Frontiers of Quantum and Mesoscopic Thermodynamics

27 July - 1 August 2015, Prague, Czech Republic

Under the auspices of

Ing. Miloš Zeman
President of the Czech Republic

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

Prof. Ing. Jiří Drahoš, DrSc., dr. h. c.
President of the Academy of Sciences of the Czech Republic

Dominik Cardinal Duka OP
Archbishop of Prague

Supported by

- Committee on Education, Science, Culture, Human Rights and Petitions of the Senate of the Parliament of the Czech Republic
- Institute of Physics, the Academy of Sciences of the Czech Republic
- 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

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

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Rudy Schild (Center for Astrophysics, Harvard)
Wolfgang Schleich (University of Ulm)
Marlan Scully (Texas A&M University and Princeton University)
Georgy Shlyapnikov (Universite Paris Sud)
Gerard 't Hooft (Spinoza Institute, Utrecht University)
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Frank Wilczek (MIT Center for Theoretical Physics)
Anton Zeilinger (University of Vienna)
Peter Zoller (Institute for Quantum Optics and Quantum Information, Innsbruck)

Organized by

- Institute of Physics, the Academy of Sciences of the Czech Republic
- Committee on Education, Science, Culture, Human Rights and Petitions of the Senate of the Parliament of the Czech Republic

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Preface

Recent progress in technologies has led to enormous improvements of measurement and observation techniques, both at microscopic as well as macroscopic scales, which allow us to measure many characteristics and observe many features of various systems. These include not only very small artificial 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 atoms (molecules) in the number range of between several and hundreds and to create 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 details to observe the quantum phenomena in order to obtain a deeper understanding of quantum physics, as represented by quantum interference phenomena, entanglement, the uncertainty principle, non-locality and quantum measurement.

All these developments have brought new questions and challenges for the understanding the behavior of various systems and structures, both of natural and of artificial origin. They have also opened a vast arena for better tests of foundations of theories, hypothesis, and models, which are being used to improve our understanding of the world around us. In this situation, it is advantageous to discuss experiences from different fields of physics which are studying various aspects of microscopic and macroscopic systems, both from the point of view of theory and experiments, in order to design new possible tests leading to better understanding of foundations.

The conference will be focused on foundations of quantum physics, quantum many body physics, and non-equilibrium statistical physics. As for systems which enable the study of these foundations, the conference will deal mainly with mesoscopic systems. The main goal of the conference is to contribute to a better understanding of the behavior of mesoscopic systems, and to provide insight into the problems of the foundations, relying on the theoretical and experimental methods of condensed matter physics and quantum optics. Special attention will be given to non-equilibrium quantum systems and physics of quantum information in terms of both theory and experiment. Subjects from astrophysics, gravitation or cosmology related to the above scope will also be included.

FQMT'15 is a follow-up to the four previous, successful Prague conferences "Frontiers of Quantum and Mesoscopic Thermodynamics" (FQMT'04, FQMT'08, FQMT'11, and FQMT'13). For the details of their programs and the history of the FQMT conferences see the www pages http://fqmt.fzu.cz/. The title of the conference is historical and survives due to tradition. Today its meaning corresponds only partly to the actual topics of the FQMT'15 conference. The contributions from the previous conferences have been published in Physica E (vol. 29, issues 1-2, 2005, and vol. 42, issue 3, 2010), and Physica Scripta (vol. T151, 2012). Contributions from the FQMT'13 will appear in the Physica Scripta journal, as well.

As in the foregoing FQMT conferences, the aim of FQMT'15 is to create a bridge between the fields of modern condensed matter physics, quantum optics and statistical physics and the quickly developing field of foundations of quantum physics. Following the tradition of the FQMT conferences, FQMT'15 will bring together a unique combination of both young and experienced scientists across a disciplinary spectrum ranging from foundations of quantum physics to emerging statistical physics approaches to the study of non-equilibrium quantum systems. The interdisciplinary character of the conference will be supported by 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, 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 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, quantum statistical physics of finite systems far from equilibrium and the physics of nanoscale systems, and further, will motivate new collaboration and intensive discussions between experts from differing fields (i.e., 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'15 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'15 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

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Emergency phone numbers (free calls):

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

Conference Sites

The FQMT'15 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:
St. Simon and Juda Church
address: Dušní ulice, Praha 1 - Staré Město

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 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.
So, participants are kindly asked to come to the Wallenstein Palace not at the last moment just before the beginning of guided tours.

When entering and moving inside the Wallenstein Palace, all participants are requested to have with them their badges which they will receive during the registration; badges will also serve as the identity card for the security guards in the Wallenstein palace.

Rooms and facilities available for the participants

Pyramida Hotel

- Pyramida Lecture Hall (ground floor): Most talks will be presented there
- Cinema Hall (basement floor) and smaller halls will be used for some parallel sessions
- Lobby of Pyramida 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'15 participants

Posters

Poster session will be held on Thursday (July 30). 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 27
- Welcome party: Wallenstein Palace Garden, Monday July 27
- First public lecture: St. Simon and Juda Church, Tuesday July 28
  This evening lecture will be given by Marlan O. Scully.
- Classical music concert: St. Simon and Juda Church, Tuesday July 28
- Second public lecture: Dvořák's Hall of Rudolfinum, Wednesday July 29
  This evening lecture will be given by Gerard 't Hooft.

- Classical music concert: Dvořák's Hall of Rudolfinum, Wednesday July 29
- Classical music concert: St. Vitus Cathedral, Thursday July 30
- Tour of Břevnov Monastery: Břevnov Monastery, Friday July 31
- Conference dinner: Břevnov Monastery, Friday July 31
- Classical music concert: St. Margaret Church of Břevnov Monastery, Friday July 31
- Guided tour through Prague: Saturday August 1

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 Marlan Scully, 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 St. Simon and Juda Church).
- **Wednesday:** There will be enough time to go for dinner before the public lecture of Gerard 't Hooft, 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, 26 July 2015

17:00 – 21:00 Registration and welcome refreshment
Location: Pyramida Hotel - lobby

Monday, 27 July 2015

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: Saar Rahav)

08:30 – 09:00	Christopher Jarzynski:	*Thermodynamics in the presence of large system-environment coupling*
09:00 – 09:30	David Jennings:	*Thermodynamics in extreme quantum regimes*
09:30 – 10:00	Gershon Kurizki:	*Quantum resources may boost the performance of heat machines*

10:00 – 10:20 Coffee break

10:20 – 12:10 **2 session: Quantum measurement**

Location: Pyramida Hotel Lecture Hall
(chairperson: Hans De Raedt)

10:20 – 10:50	Andrew Jordan:	*The quantum road most taken*
10:50 – 11:20	Paul Kwiat:	*Making weak measurements stronger*
11:20 – 11:50	Wolfgang Belzig:	*Non-Markovian weak measurements in quantum transport*
11:50 – 12:10	Lawrence S. Schulman:	*Quantum mechanics, special states and experiment*

12:10 – 13:00 Lunch

13:00 – 14:30 **3 session: Quantum experiments**

Location: Pyramida Hotel Lecture Hall
(chairperson: David Vitali)

13:00 – 13:30	Markus Arndt:	*Quantum optics experiments with biomolecular matter*
13:30 – 14:00	Jakob Reichel:	*Many-body entanglement of ultracold atoms in optical fiber microcavities*

14:00 – 14:30	Marco Gramegna:	*Time emerging from quantum entanglement: Illustration of a first experimental approach*
14:30 – 14:50	Coffee break	

14:50 – 16:50 **4 session: Foundations of quantum physics**

Location: Pyramida Hotel Lecture Hall

(chairperson: Ana María Cetto)

14:50 – 15:20	Gerard 't Hooft:	*The cellular automaton interpretation of quantum mechanics*
15:20 – 15:50	Gerard J. Milburn:	*Time and temperature in quantum physics*
15:50 – 16:20	Roger Balian:	*Minimalist principles needed to interpret ideal quantum measurements*
16:20 – 16:50	Shmuel Gurvitz:	*Does the measurement take place when nobody observes it?*
16:50 – 17:50	Free time and transfer to Wallenstein Palace	

17:50 – 22:30 **Guided tour and Welcome party**

Location: Wallenstein Palace and its Garden

17:50 – 19:20	Guided tour through the Wallenstein Palace
19:30 – 22:30	**Welcome party in the Wallenstein Palace Garden**

Tuesday, 28 July 2015

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

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

08:00 – 08:30	Georgy Shlyapnikov:	*Many-body physics with ultracold quantum gases in disorder*
08:30 – 09:00	Frédéric Chevy:	*Counterflowing superlfuid mixtures*
09:00 – 09:30	Michel Brune:	*Dipole interactions in a cold Rydberg gas for quantum simulation*
09:30 – 10:00	Rainer Blatt:	*Quantum information science with trapped Ca^+ ions*

10:00 – 10:20	Coffee break

10:20 – 12:10	**2 session: Entanglement**

Location: Pyramida Hotel Lecture Hall
(chairperson: Jakob Reichel)

10:20 – 10:50	Nicolas Gisin:	*"Macroscopic" entanglement*
10:50 – 11:20	Jonathan Lavoie:	*Light-matter micro-macro entanglement*
11:20 – 11:50	Yeong-Cherng Liang:	*Exploring the limits of quantum nonlocality with entangled photons*
11:50 – 12:10	Thomas L. Schmidt:	*Detecting nonlocal Cooper pair entanglement by optical Bell inequality violation*

12:10 – 13:00	Lunch

13:00 – 14:40	**3 session - A parallel: Topological states of matter**

Location: Pyramida Hotel Lecture Hall A
(chairperson: Thomas Vojta)

13:00 – 13:30	Ady Stern:	*The making and breaking of non-abelian anyons*
13:30 – 14:00	Yigal Meir:	*Edge reconstruction and spontaneous time reversal symmetry breaking in topological insulators*
14:00 – 14:20	Sam T Carr:	*Emergent topological properties in interacting 1D systems with spin-orbit coupling*

14:20	–	14:40	Nathan Goldman:	*Creating topological matter in cold atomic gases: The Chern-number measurement*

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

Location: Pyramida Hotel Lecture Hall B
(chairperson: Michael Kastner)

13:00	–	13:30	Giuseppe Falci:	*Adiabatic manipulation of architectures of multilevel artificial atoms*
13:30	–	14:00	Elisabetta Paladino:	*Quantum control of two-qubit gates via dynamical decoupling filtering of 1/f noise*
14:00	–	14:20	Alex Retzker:	*Increasing sensing resolution with error correction*
14:20	–	14:40	Wilfred G. van der Wiel:	*Evolution of a disordered nanoparticle network into Boolean logic*

13:00 – 14:40 **3 session - C parallel: Quantum transport**

Location: Pyramida Hotel Conference Room 3
(chairperson: Yaroslav Blanter)

13:00	–	13:30	David K Ferry:	*Conductance fluctuations in semiconductors*
13:30	–	14:00	James Freericks:	*Theoretical description of pump/probe experiments in electron-phonon coupled superconductors*
14:00	–	14:20	Irena Knezevic:	*Quantum cascade lasers: A nonequilibrium physics playground*
14:20	–	14:40	Frithjof Anders:	*Spin noise in the anisotropic central spin model*
14:40	–	15:00	Coffee break	

15:00 – 16:40 **4 session - A parallel: Many body physics**

Location: Pyramida Hotel Lecture Hall A
(chairperson: Dietrich Belitz)

15:00	–	15:30	Jens Eisert:	*10 people in the room, 10 opinions on many-body localisation*
15:30	–	16:00	Maxim G Vavilov:	*Response to a local quench of a system near many body localization*

16:00	–	16:20	Meydi Ferrier:	*Universality of non-equilibrium fluctuations in strongly correlated quantum liquids*
16:20	–	16:40	Bryan Dalton:	*Grassmann phase space theory for fermions*

15:00 – 16:40 **4 session - B parallel: Astrophysics and cosmology**

Location: Pyramida Hotel Lecture Hall B

(chairperson: Mordehai Milgrom)

15:00	–	15:30	Pavel Kroupa:	*The emergence of super massive black holes and their correlation with galaxy properties*
15:30	–	16:00	Philipp Haslinger:	*Atom-interferometry limits on dark energy*
16:00	–	16:20	Theo M. Nieuwenhuizen:	*Neutrino dark matter and turbulence in the plasma: A perfect couple*
16:20	–	16:40	Nader Inan:	*The interaction of gravitational waves with superconductors*

15:00 – 16:40 **4 session - C parallel: Quantum transport**

Location: Pyramida Hotel Conference Room 3

(chairperson: Michael Thorwart)

15:00	–	15:30	Uri Peskin:	*Coherent and incoherent control of single molecule junctions: Steady states and beyond*
15:30	–	16:00	Fabio Taddei:	*Improving thermoelectric conversion with multi-terminal superconducting systems*
16:00	–	16:20	Mauro Antezza:	*Non-equilibrium quantum manipulation: From robust entanglement to quantum thermal machines*
16:20	–	16:40	Andrea Hofmann:	*Out-of equilibrium thermodynamics with single electron counting experiments*

16:40 – 18:30 Free time and transfer to Simon and Juda

18:30 – 21:30 **Evening session: Public lecture of Marlan Scully and concert**

Location: St. Simon and Juda Church

(chairperson: Peter Keefe, Václav Špička)

18:30	–	18:45	Music introduction and opening address
18:45	–	20:00	Public lecture

18:45	–	19:45	**Marlan O. Scully:** ***The photon sheds light on the quantum***
19:45	–	20:00	Discussion after the lecture of Marlan Scully
20:00	–	20:20	Break
20:20	–	21:30	**Concert of classical music**

Wednesday, 29 July 2015

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

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

08:00	–	08:30	Udo Seifert:	*Universal thermodynamic inequalities for biomolecular processes*
08:30	–	09:00	Ivan M. Khaymovich:	*Stochastic thermodynamics in single electron circuits*
09:00	–	09:30	Peter Hänggi:	*Quantum fluctuation theorems: The state of the art*
09:30	–	10:00	Yuli Nazarov:	*Rényi entropy flows from quantum heat engines*

10:00	–	10:20	Coffee break	

10:20	–	12:10	**2 session - A parallel: General physics**	

Location: Pyramida Hotel Lecture Hall A
(chairperson: Roger Balian)

10:20	–	10:50	Amir Ordacgi Caldeira:	*Testing time reversal symmetry in artificial atoms*
10:50	–	11:20	Luiz Davidovich:	*Quantum metrology: Towards the ultimate precision limits in parameter estimation*
11:20	–	11:50	Alexander Unzicker:	*On the origin of the constants c and h*
11:50	–	12:10	Jiří J. Mareš:	*Infiniteness – a fundamental misconception in physics*

10:20	–	12:10	**2 session - B parallel: Biological systems, quantum physics**	

Location: Pyramida Hotel Lecture Hall B
(chairperson: Joan Vaccaro)

10:20	–	10:50	Reinhard Lipowsky:	*From in-vitro to in-vivo kinetics of biomolecular machinesvia kinetic distance minimization*
10:50	–	11:20	Ofer Biham:	*Competition, feedback and fluctuations in transcriptional and post-transcriptional regulatory networks in cells*
11:20	–	11:50	Andrei Khrennikov:	*Quantum-like modeling of cognition: On violation of Aumann theorem*

11:50	–	12:10	Michael J W Hall:	*Can quantum phenomena be modelled via interactions between many classical worlds?*

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

Location: Pyramida Hotel Conference Room 3

(chairperson: Uri Peskin)

10:20	–	10:50	Michael Thorwart:	*Iterative path integral approach to nonequilibrium quantum transport*
10:50	–	11:20	Michael Thoss:	*Quantum transport in molecular junctions: Vibrational effects and time-dependent phenomena*
11:20	–	11:50	Michele Campisi:	*Nonequilibrium fluctuations in quantum heat engines: Theory, example, and possible solid state experiments*
11:50	–	12:10	Rafael Sánchez:	*Three terminal quantum Hall thermoelectrics*

12:10	–	13:00	Lunch

13:00	–	14:40	**3 session - A parallel: Optomechanics**

Location: Pyramida Hotel Lecture Hall A

(chairperson: Yaroslav Blanter)

13:00	–	13:30	Andrew Armour:	*Quantum non-linear dynamics of photons and Cooper-pairs in a Josephson junction-cavity system*
13:30	–	14:00	Pascal Simon:	*Quantum electrodynamics of quantum conductors in micro-waves cavity*
14:00	–	14:20	Oriol Romero-Isart:	*Near-field levitated quantum optomechanics with nanodiamonds*
14:20	–	14:40	Alexia Auffèves:	*Reversible work extraction in a hybrid opto-mechanical system*

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

Location: Pyramida Hotel Lecture Hall B
(chairperson: Frédéric Chevy)

13:00	–	13:30	Linda E. Reichl:	*Sound mode decay in Bose-Einstein condensates*
13:30	–	14:00	Fernando Sols:	*Hawking radiation from sonic black holes in flowing atom condensates*
14:00	–	14:20	Nir Navon:	*Exploring the dynamics of BEC in a box potential*
14:20	–	14:40	Jean-Philippe Brantut:	*Quantum point contacts for cold atoms*

13:00	–	14:40	**3 session - C parallel: Quantum transport**	

Location: Pyramida Hotel Conference Room 3
(chairperson: James Freericks)

13:00	–	13:30	Howard J. Carmichael:	*Time-local master equations: The coherently driven qubit with delayed coherent feedback*
13:30	–	14:00	Ilya Sinayskiy:	*Microscopic derivation of open quantum Brownian motion*
14:00	–	14:20	Michael Marthaler:	*Switching between stable states in quantum systems far from equilibrium*
14:20	–	14:40	Vyacheslavs Kashcheyevs:	*Shaping of on-demand electron wave-packets by tunnel-barrier design*
14:40	–	15:00	Coffee break	

15:00	–	17:00	**4 session - A parallel: Optomechanics**	

Location: Pyramida Hotel Lecture Hall A
(chairperson: Andrew Armour)

15:00	–	15:30	Yaroslav M. Blanter:	*Non-linear microwave optomechanics*
15:30	–	16:00	Vittorio Peano Cavasola:	*Topological phases of sound and light in an optomechanical array*
16:00	–	16:20	David Vitali:	*Probing deformed commutators with macroscopic harmonic oscillators*
16:20	–	16:40	Nikolai Kiesel:	*Thermodynamic cycles using levitated optomechanics*
16:40	–	17:00	Jason Twamley:	*Engineering mesoscopic quantum systems using quantum magneto-mechanics*

15:00	–	17:00	**4 session - B parallel: Spins, quantum transport**	
			Location: Pyramida Hotel Lecture Hall B	
			(chairperson: Fernando Sols)	
15:00	–	15:30	Kenji Maeda:	*Ultracold molecules: Quantum simulation of many-body spin and dipolar systems*
15:30	–	16:00	Oren Tal:	*Controlling spin transport and magnetoresistance at the atomic scale*
16:00	–	16:20	Etienne Maréchal:	*Dipolar chromium atoms: Spin dynamics in optical lattices and thermodynamics*
16:20	–	16:40	Boris Fine:	*Nonsecular resonances of interacting nuclear spins in solids*
16:40	–	17:00	Andrei D. Zaikin:	*Noise and full counting statistics of quantum phase slips*

15:00	–	17:00	**4 session - C parallel: Thermalisation**	
			Location: Pyramida Hotel Conference Room 3	
			(chairperson: Joachim Ankerhold)	
15:00	–	15:30	Vladimir G Zelevinsky:	*Quantum chaos and thermalization in a mesoscopic many-body system*
15:30	–	16:00	Gregoire Ithier:	*Thermalisation of a quantum system from first principles*
16:00	–	16:20	Lea F Santos:	*Relaxation process of interacting quantum systems*
16:20	–	16:40	Doron Cohen:	*Minimal models for superfluidity and thermalization*
16:40	–	17:00	Hyunggyu Park:	*Energetics and efficiency of an information engine*
17:00	–	18:30	Free time and transfer to Rudolfinum	

18:30	–	21:30	**Evening session: Public lecture of Gerard ’t Hooft and concert**	
			Location: Rudolfinum - Dvořák’s Hall	
			(chairperson: Peter Keefe, Václav Špička)	
18:30	–	18:45	Music introduction and opening address	
18:45	–	20:00	Public lecture	
18:45	–	19:45	**Gerard ’t Hooft:**	***The quantum deep down***
19:45	–	20:00	Discussion after the lecture of Gerard ’t Hooft	
20:00	–	20:20	Break	
20:20	–	21:30	**Concert of classical music**	

Thursday, 30 July 2015

08:00 – 10:00	**1 session: Electrons, photons, optomechanics**	

Location: Pyramida Hotel Lecture Hall
(chairperson: Michel Brune)

08:00 – 08:30	Daniel Esteve:	*Quantum optics with microwave photons in superconducting circuits*
08:30 – 09:00	Joachim Ankerhold:	*Charge transfer meets circuit quantum electrodynamics: From Coulomb blockade to nonlinear quantum dynamics*
09:00 – 09:30	Christoph Bruder:	*Quantum synchronization*
09:30 – 10:00	Christian Schönenberger:	*Cooper-pair splitting and spectroscopy in quantum dot devices with superconducting charge injectors*

10:00 – 10:20 Coffee break

10:20 – 12:10	**2 session: Many body physics**	

Location: Pyramida Hotel Lecture Hall A
(chairperson: Ted Kirkpatrick)

10:20 – 10:50	Giorgio Parisi:	*Low temperature behaviour of supercooled liquids in the quantum regime*
10:50 – 11:20	Yoseph Imry:	*Slow relaxation in the electron glass*
11:20 – 11:50	Michael Pollak:	*Many body effects in strongly disordered electronic systems*
11:50 – 12:10	Igor Lerner:	*The role of duality in a 1D transport of interacting particles through a constriction*

12:10 – 13:00 Lunch

13:00 – 14:40	**3 session - A parallel: Phase transitions**	

Location: Pyramida Hotel Lecture Hall A
(chairperson: Igor Lerner)

13:00 – 13:30	Thomas Vojta:	*How random is topological disorder? Phase transitions and localization on random lattices*

13:30	–	14:00	Ted Kirkpatrick:	*Scaling at quantum phase transitions: General concepts with applications to clean metallic ferromagnets*
14:00	–	14:20	Dietrich Belitz:	*Scaling at quantum phase transitions: Disordered quantum ferromagnets*
14:20	–	14:40	Pavel Holba:	*Ehrenfest classification of phase transitions and phase diagrams*

13:00 – 14:40 **3 session - B parallel: Spin systems, superconductivity**

Location: Pyramida Hotel Lecture Hall B

(chairperson: Andrei Zaikin)

13:00	–	13:30	Nadav Katz:	*Quantifying and controlling superconducting circuits*
13:30	–	14:00	Yoram Alhassid:	*Mesoscopic superconductivity in nanoscale metallic grains*
14:00	–	14:20	Gilles Montambaux:	*Geometric effects on the orbital magnetism*
14:20	–	14:40	Jan von Delft:	*DMFT+NRG study of spin-orbital separation in a three-band Hund's metal*

13:00 – 14:40 **3 session - C parallel: Foundations of quantum physics**

Location: Pyramida Hotel Conference Room 3

(chairperson: Kristel Michielsen)

13:00	–	13:30	Gregg Jaeger:	*Conceptualizing measurement*
13:30	–	14:00	Ana María Cetto:	*Contribution of the vacuum fluctuations to blackbody radiation*
14:00	–	14:20	Luis de la Peña:	*Dynamics of a confined quantum particle*
14:20	–	14:40	Ehtibar Dzhafarov:	*Contextuality in systems with measurement errors and signaling*

14:40 – 15:00 Coffee break

15:00 – 16:00 **4 session - A parallel: Quantum information, entanglement**

Location: Pyramida Hotel Lecture Hall A

(chairperson: Elisabetta Paladino)

15:00	–	15:20	Mazyar Mirrahimi:	*Cat-qubits: A new protocol for quantum information processing with superconducting circuits*
15:20	–	15:40	Erhan Saglamyurek:	*A multiplexed quantum light-matter interface for fiber-based quantum networks*

15:40	–	16:00	Michael Kastner:	*Propagation of correlations and entanglement in long-range lattice models*

15:00	–	16:00	**4 session - B parallel: Quantum optics**

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

15:00	–	15:20	Radim Filip:	*Nonlinear operations with quantum states of light*
15:20	–	15:40	Serge Rosenblum:	*Demonstration of deterministic photon-photon interactions with a single atom*
15:40	–	16:00	Carsten Robens:	*Quantum walks with neutral atoms*

15:00	–	16:00	**4 session - C parallel: Quantum thermodynamics**

Location: Pyramida Hotel Conference Room 3
(chairperson: Marlan Scully)

15:00	–	15:20	Peter David Keefe:	*Bardeen hysteresis: A quantum mechanical basis for the second law?*
15:20	–	15:40	Daniel P. Sheehan:	*Breakdown of the second law of thermodynamics in heterogeneous gas-surface reactions: Theory and experiment*
15:40	–	16:00	Dragos-Victor Anghel:	*The BCS theory in the fractional exclusion statistics formalism*

16:00	–	16:20	Free time

16:20	–	18:00	**Special talks**

Location: Pyramida Hotel Lecture Hall
(chairperson: Pavel Kroupa, Václav Špička)

16:20	–	17:00	Francois Hammer:	*Dark matter probes at different astronomical scales*
17:00	–	17:40	Mordehai Milgrom:	*Scale invariance at low accelerations: An alternative to dark matter*
17:40	–	18:00	Discussion	

18:00 – 20:00	**Poster session and refreshment**
	Location: Pyramida Hotel - first floor
20:00 – 21:00	Free time and transfer to St. Vitus Cathedral
21:00 – 22:10	**Concert of classical music**
	Location: Prague Castle - St. Vitus Cathedral

Friday, 31 July 2015

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

Location: Pyramida Hotel Lecture Hall
(chairperson: Jürgen Stockburger)

08:00 – 08:30	Hermann Grabert:	*Response of dissipative quantum systems to driven bath modes*
08:30 – 09:00	Ulrich Weiss:	*Functional integral approach to time-dependent heat exchange in open quantum systems*
09:00 – 09:30	Alfredo Levy Yeyati:	*Electron-phonon interactions and quantum noise in molecular junctions*
09:30 – 10:00	Andrew White:	*Going down drains into blind alleys: From reality to causality in the quantum world*
10:00 – 10:20	Coffee break	

10:20 – 12:10	**2 session - A parallel: Fluctuations**	

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

10:20 – 10:50	Liliana Arrachea:	*Time-resolved heat transport and extended thermoelectrics for ac-driven quantum systems*
10:50 – 11:20	Yasuhiro Utsumi:	*Fluctuation theorem for a small engine and magnetization switching by spin torque*
11:20 – 11:50	Jerzy Łuczka :	*Efficiency of the SQUID ratchet*
11:50 – 12:10	Saar Rahav:	*Stochastic pumps of interacting particles*

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

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

10:20 – 10:50	Angus MacKinnon:	*Transport in a quantum shuttle*
10:50 – 11:20	Gianluca Stefanucci:	*NEGF approach to pump-probe photoabsorption spectroscopy*
11:20 – 11:50	Jürgen T. Stockburger:	*Nonequilibrium steady states in open quantum systems: Stochastic mapping and exact results*

11:50	–	12:10	Peter Schmitteckert:	*Electronic transport through interacting nano structures: beyond the scattering state solution*

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

Location: Pyramida Hotel Conference Room 3
(chairperson: Yoram Alhassid)

10:20	–	10:50	Mike Guidry:	*SO(8) fermion dynamical symmetry and quantum Hall states for graphene in a strong magnetic field*
10:50	–	11:20	Ralf Schützhold:	*Giant magneto-photoelectric effect in suspended graphene*
11:20	–	11:50	Efrat Shimshoni:	*Collective edge modes near the onset of a graphene quantum spin Hall state*
11:50	–	12:10	Alessandro De Martino:	*Electric-dipole-induced universality for Dirac fermions in graphene*

12:10 – 13:00 Lunch

13:00 – 14:40 **3 session: Quantum optics**

Location: Pyramida Hotel Lecture Hall
(chairperson: Wolfgang Schleich)

13:00	–	13:30	Marlan O. Scully:	*Single photon superradiance and subradiance*
13:30	–	14:00	Marc Cheneau:	*Atomic Hong-Ou-Mandel experiment*
14:00	–	14:30	Norbert Kroo:	*Surface plasmon assisted electron pairing in gold at room temperature*
14:30	–	15:00	Tamar Seideman:	*Coherent alignment in complex systems*

15:00 – 15:20 Coffee break

15:20 – 16:50 **4 session: General physics**

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

15:20	–	15:50	Ulf Leonhardt:	*Cosmology in the laboratory*
15:50	–	16:20	Dirk Bouwmeester:	*Knots of light, gravitational radiation, and plasma*

16:20 – 16:50	Thierry Martin:	*Interactions and charge fractionalization in an electronic Hong-Ou-Mandel interferometer*
16:50 – 17:30	Free time and transfer to Břevnov Monastery	

17:30 – 23:00 **Conference dinner and concert**

Location: Břevnov Monastery

17:30 – 18:00	Welcome
18:00 – 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, 1 August 2015

08:00	–	10:00	**1 session: Nonequilibrium statistical physics**	
			Location: Pyramida Hotel Lecture Hall	
			(chairperson: Michael Thoss)	
08:00	–	08:30	Juan Carlos Cuevas:	*Near-field radiative heat transfer at the nanoscale*
08:30	–	09:00	Michael Galperin:	*Energy transport and heating in molecular junctions*
09:00	–	09:30	Rudolf Hilfer:	*Experimental implications of Bochner-Levy-Riesz diffusion*
09:30	–	10:00	Marcelo Lozada-Cassou:	*Molecular recognition and information theory in the self-assembling of charged particles*
10:00	–	10:20	Coffee break	
10:20	–	12:00	**2 session: General physics**	
			Location: Pyramida Hotel Lecture Hall	
			(chairperson: Dirk Bouwmeester)	
10:20	–	10:50	Wolfgang Schleich:	*The Stefan-Boltzmann law: Two classical laws give a quantum one*
10:50	–	11:20	Kimball A. Milton:	*Negative Casimir entropies in nanoparticle interactions*
11:20	–	11:40	Mikhail Baranov:	*Majorana fermions in atomic-wire networks - realization of non-Abelian anyons*
11:40	–	12:00	Joan A. Vaccaro:	*Quantum mechanism that makes time different to space*
12:00	–	13:00	Lunch	
13:00	–	14:30	**3 session: Quantum physics**	
			Location: Pyramida Hotel Lecture Hall	
			(chairperson: Jonathan Lavoie)	
13:00	–	13:30	Mikko Möttönen:	*Discoveries of magnetic-monopole analogues in Bose-Einstein condensates*

13:30 – 14:00	Hans De Raedt:	*Quantum theory as a description of robust experiments: Derivation of the Pauli equation*
14:00 – 14:30	Kristel F Michielsen:	*Disillusion: Quantum Cheshire cat is an illusion*
14:30 – 14:50	Coffee break	

14:50 – 15:30 **4 session: General physics**

Location: Pyramida Hotel Cinema Hall

(chairperson: Peter Keefe)

14:50 – 15:10	Mario Krenn:	*Twisted photon entanglement through turbulent air across Vienna*
15:10 – 15:30	Václav Špička:	*Non-equilibrium dynamics: Initial conditions and asymptotic evolution*

15:30 – 16:00 **Closing and refreshment**

Location: Pyramida Hotel Cinema Hall

Public Lectures

The photon sheds light on the quantum

Marlan O. Scully

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Baylor University, Waco, TX 76798, USA
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Light has held center stage from the dawn of civilization. Indeed as it says in Genesis:

In the beginning ... God said, “Let there be light,” and there was light.

The first person to test a hypothesis by experiment (i.e., the first scientist) was Alhazen who lived in Bagdad (965-1040) and gave us many insights into optics. Around 1600, observational astronomer Tycho Brahe recruited Johannes Kepler to work with him in Prague; and the heliocentric picture was put on a firm footing. Isaac Newton (1624-1727), gave us his theory of color (“white light consists of many colors”) and argued for a corpuscular theory of light. Robert Hooke (1635-1703), Christian Huygens (1629-1695) and later Thomas Young (1773-1829), supported a wave picture of light. But it was left to James Maxwell (1831-1879) to show that light is an electromagnetic wave.

In 1900, Max Planck (1858-1947), studied the entropy of light and arrived at a quantum theory to solve “the ultraviolet catastrophe”. In 1905, Albert Einstein (1879-1955) continued the study of the entropy of light and arrived at the photon concept, i.e., the wave-particle picture of light.

Then between 1925 -1930, Werner Heisenberg, Paul Dirac, and others arrived at the quantum theory of light. Unfortunately, it was plagued with nonsensical (infinite) prediction. After World War II, Willis Lamb used the hydrogen atom as a “laboratory” and gave us an experimental framework for quantum electrodynamics (QED). This led Julian Schwinger and others to develop renormalized quantum field theory and put the photon concept on a firm mathematical footing in excellent agreement with experiment.

Around 1960, a pantheon of heroes, led by Charles Townes, gave us the laser. This has made possible many experiments probing the foundations of quantum mechanics, e.g., the Bell inequalities, quantum eraser, and many other insights.

In the lecture I will summarize the history of research on the nature of light and recent exciting developments in the fields of quantum optics and the foundations of quantum mechanics.

The quantum deep down

Gerard 't Hooft

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The world of the tiniest building blocks, such as molecules, atoms and the sub-atomic particles appears to be completely governed by a doctrine of logic called "quantum mechanics". Usually, quantum mechanics is described as something fundamentally different from the "classical world". How far does that difference go? Could there be a world of far more tiny objects behaving erratically, a world deep down, where the laws of motion are again classical? It would be a lot easier to understand nature's logic that way, in particular the gravitational force. Although most physicists have their answer ready: "No, that's definitely impossible", there is some evidence in favor of such a theory. Maybe the counter arguments are not as clean as they seem ...

Invited Talks

Mesoscopic superconductivity in nano-scale metallic grains

Yoram Alhassid

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A nano-scale metallic grain (nanoparticle) with irregular boundaries is described by the so-called universal Hamiltonian. The interaction part of this Hamiltonian includes a superconducting pairing term and a ferromagnetic exchange interaction. The latter interaction is suppressed in the presence of strong spin-orbit scattering. The smallest grains in the experiments are described by the fluctuation-dominated regime, in which the single-particle level spacing is comparable to or larger than the bulk pairing gap, and the Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity is no longer valid. The crossover regime between the BCS and fluctuation-dominated regimes is common to both nanoparticles and nuclei [1].

(i) Superconducting nanoparticles without spin-orbit scattering

We identified signatures of the competition between pairing and exchange correlations in thermodynamic properties of the nanoparticle [2]. Number-parity effects, induced by pairing correlations, are modified by the exchange interaction; they are suppressed in the fluctuation-dominated regime, but enhanced in the BCS regime. Our approach goes beyond the BCS theory by considering both large-amplitude static fluctuations and small-amplitude quantum fluctuations of the pairing gap order parameter.

(ii) Superconducting nanoparticles with spin-orbit scattering

The addition of spin-orbit scattering breaks spin symmetry but preserves time-reversal symmetry. The exchange interaction is then suppressed while the pairing interaction remains unaffected. We studied the response of discrete energy levels of such a nanoparticle to an external magnetic field [3,4]. In particular, we investigated the linear and quadratic terms in the magnetic field that are parametrized by the g-factor and level curvature, respectively. The g-factor statistics are unaffected by pairing correlations, but the level curvature statistics are very sensitive to pairing and can thus be used to probe pairing correlations in the single-electron tunneling spectroscopy experiments. This probe is particularly useful in the fluctuation-dominated regime, in which the pairing gap cannot be directly observed in the excitation spectrum.

[1] Y. Alhassid, in Fifty Years of Nuclear BCS: Pairing in Finite Systems, eds. R. A. Broglia and V. Zelevinsky, World Scientific (2013).

[2] K. Nesterov and Y. Alhassid, Phys. Rev. B 87, 014515 (2013).

[3] Y. Alhassid, and K. Nesterov, arXiv:1407.8547, AIP Conf. Proc. 1619, 24 (2014).

[4] K. N. Nesterov and Y. Alhassid, arXiv:1507.01575 (2015).

Spin noise in the anisotropic central spin model

Frithjof Anders

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Spin-noise measurements can serve as a direct probe for the microscopic decoherence mechanism of an electronic spin in semiconductor quantum dots (QDs). We have calculated the spin-noise spectrum in the anisotropic central spin model using a Chebyshev expansion technique which exactly accounts for the dynamics up to an arbitrary long but fixed time in a finite-size system. In the isotropic case, describing QD charge with a single electron, the short-time dynamics is in good agreement with quasistatic approximations for the thermodynamic limit. In the generic anisotropic central spin model we have found a crossover from a Gaussian type of spin-noise spectrum to a more Ising-type spectrum with increasing anisotropy in a finite magnetic field. In order to make contact with experiments, we extended our Hamiltonian and include nuclear quadrupolar electric field effects. We could show that the nuclear quadrupolar couplings caused by growth induced stress fields leads to approximate the same life-time of electron and hole charged spins in quantum dots in qualitativ agreement with the experiment.

The BCS theory in the fractional exclusion statistics formalism

Dragos-Victor Anghel and George Alexandru Nemnes

Institutul National de Fizica si Inginerie Nucleara - Horia Hulubei, 30 Reactorului Street, Magurele, Romania

We compare the standard description of a BCS superconductor with a description based on fractional exclusion statistics. In the BCS description the total energy of the system (up to a constant) equals the energy of the condensate plus the sum of quasiparticle energies. The quasiparticle energies and the condensate energy depend on the number of quasiparticle excitations.

In the FES description we redefine the quasiparticle energies, such that the total energy of the system (up to the same constant) equals the sum of the energies of the quasiparticles which, furthermore, do not depend on the populations. The thermodynamics is the same in both descriptions and their equivalence is proved analytically. Nevertheless, some important parameters still differ in the two models. One such parameter is the energy gap and this has implications in the interpretation of tunneling processes.

Charge transfer meets circuit quantum electrodynamics: From Coulomb blockade to nonlinear quantum dynamics

Joachim Ankerhold, Bjoern Kubala, Vera Gramich, and Selina Rohrer

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With the advent of new experimental devices in the last decade, nonlinear quantum dynamics has been studied in a variety of realizations in atomic, molecular, and condensed matter physics. In particular, superconducting circuits, originally designed as promising resources for quantum information processing, provide means to access nonlinear dynamics under well-controlled conditions from the classical down to the deep quantum regime. Very recently, in an extension of circuit quantum electrodynamics, quantum electronics has been combined with photonics to the new field of Josephson photonics, where the interaction of charge quanta with photons gives rise to a wealth of phenomena [1,2]. Theory is thus challenged to capture nonlinear resonances far from equilibrium, non-classical states of light, photon entanglement and various quantum-classical crossovers [3,4]. In this talk I will discuss the background, specific examples and future perspectives.

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

[2] F. Chen, J. Li, A. D. Armour, E. Brahimi,J. Stettenheim, A. J. Sirois, R. W. Simmonds, M. P. Blencowe, and A. J. Rimberg, Phys. Rev. B 90, 020506(R) (2014)

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

[4] B. Kubala, V. Gramich, and J. Ankerhold, arXiv: 1404.6259

Non-equilibrium quantum manipulation: From robust entanglement to quantum thermal machines

Mauro Antezza

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We will discuss the behavior of one or more elementary quantum system (atom, molecules, quantum dot, ...) interacting with a stationary, simple and rich electromagnetic environment out of thermal equilibrium: The electromagnetic field is produced by a simple configuration of macroscopic objects held at thermal equilibrium at different temperatures. We will show how the internal atomic dynamics can be deeply affected by the non equilibrium configuration leading to unexpected phenomena like a spontaneous inversion of population, new cooling mechanisms obtained by heating the system [1], and the possibility to create and protect entanglement in a stationary and robust way [2]. Finally, we will discuss how this system may directly allow the realization of atomic quantum thermal machines, with high efficiency and a genuine quantum behavior [3].

[1] B. Bellomo, R. Messina, and M. Antezza, Europhys. Lett. 100, 20006 (2012)

[2] B. Bellomo and M. Antezza, Europhys. Lett. 104, 10006 (2013)

[3] B. Leggio, B. Bellomo, and M. Antezza, Phys. Rev. A 91, 012117 (2015)

Quantum non-linear dynamics of photons and Cooper-pairs in a Josephson junction-cavity system

Andrew Armour

University of Nottingham, University Park, Nottingham, United Kingdom

Embedding a voltage-biased Josephson junction within a high-Q superconducting microwave cavity provides a novel way of exploring strongly non-linear quantum dynamics. At resonances where the energy given to a tunnelling Cooper pair by the voltage bias is equal to a multiple of the cavity photon frequency the cavity can be pumped to far-from-equilibrium states containing many microwave photons. Intriguingly, the cavity states produced by the flow of Cooper-pairs have distinct non-classical features. In this talk I will describe a simple theoretical model for this type of system and outline how the coupled dynamics of the cavity photons and Cooper-pairs can be uncovered using a combination of analytical approximations and numerical methods.

Quantum optics experiments with biomolecular matter

Markus Arndt

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Quantum physics is the uncontested best description of the inanimate world but it leads to phenomena which are in radical conflict with our common sense perception of the world. While we have grown to accept this for electrons, neutrons or atoms it is intriguing to explore how the complexity of an object will influence the possibility of preparing it in genuine quantum states. We ask in particular how to enable quantum superposition experiments with the diverse set of biological nanomatter that nature provides, starting from vitamins, biodyes and amino acids over polypeptides and proteins to possibly self-replicating molecules, in the future. This is an ongoing journey. I will discuss how our experiments are connected to established matter-wave interferometry and which universal sources, diffraction and detection methods have been developed to open a window to quantum optics with complex biomolecules.

Time-resolved heat transport and extended thermoelectrics for ac-driven quantum systems

Liliana Arrachea

Universidad de Buenos Aires, Pabellon I, Ciudad Universitaria, 1428 Buenos Aires, Argentina

We analyze the time-dependent energy and heat flows in a ac driven system coupled to electron reservoirs. We discuss the different contributions to the total energy flux as a function of time. We then derive the appropriate expression for the dynamical dissipation, in accordance with the fundamental principles of thermodynamics. Interestingly, we find that it follows a time-dependent Joule law [1].

Then, we present an extension of the theory of linear response and thermoelectrics to describe the charge, heat and work exchange in electron systems under adiabatic time-periodic driving. We consider work exchange between the electrons and the ac driving fields on equal footing with the charge and heat fluxes. The corresponding Onsager coefficients obey non-standard reciprocity relations. We identify operational modes corresponding to motors, battery-chargers, heat engines and heat pumps, which we characterize by efficiencies and figures of merit [2].

[1] M. F. Ludovico, J. S. Lim, M. Moskalets, L. Arrachea and D. Sanchez, Phys. Rev. B (RC) 89, id. 161306 (2014)

[2] M. F. Ludovico, F. Battista, L. Arrachea and F. von Oppen, ArXiv:2015

Reversible work extraction in a hybrid opto-mechanical system

Cyril Elouard, Maxime Richard, and Alexia Auffèves

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With the progress of nano-technology, thermodynamics also has to be scaled down, calling for specific protocols to extract and measure work. Usually, such protocols involve the action of an external, classical field (the battery) of infinite energy, that controls the energy levels of a small quantum system (the calorific fluid). Here we suggest a realistic device to reversibly extract work in a battery of finite energy: a hybrid optomechanical system. Such devices consist of an optically active two-level quantum system interacting strongly with a nano-mechanical oscillator that provides and stores mechanical work, playing the role of the battery. We identify protocols where the battery exchanges large, measurable amounts of work with the quantum emitter without getting entangled with it. When the quantum emitter is coupled to a thermal bath, we show that thermodynamic reversibility is attainable with state-of-the-art devices, paving the road towards the realization of a full cycle of information-to-energy conversion at the single bit level [1]. Applications of opto-mechanical systems as quantum heat engines will also be considered [2].

[1] C. Elouard, M. Richard, A. Auffèves, Reversible work extraction in a hybrid optomechanical system, New Journal of Physics 17, 055018 (2015) (Special focus on Quantum Thermodynamics)

[2] M. Richard, A. Auffèves, Optical driving of macroscopics mechanical motion by a single two-level system, Physical Review A 90, 023818 (2014)

Minimalist principles needed to interpret ideal quantum measurements

Armen Allahverdyan[1], Roger Balian[2], and Theo M. Nieuwenhuizen[3]

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[3]*Institute for Theoretical Physics, Science Park 904, 1090 GL Amsterdam, The Netherlands*

Arbitrary ideal measurements are tackled in a first stage within a standard but abstract formulation of quantum statistical mechanics, applied to the interaction between the tested system S and a macroscopic apparatus A. There, density operators encode knowledge about ensembles (or sub-ensembles) of systems, in the form of q-probabilities having no a priori interpretation, especially in terms of individual systems. The general form of Hamiltonians H of S+A that may describe an ideal measurement process is given. The density operators that S+A is desired to reach at the end of the process, for both a large ensemble of runs of the measurement and for its sub-ensembles, are shown to have a thermodynamic equilibrium form. Relaxation towards such states is ensured for suitable parameters of H, the increase of entropy of A allowing a gain of information. However, this result is not sufficient to provide a solution of the measurement problem, that is, to ensure that individual runs are governed by ordinary probabilities, and that each one yields a single result.

Interpretative principles must therefore be introduced. In a second stage, we present the most economic ones, which pertain mainly to the (quantum) apparatus. One of them deals with the identification of sub-ensembles within the full ensemble of runs near the end of the process. Another one amounts to identify q-probabilities with ordinary probabilities, but only for a macroscopic observable subject to some stringent conditions, which are satisfied by the macroscopic pointer of A after achievement of the process. The properties currently attributed to ideal measurements are thereby recovered, and the status of Born's rule is re-evaluated.

