. Schmidt-Kaler, and K. Singer, Science 352, 325 (2016).

[5] D. W. Utami, H.-S. Goan, C. Holmes, and G. Milburn, Phys. Rev. B 74, 014303 (2006).

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Bose-Einstein condensation of just a few photons

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Bose-Einstein condensation is a phase transition which does not depend on particle interactions, so is possible for bosons such as photons which interact only very weakly, if there are mechanisms which achieve thermalisation and non-zero chemical potential. We present how these conditions can be met by optically pumping a 1.5-micron long, dye-filled resonator.

The boson number at threshold for condensation depends on the confinement, in our case defined by the curvature of the mirrors. Our typical experiments use mirrors of 250 mm radius of curvature, giving about 20,000 photons at threshold. We present our recent progress using microscopic mirrors fabricated by the group of Jason Smith in Oxford using focussed ion beam milling (FIB). They have radii of curvature less than 1 mm, giving threshold numbers of fewer than 100 photons. We observe BEC threshold behaviour in the fast thermalising regime, and laser type threshold in the slow thermalising regime.

[1] J. Keeling and P. Kirton, arXiv:1506.00280 (2015)

[2] J. Klaers et al, Nat. Physics 6 (2010) 512

[3] J. Klaers et al, Nature 468 (2010) 545

[4] J. Marelic and R.A. Nyman, PRA 91 (2015) 033813

Electron waiting times of a Cooper pair splitter

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An important building block in solid-state quantum computing, is a device that can generate non-local entangled electron pairs. One such device is a Cooper pair splitter which consists of a superconducting source of Cooper pairs coupled to two normal-state drains via a double quantum dot. We study and characterize the statistical nature of a Cooper pair splitter by means of distributions of waiting times (the time between consecutive tunneling events to the normal-state drains) as well as current correlations. The splitting of a Cooper pair can be clearly identified in the distribution of waiting times. In particular, Cooper pair splitting gives a large cross waiting time distribution (the waiting time between tunneling events to different drains) at short times. We show that this signature only survives for electrons with opposite spins, thus providing evidence that the pairs originate from spin-entangled Cooper pairs. Furthermore, waiting time distributions give detailed information about the important time-scales of the transport processes. Correlations and the statistical ordering of transport processes is studied further by means of the joint waiting time distribution, and the statistical ordering of transport can be exploited in the course of time-dependent manipulation.

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Unconventional superconductivity in quantum dot systems

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The formation of electron pairs is a prerequisite of superconductivity. Due to the fermionic nature of electrons four possible classes of superconducting correlations with definite symmetry in spin, space and time exist. We present our recent work on quantum dot systems coupled weakly to conventional s-wave superconductors with infinite gap in the presence of inhomogeneous magnetic fields as a model system exhibiting unconventional pairing [1,2]. The angle resolved Andreev current is able to witness unconventional pairing correlations in the system [2], whereas the current noise gives insight into the coherent dynamics of the system. Due to their small number of degrees of freedom, tunable by gate voltages, quantum-dot systems are ideal to gain fundamental insight in unconventional pairing. Since the investigation of a finite superconducting gap is interesting and conceptually difficult to handle by perturbation theory in the tunneling strength, we extend the ISPI (iterative summation of path integrals) approach [3,4] to systems that involve superconducting leads. It is a numerically exact scheme, covering resonant tunnelling effects to all orders. The main objective to be addressed in the first place are multiple Andreev reflections in transport through quantum dot systems with finite interactions and their modifications in the presence of magnetic fields.

[1] S. Weiss and J. König, submitted (2017)

[2] B. Sothmann, S. Weiss, M. Governale and J. König, Phys. Rev. B 90, 220501 (R) (2014)

[3] S. Weiss, J. Eckel, M. Thorwart, and R. Egger, Phys. Rev. B 77, 195316 (2008)

[4] R. Hützen, S. Weiss, M. Thorwart, R. Egger, Phys. Rev B 85, 121408 (R) (2012)

Power-law decay of superconducting gap above the transition temperature by dissipation

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Stabilizing the superconductivity at higher temperature, possibly at room temperature, is one of the most important and long-standing challenges in science and technology. Nevertheless, the superconductivity is per se not exceptional: a lot of materials become superconducting near the zero temperature. The difficulty lies in preventing the closing of the superconducting gap in the thermal-equilibrium environment.

