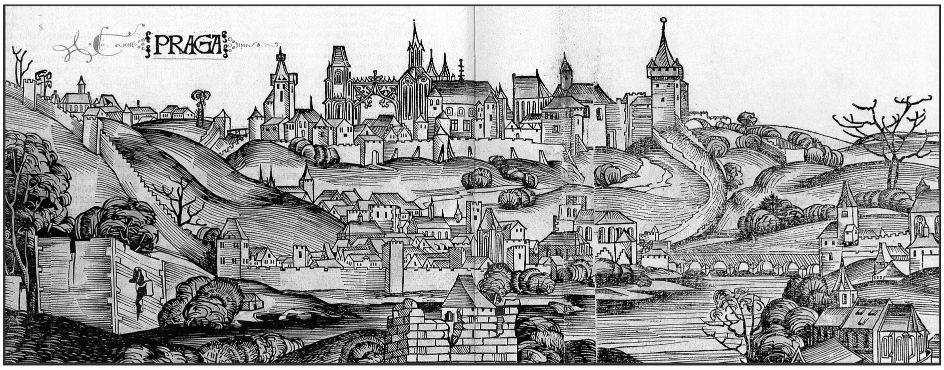
Frontiers of Quantum and Mesoscopic Thermodynamics

29 July - 3 August 2013, 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
- Institut de Physique Théorique, CEA/CNRS Saclay, France

Topics

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

Scientific Committee

Chair: Theo M. Nieuwenhuizen (University of Amsterdam)
Co-Chair: Václav Špička (Institute of Physics, Acad. Sci. CR, Prague)
Raymond Dean Astumian (University of Maine, Orono)
Roger Balian (IPhT, Saclay)
Gordon Baym (University of Illinois at Urbana - Champaign)
Dietrich Belitz (University of Oregon)
Rainer Blatt (Innsbruck University)
Miles Blencowe (Dartmouth College, New Hampshire)
Dirk Bouwmeester (University of California, Santa Barbara; Institute of Physics, Leiden)
Amir Caldeira (Universidade Estadual de Campinas)
Raymond Chiao (University of California, Merced)
Jean Ignacio Cirac (Max Planck Institute, Garching)
Claude Cohen-Tannoudji (École Normale Supérieure, Paris)
Jean Dalibard (École Normale Supérieure, Paris)
Pavel Danielewicz (Michigan StateUniversity)
Michel Devoret (Yale University and College de France)
Daniel Esteve (CEA-Saclay)
Jürg Fröhlich (ETH Zurich)
Peter Hänggi (Augsburg University)
Serge Haroche (École Normale Supérieure, Paris)
Dudley Herschbach (Harvard University)
Gregg Jaeger (Boston University)
Andrej Khrennikov (University of Vaxjo)
Hagen Kleinert (Freie Universität, Berlin)
Norbert Kroó (HAS, Budapest)
Franck Laloë (École Normale Supérieure, Paris)
David Lee (Texas A&M University)
Anthony Leggett (University of Illinois at Urbana - Champaign)

Igor Lerner (University of Birmingham)
Reinhard Lipowsky (Max Planck Institute, Potsdam)
Daniel Loss (University of Basel)
Henri Orland (CEA-Saclay)
Martin Plenio (University of Ulm; Imperial College, London)
Rudy Schild (Center for Astrophysics, Harvard University)
Wolfgang Schleich (University of Ulm)
Gora Shlyapnikov (University of Amsterdam)
Marlan Scully (Texas A&M and Princeton Universities)
Francesco Sylos Labini (Universita di Roma "La Sapienza")
Vlatko Vedral (University of Oxford)
Anton Zeilinger (Institute for Quantum Optics and Quantum Information, Vienna)

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

Organizing Committee

Conference chair: Václav Špička (Institute of Physics, Acad. Sci. CR, Prague)
Jiří Bok (Charles University, Prague)
Howard Brubaker (Detroit)
Pavla Bušová (Prague)
Barbora Chudíčková (Institute of Physics, Acad. Sci. CR, Prague)
Soňa Fialová (Prague)
Etienne Hofstetter (London)
Pavel Hubík (Institute of Physics, Acad. Sci. CR, Prague)
Peter D. Keefe (University of Detroit Mercy)
Souheil Khaddaj (Kingston University, London)
Zdeněk Kožíšek (Institute of Physics, Acad. Sci. CR, Prague)
Ján Krajník (MD Agency, Prague)
Josef Kšica (Prague)
Karla Kuldová (Institute of Physics, Acad. Sci. CR, Prague)
Jiří J. Mareš (Institute of Physics, Acad. Sci. CR, Prague)
Theo M. Nieuwenhuizen (University of Amsterdam)
Claudia Pombo (Amsterdam)
Jaroslav Šesták (Institute of Physics, Acad. Sci. CR, Prague/Pilsen)
Jarmila Šidáková (Institute of Physics, Acad. Sci. CR, Prague)
Marie Svobodová (Prague)
David Vyskočil (MD Agency, Prague)
Yuval Waldman (Music Bridge International, New York)