[1] A. Allahverdyan, R Balian, Th.Nieuwenhuizen, An ensemble theory of ideal quantum measurement processes, arXiv 1303.7257v2 [quant-phys]

Majorana fermions in atomic-wire networks - realization of non-Abelian anyons

Mikhail Baranov

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Majorana fermions (Ising anyons) are the simplest example of non-Abelian anyons. I consider their particular realization as edge states in topological quantum wires in systems of ultracold atoms and molecules, discuss the protocol for braiding Majorana fermions in this setup, signatures of their non-Abelian statistics, and their usage for quantum computation.

Scaling at quantum phase transitions: Disordered quantum ferromagnets

Dietrich Belitz[1] and Ted R Kirkpatrick[2]

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We apply general scaling concepts for quantum phase transitions to the case of quantum ferromagnets in the presence of quenched disorder. Depending on the disorder strength, various fixed points control the observable behavior in different regimes, and crossover phenomena need to be considered in order to analyze experimental data. As illustrative examples, we discuss the shape of the phase diagram and the behavior of the electrical conductivity at the ferromagnetic quantum phase transition in disordered metals.

Non-Markovian weak measurements in quantum transport

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Generalized quantum measurement schemes are described by positive operator-valued measures going beyond the projection postulate, which predicts the instantaneous collapse of the systems wave function. This allows to take the noninvasive limit and investigate the correlations of such weak measurements which facilitate the observation of non-commuting observables within the same system. We propose a scheme in which the detector is coupled to the measured system for a finite time, as it is the case in many real quantum transport setups. This leads to non non-Markovian effects, in accordance to previous conjectures [1]. For the measured correlations this scheme predicts memory functions, which are related to symmetric and antisymmetric correlators of the detector variables. We investigate the memory functions under different general assumptions: (a) equilibrium detectors, (b) the role of non-equilibrium detectors and how they could realize the standard Markovian measurement. The latter scheme leads to the symmetrized operator order (aka Keldysh ordering), which is widely used in quantum measurement discussions. We discuss setups in which the non-Markovian measurement scheme yields information beyond the standard approach, allowing e.g. for the prove of the non classical nature of a system (quasiprobability statistics) by second-order correlation functions, which for every symmetrized order measurement have been shown to be classically reproducible.

[1] A. Bednorz, C. Bruder, B. Reulet and W. Belzig, Phys. Rev. Lett. 110, 250404 (2013).

T14 Wed, 29 July, 10:50 - 11:20, 2 session - B parallel

Competition, feedback and fluctuations in transcriptional and post-transcriptional regulatory networks in cells

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The processing of information in genetic networks involves several levels of regulation, including the transcriptional regulation of gene expression as well as post-transcriptional regulation by small non-coding RNA's. The interplay between these different levels of regulation will be discussed, using dynamical modeling and simulations. It will be shown that the combination of different regulation mechanisms enables fast, efficient and reliable processing of information. The effects of competition, feedback and fluctuations will be considered using deterministic and stochastic methods.

Non-linear microwave optomechanics

Yaroslav M. Blanter

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Optomechanically induced transparency is one of basic phenomena in optomechanics. It was experimentally demonstrated in both optical and microwave setups and results in strong enhancement of a light transmission through a cavity if the cavity is driven at resonance shifted to red mechanical sideband. In experiments, the cavity and a coupled mechanical resonator are usually perfectly linear. Recent experiments in microwave cavities with graphene resonators opened access to non-linear optomechanics, since both the cavity and the resonator can be non-linear. In the talk, we concentrate on a non-linear mechanical resonator coupled to a linear cavity and present theory which explains recent experiments by the Steele group in Delft. We demonstrate that the shape of resonances in optically-induced absorption is more complicated than just the Duffing shape of a driven non-linear resonator, and the backaction of the resonator to the cavity need to be taken into account to explain the experimental data. We will furthermore show that the results are strongly sensitive to (i) whether the cavity is overcoupled or undercoupled; (ii) whether it is red-sideband or blue-sideband driven. We also analyze what happens if the probe power is not negligibly small compared to the drive power of the cavity.

Quantum information science with trapped Ca^+ ions

Rainer Blatt

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In this talk, the basic tool box of the Innsbruck quantum information processor based on a string of trapped Ca^+ ions will be reviewed. For quantum information science, the toolbox operations are used to encode one logical qubit in entangled states distributed over seven trapped-ion qubits. We demonstrate the capability of the code to detect one bit flip, phase flip or a combined error of both, regardless on which of the qubits they occur. Furthermore, we apply combinations of the entire set of logical single-qubit Clifford gates on the encoded qubit to explore its computational capabilities. The quantum toolbox is further applied to carry out both analog and digital quantum simulations. The basic simulation procedure will be presented and its application will be discussed for a variety of spin Hamiltonians. Finally, the quantum toolbox is applied to investigate the propagation of entanglement in a quantum many-body system represented by long chains of trapped-ion qubits. Using the ability to tune the interaction range in our system, information propagation is observed in an experimental regime where the effective lightcone picture does not apply. These results will enable experimental studies of a range of quantum phenomena, including transport, thermalization, localization and entanglement growth, and represent a first step towards a new quantum-optic regime of engineered quasiparticles with tunable nonlinear interactions.

Knots of light, gravitational radiation, and plasma

Dirk Bouwmeester

Department of Physics, University of California, Santa Barbara, USA
Huygens Kamerlingh Onnes laboratory, University of Leiden, The Netherlands

The Maxwell equations in vacuum are invariant under conformal transformations. This allows for the construction of topologically nontrivial solutions of light. The most elementary of such solutions is based on the Hopf map and leads to electric field lines and magnetic fields lines that are all circles that lie on nested toroidal surfaces. Each E (B) field circle is linked once with every other circle. We show how this concept can be generalized and expanded to include also gravitational radiation. Furthermore we show how the linked structures of the magnetic field can form the skeleton of realistic plasma configurations. Using full MHD simulations we present a self-confining plasma knot.

Quantum point contacts for cold atoms

Jean-Philippe Brantut, Sebastian Krinner, Dominik Husmann, Martin Lebrat, Shuta Nakajima, Charles Grenier, Samuel Häusler, and Tilman Esslinger

ETH Zürich, Otto Stern Weg 1, Zurich, Switzerland

In transport experiments the quantum nature of matter becomes directly evident when changes in conductance occur only in discrete steps, with a size determined solely by Planck's constant h. Here we report on the observation of quantized conductance in the transport of neutral atoms. We employ high resolution lithography to shape light potentials that realizes a quantum point contact for atoms. These constrictions are imprinted on a quasi two-dimensional ballistic channel connecting two adjustable reservoirs of quantum degenerate fermionic lithium atoms. By tuning either a gate potential or the transverse confinement of the constrictions, we observe distinct plateaus in the conductance for atoms. The conductance in the first plateau is found to be equal to 1/h, the universal conductance quantum. For low gate potentials we find good agreement between the experimental data and the Landauer formula, with all parameters determined a priori.

We then use the unique opportunity offered by cold atom systems to control the interactions between particles, and observe the progressive disappearance of quantized conductance as attractive interactions are raised. For unitary limited interactions, the system features a strongly non linear current-bias characteristic, related to the superfluid nature of the gas. The results are compared with a non-equilibrium mean-field theory, with quantitative agreement at low temperature.

Quantum synchronization

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Synchronization of driven self-sustained oscillators is a universal phenomenon that is important both in fundamental studies and in technical applications. Recent studies of optomechanical systems have motivated the study of synchronization in quantum systems. I will discuss some approaches to this question and will then describe our own work. We have studied one quantum Van der Pol oscillator subject to an external drive [1], and two dissipatively coupled Van der Pol oscillators in the quantum regime [2].

[1] S. Walter, A. Nunnenkamp, and C. Bruder, Phys. Rev. Lett. **112**, 094102 (2014).

[2] S. Walter, A. Nunnenkamp, and C. Bruder, Ann. Phys. (Berlin) **527**, 131 (2015).

Dipole interactions in a cold Rydberg gas for quantum simulation

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Due to their huge polarizability, Rydberg atoms present strong, long-range dipole-dipole interactions. Studying many-body correlations in a dense cold cloud of Rydberg atoms may be of interest as a quantum simulator of model many-body hamiltonians [1,2] of importance for understanding more complex and less controllable solid-states systems.

We study a cold 87Rb atomic sample magnetically trapped on a superconducting atom chip. The temperature of the cloud can be lowered down to the BEC transition by evaporative cooling. Due to the large polarizability of Rydberg atoms, an essential experimental issue is the control of stray electric fields in the vicinity of the atom chip surface. We solved this problem by coating the chip surface with a thick layer of Rubidium. We observed coherence times in the ms range for the 60s to 61s microwave two-photon transition [3]. This opens interesting perspectives for the study of dipole interactions at higher density of Rydberg atoms.

We then use microwave spectroscopy for a direct measurement of the interaction energy distribution of a single Rydberg atom with its neighbors in a dense cold atom cloud close to Bose-Einstein condensation [4]. The observed energy distribution carries information on spatial correlations between Rydberg atoms prepared in the strong dipole blockade regime. We study the energy distribution as a function of the detuning of the excitation laser. For blue detuning, we observe that we preferentially excite atoms in the neighborhood of previously excited atoms so that interaction energy shift compensates for laser detuning.

This interaction energy measurement also allows us to observe the expansion of the Rydberg atom cloud as a function of time due to repulsive dipole interaction. We show that the cloud rapidly goes out of the "frozen gas approximation" usually used in previous work. We also observe that the density is high enough so that the expansion is not simply governed by two-body repulsion. We enter a hydrodynamic regime where many-body interaction play an essential role.

[1] Hendrik Weimer, Markus Müller, Igor Lesanovsky, Peter Zoller and Hans Peter Büchler, Nature Physics 6, 382 - 388 (2010)

[2] G.Pupillo, A. Micheli, M. Boninsegni, I. Lesanocsky and P. Zoller, Pys Rev. Lett. 104, 223002 (2010)

[3] C. Hermann-Avigliano et al., Phys. Rev. A 90, 040502(R) (2014)

[4] R. Celistrino Teixeira et al. arXiv:1502.04179, accepted at PRL.

Testing time reversal symmetry in artificial atoms

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Over the past several decades, a rich series of experiments has repeatedly verified the quantum nature of superconducting devices, leading some of these systems to be regarded as artificial atoms. In addition to their application in quantum information processing, these 'atoms' provide a test bed for studying quantum mechanics in macroscopic limits. Regarding the last point, we present here a feasible protocol for directly testing time reversal symmetry in a superconducting artificial atom. Time reversal symmetry is a fundamental property of quantum mechanics and is expected to hold if the dynamics of the artificial atom strictly follow the Schrödinger equation. However, this property has yet to be tested in any macroscopic quantum system. The test we propose is based on the verification of the microreversibility principle, providing a viable approach to verify quantum work fluctuation theorems - an outstanding challenge in quantum statistical mechanics. For this, we outline a procedure that utilizes the microreversibility test in conjunction with numerical emulations of Gibbs ensembles to verify these theorems over a large temperature range.

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

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

[1] M. Campisi, J. Phys. A: Math. Theor. 47 (2014) 245001

[2] M. Campisi, J. Pekola, R. Fazio, New J. Phys. 17 (2015) 035012

Time-local master equations: The coherently driven qubit with delayed coherent feedback

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Following the derivation by Hu et al. [1] of an exact master equation with colored noise for quantum Brownian motion, time-local master equations have been reported for a number of model systems interacting with a general – arbitrary spectral density – bosonic environment. Examples include the two-state system and an environment in the vacuum state (spontaneous emission) [2], a single mode of the electromagnetic field [3], a collection of coherently driven harmonic oscillators [4], and one squeezed oscillator with a coherent drive [4]. Notable for its omission from the list is the coherently driven two-state system, or qubit. Although Shen et al. reported a time-local master equation for the coherently driven qubit in 2014 [6], we show here that results computed from their equation disagree with a direct numerical integration of the full – driven qubit plus environment – model. We consider, in particular, a coherently driven qubit embedded in a 1-D waveguide, where the field in the environment interacts with the qubit twice with a time delay – e.g., is retro-reflected from a distant mirror [7]. We report the following results: (i) for a π phase shift of the fed back field (negative feedback), the solution to the Shen et al. master equation [6] evolves to a dark state in the strong-drive limit, i.e., supports a trapped (non-radiating) Rabi oscillation; (ii) direct numerical integration yields a dark state if truncated to allow just one photon in the feedback loop, but only for delays of 0, 1, 2, etc. half-Rabi-periods; and (iii) direct numerical integration without the one-photon truncation shows the dark state to be unstable in the presence of two or more photons in the feedback loop, in agreement with recent simulations based on a "wrapped around" cascaded system [8]. Our results are supported by the requirements for quantum interference of output fields. We show further that the Shen et al. equation can violate the positivity of ρ and conclude that a time-local master equation for the coherently driven qubit remains an open problem.

[1] B. L. Hu, J. P. Paz, and Y. Zhang, Phys. Rev. D 45, 2843 (1992)
[2] C. Ananstopoulos and B. L. Hu, Phys. Rev. A 62, 033821 (2000)
[3] J.-H. An, Y. Yeo, and C. H. Oh. Ann. Phys. (N.Y.) 324, 1737 (2009)
[4] C. U. Lei and W. M. Zhang, Ann. Phys. (N.Y.) 327, 1408 (2012)
[5] C. W. Chang and C. K. Law, Phys. Rev. A 81, 052105 (2010)
[6] H. Z. Shen, M. Qin, X.-M. Xiu, and X. X. Yi, Phys. Rev. A 89, 062113 (2014)
[7] U. Dorner and P. Zoller, Phys. Rev. A 66, 023816 (2002)
[8] A. Grimsmo, arXiv:1502.06959 (2015)

Emergent topological properties in interacting 1D systems with spin-orbit coupling

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We present analysis of a single channel interacting quantum wire problem in the presence of spin-orbit interaction. The spin-orbit coupling breaks the spin-rotational symmetry from SU(2) to U(1) and breaks inversion symmetry. The low energy theory is then a two band model with a difference of Fermi velocities δv. Using bosonization and a two-loop RG procedure we show that electron-electron interactions can open a gap in the spin sector of the theory when the interaction strength U is smaller than δv in appropriate units. For repulsive interactions the resulting strong coupling phase is of the spin-density wave type. We show that this phase has peculiar emergent topological properties. The gapped spin sector behaves as a topological insulator, with zero-energy edge modes with fractional spin. On the other hand, the charge sector remains critical, meaning the entire system is metallic. However this bulk electron liquid as a whole exhibits properties commonly associated with the one-dimensional edge states of two-dimensional spin-Hall insulators, in particular the conduction of $2e^2/h$ is robust against nonmagnetic impurities.

[1] arxiv/1504.05016

Contribution of the vacuum fluctuations to blackbody radiation

Ana María Cetto, Luis de la Peña, and Andrea Valdés-Hernández

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A careful dynamical and statistical analysis of the radiation field in thermal equilibrium, including the zero-point component, serves to disclose the key elements leading to Planck's blackbody radiation formula. This allows to assign a clear physical meaning to the vacuum fluctuations of QED as representing a real fluctuating field with fixed energy $E = \hbar\omega/2$ per normal mode. The relationship between continuous and discrete energy distributions is briefly discussed. The physical meaning of Unruh's formula for the vacuum field viewed by an accelerated detector is discussed from the present perspective.

Atomic Hong-Ou-Mandel experiment

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The celebrated Hong, Ou and Mandel (HOM) effect is one of the simplest illustrations of two-particle interference, and is unique to the quantum realm. In the original experiment, two photons arriving simultaneously in the input channels of a beam-splitter were observed to always emerge together in one of the output channels. Here, I will report on the realisation of a closely analogous experiment with atoms instead of photons. This opens the prospect of testing Bell's inequalities involving mechanical observables of massive particles, such as momentum, using methods inspired by quantum optics, with an eye on theories of the quantum-to-classical transition. Our work also demonstrates a new way to produce and benchmark twin-atom pairs that may be of interest for quantum information processing and quantum simulation.

Counterflowing superlfuid mixtures

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Since the discovery of superfluid ^{3}He in 1972, the realization of a doubly-superfluid Bose-Fermi mixture has been one the major goals in the field of quantum liquids. However, due to strong repulsive interactions between helium atoms, the fraction of ^{3}He inside ^{4}He cannot exceed 6%. This high dilution of the fermionic species reduces dramatically its critical temperature from 2.5 mK for pure ^{4}He to a predicted value of 40 μK in the mixture. Despite decades of efforts, this range of temperature is still inaccessible to experimental investigation and has prevented the observation of a dual superfluid phase in liquid helium. In cold atoms however, Feshbach resonances make it possible to control the strength of interatomic interactions and realize stable Bose-Fermi mixtures. In my talk I will discuss the physical properties of weakly-coupled superfluid mixtures of ^{6}Li and ^{7}Li [1]. Superfluidity was revealed by the existence of a critical velocity below which the relative motion of the two species is undamped and the energy transfer between the two gases is coherent. We could interpret this critical velocity using a generalized Landau mechanism in which excitations are shed in both superfluids.

[1] I. Ferrier-Barbut et al., Science **345**, 1035 (2014)

Minimal models for superfluidity and thermalization

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Chaos plays a major role in the dynamics of low dimensional Bose-Hubbard Circuits. Specifically we are interested in the two themes: (i) Superfluidity [1,2]; (ii) Thermalization [3,4]. I will focus mainly on the first theme. It turns out that the standard Landau and Bogoliubov superfluidity criteria fail in low-dimensional circuits. Proper determination of the superfluidity regime-diagram must account for the crucial role of chaos, an ingredient missing from the conventional stability analysis. Accordingly, we find novel types of superfluidity, associated with irregular or chaotic or breathing vortex states.

[1] G. Arwas, A. Vardi, D. Cohen, PRA 89, 013601 (2014)
[2] G. Arwas, A. Vardi, D. Cohen, arXiv:1412.5929
[3] I. Tikhonenkov, A. Vardi, J. Anglin, D. Cohen, PRL 110, 050401 (2013)
[4] C. Khripkov, A. Vardi, D. Cohen, NJP 17, 023071 (2015)

Near-field radiative heat transfer at the nanoscale

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Radiative heat transfer between objects at different temperatures is of fundamental importance in applications such as energy conversion, thermal management, lithography, data storage, and thermal microscopy [1,2]. It was predicted long ago that when the separation between objects is smaller than the thermal wavelength, which is of the order of 10 μm at room temperature, the radiative heat transfer can be greatly enhanced due to the contribution of evanescent waves (or photon tunneling) [3]. In recent years, different experimental studies have confirmed this long-standing theoretical prediction. However, in spite of this progress, there are still many basic open questions in the context of near-field radiative heat transfer. In this talk, I will review our recent theoretical and experiment efforts to shed new light on this fundamental problem. In particular, I will discuss the following two basic issues: (i) the enhanced near-field radiative heat transfer using polar dielectric thin films [4] and (ii) the radiative heat transfer in the extreme near-field regime when objects are separated by nanometer-size distances [5].

[1] S. Basu, Z. M. Zhang, and C. J. Fu, Int. J. Energy Res. 33, 1203 (2009).

[2] D. G. Cahill et al., Appl. Phys. Rev. 1, 011305 (2014).

[3] D. Polder and M. Van Hove, Phys. Rev. B 4, 3303 (1971).

[4] B. Song, Y. Ganjeh, S. Sada, D. Thompson, A. Fiorino, V. Fernández-Hurtado, J. Feist, F. J. García-Vidal, J. C. Cuevas, P. Reddy, E. Meyhofer, Nature Nanotechnology 10, 253 (2015).

[5] K. Kim, V. Fernández-Hurtado, B. Song, W. Lee, W. Jeong, J. Feist, F. J. García-Vidal, J. C. Cuevas, E. Meyhofer and P. Reddy, in preparation.

Grassmann phase space theory for fermions

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In both quantum optics and cold atom physics, the behaviour of bosonic photons and atoms is often treated using phase space methods, where mode annihilation and creation operators are represented by c-number phase space variables, with the density operator equivalent to a distribution function of these variables. The anti-commutation rules for fermion annihilation, creation operators suggests the possibility of using anti-commuting Grassmann variables [1] to represent these operators. However, in spite of the seminal work by Cahill and Glauber [2] and a few applications [3, 4], the use of Grassmann phase space methods in quantum - atom optics to treat fermionic systems is rather rare, though fermion coherent states using Grassmann variables are widely used in particle physics.

The theory of Grassmann phase space methods for fermions is developed, showing how the distribution function is defined and used to determine quantum correlation functions, Fock state populations and coherences via Grassmann phase space integrals, how the Fokker-Planck equations are obtained and converted into equivalent Ito equations for stochastic Grassmann variables. Unlike the bosonic case, the sign for the drift term in the Ito equation is reversed and the diffusion matrix in the Fokker-Planck equation is anti-symmetric rather than symmetric. Using the un-normalised B distribution [3, 5] we show the Ito stochastic equations can be solved numerically via c-number stochastic quantities plus averages of products of initial Grassmann stochastic variables determined from the initial quantum state. A major problem in carrying out numerical calculations based on Grassmann phase space theories for fermion systems is now resolved.

Typical applications involving spin conserving collisions between spin 1/2 fermions are presented.

[1] F. A. Berezin, The Method of Second Quantization (Academic Press, New York, 1966).
[2] K. E. Cahill and R. J. Glauber, Phys. Rev. A 59, 1538 (1999).
[3] L. Plimak, M. J. Collett & M. K. Olsen, Phys. Rev. A 64, 063409 (2001).
[4] B. J. Dalton, B. M. Garraway, J. Jeffers & S. M. Barnett, Ann. Phys. 334, 100 (2013).
[5] B. J. Dalton, J. Jeffers & S. M. Barnett, Phase Space Methods for Degenerate Quantum Gases, (Oxford University Press, Oxford, 2015).

Quantum metrology: Towards the ultimate precision limits in parameter estimation

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Quantum Metrology concerns the estimation of parameters, like a phase shift in an interferometer, the magnitude of a weak force, or the time duration of a dynamical process, taking into account the quantum character of the systems and processes involved. Quantum mechanics brings in some new features to the process of parameter estimation. The precision of the estimation becomes now intimately related to the possibility of discriminating two different quantum states of the probe corresponding to two different values of the parameter to be estimated. Also, possible measurements must abide by the rules of quantum mechanics. At the same time, quantum properties, like squeezing and entanglement, may help to increase the precision, reaching eventually the ultimate precision limits allowed by quantum mechanics. Analytic expressions for this ultimate limit are available for noiseless systems. Recently, a method to tackle the problem of parameter estimation for noisy systems has been introduced [1], leading to very good analytical approximations [1,2,3], and even exact results in some cases [3,4]. This talk will review recent results concerning the application of quantum metrology methods to the problem of weak-value amplification [5] and also to the quantum speed limit in the presence of noise [3].

[1] B. M. Escher, R. L. de Matos Filho, and L. Davidovich, "General framework for estimating the ultimate precision limit in noisy quantum-enhanced metrology," Nat. Phys. 7, 406 (2011); “Quantum metrology for noisy systems,’” Braz. J. Phys. 41, 229, (2011).

[2] B. M. Escher, L. Davidovich, N. Zagury, and R. L. de Matos Filho, "Quantum metrological limits via a variational approach," Phys. Rev. Lett. 109, 190404 (2012).

[3] M. M. Taddei, B. M. Escher, L. Davidovich, and R. L. de Matos Filho, "Quantum speed limit for physical processes," Phys. Rev. Lett. 110, 050402 (2013).

[4] C. L. Latune, B. M. Escher, R. L. de Matos Filho, and L. Davidovich, "Quantum limit for the measurement of a classical force coupled to a noisy quantum-mechanical oscillator," Phys. Rev. A 88, 042112 (2013).

[5] G. Bié Alves, B. M. Escher, R. L. de Matos Filho, N. Zagury, and L. Davidovich, "Weak-value amplification as an optimal metrological protocol," to be published in Phys. Rev. A.

Dynamics of a confined quantum particle

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An analysis of the dynamics of a particle trapped in a box with perfectly rigid walls, is made using the tools of stochastic electrodynamics. This approach enriches substantially the usual quantum description, by providing a realistic picture of the problem.

Electric-dipole-induced universality for Dirac fermions in graphene

Alessandro De Martino

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I present a study of the physics of Dirac fermions in a gapped graphene monolayer (and related materials) containing two Coulomb impurities [1-2]. For the case of equal impurity charges, I discuss the ground state energy using a simple LCAO approach. For opposite charges of the Coulomb centres, an electric potential results at large distances. I show that the dipole potential accommodates towers of infinitely many bound states exhibiting a universal Efimov-like scaling hierarchy. The dipole moment determines the number of towers, but there is always at least one tower. The corresponding eigenstates show a characteristic angular asymmetry, observable in tunnel spectroscopy. However the charge transport properties inferred from scattering states are highly isotropic.

[1] A. De Martino, D. Klöpfer, D. Matrasulov, and R. Egger, Phys. Rev. Lett. 112, 186603 (2014).

[2] D. Klöpfer, A. De Martino, D. Matrasulov, and R. Egger, Eur. Phys. J. B 87, 187 (2014).

Quantum theory as a description of robust experiments: Derivation of the Pauli equation

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It is shown that the Pauli equation and the concept of spin naturally emerge from the analysis of experimental data on charged particles with magnetic moments under the conditions that (i) space is homogeneous (ii) the observed events are logically independent, and (iii) the observed frequency distributions are robust with respect to small changes in the conditions under which the experiment is carried out.

The derivation is based on the same principles of logical inference which have already been shown to lead to e.g. the Schrödinger equation and the probability distributions of pairs of particles in the singlet or triplet state, without taking recourse to any concept of quantum theory [1].

The general principle is further applied to Stern-Gelach experiments with chargeless particles, giving further support to the thesis that quantum theory follows from logical inference applied to a well-defined class of experiments, without any commitment to further notions of reality.

[1] H. De Raedt, M.I. Katsnelson, and K. Michielsen, Ann. Phys. 347 (2014) 45; H. De Raedt, M.I. Katsnelson, H.C. Hylke, and K. Michielsen, Ann. Phys. 359, 166–186 (2015)

Contextuality in systems with measurement errors and signaling

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Based on a *general definition of contextuality*, we derive necessary and sufficient conditions for (non)contextuality in what we call *cyclic systems of dichotomic measurements*: those in which physical properties are measured in pairs (contexts), and each property enters in precisely two such contexts. The generality of our approach allows one to determine contextuality or lack thereof in systems of measurements with *context-dependent errors* and/or with contexts physically interacting with ("*signaling to*") the measurements they contain. The class of cyclic systems includes as a special case the Klyachko-Can-Binicioglu-Shumovsky systems, which include as their special case the EPR/Bell systems, which in turn include as their special case the Leggett-Garg systems. This mathematical nestedness of the cyclic systems holds despite their very different physical nature. This is not surprising, as the notion of contextuality belongs to abstract probability theory rather than to physics or any other empirical domain. The special role of quantum physics is, however, in that it provides the only known to us examples of contextual systems.

[1] E.N. Dzhafarov, J.V. Kujala, and J.-Å. Larsson, Found. Phys. 6, 672 (2015)

10 people in the room, 10 opinions on many-body localisation

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The phenomenon of many-body localisation received a lot of attention recently, both for its implications in condensed-matter physics of allowing systems to be an insulator even at non-zero temperature as well as in the context of the foundations of quantum statistical mechanics, providing examples of systems showing the absence of thermalisation following out-of-equilibrium dynamics. Still, many aspects of it are still unsatisfactorily understood, specifically when taking a rigorously-oriented mindset.

In this talk, following a brief introduction to the study of many-body systems out of equilibrium [1-2], I will review some of the recent quantum information-inspired approaches to attain new insights into mathematical connections between seemingly unrelated features of many-body localisation [3-10]. Ideas of entanglement area laws, Lieb-Robinson bounds, approximately local constants of motion and tensor networks will feature strongly.

[1] Quantum many-body systems out of equilibrium, J. Eisert, M. Friesdorf, C. Gogolin, Nature Physics 11, 124 (2015).

[2] Equilibration, thermalisation, and the emergence of statistical mechanics in closed quantum systems, C. Gogolin, J. Eisert, arXiv:1503.07538.

[3] Many-body localisation implies that eigenvectors are matrix-product states, M. Friesdorf, A. H. Werner, W. Brown, V. B. Scholz, J. Eisert, Phys. Rev. Lett. in press (2015), arXiv:1409.1252.

[4] Local constants of motion imply transport, M. Friesdorf, A. H. Werner, M. Goihl, J. Eisert, W. Brown, arXiv:1412.5605.

[5] Absence of thermalisation in non-integrable systems, C. Gogolin, M. P. Mueller, J. Eisert, Phys. Rev. Lett. 106, 040401 (2011).

[6] Local integrals of motion and the logarithmic lightcone in many-body localised systems, I. H. Kim, A. Chandran, D. A. Abanin, arXiv:1412.3073.

[7] Spectral tensor networks for many-body localisation, A. Chandran, J. Carrasquilla, I. H. Kim, D. A. Abanin, G. Vidal, arXiv:1410.0687.

[8] Constructing local integrals of motion in the many-body localised phase, A. Chandran, I. H. Kim, G. Vidal, D. A. Abanin, arXiv:1407.8480.

[9] Phenomenology of fully many-body-localised systems, D. A. Huse, R. Nandkishore, V. Oganesyan, Phys. Rev. B 90, 174202 (2014).

[10] Many-body localisation edge in the random-field Heisenberg chain, D. J. Luitz, N. Laflorencie, F. Alet, arXiv:1411.0660.

Quantum optics with microwave photons in superconducting circuits

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Microwave radiation is most often generated by alternating currents driven through classical conductors. In the case of a simply dc biased quantum conductor, quantum fluctuations of the current due to the probabilistic character of charge transfer are already enough to emit radiation in the embedding circuit of the conductor, resulting in inelastic charge tunneling. Whereas a classical source yields a coherent state for the emitted radiation, much less is known when the emission arises from quantum fluctuations [1-2]. Is the quantum nature of charge transfer imprinted on the emitted radiation? For a Josephson junction, and at sub-gap voltage, quasiparticle excitations cannot take away energy, and a dc current flows across the junction only if the entire energy 2eV of tunneling Cooper pairs is transferred into the electromagnetic environment of the junction. The basic features of this peculiar quantum source of radiation were recently characterized in the simple case of a Josephson tunnel junction embedded in a single electromagnetic mode circuit [1]. We report here an experiment where a Josephson junction is embedded in circuit with two microwave resonators of different frequencies in series. The junction emits photons into the resonators, which in turn leak into an amplifying chain, allowing us to measure the photon emission rate and their second order coherence function via an Hanbury-Brown-Twiss (HBT) experiment [3]. We show that if the energy of a Cooper pair transferred through the junction matches the sum of the energies of photons in both resonators, photons are emitted as pairs. The emitted radiation then violates a Cauchy-Schwartz inequality obeyed by classical states of radiation, showing that the relative fluctuations of the outgoing modes are suppressed below the classical limit. This experiment sheds light on the cross-over between the pair-number regime and the phase regime for the charge transferred across a Josephson junction. On the quantum optics side, this setup provides a particularly simple and bright source of non-classical radiation for performing quantum optics experiments in the microwave domain.

[1] M. Hofheinz et al., Phys. Rev. Lett. 106, 217005 (2011)
[2] C. Altimiras et al., Phys. Rev. Lett. 112, 236803 (2014)
[3] O. Parlavecchio et al., in preparation

Adiabatic manipulation of architectures of multilevel artificial atoms

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Manipulating multilevel coherence in solid-state "artificial atoms" architectures is a key issue both in fundamental and in applied physics. With respect to their quantum optical counterparts, such systems allow design flexibility, integration of strongly coupled individual units and peculiar quantum control. This may compensates drawbacks due to a stronger interaction with the environment, leading to decoherence [1]. Applications range from quantum information (quantum gates and buses), to microwave quantum photonics (routers for quantum networks) and to the possibility to build emulators of artificial nanostructures for given functional tasks. In this contribution we address the implementation of a fundamental building block, namely a Lambda system in superconducting N>3 "artificial atoms". We study coherent population transfer (CPT), a benchmark process for quantum control, which is still an unsettled experimental issue. We have shown [2] that implementing an efficient Lambda system in a "qutrit" depends on the tradeoff between non-Markovian (low-frequency 1/f [1]) noise, and selection rules preventing efficient coupling. Both issues crucially depend on the (tunable) symmetry of the Hamiltonian. We propose two strategies to achieve large efficiencies [3]. We next introduce two new protocols to implement quantum state engineering by population transfer in solid-state Circuit-QED or nanoelectromechanichal architectures. The first is a 2+1-photon scheme allowing for a Lambda configuration at a symmetry point (minimizing noise) despite of selection rules[4], which can be applied to present technology devices. In the second CPT is obtained with the constraint of an always on field, mimicking an unswitchable hardware coupling [5]. We finally address the problem of detecting atom-cavity ultrastrong coupling. This opens a new channel for CPT, whose detection is a "smoking gun" for the existence in Nature of this new regime of coherent coupling with the electromagnetic field. We show how a 100% efficiency of detection can be achieved coupling many artificial atoms to a cavity, a system fabricable within present technology.

[1] E. Paladino, Y. Galperin, G. Falci, B. Altshuler, "1/f noise: implications for quantum information", Rev. Mod. Phys. 86, 361 (2014).

[2] G. Falci et al., Phys. Rev. B 87, 214515 (2013).

[3] P.G. Di Stefano et al. Rom. Jour. Phys. 60 (2015); arXiv:cond-mat 1502.05924.

[4] G. Falci et al., Phys. Scr. T151, 014020 (2012).

[5] P.G. Di Stefano et al., arXiv:cond-mat 1505; to be published in Phys. Rev. B.

Universality of non-equilibrium fluctuations in strongly correlated quantum liquids

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In a quantum dot, Kondo effect occurs when the spin of the confined electron is entangled with the electrons of the leads forming locally a strongly correlated Fermi-liquid. By using such a dot, we have investigated non-equilibrium universal behaviours of two different Fermi-liquids. In particular, we have extracted the effective charge e^* for quasi-particles due to a residual interaction, which is a key point of the extended Fermi-liquid theory.

Our quantum dot was formed in a single carbon nanotube, where Kondo effect with different symmetry groups, namely SU(2) and SU(4), shows up. In the latter case, as spin and orbital degrees of freedom are degenerate, Kondo resonance emerges for odd and even number of electrons. With our sample it was possible to investigate both symmetries near the unitary limit.

In the Kondo regime, strong interaction should create a peculiar two-particle scattering which appears as an effective charge e^* for the quasi-particles [1,2]. We have extracted the signature of this effective charge in the shot noise for both symmetry in good agreement with theory [3,4]. This result demonstrates that Fermi-liquid theory can be safely extended out of equilibrium even in the unconventional SU(4) symmetry[5].

Surprisingly, the SU(4) Kondo effect for two electrons persists until very high perpendicular magnetic field (13 T). We have measured this evolution in the conductance and shot noise. Our results show that only one perfect channel persists and the effective charge increases up to the SU(2) value. It suggests that the symmetry of the Kondo effect changes from SU(4) to the singlet-triplet SU(2) at high field.

[1] E. Sela et al, Phys. Rev. Lett. 97, 086601 (2006)

[2] A. O. Gogolin and A. Komnik, Phys. Rev. Lett. 97, 16602 (2006)

[3] C. Mora et al. Phys. Rev. B 80, 125304 (2009)

[4] R. Sakano et al, Phys. Rev. B 83, 075440 (2011)

[5] M. Ferrier et al. (submitted)

Conductance fluctuations in semiconductors

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Conductance fluctuations (CF) due to a disorder potential arising from the impurities was first discovered in small Si MOSFETs. These reproducible CF are thought to arise from phase interference effects as one varies either the density or an applied magnetic field. It was earlier thought that these effects were universal (ubiquitous and appearing in every device) and ergodic (appeared the same whether gate voltage or magnetic field was varied). However, recent results for both theory and experiment have cast doubt upon these suggestions. Here, we discuss a study of these fluctuations in both normal semiconductors and graphene. For example, in GaAs, we use a finite different lattice with different computational techniques to obtain meaningful results. In graphene, we use an atomic basis tight-binding formulation, in which the random disorder potential arises from impurities remote from the graphene sheet itself. From these studies, and comparisons with experimental results, it is clear that there is no universality, nor ergodicity, in either the experimental results or in the simulations. The CF are, however, very specific to the details of the device. We suggest a different version of universality, in which the observed fluctuations depend very critically on the form and on the amplitude of the perturbing potential which arises from the disorder. Moreover, it is simple to understand that in the worst case, the CF have an rms amplitude that is arises from the switching of a single transverse mode, a result that agrees well with experiment.

Nonlinear operations with quantum states of light

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The invited talk will describe both theoretical and experimental approaches to first time obtain cubic quantum nonlinearity for traveling quantum states of light. This nonlinearity exhibits interesting nonlinear stochastic aspects and even more exotic quantum phenomena. It is also a key element for future highly nonlinear quantum processing and quantum simulations with linear harmonic oscillators. We will explain theoretical approaches to construct an optical circuit for the cubic nonlinearity, including quantum gates for traveling light beams, cubic state preparation, and recent nonlinear electro-optical feed-forward correction and adaptive heterodyne measurement. We will then describe all already experimentally developed techniques and achieved results. Finally, we will shortly report about an alternative method to obtain the cubic states of light from quantum optomechanics and present outlook of this important direction of quantum optics.

Nonsecular resonances of interacting nuclear spins in solids

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Spin-spin relaxation in solid-state nuclear-magnetic resonance in strong magnetic fields is normally described only with the help of the secular part of the full spin-spin interaction Hamiltonian. This approximation is associated with the averaging of the spin-spin interaction over the fast motion of spins under the combined action of the static and the radio-frequency (rf) fields. Here, we report a set of conditions (nonsecular resonances) when the averaging over the above fast motion preserves some of the nonsecular terms entering the full interaction Hamiltonian. When the above conditions are satisfied, the effective spin-spin interaction Hamiltonian has an unconventional form with tunable parameters. This tunable Hamiltonian offers new ways to manipulate nuclear spins in solids. In a broader context, the same approach can be used to manipulate qbits or similar two-level quantum systems.

Theoretical description of pump/probe experiments in electron-phonon coupled superconductors

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In recent work [1-3], we have investigated the theory for pump/probe angle resolved photoemission experiments for systems that have strong electron-phonon coupling. In these experiments, a short pulse laser (typically less than 50 fs temporal width), is shone onto the material, and then a higher energy probe pulse is applied with some time delay relative to the pump. The photoelectrons are collected as a function of angle and are analyzed for their energy to allow one to construct the angle-resolved photoemission spectroscopy of the material. Our focus in this work is on systems that are governed by the electron-phonon interaction. In particular, we have described how one can directly measure the equilibrium self-energy for the electrons by analyzing the oscillations in the photoemission spectra at momenta that lie close to the Fermi surface [1]. As the pump fluence increases, we show how the electronic self-energy changes by allowing additional scattering due to the changing phase space of the electrons [2] and how exact sum rules restrict the change in the shape of the spectral function and ensure that the net electron-phonon coupling is unchanged due to the pumping of the system [3]. If time permits, I will also describe how these experiments can allow one to directly see the effects of the Higgs mode oscillation in the photoemission spectra when the system is in the superconducting phase. While the Higgs mode does not directly couple to the field, when the field is a high enough amplitude, nonlinear effects allow for a strong coupling to the Higgs mode.

[1] M. A. Sentef, A. F. Kemper, B. Moritz, J. K. Freericks, Z.-X. Shen, and T. P. Devereaux, Examining Electron-Boson Coupling Using Time-Resolved Spectroscopy, Phys. Rev. X 3, 041033 (2013).

[2] A. F. Kemper, M. A. Sentef, B. Moritz, J. K. Freericks, and T. P. Devereaux, Effect of dynamical spectral weight redistribution on effective interactions in time-resolved spectroscopy, Phys. Rev. B 90, 075126 (2014).

[3] J. K. Freericks, Khadijeh Najafi, A. F. Kemper, and T. P. Devereaux, Nonequilibrium sum rules for the Holstein model, submitted to Advances in Electron Physics, arXiv:1403.5604 (2014).

Energy transport and heating in molecular junctions

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Small size and open character of molecular junctions implies importance of nonequilibirum and quantum character of their response, as well as stochastiicity of the processes in the system. Studying thermal transport (and heating) in such systems is challenging both experimentally and theoretically. Such studies are crucial in developing effective thermoelectric devices at nanoscale and in engineering low heating molecular junctions. In the talk I will review recent progress in theoretical understanding of the tools utilized experimentally to estimnate extent of heating in junctions (effective temperature) and to judge about effectiveness of thermoelectric devices (figure of merit). I will discuss effects of quantum coherence and stochastic fluctiuations on experimentally measurable quantities and introduce the effeciency fluctuations, which are more accurately characterize the junction performance than the figure of merit. An experimental methodology to measure these fluctuations will be proposed. Finally, I will discuss shortly our attempts to formulate quantum thermodynamics of systems strongly coupled to the environment, and discuss theoretical definition of the heat flux which are in agreement with the laws of thermodynamics.

[1] A. J. White, S. Tretiak, and M. Galperin, Nano Lett. 14, 699-703 (2014).

[2] A. J. White, M. A. Ochoa, and M. Galperin, J. Phys. Chem. C 118, 11159-11173 (2014).

[3] A. J. White, B. D. Fainberg, and M. Galperin, J. Phys. Chem. Lett. 3, 2738-2743 (2012).

[4] M. Galperin and A. Nitzan, Phys. Rev. B 84, 195325 (2011).

[5] M. Esposito, M. A. Ochoa, and M. Galperin, Phys. Rev. B 91, 115417 (2015).

[6] M. Esposito, M. A. Ochoa, and M. Galperin, Phys. Rev. Lett. 114, 080602 (2015).

“Macroscopic” entanglement

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The question whether quantum theory applies at all scales is with us since the inception of quantum mechanics. The measurement problem seems still outstanding and no easy solution is in view. However, technological and conceptual progresses over the last decade made it timely to address questions about “macroscopic” quantum effects, states and entanglement. These questions cover a large variety of physical systems and of types of answers, illustrating that “macroscopic quantum” is a rich concept with many facets.

Several of these facets will be addressed, both experimentally and theoretically.

Creating topological matter in cold atomic gases: The Chern-number measurement

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Quantum systems can reach unusual states of matter when they are driven by fast time-periodic modulations. In this context, optical lattices are ideally suited for generating a wide family of time-dependent potentials, which can be used to prepare interesting band structures for cold atoms. In this talk, I will show how topological Bloch bands can be prepared using modulated optical superlattices. I will present an effective-Hamiltonian framework, which thoughtfully describes the dynamics of the periodically-driven atomic gas. I will then discuss methods to probe the topological features of the underlying band structure, such as the topologically invariant Chern number. Finally, I will report on recent experimental measurements, which revealed the Chern number in an optical-lattice setup. These results constitute an important step towards the realization of novel topological states of matter, such as fractional Chern insulators.

[1] M. Aidelsburger, M. Lohse, C. Schweizer, M. Atala, J. T. Barreiro, S. Nascimbene, N. R. Cooper, I. Bloch, and N. Goldman, Measuring the Chern number of Hofstadter bands with ultracold bosonic atoms, Nature Physics 11, 162–166 (2015).

[2] N. Goldman, J. Dalibard, M. Aidelsburger, and N. R. Cooper, Periodically driven quantum matter: The case of resonant modulations, Phys. Rev. A 91, 033632 (2015).

Response of dissipative quantum systems to driven bath modes

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Systems investigated in the laboratory typically interact with an environment causing dissipation and fluctuations. The response of these dissipative quantum systems to externally applied forces is well established. Motivated by new experimental techniques, we explore here the response of the system to driven environmental modes. This problem can be addressed theoretically in terms of an extended Caldeira-Leggett model. Results will be presented both for a damped quantum particle in a potential field and a dissipative two-level system (extended spin boson model). Specifically we investigate a dipolar system surrounded by a dielectric medium constituting a heat bath. Driving the system by an electric field will polarize the dielectric medium which then causes a response of the dipolar system. We show that for parameters adequate for a molecular system immersed in water, this bath mediated response can be very pronounced. Our findings are, however, quite general and apply to all quantum systems with linear dissipation when environmental modes are driven by external forces.

Time emerging from quantum entanglement: Illustration of a first experimental approach

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Time as an emergent property deriving from quantum correlations remains an open and controversial question in contemporary physics. The "problem of time" [1] substantially consists in the fact that a straightforward canonical quantization of general relativity yields the Wheeler-DeWitt evolution equation [2] describing a static state of the universe, that clashes with our everyday experience of an evolving world. Page and Wootters [3] speculated that by means of quantum correlations, a static system may describe an evolving "universe" from the point of view of the internal observers.

Entanglement between a "clock" system and the rest of the universe can yield a stationary state for an (hypothetical) external observer capable to test the entanglement with respect to abstract coordinate time. Concurrently, the same state will be evolving for internal observers that test the correlations between the clock and the rest [3], uniquely. Thus, time would be an emergent property of subsystems of the universe deriving from their intrinsically entangled nature.

The present work reports on an experimental approach [4] to this problem addressed to realize an emblematic example of Page and Wootters' idea at work into a laboratory, visualizing how time could emerge from a static (with respect to an abstract external time) entangled state. Even though the total state of a system is static, time is recovered as correlations between a subsystem that acts as a clock and the rest of the system that evolves according to such a clock. The physical system epitomizing the universe into a lab is composed by two entangled photons generated *via* Spontaneous Parametric Down-Conversion phenomenon: the rotation of the polarization of the first photon acts as a clock for proving an evolution of the polarization of the second one. Nonetheless, we demonstrate that the joint polarization state of both photons does not evolve.