Here we show that the engineered dissipation that destabilizes quasiparticles in superconductors is particularly helpful in preventing the gap closing because the closing is caused by the stable generation of thermally-excited quasiparticles. Calculating the steady state determined by the quantum master equation and the superconducting gap equation, we clarify the dissipation effects on the gap closing of the conventional s-wave superconductor in the thermal-equilibrium environment. It is shown that the finite-superconducting-gap state is always dynamically stable in the case with dissipation even in the environment above the thermodynamic transition temperature, accompanying a power-law decay of the gap with an increase in temperature. The decay exponent is given by the inverse of the non-dimensional dissipation strength normalized by the coupling strength to the thermal environment. We also discuss a promising system and the condition to establish the dissipation: the semiconductor-superconductor-semiconductor junction where the semiconductors is two-dimensional with the particle-hole symmetry, and the bias voltage $eV = \Delta_{\mathrm{SM}}$ is symmetrically applied between the semiconductors with Δ_{SM} being the band gap.

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Quantum spectroscopy with undetected photons

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We present our experimental progress for the first demonstration of high-resolution quantum spectroscopy experiment consisting of two type-0 SPDC (spontaneous parametric down conversion) crystals pumped by a phase-locked optical frequency comb. Our quantum spectroscopy setup resembles that of the quantum Mach-Zehnder interferometer of Zeilinger's recent quantum imaging experiment [1], where the cw pump laser is replaced with the optical frequency comb in order to perform a high-resolution quantum spectroscopy. The optical samples (Fabry-Perot interferometer or an atomic/molecular cell) is positioned within the propagation path of the idler beam from the first SPDC crystal, and the transmitted idler photons from the optical sample are arranged into the second SPDC crystal and transmitted through it so that two idler photons, from the first and second SPDC crystals, becomes indistinguishable in their quantum states and reflected off the interferometer, making the two signal photons from the first and second SPDC crystals get path-entangled after the beam splitter. The spectrum of the signal photons can be analyzed by a high-resolution spectrometer in frequency domain.

A 250-MHz fiber-laser optical frequency comb of 1 W optical power with 100 fs pulse-width at 1060 nm is frequency-doubled into 530 nm with the bandwidth of 3 nm by using a non-critically phase-matched LBO crystal. The type-0 MgO:PPLN SPDC crystals emit spectrally overlapped signal beams at 810 nm and idler beams at 1540 nm, respectively. Total power of 25 mW pump beam at 530 nm is used to pump two SPDC crystals and effectively filtered out by using proper dichroic mirrors. In order to form a quantum Mach-Zehender interferometer, we overlapped not only the spatial modes of the Gaussian idler and signal beams, but also the path-lengths of the two pair of conjugate beams taking into account the dispersion of the 100 fs pulses at two non-degenerate signal and idler wavelengths. As an optical sample for the proof-of-principle experiment of high-resolution quantum spectroscopy, we used a 10 GHz Fabry-Perot scanning spectrometer so that every 40 longitudinal modes of the frequency comb modes of the idler beam intensity is modulated in their transmitted spectrum and in turn their corresponding conjugate signal beam spectral intensities. The spectral intensity modulation of the signal beam is detected by a mode-resolved VIPA (virtually imaged phase array) and grating spectrometer with a 2D array detector in the optical frequency domain.

This work was supported by IBS-R023-D1.

[1] G. B. Lemos, V. Borish, G. D. Cole, S. Ramelow, R. Lapkiewicz, and A. Zeilinger, Nature 512 (2014) 209.

The emigrated Czech scientists and music

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We want to discuss the results of the decision process that quite a number of multi-talented people had to make when they faced the alternative to devote themselves either to science or to music. We shall mainly restrict our attention to a group of Czech scientists who emigrated during the period 1952-1989 from Czechoslovakia and had been employed in the Institutes of the Czechoslovak Academy of Sciences. The fates and biographies of one hundred of them, who became widely known because of their scientific activities and achievements either before and/or during their exile, are collected in [1]. We hope that this ensemble is sufficiently large to make some, at least partial, quantitative conclusions on the distribution of interests of prospective musicians who decided in favour of and further pursued their scientific careers. On the other hand we must be rather careful with our conclusions as the mentioned set of people is not randomly selected but all of them had also decided the problem "to stay or to emigrate?" in favour of the latter possibility.

We shall be mainly interested in which categories of the later scientific specialization the strong musical temptations are found, and on the other hand, which musical field was the option [2]. The discovered tendencies will be accompanied by some characteristic examples of general concern illustrating also the level the scientists reached in music. We have to admit that our analysis is "one-sided" – we did not attempt to gather complementary information on the other group of people who decided in favour of music. And let us remark that in many cases the decision was not so hard and fast – for numerous scientists music remained their beloved hobby and *vice versa*.