This conference is dedicated to the memory of Avi Schiller

In memoriam of Avi Schiller (1963-2013)

Professor Avraham (Avi) Schiller of the Hebrew University of Jerusalem died of cancer on June 22, 2013. He was 50 years old. Avi participated in several FQMT conferences, and he planned to attend FQMT'13.

Avi received his B. Sc., M. Sc. and Ph. D. degrees from the Hebrew University, graduating in 1993. After post-doctoral positions at the University of Florida and the Ohio State University, he returned to the Hebrew University in 1998, and was a member of its Racah Institute of Physics.

Avi made important contributions to the theories of strongly correlated electron systems; the Kondo effect; magnetic impurities away from equilibrium; interacting mesoscopic systems; non-Fermi-liquid behavior and magnetism in heavy-fermion compounds; and the dynamical mean-field theory for correlated electron systems. His research papers are exemplary in their calculational insight, precision and clarity. He collaborated with many physicists all over the world, and they will all feel the loss of his profound intellect, his ability to attack complex questions, and his high standards in research.

Avi was also an exceptional teacher. Last year he received the prestigious Michael Milken prize for excellence in teaching at the Hebrew University. His students fondly remember his ability to impart to them a deep appreciation of physics, through his brilliant organization of the material, his patience in answering questions (both in class and afterwards), his kindness and empathy with every student, and his modest demeanor. Despite his illness, Avi continued to teach the heavy course on Quantum Mechanics II up to the end of the last semester. He will be remembered by generations of students who both enjoyed and benefitted from the courses he gave over the years. Many of them attended the funeral and later visited the family.

Avi was deeply concerned with the future of the Racah Institute (and of physics in general); and his valuable advice was often sought out by both junior and senior colleagues. Avi had a keen enthusiasm and love for physics (even above his interest in soccer). Avi was both a family man and an outstanding researcher and teacher. He is survived by his wife, Ruth (who joined him at FQMT conferences) and their three sons, Noam, Amit and Eran. He will be greatly missed and affectionately remembered by his many friends and colleagues in the physics community.

On behalf of Avi's friends and FQMT'13 organizers

Amnon Aharony, Ofer Biham, Ora Entin-Wohlman, Joe Imry, Václav Špička

Preface

Nowadays, advances of measurement techniques have opened the possibility to investigate not only well-defined artificial structures composed of atoms (molecules), but also structures of similar nanoscale size occurring in nature, as for example complex molecules, molecular motors in living cells, proteins and viruses. Depending on conditions, nanoscale systems can demonstrate characteristics of mesoscopic systems. Due to their position between the macro and micro world, mesoscopic systems exhibit many surprising phenomena which can lead not only to novel devices, but also to a better understanding of quantum mechanics and the relation between the classical and quantum behavior by sensitive choice of parameters of the studied mesoscopic systems.

The purpose of the FQMT'13 conference is to discuss all the above aspects of mesoscopic systems and to address related fundamental problems. To understand these systems is a challenging task due to the complexity of these systems, their diversity, and the fact that these systems are on the borderline between different disciplines (i.e., physics, chemistry, and biology) where the diverse dynamic behavior of these systems and corresponding various methods of their description (individual and statistical, microscopic and macroscopic, classical and quantum) meet. The development of theoretical concepts for their description and reliable experimental methods are of great importance for investigating these systems and designing new nanostructures with well-defined, desired behavior.

The conference will address the foundations of quantum physics and non-equilibrium statistical physics. The systems considered will be mainly on the order of mesoscopic (nanoscale) size, and include those of both natural and artificial origin. The main goal of the conference is to contribute to better understanding of the behavior of mesoscopic systems, and to provide insight into the recent problems of the foundations, relying on the theoretical and experimental methods of condensed matter physics and quantum optics. Special attention will be given to problems of measurement of non-equilibrium quantum systems, physics of quantum information and biological systems, in terms of both theory and experiment. Subjects from astrophysics, gravitation or cosmology related to the above scope will be included.

FQMT'13 is a follow-up to the three previous, successful Prague conferences "Frontiers of Quantum and Mesoscopic Thermodynamics" (FQMT'04, FQMT'08, and FQMT'11). For the details of their programs and the history of the FQMT conferences see the www pages: http://fqmt.fzu.cz/. The contributions from these conferences are published in Physica E (Vol. 29, Issues 1-2, 2005, and Vol. 43, Issue 3, 2010), and Physica Scripta (Vol. T151, 2012).