[1] C. J. Isham, arxiv:gr-qc/9210011 (1992)

[2] B. S. DeWitt, Phys. Rev. 160, 1113-1148 (1967)

[3] D. N. Page and W.K. Wootters, Phys. Rev. D 27, 2885 (1983)

[4] E. Moreva, et.al., Phys. Rev. A 89, 052122 (2014)

SO(8) fermion dynamical symmetry and quantum Hall states for 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 includes pairing as well as particle–hole generators. The graphene SO(8) algebra is isomorphic to an SO(8) algebra that has found broad application in nuclear physics, albeit with physically very different generators, and exhibits a strong formal similarity to SU(4) symmetries that have been proposed to 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.

Does the measurement take place when nobody observes it?

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Quantum tunneling of a particle to a reservoir of a finite band-width (Λ) is considered. The reservoir is continuously monitored by frequent projective measurements, separated by a time-interval τ. We concentrate on non-selective measurements (averaged over the measurement record). For the Markovian reservoir ($\Lambda \to \infty$), no effect of the measurements on the decay rate (Γ) is found. However, for the non-Markovian reservoir (finite Λ), the decay rate would always depend on the measurement time τ. We found a simple analytical expression for the tunneling rate (Γ) as a function of Λ and τ.

The above result is compared with alternative calculations, without intermediate projection measurements, but the measurement device is included in the Schrödinger evolution. We considered a point-contact detector, which monitors tunneling to the reservoir via variation of its current (the signal). It appears that the detector generates dephasing rate (γ), corresponding to the inverse minimal time when the signal-to-noise ratio of the detector current close to unity. We found the decay rate Γ, as a function of Λ and γ in analytical form, which displays the influence of γ on the tunneling rate in the case of non-Markovian reservoirs.

Although the both treatments are different, the final results becomes very close if $\tau = 1/\gamma$. This indicates that the measurement during the quantum evolution (quantum trajectory) takes place, whenever the signal can be distinguished by a potential observer. It suggests that the information can affect the quantum mechanical motion on the fundamental level.

Can quantum phenomena be modelled via interactions between many classical worlds?

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We investigate whether quantum theory can be understood as the continuum limit of a mechanical theory, in which there is a huge, but finite, number of classical “worlds,” and quantum effects arise solely from a universal interaction between these worlds, without reference to any wave function. Here, a “world” means an entire universe with well-defined properties, determined by the classical configuration of its particles and fields. In our approach [1], each world evolves deterministically, probabilities arise due to ignorance as to which world a given observer occupies, and we argue that in the limit of infinitely many worlds the wave function can be recovered (as a secondary object) from the motion of these worlds.

We introduce a simple model of such a “many interacting worlds” approach and show that it can reproduce some generic quantum phenomena—such as Ehrenfest’s theorem, wave packet spreading, barrier tunneling, and zero-point energy—as a direct consequence of mutual repulsion between worlds. We have performed numerical simulations using our approach. These demonstrate, first, that it can be used to calculate quantum ground states, and second, that it is capable of reproducing, at least qualitatively, the double-slit interference phenomenon.

[1] M.J.W. Hall, D.-A. Deckert and H.M. Wiseman, Phys. Rev. X 4 (2015) 041013.

Dark matter probes at different astronomical scales

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Since the early 1970s and the discovery of flat rotation curves beyond the optical radius of spiral galaxies, the dark matter (DM) paradigm has been widely accepted by the astronomical community. It has been extended in the 1980s to galaxy clusters supposedly from the gravitational lensing forming the giant luminous arcs in their cores. During the 1990s, Local Group dwarfs have been assumed to be the most DM-dominated objects from the velocity dispersion of their stars. I will review the remarkable progresses in the understanding of galaxy and structure formation and of baryonic matter inventories. Among the latter, there are (1) the Bosma effect showing that the supposed DM kinematics present a similar behavior than the HI gas; (2) the warm and very hot gas that may contribute to a significant fraction of the spiral galaxy mass; and (3) the growing evidences that spiral galaxies, including our neighbor, the giant Andromeda galaxy, have acquired their angular momentum through gas-rich major mergers. A robust alternative to the DM paradigm has been found for Local Group dwarfs, since their high velocity dispersion can be well understood if they are tidal dwarf galaxies being gas-stripped by the hot gas of either the Milky Way or Andromeda. Definitive answers to the DM paradigm require further investigations of distant galaxies and their ionized gas content using spatially resolved kinematic observations with the Extremely large Telescopes.

Quantum fluctuation theorems: The state of the art

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

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

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

Talk based on joint collaborations with Peter Talkner and Michele Campisi.

For feature articles, talks and ref. materials see: (Quantum)-Fluctuation Theorems

http://www.physik.uni-augsburg.de/theo1/hanggi/Fluctuation.html

Pertinent references are:

[1] M. Campisi, P. Hänggi, and P. Talkner, Colloquium: Quantum fluctuation relations: Foundations and applications, Rev. Mod. Phys. 83, 771-791 (2011); M. Campisi, P. Hänggi, and P. Talkner, Addendum and Erratum: Quantum fluctuation relations: Foundations and applications Rev. Mod. Phys. 83, 1653 (2011).

[2] P. Hänggi and P. Talkner, The other QFT, Nature Physics 11, 108-110 (2015).

Atom-interferometry limits on dark energy

Philipp Haslinger[1], Paul Hamilton[1], Matt Jaffe[1], Quinn Simmons[1], Justin Khoury[2], and Holger Müller[1]

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Atom interferometry has developed within the last decades to an ideally tool for detecting weak forces. A recent proposal [1] suggests using this sensitivity to search for dark energy in the form of scalar fields. The simplest such models would lead to fifth forces in conflict with results from experiments using macroscopic test masses such as torsion balances [2]. These limits can be evaded through a variety of screening mechanisms in the presence of typical laboratory matter densities. However, single atoms in an ultra-high vacuum environment can serve as ideal test masses which avoid this screening. In our recently developed optical cavity atom interferometer [3] we place limits [4] on anomalous accelerations below 5.5 μm/s^2 (95% confidence level) at millimeter scale distances from a spherical source mass. These limits rule out a large range of scalar field theories, such as chameleons, which would be consistent with the cosmological dark energy density. With further improvements in sensitivity, this atom interferometer will be able to rule out many scalar field dark energy theories with coupling strengths up to the Planck mass scale.

[1] C. Burrage, E. J. Copeland, and E. A. Hinds, arXiv:1408.1409v1 (2014)

[2] D. J. Kapner, T. S. Cook, E. G. Adelberger, J. H. Gundlach, B. R. Heckel, C. D. Hoyle, and H. E. Swanson Phys. Rev. Lett. 98, 021101 (2007)

[3] P. Hamilton, M. Jaffe, J. Brown, L. Maisenbacher, B. Estey and H. Müller Phys. Rev. Lett. 114, 100405 (2015)

[4] P. Hamilton, M. Jaffe, P. Haslinger, Q. Simmons, J. Khoury and H. Müller, arXiv:1502.03888v2 (2015)

Experimental implications of Bochner-Levy-Riesz diffusion

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Fractional Bochner-Levy-Riesz diffusion arises from ordinary diffusion by replacing the Laplacean with a noninteger power of itself. Bochner-Levy-Riesz diffusion as a mathematical model leads to nonlocal boundary value problems. As a mesoscopic model for physical or thermal transport processes it seems to predict phenomena that have yet to be observed in experiment [1].

[1] R. Hilfer, Experimental Implications of Bochner-Levy-Riesz Diffusion, Frac. Calc. Appl. Analysis, vol.18, page 333, (2015)

Out-of equilibrium thermodynamics with single electron counting experiments

Andrea Hofmann, Ville F. Maisi, Clemens Rössler, Julien Basset, Thomas Ihn, Klaus Ensslin, Christian Reichl, and Werner Wegscheider

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In the recent trend towards smaller systems, the relative fluctuations away from the equilibrium state become prominent and non-equilibrium dynamics needs to be accounted. We study out-of equilibrium properties of a quantum dot in a GaAs/AlGaAs two-dimensional electron gas. By means of single electron counting experiments [1], we measure the distributions of work and dissipated heat of the driven system and relate these quantities to the equilibrium free energy change, as it is proposed by Jarzinsky [2]. We discuss the influence of the degeneracy of the quantized energy state on the free energy change as well as its relation to the tunnel coupling of the dot to the reservoir.

[1] S. Gustavsson, R. Leturcq, B. Simovic, R. Schleser, T. Ihn, P. Studerus, K. Ensslin, D. C. Driscoll, and A. C. Gossard, Phys. Rev. Lett. 96 (2006) 7

[2] C. Jarzynski, Nonequilibrium equality for free energy differences, Phys. Rev. Lett. 78 (1997) 14

Ehrenfest classification of phase transitions and phase diagrams

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In 1933 Ehrenfest [1] published his classification of phase transitions into two categories: first-order transitions (where Clausius-Clapeyron equation is valid) and second-order transitions (where Ehrenfest equations, derived from Clausius-Clapeyron equation using l'Hopital rule, are valid). The Ehrenfest classification was initiated by report by Keesom & Haas [2] on observation of unusual transition (lately called λ-transition) of liquid helium. However, the Ehrenfest equations did not fit the experimental temperature dependences of heat capacity at λ-transitions. In 1937 Landau [3] published his "*theory of phase transitions*" where "*two possible types of transitions*" are considered: "*(1) Curie points with a discontinuity in the specific heat which lie in the* p, T*–diagram and (2) isolated points in the* p, T*–diagram which lie in the certain way on intersections of curves of normal phase transitions.*" The Ehrenfest classification was widely accepted after publishing the book by A. Brian Pippard in 1957 [4] where the existence of higher-order phase transitions is admitted. Starting from binary $T, x-$diagrams, Hillert [5] distinguished *sharp transitions* $\alpha = \beta$ (as first-order transitions a tone temperature) and *gradual transitions* – transitions $\alpha = \beta$ realized gradually in defined temperature interval $< T_{in}, T_{fin} >$. If we consider the extreme temperatures of the mentioned interval as *partial transitions* $\alpha = \alpha + \beta$ (at T_{in}) and $\alpha + \beta = \beta$ (at T_{fin}) we found the validity of Ehrenfest equations for these partial transitions [6]. Partial transition ($\alpha_1 + \alpha_2 = \alpha_1$ or $\alpha_1 + \alpha_2 = \alpha_2$) can exist also individually (not as a part of gradual transition) on the boundary of miscibility gaps (two-phase regions $\alpha_1 + \alpha_2$), where Ehrenfest equations are also valid excluding the critical (consolution) point (T_{cr}, x_{cr}) where the tangent line of boundary of miscibility gap becomes a horizontal line. This consolution critical point corresponds to "*critical transition*" $\alpha_1 + \alpha_2 = \alpha$ which can be understand as a *third-order* transition (when Ehrenfest equations are invalid but a new series of equations can be derived from Ehrenfest equations using l'Hopital rule.

[1] Ehrenfest, P. (1933) Verhandelingen der Koninklijke Akademie van Wetenschappen. Amsterdam/ 36: 153–157

[2] Keesom, W. H. and de Haas, W. J. (1932) Verhandelingen der Koninklijke Akademie van Wetenschappen. Amsterdam/ 34: 605

[3] Landau, L. (1937) Zh. Eksp. Teor. Fiz. 7: 19-32

[4] Pippard, A. B. (1957): Elements of Classical Thermodynamics. Cambridge Univ. Press

[5] Hillert, Mats (1998): Phase Equilibria, Phase Diagrams and Phase Transformation. Their Thermodynamic Basis. Cambridge Univ. Press

[6] Holba, P. (2015) J. Thermal Anal. Cal. 120 [1]: 175-181

T58 Thu, 30 July, 10:50 - 11:20, 2 session

Slow relaxation in the electron glass

Ariel Amir[1,2], Yasmine Meroz[1,2], Yuval Oreg[1], and Yoseph Imry[1]

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Our (with Amir, Meroz and Oreg) picture for the slow relaxational behavior in the glass model of interacting, localized, electrons will be expounded. First, in the linear approximation, where a universal 1/ ν distribution will be obtained for the relaxation rates, ν, will be obtained, emphasizing small ν. Then, the relaxation will be obtained beyond the linear approximation, leading to a description of the "memory" dip and its time evolution in qualitative agreement with experiment.

The interaction of gravitational waves with superconductors

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Applying the Helmholtz Decomposition theorem to linearized General Relativity leads to a gauge-invariant formulation where the transverse-traceless part of the metric describes gravitational waves in matter. Gravitational waves incident on a superconductor can be described by a linear London-like constituent equation characterized by a "gravitational shear modulus" and a corresponding plasma frequency and skin depth. The Cooper pair density is described by the Ginzburg-Landau theory embedded in curved space-time. The ionic lattice is modeled by an ensemble of quantum harmonic oscillators coupled to gravitational waves and characterized by quasi-energy eigenvalues for the phonon modes. The formulation predicts a dynamical Casimir effect in which the zero-point energy of the ionic lattice phonons are modulated by the gravitational wave. Applying periodic thermodynamics and the Debye model in the low-temperature limit leads to a free energy density for the ionic lattice. Lastly, we relate the gravitational strain of space to the strain of matter to show that the Cooper pair density is far less responsive to gravitational waves than the ionic lattice. This predicts a charge-separation effect which may lead to the possibility of reflection of gravitational waves by a superconductor.

Thermalisation of a quantum system from first principles

Gregoire Ithier[1] and Florent Benaych-Georges[2]

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[2] *MAP5, Université Paris Descartes, France*

How does a quantum system reach thermodynamical equilibrium? Answering such a question from first principles is, perhaps surprisingly, still an open issue[1-3]. We present here a new model comprising an arbitrary quantum system interacting with a large arbitrary quantum environment, both initially prepared in a quantum pure state. We then demonstrate that thermalisation is an emergent property of the unitary evolution under a Schrödinger equation of this large composite system. The key conceptual tool of our method is the phenomenon of « measure concentration » appearing with functions defined on large dimension Hilbert spaces, a phenomenon which cancels out any effect of the microscopic structure of interaction Hamiltonians. Using our model, we first characterize the transient evolution or decoherence of the system and show its universal character. We then focus on the stationary regime and recover the canonical state well known from statistical thermodynamics. This finding leads us to propose an alternative and more general definition of the canonical partition function, that includes, among other things, the possibility of describing partial thermalisation.

[1] S. Popescu, A. J. Short, and A. Winter, Nature Physics 2, 754-758 (2006)

[2] S. Goldstein, J. L. Lebowitz, R. Tumulka, and N. Zanghì, Phys. Rev. Lett. 96, 050403 (2006)

[3] S. Genway, A. F. Ho, and D. K. K. Lee, Phys. Rev. Lett. 111, 130408 (2013)

Conceptualizing measurement

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The notion of macroscopic realism has often been used in attempts to achieve consistency between physics and everyday experience and to locate some boundary between the realms of classical mechanics and quantum mechanics. Its underlying conceptual components, realism and macroscopicity, have most often appeared in the foundations of physics in relation measurement. However, macroscopicity turns out to be a more vague and less consistently understood notion than typically assumed. For this reason, it is wise to explore alternative groundings for quantum measurement, with a prime value placed on the avoidance of anthropocentrism, something clearly pointed out by realists such as John Bell. Moreover, in the standard mathematical formulation of quantum mechanics, measurement is an additional, exceptional fundamental process, connected by some with the presence of "macroscopic systems," rather than an often complex, but ordinary process which happens also to serve a particular epistemic function.

Accordingly, many have been concerned about the fundamental role given to measurement, and with it macroscopicity, in the foundation of the theory. Others, including the early Bohr and Schwinger, have suggested that quantum mechanics naturally incorporates an unavoidable uncontrollable disturbance of physical state that accompanies any measurement without the need for an exceptional fundamental process. Such state change was unanalyzable for Bohr, but for Schwinger it was due to physical interactions' being borne by fundamental particles having discrete properties and behavior which is beyond physical control and is the subject of a theory of quantum fields. In this talk, the possibility of a quantum theory of measurement on a coherent physical basis without exceptional physical events is explored.

[1] G. Jaeger, Am. J. Phys. 82, 896 (2014).

[2] G. Jaeger, Phys. Scr. 2014, 014017 (2014).

[3] G. Jaeger, Found. Phys. (in press) online doi 10.1007/s10701-015-9893-6.

[4] G. Jaeger, in Mary Bell and Shan Gao (eds.) Quantum Nonlocality and Reality (Cambridge: Cambridge University Press, in press).

T62 Mon, 27 July, 8:30 - 9:00, 1 Session

Thermodynamics in the presence of large system-environment coupling

Christopher Jarzynski

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In macroscopic thermodynamics, any amount of energy that is gained by a system must be lost by its surroundings (or vice-versa), in accordance with the first law of thermodynamics. However, if the system-environment interaction energy cannot be neglected – as for example in the case of a single molecule in solution – then it is not immediately clear how to define unambiguously the energy of the system and that of the environment. To which subsystem does the interaction energy belong? I will describe a microscopic formulation of both the first and second laws of thermodynamics that applies to this situation. In this framework, quantities such as heat, work, internal energy and entropy are given precise definitions, and the structure of the first and second laws is preserved without introducing corrections due to non-negligible system-environment coupling. These definitions reduce to the usual ones in the limit of macroscopic systems of interest. This framework is developed within a classical approach, and its extension to quantum systems remains an open question.

Thermodynamics in extreme quantum regimes

David Jennings

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How should we analyse the thermodynamics of intrinsically quantum-mechanical features, such as coherence and entanglement? I shall discuss possible limitations of a direct statistical mechanical approach, and then describe recent work that applies techniques from the theory of quantum information to foundational thermodynamics. In particular, recent results from the study of entanglement suggest a broad paradigm of quantum resource theories that can be applied to the thermodynamics of quantum systems. This framework provides us with flexible and unifying ways to describe nanoscale irreversibility, and is well suited to the quantification and manipulation of intrinsically quantum-mechanical features in thermodynamic processes.

The quantum road most taken

Andrew Jordan

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New features in fundamental quantum physics appear in generalized (or weakened) measurements that are no longer simple projections. A sequence of weak measurements can also be made effectively continuous, producing monitored state evolution in the form of a quantum stochastic process. Previous theoretical investigations of this topic have mainly focused on using Langevin-type Stochastic Schrodinger equations to generate and study the quantum trajectories. Here, we reformulate the theory of continuous quantum measurement as a stochastic path integral, describing all possible quantum trajectories moving between initial and final quantum states. In order to do this, an auxiliary set of variables is introduced to impose the intrinsic state disturbance, doubling the state space of the system. The stochastic action encodes both the Hamiltonian and measurement dynamics. This formulation is well suited to finding the most-likely quantum path between chosen boundary conditions on the quantum states separated in time via a principle of least action. This action principle leads to a set of coupled nonlinear ordinary differential equations for the most likely path, structurally similar to Hamilton's equations. I will present predictions for the single and multiple qubit cases. Comparison to recent experiments with superconducting transmon qubits will be discussed. This formalism sheds new light on the conditional dynamics of monitored open quantum systems.

[1] Mapping the optimal route between two quantum states, S. J. Weber, A. Chantasri, J. Dressel, A. N. Jordan, K. W. Murch, and I. Siddiqi, Nature 511, 570–573 (2014)

[2] Action principle for continuous quantum measurement, A. Chantasri, J. Dressel, and A. N. Jordan, Phys. Rev. A 88, 042110 (2013)

Shaping of on-demand electron wave-packets by tunnel-barrier design

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On-demand generation of quantum excitations along ballistic edges in high-mobility semiconductor nanostructures offers exciting prospects for studying collider-type physics with quasiparticles and developing solid states electron analogues of quantum optics [1,2,3]. Transition from a localized state in a zero-dimensional structure (such as a mesoscopic capacitor [1,2], a semiconductor quantum dot [1,3] or a metallic island [1]) to a wave-packet propagating in a one-dimensional continuum is typically triggered by an external voltage pulse on a gate controlling the electrostatic confinement potential.

Tailoring the quantum state of a generated wave-packet is challenging if done conventionally by pulse-shaping in time-domain. Here, we consider the simplest possible driving - increasing the energy of a localized level linearly in time, but allow for arbitrary energy-dependence of the tunnel coupling $\Gamma(E)$ (which is tunable by quasi-static voltages and/or the lithographic design). Using the Demov-Osherov solution [4] for a multi-level Landau-Zener problem we derive the exact wave function of the emitted particle, and give it an interpretation in terms of a continuously decaying quasi-bound state dressed by the self-energy due to coupling to the continuum. Two generic emission regimes are identified, corresponding to (a) semiclassical out-tunneling with a well-defined time-dependent rate $\Gamma[E(t)]/\hbar$, and (b) strongly non-adiabatic quantum emission regime in which the energy filtering effect of the tunnel-barrier is essential, $d\Gamma(E)/dE > 1$, and the quasi-bound state picture breaks down.

We find analytical expressions for the uncertainties in energy ΔE and time Δt, and show that the uncertainty product can approach the Kennard bound of $(1/2)\hbar$ for a Fermi-function-like energy dependence of the tunnel rate, characteristic for tuneable barriers of electrostatically-defined semiconductor quantum dots [3].

[1] J. P. Pekola, O. P. Saira, V. F. Maisi, A. Kemppinen, M. Möttönen, Y. A. Pashkin and D. V. Averin, Rev. Mod. Phys. 85 (2013) 1421-1472.

[2] E. Bocquillon, V. Freulon, F. D. Parmentier, J. M. Berroir, B Plaçais, C. Wahl, J. Rech, T. Jonckheere, T. Martin, C. Grenier, D. Ferraro, P. Degiovanni and G. Fève, Ann. Phys. 526 (2014) 1-30.

[3] B. Kaestner and V. Kashcheyevs, arXiv:1412.7150, to appear in Rep. Prog. Phys. (2015).

[4] Yu. N. Demkov and V. N. Ostrovsky, Zh. Eksp. Teor. Fiz. 60 (1971) 2011.

T66 Thu, 30 July, 15:40 - 16:00, 4 session - A parallel

Propagation of correlations and entanglement in long-range lattice models

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We study the spreading of correlations and other physical quantities in quantum lattice models with interactions or hopping decaying like $r^{-\alpha}$ with the distance r. Our focus is on exponents α between 0 and 6, where the interplay of long- and short-range features gives rise to a complex phenomenology and interesting physical effects, and which is also the relevant range for experimental realizations with cold atoms, ions, or molecules. We present analytical and numerical results, providing a comprehensive picture of spatio-temporal propagation. Lieb-Robinson-type bounds are extended to strongly long-range interactions where α is smaller than the lattice dimension, and we report particularly sharp bounds that are capable of reproducing regimes with soundcone as well as supersonic dynamics. Complementary lower bounds prove that faster-than-soundcone propagation occurs for α<2 in any spatial dimension, although cone-like features are shown to also occur in that regime. Our results provide guidance for optimizing experimental efforts to harness long-range interactions in a variety of quantum information and signaling tasks.

Quantifying and controlling superconducting circuits

Nadav Katz

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Superconducting Josephson circuits have recently emerged as one of the major implementations of quantum information processing, including advanced quantum optical experiments. I will present some of our experiments in this field, characterizing multi-level coherence in phase circuits, via new tomography and control techniques. Next I will show data for coupled coplanar resonator arrays (ranging for 2 to 90 coupled resonators), characterizing the various nonlinearities of these critical components down to the single photon level via multi-tone spectroscopy. Prospects for multi-particle quantum walk experiments will be presented.

Bardeen hysteresis: A quantum mechanical basis for the second law?

Peter David Keefe

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The adiabatic phase transition of a bulk-size Type I superconductor is reversible and isentropic, consistent with the second law of thermodynamics. However, it has been proposed [1] that the adiabatic phase transition of a mesoscopic-size Type I superconductor is irreversible and non-isentropic, inconsistent with the second law of thermodynamics. In response to this proposal, John Bardeen, in a private communication to the author, [2] proposed magnetic hysteresis at the phase transition which would provide a magnetodynamic loss of sufficient magnitude to bring the adiabatic phase transition of a Type I particle into consistency with the second law of thermodynamics. This magnetic hysteresis, referred to herein as "Bardeen Hysteresis", has not been reported in the literature. [3] This talk will explore the possible origin of Bardeen Hysteresis and whether it may suggest a quantum mechanical basis for the second law.

[1] P.D. Keefe, U.S. Patent 4,638,197 (1987).

[2] Private letter communication of John Bardeen to the author (1987). Letter courtesy of the University of Illinois at Urbana-Champaign Archives, Record series: Box 28 of the Bardeen papers.

[3] P.D. Keefe, Physica Scripta, 151, 014029 (2012).

Stochastic thermodynamics in single electron circuits

Ivan M. Khaymovich[1], Jonne V. Koski[1], Olli-Pentti Saira[1], Vladimir E. Kravtsov[2], and Jukka P. Pekola[1]

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Energy fluctuations play an important role in small systems. The distribution of entropy production and the work performed under non-equilibrium conditions are governed by fluctuation relations; the second law of thermodynamics applies only for averages over long times or many experiments. We apply the concepts of stochastic thermodynamics to our experiments in single-electron and superconducting circuits. The focus is on fluctuation relations [1,2], Maxwell's demon [3,4] and calorimetry for quantum thermodynamics [5-7]. Single-electron circuits provide a basic set-up for realizing a Maxwell's Demon which utilizes information to extract heat (and work) of 75% of k_B T log(2) in a cycle on the average [3]. We also discuss a recent experiment on an "all-in-one" autonomous Maxwell's demon. Then we present on-going activity on fast calorimetry of dissipation down to single quantum level [7]. In the final part we consider the analogy between the distribution of wave function (WF) amplitudes in disordered systems close to the Anderson localization transition and the fluctuations of the work dissipated in driven systems (single-electron box in our case). We exploit this analogy and uncover new relations which generalize the Jarzynski equality, which are checked experimentally. Our results [8] represent an important universal feature of the work statistics in systems out of equilibrium and help to understand the nature of the symmetry of multifractal exponents in the theory of Anderson localization.

[1] O.-P. Saira, Y. Yoon, T. Tanttu, M. Möttönen, D. V. Averin, and J. P. Pekola, Phys. Rev. Lett. 109 (2012) 180601.

[2] J. V. Koski, T. Sagawa, O.-P. Saira, Y. Yoon, A. Kutvonen, P. Solinas, M. Möttönen, T. Ala-Nissila, and J. P. Pekola, Nat. Phys. 9 (2013) 644.

[3] J. V. Koski, V. F. Maisi, J. P. Pekola, and D. V. Averin, PNAS 111 (2014) 13786.

[4] J. V. Koski, V. F. Maisi, T. Sagawa, and J. P. Pekola, Phys. Rev. Lett. 113 (2014) 030601.

[5] J. P. Pekola, P. Solinas, A. Shnirman, and D. V. Averin, New J. Phys. 15 (2013) 115006.

[6] F. W. J. Hekking and J. P. Pekola, Phys. Rev. Lett. 111 (2013) 093602.

[7] S. Gasparinetti, K. L. Viisanen, O.-P. Saira, T. Faivre, M. Arzeo, M. Meschke, and J. P. Pekola, Phys. Rev. Appl. 3 (2015) 014007.

[8] I.M. Khaymovich, J.V. Koski, O.-P. Saira, V.E. Kravtsov, and J.P. Pekola, Nat. Comm. 6 (2015) 7010.

Quantum-like modeling of cognition: On violation of Aumann theorem

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The celebrated Aumann theorem states that if two agents have common priors, and their posteriors for a given event E are common knowledge, then their posteriors must be equal; agents with the same priors cannot agree to disagree. The aim of this note is to show that in some contexts agents using a quantum probability scheme for decision making can agree to disagree even if they have the common priors, and their posteriors for a given event E are common knowledge. We also point to sufficient conditions guaranteeing impossibility to agree on disagree even for agents using quantum(-like) rules in the process of decision making. A quantum(-like) analog of the knowledge operator is introduced; its basic properties can be formulated similarly to the properties of the classical knowledge operator defined in the set-theoretical approach to representation of the states of the world and events (Boolean logics). However, this analogy is just formal, since quantum and classical knowledge operators are endowed with very different assignments of truth values. A quantum(-like) model of common knowledge naturally generalizing the classical set-theoretic model is presented. We illustrate our approach by a few examples; in particular, on attempting to escape the agreement on disagree for two agents performing two different political opinion polls. We restrict our modeling to the case of information representation of an agent given by a single quantum question-observable (of the projection type). A scheme of extending of our model of knowledge/common knowledge to the case of information representation of an agent based on a few question-observables is also presented and possible pitfalls are discussed.

[1] A. Khrennikov and I. Basieva, Possibility to agree on disagree from quantum information and decision making. J. Math. Psychology 62–63, 1–15 (2014).

Thermodynamic cycles using levitated optomechanics

Nikolai Kiesel[1], Florian Blaser[1], Uros Delic[1], David Grass[1], Markus Aspelmeyer[1], Andreas Dechant[2], and Eric Lutz[2]

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Coupling levitated nanoparticles to an optical cavity field has recently received significant attention as it promises access to a unique parameter regime for macroscopic quantum experiments and for high-precision force sensing. Here we will present levitated cavity optomechanics from a different perspective and illustrate that it also enables unique studies of thermodynamics on the single particle level.

We discuss the implementation of thermodynamic processes in cavity optomechanics. In particular, we propose and analyze a nanomechanical Sterling cycle controlled by light fields [1]. We determine the optimal protocols in the underdamped regime and show that levitated optomechanics should allow demonstrating the characteristic features of these protocols in our experimental setup [2].

Further we will discuss recent advancements in the experimental realization of levitated optomechanics towards the implementation of such thermodynamics processes in the classical and the quantum regime.

[1] Dechant A. et al., An all-optical nanomechanical heat engine. Phys. Rev. Lett. 114, 183602 (2015)

[2] Kiesel N. et al. Cavity cooling of an optically levitated submicron particle. PNAS 110, 14180 (2013)

Scaling at quantum phase transitions: General concepts with applications to clean metallic ferromagnets

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We generalize scaling concepts and relations between critical exponents that are well known from classical phase transitions to the case of quantum phase transitions. The special role of temperature at a quantum phase transition requires the introduction of several new exponents, and the presence of multiple time or energy scales at many quantum phase transitions requires a careful analysis of dynamical scaling phenomena. We also show that the scaling concepts for classical first-order transitions due to Fisher and Berker can be generalized to the quantum case. As an example of how to apply all of these concepts, we discuss the quantum ferromagnetic transition in clean metals, which generically is first order at low temperatures. We show that Clausius-Clapeyron relations in conjunction with the Third Law of Thermodynamics have profound consequences for the shape of the coexistence curve in the zero-temperature limit.

Quantum cascade lasers: A nonequilibrium physics playground

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Quantum cascade lasers (QCLs) are electrically driven, unipolar, coherent light sources in the midinfrared (mid-IR) and terahertz (THz) parts of the electromagnetic spectrum. In addition to being of great technological importance, QCLs are fascinating nonequilibrium systems that are typically thoroughly characterized via electrical, optical, and thermal measurements precisely because of their practical value. As a result, QCLs are excellent as model systems for far-from-equilibrium theoretical studies.

During typical QCL operation, large amounts of energy are pumped into the electronic system, of which a small fraction is given back through the desired optical transitions, while the bulk of it is deposited into the optical phonon system. Optical phonons decay into acoustic phonons (so-called anharmonic decay), which have high group velocity and are the dominant carriers of heat. Anharmonic decay is typically an order of magnitude slower than the rate at which the electron system deposits energy into the optical-phonon system. Consequently, in the steady state, there is a considerable population of excess, nonequilibrium optical phonons, which, in turn, affect electronic transport and the laser optical power.

In this talk, I will discuss the highly nonequilibrium physics of the strongly coupled electron and phonon systems in quantum cascade lasers. In mid-IR QCLs, both electronic and phononic systems are largely semiclassical and described by coupled Boltzmann transport equations, which we solve using the semiclassical ensemble Monte Carlo technique [1]. In THz QCLs, however, electronic transport features a considerable degree of coherence. We employ, for the first time, the Wigner transport equation for electronic transport in THz QCLs [2], which can be solved using the stochastic Wigner Monte Carlo technique [3]. We discuss the roles of nonequilibrium phonons in QCLs, modeling tunneling through multiple barriers concurrently with decoherence due to inelastic scattering in THz QCLs within the Wigner formalism [2], and QCL transport as a multiscale simulation problem [4].

[1] Y. B. Shi and I. Knezevic, "Nonequilibrium phonon effects in midinfrared quantum cascade lasers," J. Appl. Phys. 116, 123105 (2014).

[2] O. Jonasson, Y. B. Shi, and I. Knezevic, "Wigner Monte Carlo simulation of terahertz quantum cascade lasers," in preparation (2015).

[3] O. Jonasson and I. Knezevic, "Coulomb-driven terahertz-frequency intrinsic current oscillations in a double-barrier tunneling structure," Phys. Rev. B 90, 165415 (2014).

[4] Y. B. Shi, S. Mei, and I. Knezevic, "Multiscale simulation of coupled electron and phonon transport in quantum cascade lasers," in preparation (2015).

Twisted photon entanglement through turbulent air across Vienna

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Photons with a twisted phase front can carry a discrete, in principle unbounded amount of orbital angular momentum (OAM). The large state space increases the number of channels available for classical communication, which can significantly improve data-rates [1]. On the quantum level, spatial modes can increase the complexity of quantum entanglement [2,3]. These non-classical correlations might be useful in quantum communication schemes between widely separated parties as well as for fundamental experiments of quantum physics. However, the distribution of such spatial photonic modes over large distances was thought to be infeasible due to significant influence of atmospheric turbulence. This would indicate a serious limitation on the usefulness of higher-order spatial modes.

Thus in 2014, we performed the first experiment in a real-world scenario, where we transmitted classical information encoded in OAM modes over a distance of 3 kilometers across the city of Vienna [4]. I will present how we encoded information in form of small gray-scale pictures with up to 16 different modes with an error rate of only 1.7 %.

Motivated by the results of the classical experiment, we performed a follow-up experiment, which brings our investigation to the quantum level. I will explain how we were able to distribute quantum entanglement encoded in OAM over the same turbulent 3-kilometer intra-city link. We encode entanglement of the first two higher-order levels (with OAM=$\pm 1\hbar$ and $\pm 2\hbar$). They constitute four new quantum channels orthogonal to all that have been used in long-distance quantum experiments so far.

[1] Wang, J. et al., Terabit free-space data transmission employing orbital angular momentum multiplexing. *Nature Photon.*, **6**(7), 488-496 (2012).

[2] Dada, A. C. et al., Experimental high-dimensional two-photon entanglement and violations of generalized Bell inequalities. *Nature Phys.*, **7**(9), 677-680 (2011).

[3] Krenn, M. et al., Generation and confirmation of a (100x100)-dimensional entangled quantum system. *PNAS*, **111**(17), 6243-6247 (2014).

[4] Krenn, M. et al., Communication with spatially modulated light through turbulent air across Vienna. *NJP*, **16**(11), 113028 (2014).

Surface plasmon assisted electron pairing in gold at room temperature

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Plasmonics is one of the fastest developing fields in science and technology.There are several unique properties of surface plasmon oscillations (SPO) behind this stormy development, Among them the lack of the diffraction limit, being a significant hurdle of classical optics, furthermore the high electromagnetic field enhancement in the near field on metal surfaces are unique and are the basic features, explored in the present work. Room and higher temperature superconductivity has been the scientific dream since a long time. This lecture presents our findings, where the above listed properties have been explored and room temperature superconductivity has been realized. Namely it has been found, that part of the conduction electrons on the surface are pairing, coupled by SPO-s, excited by intense femtosecond Ti:Sa laser pulses. The experimental proofs are based on STM and electron emission experiments. The STM has scanned the near field of surface plasmons on the gold films, which were excited via glass prisms in the Kretschmann geometry. The electron pairing occured in a 40GW/cm^2 laser intensity range around 80GW/cm^2 as indicated by the anomaly in the laser intensity dependence of the amplitude and temporal width of the STM signal, measured at hot spots on the gold surface. The spectra of multiplasmon emitted electrons were also studied, using the time-of-flight technique. These experiments showed also electron pair condensation in the same laser intensity range as in the STM case. In addition from laser polarization dependence of the electron spectra Meissner and Faraday-rotation type anomalies have also been found. The observation of delayed photons with tens of microseconds after the exciting laser pulses is an additional proof of the existence of SPO assisted superconductivity in these high laser fields. Some theoretical background, supporting our observations is also given.

The emergence of super massive black holes and their correlation with galaxy properties

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Starting with the correlation between the star formation rate (SFR) of a galaxy and the most massive star cluster forming in it, I show that for very high SFRs such as were occurring in the early Universe, the most massive star cluster achieved a mass near 100 million Solar masses. Under the densities of star formation in such extreme star-burst clusters the stellar population becomes top-heavy. The very large number of massive stars leave a very massive sub-cluster of stellar mass black holes. These merge effectively under the radiation of gravitational waves building up a massive seed-BH which ranges from 0.1 to 1 or more million Solar masses within less than a Gyr. This result leads directly to a correlation between the mass of the host galaxy and its central BH.

Quantum resources may boost the performance of heat machines

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I will discuss the governing principles of heat machines that operate at micro-/nano-scales, where quantumness is essential for understanding their functioning. I will address the core issue pertaining to the operation of such machines: the bounds on the efficiency and power of quantum heat engines (QHE) and quantum refrigerators (QR). To resolve this issue, I will invoke: (i) bath engineering, centered on thermalization control, which may be exploited as a resource in QHE and QR; (ii) heat machines based on a single-qubit, single-qutrit or multiple qubits that may benefit from extra resources provided by the quantum-state preparation of the piston, the system (coherence or entanglement) and nonthermal bath states. These quantum resources may be exploited in advantageous, novel heat machines based on NV-center spin-ensembles and nanomechanical platforms. The envisaged advancement along this path is important for overcoming obstacles to nanotechnological progress.

Making weak measurements stronger

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Weak-value measurements have been shown to be useful for making precision optical measurements, owing to the huge amplification of tiny effects which is achievable with the technique [1-3]. This amplification is especially helpful in the case where technical noise limits the resolution [4-5]. However, if the intrinsic shot noise limits the resolution, weak-value measurements offer no advantage because the amplification is achieved via a postselection which discards most of the photons input into the measuring system. The reduction in photon number cancels the increase in signal from the amplification, and the resolution is not increased. To overcome this, we implement a method for recycling the discarded photons [6]. We show that, for a given number of photons input to the system, recycling gives an improvement over the resolution of a conventional measurement. Our work with a simple double-pass recycling system demonstrated a $1.4\times$ improvement over the standard shot-noise limit. We also present our work toward achieving a many-pass recycling system, for which we expect a five-fold improvement over the shot-noise limit. Such a weak-measurement recycling system could be combined with quantum states to further enhance the achievable resolution. We also discuss a related approach, using a cw beam. Here we introduce a power-recycling mirror, creating a resonant cavity, so that again all the light exits to the detector with a large deflection, thus eliminating the inefficiency of the rare postselection [7]. The signal-to-noise ratio of the deflection is itself magnified by the weak value. We discuss our attempt to realize this proposal.

[1] O. Hosten and P. G. Kwiat, Science 319 (2008) 787.

[2] P. B. Dixon, D. J. Starling, A. N. Jordan, and J. C. Howell, Phys. Rev. Lett. 102 (2009) 173601.

[3] P. Egan and J. A. Stone, Opt. Lett. 37 (2012) 4991.

[4] A. N. Jordan, J. Martínez-Rincón, and J. C. Howell, Phys. Rev. X 4 (2014) 011031.

[5] G. I. Viza, J. Martínez-Rincón, G. B. Alves, A. N. Jordan, and J. C. Howell, quant-ph 1410.8461v2 (2014).

[6] J. Dressel, K. Lyons, A. N. Jordan, T. M. Graham, and P. G. Kwiat, Phys. Rev. A 88 (2013) 023821.

[7] K. Lyons, J. Dressel, A. N. Jordan, J. C. Howell, and P.G. Kwiat, Phys. Rev. Lett. 114 (2015) 170801.

Light-matter micro-macro entanglement

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In contrast with the "classical" framework, quantum mechanics provides tools to understand and predict phenomena in the microscopic world. However, adoption of the classical or quantum description seems to not be simply a matter of the size of the system under study. Indeed, there exists an increasing amount of successful experiments demonstrating the quantum nature of macroscopic systems. In this work, we take one step further in this direction and demonstrate the generation of entanglement between a single photon and a macroscopic number of atomic excitations stored in an atomic ensemble embedded in a solid-state crystal host.

The first step in our experiment is to generate a signal-idler polarization-entangled photon pair via spontaneous down-conversion. We refer to this state as a "micro-micro" state. The second step is to displace one polarization mode of the signal photon using a pulsed coherent state, leading to a "micro-macro" state. We then store our displaced single photon into a rare-earth doped crystal using the atomic frequency comb protocol, thereby creating a light-matter micro-macro entangled state. To reveal this micro-macro entanglement, the state re-emitted by the memory is displaced back to the micro domain using a second tailored pulsed coherent state. Our scheme relies of the fact that displacement back to a microscopic scale is a local operation which cannot increase entanglement. Finally, we perform quantum state tomography of the output of the memory together with a Bell test of nonlocality. Our state is shown to violate Bell-CHSH inequalities for micro-macro states containing up to 10 photons per pulse on average before storage, and we show it is entangled for up to 85 photons in the displacement pulse.

Our results provide a new tool to address fundamental questions about entanglement involving large atomic ensembles and macroscopic quantum photonic states, and constitute a first step towards demonstrating nonlocality using macroscopic quantum states of light and matter.

Cosmology in the laboratory

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Dielectric media appear to light as changes in the geometry of space. This analogy between media and geometries has been fruitful in the development of transformation optics where concepts from General Relativity inspired ideas for novel applications such as invisibility cloaking. The lecture explores whether and how ideas from quantum optics can, in turn, help understanding some problems in astrophysics and cosmology. In particular, it discusses (1) ideas and experiments for probing the quantum physics of the event horizon and (2) a problem in the theory of Casimir forces that may be related to the riddle of dark energy.

The role of duality in a 1D transport of interacting particles through a constriction

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Many (if not all) transport and thermodynamical properties of strongly correlated one-dimensional systems are described by the Luttinger liquid (LL) model. One of the best way of treating the model is bosonization where the pure strongly correlated LL is represented as an ideal gas of effective excitations, in terms of either density or phase (current) fluctuations. Both representations are equivalent and dual to each other. We study the effect of an embedded constriction, like a weak scatterer (WS) or a weak link (WL), on transport of a LL made of two sorts of interacting particles (e.g., electrons coupled to acoustic phonons in a quantum wire/nanotube or Fermi-Bose mixtures of cold atoms). We find that a duality relation between scaling dimensions of the electron backscattering in the WS and WL limits, well-known for the standard LL, holds in the presence of the additional coupling for any uncorrelated strengths of boson and fermion scattering from the constriction. This means that at low temperatures such a system remains either an ideal insulator or an ideal conductor, regardless of the scattering strength. In particular, this leads to "sympathetic superflow" of fermions through the constriction provided that bosons are superfluid, i.e. in a quasi-condensate. On the other hand, when fermion and boson scatterings from the impurity are correlated, the system has a rich phase diagram that includes a conductor-insulator transition at some intermediate value of the scattering strength.

Electron-phonon interactions and quantum noise in molecular junctions

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Noise in nanoscale devices contains valuable information on interactions and quantum correlations between electrons. In atomic or molecular junctions current noise is affected by the coupling of electrons to localized vibrational modes. The aim of this presentation is to summarize work done by our group for analyzing the effect of electron-phonon interactions in this type of systems in different parameters regimes both in stationary and non-stationary situations. I will discuss first the case of weak coupling where phonons can either enhance or decrease the current noise, in agreement with experimental measurements for atomic chains [1]. Then I shall consider the regime of strong coupling and present results obtained using different approximations for the stationary and the transient regime [2,3]. The possibility of bistable behavior will be analyzed. I shall finally discuss how to characterize the system short time dynamics in terms of waiting time distributions and time-dependent counting statistics [4].

[1] M. Kumar, R. Avriller, A. Levy Yeyati and J. M. van Ruitenbeek, Phys. Rev. Lett. 108, 146602 (2012)

[2] K.F. Albrecht, A. Martín-Rodero, R.C. Monreal, L. Muhlbacher and A. Levy Yeyati, Phys. Rev. B 87, 085127 (2013)

[3] R. Seoane Souto, A. Levy Yeyati, A. Martín-Rodero, and R. C. Monreal, Phys. Rev. B 89, 085412 (2014)

[4] R. Seoane et al., in preparation

Exploring the limits of quantum nonlocality with entangled photons

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Quantum nonlocality is arguably among the most counter-intuitive phenomena predicted by quantum theory. In recent years, the development of an abstract theory of nonlocality has brought a much deeper understanding of these effects. In parallel, experimental progress allowed for the demonstration of quantum nonlocality in a wide range of physical systems, and brings us close to a final loophole-free Bell test. Here we combine these theoretical and experimental developments in order to explore the limits of quantum nonlocality. This approach represents a thorough test of quantum theory, and could provide evidence of new physics beyond the quantum model. Using a versatile and high fidelity source of pairs of polarization entangled photons, we scan the boundary of quantum correlations, present the most nonlocal correlations ever reported, and demonstrate the phenomenon of more nonlocality with less entanglement. Our results are in remarkable agreement with quantum predictions.