[1] Soňa Štrbáňová and Antonín Kostlán, eds., Sto českých vědců v exilu, Praha, Academia 2011

[2] K. Závěta, in *Scholars in Exile and Dictatorships of the 20th Century*, Conference Proceedings, edited by Marco Stella, Soňa Štrbáňová & Antonín Kostlán (2012), pp. 399-403

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Conference Site Buildings

Pyramida Hotel

Pyramida Hotel was built in 1980 in the neo-functionalist style with an interesting star-like ground plan and pyramid-like outer shape. During 2010-2013, the hotel was modernized and some rooms were upgraded to business class. The hotel offers a wide selection of conference services.

The Pyramida Hotel is situated in the residential area of Prague called Břevnov near the Prague Castle - see map 'Prague center'. It is in the same time very near the historical center of Prague and Prague international airport - about 20 minutes by car. From the Pyramida Hotel you can reach easily many historical and important places of Prague taking trams No. 22 or No. 23 which have their stops nearly in front of the Pyramida Hotel: Prague Castle within about 5 minutes, Lesser Town is about 10 minutes, Charles Bridge area, too, Old Town and New Town centers (in the vicinity of Old Town Square and Wenceslas Square) within about 20 minutes ride.

Wallenstein Palace

Wallenstein Palace (Valdštejnský palác) is situated in the very center of the Lesser Town in close vicinity of the Lesser Town Square and the Charles Bridge. The origin of the settlement in the Lesser Town is directly linked to Prague Castle, which was founded around 880 AD. The oldest settlement of the future city named Prague was concentrated just to places below the castle. In this area the second town of Prague was later formed: the space between the river of Vltava and Prague Castle was fortified in the 13th century and the Lesser Town was founded in 1257 by the Czech King Přemysl Otakar II.

The Wallenstein Palace was built from 1624 to 1630 as a seat of the Imperial Generalissimo, Admiral of the Atlantic Ocean and the Baltic Sea, Albrecht Eusebius of Valdstein (Wallenstein) who was one of the most important figures of the Thirty Year's War. Apart from being famous as a very influential soldier (Commander-in-Chief of the Imperial Army), Wallenstein is also known for his belief in the influence of the stars. It is a very interesting experience to read personal characterization of Wallenstein in the horoscope written for him personally by Johannes Kepler. This link is not the only one which connects Wallenstein Palace with astronomy and physics: inside the Palace there is the astronomical-astrological corridor with allegories of seven planets, the leading architect who designed the Wallenstein Palace and its Sala Terrena in the huge Baroque garden was Italian Giovanni Battisto Pieronni, a student of Galileo Galilei. When designing the huge palace complex of the Wallenstein Palace, Pieronni (together with two other Italian architects A. Spezza and N. Sebregondi) combined elements of the Late Renaissance with those of the Early Baroque. He also hired the most renowned artists to participate on the art works and decoration of the palace. This resulted in the first Baroque palace complex in Prague which became a really representative and up to date as for fashion seat of Albrecht Wallenstein. By this palace the idea of Wallenstein to express his power and glory by building a magnificent palace whose size and decoration even surpassed those of the Prague Castle, was fulfilled.

To imagine the size of the Wallenstein Palace consider the fact that Wallenstein purchased twenty three houses, three gardens and the municipal brick-kiln to gain the place for his palace. The palace complex has a perimeter of almost 750 meters. It is completely separated from the outside world by walls and concentrated around a landscaped garden and five courtyards. The huge garden is famous for its monumental Baroque Sala Terrena with three open arches as well as for a number of bronze statues of ancient gods by Adriano de Vries. As for the palace rooms, the most famous place there is the Main Hall. This hall reaches to the height of two floors and its dimensions are further enlarged optically by mirror windows.

The Wallenstein Palace is nowadays the seat of the Senate of the Parliament of the Czech Republic.

How to get there:
The entrance to the Wallenstein Palace is from the Wallenstein Square which you can reach within five minutes walk either from tram and underground station Malostranská or from tram station on the Lesser Town Square (Malostranské náměstí) - see map 'Prague Castle and Wallenstein Palace neighborhood'.
Special tram will depart from the Pyramida Hotel to the Malostranská station on Monday afternoon to facilitate FQMT'17 participants transfer. Exact departure time will be announced during the Conference.
Stops Malostranská or Malostranské náměstí can also be reached from the Pyramida Hotel by tram No. 22 (23) - 5th or 6th stop.
Alternatively, you can get to the Wallenstein Palace directly from the Pyramida Hotel within 30-40 minutes of a nice walk - see maps 'Pyramida Hotel - access and nearest neighborhood' and 'Prague Castle and Wallenstein Palace neighborhood'.

National House of Vinohrady

The Neo-Renaissance National House of Vinohrady (Národní dům na Vinohradech) was built in 1894. At the end of 19th century the area of Royal Vinohrady (then an independent town) developed rapidly. The construction of the National House became one the symbols of this development. After its completion the National House of Vinohrady served as theatre and seat of various associations and clubs. Nowadays, it is a center where numerous cultural events, conferences and exhibitions take place.

The National House and the closely situated, neo-Gothic Church of St. Ludmila make prominent buildings of the Náměstí Míru (Peace Square), a main square of this part of Prague.

How to get there:
Special tram will depart from the Pyramida Hotel to the Náměstí Míru tram stop on Tuesday afternoon to facilitate FQMT'17 participants transfer. Exact departure time will be announced during the Conference.

For those who will use an **individual transfer**: The easiest way from the Pyramida Hotel is to use tram No. 22 from Malovanka stop to the Náměstí Míru stop (14 stops, about 30-35 minutes) - see the map 'National House of Vinohrady'.
Alternatively, e.g. if you want to have a dinner in some restaurant located in the Lesser Town, Old Town or New Town areas, or if your prefer speed over convenience, you can reach the Náměstí Míru by underground (metro) line A. Náměstí Míru is one of the underground station of this line - see the map 'National House of Vinohrady'. In this case, the total traveling time from the Pyramida Hotel to the National House of Vinohrady (with the change from tram No. 22 (23) to underground A at the Malostranská station) should be about 25 minutes.

Rudolfinum

The Rudolfinum was built in neo-Renaissance style in 1880's. It was originally designed as the House of Artists, in the beginning of the Czechoslovak Republic it was a seat of its Parliament, and from 1946 the Czech Philharmonic Orchestra has resided here. Dvořák's Hall of Rudolfinum is supposed to be the best Prague concert hall. Numerous classical music concerts, including events of the famous Prague Spring Festival take place there.

How to get there:
Special tram will depart from the Pyramida Hotel to the Malostranská tram stop on Wednesday afternoon to facilitate FQMT'17 participants transfer. Exact departure time will be announced during the Conference.
For those who will use an **individual transfer**: The best way from the Pyramida Hotel is first to reach the Malostranská stop by tram No. 22 (23). From this stop you can cross on foot, within 5-7 minutes, the Vltava River using the Mánesův most (Mánes Bridge). At the end of the bridge you will reach the Náměstí Jana Palacha (Jan Palach Square). The Rudolfinum building is located on the left side of this square. Alternatively, the River can be crossed by trams No. 2 or 18 or by underground (metro) line A (from Malostranská to Staroměstská stations) - see the map 'Rudolfinum'.

Prague Castle, St. Vitus Cathedral

The **Prague Castle**, the ancient seat of Czech sovereigns, now the seat of the president of the Czech Republic, is the most important historical and cultural place of Prague. Its palaces, Saint Vitus Cathedral and churches situated at the hill above the Vltava River represent the symbol of the Czech Lands. These palaces, gardens and churches create the largest castle complex in Europe. You can read more about the Prague Castle in various books on the European and Czech history besides much special literature devoted just to the Prague Castle, its history and architecture.

St. Vitus Cathedral (St. Vitus, St. Wenceslas and St. Adalbert Cathedral in full name) has been always considered to be the most important church of the Czech Lands and intimately related to the history of the Czech state. The coronations of Czech kings took place in it, and many kings are buried there.

How to get there:
Special tram will depart from the Pyramida Hotel to the Pražský Hrad tram stop on Thursday afternoon to facilitate FQMT'17 participants transfer. Exact departure time will be announced during the Conference.
For those who will use an **individual transfer**: From the Pyramida Hotel you can reach the Prague Castle (see maps 'Pyramida Hotel - access and nearest neighborhood' and 'Prague Castle and Wallenstein Palace neighborhood'):

1. either by about 20 minutes walk, starting down along the Bělohorská street (the main street where the Pyramida Hotel is situated)
2. or by tram No. 22 or 23 (1 stop, about 2 minutes) down along Bělohorská street from the stop Malovanka to the stop Pohořelec, from where you can reach the Prague Castle within 15 minutes walk
3. or going by tram No. 22 or 23 (3 stops, 5 minutes) to the Pražský Hrad stop from where you can reach the central part of the Prague Castle by a side entrance within 5 minutes walk.

The St. Vitus Cathedral is situated in the central part of the Prague Castle - see map 'Prague Castle and Wallenstein Palace neighborhood'.