From in-vitro to in-vivo kinetics of biomolecular machinesvia kinetic distance minimization

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The molecular machinery of life relies on complex multistep processes that involve numerous individual transitions, such as molecular association and dissociation steps, chemical reactions, and mechanical movements. The corresponding transition rates can be typically measured in vitro but not in vivo. Recently, we have developed a general method to predict the in-vivo rates from their in-vitro values. [1,2] Our method has two basic components. First, we define the 'kinetic distance' which represents a distance metric for the kinetics and provides a quantitative measure for the similarity or dissimilarity of multistep processes in different environments. The kinetic distance depends logarithmically on the rates and has an intuitive interpretation in terms of the associated free energy barriers. Second, we minimize the kinetic distance between the in-vitro and the in-vivo process, imposing the constraint that the deduced rates reproduce a known global property such as the overall in-vivo speed. Computationally, this constraint defines a hypersurface in the multi-dimensional space of transition rates. In order to demonstrate the predictive power of our method, we applied it to protein synthesis by ribosomes, a key process of gene expression, and validated the predicted rates by three independent sets of in-vivo data. [1,2]

[1] S. Rudorf, M. Thommen, M. Rodnina, and R. Lipowsky, PLoS Comp. Biol. 10 (2014) e1003909.

[2] S. Rudorf and R. Lipowsky, submitted to PLoS ONE

Molecular recognition and information theory in the self-assembling of charged particles

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Self-assembling have been experimentally shown to exists in a wide range of molecular and particle sizes, from large molecules (1 nm) to small particles (5 microns), whether in supra-molecular chemistry or colloidal systems. However, the self-assembling seems to obey strict and specific rules. For example, enzymatic reactions are very specific. To explain the observed specificity of enzymes-substrate reactions, in 1894 Emil Fischer proposed that both the enzyme and the substrate possess specific complementary geometric shapes that fit exactly into one another. This is often referred to as "the lock and key" model [1]. This model is now widely used in supramolecular chemistry [2]. To explain the observed supra-molecular self-assembling, concepts such as molecular complementarity and molecular recognition are proposed as the mechanism of lock-key associations. However, these concepts lack a precise definition and, hence, this mechanism is somewhat unclear. In this presentation we present and discuss the physical basis of a mechanism, based on formal statistical mechanics, present our recent Monte Carlo simulation and compare our results with experimental data for charged and uncharged colloids [3]. The relation of the lock-key self-assembling with the information theory is discussed [4,5].

[1] E. Fischer, Ber Dtsch. Chem. Ges. 27 (1894) 2985.

[2] J. M. Lehn, Supramolecular Chemistry (Wiley-VCH, Weinheim, 1995).

[3] S. Sacanna, W. T. M. Irvine, P. M. Chaikin, and D. J. Pine, Nature (London) 464 (2010) 575.

[4] C. E. Shannon, Bell Syst. Tech. J. 27, 379 (1948); 27 (1948) 623.

[5] G. Odriozola and M. Lozada-Cassou, Phys. Rev. Letts. 110 (2013) 105701.

Efficiency of the SQUID ratchet

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Efficiency of an asymmetric superconducting quantum interference device (SQUID) is studied. The SQUID is constructed as a ring with three capacitively and resistively shunted Josephson junctions. Two junctions are placed in series in one half-piece of the ring and the third junction is disposed in the other half of the ring. The SQUID is driven by a time-periodic (ac) current and subjected to an external constant magnetic flux [1]. This system acts as a nonequilibrium ratchet for the dc voltage across the SQUID with the external ac current as a source of energy. We consider the power delivered by the external current and find that it strongly depends on thermal noise and the external magnetic flux. We analyze three quantifiers for evaluation of transport quality: average voltage, its fluctuations and efficiency of the SQUID for wide parameter regimes: covering the overdamped to moderate damping regime up to its fully underdamped regime. We explore a set of system parameters to reveal a regime for which the SQUID efficiency attains its global maximum. We detect the intriguing feature of the thermal noise enhanced efficiency and show how the efficiency of the device can be tuned by tailoring the external magnetic flux [2].

[1] J. Spiechowicz, P. Hanggi, J. Łuczka, Phys. Rev. B 90 (2014) 054520.

[2] J. Spiechowicz and J. Łuczka, New. J. Phys. 17 (2015) 023054.

Transport in a quantum shuttle

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We consider a simple shuttle in which a quantum dot is free to move between 2 contacts, carrying a single electron across in each cycle. This system represents a simple non-trivial model of a nano-electro-mechanical system (NEMS), which is not only interesting in its own right, but represents a useful test bed for the development of a methodology for the study of more complex systems, such as single molecules between metallic leads, nanotubes or graphene strips. Such systems are intrinsically non-Born-Oppenheimer: the electronic and mechanical degrees of freedom are strongly coupled. For sufficiently low temperatures we expect non-ohmic behaviour depending on the relative values of the electronic and mechanical energy scales. The electronic transport is strongly correlated with the motion of the dot and exhibits shot-noise with a low Fano factor, indicating periodic transit of electrons. The non-equilibrium Green's function (NEGF) approach is well suited to the study of such systems and a version of it is applied here.

Ultracold molecules: Quantum simulation of many-body spin and dipolar systems

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Ultracold polar molecules offer a unique opportunity in table-top experiments to study quantum phenomena originating from strong dipole-dipole interactions and incorporating internal degrees of freedom controllable by external electric and magnetic fields. We established a correspondence between a symmetric top molecule and a magnetic atom [1]. It was shown that this correspondence makes it possible to perform quantum simulation of the single-particle spectrum and the dipole-dipole interactions of magnetic dipoles in a static magnetic field with symmetric top molecules subject to a static electric field. The effective spin angular momentum of the simulated magnetic dipole corresponds to the rotational angular momentum of the symmetric top molecule, and so quantum simulation of arbitrarily integer spins is possible. Further, taking the methyl fluoride as an example, we showed that the dipole-dipole interaction energies of the simulated magnetic dipole are by a factor of 620, 600, and 310 larger than for the highly magnetic atoms chromium, erbium, and dysprosium, respectively. Then, we demonstrated that ultracold symmetric top molecules loaded into an optical lattice can realize highly tunable and unconventional models of quantum magnetism, such as an XYZ Heisenberg spin model [2]. We showed that anisotropic dipole-dipole interactions between molecules can lead to effective spin-spin interactions which exchange spin and orbital angular momentum. This exchange produces effective spin models which do not conserve magnetization and feature tunable degrees of spatial and spin-coupling anisotropy. Our results are germane not only for experiments with polyatomic symmetric top molecules, such as methyl fluoride ($\mathrm{CH_3F}$), but also diatomic molecules with an effective symmetric top structure, such as the hydroxyl radical OH recently evaporatively cooled at JILA to millikelvin temperatures. However, in the presence of electric and magnetic fields, the energy spectra of OH were calculated only to energy scales of millikelvin, far from the sub-microkelvin temperatures at which OH molecules will become quantum degenerate. We investigated single-particle energy spectra of the OH radical under combined electric and magnetic fields [3]. The hyperfine interactions and centrifugal distortion effects were taken into account, yielding the zero-field spectrum of the lowest $^2\Pi_{3/2}$ manifold to an accuracy of less than 2 kHz $\sim$ 100 nK. We also examined level crossings and repulsions in hyperfine structures induced by applied electric and magnetic fields.

[1] M. L. Wall, K. Maeda, L. D. Carr, Ann. Phys. (Berlin) 525 (2013) 845.

[2] M. L. Wall, K. Maeda, L. D. Carr, New J. Phys. 17 (2015) 025001.

[3] K. Maeda, M. L. Wall, L. D. Carr, New J. Phys. 17 (2015) 045014.

Dipolar chromium atoms: Spin dynamics in optical lattices and thermodynamics

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Dipole-dipole interactions profoundly modify the magnetic properties of Bose-Einstein condensates made of strongly magnetic atoms such as chromium. First, the anisotropy of the interaction introduces the possibility of magnetization-changing collisions, which creates an intrinsic coupling between the spin degrees of freedom and the orbital degrees of freedom. Second, dipole-dipole interactions are long-ranged, which leads to non-local spin-spin interactions, for example in an optical lattice. For these reasons, dipolar gases in optical lattices are a fascinating new platform to study quantum magnetism and quantum many-body physics.

In this presentation, I will first describe an experiment where magnetic atoms in different sites of a 3D optical lattice undergo spin-exchange processes due to dipole-dipole interactions. A Bose-Einstein condensate of chromium atoms is loaded into deep 3D optical lattices. After the atoms are transferred into a spin-excited state, we observe a non-equilibrium spinor dynamics resulting from inter-site Heisenberg-like spin-spin interactions provided by non-local dipole-dipole interactions. This spin dynamics is inherently many-body, as each atom is coupled to its many neighbors. Our experiment thus reveals the interest of chromium lattice gases for the study of quantum magnetism of high-spin systems.

We have also studied the thermodynamics of chromium atoms at low magnetic field. Due to the anisotropy of dipolar interactions, magnetization is free and adapts to temperature. We observe that the BEC always forms in the lowest energy Zeeman state. When linear Zeeman energy is decreased below the initial temperature, excited spin states are thermally populated due to magnetic dipole-dipole interactions. By applying a magnetic field gradient, we introduce a selective loss of atoms in spin-excited states, which provides a specific loss channel for thermal atoms. This new cooling mechanism based on spin filtering results in purification of the BEC and an increased phase-space density. Our experimental demonstration with chromium atoms can be generalized to non-dipolar species. The two key ingredients of this new cooling protocol are a spin changing mechanism and a spin filtering procedure that allows removing excited states. We discuss the case of Na and Rb atoms that are very favorable with a temperature limit in the pK range set by the quadratic Zeeman shift.

Infiniteness – a fundamental misconception in physics

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Based on the previously established peculiar fact that the results of all physical observations ever made can be presented in the form of ordered finite sets, the redundancy of actual infinity for the description of physical phenomena is pointed out. The elimination of actual infinity from the physical reasoning ensures, among others, the commensurability of physical quantities, enables one to draw a sharp borderline between physics and metaphysics and to realize the discretization program, the aim of which is the complete arithmetization of physics in close analogy with the theory of cellular automata. Moreover, admitting finite mathematics one can quite naturally interpret the gradual transition from classical to discrete quantum description as a direct consequence of increasing precision of measurement. In this connection, the distinguished role of four-fold symmetry of measuring process is further discussed. This provides the basis for 'physical numerology'. To illustrate this approach, we investigate the analogy between the distribution of ordinary matter in the observable Universe and the distribution of prime numbers in the sequence of integers and also the relation of such distributions to the so called cosmical number and other universal constants.

Switching between stable states in quantum systems far from equilibrium

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We study switching between period-two states of an underdamped quantum oscillator modulated at nearly twice its natural frequency. For all temperatures and parameter values switching occurs via quantum activation: it is determined by diffusion over oscillator quasienergy, provided the relaxation rate exceeds the rate of interstate tunneling. We show that close to the stable state it is possible to define an effective quantum temperature which can be directly observed by measuring the spectrum of the driven oscillator. As temperature decreases we show that pure quantum activation competes with thermally assisted activation which leads to thermal effects even for an exponentially small number of thermal photons.

Interactions and charge fractionalization in an electronic Hong-Ou-Mandel interferometer

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We consider an electronic analog of the Hong-Ou-Mandel (HOM) interferometer, where two single electrons travel along opposite chiral edge states and collide at a quantum point contact. Studying the current noise, we show that because of interactions between copropagating edge states, the degree of indistinguishability between the two electron wave packets is dramatically reduced, leading to reduced contrast for the HOM signal. This decoherence phenomenon strongly depends on the energy resolution of the packets. Insofar as interactions cause charge fractionalization, we show that charge and neutral modes interfere with each other, leading to satellite dips or peaks in the current noise. Our calculations explain recent experimental results [E. Bocquillon, et al., Science 339, 1054 (2013)] where an electronic HOM signal with reduced contrast was observed.

Edge reconstruction and spontaneous time reversal symmetry breaking in topological insulators

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Topological insulators (TIs) are electronic materials that have a bulk band gap like an ordinary insulator but, due to the combination of spin-orbit interactions and time-reversal symmetry (TRS), have protected conducting states on their edge or surface. In two dimensional TIs these edge states are quasi one-dimensional helical edge modes that are expected to come in counterpropogating pairs, due to the time-reversal symmetry. The time-reversal protection of these edge states led to various suggested applications of TIs, ranging from spintronics to quantum computation. We show, that unlike the infinitely sharp edge used in previous calculations, a realistic smooth edge may lead to edge reconstruction, spontaneous TRS breaking, a finite Hall resistance at zero magnetic field and possible spin current. We demonstrate such edge reconstruction in both the Bernevig-Zhang and the Bernevig-Hughes-Zhang models, the standard models for time reversal invariant TIs, in smooth confining potentials, using Hartree-Fock approximation and exact diagonalization. Such spontaneous TRS breaking may have important implications on transport properties, as we demonstrate below, and possible applications.

Disillusion: Quantum Cheshire cat is an illusion

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The quantum Cheshire cat was introduced by Aharonov et al. [1] in the form of a circularly polarized photon, whereby the photon represents the cat and its polarization state the grin. It was shown analytically that in a pre- and post-selected experiment measuring weak values for the location of the photon and its polarization, the photon can be disembodied from its polarization. This effect was called the Cheshire cat effect after the mysterious behavior of the grinning Cheshire cat in the novel “Alice’s Adventures in Wonderland” by Lewis Carroll [2]. Recently, Denkmayr et al. [3] performed weak measurements to probe the location of a neutron and its magnetic moment in a neutron interferometry experiment to demonstrate the quantum Cheshire cat effect.

We show that an event-based simulation model [4] of the neutron interference experiment of Denkmayer et al. reproduces all the reported experimental data. In the simulation it is explicit that neutrons and their magnetic moments never separate. As the simulation does not rely on concepts of quantum theory and reproduces the results of the laboratory experiment, the experimental observations can be explained without introducing concepts such as particle-wave duality, weak measurements, and the like. In other words, the quantum Cheshire cat is an illusion.

[1] Y. Aharonov, S. Popescu, D. Rohrlich, and P. Skrzypczyk,New J. Phys. 15 (2013) 113015

[2] L. Carroll, Alice’s Adventures In Wonderland (reprinted in The Annotated Alice) ed. Gardner, Penguin Books (1965)

[3] T. Denkmayr, H. Geppert, S. Sponar, H. Lemmel, A.Matzkin, J. Tollaksen, and Y. Hasegawa, Nature Comm. 5 (2014) 4492

[4] H. De Raedt, F. Jin, and K. Michielsen, Quantum Matter 1 (2012) 20

Time and temperature in quantum physics

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For many people a clock is the epitome of a predictable reversible dynamical system. Yet we are all familiar with the irreversible clocks used in radio-carbon dating. Much earlier, Mach[1] and Eddington[2] both proposed irreversible thermal clocks. In general relativity the Tolman relations[3] connect the local measurements of time and temperature. Rovelli's thermal time hypothesis[4] uses thermal equilibrium states to define the local flow of time in general relativity. Given a good clock it is possible to make local measurements of temperature and, conversely, given a good thermometer it is possible to make a local clock. There is thus a kind of duality to time and temperature. I will illustrate this concept using the quantum theory of irreversible processes and statistical distance[5]. I will describe a possible experimental test based on quantum opto-mechanics.

[1] E. Mach, "Knowledge and error: sketches on the psychology of enquiry", Vienna circle collection, (Reidel Dordrecht 1976)

[2] A. S. Eddington, "The Nature of the Physical World" (Macmillan London 1928).

[3] R. C. Tolman, "On the Weight of Heat and Thermal Equilibrium in General Relativity", Phys. Rev. 35, 904 (1930); R. C. Tolman and P. Ehrenfest, "Temperature Equilibrium in a Static Gravitational Field", Phys. Rev. 36, 1791 (1930).

[4] C. Rovelli, "Quantum Gravity" (Cambridge University Press Cambridge, 2004).

[5] S. L. Braunstein and G. J. Milburn, "Dynamics of statistical distance: Quantum limits for two-level clocks", Phys. Rev. A 51, 1820 (1995).

Scale invariance at low accelerations: An alternative to dark matter

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Galactic systems exhibit large mass discrepancies: The observed matter in them falls very short of providing enough gravity to hold them together. The mainstream solution of this conundrum is the evocation of large quantities of "dark matter", which purportedly supplies the extra gravity. Its nature is not known, but it is clear that it cannot be made of any presently known form of matter.

The MOND paradigm offers a different solution: a breakdown of standard dynamics (gravity and/or inertia) in the limit of low accelerations (below some acceleration constant a0), such as are found in galactic systems. In this limit, dynamics become space-time scale invariant, and is controlled by a scale-invariant gravitational constant that replaces G. With the new dynamics, the various detailed manifestations of the galactic mass discrepancies disappear with no need for exotic dark matter. I will briefly describe the achievements and the remaining shortcomings of the paradigm.

Negative Casimir entropies in nanoparticle interactions

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[2]*Laboratoire Kastler Brossel, CNRS, ENS, UPMC, Case 74, F-75252, Paris, France*
[3]*Institut fur Physik, Universitat Augsburg, Universitatsstrasse, 1, D-86135 Augsburg, Germany*

Negative entropy has been known in Casimir systems for some time. For example, it can occur between parallel metallic plates modelled by a realistic Drude permittivity. Less well known is that negative entropy can occur purely geometrically, say between a perfectly conducting sphere and a conducting plate. The latter effect is most pronounced in the dipole approximation, which is reliable when the size of the sphere is small compared to the separation between the sphere and the plate. Therefore, here we examine cases where negative entropy can occur between two electrically and magnetically polarizable nanoparticles or atoms, which need not be isotropic, and between such a small object and a conducting plate. Negative entropy can occur even between two perfectly conducting spheres, between two electrically polarizable nanoparticles if there is sufficient anisotropy, between a perfectly conducting sphere and a Drude sphere, and between a sufficiently anisotropic electrically polarizable nanoparticle and a transverse magnetic conducting plate.

Cat-qubits: A new protocol for quantum information processing with superconducting circuits

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I will present a new hardware-efficient paradigm for encoding, protecting and manipulating quantum information in a quantum harmonic oscillator, more specifically a superconducting cavity mode. Engineering a non-standard multi-photon driven dissipative process, using a Josephson circuit, one confines the dynamics to a degenerate manifold of quantum states [1]. Repetitive quantum non-demolition monitoring of photon-number parity then enables the protection of quantum information against major decay channels [2]. I will finally discuss, through Zeno type arguments, how the addition of some appropriate Hamiltonian dynamics enables a complete set of fault-tolerant logical gates. I will finish with the experimental results for the particular case of a two-photon driven dissipative process [3].

[1] Mirrahimi et al., Dynamically protected cat-qubits: a new paradigm for universal quantum computation, New J. of Physics, 16, 045014, 2014.

[2] Sun et al., Tracking photon jumps with repeated quantum non-demolition parity measurements, Nature 511, 444-448, 2014.

[3] Leghtas et al., Confining the state of light to a quantum manifold by engineered two-photon loss, Science 347, 853-857, 2015.

Geometric effects on the orbital magnetism

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Although being an equilibrium property, the orbital magnetic susceptibility is a complex quantity because, contrary to transport properties, it involves the full energy spectrum and the structure of the wave functions. Beyond the simplest Landau picture of orbital diamagnetism valid for free electrons, the generalization proposed by Peierls is valid for a single band and cannot describe multiband systems, like graphene which is known to exhibit a diverging diamagnetic response at the Dirac point, but more surprisingly becomes paramagnetic away from the Dirac point. In this talk, after a brief historical overview showing that the orbital response may be as well paramagnetic as diamagnetic, we present recent results that show the importance of band structure and interband effects (Berry curvature) on the orbital response of Bloch electrons in metals and insulators. Beyond the simplest examples of graphene and boron-nitride, we review recent simple models in which the coupling between bands can be tuned. We present a simple example where two systems having the same energy spectrum exhibit a totally different magnetic response. We also show how a flat band may exhibit an orbital response. From these surprising features in the orbital susceptibility we draw general conclusions on the orbital magnetism of itinerant electrons in multi-band tight-binding models

[1] A. Raoux, F. Piéchon, J.-N. Fuchs and G. Montambaux, Orbital magnetism of coupled bands models, Phys. Rev. B 91, 085120 (2015)

[2] A. Raoux, M.Morigi, J.-N. Fuchs, F. Piéchon and G. Montambaux, From dia- to paramagnetic orbital susceptibility of Dirac cones, Phys. Rev. Lett. 112, 026402 (2014)

Discoveries of magnetic-monopole analogues in Bose-Einstein condensates

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More than 80 years ago, Paul A. M. Dirac found a pioneering solution for the wavefunction of a charged particle in the magnetic field of a magnetic monopole [1]. This celebrated result also reveals that electronic charge must be quantized provided that even a single magnetic monopole exists. However, no magnetic monpoles have been convincingly found. Even the experimental observation of the quantum-mechanical structure acquired by the electron wavefunction found by Dirac is lacking. In fact, there has been no prior confirmed experimental observations of monopoles in any quantum field.

Based on the method proposed in Ref. [2], we present the experimental observation of Dirac monopoles formed in a synthetic magnetic field of an atomic Bose-Einstein condensate with spin degree of freedom [3]. The experiments are accurately simulated using a mean-field approach, and a very good quantitative agreement is obtained without any fitting parameters.

After Dirac's seminal work [1], 't Hooft and Polyakov found a finite-energy solution for the magnetic monopole particle in the grand unified field theories [4]. Here, we report on the first experimental observation of a topological point defect in a quantum field [5]. These observations also provide the first quantum-mechanical analogue for the magnetic monopole considered by 't Hooft and Polyakov.

Strikingly, we observe that the polar order parameter supporting the topological point defect naturally undergoes a dynamical quantum phase transition into the ferromagnetic phase, giving rise to a Dirac monopole [6].

[1] Dirac, P. A. M.. Proc. R. Soc. Lond. A 133 (1931) 60.

[2] V. Pietilä and Mikko Möttönen, Phys. Rev. Lett. 103 (2009) 030401.

[3] M. W. Ray, E. Ruokokoski, S. Kandel, M. Möttönen, and D. S. Hall, Nature 505 (2014) 657.

[4] G. 't Hooft, Nuclear Physics B 79 (1974) 276; A. M. Polyakov, JETP Lett. 20 (1974) 194.

[5] M. W. Ray, E. Ruokokoski, K. Tiurev, M. Möttönen, and D. S. Hall, Science 348 (2015) 544.

[6] K. Tiurev, E. Ruokokoski, H. Mäkelä, D. S. Hall, and M. Möttönen, arXiv:1504.07770.

Exploring the dynamics of BEC in a box potential

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In this talk, I will present a study of the dynamics of spontaneous symmetry breaking, by thermally quenching a box-trapped Bose gas [1] through the BEC phase transition [2]. We use homodyne matter-wave interferometry to measure first-order correlation functions and this allow us to verify the central quantitative prediction of the Kibble-Zurek theory, namely the homogeneous-system power-law scaling of the coherence length with the quench rate. We also investigate the behaviour of the quasi-uniform Bose-Einstein Condensate to a shaken constant-gradient potential. By tuning the amplitude and frequency of the modulation, as well as the atom number, we study the response of the BEC, from excitationless superflow to the turbulent regime.

[1] A. L. Gaunt et al., Phys. Rev. Lett. 110, 200406 (2013)

[2] N. Navon, A. L. Gaunt, R. P. Smith, Z. Hadzibabic, Science 347, 167 (2015)

Rényi entropy flows from quantum heat engines

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We evaluate Renyi entropy flows from generic quantum heat engines (QHE) to a weakly-coupled probe environment kept in thermal equilibrium. We show the flows are determined by two quantities: heat flow and fictitious disspation that manifest the quantum coherence in the engine. This pertains also the common Shanon entropy flow. The results appeal for revision of the concept of entropy flows in quantum non-equlibrium thermodynamics.

Extending these results, we present a universal relation between the flow of a Renyi entropy and the full counting statistics of energy transfers. We prove the exact relation for a flow to a system in thermal equilibrium that is weakly coupled to an arbitrary time-dependent and non-equilibrium system. The exact correspondence, given by this relation, provides a simple protocol to quantify the flows of Shannon and Renyi entropies from the measurements of energy transfer statistics.

Neutrino dark matter and turbulence in the plasma: A perfect couple

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Modelling of the strong and weak lensing properties of the galaxy cluster Abell 1689 has put forward that neutrinos may make up the dark matter in the cosmos. Our initial work in 2009 [1] was confirmed in 2011 and 2013 [2] when better data became available. Recent observations lead to an even better fit. The baryon fraction emerges right at the cosmic value. This solution of the "missing baryon problem" does not occur for NFW cold dark matter or isothermal dark matter. Non-Newtonian gravities like MOND and Emergent Gravity work only when neutrinos or isothermal dark matter are added, but keep the missing baryon problem.

The cluster leaves a degeneracy between the neutrino mass and the number of families, but it is lifted in the cosmic budget. A perfect match occurs for a mass of 1.83 ± 0.13 eV of the active (electron, muon, tau) neutrinos and their "sterile" right handed partners. The case will be tested in the upcoming KATRIN experiment.

In the standard model of cosmology neutrino dark matter is ruled out by neutrino free streaming. Small perturbations that should form galaxies will be washed out by massive neutrinos. Planck sets an upper limit of 0.17 eV for the sum of all neutrino masses.

Arguing that the protoplasma is turbulent, we question the theory of linear structure formation. We estimate the Reynolds number in the quark-gluon phase as 10^{19}; it remains above 100 up to the end of the plasma phase (recombination). Turbulence in the plasma has been dismissed because the acoustic horizon exceeds the causal horizon. However, on subhorizon scales turbulence can (and thus must) arise, in the expanding Universe. Dimensional analysis puts forward a viscous length scale, beyond which gravity will induce instabilities. When this length scale "enters the horizon" (becomes less than ct) nonlinear structure formation is expected. Its mass scale corresponds to galaxy clusters [3]. Also proto-galaxies form in the plasma phase. Free streaming neutrinos will not wash out these nonlinear structures.

Neutrino dark matter and the turbulent plasma form the basis for Gravitational Hydrodynamics. This theory explains many of the "perplexing" features that are routinely discovered, such as "old but mature galaxies", the spin correlation of Active Galactic Nuclei on Gpc scale and 4 quasars lying on a line of 150 kpc. While in the standard theory their probabilities for occurrence are very small, in GHD they derive from breaking up plasma vortex lines.

[1] T.M. N., 2009, EPL 86, 59001: Do non-relativistic neutrinos constitute the dark matter?

[2] T.M. N. & A. Morandi, 2013, MNRAS 434, 2679: A1689 consistent with ν-dark matter

[3] T.M. N. et al, 2009, EPL 88, 49001: Gravitational hydrodynamics of structure formation

Quantum control of two-qubit gates via dynamical decoupling filtering of 1/f noise

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Achieving high-fidelity universal two-qubit gates is a central requisite of any implementation of quantum information processing. In solid-state nanocircuits, noise with 1/f power spectrum represents a severe obstacle towards this goal [1]. For single-qubit gates considerable improvement has been achieved by operating at optimal points and further enhancement has been obtained by open-loop dynamical decoupling. However, protection of qubit coherence during a multi-qubit gate poses non-trivial additional problems. In fact decoupling may disrupt the inter-qubit dynamics thus conflicting with gate operation. Here we present the integration of dynamical decoupling into a universal two-qubit gate in the presence of 1/f noise acting locally on each of the qubits forming the entangling gate. We address both the case of pure dephasing and of depolarizing noise and investigate the gate efficiency under periodic, Carr-Purcell, and Uhrig dynamical decoupling sequences. Our analysis is based on the exact numerical evaluation of gate operation for 1/f noise measured in superconducting qubits and on perturbative (Magnus) expansion for quasi-static noise. For transverse noise we find that a threshold value of the number of pulses exhists above which the gate error is reduced as n^{α} with α depending on the dynamical decoupling sequence. For smaller pulse numbers, dynamical decoupling may even increase the error with respect to the unconditioned evolution, a behavior reminiscent of the anti-Zeno effect. For pure dephasing 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. The possibility to reach the accuracy threshold for fault- tolerant quantum information processing with solid-state devices by quantum gates with integrated decoupling is critically discussed.

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

Low temperature behaviour of supercooled liquids in the quantum regime

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In the recent years we have learned many interesting properties of the landscape of glasses and of other disordered systems in the classical regime.

I this talk I would like to review these progresses and to describe some applications to the study of the quantum landscape. These results are relevant for understanding the behaviour of low temperature glasses.

Energetics and efficiency of an information engine

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We study a two-level system controlled in a discrete feedback loop, modeling both the system and the controller in terms of stochastic Markov processes. We find that the extracted work, which is known to be bounded from above by the mutual information acquired during measurement, has to be compensated by an additional energy supply during the measurement process itself, which is bounded by the same mutual information from below. Our results confirm that the total cost of operating an information engine is in full agreement with the conventional second law of thermodynamics. We also consider the efficiency of the information engine as function of the cycle time and discuss the operating condition for maximal power generation. Moreover, we find that the entropy production of our information engine is maximal for maximal efficiency, in sharp contrast to conventional reversible heat engines.

Topological phases of sound and light in an optomechanical array

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Topological states of matter are particularly robust, since they exploit global features of a material's band structure. Topological states have already been observed for electrons, atoms, and photons. It is an outstanding challenge to create a Chern insulator of sound waves in the solid state. In this work, we propose an implementation based on cavity optomechanics in a photonic crystal. The topological properties of the sound waves can be wholly tuned in-situ by adjusting the amplitude and frequency of a driving laser that controls the optomechanical interaction between light and sound. The resulting chiral, topologically protected phonon transport can be probed completely optically. Moreover, we identify a regime of strong mixing between photon and phonon excitations, which gives rise to a large set of different topological phases and offers an example of a Chern insulator produced from the interaction between two physically distinct particle species, photons and phonons.

[1] Topological Phases of Sound and Light, V. Peano, C. Brendel, M. Schmidt, and F. Marquardt, arXiv:1409.5375

T108 Tue, 28 July, 15:00 - 15:30, 4 session - C parallel

Coherent and incoherent control of single molecule junctions: Steady states and beyond

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The study of charge and energy transport in molecular junctions out of equilibrium introduces unique theoretical and computational challenges. In the talk, we introduce theoretical studies of field-driven molecular junctions which suggest new possibilities for relating the unique transport properties of molecular junctions to electronic and energy-conversion electronic devices. Having a molecule as the 'bottle neck' for transport, the characteristic length and time scales suggest that coherent (phase conserving) transport dominates the transport properties, and therefore the transport can be coherently controlled. In particular we shall focus on a molecular coherent 'electron pump' which converts radiation field into directed electronic current. The principle of operation will be analyzed theoretically under conditions ranging from a sudden pulse to cw excitation, and the principles of coherent control by the radiation field in the presence of de-coherence by the leads will be outlined. Finally, we shall propose an experimental design for measuring the field induced dynamics within the molecule (with sub-pico-second resolution) using steady state current, with an eye to ultrafast electronic devices operating in the terahertz frequency regime.

Many body effects in strongly disordered electronic systems

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Over half a century ago Anderson [1] and Mott [2] initiated a new discipline in condensed matter physics – the physics of disorder, (earning them the 1977 Nobel Prize). At the core of the new discipline is the Anderson localization which dramatically alters the physical properties exhibited by more traditional solids. In [3] it was established that disordered 1D and 2D electronic eigenstates are always localized while in 3D they may be localized or delocalized, leading to a metal-insulator transition. The works [1-3] dealt with disordered non-interacting particles as will be briefly summarized. It turns out that interaction can further very strongly affect the physical properties [4]. The talk will focus on electrons in disordered solids. Much of the literature on the subject ignores many-electron effects. Here the role of static and dynamic many-electron effects is emphasized. Focus will be on these effects resulting from long range Coulomb interactions, in particular on the density of states, on transport, on relaxation and on the effect on the Anderson localization itself.

Probably the most interesting effects of long range interaction at high electronic densities is that the very light electrons' response is extremely slow, non-ergodic (in the sense that relaxation to equilibrium can take much longer than the duration of any reasonable experiment), and so called aging, a term coined for violation of time homogeneity: performing an identical experiment at different times leads to different results. Theoretical arguments for these unusual phenomena shall be presented.

Experimental results will be shown where relevant.

[1] P.W. Anderson, Phys. Rev. 109 (1958) 1492

[2] N.F. Mott and W.D. Twose, Adv. Phys. 10 (1961) 107

[3] F. Abrahams et. al., Phys. Rev. Lett. 42 (1979) 673

[4] M. Pollak, Disc. Faraday Soc. 50 (1970) 13

Stochastic pumps of interacting particles

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The design and synthesis of molecules that operate like microscopic machines is of fundamental importance. Such systems can be modelled theoretically by stochastic dynamics in which the system makes thermally activated transitions between a finite set of coarse-grained states. Artificial molecular machines can be driven away from thermal equilibrium in ways not found in biological molecular motors, in particular by time variation of external parameters. Such systems are often termed stochastic pumps. We demonstrate that a seemingly natural protocol of driving such systems does not work. We argue that this result holds also for systems of several particles with zero range interactions.

Many-body entanglement of ultracold atoms in optical fiber microcavities

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Entanglement has grown up from yet another quantum curiosity into a cornerstone of modern quantum theory. It acts as a resource in new applications currently under development, such as quantum metrology. High-fidelity control over light-matter coupling plays a prominent role in all such quantum technologies. I will discuss a series of experiments where multiparticle entanglement is created in ensembles of ~ 40 atoms using novel experimental tools: optical fiber microcavities and atom chips. The cavity enables both the entanglement creation and its analysis. It enables us to perform a direct measurement of the Husimi-Q distribution of the atomic state, with a resolution at the single-particle level. In collaboration with a leading time-frequency metrology laboratory, SYRTE, we are also testing the application of these tools to atomic clocks at the 10^{-13} s$^{-1/2}$ fractional stability level.

Sound mode decay in Bose-Einstein condensates

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We obtain expressions and values for the speed and lifetimes of the sound modes in a dilute Bose-Einstein condensate using Bogoliubov mean field theory. The condensate has two pairs of sound modes which undergo an avoided crossing as the equilibrium temperature is varied. The two pairs of sound modes decay at very different rates, except in the neighborhood of the avoided crossing, where the identity of the longest lived mode switches. The predicted speed and lifetime of the longest-lived sound mode are consistent with recent experimental observations on sound in an rubidiium Bose-Einstein condensate.

[1] E. D. Gust and L. E. Reichl, J. Low Temp. Phys. 170 (2013) 43

[2] E. D. Gust and L. E. Reichl, Phys. Rev. E 87 (2013) 042109

[3] L. E. Reichl and E. D. Gust, Phys. Rev. A 88 (2013) 053603

[4] E. D. Gust and L. E. Reichl, Phys. Rev. A 90 (2014) 043615

Increasing sensing resolution with error correction

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The signal to noise ratio of quantum sensing protocols scales with the square root of the coherence time. Thus, increasing this time is a key goal in the field. Dynamical decoupling has proven to be efficient in prolonging the coherence times for the benefit of quantum sensing. However, dynamical decoupling can only push the sensitivity up to a certain limit. In this talk I will present a new approach to increasing the coherence time further through error correction which can improve the efficiency of quantum sensing beyond the fundamental limits of current state of the art methods. The talk is based on contribution[1].

[1] Gilad Arrad, Yuval Vinkler, Dorit Aharonov, Alex Retzker, Phys. Rev. Lett. 112, 150801 (2014).

Quantum walks with neutral atoms

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The quantum walk is a prime example of quantum transport: a spinor particle is delocalised over a very large Hilbert space through discrete steps in space and time. We implement this transport using ultracold atoms moving in a deep optical lattice.

By creating artificial electric fields, we observe textbook transport phenomena like spin orbit coupling, Bloch oscillations, or Landau-Zener tunnelling in a single experiment. We unravel the unique character of electric quantum walks by studying very different transport regimes, which depend on the commensurability of the electric field [1]. We experimentally observe ballistic delocalization for rational fields and dynamical localization for irrational ones [2]. Physical insight into the "quantumness" of the walk is obtained by an analysis of decoherence phenomena [3] and application of ideal negative measurements, i.e. interaction-free measurements [4].

The controlled interaction of exactly two quantum walkers remains a daunting but highly attractive experimental challenge.

[1] C. Cedzich, T. Rybár, A. H. Werner, A. Alberti, M. Genske and R. F. Werner, Propagation of quantum walks in electric fields, Phys. Rev. Lett. 111, 160601 (2013)

[2] M. Genske, W. Alt, A. Steffen, A. H. Werner, R. F. Werner, D. Meschede, A. Alberti, Electric quantum walks with individual atoms, Phys. Rev. Lett. 110, 190601 (2013)

[3] A. Alberti, W. Alt, R. Werner, and D. Meschede, Decoherence models for discrete-time quantum walks and their application to neutral atom experiments, New J. Phys. 16, 123052 (2014)

[4] C. Robens, W. Alt, D. Meschede, C. Emary, and A. Alberti, Ideal Negative Measurements in Quantum Walks Disprove Theories Based on Classical Trajectories, Phys. Rev. X 5, 011003 (2015)

Near-field levitated quantum optomechanics with nanodiamonds

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We show that the dipole force of an ensemble of quantum emitters embedded in a dielectric nanosphere can be exploited to achieve a strong single-photon quantum optomechanical coupling, in the resolved sideband regime and at room temperature, with experimentally feasible parameters. The key ingredient is that the polarizability from an ensemble of embedded quantum emitters can be larger than the bulk polarizability of the sphere, thereby enabling the use of repulsive optical potentials and consequently the levitation at near-fields. This allows to boost the single-photon coupling by combining larger polarizability to mass ratio, larger field gradients, and smaller cavity volumes. A case study is done with a nanodiamond containing a high-density of silicon-vacancy color centers that is optically levitated in the evanescent field of a high-finesse microsphere cavity.

T116 Thu, 30 July, 15:20 - 15:40, 4 session - B parallel

Demonstration of deterministic photon-photon interactions with a single atom

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We demonstrate all-optical deterministic photon-photon interactions with a single Rb atom coupled to high-Q fiber-coupled microresonator. Our scheme enables all-optical photon routing, photon extraction, passive quantum memory and quantum gates activated solely by single photons.

A multiplexed quantum light-matter interface for fiber-based quantum networks

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The realization of fiber-based quantum networks requires developing photonic quantum hardware compatible with wavelengths at which light can be transmitted with low loss through standard telecommunication fibers. There has been significant progress towards developing such devices, e.g. quantum circuits, single photon sources and detectors. However, a missing element is an atomic interface that allows storage and manipulation of quantum states of telecom-wavelength photons. In my presentation, first, I will introduce our quantum light-matter interface based on a cryogenically cooled commercial erbium-doped optical fiber that can directly operate at telecom wavelengths [1]. Next, I will present our recent experimental demonstrations, which include quantum storage of heralded polarization qubits and reversible mapping of entanglement between telecom-wavelength photons and matter. I will also show multiplexed quantum storage and manipulation with large time-bandwidth products, which can potentially reach several thousands. I will conclude my presentation with a discussion of potential improvements and future directions.

[1] Quantum storage of telecom-wavelength entangled photons in an erbium-doped optical fibre, E. Saglamyurek et al, Nature Photonics, 9, 83-87, 2015

Three terminal quantum Hall thermoelectrics

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In an electronic circuit, current can be generated by the conversion of heat absorbed from a hot region. In the absence of a magnetic field, such thermoelectric response requires broken left-right and particle-hole symmetries. We investigate the thermoelectric properties of a three-terminal quantum Hall conductor. We identify a contribution to the thermoelectric response that relies on the chirality of the carrier motion rather than on spatial asymmetries [1]. The Onsager matrix becomes maximally asymmetric with configurations where either the Seebeck or the Peltier coefficients are zero while the other one remains finite. Reversing the magnetic field direction exchanges these effects. Our results show that thermoelectric measurements are sensitive to the chiral nature of the quantum Hall edge states, opening the way to control quantum coherent heat flows. In particular, powerful and efficient energy harvesters can be proposed [1,2]. The possibility to generate spin-polarized currents in quantum spin Hall samples is also discussed.

[1] R. Sánchez, A. N. Jordan, B. Sothmann, Phys. Rev. Lett. 114, 146801 (2015)

[2] B. Sothmann, R. Sánchez, A. N. Jordan, Europhys. Lett. 107, 47003 (2014)

Relaxation process of interacting quantum systems

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We study the evolution of isolated finite interacting quantum systems after an instantaneous perturbation. Both cases are considered: a clean one-dimensional spin-1/2 system and a disordered one.

In the first case, we show three scenarios in which the probability for finding the initial state later in time (survival probability) decays nonexponentially, often all the way to saturation. The decay is Gaussian in systems with two-body interactions in the limit of strong global perturbation; it involves a Bessel function for evolutions under random matrices; and it approaches the fastest decay as established by the energy-time uncertainty relation when a very strong local perturbation is applied.

In the disordered case, we report the observation of a power-law decay of the survival probability near the many-body localization transition. We provide numerical evidence suggesting that the exponent of this decay is related to the multifractal structure of the eigenstates through the so-called correlation dimension.

The Stefan-Boltzmann law: Two classical laws give a quantum one

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Due to the universality of blackbody radiation the constant in the Stefan-Boltzmann law connecting the energy density and temperature of blackbody radiation is either a universal constant, or built out of several universal constants. Since the Stefan-Boltzmann law follows from thermodynamics and classical electrodynamics this constant must involve the speed of light and the Boltzmann constant. However, a dimensional analysis [1] points to the existence of an additional universal constant not present in the two classical theories giving birth to the Stefan-Boltzmann law. In the most elementary version this constant has the dimension of an action and is thereby proportional to Planck's constant. We point out this unusual phenomenon of the combination of two classical laws creating a quantum law and speculate about its deeper origin.

[1] H. Paul, D.M. Greenberger, S.T. Stenholm, and W.P. Schleich, The Stefan-Boltzmann law: two classical laws give a quantum one, Physica Scripta FQMT13 special volume, accepted for publication (March 2015)

Detecting nonlocal Cooper pair entanglement by optical Bell inequality violation

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Based on the Bardeen Cooper Schrieffer (BCS) theory of superconductivity, the coherent splitting of Cooper pairs from a superconductor to two spatially separated quantum dots has been predicted to generate nonlocal pairs of entangled electrons. In order to test this hypothesis, we propose a scheme to transfer the spin state of a split Cooper pair onto the polarization state of a pair of optical photons. We show that the produced photon pairs can be used to violate a Bell inequality, unambiguously demonstrating the entanglement of the split Cooper pairs.

[1] arXiv:1411.3945 [cond-mat.mes-hall]

Electronic transport through interacting nano structures: beyond the scattering state solution

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The properties of charge transport through nano structures are typically described within a scattering state description, most prominently the Landauer-Büttiker theory for non-interacting systems or the Meir-Wingreen extension for interacting systems. Recently the description of charge transport through nano structures based on quenches in the charge imbalance has been established as a powerful technique to obtain not only the I/V characteristics, but also shot noise and even the full counting statistics of charge transport. From the scattering state point of view one hopes to reach a quasi stationary state which contains the infinite time solution. Here I report on physics beyond the scattering state. Specifically I discuss the finite time effects, that are not induced by finite size effects, and an AC response to a DC quench.

Cooper-pair splitting and spectroscopy in quantum dot devices with superconducting charge injectors

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An elegant idea for the creation of entangled electrons in a solid-state device is to split Cooper pairs by coupling a superconductor (S) to two parallel quantum dots (QDs) realized with semiconducting nanowires (NWs) or carbon nanotubes (CNTs) [1-4]. A high CPS efficiency [5] is a prerequisite for entanglement tests [6]. In the first part I will review CPS.

S contacts to NWs are not only important for CPS, but are a key ingredient in the search for Majorana bound states. In theory an effective proximity induced pair correlation parameter Δ^* is introduced. However, in the experiment it is not even clear how to measure this parameter. Both for CPS and Majorana physics it is crucial to control all coupling strength. NW samples with multiple bottom gates have been developed and the expected dependence of the CPS efficiency on the coupling strength could be reproduced [7]. I will further discuss how an Andreev bound state can induce nonlocal effects [8] and I will present data where intriguing inelastic Cooper-pair tunneling lines appear in the gap. These lines appear almost equidistantly suggesting that they are linked to the emission of photons or phonons.

This is a collaborative effort with the groups of Szabolcs Csonka, Budapst University of Technology and Economy, Jesper Nygard, Nano-Science Center, Niels Bohr Institute of the University of Copenhagen, and Jan Martinek, IFM-PAN, Poznan, Poland. I acknowledge funding from the Swiss NFS, SNI, NCCR-QSIT, FP7-SE2ND and ERC-QUEST.

[1] P. Recher, E. V. Sukhorukov, and D. Loss, Phys. Rev. B 63, 165314 (2001).

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

[3] L. Hofstetter, S. Csonka, A. Baumgartner, G. Fülöp S. d'Hollosy, J. Nygård, and C. Schönenberger, Phys. Rev. Lett. 107, 136801 (2011).

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

[5] J. Schindele, A. Baumgartner, and C. Schönenberger, Phys. Rev. Lett. 109, 157002 (2012).

[6] W. Kłobus, A. Grudka, A. Baumgartner, D. Tomaszewski, C. Schönenberger, and J. Martinek, Phys. Rev. B 89, 125404 (2014).

[7] G. Fülöp, S. d'Hollosy, A. Baumgartner, P. Makk, V. A. Guzenko, M. H. Madsen, J. Nygård, C. Schönenberger, and S. Csonka, Phys. Rev. B 90, 235412 (2014).

[8] J. Schindele, A. Baumgartner, R. Maurand, M. Weiss, and C. Schönenberger, Phys. Rev. B 89, 045422 (2014).

Giant magneto-photoelectric effect in suspended graphene

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Graphene offers many advantages for photoelectric applications. First, its pseudo-relativistic (linear) dispersion relation leads to a broad absorption bandwidth. Second, the comparably strong Coulomb interaction facilitates an effective way for charge carrier multiplication. Third, the mean free path length exceeds the typical magnetic length scales for experimentally accessible magetic field strengths (which allows us to observe Hall and even quantum Hall physics at room temperature).