Břevnov Monastery

The **Břevnov Monastery** (Břevnovský klášter) was founded as the first monastery in Bohemia by Prince Boleslav II and Saint Adalbert (Vojtěch) of the Slavnik dynasty, Bishop of Prague already in 993 AD. The monastery was built amidst forests, at the source of the Brusnice stream and on a road leading westwards from Prague. For centuries there was only a small settlement around the monastery which was later on surrounded by farms. This Benedictine monastery, however, played the decisive role for the spreading of culture and art in Czech Lands.

The oldest parts of the monastery date back to the 10th century. In 1964 the Pre-Romanesque crypt (open nowadays to the public) of the original 10th century church was discovered below the choir of the present St. Margaret Church. Neither the Romanesque nor the Gothic buildings of the monastery survived. From the 15th century on, the monastery was in a state of poverty for three centuries. During 18th century it was largely rebuilt in the Baroque style.

Most of the Monastery's present day buildings are dated from 1708 to 1745 and were built in Baroque style by Christoph Dientzenhofer. The same architect also erected the Church of St. Margaret, which is considered to be one of the most remarkable works of Czech Baroque architecture. The presbytery of the church was built by Christoph's son, Kilian Ignaz Dientzenhofer, architect of many important Baroque churches and palaces of Prague. The altarpieces are the work of Peter Brandl, one of the best Czech painters of high Baroque era.

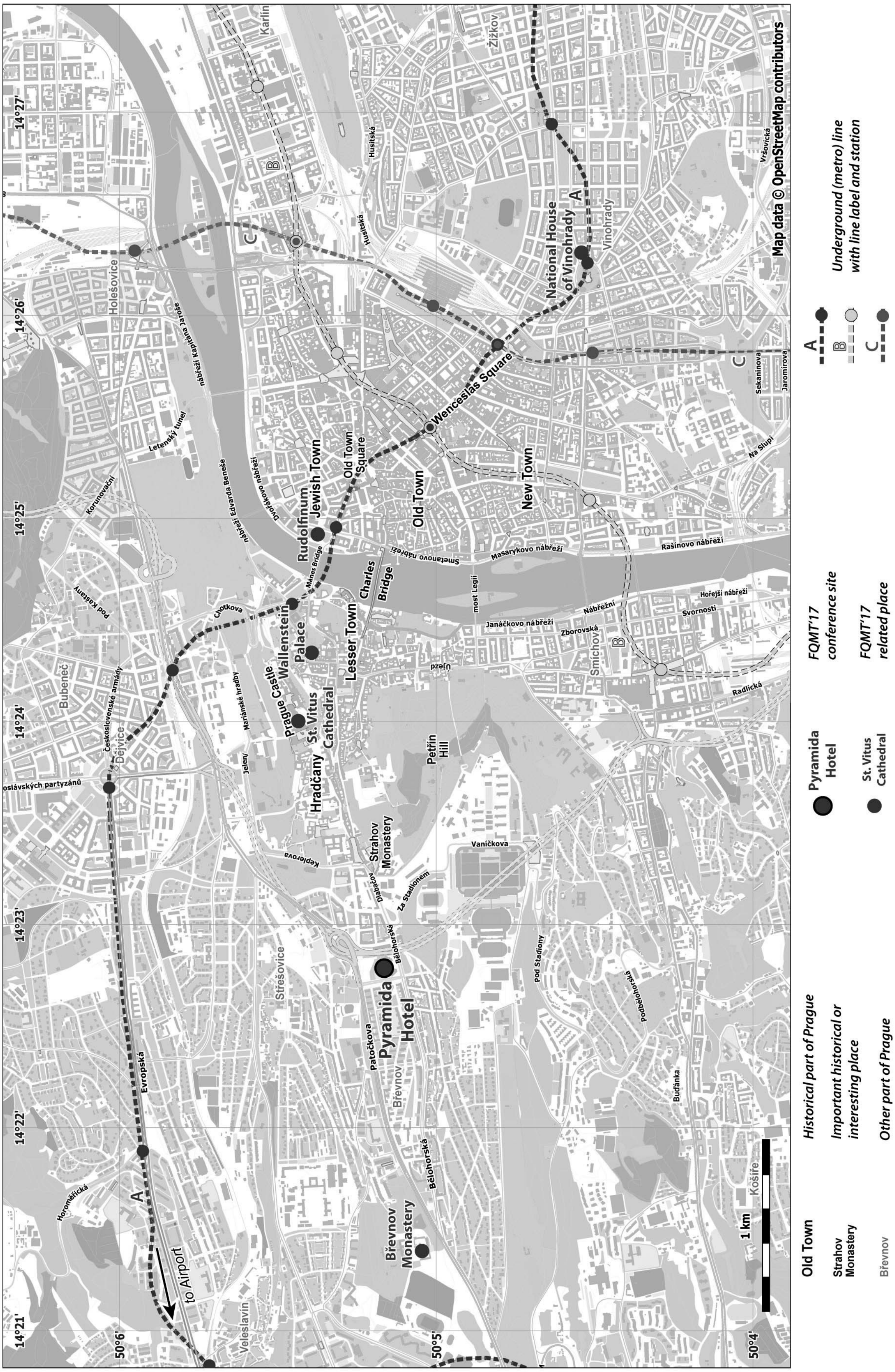
The interiors of the Břevnov Monastery are decorated by valuable paintings; e.g. in the former ceremonial hall of the monastery, nowadays called Theresian Hall, there is a ceiling painting the Miracle of the Blessed Gunther painted by Kosmas Damian Asam of Bavaria in 1727. This is one of the best preserved ceiling paintings in Prague. The entrance to the monastery is through the ornamented main gateway built by Kilian Ignaz Dientzenhofer in 1740 and decorated with a statue of St. Benedictine. The main building of the monastery complex can be reached then by crossing a large courtyard.