Based on these findings, we proposed employing the magneto-photoelectric effect along a graphene fold or edge. Recently, our experimental colleagues managed to realize this proposal experimentally. An illumination power of only 3 μW yields a photo-current of up to 400 nA without an applied bias, i.e., a photo-responsivity of 0.14 A/W, which we believe to be one of the highest values ever measured in single-layer graphene. We estimate that every absorbed photon creates more than 8 electron-hole pairs, so that carrier multiplication is present.

After a brief introduction into the basics of this effect, this talk will shortly present the experimental results and discuss the correponding theoretical model.

Quantum mechanics, special states and experiment

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An experimental test of the “special state” theory of quantum measurement is proposed. It should be feasible with present-day laboratory equipment. In this talk background material is given on the special state theory, a theory that is conservative with respect to quantum mechanics (only unitary time evolution occurs) but radical with respect to statistical mechanics. The test, involving modified Stern-Gerlach apparatus, is based on a feature of this theory that was found necessary in order to recover standard (Born) probabilities in quantum measurements, namely the occurrence of a long-tailed fluctuation distribution in materials.

Single photon superradiance and subradiance

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Single photon superradiance [1] began as a quantum curiosity: "Can we have phase matching at the single photon level?" The answer is yes. [2] But in solving this problem it was found that the subject of collective single photon emission from an ensemble of resonate two-level atoms is a rich field of study. [3,4] Indeed, it is interesting that single photon superradiance from an extended ensemble yields directional spontaneous emission. But even more interesting are the new insights from quantum field theory (e.g., the collective Lamb shift [5]) to condensed matter physics (e.g., topological insulators [6]) on the one hand to new device physics (e.g., Cavity QED and quantum informatics [7]) on the other. Present work also addresses the flip side of superradiance, i.e., subradiance. The single photon subradiant states are protected against vacuum fluctuations and can be addressed in ultrashort times.

[1] R. Dicke, Phys. Rev. 93, 99 (1954).
[2] M. Scully, E. Fry, C. Ooi, and K. Wódkiewicz, Phys. Rev. Lett. 96, 010501 (2006).
[3] W. Feng, Y. Li and S. Zhu, Phys. Rev. A 89, 013816 (2014).
[4] M. Scully and A. Svidzinsky, Science 325, 1510 (2009).
[5] J. Mannassah, Phys. Rep. 101, 359 (1983); M. Scully, Phys. Rev. Lett. 102, 143601 (2009); A. Svidzinsky and J. Chang, Phys. Rev. A 77, 043833 (2008).
[6] D. Wang, H. Cai, L. Yuan, R. Liu and S. Zhu, arXiv:1501.04099v2 (2015).
[7] M. Scully, arXiv:1505.03073v1 (2015).

Coherent alignment in complex systems

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Nonadiabatic alignment is a coherent approach to control over the spatial properties of molecules, wherein a short, moderately-intense laser pulse is applied to populate a broad rotational wavepacket with fascinating properties. In the limit of small isolated molecules, nonadiabatic alignment has evolved during the past 2 decades into an active field of theoretical and experimental research with a rich variety of applications. In the present talk we extend the alignment concept to complex systems, including large polyatomic molecules, dissipative media, nonrigid systems, molecular assembly, molecular conduction junctions and dense molecular ensembles. Following a brief review of the essential physics underlying laser alignment, we consider the case of asymmetric top molecules, where alignment overcomes the mechanisms that render the rotations unstable in the classical limit. Next we focus on dissipative media, and illustrate the application of rotational wavepackets as a probe of the decohering properties of the environment. We extend alignment to control the torsional motions of polyatomic molecules, and apply torsional control to manipulate charge transfer events in solutions, suggesting a potential route to light controlled molecular switches. Turning to interfaces, we introduce a route to guided molecular assembly, wherein laser alignment is extended to induce long-range orientational order in molecular layers. Combining the nonadiabatic alignment concept with recent research on nanoplasmonics and on conductance via molecular junctions, we develop an approach to coherent control of transport in the nanoscale [1]. Finally, we explore the case of dense molecular ensembles, where alignment generalizes into a collective phenomenon that gives rise to formation of molecular assembly with long range translational and orientational order.

[1] M. Reuter, M. Sukharev, and T. Seideman, Phys.Rev.Lett, 101, 208303 (2008); Nature Photonics 3, 4-5 (2009); Phys.Rev. A 86 013426 (2012).

Universal thermodynamic inequalities for biomolecular processes

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Stochastic thermodynamics provides a framework for describing small driven systems like molecular motors along their fluctuating trajectories using notions from classical thermodynamics like work, heat and entropy production [1].

After briefly recalling the basic principles, I will focus on our recent work showing how these principles provide universal constraints on the "performance" of biomolecular processes. First, I will show how dissipation constrains the rate at which a sensory system can acquire information about an external process [2]. Second, I will discuss a new thermodynamic uncertainty relation: The dispersion of an "output" observable like the number of produced molecules in an enzymatic process or the number of steps of a molecular motor is constrained by the thermodynamic cost of generating it. An uncertainty ϵ requires at least a cost of $2k_BT/\epsilon^2$ independent of the time required to generate this output [3].

[1] US, Rep. Prog. Phys. 75, 126001, 2012.

[2] AC Barato, D Hartich, and US, New. J. Phys. 16, 103024, 2014.

[3] AC Barato and US, Phys. Rev. Lett. 114, 158101, 2015.

Breakdown of the second law of thermodynamics in heterogeneous gas-surface reactions: Theory and experiment

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In 2000, Duncan proposed a simple, foundational thermodynamic paradox in which a sealed blackbody cavity contains a diatomic gas and a radiometer whose apposing vane surfaces dissociate and recombine the gas to different degrees [1]. As a result of differing desorption rates for the monomer and dimer, there arise between the vane faces permanent pressure and temperature differences, either of which can be harnessed to perform work, in apparent conflict with the second law of thermodynamics. Here we report on the first experimental realization of this paradox, involving the dissociation of low-pressure hydrogen gas on high-temperature refractory metals (tungsten and rhenium) under blackbody cavity conditions [2]. Our results, corroborated by other laboratory studies and supported by theory [3], confirm the paradoxical temperature difference and point to physics beyond the traditional understanding of the second law.

1 T.L. Duncan, Phys. Rev. E 61 (2000) 4661.

2 D.P. Sheehan, D.J. Mallin, J.T. Garamella, and W.F. Sheehan, Found. Phys. 44 (2014) 235.

3 D.P. Sheehan, Phys. Rev. E 88 (2013) 032125.

Collective edge modes near the onset of a graphene quantum spin Hall state

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Graphene subject to a strong, tilted magnetic field exhibits an insulator-metal transition tunable by tilt-angle, which is attributed to the transition from a canted antiferromagnetic (CAF) to a ferromagnetic (FM) bulk quantum Hall state at filling factor zero. We develop a theoretical description for the spin and valley edge textures in the two phases, and the implied evolution in the nature of their collective excitations throughout the transition. In both phases, the low-energy edge excitations are found to be dominated by mutually coupled charged and neutral modes. In particular, we show that the CAF phase supports a gapped charged edge mode, constructed by the binding of a vortex (meron) in the bulk to a spin twist at the edge. The energy gap of this edge mode is therefore dictated by the bulk spin stiffness. At the transition to the FM state where the stiffness vanishes, this charged edge mode becomes gapless and is smoothly connected to the helical edge mode characteristic of the FM state. We further discuss possible experimental consequences: most notably, the saturation of conductance in the FM phase below the ideal quantized conductance, and a doping-induced insulator-metal transition.

Many-body physics with ultracold quantum gases in disorder

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I will first give a brief overview of the studies of ultracold quantum gases in disorder and then turn to one-dimensional interacting disordered bosons at finite temperatures. It will be shown that they may undergo an interaction-induced non-conventional insulator-fluid transition, and I will present the phase diagram. The next issue will be interacting bosons in the quasiperiodic potential (superposition of two incommensurate one-dimensional lattices). I will demonstrate the presence of finite temperature many-body localization-delocalization transition induced by the interaction between the bosons. It will be shown that in a wide range of parameters an increase in temperature favors the insulator state, so that in this sense one has an anomalous "freezing with heating" phenomenon. The origin of this phenomenon lies in a peculiar behavior of single-particle states.

Quantum electrodynamics of quantum conductors in micro-waves cavity

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Motivated by recent experiments where superconducting microwave circuits have been coupled to electrons in semiconductor nanostructures, a generic mesoscopic conductor (a tunnel or Josephson junction) driven by a quantum microwave field is analyzed. Such system combines in a elegant manner quantum electronic transport and quantum microwave optics where both optical and electronic observables can be measured. Therefore it offers a new paradigm to test and foster our understanding of the light-matter interaction. Focusing first on the electronic side, I will show how transport is modified when the microwave cavity is prepared in some excited quantum state. This proves that dc current through the electronic conductor can thus be used as a detector of nonclassical light [1]. Then focussing on the optical side, I will show that the measurement of the cavity microwave field can be used to extract a lot of informations on the properties of the quantum conductor in a non-invasive manner. I will apply this general framework on the specific case of a one-dimensional p-wave superconductor capacitively coupled to the microwave cavity and show that this allows us to determine the topological phase transition point, the emergence of the Majorana fermions, and the parity of the ground state of the topological superconductor [2].

[1] J.-R. Souquet, M.J. Woolley, J. Gabelli, P. Simon, A. A. Clerk, Nature Communications 5, 5562 (2014).

[2] Olesia Dmytruk, Mircea Trif, Pascal Simon, arXiv:1502.03082.

Microscopic derivation of open quantum Brownian motion

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Open Quantum Brownian Motion (OQBM) is a new type of quantum brownian motion (QBM). In the case of OQBM the brownian particle has some internal degrees of freedom which are coupled to the same environment as the external one. This coupling provides a quantum walk like - quantum coin decision making mechanism which affects the position of the brownian particle. Originally, OQBM were derived as a scaling limit of Open Quantum Walks. Starting from a microscopic system plus bath model we will derive OQBM in two cases. First, we will consider a free open quantum Brownian particle. The master equation for the free open quantum Brownian particle is derived using the Quantum Langevin Equation with the expansion in small noise terms. Second, we will consider an open quantum Brownian particle in a harmonic potential. The master equation for this system is derived in the weak coupling limit and with the rotating wave approximation.

Hawking radiation from sonic black holes in flowing atom condensates

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We study the stationary transport through a double-barrier interface separating regions of asymptotically subsonic and supersonic flow of Bose-condensed atoms. Multiple coherent scattering by the double-barrier gives rise to highly non-thermal Hawking radiation displaying sharp peaks which are mostly associated with decaying resonances and only occasionally with dynamical instabilities. Even at achievable non-zero temperatures, the radiation peaks can be dominated by spontaneous emission [1]. We also investigate the possibility of using the violation of classical Cauchy-Schwarz inequalities by the outgoing radiation beams as a conclusive signature of spontaneous Hawking radiation [2]. We find that the violation can be large in resonant boson structures. Finally, we perform numerical simulations to identify the best protocols to create quasi-stationary black-hole configurations in realistic setups [3].

[1] I. Zapata, M. Albert, R. Parentani, F. Sols. Resonant Hawking radiation in Bose-Einstein condensates. New J. Phys. 13, 063048 (2011).

[2] J. R. M. de Nova, F. Sols, I. Zapata. Violation of Cauchy-Schwarz inequalities by spontaneous Hawking radiation in resonant boson structures. Phys. Rev. A 89, 043808 (2014).

[3] J. R. M. de Nova, D Guéry-Odelin, F. Sols, I. Zapata. Birth of a quasi-stationary black hole in an outcoupled Bose–Einstein condensate. New J. Phys. 16, 123033 (2014).

Non-equilibrium dynamics: Initial conditions and asymptotic evolution

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This contribution deals with perspectives of description of full non-equilibrium quantum many body system dynamics using the Non-equilibrium Greens Functions (NGF) [1]. The basic aim of this approach is to describe time development of a many-body system out of equilibrium from its initial state over its transient period to its very long time dynamics. A transient response of electrons depends on the joint effect of the initial state with correlations and of the driving external disturbances abruptly setting on at the initial time. The early period of the transient requires the full NGF for its description. After the disturbances cease acting the system may enter, under some favorable conditions, the non-equilibrium quasi-particle mode. The loss of initial correlations due to interactions and related renormalization processes permits reduced description by a quantum transport equation. This simplified description is based on an exact formulation in terms of reconstruction equations generating the correlation functions in terms of the propagators and the non-equilibrium distribution function. From these equations, a Generalized Master equation (GME) or even a Markovian master equation (ME) can emerge [1].

This approach will be related to the dynamics of open quantum systems, which will be represented by a simple structure of a molecular bridge without interactions. Interactions at the bridge are mimicked by the tunneling of electrons to the leads. We first explore this analogy and obtain a complete description of the transients for arbitrary initial correlations. Three stages of dynamics, the first described by the full NGF description, the second, ruled by the asymptotically exact GME, and the third, governed by ME, will be related to each other [1]. Second, we show the calculation of the excess magnetic current carried by a molecular bridge shunting a magnetic junction. The system is represented by two ferromagnetic electrodes bridged by a molecular size island with a few discrete electronic levels and a local Hubbard type correlation. The switching events controlling the junctions give rise to transient changes of magnetisation of the island. They strongly depend on the static galvanic bias between the electrodes, mutual alignment of their magnetisation and on the time scale of the switching. Depending on the time scale of the switching, the transients are dominated by the initial quantum correlations, or reach the kinetic stage controlled by a simple relaxation mechanism [2].

[1] V. Špička, A. Kalvová, B. Velický, Int. J. Mod. Phys B 28, 1430013 (2014).

[2] A. Kalvová, V. Špička and B. Velický, J. Supercon. and Novel Mag. 28, 1087 (2015).

NEGF approach to pump-probe photoabsorption spectroscopy

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After revisiting the theory of pump-probe photoabsorption spectroscopy we propose a nonequilibrium Green's function (NEGF) approach to calculate the transient spectrum of nanoscale systems. We can deal with arbitrary shape, intensity, duration and relative delay of the pump and probe fields and we can include ionization processes as well as hybridization effects due to surfaces. We present numerical simulations of atomic systems using different approximate self-energies and, whenever possible or available, find good agreement with CI calculations and experiments. The NEGF approach offers a first-principle methodology to predict and interpret pump-probe photoabsorption spectra of systems that are out of reach with other methods. If time permits we will also discuss future challenges and reachable goals.

[1] "Some Exact Properties of the Nonequilibrium Response Function for Transient Photoabsorption", Enrico Perfetto and Gianluca Stefanucci Physical Review A 91, 033416 (2015).

[2] "Charge Dynamics in Molecular Junctions: Nonequilibrium Green's Function Approach Made Fast", Simone Latini, Enrico Perfetto, Anna-Maija Uimonen, Robert van Leeuwen and Gianluca Stefanucci Physical Review B 89, 075306 (2014).

The making and breaking of non-abelian anyons

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Under certain conditions quantum electronic systems form non-abelian states of matter. In these states an interchange of two fundamental excitations ("non-abelian anyons") does not merely multiply the wave function by a sign, but rather transforms the system from one quantum state to another, where the transformation is determined by topological considerations. If realized, such states may form the basis to "Topological Quantum Computation", with a very high degree of immunity to de-coherence. In my talk I will describe what non-abelian states of matter are, how electrons may be engineered to form such states, what are the observable consequences of non-abelian anyons, and how non-abelian anyons may be fractionalized.

Nonequilibrium steady states in open quantum systems: Stochastic mapping and exact results

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For our numerical exploration of open-system quantum dynamics and non-equilibrium steady states (NESS), we take the c-number representation of quantum reservoirs [1] as a starting point, an exact method for the stochastic simulation of open quantum systems.

We derive a compact set of *deterministic* equations for the open-system quantum dynamics of arbitrary combinations of harmonic systems and ohmic thermal reservoirs, allowing flexible and efficient simulations all the way to equilibrium or non-equilibrium steady states. Energy flux and thermal fluctuations in both transient dynamics and NESS are computed.

In addition to thermodynamic driving, where reservoirs differ in temperature or other intensive quantities, we also present an extension of the method suitable for arbitrary dynamical driving, allowing the simulation of quantum heat engines beyond perturbation theory, and linking dynamics with finite-time thermodynamics.

[1] J.T. Stockburger and H. Grabert, Phys. Rev. Lett. 88 (2002) 170407

Improving thermoelectric conversion with multi-terminal superconducting systems

Fabio Taddei[1], Francesco Mazza[2], Stefano Valentini[2], Riccardo Bosisio[1,3], Giuliano Benenti[4,5], Vittorio Giovannetti[2], and Rosario Fazio[2]

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In this work we have analyzed the performance of a thermal machine which, by involving three reservoirs, allows for the implementation of a spatial separation between heat and charge currents in linear response. Such machine can be naturally realised by connecting a conductor to a superconducting lead, a voltage probe and a normal lead (SPN system). Interestingly, the linear-response transport equations, written in terms of the Onsager matrix, turn out to be formally equal to those of a two-terminal conventional system. Using this property we have made a comparison between the performance of these two thermal machines in terms of the power factor Q (that controls the maximum extracted power), and the figure of merit ZT (that controls the efficiency at maximum power and the maximum efficiency). Within the scattering approach we have described the SPN system with a parametrised scattering matrix. We have shown that in the low temperature limit (where the Sommerfeld expansion holds) the SPN system violates the Wiedemann-Franz law and allows, to some extent, an independent control of electrical conductance, thermal conductance and thermopower (i.e. of heat and charge currents). To assess the consequences of this on the thermoelectric performance of the SPN system we have made a statistical analysis by taking random values, over a uniform distribution, of the parameters contained in the scattering matrix. We have thus shown, on statistical grounds, that the SPN system exhibits much larger values of Q and ZT with respect to the two-terminal counterpart. Further improvements (more than one order of magnitude) of the thermoelectric performance of the SPN setup has been confirmed on a specific physical system composed of three coupled quantum dots. We believe that our results can be relevant in the experimental activity on thermoelectricity of nanoscale structures, which are typically conducted at low temperatures.

T140 Wed, 29 July, 15:30 - 16:00, 4 session - B parallel

Controlling spin transport and magnetoresistance at the atomic scale

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Typically, manipulations of electronic spin currents require length scales larger than the length of individual atoms. However, when spin transport is confined to atomic-scale constrictions it is very sensitive to the fine details of the local electronic structure. We use this sensitivity to demonstrate perfect spin filtering in nickel-oxide atomic junctions and tunable giant anisotropic magnetoresistance in molecular junctions. The presented effects are achieved by different manifestations of selective orbital hybridization, paving the way for controlled atomic scale spin transport by "orbital engineering".

The cellular automaton interpretation of quantum mechanics

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This interpretation allows for completely natural resolutions of the measurement problem, the questions of the collapse of the wave function and Schroedinger's cat. Furthermore, it suggests quite novel approaches to the holographic principle and the question of the arrow of time. As for Bell's inequalities, they are seen to be part of a more basic puzzle, which can be addressed using the formal loophole associated to superdeterminism, spacelike correlations, and an ontological conservation law. These matters will be discussed.

Iterative path integral approach to nonequilibrium quantum transport

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We have developed a numerically exact approach to compute real-time path integral expressions for quantum transport problems out of equilibrium. The scheme is based on a deterministic iterative summation of the path integral (ISPI) for the generating function of nonequilibrium observables of interest, e.g., the current or dynamical quantities of the central part. Self-energies due to the leads, being non-local in time, are fully taken into account within a finite memory time, thereby fully including non-Markovian effects. Numerical results are extrapolated first to vanishing (Trotter) time discretization and, second, to infinite memory time. The method is applied to nonequilibrium transport through a single-impurity Anderson dot in the first place [1,2]. Secondly, we determine the nonequilibrium current $I(V)$ through a molecular junction in presence of a vibratinal mode. We have found an exact mapping of the single impurity Anderson-Holstein model to an effective spin-1 problem [3]. The third system under investigation here is the magnetic Anderson model which consists of a spinful single-orbital quantum dot with an incorporated quantum mechanical spin-1/2 magnetic impurity [4].

[1] S. Weiss, R. Hützen, D. Becker, J. Eckel, R. Egger, and M. Thorwart, Iterative path integral summation for nonequilibrium quantum transport, Phys. Status Solidi B 250, 2298 (2013) (Feature Article)

[2] S. Weiss, J. Eckel, M. Thorwart, and R. Egger, Iterative real-time path integral approach to nonequilibrium quantum transport, Phys. Rev. B 77, 195316 (2008)

[3] R. Hützen, S. Weiss, M. Thorwart, and R. Egger, Iterative summation of path integrals for nonequilibrium molecular quantum transport, Phys. Rev. B 85, 121408 (R) (2012)

[4] D. Becker, S. Weiss, M. Thorwart, and D. Pfannkuche, Nonequilibrium quantum dynamics of the magnetic Anderson model, New J. Phys. 14, 073049 (2012)

Quantum transport in molecular junctions: Vibrational effects and time-dependent phenomena

Michael Thoss

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Molecular junctions, i.e. single molecules bound to metal or semiconductor electrodes, represent interesting systems to study nonequilibrium many-body quantum physics at the nanoscale. In this talk, I will discuss our recent theoretical studies on charge transport in molecular junctions. In particular, various aspects of vibrationally coupled electron transport are analyzed, including current-induced vibrational excitation [1], quantum interference effects and their quenching [2], as well as fluctuations [3]. Furthermore, time-dependent phenomena and signatures of multistability in nonequilibrium transport are discussed [4]. The studies employ a combination of generic as well as first-principles based models and different transport methods, including nonequilibrium Green's functions and the multilayer multiconfiguration time-dependent Hartree method [5]. The latter method, which allows a numerically exact treatment of the time-dependent transport problem, can be combined with density matrix approaches [4] and provides benchmark results for approximate approaches.

[1] R. Härtle, U. Peskin and M. Thoss, Phys. Status Solidi B 250, 2365 (2013).

[2] R. Härtle, M. Butzin, O. Rubio-Pons, and M. Thoss, Phys. Rev. Lett. 107, 046802 (2011); Phys. Rev. B 87, 085422 (2013); S. Ballmann, R. Härtle, P.B. Coto, M. Mayor, M. Elbing, M. Bryce, M. Thoss, and H.B. Weber, Phys. Rev. Lett. 109 , 056801 (2012).

[3] C. Schinabeck, R. Härtle, H.B. Weber, and M. Thoss, Phys. Rev. B 90, 075409 (2014).

[4] E. Wilner, H. Wang, G. Cohen, M. Thoss, and E. Rabani, Phys. Rev. B 88, 045137 (2013); 89, 205129 (2014).

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

Engineering mesoscopic quantum systems using quantum magneto-mechanics

Jason Twamley

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Mechanical quantum systems have begun to play crucial roles in a variety of quantum systems, devices and technologies including hybrid quantum devices and quantum sensors. The control of the quantum state of mechanical systems has primarily been investigated via electrical or optical means, e.g. via incorporation in superconducting circuits and actuation via piezo-electric or capacitive means, or via light forces in optomechanical setups. Magnetic control of mechanical quantum systems has received little attention yet potentially offers the prospect of strong coupling and low loss and decoherence. We will describe several concepts relating to the generation of macroscopic Schrodinger cat states, an optical-microwave quantum interface and an ultra-sensitive quantum inertial sensor, that make fundamental use of magnetic quantum mechanical control. We will argue that magneto-mechanical quantum control presents new opportunities for research and engineering of the quantum world.

On the origin of the constants c and h

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Isaac Newton postulated space and time as axiomatic concepts that set the stage for the development of modern physics. Despite two scientific revolutions, relativity and quantum physics, the concepts themselves of space and time have rarely been questioned.

c and h were essential for the success of relativity and quantum physics. Yet, they may also be seen as anomalies that cast doubt at the very basis of Newtonian physics, space and time. c and h might be failures of the spacetime concept at the large and at the small scale, conventionally called light and matter.

Besides an unexpected phenomenology, there is no mathematical reason for the existence of constants such as c and h. Nor there is a justification why Nature chose the peculiar form of a 3+1-dimensional spacetime.

We develop the hypothesis that physical reality is described by the most simple three-dimensional manifold - the unit sphere S^3 and its equivalent with unique properties, the Lie group $SU(2)$.

We observe that a sequence of tangent spaces on a three-dimensional manifold may be perceived as 3+1-dimensional phenomenology. Though such a picture presents unique challenges to human imagination, a series of intriguing coincidences is discussed.

c might be a consequence of linearization, h a consequence of the noncommutativity of $SU(2)$. From a differential geometry viewpoint, the arising 1-forms and 2-forms are qualitatively different objects that can mimic 'physical units' when being inappropriately equated.

The goal is to develop mathematical concepts more fundamental than space and time, while providing a necessity for the emergence of c and h.

Fluctuation theorem for a small engine and magnetization switching by spin torque

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We consider a reversal of the magnetic moment of a nano-magnet by the fluctuating spin-torque induced by a non-equilibrium current of electron spins. This is an example of the problem of the escape of a particle from a metastable state subjected to a fluctuating non-conservative force. The spin-torque is the non-conservative force and its fluctuations are beyond the description of the fluctuation-dissipation theorem. We estimate the joint probability distribution of work done by the spin torque and the Joule heat generated by the current, which satisfies the fluctuation theorem for a small engine. We predict a threshold voltage above which the spin-torque shot noise induces probabilistic switching events and below which such events are blocked. We adopt the theory of the full-counting statistics under the adiabatic pumping of spin angular momentum. This enables us to account for the backaction effect, which is crucial to maintain consistency with the fluctuation theorem.

Quantum mechanism that makes time different to space

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In special relativity, time and space are necessarily interconvertible in order that the speed of light is invariant. This places time and space on an equal footing which, perplexingly, does not carry over to other areas of physics. In quantum mechanics, in particular, conservation of mass requires matter to be represented by a quantum state vector whose norm is fixed over time but not over space—in other words the state vector is required axiomatically to be extremely *delocalized* in time but *localized* in space. Time then becomes a classical parameter whereas the description of matter in space is treated by quantum variables. As a consequence, the status of time and space are quite different from the very outset.

However, time and space could have an equivalent footing in quantum mechanics if their differences were to arise *phenomenologically* from the theory rather than being imposed axiomatically on it. Such a prospect is well worth pursuing because it would help us to understand the relationship between time and space. It would require finding an underlying mechanism that allows states to be localized in space but not in time. As localization entails a constraint on the corresponding translational degree of freedom, we need to look for the mechanism in terms of translations. The generators of translations in space and time are given by the momentum and Hamiltonian operators, respectively, and with them lies a difference that sets space and time apart *phenomenologically*. In fact, the last fifty years has shown that the Hamiltonian is not invariant to particular combinations of the discrete symmetry operations of charge conjugation (C), parity inversion (P) and time reversal (T), whereas the momentum operator is.

We show here [1,2] that when the C, P and T symmetry violations are included explicitly in a quantum formalism, remarkable differences arise between the character of quantum states in time and space. In particular, despite time and space having an equal footing at a fundamental level, we find that quantum states can be localized in space and yet have unbounded evolution in time. Moreover, the conservation of mass principle emerges phenomenologically through the persistence of the states over time. As such, the violations are shown to play a defining role in the asymmetry between time and space in quantum mechanics.

[1] J.A.Vaccaro, *T Violation and the Unidirectionality of Time*, Foundations of Physics **41**, 1569-1596 (2011) http://arxiv.org/abs/0911.4528

[2] J.A.Vaccaro, *Quantum asymmetry between time and space*, http://arxiv.org/abs/1502.04012

Evolution of a disordered nanoparticle network into Boolean logic

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Present-day computers are based on integrated circuits, constructed according to fixed design rules and making use of well-defined components. Living systems, however, are able to achieve extraordinary feats of computation without the need for a specific design. Darwinian evolution has resulted in sophisticated information processing systems in which the emergent properties and huge parallelism of complex networks are exploited. Inspired by this, we here report on an artificial system of randomly assembled gold nanoparticles coupled via molecular tunnel barriers, acting as a disordered network of single-electron transistors at low temperature [1]. Using artificial evolution, we demonstrate that this designless system can be configured into any basic Boolean logic gate with a very high degree of stability and reproducibility. Our results comprise the first experimental demonstration of fully reconfigurable logic based on randomly distributed nanoscale components, and bear direct relevance for future unconventional computer architectures.

[1] S.K. Bose, C.P. Lawrence, Z. Liu, K.S. Makarenko, R.M.J. van Damme, H.J. Broersma and W.G. van der Wiel, manuscript under review

Response to a local quench of a system near many body localization

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We consider a one dimensional chain of spin 1/2 with Heisenberg interaction in a random magnetic field along z-axis. This system shows a many body localization transition at moderate disorder when the amplitude of the random field is comparable to the Heisenberg coupling. We analyze the spin response to a local magnetic field perpendicular to z-axis. We show that the response of individual spins has a different behavior in the localized and delocalized regimes and the spin correlation function can be used for accurate determination of the mobility edge. In the localized regime, the response decays exponentially along the chain at distances larger than the localization length. We utilize this exponential decay of spin response to study dependence of the localization length on disorder strength.

Probing deformed commutators with macroscopic harmonic oscillators

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A minimal observable length is a common feature of theories that aim to merge quantum physics and gravity. Quantum mechanically, this concept is associated to a nonzero minimal uncertainty in position measurements, which is encoded in deformed commutation relations. In spite of increasing theoretical interest, the subject suffers from the complete lack of dedicated experiments and bounds to the deformation parameters are roughly extrapolated from indirect measurements. As recently proposed, low-energy mechanical oscillators could allow to reveal the effect of a modified commutator. Here we analyze the free evolution of high quality factor micro- and nano-oscillators, spanning a wide range of masses around the Planck mass, and compare it with a model of deformed dynamics. Previous limits to the parameters quantifying the commutator deformation are substantially lowered.

[1] M. Bawaj et al., arXiv:1411.6410 [gr-qc].

[2] I. Pikovski et al., Nature Phys. 8, (2012) 393-397.

[3] F. Marin et al. , Nature Phys. 9, (2013) 71-73.

How random is topological disorder? Phase transitions and localization on random lattices

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We study the effects of topological (connectivity) disorder on phase transitions. We identify a broad class of random lattices whose disorder fluctuations decay much faster with increasing length scale than those of generic random systems, yielding a wandering exponent of $\omega = (d-1)/(2d)$ in d dimensions instead of the generic value $\omega = 1/2$. This is caused by coordination number anticorrelations due to a topological constraint. A prominent example is the random Voronoi-Delaunay lattice.

The stability of clean critical points in systems defined on such lattices is thus governed by the criterion $(d+1) > 2$ rather than the usual Harris criterion $d > 2$, making topological disorder less relevant than generic randomness. The Imry-Ma criterion is also modified, allowing first-order transitions to survive in all dimensions $d > 1$. These results explain a host of puzzling violations of the original criteria for equilibrium and nonequilibrium phase transitions on random lattices. We discuss applications, and we illustrate our theory by computer simulations of random Voronoi and other lattices.

We also consider the transport of non-interacting electrons on random Voronoi-Delaunay lattices and study the electronic wave functions by multifractal analysis. We observe localized states for all energies in the two-dimensional system. In three dimensions, we find two phase transitions towards extended states very close to the band edges. The scaling analysis shows that the scaling exponent of the localization length is 1.6, in accordance with the usual orthogonal universality class. Additional generic energetic randomness by on-site potentials does not lead to qualitative changes. This implies that the unusual coordination number anticorrelations do not lead to qualitatively different behavior compared to the well-known Anderson model of localization on regular lattices.

[1] H. Barghathi and T. Vojta, Phys. Rev. Lett. 113 (2014), 120602

DMFT+NRG study of spin-orbital separation in a three-band Hund's metal

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We show that the numerical renormalization group (NRG) is a viable multi-band impurity solver for Dynamical Mean Field Theory (DMFT), offering unprecedent real-frequency spectral resolution at arbitrarily low energies and temperatures. We use it to obtain a numerically exact DMFT solution to the Hund's metal problem for a three-band model with filling factor $n_d = 2$. The ground state is a Fermi liquid. The one-particle spectral function undergoes a coherence-incoherence crossover with increasing temperature, with spectral weight being transfered from low to high energies. Further, it exhibits a strong particle-hole asymmetry. In the incoherent regime the one-particle self-energy displays approximate power-law behavior for positive frequencies only. The spin and orbital spectral functions show "spin-orbital separation": spin screening occurs at much lower energies than orbital screening. The renormalization group flows clearly reveal the relevant physics at all energy scales.

[1] arXiv:1503.06467 [cond-mat.str-el]

Functional integral approach to time-dependent heat exchange in open quantum systems

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The functional integral approach for the time-dependent heat exchange of an externally driven quantum system coupled to a thermal reservoir is presented. The exact formal functional expression for the moment generating function is derived for arbitrary frequency-dependent dissipation. The relevant influence functional includes apart from the friction action and the noise action accounting for the quantum-dissipative dynamics of the reduced system additional time-nonlocal actions encapsulating all quantum-statistical features of the heat exchange process. The potential of the new approach is checked out by application to the dissipative two-state system. Results in analytic form for the heat current and current cumulants are presented both for weak and strong Ohmic dissipation. It is shown that the method yields a complete description of the time-dependent heat exchange process ranging from the classical regime down to zero temperature. The method is also applied to heat transfer in quantum transport systems.

Going down drains into blind alleys: From reality to causality in the quantum world

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The quantum wavefunction is at the heart of our best description of nature, yet we don't know what this object actually represents. Does it correspond to physical reality—the psi-ontic interpretation—is it a representation of knowledge or information about an underlying reality—the psi-epistemic interpretation—or is there no reality at all and the wavefunction just represents our subjective experience?

The psi-epistemic viewpoint appears very compelling in that it offers intuitive and simple explanations for many puzzling quantum phenomena. Whether it is indeed compatible with quantum mechanics and the notion of an objective observer-independent reality has, on the other hand, long been an open question. We have recently demonstrated experimentally that no realist psi-epistemic model can fully explain the imperfect distinguishability of non-orthogonal quantum states—one of the fundamental features of the theory.

Here we discuss improvements on this experiment and challenges on the way to more and more stringent bounds on the explanatory power of such models. In contrast to the no-go theorems of Pusey, Barrett, Rudolph and others, our experiment requires no fundamental assumptions such as a certain structure of the underlying ontic state space. We thus capture all interpretations of quantum mechanics that feature an observer-independent reality and just require a fair-sampling assumption due to imperfect detection efficiencies.

Our results thus suggest that maintaining a notion of objective, observer-independent reality requires a psi-ontic interpretation, which assigns objective reality to the wavefunction. If we wish to maintain the epistemic character of the wavefunction we are thus led to rejecting the notion of observer-independent reality in our physical world.

Alternatively one could also reject the ontological model framework and consider more exotic alternatives, such as retrocausal influences. Indeed, Bell's famous theorem already show that our classical notion of causality is incompatible with quantum mechanics. Well-established causal discovery methods fail to produce conclusive results in the face of Bell-inequality scenarios unless one considers loopholes such as fine-tuned communication channels.

We explore generalization of causality to the quantum regime and revisit the role of cause and effect. Going a step further, we experimentally demonstrate that not even a causal connection between Alice and Bob can explain quantum correlations. These and other results suggest that the notion of causality might have to change at the quantum level and could possibly even be harnessed as a resource for quantum computation.

Noise and full counting statistics of quantum phase slips

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We develop a detailed theory of fluctuations in superconducting nanowires in the presence of Quantum Phase Slips (QPS) [1]. Exploiting the charge-phase duality we demonstrate that QPS effects cause voltage noise in such nanowires. The expression for the voltage-voltage correlation function consists of several physically different contributions. One of these contributions has the same origin as that analyzed earlier in the case of superconducting nanorings [2]. In the zero temperature limit this contribution survives only at non-zero frequencies and behaves similarly to 1/f noise. Another contribution describes QPS-induced shot noise in superconducting nanowires. We also investigate Full Counting Statistics of quantum phase slips and derive the generating function that allows to recover all cumulants of the voltage operator in such nanowires.

[1] K.Yu. Arutyunov, D.S. Golubev and A.D. Zaikin, Physics Reports, **464**, 1 (2008)

[2] A.G. Semenov and A.D. Zaikin, Physical Review B, **88**, 054505 (2013)

T156 Wed, 29 July, 15:00 - 15:30, 4 session - C parallel

Quantum chaos and thermalization in a mesoscopic many-body system

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An isolated many-body quantum system of interacting constituents has a density of stationary quantum states exponentially growing with excitation energy just because of combinatorics of single-particle excitations. Then the interactions are effectively strong and stationary wave functions become exceedingly complicated superpositions of basis simple states. This situation can be described in terms of quantum chaos with spectral characteristics close to those of Gaussian random matrix ensembles. The equivalent description is possible in terms of thermalization where the role of a heat bath is played by the interparticle interaction. Each complicated eigenfunction can be characterized by effective temperature and entropy which smoothly evolve along the spectrum. This will be illustrated by exact numerical solutions of nuclear many-body problem. As an example of practical applications, the algorithm for the calculation of the level density in any subclass of states with given quantum numbers was developed that does not require full diagonalization of large Hamiltonian matrices.

Invited Posters

Physical microscopic free-choice model in the framework of a Darwinian approach to quantum mechanics

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The structure assigned in this study to a fundamental particle in the framework of an abstract landscape of all possible physical theories contains as main ingredient a methodological classical Turing machine that makes every system an active subject in addition to its usual passive object character in the frame of a traditional physical theory with immutable laws or regularities. In this way, the physical space inhabited by bare particles is supplemented, for every particle, with a methodological informational space for the associated Turing machine on which Darwinian evolution acts driving the generation of physical laws from an initial blank state. These laws are bottom-up evolving patterns subject to natural selection on the informational space, and resulting from the interplay among particles. Therefore, in this scheme [1], from which quantum mechanics should emerge as an evolutionarily stable strategy, every system acts not under a general law, but as a consequence of the command of a particular, evolved algorithm issued after a run of this programme for input data that reflect the environment in which the system is immersed. The presence of the Turing machine and the particular algorithm seems to entail a certain amount of free choice in the particle. But is this just apparent free-choice behaviour? Or, on the contrary, might it be considered meaningful, real free choice? This last question is answered in the affirmative. Two lines of reasoning are adduced. First, the algorithm on every system is unique, determined by its particular world line, and in addition at least partially unknown for the other systems, what makes its operations unpredictable not only because randomness is included in the programme, but for lack of universal laws. However it might still be argued that the model doesn't include any genuine free element, since the decisions made by the system although uncertain for the rest of the universe are either deterministic, and then they only depend on the past history of the system, or random, and then they don't add real free elements. But the second argument rebuts those objections: The Turing machine allows the system to algorithmically anticipate possible future configurations, and as a consequence to incorporate elements to the decision making procedure that are not strictly in the past, but in a possible future. The proposed free-choice model is discussed in the context of the recent progress that this concept has experienced in the field of physics [2].

[1] C. Baladrón, Physica E 42 (2010) 335

[2] J. Conway and S. Kochen, Found. Phys. 36 (2006) 1441

I2

Heat-exchange statistics in driven open quantum systems

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We set up a formalism that allows to calculate the full probability distribution of energy exchanges in a open quantum system[1, 2]. We apply it to a periodically driven quantum system and a thermalized heat reservoir. The formalism combines Floquet theory with a generalized master equation approach. For a driven two-level system and in the long-time limit, we obtain a universal expression for the distribution, providing clear physical insight into the exchanged energy quanta. We illustrate our approach in few analytically solvable cases and discuss the differences in the corresponding distributions[3]. Our predictions could be directly tested in a variety of systems, including optical cavities and solid-state devices. Finally we discuss some possible generalisation using standard quantum dissipative techniques in order to solve the problem also beyond the weak-coupling prescription.

[1] P. Solinas, D. V. Averin and J. P. Pekola, Phys. Rev. B 87, 060508 (2013)

[2] M. Esposito, U. Harbola and S. Mukamel, Rev. Mod. Phys. 81, 16651702 (2009); M. Campisi, P. Hänggi and P. Talkner Rev. Mod. Phys. 83, 771 (2011)

[3] S. Gasparinetti, P. Solinas, A. Braggio and M. Sassetti, New J. Phys. 16, 115001 (2014)

Fractional quantum Hall spectroscopy with a resonant detector

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We investigate the finite frequency (f.f.) noise properties of edge states for a quantum point contact (QPC) in the fractional quantum Hall regime[1]. We propose the most prototypical scheme for the emission-absorption noise measurement scheme with a resonant LC circuit coupled to a QPC in the weak-backscattering limit[2]. We investigate the Laughlin[3] and Jain[4] sequences, studying the behaviour of multiple quasiparticle tunnelling excitations[5,6]. The measured quantity clearly distinguish between the different excitations in a realistic and experimentally relevant range of parameters[7]. We show that we can efficiently use this setup to perform a detailed spectroscopy of the tunnelling excitations. Finally, we also illustrate the effects of the detector temperature on the sensibility of the measure. Results are reported in Ref.[8]

[1] Chamon C, Freed D E and Wen X G, Phys. Rev. B 51, 2363 (1995)

[2] Lesovik G B and Loosen R, JETP Lett. 65, 295 (1997)

[3] Laughlin R B, Phys. Rev. Lett. 50, 1395 (1983)

[4] Jain J K, Phys. Rev. Lett. 63, 199 (1989)

[5] Ferraro D, Braggio A, Merlo M, Magnoli N and Sassetti M, Phys. Rev. Lett. 101, 166805 (2008)

[6] Carrega M, Ferraro D, Braggio A, Magnoli N and Sassetti M, Phys. Rev. Lett. 107, 146404 (2011)

[7] Zakka-Bajjani E, Segala J, Portier F, Glattli D C, Cavanna A and Jin J, Phys. Rev. Lett. 99, 236803 (2007)

[8] Ferraro D, Carrega M, Braggio A and Sassetti M, New. J. Phys. 16, 043018 (2014)

I4

Quasiparticle effects in superconducting qubits

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Superconducting qubits based on Josephson junctions are a promising platform for quantum computation, reaching quality factors of over one million [1]. Such high quality factors enable the investigation of decoherence mechanisms with high accuracy. An intrinsic decoherence process originates from the coupling between the qubit degree of freedom and the quasiparticles that tunnel across Josephson junctions [2-3]. Here I summarize the general theory of quasiparticle-induced decoherence, valid both for equilibrium and non-equilibrium quasiparticles [4-6]. I also present theoretical results for the single-junction transmon [7], and comment on experimental measurements of quasiparticle effects in this type of qubit [8].

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

[2] R. M. Lutchyn, L. I. Glazman, and A. I. Larkin, Phys. Rev. B 72, 014517 (2005).

[3] H. Paik *et al.*, Phys. Rev. Lett. 107, 240501 (2011).

[4] G. Catelani *et al.*, Phys. Rev. Lett. 106, 077002 (2011).

[5] G. Catelani *et al.*, Phys. Rev. B 84, 064517 (2011).

[6] G. Catelani *et al.*, Phys. Rev. B 86, 184515 (2012).

[7] G. Catelani, Phys. Rev. B 89, 094522 (2014).

[8] D. Ristè *et al.*, Nat. Commun. 4, 1913 (2013).

Superfluidity and chaos in low dimensional circuits

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We show that the standard Landau and Bogoliubov superfluidity criteria fail in low-dimensional circuits. Proper determination of the superfluidity regime-diagram must account for the crucial role of chaos, an ingredient missing from the conventional stability analysis. Accordingly, we find novel types of superfluidity, associated with irregular or chaotic or breathing vortex states.

[1] G. Arwas, A. Vardi, D. Cohen, PRA 89, 013601 (2014)

[2] G. Arwas, A. Vardi, D. Cohen, arXiv:1412.5929

I6

Leggett–Garg inequalities for qubits in thermal environment

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We study violation of Leggett–Garg inequalities in the presence of thermal environment modeled in terms of Davies maps. We consider two instances: in the first dissipative evolution of a single qubit and in the second a pair of qubits, one of them locally coupled to thermal bath. We identify conditions depending both on the initial preparation and the particular form of a measurement carried on the system, when the violation of the simplest Leggett–Garg inequality becomes independent on certain parameters of the environment.

[1] M. Lobejko, J. Luczka, J. Dajka, Phys. Rev. A 91, 042113 (2015)

Jarzynski equality in PT-symmetric quantum mechanics

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We show that the quantum Jarzynski equality generalizes to PT-symmetric quantum mechanics with unbroken PT symmetry. In the regime of broken PT symmetry, the Jarzynski equality does not hold as also the CPT norm is not preserved during the dynamics. These findings are illustrated for an experimentally relevant system—two coupled optical waveguides. It turns out that for these systems the phase transition between the regimes of unbroken and broken PT symmetry is thermodynamically inhibited as the irreversible work diverges at the critical point.

[1] S. Deffner and A. Saxena, Phys. Rev. Lett. 114, 150601 (2015)

I8

Correlations between probes for precision metrology

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We establish a result apparently contradicting the common belief that a position measurement disturbs a subsequent momentum measurement: on the contrary, we show that a momentum measurement can be made more precise by making first a position measurement, provided that the two apparatuses are suitably entangled. This work was supported by CAPES through process No. 3835-15-4.

[1] Antonio Di Lorenzo, Phys. Rev. Lett. 110 (2013) 120403

Post-selection induced entanglement with strong, weak, and intermediate measurements

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We propose a method to entangle deterministically two distant photons by having them interact with an ancillary particle in a Mach-Zehnder interferometer through a hypothetical device that changes the state of a photon or not, depending on the presence of a trigger particle. Then, an appropriate post-selecting measurement is made on the ancillary photon, and finally a local transformation is applied to one of the photon to be entangled, based on the result of the post-selecting measurement. We show that for a weak measurement, the maximum entanglement can be recovered, paying the price of a reduced probability of success, while for a strong measurement, the maximum entanglement can be obtained with unit probability of success. This work was supported by CAPES through process No. 3835-15-4.

[1] Antonio Di Lorenzo, Phys. Rev. A 90 (2014) 022121.