Behind the monastery is situated its large Baroque garden. At its gate is a nice Baroque pavilion called Vojtěška with a chapel above a well which marks the spot where Prince Boleslav and Bishop Vojtěch are supposed to have met and decided to build the Břevnov Monastery.

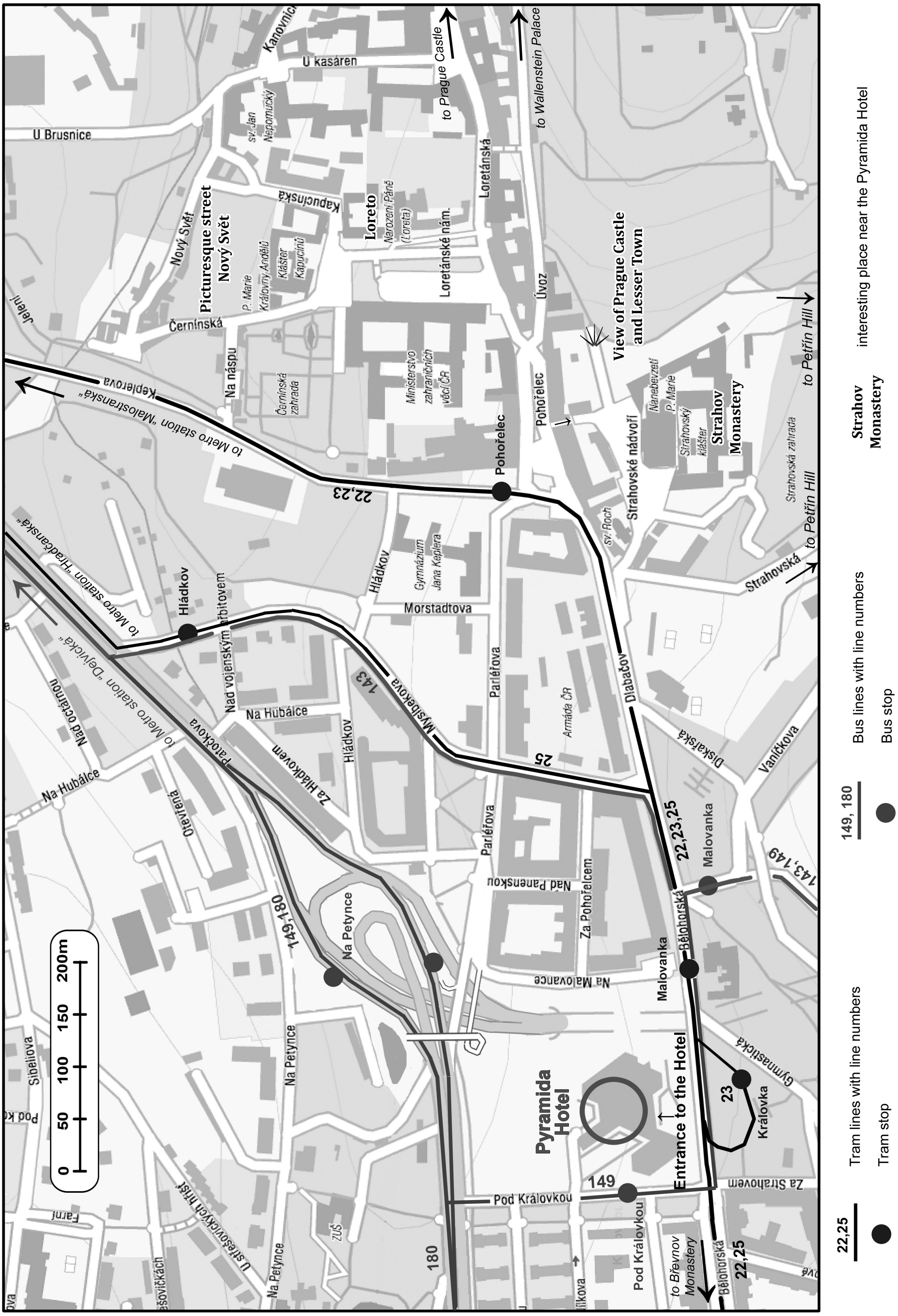
How to get there:
Special tram will depart from the Pyramida Hotel to the Břevnovský klášter stop on Friday afternoon to facilitate FQMT'17 participants transfer. Exact departure time will be announced during the Conference.
For those who will use an **individual transfer**: The best way from the Pyramida Hotel is to use tram No. 22 or No. 25 (starting up along the Bělohorská street) and reach the Břevnovský klášter stop (4th stop, about 5 minutes). From this stop walk right with respect to the direction in which the tram arrived, cross a wide road (Patočkova street). From here you will see the monastery entrance within about 100 m distance.