I10

Quantum networks: Transport, decoherence and control

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Optimizing excitation transport in quantum networks is an important precursor to the development of highly-efficient light-harvesting devices. We investigate the phenomenon of dephasing-assisted leakage from trapped states, which may ensure efficient transport of excitations across a network. We consider three small networks with known trapped states and study the effect of Markovian quantum noise and classical noise sources with different correlation times, from very low frequency non-Markovian noise to white noise. We show that the excitation - otherwise stalled in trapped states - is able to diffuse rapidly through the networks from a source to a sink, with efficiency being generally maximized for intermediate correlation times [1]. We apply these ideas to a network of pseudospin presenting a regular geometry with large inhomogeneity of on-site excitation energies. This model may simulate a nanofablicated antenna based on closely spaced quantum dots of different sizes, haing a broad-band absorption spectrum. We show that even a small local dephasing largely increases the efficiency of transfer of excitations to a reaction center. We finally study in detail the phenomnon of detrapping in Delta systems, in order to foucus experimentallt detectaable signatures of non-Markovianity of the dynamics. These are found in the peculiar behavior of the "dark resonance" i.e. of the efficiency of trapping as a function of diagonal vs non diagonal couplings in the presence of noise.

[1] T.J. Pope et al., Rom. Jour. Phys. Volume 60, Number 5-6 (2015).

Dot-bound and dispersive states in gated-defined graphene quantum dots and superlattices

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We study analytically the scattering of an Dirac electron by a circular step in a graphene monolayer in analogy to Mie scattering of light by a sphere. Constructive and destructive interference between resonant scattering and the background partition of scattering can give rise to a Fano resonance. This can entail dramatic changes in the near field, such as an inversion of the vortex pattern, which can even lead to a suppression of Klein tunnelling. Our results suggest that a circular gated region might be used as a switch, which by tuning its potential manipulates the preferred scattering direction. [1]

In a next step, we employ numerically exact Chebyshev expansion and kernel polynomial techniques and study the electron dynamics in graphene with gate-defined quantum dots in the framework of an tight-binding honeycomb lattice model. In particular, we trace the time-evolution of a wave packet and find temporary particle trapping at the dot when normal modes become resonant. Transport through a linear array of dots is analysed as well. [2]

Finally we consider a square lattice configuration of circular quantum dots in an unbiased graphene sheet and calculate the electronic, particularly spectral properties of finite albeit actual sample sized systems. Analysing the local density of states and the momentum resolved photoemission spectrum we find clear evidence for a series of quasi-bound states at the dots, which can be probed by optical measurements. We further analyse the interplay of the superlattice structure with dot-localized modes on the electron energy dispersion. Effects of disordered dot lattices are discussed too. [3]

[1] R. L. Heinisch, F. X. Bronold, and H. Fehske, PRB 87 (2013) 155409

[2] A. Pieper, R. L. Heinisch, and H. Fehske, EPL 104 (2013) 47010

[3] A. Pieper, R. L. Heinisch, G. Wellein, and H. Fehske, PRB 89 (2014) 165121

I12

Underlying non-Hermitian character of the Born rule in decaying quantum systems

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In a recent work [1] it is shown that the usual Hermitian formulation, based on continuum wave functions, and a non-Hermitian formulation that involves resonant or quasi-normal modes, yield an identical description of the time evolution of decay of a particle initially confined within an interaction potential region along the distinct decaying regimes. Both approaches are analytically exact and are based on properties of the outgoing Green's function to the problem.

Here we present a link between the above Hermitian and non-Hermitian formulations by exhibiting the underlying non-Hermitian character of the Born rule in these open quantum systems. This is obtained by expanding the states of the continuum that appear in the usual expression of the Born rule, in terms of the discrete quasi-normal modes and complex poles of the outgoing Green's function of the problem. The analytical exact expansion exhibits in general Lorentzian and overlapping contributions that are weighted by coefficients that possess a quasi-probabilistic nature.

[1] G. García-Calderón, A. Máttar and J. Villavicencio, Phys. Scr. T151 (2012) 014076.

Casimir forces in inhomogeneous media: Towards a workable regularization

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Recent advances in computational and experimental techniques have initiated a renaissance in the physics of the Casimir effect [1] and related phenomena, ranging from manipulations of van der Waals forces in nanostructured materials to heat transfer across subwavelength distances. Casimir forces have also become technologically relevant for micromechanical devices where they are the cause of friction and stiction. Casimir forces originate from vacuum fluctuations that induce fluctuating dipoles in dielectric materials. These dipoles interact with each other, creating a macroscopic force between dielectric bodies: the Casimir force. The theory on which the modern computational tools for Casimir forces in realistic materials are based, Lifshitz theory [2] has been put on firm foundations since 1961. Lifshitz theory gives accurate predictions of the Casimir forces between different objects. However, it fails in predicting the Casimir force inside an object if the object consists of smoothly varying inhomogeneous media: here the theory diverges [3,4]. As the Casimir effect is ultimately caused by vacuum fluctuations, the self-effect of those fluctuations need to be removed by a suitable regularizer. It turned out [3,4] that the original Lifshitz regularizer [2] that works perfectly well in the uniform space between different objects, fails in inhomogeneous materials. After a five-year quest of finding the right regularizer we believe to have discovered a procedure that works, at least in planar materials where we tested it. Our inspiration comes from transformation optics [5,6] and in particular from the in terpretation of dielectric materials as effective spatial geometries. We use this geometrical perspective to identify the regularizer that makes Lifshitz theory convergent in inhomogeneous planar materials.

[1] A. W. Rodriguez, F. Capasso, and S. G. Johnson, Nat. Photon. 5, 211 (2011).

[2] I. E. Dzyaloshinskii, E. M. Lifshitz, and L. P. Pitaevskii, Adv. Phys. 10, 165 (1961).

[3] T. G. Philbin, C. Xiong, and U. Leonhardt, Ann. Phys. (New York) 325, 579-595 (2010).

[4] W. M. R. Simpson, S. A. R. Horsley, and U. Leonhardt, Phys. Rev. A 87, 043806 (2013).

[5] H. Chen, C. T. Chan, and P. Sheng, Nat. Mat. 9, 387 (2010).

[6] U. Leonhardt and T. G. Philbin, Geometry and light: the science of invisibility (Dover, 2010).

I14

A comprehensive understanding of high-temperature superconductivity in terms of fermion dynamical symmetry

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For almost 30 years the cuprate high-temperature superconductors have presented a challenge to our understanding of superconductivity, and more generally to our understanding of strongly-correlated electron systems. The primary reason is that many questions are raised by these superconductors for which there is no agreement that any particular theoretical framework has provided a comprehensive set of answers. Here we pose a set of key questions that must be answered to say that we understand high-temperature superconductivity, and outline how the SU(4) fermion dynamical symmetry model of unconventional superconductivity provides a plausible answer to all within a unified theoretical framework. A corollary of this unified description is a natural explanation for why the superconducting transition temperature for unconventional superconductors may be expected to be systematically larger than that for conventional superconductors. Thus, we shall endeavor to account on fundamental grounds for the "high" in high-temperature superconductivity.

Noise vs disturbance: Experimental test of an information tradeoff

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Information-theoretic definitions for noise and disturbance in quantum measurements have recently been given, and a state-independent noise-disturbance uncertainty relation obtained [1]. This is a fundamental tradeoff relation obeyed by any measurement apparatus: information gain about one observable entails the irreversible loss of information about another observable. We have further sharpened this tradeoff to a tight noise-disturbance uncertainty relation for two complementary qubit observables, and carried out an experimental test [2]. Successive projective measurements on the neutron's spin-1/2 degree of freedom, together with a correction procedure which reduces the disturbance, were performed. Our experimental results saturate the tight noise-disturbance uncertainty relation when an optimal correction procedure is applied.

[1] F. Buscemi, M.J.W. Hall, M. Ozawa and M.M. Wilde, Phys. Rev. Lett. 112 (2014) 050401.

[2] G. Sulyok, S. Sponar, B. Demirel, F. Buscemi, M.J.W. Hall, M. Ozawa and Y. Hasegawa, eprint arXiv:1504.4200 [quant-ph].

I16

Correlated scattering of on-demand electron pairs in ballistic chiral channels

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Recent experimental realisation of on-demand electron pair emission from tuneable-barrier quantum dots [1-3] enables studies of elementary excitation propagation and scattering in quantum Hall edge channels at atypically large energies (an order of magnitude above the Fermi energy). In particular, a recent measurement of the full counting statistics of electron pair scattering [2] from an electrostatically controlled barrier (a "drained point contact") has revealed anomalous bunching [2] beyond the independent-particle Landauer-Buttiker picture.

Here we explore the role of electron-electron interaction at the scattering barrier, employing the exact solvability of the two-body scattering problem [4]. Results are formulated in terms of counting statistics and compared to experimental observations.

[1] J. D. Fletcher, P. See, H. Howe, M. Pepper, S. P. Giblin, J. P. Griffiths, G. A. C. Jones, I. Farrer, D. A. Ritchie, T. J. B. M. Janssen and M. Kataoka, Phys. Rev. Lett. 111 (2013) 216807.

[2] N. Ubbelohde, F. Hohls, V. Kashcheyevs, T. Wagner, L. Fricke, B. Kaestner, K. Pierz, H. W. Schumacher and R. J. Haug, Nature Nanotech. 10 (2015) 46-49.

[3] J. Waldie, P. See, V. Kashcheyevs, J. P. Griffiths, I. Farrer, G. A. C. Jones, D. A. Ritchie, T. J. B. M. Janssen and M. Kataoka, arXiv:1503.07140 (2015).

[4] O. Entin-Wohlman, A. Aharony, Y. Imry and Y. Levinson, Europhys. Lett. 50 (2000) 354-360.

Does quantum operational formalism powerful enough to cover statistical data from cognitive psychology?

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We study the problem of a possibility to use quantum observables to describe a possible combination of the order effect with sequential reproducibility for quantum measurements. By the order effect we mean a dependence of probability distributions (of measurement results) on the order of measurements. We consider two types of the sequential reproducibility: adjacent reproducibility ($A - A$) (the standard perfect repeatability) and separated reproducibility($A - B - A$). The first one is reproducibility with probability 1 of a result of measurement of some observable A measured twice, one A measurement after the other. The second one, $A - B - A$, is reproducibility with probability 1 of a result of A measurement when another quantum observable B is measured between two A's. Heuristically, it is clear that the second type of reproducibility is complementary to the order effect. We show that, surprisingly, for an important class of quantum observables given by positive operator valued measures (POVMs), this may not be the case. The order effect can coexist with a separated reproducibility as well as adjacent reproducibility for both observables A and B. However, the additional constraint in the form of separated reproducibility of the $B - A - B$ type makes this coexistence impossible. Mathematically, this paper is about the operator algebra for effects composing POVMs. The problem under consideration was motivated by attempts to apply the quantum formalism outside of physics, especially, in cognitive psychology and psychophysics. However, it is also important for foundations of quantum physics as a part of the problem about the structure of sequential quantum measurements.

[1] A. Khrennikov, Basieva, I., Dzhafarov, E.N., Busemeyer, J.R. (2014). Quantum Models for Psychological Measurements : An Unsolved Problem. PLoS ONE. 9. Article ID: e110909

I18

Microwave detector and heat conduction in the framework of circuit quantum electrodynamics

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During the past decade, circuit quantum electrodynamics (cQED) has shown trailblazing progress in the accurate control of quantum systems with decreasingly weak dissipation [1]. In fact, the current state-of-the-art superconducting qubits have reached the surface code threshold for fault tolerance [2]. However, significant improvements in qubit measurement and control are still required for efficient large-scale quantum computing. In this work, we access two such requirements, namely, measurement and initialization.

Firstly, we present our latest results on a microwave detector. We extend our previous studies on the thermal isolation of the detector [3] to real-time counting of single wave packets of microwave photons. These results are encouraging also in terms of ultra-sensitive microwave bolometry using our detector.

Secondly, we study the quantum of thermal conductance arising from microwave photons travelling in a long transmission line. We clearly distinguish this mechanism as the dominating heat conduction channel. Furthermore, we observe single-photon microwave heat conduction with two resistors integrated in a co-planar wave guide resonator [4].

These studies lay the experimental foundation for integrated microwave detectors and engineered environments in the framework of cQED [5]. Possible future application include accurate qubit initialization and measurement.

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

[2] R. Barends et al., Nature 508 (2014) 500.

[3] J. Govenius et al, Phys. Rev. B 90 (2014) 064505.

[4] P. J. Jones et al., Phys. Rev. B 85 (2012) 075413.

[5] P. J. Jones et al., Sci. Rep. 3 (2013) 1987.

Reformulation of the Feynman-Vernon model

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The oscillator model of linear dissipative systems of Feynman and Vernon [1] has represented a breakthrough in the theory of quantum Brownian motion but its relevance was not recognized until about twenty years later thanks to the works of Caldeira and Leggett [2]. However, the Caldeira-Leggett model of quantum dissipation presents problems of internal consistency exemplified by the appearance of infinite quantities that have to be ignored in the final steps of the calculations in order to get meaningful results [2]. Closely related problems concern the choice between correlated or uncorrelated initial conditions that may also lead to unphysical results or to contradicting conclusions regarding the effects of dissipation. The role of bath-particle statistical correlations in the initial conditions or in the Lagrangian of the total system particle + environment has been discussed already in Refs. [3] and has led to the general recognition of the relevance of statistical correlations between the Brownian particle and the thermal environment.

The proper way to construct the Lagrangian of the total system and formulate the (correlated) initial conditions was discussed in Ref. [4], where it was shown that there is a unique way to do this providing a consistent classical limit and avoiding the mentioned inconsistencies. Such a formulation is related to the space-time invariance properties of the Lagrangian and is necessary for generalizations of the Caldeira-Leggett model to e.g. thermal environment moving with with respect to the laboratory frame [5].

The inconsistencies characterizing the oscillator model in its original formulation have continued to appear from time to time, reported in various works, in particular the questions concerning the form of (un-)correlated initial conditions. The goal of this contribution is to provide a transparent and exhaustive clarification of all such issues in terms of the physical interpretation of the Lagrangian (coordinates) of a quantum dissipative system. The issues considered can be traced back to the original formulation of the Feynman-Vernon model that is shown to require a suitable correction, depending on the system under study, in order to describe consistently the dynamics and the initial conditions.

[1] Feynman, R.P., Vernon, F.L., Ann. Phys. (N.Y.) 24, 118 (1963)

[2] Caldeira, A.O., Leggett, A.J., Physica A121, 587 (1983); Ann.Phys.(N.Y.)149, 374 (1983)

[3] Grabert, H., Schramm, P., Ingold, G.-L., Phys. Rep. 168, 115 (1988). Morais Smith, C., Caldeira, A.O., Phys. Rev. A 41, 3103 (1990); A 36, 3509 (1987)

[4] Patriarca, M., Il Nuovo Cimento B 111, 61 (1996)

[5] Patriarca, M., Physica E 29, 243 (2005)

I20

Quantum and classical Brownian motion in an electromagnetic field

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The general problem of Brownian motion in a magnetic field is by now a classical problem from the point of view of fundamental physics as well as for its applications, both at a classical [1] and quantum [2] level. At a general level, while a quantum particle in a magnetic field presents close analogies with a harmonic oscillator, a minimal amount of internal noise can change the motion qualitatively making it more similar to free Brownian motion. In this contribution we study this and other peculiarities of a Brownian particle in magnetic field, considering both the classical and the quantum dynamics in the presence of a constant magnetic field and a time-dependent electric field in the limit of white noise. We employ the path-integral framework of the Feynman-Vernon and Caldeira-Leggett model, suitably reformulated as described in Refs. [3] in order to avoid physical inconsistencies and reobtain the proper classical limit.

It is shown that an initial pure state represented by a Gaussian wave function evolves at later times into a probability distribution that maintains a Gaussian shape that can be described as resulting from the superposition of (a) the classical motion of the mean wave packet position, (b) a rotation of the probability wave packet around the mean position — interestingly taking place with an angular frequency that is half the cycloctron frequency, and (c) a spreading process along the two principal axes of the Gaussian distribution. Analogies and differences between the quantum and the classical cases are discussed, in particular concerning the influence of different forms of the vector potentials on the spreading process.

[1] R. Czopnik, P. Garbaczewski, Brownian motion in a magnetic field, Phys. Rev. E 63, 021105 (2001). B. Kursunoglu, Brownian motion in a magnetic field, Ann. Phys. 17, 259 (1962). J. Singh, S. Dattagupta, Stochastic motion of a charged particle in a magnetic field: I Classical treatment. Pramana J. Phys., 47, 199 (1996). J.B. Taylor, Diffusion of plasma across a magnetic field, Phys. Rev. Lett. 6, 262 (1961).

[2] S. Dattagupta, J. Singh, Stochastic motion of a charged particle in a magnetic field: II Quantum Brownian treatment, Pramana J. Phys., 47, 211 (1996). X.L. Li, G.W. Ford, R.F. O'Connel, Magnetic-field effects on the motion of a charged particle in a heat bath, Phys. Rev. A 41, 5287 (1990). Y. Marathe, Dissipative quantum dynamics of a charged particle in a magnetic field, Phys. Rev. A 39, 5927 (1989).

[3] M. Patriarca, Statistical correlations in the oscillator model of quantum Brownian motion, Il Nuovo Cimento B 111, 61 (1996); Physica E 29, 243 (2005).

The concept of possibility in quantum mechanics

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One of the most peculiar feature of quantum objects is that they exhibit the behavior alternatives. That is, under the given state of the macroscopic world, a quantum object may assume a number of alternative property values. Since the macroscopic state is uniquely characterized by definite parameters of classical physics, then it is reasonably to suppose that it is the very quantum object which could be responsible for such a state of affairs; it gives its own contribution in the acquiring of a particular property value. That would mean that at quantum and classical levels the being of physical properties cardinally differs. If so, then the radical difference between classical and quantum physics might be understood by assuming that the corresponding regions of reality they described are determined by different types of the being called by the *being-in-itself* and the *being-for-itself* correspondingly [1]. The main characteristic of the *being-in-itself* is that it is what it is. It grounds a substantial or absolute existence of macroscopic objects and their properties. The *being-for-itself* as a non substantial one, is the condition of the existence of quantum properties. Its main characteristic is that is what it is not and not what it is, but its structure describes by the notion of possibility[1]. A possibility may be understood as an internal power of a quantum object to constitute and sustain its properties. Mathematically, a possibility is represented by an eigenstate. A possibility cannot exist in a singular but upsurges out of all available possibilities by spontaneously combining them into the constituted possibility on the expense of the others as non realised possibilities. In this respect, their functioning mechanism is akin to that how in the perception a figure arises on a ground.

The superposition quantum state represents a list of all eigenstates, i.e., possibilities, of an observable, while in the measurement realizes a particular one. It would mean that it was already present or constituted in the superposition. Namely, the superposition state effectively is equivalent to a particular eigenstate which is constituted by withdrawing all the others into the ground. However, these withdrawn or non realised eigenstates still present in the total state of the superposition. As soon as a macroscopic state changes, the initial superposition state changes into a new one. In this process take part the previous non realised eigenstates thus providing quantum states interference feature. In an eigenstate interpretation by possibility, the quantum state collapse concept is replaced by the quantum state constitution concept. In addition, in a constitution act manifests an intrinsic freedom of a quantum object to come into a particular eigenstate, i.e., to acquire a particular property value, which ultimately might be responsible for the origin of Bohr's probabilities.

[1] J.P. Sartre, Being and Nothingness, Routledge, London and NY, 2003

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Microscopic and macroscopic regions of reality in physics

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In quantum physics, the used concepts are not derived directly from the phenomena caused by microscopic objects as it is in case of classical physics. In the same time, its theory gives a perfect description of the observed phenomena. It would suggest that the conceptual language of quantum theory might refer to a realm of existence, resting on a cardinally different type of being, in comparison to a macroscopic world. That would be a realm of existence - quantum world, which doesn't appear on its own accord. However, the quantum world is not totally separated from the world of appearances. The point is that, in the measurement process, a quantum object causes a phenomenon. In this moment quantum and macroscopic worlds meet together. On one side, the phenomena are described by quantum theory, although, they meaning is inexpressible within the quantum framework itself. On the other side, these phenomena can be conceptualized in terms of classical physics, ordinary language. Thus the phenomena, ineffable in quantum terms, can be described in classical terms. However, this description cannot be precise and exhausted in principle. Because it is rather the description of the sphere of "invisible" is in terms of the sphere of visible. And as such it resembles more a metaphor [1] and cannot pretend to explain the meaning of quantum terms. In a word, if interpretation of quantum mechanics there were possible, it would be metaphoric by nature. Because, a metaphor is that linguistic tool which can bridge the sphere of invisible with the sphere of visible. That is, in this moment quantity described by quantum terms can be expressed in classical concepts, i.e., interpreted.

In metaphoric language manifests one significant feature - the priority of the world of appearances, i.e., the macroscopic world, over the world of invisible, i.e., the microscopic world. It contrasts with a widespread view, according to which quantum physics is a that single fundamental theory capable of universal description of the world. It seems that situation is more complicated and subtle. Quite possible that the all reality is split up into two regions of reality, described by the corresponding physics.

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[1] H. Arendt, The Life of the Mind, NY and London: Harcourt Brace Jovanovich, 1978

Towards hybrid quantum systems using ultracold quantum gases

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One of the critical challenges in realizing quantum information processing is manipulating quantum bits while maintaining coherence. One of the possible solutions is to use a hybrid system that combines the long coherence times available in microscopic quantum systems with integrability of solid-state devices [1]. In this context an ensemble of cold atoms as a part of a hybrid system is a very promising platform due to two main reasons; it can possess long coherence times using Zeeman sublevels whose splitting can be controlled by external magnetic fields, and it can be localized in magnetic, optical or magneto-optical traps and even form a lattice pattern, which potentially allows for integration with solid-state quantum systems.

Here we report our progress towards a hybrid quantum system based on ultracold quantum gases. We aim to couple a nanomechanical resonator to a cloud of ultracold Rb atoms in a Bose-Einstein condensate as previously discussed in [2] and recently demonstrated in [3]. To realize a such hybrid system we develop an apparatus that allows for cold atom preparation, interaction between atoms and devices, and rapid device loading. Our system features several important functionalities, such as rapid prototyping of devices in and out of the ultrahigh vacuum environment, and all-optical transport and atom trapping for magnetic field flexibility. We anticipate that our development will allow us to explore controlled interactions between ultracold atoms and nanomechanical systems, and eventually will lead to a quantum memory that can overcome the limitation of short decoherence times in solid-state quantum systems.

[1] Quantum technologies with hybrid systems, G. Kurizki et al., PNAS, 112, 13 (2015).

[2] Bose-Einstein condensate coupled to a nanomechanical resonator on an atom chip, P. Treutlein et al., Phys. Rev. Lett. 99, 1 (2007).

[3] Resonant interaction of trapped cold atoms with a magnetic cantilever tip. C. Montoya et al. arxiv.org: 1503.07825 (2015).

I24

Long-range transfer of spin qubits

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Quantum mechanics allows for superpositions of indirectly coupled states even if the intermediate states are far in energy. This is done via higher-order transitions in which the energetically forbidden intermediate states are only virtually occupied. These transitions have been recently detected in the form of long-range charge transport through quantum dot chains [1,2,3]. We present the first evidence of long-range transfer of a spin qubit in a triple quantum dot [4]. This process is detected via a very narrow resonance in the current through the system at the degeneracy point of three-electron charge configurations (2,0,1) and (1,0,2). There, an electron is delocalized between the two dots without ever occupying the center dot. The mechanism takes advantage of Pauli's exclusion principle which prevents two electrons with the same spin from occupying the same orbital: Of the two electrons forming a spin singlet in one (say the leftmost) dot, only the one with a spin opposite to that of the electron in the other edge dot will be allowed to tunnel. The emptiness of the centre dot warranties the conservation of the spin of the tunneling electron. An important aspect of our results is that the electron which is left alone in the left dot has the same spin state of the electron initially alone on the right. Thus, the long-range electron tunneling between edges enables the long-range transfer of an arbitrary spin state (the qubit) in the opposite direction. Our work opens the way to low decoherence transport of qubits essential for quantum information architectures.

[1] M. Busl et al., Nature Nanotech. 8, 261 (2013)
[2] F. R. Braakman et al., Nature Nanotech. 8, 432 (2013)
[3] R. Sánchez, F. Gallego-Marcos, G. Platero, Phys. Rev. B 89, 161402 (2014)
[4] R. Sánchez et al., Phys. Rev. Lett. 112, 176803 (2014)

Generic helical edge states of 2D topological insulators

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Time-reversal invariant two-dimensional topological insulators (2D TIs) host one-dimensional edge states. These states are helical: electrons with opposite spins propagate in opposite directions. We study time-reversal invariant 2D TIs with broken axial spin symmetry, e.g., due to Rashba spin-orbit coupling or structural inversion asymmetry. The absence of a conserved spin allows new scattering mechanisms which change the edge state properties profoundly compared to systems with conserved spin.

First, we present results for the temperature-dependent conductance of the edge states in the presence of disorder [2]. We found that in the absence of axial spin symmetry, the correction to the quantized conductance scales as $\delta G \propto T^4$ and is thus much stronger than for conserved spin. Next, we studied point contacts between opposite edges of a 2D TI as well as antidots as a way to directly measure the spin structure of helical edge states [1,3,5]. Finally, we investigated the interplay of induced superconductivity and strong interactions [4], and demonstated that the system can host exotic quasiparticle excitations which obey Z_4 parafermionic exchange statistics.

[1] T. L. Schmidt, PRL 107, 096602 (2011)

[2] T. L. Schmidt, S. Rachel, F. von Oppen, L. I. Glazman, PRL 108, 156402 (2012)

[3] C. Orth, G. Strubi, T. L. Schmidt, PRB 88, 165315 (2013)

[4] C. Orth, R. Tiwari, T. Meng, T. L. Schmidt, PRB 91 081406(R) (2015)

[5] A. Rod, T. L. Schmidt, S. Rachel, in preparation

I26

Theory of decay luminescence of excitons

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Bose-Einstein condensation (BEC) is one of the most fascinating quantum effects in many-particle systems. Excitons in excited semiconductors have been promising candidates for the observation of BEC for several decades. At present, cuprous oxide (Cu_2O) is in the focus of experimental efforts due to the large binding energy and long lifetime of the exciton states [1,2]. Signatures for the occurrence of BEC should appear in the luminescence arising from the excitonic decay, i.e., the recombination of electron and hole. Previous theoretical approaches to the luminescence of excitons relied on the assumption of a homogeneous system in thermodynamic equilibrium [3,4]. In current experiments, however, entrapment of the excitons by an external potential is an approved method in order to obtain sufficiently high particle densities. Furthermore, the excitons are often produced by continuous wave excitation leading to a stationary nonequilibrium state of the exciton gas [1,2,5,6].

It is, therefore, necessary to develop a theory of the decay luminescence of an inhomogeneous exciton gas in nonequilibrium. We present an approach to such a theory relying on equations of motion for the photon operators. The central quantity is given by the field-field correlation function which allows to compute the intensity as well as the first-order coherence function. We show first results for the spatially resolved luminescence intensity and compare with measured spectra for paraexcitons in Cu_2O [2,7].

[1] R. Schwartz, N. Naka, F. Kieseling, and H. Stolz, New J. Phys. 14 (2012) 023054.

[2] H. Stolz, R. Schwartz, F. Kieseling, S. Som, M. Kaupsch, S. Sobkowiak, D. Semkat, N. Naka, Th. Koch, and H. Fehske, New J. Phys. 14 (2012) 105007.

[3] H. Haug and H. Kranz, Z. Phys. B 53 (1983) 151.

[4] H. Shi, G. Verechaka, and A. Griffin, Phys. Rev. B 50 (1994) 1119.

[5] S. Sobkowiak, D. Semkat, and H. Stolz, Phys. Rev. B 90 (2014) 075206.

[6] S. Sobkowiak, D. Semkat, and H. Stolz, Phys. Rev. B 91 (2015) 075209.

[7] S. Sobkowiak, D. Semkat, H. Stolz, Th. Koch, and H. Fehske, Phys. Rev. B 82 (2010) 064505.

Hydrodynamic description of ultracold trapped excitons in Cu_2O

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Excitons have been suggested for the experimental realisation of Bose-Einstein condensation (BEC) several decades ago. Due to the large binding energy and long lifetime the 1S paraexciton state of the yellow series in Cu_2O is the most promising candidate for a BEC of excitons in a bulk material. In order to create high densities, in typical experiments excitons created by a pump laser are collected in a stress induced potential trap. However, despite all experimental efforts, only recent experiments with bath temperatures below 50 mK showed for the first time strong evidence pointing to a BEC [1]. The experiments were carried out creating excitons outside the trap minimum using continuous-wave (cw) excitation. The results suggest that the excitons do not reach global thermal equilibrium during their finite lifetime. In particular, the temperatures determined from the spectra do not agree with the bath temperature. In order to understand the experimentally observed features, a theoretical model of excitons in non-equilibrium is needed. This comprises the creation of the excitons by the pump laser, the drift towards the trap center and the thermalisation. In order to model these non-equilibrium processes we adapt the well established Zaremba-Nikuni-Griffin (ZNG) equations of atomic Bose gases [2] and extend them for excitonic systems inside a bulk semiconductor (finite lifetime, phonon scattering, ...). Due to strong elastic scattering, the relaxation in k-space is much faster than in real space resulting very quickly in a local quasi-equilibrium distribution of the excitons [3,4]. Under this assumption the ZNG equations can be cast into a closed set of hydrodynamic equations which we numerically solved. We present numerical results for pulsed as well as cw excitation and compare with experimental results. In both cases our main focus is on the thermalisation process of the excitons and the possible onset of a condensate.

[1] H. Stolz, R. Schwartz, F. Kieseling, S. Som, M. Kaupsch, S. Sobkowiak, D. Semkat, N. Naka, Th. Koch, and H. Fehske, New J. Phys. 14 (2012) 105007.

[2] A. Griffin, T. Nikuni, and E. Zaremba, *Bose-Condensed Gases at Finite Temperatures* (Cambridge University Press, 2009).

[3] S. Sobkowiak, D. Semkat, and H. Stolz, Phys. Rev. B 90 (2014) 075206.

[4] S. Sobkowiak, D. Semkat, and H. Stolz, Phys. Rev. B 91 (2015) 075209.

I28

Universal definition of non-Markovianity in the theory of open quantum and classical systems

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Recently, a universal definition of Markovianity for the dynamics of open quantum and classical systems was proposed. The main idea of the proposed definition is the fact that the knowledge of both the initial state of the reduced system and the solution of the quantum master equation for the density matrix are not always enough to fully characterise the reduced system. To distinguish Markov and non-Markov processes one needs to compare directly measured correlation functions and those constructed from the results of quantum process tomography. Using the example of the spontaneous emission in the d-level system it is shown explicitly that the proposed definition is essential for an adequate description of the typical multi-time observables such as 2D spectra.

[1] N. Lo Gullo, I. Sinayskiy, Th. Busch, and F. Petruccione, arxiv.org/abs/1401.1126
[2] I. Sinayskiy and F. Petruccione (in preparation)

Relaxation of an electron wave packet in the quantum Hall edge at filling factor ν=2

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We consider the effects of relaxation of single-electron state of the quantum Hall edge (QHE) with filling factor ν=2. To do that, we investigate a system consisting with a single-electron source that creates an electron excitation in the edge channel and the Mach-Zehnder interferometer (MZI) through which this excitation passes. On the base of the transmitted charge through the MZI the visibility is calculated. The obtained result is non-trivial function of parameters of the initial state. Analysis of the visibility leads to the following important conclusions: the charged and neutral modes of the QHE in the MZI can be considered independently; the Coulomb interaction in the channels does not fully equilibrate the initial state. In order to clarify these statements, the evolution of the Wigner function of the single-electron state in QHE is studied. It is shown that an absence of the full equilibration is a result of integrability of considered system. Our result can be compared with the recent experimental work [1].

[1] S. Tewari *et al.*, arXiv:1503.05057v1

I30

Electron-vibration interaction in a switchable Kondo system realized in a molecular junction

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Vibration-mediated Kondo effect was the focus of many theoretical papers in recent years. However, suitable experimental systems that serve as a controllable test-bed for both Kondo physics and electron-vibration interactions are rare. Molecular junctions formed in a break-junction setup are natural candidates for this task due to the ability to modify the molecule coupling to the electrodes and mechanically shift the energies of the vibrations in the molecular junction. Here, we focus on a vibration-mediated Kondo system in molecular junctions composed of silver electrodes and copper-phthalocyanine molecules [1]. Using differential conductance spectroscopy the system is characterized in details as a function of temperature, magnetic field and inter-electrode separation. Our experimental results shed light on the interplay between the Kondo system and the inelastic conductance induced by vibrations.

[1] D. Rakhmilevitch, R. Korytar, A. Bagrets, F. Evers and O. Tal, Phys. Rev. Lett. 113 (2014) 236603

Vibronic quantum coherence in the dynamics of biomolecular excitons

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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 [1-3]. Using numerically exact model simulations, we address the exciton dynamics in the particularly well characterized Fenna-Matthews-Olson complex. The non-standard environmental noise spectrum is known from experiment and is fully taken into account. Furthermore, it is shown how nonequilibrium molecular vibrational modes can enhance the exciton transfer efficiency considerably. Moreover, I discuss a simpler dimer of an artifical dye molecule [4]. We formulate an accurate vibronic exciton model with parameters directly taken from experimental data. This complex shows a clean separation of the excitonic and vibrational dynamics and their interaction, and clearly separated resonances in 2D optical spectra (in contrast to the large molecular complexes mentioned above). Electronic dephasing and relaxation induce rapidly decaying large-amplitude oscillations of the quantum coherent cross peaks. It is not sensitive to the vibrational damping. Moreover, vibrational dephasing and relaxation survives over longer time scales, but leads to small-amplitude oscillations in the coherences only.

[1] P. Nalbach, C. A. Mujica-Martinez, and M. Thorwart, Phys. Rev. E 91, 022706 (2015)

[2] C. Mujica-Martinez, P. Nalbach, and M. Thorwart, Phys. Rev. E 88, 062719 (2013)

[3] P. Nalbach, D. Braun, and M. Thorwart, Phys. Rev. E 84, 041926 (2011)

[4] H.-G. Duan, P. Nalbach, V. I. Prokhorenko, S. Mukamel, and M. Thorwart, submitted (2015)

I32

Cavity-free nondestructive detection of a single optical photon

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Detecting a single photon without absorbing it is a long standing challenge in quantum optics. All experiments demonstrating the nondestructive detection of a photon make use of a high quality cavity. We present a cavity-free scheme for nondestructive single-photon detection [1]. By pumping a nonlinear medium we implement an inter-field Rabi-oscillation which leads to a $\sim \pi$-phase shift on weak probe coherent laser field in the presence of a single signal photon without destroying the signal photon. Our cavity-free scheme operates with a fast intrinsic time scale in comparison with similar cavity-based schemes. We implement a full real-space multimode numerical analysis of the interacting photonic modes and confirm the validity of our nondestructive scheme in the multimode case.

[1] K. Xia, M. Johnnsson, P. L. Knight, and J. Twamley, arXiv:1506.06316 (2015).

Einstein's unrecognized masterstroke - general relativity with a variable speed of light

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It is little known that when developing general relativity, Einstein's very first idea [1] was a variable speed of light theory. Indeed spacetime curvature can be mimicked by a speed of light $c(r)$ that depends on the distribution of masses. Einstein's 1911 theory [2] was considerably improved by Robert Dicke [3] in 1957, but only recently the equivalence of the variable speed of light approach to the conventional formalism has been demonstrated [4]. Using Green's functions, we show that Einstein's 1911 idea can be expressed in an analytic form, similar to the Poisson equation. Using heuristic arguments, we derive then a simple formula that directly relates curvature w to the local speed of light, $w = -c^2 \Delta \frac{1}{c^2}$. In contrast to the conventional formulation, this allows for a Machian interpretation of general relativity and the gravitational constant G. Gravity, though described by local equations, would be a related of all other masses in the universe.

[1] Albert Einstein (1907). Uber das Relativitätsprinzip und die daraus gezogenen Folgerungen. Jahrbuch für Radioaktivität und Elektronik 4: 411–462.

[2] Albert Einstein (1911). Über den Einfluß der Schwerkraft auf die Ausbreitung des Lichtes. Annalen der Physik 35: 898–906.

[3] R. Dicke (1957). Gravitation without a Principle of Equivalence. Reviews of Modern Physics 29: 363–376.

[4] J. Broekaert (2008). A Spatially-VSL Gravity Model with 1-PN Limit of GRT. Foundations of Physics 38: 409–435.

I34

Nonadiabatic dynamics of a slowly driven dissipative quantum system

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We study the dynamics of a two-level system described by a slowly varying Hamiltonian and weakly coupled to the Ohmic environment. We follow the Bloch–Redfield perturbative approach to include the effect of the environment on qubit evolution and take into account modification of the spectrum and matrix elements of qubit transitions due to time-dependence of the Hamiltonian. This formalism is applied to two problems. (1) We consider a qubit, or a spin-1/2, in a rotating magnetic field. We show that once the rotation starts, the spin has a component perpendicular to the rotation plane of the field that initially wiggles and eventually settles to the value proportional to the product of angular rotation velocity of the field and the Berry curvature. (2) We re-examine the Landau–Zener transition for a system coupled to environment at arbitrary temperature. We show that as temperature increases, the thermal excitation and relaxation become leading processes responsible for transition between states of the system. We also apply the Lindblad master equations to these two problems and compare results with those obtained from the Bloch-Redfield equations.

Disorder driven transition between a topological and a Chern insulator

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Topological insulators, in addition to exhibit a wealth of fundamental physical phenomena at the frontier of condensed matter and relativistic field theory, are a promising material for a variety of applications. In particular, their property of coupling spin and momentum, is ideally suitable for applications in the domain of spintronics, whose goal is to control the spin degree of freedom by pure electrical means. One may, for instance, exploit their ability to support different quantized conduction regimes according to the number of protected edge states. A way to select the edge states depending on their spin is by using magnetic impurities to open a gap. Indeed, as a function of the magnetic ordering, a topological insulator doped with a transition metal can support a quantum anomalous Hall state. We investigate a transition between a two-dimensional topological insulator conduction state, characterized by a conductance $G = 2$ (in fundamental units e^2/h) and a Chern insulator with $G = 1$, induced by magnetic impurities polarized in ferromagnetic or antiferromagnetic order. We demonstrate that, for strong disorder, a phase $G = 1$ exists even for ferromagnetic order, in contrast with the prediction of the mean field approximation. This result is supported by direct numerical computations using Landauer transport formula, and by analytical calculations of the chemical potential and mass renormalization as a function of the disorder strength, in the self-consistent Born approximation.

Posters

The correspondence between Renyi entropy flow and full counting statistics of energy flows

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We understood how to measure the Renyi entropy flow in quantum heat engines from the full counting statistics of energy transfers. The exact relation is for a flow to a system in thermal equilibrium that is weakly coupled to an arbitrary time-dependent and non-equilibrium system. The exact correspondence, given by this relation, provides a simple protocol how to quantify the flows of Shannon and Renyi entropies.

[1] Physical Review B 91 (17), 174307

[2] Physical Review B 91 (10), 104303

P2

Thermodynamics of boundary driven quantum systems

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We formulate the thermodynamic of boundary driven open quantum systems in two related scenarios. One is the repeated interaction scheme [1,2] and the other is the Lindblad dynamics for the open system with Lindblad operators acting on its boundaries [3]. This Lindblad dynamics is obtained from the repeated interaction scheme in an appropriate limit. Starting from a unitary description of the system plus environment, we show that those operations either require power or extract it from the heat baths even for time independent systems hamiltonians. We illustrate our findings in open spin 1/2 chains and show that an XY spin chain coupled in this way to a single heat bath does not relax to thermodynamic equilibrium because is always driven. Also an XX spin chain coupled to a left and right heat baths behave as a quantum engine, a heater or fridge, depending on the parameters, with efficiencies bounded by Carnot efficiencies.

[1] S. Attal, Y. Pautrat, Ann. Inst. Henri Poincaré 7, 59 (2006).

[2] D. Karevski and T. Platini, Phys. Rev. Lett 102, 207207 (2009).

[3] T. Prosen and I. Pivzorn, Phys. Rev. Lett. 101, 105701 (2008); H. Wichterich, M. Henrich, H-P. Breuer, J. Gemmer, and M. Michel, Phys. Rev. E 76, 31115 (2007); V. Popkov, R. Livi, New J. Phys. 15, 023030 (2013).

Relativistic quantum noninvasive measurement

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Quantum weak, noninvasive measurements are defined in the framework of relativity, which allows to assign fundamental realism to most general states. Invariance with respect to reference frame transformations of the results in different models is discussed. Surprisingly, the bare results of noninvasive measurements are invariant for certain class of models, but not the detection error. Consequently, any stationary quantum realism based on noninvasive, weak and in principle general measurements will break, at least spontaneously, relativistic invariance and correspondence principle at zero temperature.

P4

A system-reservoir model for self-excited oscillators using perturbative expansion

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In this paper we present a plausible system-reservoir approach that results in self-excitation of non-linear oscillators. We show that all the basic dynamical features of such oscillators, the existence of single or multiple limit cycles being most prominent, are preserved in a statistical sense. The sanctity of the Fluctuation-Dissipation Relations(FDR) are also investigated through additive as well as multiplicative couplings of the system to multiple reservoirs.

The fundamental dynamical feature common to all self-excited oscillators is the existence of one or several limit cycles in phase space. This formation of limit cycles depends on a balanced interplay between energy-damping and energy-pumping mechanisms which go hand-in-hand in every periodic cycle. Statistical mechanical studies in regard to the type of interactions which might lead to such dynamical features have not made significant progress in recent years. The aim of this paper is to address this core issue.

Starting with a system-reservoir Hamiltonian, we have addressed the problem perturbatively. In the structure of the damping function in a self-excited oscillator (for example, the Van der Pol oscillator) there is always a positive part and a negative part. The positive damping can be handled suitably by coupling the system linearly/non-linearly (in the system variable) to a bath, modelled as a series of harmonic oscillators. Effective noise-terms are generated which are multiplicative in nature. However, a similar approach to generate a negative-damping term fails. Instead, we have introduced a "quartic term" for the reservoir, coupled the system linearly to it and then have proceeded to write the Langevin equation by invoking standard perturbation techniques (as closed solutions do not exist for quartic terms), used in studying nonlinear dynamical systems. With the complete dynamical equation for the self-excited oscillator(along with the noise-terms) at our disposal, we obtain explicit expressions for the multiple FDRs arising due to the presence of multiple reservoirs. Interestingly, for the negative-damping case,the FDR remains valid upto a desired order of perturbation with finer corrections occurring only at higher orders.

Another impetus for this work comes from a recent study of Van der Pol oscillator made in the quantum domain for a typical multi-photon process where coupling to multiple reservoirs has been suggested. Though not an exact classical analogue,our work addresses a much more general problem for self-excited oscillators thus allowing to address the quantum domain from the system-reservoir parlance in recent future using standard methods.

Photon-assisted thermoelectric effects in quantum dot system with noncollinear ferromagnetic leads

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Normal and spin thermoelectric transport properties of a single level quantum dot coupled to two ferromagnetic and one superconducting leads are examined in linear response regime. The level of the quantum dot is modulated by additional external harmonic ac field so that electrons and holes can interact with photons creating an inelastic photon-assisted transmission channels in the energy spectrum.

Using the equation of motion for nonequilibrium Green's functions of the system we discuss an influence of different magnetic configurations of the ferromagnetic leads polarizations on thermoelectric characteristics such as conductance, Seebeck coefficient as well as thermoelectric figure of merit. It is shown that controlling the tilt of magnetizations we can modulate the thermoelectric characteristics of the system and in particular we can block spin transmission. We also discuss the influence of the third superconducting lead and thus so-called superconducting proximity effect is taken into account. The most notable feature of this effect is emergence of Andreev states in transport characteristics.

P6

Discrete models of the Dirac equation, inspired by graphene

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There is continued interest in discrete models of quantum physics ('t Hooft, etc.) as a cutoff near the Planck scale could solve ultraviolet divergences and explain the Bekenstein bound. The material graphene shows energy levels described by the Dirac equation, even though relativistic energies are not involved. Purely analytic models such as the Feynman checkerboard have shown that relativistic QM (at least in reduced dimensions) can emerge from discrete structures. Here we build an original model, based on an abstract hexagonal lattice, that expresses the 3+1 dimensional Dirac equation in either Weyl or Dirac representation. We hope that aspects of this model may be of further use in exploring the foundations of relativistic QM.

Study of two dimensional photonic crystal microcavity with elliptical holes

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Yablonovitch and John first illustrated the enhancement and inhibition of light in the photonic crystal (PC) band [1]. Since then, PC has become a focal point. Ideally three-dimensional (3D) PC has properties to control photons perfectly, however difficulties in the fabrication of 3D PC has slowed the research on it. Meanwhile a variety of experimental and theoretical investigations on properties of 2D PC have found that this crystal shows most functionality of 3D structures. Column dielectric rod and column hole structures are two fundamental 2D PC structures, and they have been fully investigated [2]. However there are relatively few papers dedicated to investigations of the bandgap and the cavity characteristics of elliptical dielectric rod or hole structure. G. Yuan et al. [3] have studies theoretical bandgap structures in 2D square lattice elliptical dielectric rods photonic crystals and Kalra et al. [4] have study, how the photonic band gap size is affected by the changing ellipticity of the constituent air holes/dielectric rods. It is observed that the size of the photonic band gap changes with changing ellipticity of the constituent air holes/dielectric rods. In this paper, we discuss the variation of photonic band gap size of the ellipticity of the constituent air holes for transverse electric (TE) polarizations. It is shown that the PBG width becomes wider by the increasing of filling ratio. We then study the effects of the variation of elliptical holes on the PC cavity. We observe that the increase in the filling ratio generates a displacement resonant wavelength towards the low wavelengths. We theoretically investigate further increasing the cavity Q factor by tailoring the envelope function of the electric field profile through change of the size of two air holes near the cavity edges. For this cavity, the highest Q factor of 4.1359 10^6 is achieved at the resonant mode located at λ=1.4970 μm when R_x=0.52a.