Maps

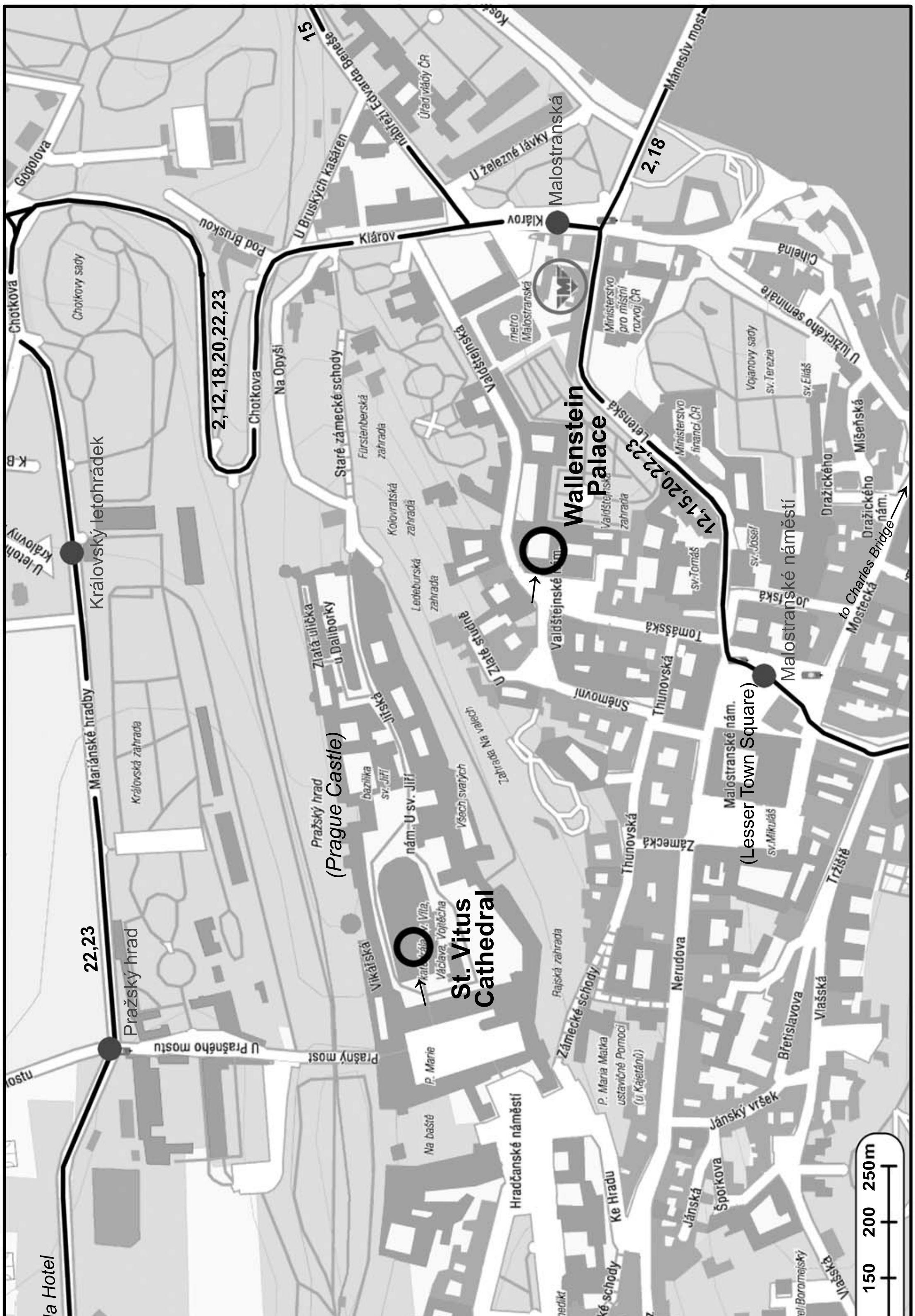
Prague center



Pyramida Hotel - access and nearest neighborhood



Prague Castle and Wallenstein Palace neighborhood



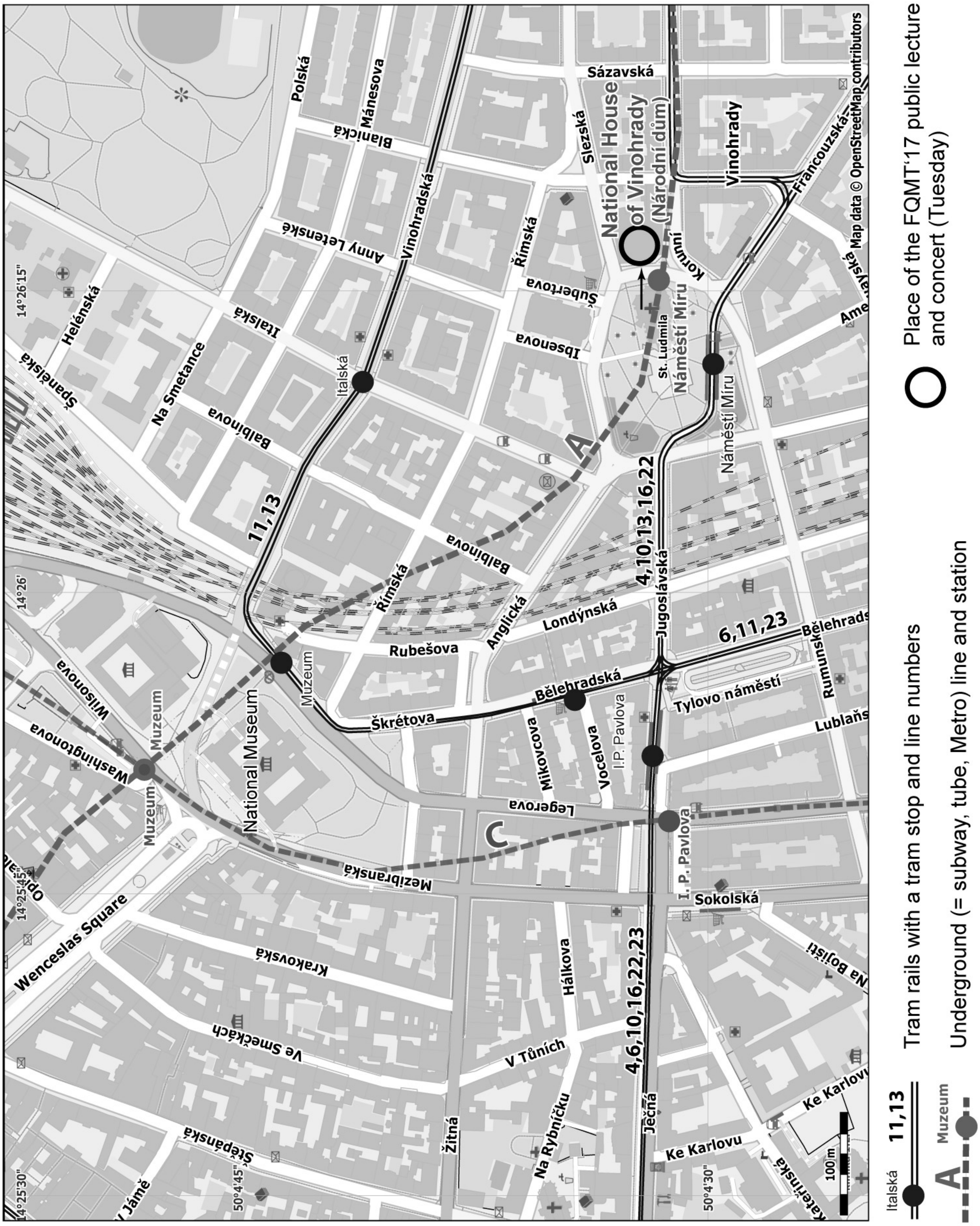
22,23 Tram line with line numbers

Tram stop

Line A underground (= subway, tube, Metro) station

FQMT'17 relevant places

National House of Vinohrady (place of Tuesday's public lecture and concert)



Rudolfinum (place of Wednesday‘s public lecture and concert)