[1] E. Yablonovitch, "Inhibited Spontaneous Emission in Solid-State Physics and Electronics", Phys. Rev. Lett. 58 (1987) 2059

[2] W. G. Chong, P. G. Tongjiang, D. Tao, "Study on Computational Method of Two dimensional Photonic Crystal Band Gap", Materials Guide, Vol. 23, Issue 9 (2009) 93

[3] G. Yuan, L. Han, Z. Yu, Y. Liu, P. Lu, "Two-Dimensional square lattice elliptical dielectric rods photonic crystal bandgap characteristics", The 9th International Conference on Optical Communications and Networks (ICOCN2010) Nanjing, China, 24-27 October (2010)

[4] Y. Kalra, R. K. Sinha, "Photonic band gap engineering in 2D photonic crystals", Pramana J. Phys. 67 (2006) 6

P8

Characteristics of T-shaped channel drop filters based on photonic crystal ring resonators

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Channel drop filters (CDFs) that access one channel of a wavelength division multiplexing (WDM) signal while leaving other channels undisturbed are essential components of photonic integrated circuits (PICs) and optical communication systems [1]. Among various types of channel drop filter [2, 3], the photonic crystal ring resonators (PCRRs) based CDFs are becoming attractive candidates for filtering purpose as they provide efficient wavelength selection, scalability, narrow linewidth, flexible mode design and small channel spacing [4]. In this study, first we propose two structures of T-shaped channel drop filters based on various photonic crystal ring resonators which differ in their inner rod configurations. The proposed structures are numerically demonstrated by using the finite-difference time-domain (FDTD) method [5]. According to the results, we note that different inner rod configurations for the photonic crystal ring resonators show different optical properties for the channel drop filters, so for the first T-shaped CDF, 99% drop efficiency with quality factor of 261.1 is achievable at wavelength λ=1.59056 μm, while for the second T-shaped CDF, 100% drop efficiency with quality factor of 344.57 is achievable at wavelength λ=1.56746 μm. Afterward, the effect of varying the refractive index on the resonance wavelength of the filters is analyzed. Our results show that by changing the refractive index of the whole rods, we can obtain different output wavelengths of the channel drop filters.

[1] S. Fan, P. R. Villeneuve, and J. D. Joannopoulos, "Channel drop filters in photonic crystals", Opt. Express, vol. 3, pp. 4-11, 1998.

[2] S.Kim, I. Park, and H. Lim, "Highly efficient photonic crystal-based multichannel drop filters of three-port system with reflection feedback", Opt. Express, vol. 22, pp. 5518–5525, 2004.

[3] Z. Zhang, and M. Qiu, "Compact in-plane channel drop filter design using a single cavity with two degenerate modes in 2D photonic crystal slabs", Opt. Express, vol. 13, pp. 2596–2604, 2005.

[4] S. Robinson, R. Nakkeeran, "PCRR based add drop filter for ITU-T G.694.2 CWDM systems", Optik, vol. 124, pp. 393–398, 2013.

[5] A. Taflove, S.C. Hagness, Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rd ed., Artech House, Norwood, MA, 2005.

Coulomb drag in Dirac-Schroedinger hybrid electron systems

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Vertical heterostructures combining different layered materials offer novel opportunities for applications and fundamental studies of collective behavior driven by inter-layer Coulomb coupling. Here we study heterostructures comprising a single-layer graphene carrying a fluid of massless chiral carriers, and a quantum well created in GaAs 31.5 nm below the surface, supporting a high-mobility two-dimensional electron gas. These are a new class of double-layer devices composed of spatially-separated electron and hole fluids. We study these new heterostructures in a Coulomb drag setup, monitoring the drag resistivity as a function of temeprature. Firstly we consider the so-called Fermi liquid regime and we compare the theoretical prediction with the experimental data, confirming the expected quadratic-in-temperature behaviour. Moreover, we find that the Coulomb drag resistivity significantly increases for temperatures below 5-10 K, following a logarithmic law. This anomalous behavior is a signature of the onset of strong inter-layer correlations, compatible with the formation of a condensate of permanent excitons. The ability to induce strongly-correlated electron-hole states paves the way for the realization of coherent circuits with minimal dissipation and nanodevices including analog-to-digital converters and topologically protected quantum bits.

P10

Functional approach to heat-exchange, application to the spin boson model: From Markov to quantum noise regime

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The emerging field of quantum thermodynamics aims to extend basic concepts of thermodynamics at the nanoscale. Indeed lowering the dimension of a system, fluctuations and quantum effects become crucial and classical thermodynamics cannot be simply applied. The question of how a small system exchanges heat and energy with a bigger one is very important both from technological and fundamental point of view. A deep understanding of heat exchange at the nanoscale is necessary in view of the realization of quantum devices such as quantum heat engines which could have great technological impact. Despite much recent efforts, the thermodynamics of quantum systems is still poorly understood, at least when compared to its classical counterpart. Here we aim to go a step forward towards a microscopic and rigorous description of heat exchange in quantum system. We face with a path-integral approach the problem of a quantum system coupled to a thermal reservoir and consider the energy flows between them. In this framework we can write a general heat influence functional which embodies all the dissipative mechanisms and allows us to study heat processes. We present the exact formal solution for the moment generating functional which carries all statistical features of the heat exchange process for general linear dissipation. As an application we study the paradigmatic case of a two-level system and we show that at low temperature non-Markovian effects could dominate the time evolution of the average heat and heat power.

Spin accumulation in out of equilibrium mesoscopic superconductors

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We study the spin accumulation in a junction between a superconductor and a ferromagnet or a normal metal in presence of a Zeeman magnetic field applied to the superconductor, and when the junction is taken out of equilibrium by applying a voltage bias. We first apply a DC voltage on the junction and show that the spin relaxation time (ns) is larger than the charge relaxation time (ps) inducing a spin-charge separation in the superconductor. Then we calculate the time-dependence of the spin accumulation for an applied AC voltage. We find that the measured spin accumulation depends on the frequency of the applied bias. This dependence allows one to extract directly the spin relaxation time in the superconductor which is in complete agreement with the experimental result.

[1] C. Quay, D. Chevallier, C. Bena, and M. Aprili, Nature Physics 9, 84 (2013)

[2] C. Quay, C. Dutreix, D. Chevallier, C. Bena, and M. Aprili, arXiv:1408.1832

[3] D. Chevallier, C. Dutreix, M. Guigou, C. Quay, M. Aprili, and C. Bena, arXiv:1408.1833

P12

Role of conditional entropy in experimental tests of Landauer principle

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Landauer principle describes the minimum heat produced by an information-processing device. Recently [1] a new term has been included in the minimum heat production: it's called conditional entropy and takes into account the internal dynamic of microstates associated with a given logic state. Usually this new term is assumed zero in binary symmetric systems. In this poster [2] we show that conditional entropy can be nonzero even for symmetric systems and that it can be expressed as the sum of three different terms related to the probabilistic features of the device. The contribution of the three terms to conditional entropy (and thus to minimum heat production) is then discussed for the fundamental example of bit-reset and it's pointed out that serious misinterpretations of data may arise if it's neglected in experiments analysis.

[1] T. Sagawa, J. Stat. Mech. P03025

[2] D. Chiuchiù et al. preprint arXiv:1406.2562v2

Ab initio calculations as a tool to understand the magnetic anisotropy of lanthanide complexes with pyridine-based macrocyclic ligands

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During the last two decades, magnetic properties of lanthanide complexes have become of increasing interest of not only chemists and magnetochemists, but also of physicists and theoreticians. Especially, studying of the single-molecule magnet (SMM) behavior and/or magnetic anisotropy of lanthanide(III) complexes with various ligands and with different coordination numbers is very progressing field today. In this perspective, new series of lanthanide(III) complexes with 15-membered pyridine-based macrocycle 15-pyN_3O_2 (3,12,18-triaaza-6,9-dioxabicyclo[12.3.1]octadeca-1(18),14,16-triene) [1] were prepared and thoroughly characterized. So far, the crystal structure of the complex [Pr(15-pyN_3O_2)(NO_3)$_3$].H_2O was determined by X-ray diffraction analysis and revealed exceptional coordination number of 11 for Pr^{III} with folded pentadentate macrocycle and three bidentate nitrato ligands. Indeed, in case of Dy^{III} and Er^{III} complexes, the slow relaxation of magnetization was observed in non-zero static magnetic field as proved by ac susceptibility measurements. That classifies these compounds as field-induced single-ion magnets (SIMs). Furthermore, the ab initio calculations based on experimental X-ray structures were performed for selected compounds in order to explain their static magnetic properties and to extract information about the magnetic anisotropy of these species. These calculations were based on state-averaged complete-active-space self-consistent field (SA-CASSCF) wave functions complemented by N-electron valence second-order perturbation theory (NEVPT2) using ORCA 3.0 software [2] with active space defined as CAS(n,7), where n is number of f-electrons for given lanthanide(III) ion. The spin-orbit coupling was treated through the Breit-Pauli form of the spin-orbit coupling operator (SOMF approximation).[3] Then, such calculations provided us energy levels, which can be classified as ligand field multiplets and calculated as

$$\mathbf{H}=\mathbf{H}_{SOC}+\mu_B(\mathbf{L}+g_e\mathbf{S})\mathbf{B}$$

where respective CASSCF/NEVPT2 spin-orbit coupling, orbital, and spin angular momentum matrices are used. After that, the calculation of molar magnetization can be done numerically by M_{mol}=R dln$Z$/dB_a where Z is the partition function and B_a is the orientation of magnetic field defined in polar coordinates as B_a=B(sin θcos ϕ, sin θsin ϕ, cos θ). Description of our calculations in more details as well as comparison of the calculated results with obtained experimental data will be discussed within the framework of the presentation.

[1] B. Drahoš, R. Herchel and Z. Trávníček, Inorg. Chem. 54 (2015) 3352

[2] F. Neese, WIREs Comput. Mol. Sci. 2 (2012) 73

[3] F. Neese, J. Chem. Phys. 122 (2005) 034107

P14

A classical theory of multichromophoric resonance energy transfer

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Several energy transfer mechanism in photosynthetic light-harvesting systems predict a dramatic enhancement of the energy transfer rates [1–3], up to the order of interacting acceptors. Since the interactions between donors and acceptors induce delocalization of the excitation and at the same time may establish quantum correlations, this unexpected enhancement has been extensively related to quantum coherence between acceptors and donors.

However, the extend to which this enhancement is the result of purely quantum features and therefore, incapable of being present in a classical description of electronic energy transfer is not well stablished [3–5]. Based on previous works [6, 7] on the description of radiationless energy transfer in molecular systems using classical electrodynamics, we formulate a classical theory capable of predicting such enhancement.

[1] S. Lloyd and M. Mohseni, New J. Phys. 12, 075020 (2010).

[2] A. K. Ringsmuth, G. J. Milburn, and T. M. Stace, Nature Physics 8, 562–567 (2012).

[3] I. Kassal, J. Yuen-Zhou, and S. Rahimi-Keshari, The Journal of Physical Chemistry Letters 4, 362 (2013).

[4] K. Pelzer, T. Can, S. Gray, D. Morr, and G. Engel, Journal of Physical Chemistry B 118, 2693 (2014).

[5] F. Fassioli, R. Dinshaw, P. Arpin, and G. Scholes, Journal of the Royal Society Interface 11, 20130901 (2014).

[6] E. N. Zimanyi and R. J. Silbey, J. Chem. Phys. 133, 144107 (2010).

[7] D. Keller and C. Bustamante, The Journal of Chemical Physics 84, 2961 (1986).

Monitoring the correlations in a quantum network of two remotely-located atomic-mechanical systems

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A hybrid atomic-mechanical quantum network formed from two remote qubits (two-level atoms) interacting with their individual harmonic oscillators, is investigated. Principally, we study thoroughly the dynamics of the main measures of quantum correlations (entanglement and discord) for different physical conditions of the entire system in order to control the generation, propagation and preservation of the correlations. The system is investigated under two approximations, first when any dissipation mechanism is neglected; and for the second, the mechanical losses of the oscillators are considered, hence simulating a more realistic model for the experimental feasibility. For the both approximations, the two qubits are initially prepared in a Bell-diagonal state with maximally mixed marginals, and consequently discover that the two-qubit correlations exhibit few interesting effects such as freezing, sudden changes and revivals in the evolution of the quantum entropic discord, as well of the geometric discord quantified by different metrics, as Bures, Hellinger and trace(Schatten 1-norm) distances. Additionally, one finds that the good witnesses for the localization of the sudden changes in the dynamics of the quantum discord could be the expectation values of the qubit operators, like $\langle\hat{\sigma}_z\rangle$ and $\langle\hat{\sigma}_x\rangle$. These quantities evidence a discontinuous evolution at the moments where the sudden changes of the discords occur, so one gets a manifestation of critical behavior. To conclude, we show illustratively how to monitor the quantum correlations by tuning the physical parameters of the model, important tools for applications in quantum information science.

P16

"Dynamical phase transition" of polaritonic states triggered by losses in cavity-QED array

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We study the transition from a superfluid like state to a Mott insulator like state, triggered by photon losses in a network with two cavities, each one coupled to the individual reservoir at zero temperature. In the literature, e.g. [1, 2] persists a common conviction that, there is a key parameter that controls this transition, which is the atom-cavity detuning, Δ. In this work we demonstrate the importance of other parameters like damping rate, hopping rate and quantum correlation quantifiers (e.g. Negativity) in detecting and controlling the mentioned phases. As one important result, we find that without cavity losses, the transition does not occur in this system. Hence, we conclude that the true triggering mechanism for this self-trapping effect is the presence of the dissipation in the cavities, as recently reported by us in [3]. Another interesting result consists in the measuring the quantum correlations between the polaritons via the Negativity; one finds a critical cavity loss rate, above which the Negativity displays a single peak in the same time region where the phase transition takes place. Therefore, we identify two regions in the space of the loss rate vs. hopping rate, where below the critical damping, oscillations of the initial superfluid state are observed along with a multi-peaked Negativity, while above the critical value, the oscillations disappear and the transition to the Mott insulator is witnessed by a neat single peaked Negativity. The study of the system with the reservoirs at finite temperature is in the progress and the new findings will be commented.

[1] D.G. Angelakis, M. F. Santos, S. Bose, Phys. Rev. A **76**, 031805(R) (2007).

[2] E. K. Irish, C. D. Ogden and M. S. Kim, Phys. Rev. A **77**, 033801 (2008).

[3] R. Coto, M. Orszag, V. Eremeev, Phys. Rev. A **91**, 043841 (2015).

Mathematical model for self renewal of epithelial intestinal tissues

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Cell differentiation consists in processes where differentiated cells (non mitotic) are originated from stem cells (mitotic) in multicellular organisms. These processes occur during the embryonic, development in which a whole organism is originated from a unique cell (totipotent) and during the tissues renewal in adults where a small number of stem cells (multipotent) give birth a whole linage with different kind of cells (according with the tissue involved). Among the renewal processes the intestinal epithelium in mammals is a prime example because due to their exposure is the fastest renewed tissue. That epithelium is organized to form cavities as finger shapes known as crypts of Lieberkühn. Under stationary conditions the cripts have a small number of steam cells in the bottom (finger tip) that when proliferate not only remain stable the number of stem cells but also give rise to the four different cell linage comprising the intestinal. These cells, as they differentiate, migrate toward the upper of the crypt and finally lost in the intestinal lumen. Any deviation from this scheme (for example some mutation in the stem cell) produces morphological changes in the crypt (adenomas). Here we present a model describing the regime for renewal.

P18

Impurity states and dynamics of a quantum *XY* spin-1/2 chain: I. General results

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We study the dynamics of a semi-infinite *XY* spin-1/2 chain with an impurity located at one end of the chain. The impurity atom introduces imperfections into the system given by its different magnetic moment and nearest-neighbor exchange interaction. The magnetic moments of the impurity and host atoms are characterized by the magnetons μ' and μ, respectively. We describe the quantum spin chain through the parameters $\Delta = -(\mu' - \mu)\, H/J$ and $\eta = J'/J$. Here, H, J and J' stand for, respectively, the external magnetic field, the nearest-neighbor exchange interaction for host atoms, and the exchange interaction between the impurity and its nearest neighbor.

Using the analytical methods of exact diagonalization and Heisenberg representation, we calculate the magnetization for each site of the spin chain. Besides a continuous band of energy states, the eigenstates of the system also include two localized states — called impurity states — which exist for $\eta^2 > 2\Delta + 2$ and $\eta^2 > -2\Delta + 2$.

Assuming a general inhomogeneous initial state for the spin chain, exact results are obtained for the time dependence of the magnetization at the chain sites as well as its long-time behavior using the stationary phase approximation. Six characteristic regions in the parameter space $(\Delta\,,\,\eta^2)$ are identified implying each a different qualitative long-time behavior. For three of these regions there exists at least one of the impurity states.

Considering a specific initial state, we graphically show that when only one of the impurity states exists, the magnetization evolves into different final values for the different sites of the chain. When both of the two impurity states exist, the quantum interference between them yields magnetization oscillations which settle over time with a constant amplitude.

The first part of this work deals with the general results for the time dependence of the magnetization at the chain sites. The second part continues with the long-time behavior including the results for 0 and 1-dimensional characteristic regions for a specific initial state.

The study of the dynamics of quantum spins with imperfections or inhomogeneities is of interest from the theoretical point of view, as well as in the current proposal to use spin chains as quantum information transfer channels [1].

[1] S. Bose, A. Bayat, P. Sodano, L. Banchi, and P. Verrucchi, "Spin chains as data buses, logic buses and entanglers", in *Quantum state transfer and network engineering*, edited by G. M. Nikolopoulos and I. Jex (Springer, 2014), p. 1.

Impurity states and dynamics of a quantum *XY* spin-1/2 chain: II. Long-time behavior through the stationary phase approximation

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We study the dynamics of a semi-infinite *XY* spin-1/2 chain with an impurity located at one end of the chain. The impurity atom introduces imperfections into the system given by its different magnetic moment and nearest-neighbor exchange interaction. The magnetic moments of the impurity and host atoms are characterized by the magnetons μ' and μ, respectively. We describe the quantum spin chain through the parameters $\Delta = -(\mu' - \mu) H/J$ and $\eta = J'/J$. Here, H, J and J' stand for, respectively, the external magnetic field, the nearest-neighbor exchange interaction for host atoms, and the exchange interaction between the impurity and its nearest neighbor.

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P20

Thermodynamic universality of quantum Carnot engines

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Harnessing energy stored in inaccessible forms such as heat or chemical energy and transforming it into useful work is one of the most important, technological achievements. Nevertheless, the underlying principles and ultimate limitations imposed by quantum mechanics on such thermodynamic processes are still an active field of research. Modern studies range from implementations of quantum heat engines in ion traps over thermodynamic cycles in optomechanical systems to the description of the principles of photosynthesis as photo-Carnot engines. The natural question arises how generic quantum features such as coherence and entanglement affect classical formulations of the thermodynamic axioms. In particular, it has been studied whether quantum correlation could be harnessed, and whether quantum devices could operate with efficiencies larger than the Carnot efficiency – therefore demanding a reformulation of the Carnot statement of the second law of thermodynamics. The present study carefully addresses this question by means of quantum (stochastic) thermodynamics for generic quantum Carnot engines.

Necessary and sufficient quantum steering inequality for arbitrary measurements

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The CHSH inequality is an expression of a necessary and sufficient condition on 2-party measurement correlations if they are derived from any theory based on local hidden variables (LHV). Following a different direction, necessary inequalities have been found in recent years for correlations that conform to a local hidden variable-local hidden state description (LHV-LHS) i.e. a local source produces a quantum state for one party and determined outcomes for the other party. Violation of these inequalities implies the nature of one party's local state is 'steered' via measurement by the other party (interpreted as a form of nonlocality) hence the entangled state shared between the parties is called 'steerable' and we dub such an inequality a 'steering inequality'. The LHV-LHS scenario is equivalent to the assumption that only one party's measurements are trusted, hence it also has an information theoretic interpretation. A necessary and sufficient 2-party steering inequality analogous to the CHSH inequality was derived recently. However this inequality applies only to measurements on observables corresponding to mutually unbiased bases on one of the parties.

We derive a new steering inequality that is necessary and sufficient and applies to measurements in any basis on any of the 2 parties. Thus the inequality is a complete steering analogy of the CHSH inequality. But this inequality is connected with boundaries of ellipses in correlation space and thus takes a different format to the CHSH inequality. We show that measuring in mutually unbiased settings is optimal for our inequality and we examine properties of the inequality for different entangled states, number of settings and relation to other steering inequalities.

P22

Symmetric steering

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Locality in modern physics has been defined in several ways. From the perspective of special relativity, locality expresses the speed limit on communication between parties separated at a distance. In the framework of quantum mechanics measurement on an entangled quantum state causes collapse to a new state, which in one interpretation is a transformation affecting the objective information associated with separated regions of space instantly. This nonlocality, distinct to the relativity definition, has the characteristic that one party can 'steer' the quantum state of the other party via measurement choice. The condition for locality in the form of 'unsteerability' has been defined in more recent years [1], analogous to the condition for local causality introduced by John Bell. It has been been used in experimental demonstrations of quantum nonlocality and connections to concepts such as joint measurability and trusted measurements have been found. However this modern definition lacks symmetry that is required in the most general conditions on probabilities, albeit that the origins of the idea are in asymmetrical state collapse.

As a remedy we introduce a new symmetric expression of 'unsteerability' that eliminates the possibility of either party steering at any time. The possibility is determined by a random distribution over a new hidden variable and opens the route for Bayesian account of locality based on degree of trust. A 'steering inequality' is also derived for this generalised account. We compare the utility of our symmetric steering inequality to other locality criteria.

[1] H. M. Wiseman, S. J. Jones and A. C. Doherty, "Steering, Entanglement, Nonlocality, and the Einstein-Podolsky- Rosen Paradox", Phys. Rev. Lett. 98, 140402 (2007).

Ramsey interference in a mesoscopic system

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The notion of Ramsey interference is generalized and applied to a quantum mesoscoic conductor. We show how Ramsey interference can be induced in the creation of electron-hole pairs in a tunnel junction. The pair creation probability is found to be proportional to the second derivative of the current noise with respect to a dc voltage. Thus, we provide a method to observe Ramsey interference in a mesoscopic system. Our results are general and can be extended to describe transport experiments of diverse physical systems.

P24

Schwinger effect in a tunnel junction

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We present an interesting and unexpected mapping between Schwinger effect, i.e. the creation of electron-positron pairs from the QED vacuum and the creation of electron-hole pairs in a tunnel junction. The Schwinger effect has never been observed and it can be solved analytically only for a few field configurations. We show how to simulate Schwinger physics at low energies and probe unexplored regimes in QED.

Nonentangling channels for multiple collisions of quantum wave packets

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We consider multiple collisions of quantum wave packets in one dimension. The system under investigation consists of an impenetrable wall and two hard-core particles with very different masses. The lighter particle bounces between the heavier one and the wall. Both particles are initially represented by narrow Gaussian wave packets. A complete analytical solution of this problem is presented. The idea of the method used is to decompose the two-particle wave function into a continuous superposition of terms (channels), such that the multiple collisions within each channel do not lead to subsequent entanglement between the two particles. For each channel, the time evolution of the two-particle wave function is completely determined by the motion of the corresponding classical pointlike particles; therefore the whole quantum problem is reduced to a classical calculation. The calculation based on the above method reveals the following unexpected result: The entanglement between the two particles first increases with time due to the collisions, but then it begins to decrease, disappearing completely when the light particle becomes too slow to catch up with the heavy one.

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Localization and recurrence of quantum walk in periodic potential on a line

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We present numerical study of a model of quantum walk in periodic potential on the line. We take the simple view that different potentials affect differently the way the coin state of the walker is changed. For simplicity and definiteness, we assume the walker's coin state is unaffected at sites without potential, and is rotated in an unbiased way according to Hadamard matrix at sites with potential. This is the simplest and most natural model of a quantum walk in a periodic potential with two coins. Six generic cases of such quantum walks were studied numerically. It is found that of the six cases, four cases display significant localization effect, where the walker is confined in the neighborhood of the origin for sufficiently long times. Associated with such localization effect is the recurrence of the probability of the walker returning to the neighborhood of the origin.

[1] C.-I. Chou, C.-L. Ho, Localization and Recurrence of Quantum Walk in Periodic Potential on a Line, Chin. Phys. B 23 (2014) 110302.

Similarity solutions of Fokker-Planck equation with time-dependent coefficients and fixed/moving boundaries

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The Fokker-Planck equation (FPE) is one of the basic tools which is widely used for studying the effect of fluctuations in macroscopic systems. Because of its broad applicability, it is therefore of great interest to obtain solutions of the FPE for various physical situations.

Generally, it is not easy to find analytic solutions of the FPE. Exact analytical solutions of the FPE are known for only a few cases. In most cases, one can only solve the equation approximately, or numerically. Most of these methods, however, are concerned only with FPE's with time-independent diffusion and drift coefficients. Solving the FPE's with time-dependent drift and/or diffusion coefficient is in general an even more difficult task. It is therefore not surprising that the number of papers on such kind of FPE is far less than that on FPE with time-independent coefficients.

Here we would like to present a general way to construct exact similarity solutions of the FPE. Such similarity solutions exist when the FPE possesses proper scaling behavior. By the introduction of the simi-larity variable, the FPE can be reduced to an ordinary differential equation. The general expression of the ordinary differential equation corresponding to the FPE with time-dependent drift and diffusion coefficients is obtained. It is interesting to find, by the natural requirement that the probability current density vanishes at the boundary, that the resulted ordinary differential equation is *integrable*, and the probability density function can be given in *closed form*. Exactly solvable FPE's with time-dependent coefficients can then be obtained whenever the drift and diffusion coefficients are such that certain integral corresponding to the ordinary differential equation can be exactly integrated. Systems with moving boundaries, and with solu-tions related to the newly discovered exceptional orthogonal polynomials are also presented.

Our work thus extends the number of exactly solvable FPE's.

[1] Lin, W.-T. and Ho, C.-L. (2012) Similarity solutions of Fokker-Planck Equations with time-dependent coefficients, Ann. Phys. 327, 386.

[2] Ho, C.-L. (2013) Similarity solutions of Fokker-Planck equation with moving boundaries, J. Math. Phys. 54, 041501.

[3] Ho, C.-L. and Sasaki, R. (2014) Extensions of a class of similarity solutions of Fokker-Planck equation with time-dependent coefficients and fixed/moving boundaries, J. Math. Phys. 55, 113301.

P28

Drift, diffusion, relaxation and the nonequilibrium fluctuation theorem

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The celebrated Einstein relation between the diffusion coefficient D and the drift velocity v is violated in nonequilibrium circumstances. We analyze how this violation emerges for the simplest example of a Brownian motion on a lattice, taking into account the interplay between the periodicity, the randomness, and the asymmetry of the transition rates. Based on the nonequilibrium fluctuation theorem the v/D ratio is found to be a nonlinear function of the affinity. Hence it depends in a nontrivial way on the microscopics of the sample [1]. We also study the spectral characteristics of the system, that determine the relaxation to the non equilibrium steady state [2].

[1] D. Hurowitz and D. Cohen, Phys. Rev. E 90, 032129 (2014)

[2] D. Hurowitz and D. Cohen (in preparation)

Magnon electrodynamics in Weyl semimetals

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Weyl fermions, which are fermions with definite chiralities, can give rise to anomalous breaking of the symmetry of the physical system which they are a part of. In their (3+1)-dimensional realizations in condensed matter systems, i.e., the so-called Weyl semimetals, this anomaly gives rise to topological electromagnetic response of magnetic fluctuations, which takes the form of non-local interaction between magnetic fluctuations and electromagnetic fields. We study the physical consequences of this non-local interaction, including electric field assisted magnetization dynamics, an extra gapless magnon dispersion, and polariton behaviors that feature "sibling" bands in small magnetic fields.

P30

Yang-Mills gauge field theory for glasses and supercooled liquids, glass-transition, and melting

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Metallic amorhous-structures are described as resulting from competition between packing of the icosahedral clusters and the frustration by topological rules to attain global space filling. We have discussed the physical origin of the Boson peak, the viscosity of supercooled metallic liquid, melting, and the glass-transition in the gauge-invariant formula[1-7]. Especially the presence of the Boson peak is required naturally in the gauge-invariant condition. In this study, we shall discuss the detailed properties of the Boson peak,the relation between the breaking of duality symmetry of order-disorder parameters and glass-transition, comparison with other glassy materials as the high Tc cuprates[8], the diluted magnetic semiconductors[9], and perovsdkite manganites[10].

[1] I. Kanazawa, J. Non-Cryst. Solids 150(1992)2712
[2] I. Kanazawa, Phys. Lett. A176(1993)1246
[3] I. Kanazawa, Prog. Theor.Phys. Suppl. 126(1997)397
[4] I. Kanazawa, J. Non-Cryst.Solids 293-295(2001)615
[5] I. Kanazawa, J. Non-Cryst.Solids 312-314(2002)608
[6] I. Kanazawa, Radial. Phys. Chem. 58(2000)457
[7] H. Suzuki and I. Kanazawa, Intermetallics 18(2010)1809
[8] I. Kanazawa, Prog. Theor.Phys.Suppl. 157(2005)107
[9] I. Kanazawa, Physica E29(2005)647
[10] T. Sasaki and I. Kanazawa, JPS Conf.Proc. 3(2014)017001

Ion and positron diffusions in liquid phase, and attractive interactions between like ions and hydrophobic interactions in water liquid

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The investigation for ion mobility in the liquid phase has been one of the central area of physical chemistry. The electrohydrodynamic theory by Hubbard and Onsager[1] and the stochastic theory for ionic conductivity in the liquid phase have been proposed. Since fluctuation from the equilibrium medium is preferable in liquid phase, localization of ions such as positrons is highly probable. Gramsh et al.[2,3] have observed very different behaviour of the diffusion length L+ of positrons in liquid and solid metals. Kanazawa and coworkers[4-6] proposed a qualitative explanation for the increase of the positron diffusion length L+ with temperature in the liquid phase. In addition, Kanazawa and coworkers[7,8] have suggested one origin of the attractive interaction between like ions in liquids. In this study, we have analyzed in more detail the positron diffusions in the liquid metals, and have discussed the field theoretical formula of like ions attractive interactions and hydrophobic interaction in water liquid and the relation to the Hubbard-Onsager dielectric theory.

[1] J. Hubbard and L. Onsager, J.Chem.Phys. 67(1977)4865

[2] E. Gramsh, K.G. Lynn, J. Throwe, I. Kanazawa, Phys.Rev.Lett. 67(1991)1282

[3] E. Gramsh, K.G. Lynn, J. Throwe, I. Kanazawa, Phys.Rev.B 59(1999)14282

[4] I. Kanazawa, Radial. Phys. Chem. 58(2000)457

[5] Y. Matsushita, H. Kitahata, I. Kanazawa, Phys.Stat.Sol.(c) 4(2007)3546

[6] H. Kitahata, Y. Matsushita, I. Kanazawa, Appl.Surf.Sci. 244(2008)167

[7] I. Kanazawa, H. Suzuki, H. Kitahata, J.Phys.CS 225(2010)012024

[8] K. Yamada, M. Saito, H. Suzuki, I. Kanazawa, Mater.Sci.Forum 733(2013)132

P32

Interconversion of magnon and electron spin currents in an interacting quantum dot

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Recent developments in spintronics rekindled the interest in magnons as possible quantum information carriers. Particular emphasis is put on the possibility of thermally generated pure spin current, which could overcome the problems of heat management that trouble electron-based transport, because magnons are chargeless particles that only carry energy and momentum. Although already many concepts of spin wave based devices, such as transistors and diodes, have been proposed, it is unlikely in the foreseeable future to envision fully magnon based electronic systems, therefore both magnon and electron-based systems have to be combined.

Here we propose a scheme of conversion of spin currents of electronic and magnonic origin in a multi-terminal quantum dot system. The terminals are assumed to be metallic reservoirs of electrons (in general spin-polarized) and dielectric reservoirs of magnons. We present different situations where a significant enhancement of spin current can be achieved along with rectification effects that could lead to obtaining a thermally driven spin diode. Moreover we consider a Coulomb blockade effect on the spin wave current conversion, that allows for enhancement of spin current. Apart from the spin, charge and heat currents, we consider more general thermodynamic properties as well. In order to solve this problem we have used a Master Equation method under the assumption of weak coupling of the dot to the leads and the Markov's short memory approximation.

The results indicate a possibility for generation of pure spin current of both magnonic and electronic nature. Additional effects such as rectification of spin and heat currents are shown as a basis for spin and heat diode devices. Moreover, the quantum dot system investigated here allows for the resulting statements to be generally true for similar low-dimensional discrete energy spectrum systems such as magnetic molecules or ultra-cold atoms.

Solitons dynamics in a polaritons condensate with defects

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The Bose Einstein condensation (BEC) is a very unique and spectacular phenomenon. It consists of the accumulation of a large number of bosons in the ground state of a system. This accumulation makes the microscopic behaviour of bosons visible at the macroscopic level and gives raises to a coherent system which is the BEC. A great work was done in these systems and allowed a better understanding of some fundamental questions like superfluidity, creation of vortex and solitons.

A more recent type of condensates was elaborated, the polaritons condensates. These condensates consist of polaritons which are non-stable quasi-particles. The finite life-time of polaritons changes dramatically the behaviour and the physics of the BEC's. We are now in front of more complicated and general systems: out of equilibrium BECs. Our work focuses on solitons excitations due to the out of equilibrium nature of the system and the presence of defects in the condensate. We want to understand how solitons react to these perturbations.

To describe this type of condensates we use the dimensionless Gross Pitaevskii equation (GPE)

$$i\Psi_t = -\frac{1}{2}\Psi_{xx} + V\Psi + g\rho\Psi + i\eta(1-\rho)\Psi$$

The potential V describes the defect. The last term is added in a phenomenological way to take into account the specific nature of these condensates. We can also describe the system with the hydraulic form of the GPE. Solving these two models analytically is not done yet but there is some solutions in very specific cases.

We use the perturbative theory to transform the GPE into a much simpler equation which is the Kortweg deVries equation (KdV equation). This last equation is valid in the long wavelength limit. It is also modified by an extra term which takes into account the out of equilibrium nature of the system and the presence of defects.

We know that the KdV equation can have solitons as solutions. We suppose that the perturbations don't change totally the initial solution. We linearize the last equation and write the solution like a soliton function and a response function. We solve the linearized equation in a numerical way.

We notice that the external perturbations (dumping and defects) disturb the solitons: they make dark solitons oscillate and they destroy bright solitons (the response function diverges). We find that fast solitons are more stable than the slow ones. We find also that the solitons density is more sensitive to the dumping than to the intensity of the external potential.

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Thermodynamical detection of light: From quantum states of light tomechanical work

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Quantum optomechanics interestingly connects quantum optics to mechanical systems, which can be then used as a bridge to classical thermodynamics.

We present a toy model of von Neumann chain connecting quantum states of light to quantum states of mechanical system and subsequently, the state of the mechanical system is translated into a classical position-distribution of a "piston". The piston represents a moving boundary used to compress a certain amount of a classical ideal gas in a cylinder.

We neglect all the back-action effects in this von Neumann chain. Our final figure-of-merit is the amount of average work done by the gas during its subsequent reversible expansion when thermal, coherent, squeezed and Fock states of light are used for the compression process described above. For the sake of simplicity, we use for the average-work evaluation a textbook example of a mass-less piston isothermally expanding the gas reversibly from an initial into a final position. We independently repeat this experiment (compression+expansion) many times and obtain an ensemble of the cylinders with different initial and final positions of the piston (corresponding to different values of the work done by the gas), due to both quantum fluctuations of light and mechanical system and classical stochastic compression dynamics of the piston. We compare the average work done per one cylinder for different quantum states of light.

This analysis of a simple gedanken experiment can be considered as an introductory formulation of the thermodynamical detector of light.

Phonon spectral density of the FMO light-harvesting complex with associated Jacobi polynomials

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Energy transfer systems like Fenna-Matthews-Olson (FMO) complex shows quantum coherence between sites of Bacteriophylla molecules in protein environment. In this paper we consider phonon spectral density (PSD) of protein environment in FMO complex and provide a assessment of PSD using associated Jacobi polynomials.

[1] Adam Kell, Ximao Feng, Mike Reppert and Ryszard Jankowiak, J. Phys. Chem. B 117 (24), 7317–7323 (2013)

[2] Alex W. Chin, Ángel Rivas, Susana F. Huelga, Martin B. Plenio, J. Math. Phys. 51, 092109 (2010)

P36

General non-Markovian dynamics of open quantum systems using exceptional polynomials

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According to Ref [1], we study a simple structure of mapping the environment of an open quantum system onto infinite chain representations with nearest neighbour interactions where the system only couples to the first element in the chain. In this paper we explore various properties of exceptional polynomials and then use exceptional jacobi polynomials that it can be applied to three types of the bath spectral density sub-Ohmic, Ohmic, and super-Ohmic in open quantum systems.

[1] Alex W. Chin, Ángel Rivas, Susana F. Huelga, Martin B. Plenio, Exact mapping between system-reservoir quantum models and semi-infinite discrete chains using orthogonal polynomials, J. Math. Phys. 51, 092109 (2010)

Multiplicity in Everett's interpretation of quantum mechanics

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Everett's relative states, or many-worlds, interpretation of quantum mechanics [1] faces problems with the meaning of probability, the selection of a preferred basis and the nature of multiplicity. Although the first and second problems have been thoroughly investigated, I have argued [2] that the third one is the most important. Multiplicity has been alternately construed as involving many worlds, many minds or decoherent sectors of the wave function. Each of these mutually exclusive views in turn divides into a number of different approaches, a given investigator sometimes proposing more than one. My objectives are (i) to draw attention to the rather large number of ways to make sense of Everett, (ii) to critically examine several particularly significant ones, and (iii) to point out that many of them lack precision and adequate definition. In the end Everett's interpretation, though almost 60 years old, is very much a work in progress.

[1] H. Everett, Rev. Mod. Phys. 29, 454 (1957).

[2] L. Marchildon, Found. Phys. 41, 357 (2011).

P38

Minimising the heat dissipation of information erasure

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Landauer's principle states that erasing the information of a quantum object, by preparing it in a pure state, must dissipate a minimum quantity of heat to a thermal reservoir. This is proportional to the entropy reduction incurred by the object. However, Landauer's principle only states that this lower bound of heat dissipation is obtained for some physical setting, but not all; in some settings there is even a limit to the probability of purification that can be attained. Furthermore, in general there is a disjunction between optimising the probability of purification and entropy reduction; one need not minimise the object's entropy to maximise its probability of being in a pure state. Consequently we develop the concept of minimal heat dissipation given probabilistic information erasure, provided knowledge of the reservoir's Hamiltonian. Precisely, we determine the unitary operator acting on the composite system of object and reservoir so that the probability of preparing the object in a pure state is brought to a desired value. Subsequently, the unitary operator is optimised to minimise the resulting heat dissipation to the reservoir. We consider two concrete models of maximising the probability of erasing a qubit. Moreover, for these models we investigate the effect of energy conserving, Markovian dephasing on the process of information erasure. Finally, we enumerate the ways in which it is possible to cheat and achieve heat dissipation lower than Landauer's limit, but in a way that terms such as heat and temperature would remain applicable.

Exactly solvable position-dependent mass Schrödinger equation: A general approach

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The position-dependent mass Schrödinger equation (PDMSE) appears in the study of the dynamics of charge carriers (electrons and/or holes) in mesoscopic systems such as semiconductor heterostructures and/or inhomogeneous crystals as well as on the linear and nonlinear optical properties of quantum well/dot and related fields. Consequently, there has been an increased interest in searching for analytic solutions of the PDMSE by means of different methods such as the kinetic energy operator, Lie algebras, supersymmetry, path integration approaches and so on. In this work, a general algorithm to find exactly solvable potentials for the PDMSE is presented. The approach is based on the point canonical transformation method used to convert a PDMSE, with m(x) and V(x), into the standard Schrödinger-like equation with constant mass and potential U(u). The proposal is general because it relates both potentials by means of a Riccati-type equation which involves the superpotential W(g(x)) or Witten equivalent. That is, according to the proposition, the choice of an ansatz for W(g(x)) let us to obtain the position-dependent mass distribution m(x) and consequently to propose a U(u) potential or a V(x) former potential in the PDMSE. In the first case to find isospectral potential partners and in the second one, to identify exactly solvable potentials for an specific m(x). As an useful application, we have considered the special case of the harmonic oscillator (HO) potential model as U(u)= βuu to obtain the V(x) isospectral partners as well as V(x)= βxx to find the exactly solvable U(u) potentials for some specific m(x). Details and concluding remarks will be given in the poster.

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One-dimensional liquid ^{4}He beyond Luttinger theory

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We investigate zero temperature liquid ^{4}He in strictly one dimension by means of state-of-the-art Quantum Monte Carlo and analytic continuation techniques [1,2]. The system displays the unique feature of spanning all the possible values of the Tomonaga-Luttinger liquid parameter K_L by only changing the density. We explore the behavior of the dynamical structure factor $S(q,\omega)$ beyond the limits of applicability of Tomonaga-Luttinger liquid theory in the whole range in K_L [3]. We observe a crossover from a weakly interacting Bose gas regime at low density ($K_L \gg 1$) to a quasi-solid regime at high density ($K_L \ll 1$), which we interpret in terms of novel analytical expressions for the spectrum of hard-rods [3]. During this transition the interplay between dimensionality and interaction makes $S(q,\omega)$ manifest a pseudoparticle-hole continuum typical of a fermionic system, while the Bogoliubov mode evolves into a remnant of the roton mode. We provide also a perturbative estimation of the drag force experienced by a soft impurity moving along the system [4].

[1] D. E. Galli and L. Reatto, Molecular Physics 101, 1697 (2003)
[2] E. Vitali, M. Rossi, L. Reatto, and D. E. Galli, Phys. Rev. B 82, 174510 (2010)
[3] A. Imambekov, T. L. Schmidt, and L. I. Glazman, Rev. Mod. Phys. 84, 1253 (2012)
[4] A. Y. Cherny, J.-S. Caux, and J. Brand, Front. Phys. 7, 54 (2012)

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Single-photon observables and preparation uncertainty relations

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We propose a procedure for defining all single-photon observables in terms of Positive-Operator Valued Measures (POVMs), in particular spin and position. We identify the suppression of 0-helicity photon states, due to the conditions of mass $m = 0$ and spin $s = 1$ [1], as a projection $\hat{\Pi} : \mathcal{H}_A \to \mathcal{H}_S$ from an extended Hilbert space $\mathcal{H}_A$ onto the single-photon Hilbert space $\mathcal{H}_S$. Following and generalizing the approach of K. Kraus to the problem of photon localization [2], we show that all single-photon observables are described by POVMs. Such POVMs are obtained by applying the projection $\hat{\Pi}$ to opportune Projection-Valued Measures (PVMs) defined on the extended Hilbert space $\mathcal{H}_A$. The POVMs associated to momentum and helicity reduce to PVMs, unlike those associated to position and spin. This fact reflects the intrinsic unsharpness of the position and spin observables, and the inherent impossibility of localizing a single photon in a bounded space region [3] or of preparing it with definite spin along a spatial direction independent on momentum [4]. We finally extensively study the preparation uncertainty relations for position and momentum and the probability distribution of spin, exploring single photon Gaussian states for several choices of spin and polarization.

[1] H.E. Moses, J. Math. Phys. 8, 1134 (1967); H.E. Moses, J. Math. Phys. 9, 16 (1968)

[2] K. Kraus "Position Observables for the Photon" in "Uncertainty Principles and the Foundations of Quantum Mechanics" W.C. Price, S.S. Chissich, ed. Wiley (1977)

[3] W.O. Amrein, Helv. Phys. Acta 42 (1969), I. Bialynicki-Birula, Phys. Rev. Lett. 80, 5247 (1998)

[4] P. Busch and F. E. Schroeck Jr, Foundations of Physics 19, 807 (1989)

P42

Electron transfer: Marcus rate and the Goldilocks principle

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We examine electron transfer between two quantum states in the presence of a dissipative environment represented as a set of independent harmonic oscillators. For this simple model, the Marcus transfer rates can be derived and we show that these rates are associated to an explicit expression for the environment correlation time. We demonstrate that as a manifestation of the Goldilocks principle, the optimal transfer is governed by a single parameter which is equal to just the inverse square root of two.

Interacting two-level systems as sources of fluctuating high-frequency noise in superconducting circuits

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Since the very first experiments, superconducting circuits have suffered from strong coupling to environmental noise, destroying quantum coherence and degrading performance. In state-of-the-art experiments it is found that the relaxation time of superconducting qubits fluctuates as a function of time. We present measurements of such fluctuations in a 3D-Transmon circuit and develop a qualitative model based on interactions within a bath of background two-level systems (TLS) which emerge from defects in the device material. Assuming both high- and low-frequency TLS are present, their mutual interaction will lead to fluctuations in the noise spectral density acting on the qubit circuit. This model is further supported by direct measurements of energy fluctuations in a single high-frequency TLS.

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Phonon-induced microwave amplification in semiconductor double quantum-dots

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We consider a voltage-biased double quantum-dot (DQD) in the transport regime which is dipole-coupled to a superconducting microwave cavity [1, 2]. We explore the effect of dissipative coupling of the DQD to a phononic environment and its influence on the parameter regime in which photon gain and loss can be observed. In order to describe phonon-induced gain and loss processes in the microwave cavity, we develop a rate equation based on fourth-order perturbation theory in the DQD interactions. We compare our findings with the recent paper Ref. [3], where a different technique based on the Polaron transformation was used.

[1] Liu, Y.Y. et al., Science 347, 285-287 (2015)

[2] Liu, Y.Y. et al., Physical Review Letters 113, 036801 (2014)

[3] Gullans, M.J. et al., arXiv:1501.03499 (2015)

Thermal transport in out of equilibrium quantum harmonic chains

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We address the problem of heat transport in a chain of coupled quantum harmonic oscillators, exposed to the influences of local environments of various nature, stressing the effects that the specific nature of the environment has on the phenomenology of the transport process. We study in detail the behavior of thermodynamically relevant quantities such as heat currents and mean energies of the oscillators, establishing rigorous analytical conditions for the existence of a steady state, whose features we analyse carefully. In particular we assess the conditions that should be faced to recover trends reminiscent of the classical Fourier law of heat conduction and highlight how such a possibility depends on the environment linked to our system.

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Bose-Einstein condensates of photons in a dye-filled microcavity

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Bose-Einstein condensation (BEC) is a universal phenomenon which occurs when a system of identical bosons at thermal equilibrium occupy the ground state in enormous numbers. By optically pumping a 1.5 μm long, dye-filled resonator, we can achieve both thermal equilibrium of photons and a well-defined ground state. Thus, the first room temperature BEC was demonstrated [1]. We have recently become only the second laboratory to create this dissipative, quantum-fluid state of light.

There are many recent published theoretical models of photon BEC, some using rate equations, other fully quantised matter-light interactions. Our current experimental efforts are aimed at testing the validity of these various theories. For example, we have observed that the critical pump power for condensation depends on the size of the pump beam, in contradiction to all of the published models [2].

We have observed the visibility of interference using delayed and displaced images of the thermalised light, which relates directly to the non-equilibrium spatiotemporal correlation function, $g^{(1)}(\mathbf{r}, \mathbf{r}', t - t')$. The coherence time increases when the condensate is present, and the coherence length is as large as the condensate itself. We have begun momentum-resolved spectroscopy, and we expect that even very weak photon-photon interactions should be detectable this way [3].

[1] J. Klaers et al, Nature 468 (2010) 545

[2] J. Marelic and R.A. Nyman, Phys Rev A 91 (2015) 033813

[3] R.A. Nyman and M.H. Szymanska, Phys Rev A 89 (2014) 033844

Control of group velocity in a quantum dot system near a plasmonic nanostructure

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Recently, there is increasing interest in the study of the interaction of quantum emitters with plasmonic nanostructures. The large fields and the strong light confinement associated with the plasmonic resonances enable strong interaction between the electromagnetic field and the quantum emitters near plasmonic nanostructures. Also, the quantum emitter can be used for the controlled optical response of the coupled quantum – plasmonic system. In this work, we study coherent control effects on the group velocity of light in a three-level V-type quantum dot system (ground to single-exciton transitions) in proximity to a plasmonic nanostructure. For the plasmonic system we consider a two-dimensional array of metal-coated dielectric nanospheres and calculate the relevant decay rates by a rigorous electromagnetic Green's tensor technique [1-4]. The quantum dot system interacts with two orthogonal circularly polarized laser fields with the same frequency, and different phases and electric field amplitudes, which couple the lowest state with the upper states. We show that the presence of the plasmonic nanostructure leads to strong modification of the group velocity value for one of the laser fields, in the presence of the other. In addition, we show that one can use the phase difference and the relative electric field amplitudes of the two laser fields for efficient control of the group velocity of light.

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[1] V. Yannopapas, E. Paspalakis and N. V. Vitanov, Phys. Rev. Lett. 103 (2009) 063602.

[2] S. Evangelou, V. Yannopapas and E. Paspalakis, Phys. Rev. A 86 (2012) 053811.

[3] E. Paspalakis, S. Evangelou, V. Yannopapas and A. F. Terzis, Phys. Rev. A 88 (2013) 053832.

[4] S. Evangelou, V. Yannopapas and E. Paspalakis, J. Mod. Opt. 61 (2014) 1458.

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Non-classicality in the decohering harmonic oscillator

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We study how non-classicality behaves during decoherence for the harmonic oscillator coupled to a linear Markovian bath, using four different non-classicality measures. Three of these measures are relative using different definitions of the distance between given quantum states and the set of all classical states. By studying the behavior of the system, we find a novel set of states which are the closest by all measures to the eigenstates of the harmonic oscillator, and hence are able to improve upon all previous measures. The fourth measure is an absolute one, the negative volume of the Wigner function of the state, and we show that it agrees well with the relative measures. We find that all four measures show that the non-classicality of the eigenstates is non-trivial as a function of time. In particular, as the system decoheres, the eigenstate that is the most non-classical changes as a function of time. Finally, we explore the dynamics of non-classicality for more general states.

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Nonlinear entanglement dynamics for coupled spin qubits

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We consider the entanglement dynamics of a nonlinear kicked spin system. This system can be thought of as a composite system of many spins with internal entanglement between the spins. We show that the degree of entanglement in the quantum system shows a strong dependence on (a) the classical limiting trajectory behavior (b) even in the extremely quantum case of 2 or 3 qubits, and that (c) this holds holds true in the presence or absence of chaos in the classical system. All three conditions (a,b,c) above make this very different from, and in fact, counter to the understanding in the literature of the relationship between classical dynamics and quantum entanglement. Further, our results are in good agreement with recent experiments performed by the Martinis laboratory using superconducting qubits.

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Noise thermal impedance: A way to access electron energy relaxation times

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In good conductors the frequency dependence of the conductance and the noise is given only by charge screening. To have access to inelastic processes or diffusion times in such samples one need to measure small quantum corrections to the conductance [1] or tunneling properties on materials with which tunnel junction can be made [2]. Those are indirect measurements of interactions and diffusion time and are sometimes hard to access. Recently B. Reulet and D.E. Prober have proposed a new technique based on out of equilibrium Johnson noise measurement to directly access the dynamic of electrons in normal metals [3]. They named it Noise Thermal Impedance (NTI). We have applied this technique to different metallic wires to investi- gate the electron-phonon interaction times and the diffusion time in function of temperature and length of the wire. This experiment demonstrate that a NTI measurement is of great interest to access dynamics of electron gazes. This could be applied to probe diffusion times in new materials such as h-graphene or to investigate electron- phonon interaction in High Tc superconductors. One could also imagine to study diffusion law in more fancy sample with a fractal dimention.

[1] D.E. Prober et al., Phys. Rev. B 29, 6 (1984)

[2] H. Pothier et al., Phys. Rev. Lett. 79, 3490 (1997)

[3] B. Reulet and D.E. Prober, Phys. Rev. Lett. 95, 066602 (2005)

The ontology of fields of interaction

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The ontology of fields of interaction is not yet properly settled. This lapse leads to several paradoxes concerning their behavior. Constancy of velocity of propagation, absence of medium in connection with wave behavior and particle-wave duality are between them.

Considering the foundations of physical theories from the point of view of the principle of 'differentiation with stratification' [1], in connection with the epistemology of the observational realism in development [2], we can show the existence of a common structural basis in the theories, where laws of different natures are present, according to observational, empirical or theoretical contexts.

The aim of this study is to compare the different structural elements, separating the observational domains of each theory, to show an observational evolution in the development of the physical theories. It clarifies the origins and shows the different positions and meanings of fields of interaction in them. This analytical method serves as a basis to review these mentioned paradoxes.

[1] C. Pombo, Differentiation with stratification: a principle of theoretical physics in the tradition of the memory art; to appear in Foundations of Physics.

[2] C. Pombo, Reflections on the nature of the concepts of field in physics, in Quantum Theory: Reconsideration of Foundations 6, AIP Conference Proceedings, Volume 1508, Issue 1, 443-458 (2012).

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Current through a nanojunction in response to a time-dependent stochastic bias

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The problem of explicit time-dependence in quantum transport is a problem of increasing importance, as the dynamical response properties of nanostructures following the switch-on of a time-dependent bias are now the subject of experimental investigation. Recent work [1] in the application of the Nonequilibrium Green's Function (NEGF) formalism to the switch-on problem has lead to the development of an efficient scheme for calculating the electronic current through a multilead nanojunction. This method enables access to both the short-time transient response of the system to the switch-on event, and to the current at long times after the transient. In this approach, the Wide-Band Limit Approximation (WBLA) was employed to enable exact integration of the Kadanoff-Baym equations and arrive at a closed integral expression for the time-dependent current. We now apply this formalism to the study of electron transport resulting from a bias that contains a noisy time-dependent part, in order to understand the quantum analogue of the Nyquist noise found in classical circuits [2]. Treating the stochastic part of the bias in an analogous manner to the Langevin equation approach, we find that the resulting bias-averaged current can be evaluated exactly in the white noise case. The asymptotic behaviour of this average at long times is found to bear a simple relation to the Landauer-Buttiker formula for the current [3], with a modified transmission function that contains information on the fluctuations of the bias.

[1] M. Ridley, A. MacKinnon and L. Kantorovich, Phys. Rev. B 91(12), 125433 (2015)

[2] H. Nyquist, Phys. Rev. 32(1), 110 (1928)

[3] G. Stefanucci and R. van Leeuwen, Nonequilibrium Many-Body Theory of Quantum Systems: A Modern Introduction, Cambridge University Press (2013)

Persistence of many body freezing in periodically driven quantum spin systems: From simple quantum magnets to disordered, non-integrable and long range models

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

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Variety of master equations based on projection operator formalism

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We study a variety of non-Markovian master equations, which are based on the formalism of projection operators. In particular, we show that the concrete form of the master equation strongly depends on initial assumptions about the open system and can be highly nonlinear. Also, there exist some projection operators, which always lead to an integrable master equation. The general ideas are discussed with the example of a harmonic oscillator in a thermal bath. Different forms of the master equations are compared.

Non-stationary and noise properties of molecular junctions in the polaronic regime

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Localized vibrations (phonons) may have an important impact in the transport properties of nanoscale conductors [1]. Such effects have been observed in many different systems such as atomic chains, semiconducting quantum dots, carbon nanotubes and other molecular junctions. In spite of this variety, from a theoretical point of view all these situations can be qualitatively described by the rather simple Anderson-Holstein model. This model considers a single resonant level coupled to fermionic reservoirs and to a localized phonon mode. While the stationary properties of this model have been extensively analyzed, by many approximations, the way the system reaches the steady state is not yet well understood.

In this work we focus in the so called polaronic regime, where the coupling between electrons and phonons is strong, compared with the coupling of the level to the electrodes. In order to study the transient regime properties of the system we use an approximation studied in a previous work, based on on a resummation of the dominant Feynman diagrams from the perturbation expansion in the coupling to the leads [2].

Using this approximation we are able to analyze the evolution of the current and the average population of the level, observing long transient behavior when increasing the electron-phonon coupling and no bistability at long time. These results are compared with numerical exact results obtained from path integral Monte Carlo [3], showing a good agreement for different range of parameters and initials preparations of the system. Using the expressions developed by Mukamel et. al. [4], we are able to evaluate the single electron probabilities transfer through the junction and the evolution of the current cumulants, showing an universal oscillatory behavior for higher order cumulants.

[1] M. Galperin, M. A. Ratner, and A. Nitzan, Journal of Physics: Condensed Matter 19 (2007).

[2] R. Seoane Souto, A. Levy-Yeyati, A. Martín-Rodero, and R. C. Monreal, Phys Rev B 89 (2014).

[3] K. F. Albrecht, A. Martín-Rodero, R. C. Monreal, L. Mühlbacher, and A. Levy-Yeyati, Phys Rev B 87 (2013).

[4] M. Esposito, U. Harbola, and S. Mukamel, Rev Mod Phys 81 (4) (2009).

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Additivity principle and stability of open systems: Extension of Le Châtelier principle

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The purpose of this poster is to present an alternative approach to the study of classical out of equilibrium systems based on a Euler-Lagrange formulation of the macroscopic fluctuation theory (MFT). This approach is versatile and useful enough to allow computing large deviation and cumulant generating functions for already studied models of classical systems. It may provide a convenient framework to study a broader class of problems including out of equilibrium quantum mesoscopic systems. We present new results relative to the validity of the additivity principle in boundary driven systems based on a generalization of the Le Chatelier principle. This proves helpful in discussing the onset of dynamical phase transitions.

On the problem of simulation of the dynamics of quantum-thermal fluctuations

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In this paper, we study the problem of fluctuations of observables dependent on the spatial coordinates and time and describing the collective motion in the long-wavelength range. The authors of [1, 2] proposed to consider the dynamics of quantum-thermal fluctuations of the density and drift velocity at equilibrium with respect to the temperature in the framework of the stochastic hydrodynamics, which is a generalization of the Nelson stochastic mechanics [3]. This allows extending the hydrodynamic form of the quantum mechanics to finite temperatures. As a result, the system of equations, which is valid at any temperatures, was obtained for a one-dimensional model taking the diffusion pressure of the warm vacuum into account. Moreover, we have managed to write these equations in the form of the equations of two-velocity hydrodynamics

$$\frac{du_{ef}}{dq} = -\frac{\partial}{\partial q}(vu_{ef}) - \frac{\partial}{\partial q}\frac{u_{ef}^2}{2},$$

$$\frac{dv}{dq} = -\frac{2D_{qu}}{\hbar}\frac{\partial U}{\partial q} + \Xi_T \frac{\partial}{\partial q}\frac{u_{ef}^2}{2},$$

where u_{ef} is the effective diffusion velocity, v is the drift velocity, D_{qu} is the quantum self-diffusion coefficient in the cold vacuum at $T = 0$, Ξ_T is the parameter taking the effective environmental influence into account, and $U(q)$ is the potential energy of the regular action. In this paper, we consider the principal validity of the given hydrodynamic model for describing the evolution of quantum-thermal fluctuations based on the self-diffusion mechanism. We show that this model leads to the parabolic type of equations, which allows using it to describe the dynamics of macroscopic fluctuations unlike the Nelson model leading to equations of the elliptic type describing stationary processes. In the numerical study of the presented system, we show that the solution has the form of a perturbation wave running with respect to the spatial coordinate and evolving with time. Thus, we assume that the hydrodynamic approach to the quantum theory allows, in principle, constructing the model of the dynamics of quantum-thermal fluctuations taking the self-diffusion mechanism into account.

[1] A. Sukhanov, J. Math. Phys. 154 (2008) 185.

[2] A. Sukhanov and O. Golubjeva, J. Math. Phys. 160 (2009) 369.

[3] E. Nelson, Dynamical theory of Brownian motion. Princeton: Princ. Univ. Pres., 1967.

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Decoherence and determinism in a one-dimensional cloud-chamber model

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A possible explanation for the seemingly random nature of the result of a measurement in quantum mechanics was recently proposed [1]. In this approach, a measurement result is simply determined by the microscopic state of the measuring device. This interpretation was shown to violate Bell's inequalities, in agreement with standard quantum mechanics, and led to a new discussion of Mott's problem [2], i.e. the paradoxical appearance of linear tracks in a cloud-chamber measurement of a spherical wave (alpha- radioactivity type). It was proposed that the appearance of particular linear tracks was actually determined by the (random) positions of atoms or molecules inside the chamber.

In the present work, we further explore this hypothesis, both analytically and numerically, in the framework of a one-dimensional model [3], where the spherical wave is replaced by a linear superposition of two wave packets moving to the left and to the right, impinging on meshes of localized spins which play the role of cloud-chamber atoms. The impact of the spin positions on the wave packets is studied and the possible origin of decoherence and entropy increase is discussed, in a deterministic approach based on the Schroedinger equation.

[1] J.-M. Sparenberg, R. Nour and A. Manco, EPJ web of conferences 58 (2013) 01016.

[2] N. F. Mott, Proc. Roy. Soc. A126 (1929) 79.

[3] R. Carlone, R. Figari and C. Negulescu, preprint arXiv:1407.4250v1.

Diffusion anomalies in ac driven Brownian ratchets

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We study diffusion in ratchet systems. As a particular experimental realization we consider an asymmetric SQUID subjected to an external ac current and a constant magnetic flux [1]. We analyze mean-square displacement of the Josephson phase and find that within selected parameter regimes it evolves in three distinct stages: initially as superdiffusion, next as subdiffusion and finally as normal diffusion in the asymptotic long-time limit. We show how crossover times that separates these stages can be *controlled by temperature and an external magnetic flux*. The first two stages can last many orders longer than characteristic time scales of the system thus being comfortably detectable experimentally. The origin of abnormal behavior is noticeable related to the ratchet form of the potential revealing an *entirely new mechanism of emergence of anomalous diffusion*. Moreover, a normal diffusion coefficient exhibits non-monotonic dependence on temperature leading to an intriguing phenomenon of *thermal noise suppressed diffusion*. The proposed setup for experimental verification of our findings provides a new and promising *testing ground* for investigating anomalies in diffusion phenomena.

[1] J. Spiechowicz, P. Hänggi and J. Łuczka, Phys. Rev. B 90 (2014) 054520

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Dynamics of the quantum state in small systems under influence of statistical field: The phase space approach

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The quantum state of a particle which moves in the finite medium and interacts with the statistical environment can be represented by means of the Wigner function which is an example of non-classical distribution function defined over the phase-space. The influence of the statistical environment on the dynamics of the particle can result in randomization of the phase. As a consequence, the loss of the quantum coherence of the considered state during its time evolution is observed. Such process is investigated for the dynamics of Wigner wave packet which moves in a small one-dimensional system in the presence of an external statistical field. The properties of the Wigner function are investigated in terms of the decoherence parameter and the linear entropy. The tunnelling time through the small system is determined as a function of the decoherence parameter.

[1] W. P. Schleich, *Quantum Optics in Phase Space* (Wiley-VCH Verlag Berlin GmbH, Berlin, 2011).

[2] P. Facchi, A. Mariano, and S. Pascazio, Phys. Rev. A 63 (2001) 052108.

[3] R. Cabrera, D. I. Bondar, and H. A. Rabitz, arXive:1212.3406v2 [quant-ph] (2013).

Thermalization in mesoscopic rings and single-electron devices

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One of the simpliest examples of a single-electron device is a single-electron box. It is composed by an isolated metallic island which is coupled via a tunneling junction to a metallic lead. By controlling the potential of the island one can change the number of excess electrons on it. It is well established that in the case when temperature is much smaller than electrostatic energy associated with conducting island, fermion degrees of freedom can be integrated out in such a way that we obtain an effective theory in terms of a phase field corresponding to angular coordinate on a ring. That is Ambegaokar-Eckern-Schon model.

It is well-known this effective theory can be interpreted as a particle on a ring with non-local self-interaction, moreover the particle's angular momentum corresponds to the number of excess electrons on the island. It can be shown that it is possible to decouple non-local term[6], thus arriving at a model where particle is in interaction with bosonic thermal bath which also lives on a ring. But in comparison with initial model describing single-electron box, the effective theory has an extra conserved quantity, the full momentum of particle and bath to be precise, which potentially can have a strong influence on the thermalization process.

If we want to look into it, it is suitable to compare Gibbs ensemble with a steady state to which the system evolves after adiabatic turning on of the interaction.

In our work we consider the thermalization process of initially decoupled system of particle and bath on a ring after adiabatic turning on of the interaction. After long enough time the system arrives at some steady-state. To compare this state with thermodinamic equilibrium we calculate in both cases the first order correction to the angular momentum of the particle. We show that in the case of a general thermal bath this results are different, but the difference vanishes in the limit of zero temperature which is in perfect agreement with the adiabatic theorem. Also we show that the thermal bath of Caldeira-Leggett type is a special case when both approaches give the same result.

[1] V. Ambegaokar, U. Eckern, G. Schon, Phys. Rev. Lett. 48 (1982) 1745.

[2] V. Ambegaokar, U. Eckern, G. Schon, Phys. Rev. B 30 (1984) 6419.

[3] D. Golubev, A. Zaikin, Phys. Rev. B 50 (1994) 8736.

[4] H. Schoeller, G. Schon, Phys. Rev. B 50 (1994) 18436.

[5] G. Schon, in *Quantum Transport and Dissipation*, edited by T. Dittrich et al., (Wiley-VCH Verlag, 1998), Ch. 3.

[6] A. Semenov, arXiv:1307.6615 (2013).

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Point information gain, point information gain entropy and point information gain entropy density as measures of semantic and syntactic information of multidimensional discrete phenomena

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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 Renyi entropy and simulate the behavior of PIG for typical distributions. The main distiction of PIE and PIED from other information measures is the possibility of the definition of information syntax and analysis of the syntactic information content. We have used these methods for the analysis of multidimensional datasets. We demonstrate the main properties of PIE/PIED spectra for the real data on the example of the chemical self-organising process, the Belousov - Zhabotinsky reaction performed in a flat Petri dish. The method enables to define states in the self-organisation state trajectory.

Normal mode engineering for quantum phase fluctuations of an inhomogeneous superconducting loop

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We propose the way to control Josephson energy of the single Josephson junction (JJ) connected to an inhomogeneous superconducting loop. The Josephson energy is renormalized from the each normal modes of quantum phase fluctuations under periodical modulating the ground capacitance and the one dimensional superfluid density. Moreover, the normal mode dispersion relation is also changed. We estimate the renormalized Josephson energy using recent experiments of JJ-chains and superconducting nanowire.

[1] W. Guichard et al., PRB 81, 064508 (2010).

[2] F. W. J. Hekking et al., PRB 55, 6551 (1997).

[3] T. Weissl et al., PRB 91, 014507 (2015).

[4] O. V. Astafiev et al., Nature 484, 355 (2012).

[5] J. T. Peltonen et al., PRB 88, 220506 (2013).

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Pauli-Heisenberg oscillations in electron quantum transport

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We measure the current fluctuations emitted by a normal-metal/insulator/normal-metal tunnel junction with a very wide bandwidth, from 0.3 to 13 GHz, down to very low temperature $T = 35$ mK. This allows us to perform the spectroscopy (i.e., measure the frequency dependence) of thermal noise (no dc bias, variable temperature) and shot noise (low temperature, variable dc voltage bias). Because of the very wide bandwidth of our measurement, we can deduce the current-current correlator in the time domain. We observe the thermal decay of this correlator as well as its oscillations with a period h/eV, a direct consequence of the effect of the Pauli and Heisenberg principles in quantum electron transport.

Information thermodynamics for a feedback with time delay

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We investigate a realistic feedback process repeated in multiple steps where a feedback protocol from measurement is applied with delay and maintains for a finite duration until next step. Unlike a feedback without delay, the mutual information for a time-delay period is found to account for the correlation between the system state and the joint state of recent and past memories. We consider the measurement of an observable with odd parity in time reversal, which is shown to give rise to an anomalous entropy production recently recognized for a stochastic system under a odd-parity force. We exemplify a cold damping case where a velocity of a particle is measured and a dissipative protocol is applied by feedback. Through repeated feedback steps, the temperature of the system can or cannot be cooled down towards a steady-state value depending on the parameters used: the delay time, the duration time, and the intensity of the protocol. We rigorously derive the stability condition for the steady-state temperature in the parameter space. We expect the instability in a repeated feedback process to be a general feature due to similar sources of imperfection in measurement and feedback.

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Quantum-classical crossover close to quantum critical point

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Mapping of the d-dimensional quantum system to a (d+1)-dimensional classical statistical mechanics is a focal point of a theory of the quantum phase transitions (QPT), most notably of the powerful finite size scaling near the quantum critical point (QCP) [1,2]. The extra dimension is imaginary time, reflecting that the quantum description is inherently dynamic. However, this relates only to non-dissipative quantum dynamics, while the question of how omnipresent dissipative processes are to be included into the description of the critical dynamics near QCP is not thoroughly understood. Here we report a general approach enabling inclusion of both adiabatic and dissipative processes into the critical dynamics on the same footing. We reveal three distinct critical modes, the adiabatic quantum mode (AQM), the dissipative classical mode [classical critical dynamics mode (CCDM)], and the dissipative quantum critical mode (DQCM). We find that as a result of the transition from the regime dominated by thermal fluctuations to that governed by the quantum ones, the system acquires effective dimension d+2 and calculate the dependence of the critical exponents on the temperature at the quantum-classical crossover. Our findings lead to a unified picture of quantum critical phenomena including both dissipation- and dissipationless quantum dynamic effects and offer a quantitative description of the quantum-to-classical crossover.

[1] Sondhi S.L., Girvin S.M., Carini J.P. & Shahar D., Continuous quantum phase transitions. Rev. Mod. Phys. 69, 315-333 (1997).

[2] Sachdev S., Quantum Phase Transitions, Second Edition. Cambridge University Press (2011).

Application of depinning theory to Josephson junction arrays

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One-dimensional arrays of Josephson junctions have been experimentally studied in various configurations for almost twenty years. Depending on the position in parameter space the Josephson junction arrays show different types of transport behaviour. One of these transport regimes is characterised by a Coulomb blockade that can be overcome by applying a critical voltage bias known as the switching voltage. It was recently pointed out that experimental studies of the switching voltage can be explained with the help of a depinning transition in an effective continuous charge model of the arrays [1]. We expand on this approach by considering parameter regimes and array setups not covered in the original experiments. We use numerical simulations of the Josephson junction arrays to compare to analytic expectations.

[1] One-dimensional Josephson junction arrays: Lifting the Coulomb blockade by depining, Nicolas Vogt, Roland Schäfer, Hannes Rotzinger, Wanyin Cui, Andreas Fiebig, Alexander Shnirman, Alexey V Ustinov, arXiv preprint arXiv:1407.3353, 2014

P68

Thermoelectric properties of T-shaped double quantum dots exhibiting Fano and Kondo effects

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In this contribution we study the thermoelectric properties of T-shaped double quantum dot systems. In particular, with the aid of the numerical renormalization group method, we calculate the linear-response transport properties: electric and thermal conductances, Seebeck coefficient, thermoelectric figure of merit and thermoelectric power factor. In the regime of strong coupling between the double dot and external leads, we analyze how do the two-stage Kondo effect and the Fano effect reveal in respective thermoelectric coefficients. We show that thermopower as a function of temperature exhibits a peak at the temperature corresponding to the second stage of Kondo effect. On the other hand, in the weak coupling regime, we seek for conditions of the highest thermoelectric performance and find a giant figure of merit.

Quantum field with time as a dynamical variable

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In quantum mechanics, the amplitude of a matter wave has no physical meaning other than the probabilistic interpretation base on Born's postulate. Assuming time as a dynamical variable, we show that the matter wave amplitude can be taken as a 4-vector with vibrations in space and time. The properties of a zero spin bosonic field (e.g., Schrödinger's equation, Klein-Gordon equation, probability density, second quantization etc.) can be reconciled base on such assumption. The problem with unobservable overall phase that supposes to hinder any physical meaning of the quantum wave amplitude can be resolved.

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Quantum critical behavior of the quantum Ising model on fractal lattices

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I study the properties of the quantum critical point of the transverse-field quantum Ising model on various fractal lattices such as the Sierpinski carpet, Sierpinski gasket, and Sierpinski tetrahedron. Using a continuous-time quantum Monte Carlo simulation method and finite-size scaling analysis, I identify the quantum critical point and investigate its scaling properties. Among others, I calculate the dynamic critical exponent and find that it is greater than one for all three structures. The fact that it deviates from one is a direct consequence of the fractal structures not being integer-dimensional regular lattices. Other critical exponents are also calculated. The exponents are different from those of the classical critical point and satisfy the quantum scaling relation, thus confirming that I have indeed found the quantum critical point. I find that the Sierpiński tetrahedron, of which the dimension is exactly 2, belongs to a different universality class than that of the two-dimensional square lattice. I conclude that the critical exponents depend on more details of the structure than just the dimension and the symmetry.

Entropy-production of stars in open clusters

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Entropy and its production have been key quantities not only for non-equilibrium statistical physics and thermodynamics but for natural science in general. They are of paramount importance when discussing variational principles of non-equilibrium physics, issues of order and disorder in nature, origin and transfer of information, problems of irreversibility and direction of time, etc. Starting from the studies by R. Clausius and his concept of heat death of the Universe and until now, this report and our previous work [1] related to entropy have always been in the centre of attention among astrophysicists and cosmologists. Entropy production, a crucial quantity from the standpoint of non-equilibrium physics, was neither calculated nor quantitatively analyzed for the most important and widespread objects in the Universe: stars. Presently, there is no other information, except for entropy production estimates of the Sun [2,3]. This report and [1] is the first step to solve this issue.

Stars belonging to open clusters were chosen as the object of study hereof. This is very convenient because, according to the modern concepts, stars of the same cluster are formed from the same molecular cloud and therefore have the same age and the same composition.

The entropy production (inside the volume bounded by a photosphere) of main-sequence stars in open clusters is calculated based on B–V photometry data from the WEBDA database [4]. The entropy-production distribution function and the dependences of entropy production on temperature and luminosity are obtained for these stars for the first time. A very small range of variation of specific (per volume) entropy production discovered for main-sequence stars (only 0.5 to 1.8 solar magnitudes) is an interesting result that can be crucial for understanding thermodynamic processes of stars.

From the perspective of nonequilibrium thermodynamics, the obtained result is important as it confirms, using a specific example, a hypothesis advanced in a number of recent papers (see, for example, [5]). So, these propose, on the basis of the maximum entropy production principle, a hypothesis that co-existing dissipative nonequilibrium systems have the same local (specific) entropy productions. This hypothesis was previously verified by the results of experiments related to nonequilibrium growth of crystals and hydrodynamic instabilities.

[1] L.M. Martyushev and S.N. Zubarev, Entropy, 17, 1152 (2015)

[2] I. Aoki, J. Phys. Soc. Jpn., 52, 1075-1078 (1983)

[3] D.C. Kennedy and S.A. Bludmanthe, ApJ, 484, 329 (1997)

[4] J.-C. Mermilliod and E. Paunzen, A&A, 410, 511 (2003)

[5] L.M. Martyushev, Entropy, 15, 1152 (2013)

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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 by tram No. 22 which has its stops nearly in front of the Pyramida Hotel: Prague Castle within about 5 minutes, Lesser Town is about 10 minutes by tram, 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 we can remind 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'.
Special tram will depart from the Pyramida Hotel to the Malostranská station on Monday afternoon to facilitate FQMT'15 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 (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'.

St. Simon and Juda Church

St. Simon and Juda Church (Kostel sv. Šimona a Judy) was built by the Czech Brethren between 1615 and 1620. After the battle of the White Mountain (1620) the Brethren were expelled from the Czech lands, the church was given to a catholic order, the brothers of Mercy and it became part of a monastery and hospital. The first anatomy lecture hall in Prague was established here in 18th century. Rebuilt monastery complex continues to serve as a hospital.

Church Baroque facade and interior decoration are of 18th century. By its entrance there is a pieta from 16th century. The main altar of the church is the work of Josef Hager from 1773 and it contains painting of St. Simon and Juda from well known painter Václav Vavřinec Rainer. The organ is decorated with sculptures by famous Prague Baroque sculptor J. Brokoff and was played by J. Haydn and W. A. Mozart. Nowadays, St. Simon and Juda church is the concert hall of Prague Symphonic Orchestra FOK.

How to get there:
Special tram will depart from the Pyramida Hotel to the Čechův most (Čech Bridge) tram

stop on Tuesday afternoon to facilitate FQMT'15 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 reach the Malostranská stop by tram No. 22. Here, you just cross the rails and ride, from the opposite tram platform, by tram No. 5 to the stop Čechův most (one stop). Then, crossing the Vltava River on foot, you will reach the St. Simon and Juda Church within 7-10 minutes - see the map 'Places of the Public Lectures'.
Alternatively, e.g. if you prefer to have a dinner in some restaurant located in the Old Town area, you can reach the St. Simon and Juda Church from the Malostranská station by 15-20 min walk. In such a case, we recommend to cross the River using the Mánesův most (Mánes Bridge). Public transport can also be used for your transfer across the River (tram No. 18) and in the Old Town (tram No. 17, bus No. 207) - see the map 'Places of the Public Lectures'. Underground (metro) line A connects both river banks (Malostranská and Staroměstská stations) as well.

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'15 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. 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 tram No. 18 or by underground (metro) line A (from Malostranská to Staroměstská stations) - see the map 'Places of the Public Lectures'.

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'15 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 (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 (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 river 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 monastery 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.

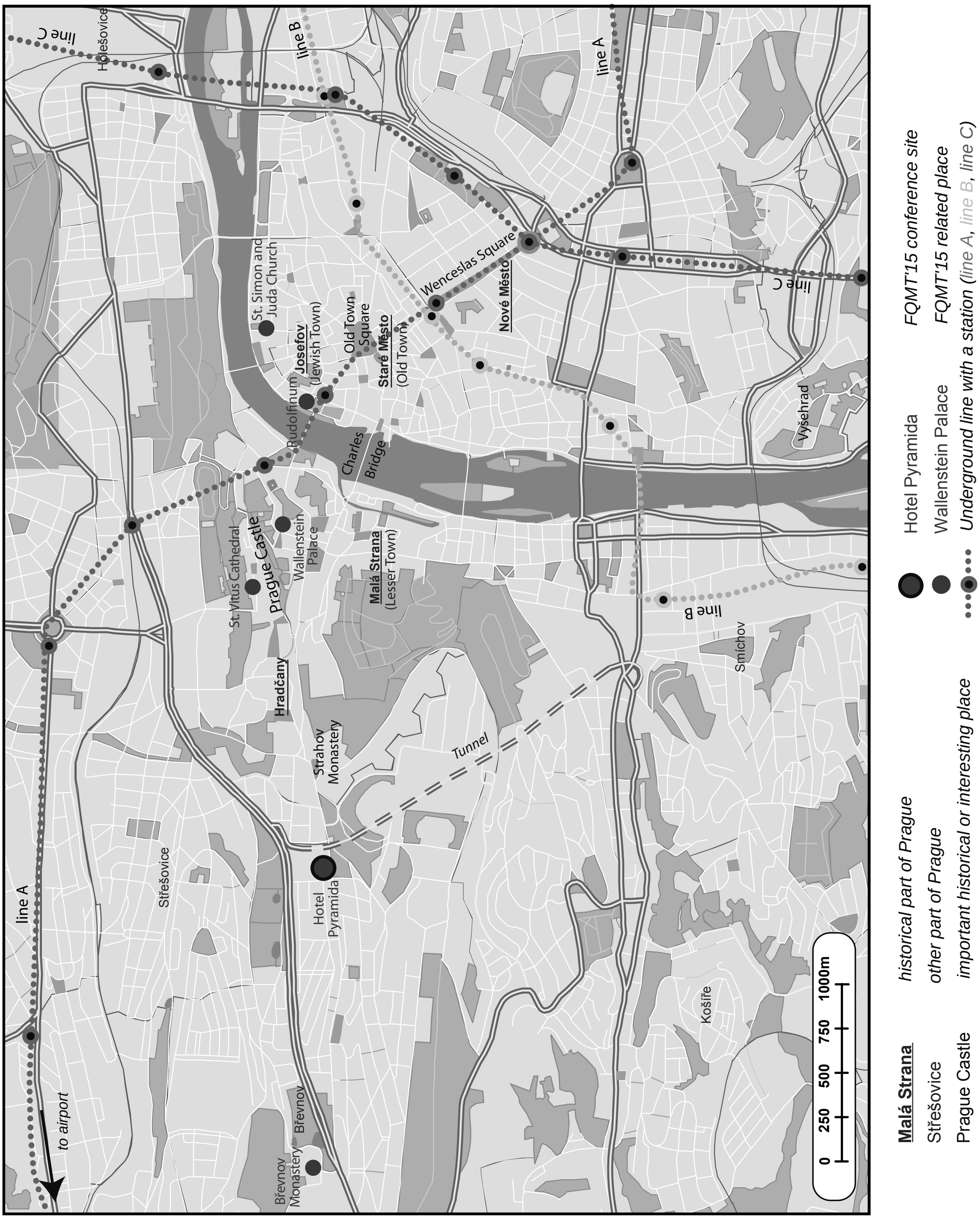
The interiors of the Břevnov Monastery are decorated by valuable paintings; e.g. in the former ceremonial hall of the monastery, nowadays called Theresian Hall, there is a ceiling painting the Miracle of the Blessed Gunther painted by Kosmas Damian Asam of Bavaria in 1727. This is one of the best preserved 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.

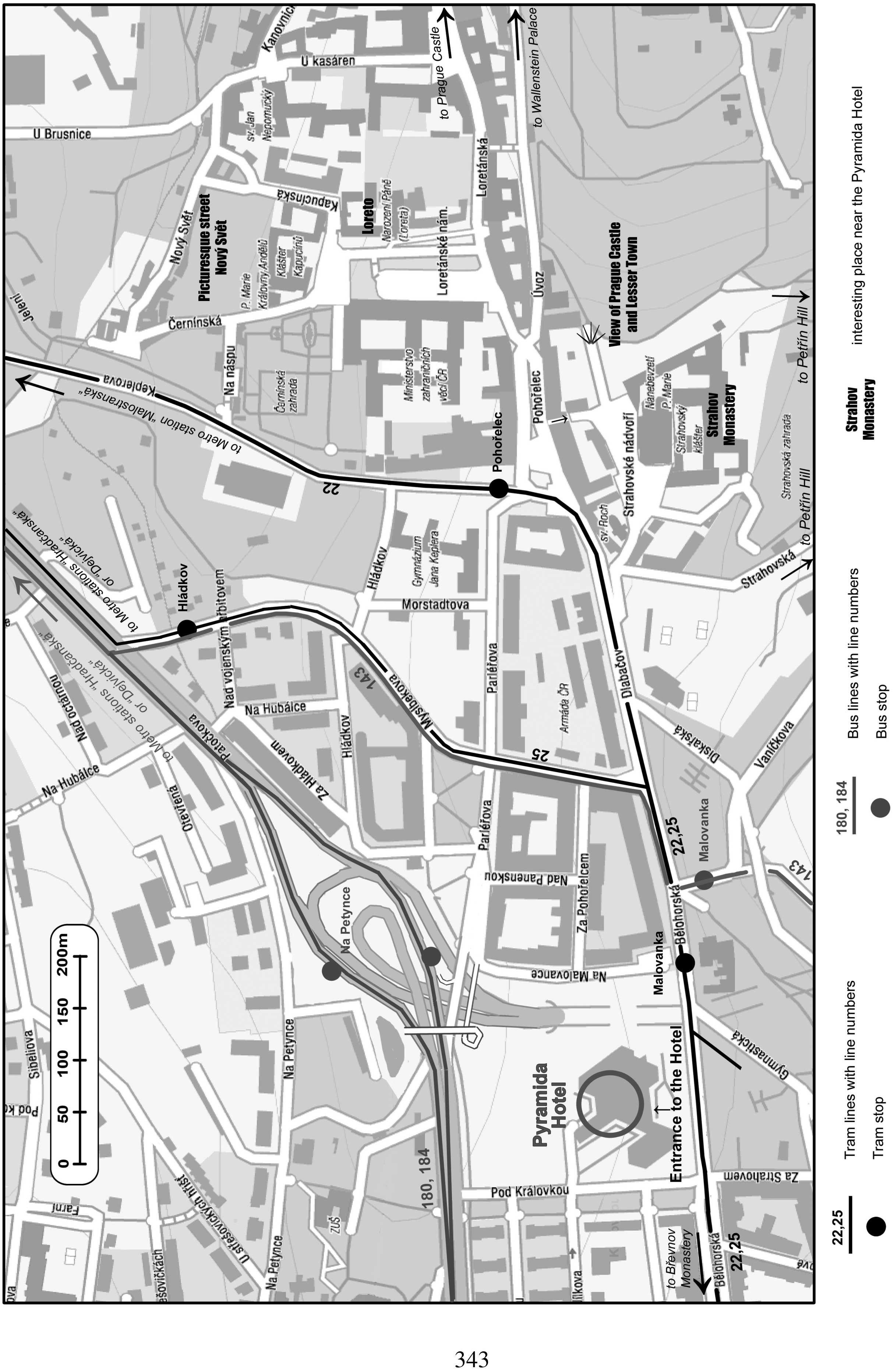
Behind the monastery is situated its large Baroque garden. At its gate is a nice Baroque pavilion called Vojtěška with a chapel above a well which marks the spot where Prince Boleslav and Bishop Vojtěch are supposed to have met and decided to built the Břevnov Monastery.

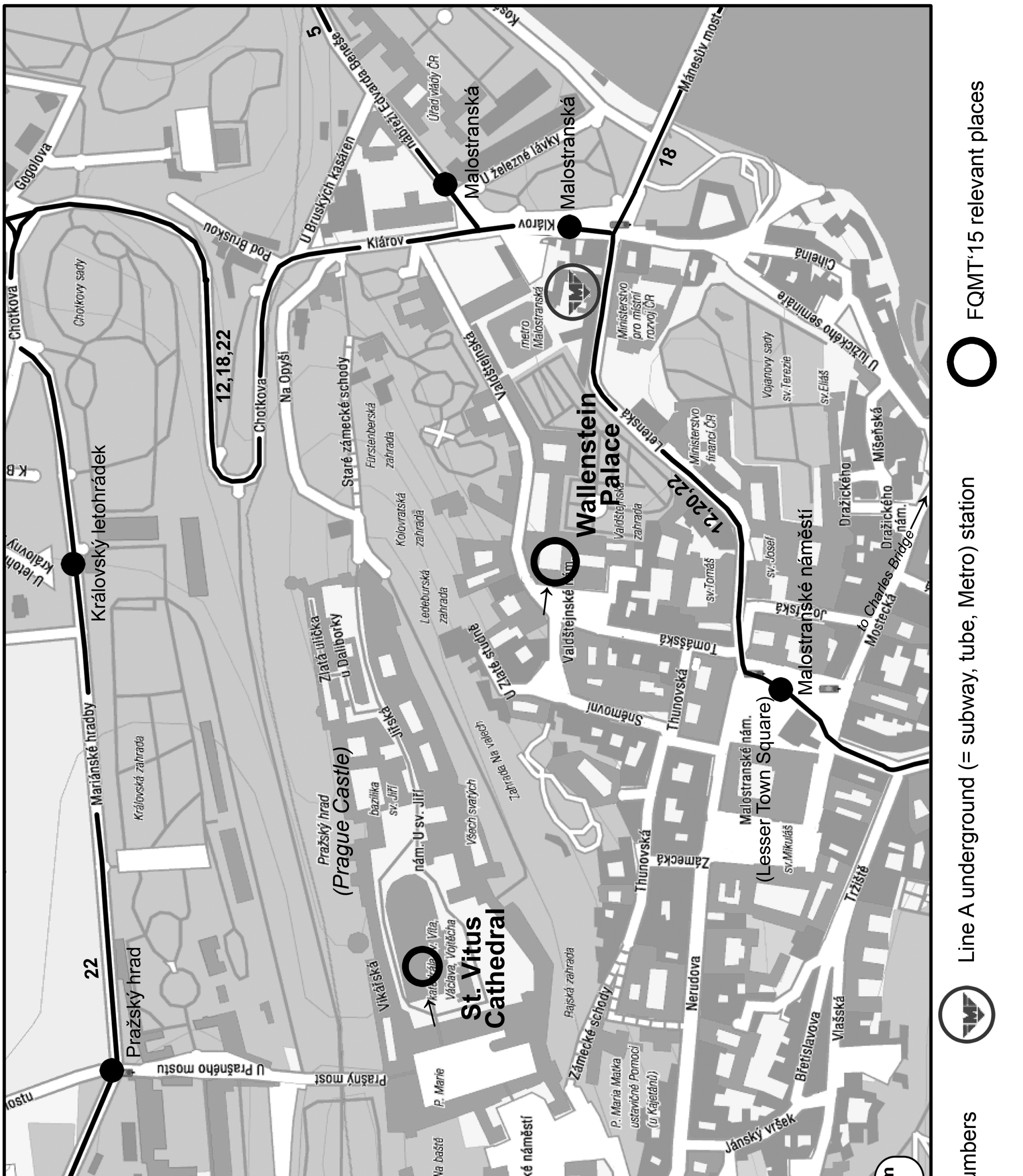
How to get there:
Special tram will depart from the Pyramida Hotel to the Břevnovský klášter stop on Friday afternoon to facilitate FQMT'15 participants transfer. Exact departure time will be announced during the Conference.
For those who will use an **individual transfer**: The best way from the Pyramida 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
Entrance to the Hotel
Strahov Monastery
Loreto
View of Prague Castle and Lesser Town
Picturesque street Nový Svět
to Prague Castle
to Wallenstein Palace
to Petřín Hill
to Břevnov Monastery
to Metro station „Malostranská"
to Metro stations „Hradčanská" or „Dejvická"
Pohořelec
Hládkov
Malovanka
Bělohorská
Dlabačov
Myslbekova
Patočkova
Keplerova
Strahovské nádvoří
Strahovská
22,25
Tram lines with line numbers
Tram stop
180, 184
Bus lines with line numbers
Bus stop
interesting place near the Pyramida Hotel
0 50 100 150 200m


St. Vitus Cathedral
Wallenstein Palace
Pražský hrad (Prague Castle)
Malostranské nám. (Lesser Town Square)
Malostranské náměstí
Hradčanské náměstí
Pražský hrad
Královský letohrádek
Malostranská
to Pyramida Hotel
to Charles Bridge
Letenská
Valdštejnská
Nerudova
Mostecká
Mánesův most
Klárov
Chotkova
Mariánské hradby
Jelení
U Prašného mostu
Prašný most
Zlatá ulička
Jiřská
Vikářská
Thunovská
Tomášská
Sněmovní
Zámecká
Tržiště
Vlašská
Úvoz
Ke Hradu
Radnické schody
Zámecké schody
Staré zámecké schody
U kasáren
Kanovnická
22
12,18,22
12,20,22
18
5
12,20,22 Tram line with line numbers
Tram stop
Line A underground (= subway, tube, Metro) station
FQMT'15 relevant places
0 50 100 150 200 250m

Places of the Public Lectures