As in the foregoing conferences, the aim of FQMT'13 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. Many aspects of the FQMT topics have been covered by a number of more specialized conferences and workshops, which the organizers of the FQMT conferences have taken an essential part in, namely Hot topics in Quantum Statistical Physics: q-thermodynamics, q-decoherence and q-motors, Leiden 2003; Non-equilibrium Green's Functions I-V conferences, Rostock 1999, Dresden 2002, Kiel 2005, Glasgow 2009, Jyvaskyla 2012; Conferences on the Second Law of Thermodynamics and Quantum Physics, San Diego 2002, and 2006; Beyond the Quantum, Leiden 2006; Advanced School on Quantum Foundations and Open Quantum Systems, Joa Pessoa 2012; and the Vaxjö meetings on Quantum Theory: Reconsideration of Foundations, Vaxjö 2001, 2003, 2005, 2007, 2009, and 2012.

Following the tradition of the FQMT conferences, FQMT'13 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).

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'13 program will feature concerts of classical and jazz 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.

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.

The organizers are particulary delighted that a special Monday afternoon session will be devoted to the birthday anniversary of Roger Balian, a friend of many participants and a key person of several fields of physics discussed at this conference.

Dear colleague, we welcome you to the FQMT'13 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

Important Information 3

Program 7

Public Lectures 27

Invited Talks 31

Invited Posters 173

Posters 185

Author Index 245

List of Participants 245

Conference Site Buildings 265

Maps 269

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

Important information

Contact address

FQMT'13
Dr. Václav Špička
Institute of Physics, Academy of Sciences of the Czech Republic
Cukrovarnická 10, CZ-162 00 Praha 6, Czech Republic
E-mail: fqmt13@fzu.cz
Phone: (+420) 220 318 446
Mobile: +420 776 127 134
FAX: (+420) 233 343 184
WWW: http://fqmt.fzu.cz/13

Emergency phone numbers (free calls):

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

Conference Sites

The FQMT'13 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 classical concert will take place at:
Dvořák's Hall of Rudolfinum
address: Palachovo náměstí, Praha 1 - Staré Město

Second public lecture and classical concert will take place at:
St. Simon and Juda Church
address: Dušní ulice, Praha 1 - Staré Město

Conference dinner will take place at:
Archbishop's Palace
address: Hradčanské náměstí 16, Praha 1 (near the main entrance to the Prague Castle)

Entrance to and stay inside 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
- 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'13 participants

Posters

Poster session will be held on Wednesday (July 31). Posters can be fixed from 7:30 a.m. on Wednesday 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 29
- Welcome party: Wallenstein Palace Garden, Monday July 29
- First public lecture: Dvořák's Hall of Rudolfinum, Tuesday July 30
  This evening lecture will be given by Serge Haroche.
- Classical music concert: Dvořák's Hall of Rudolfinum, Tuesday July 30
- Jazz concert: Cinema Hall of the Pyramida Hotel, Wednesday July 31

- Second public lecture: St. Simon and Juda Church, Thursday August 1
  This evening lecture will be given by Pavel Kroupa.
- Classical music concert: St. Simon and Juda Church, Thursday August 1
- Tour of Archbishop's Palace: Archbishop's Palace, Friday August 2
- Conference dinner: Archbishop's Palace, Friday August 2
- Classical music concert: St. Vitus Cathedral, Friday August 2
- Guided tour through Prague: Saturday August 3

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 Serge Haroche, 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).
- **Wednesday:** Buffet during the poster session in the **Pyramida Hotel**.
- **Thursday:** There will be enough time to go for dinner before the public lecture of Pavel Kroupa, 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).
- **Friday:** Conference dinner in **Archbishop's Palace**.
  Price: 60 EUR per person - tickets for this dinner will be available during the registration.

PROGRAM

Sunday, 28 July 2013

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

Monday, 29 July 2013

08:00 – 08:30 **Opening addresses**

Location: Pyramida Hotel Lecture Hall

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

Location: Pyramida Hotel Lecture Hall

08:30 – 09:00	Guenter Mahler:	*Observational quantum-thermodynamics: Fluctuation of intensive thermodynamic variables*
09:00 – 09:30	Gershon Kurizki:	*Work and cooling bounds in quantum thermodynamics*
09:30 – 10:00	Peter Hänggi:	*On the use and abuse of thermodynamic entropy*

10:00 – 10:20 Coffee break

10:20 – 12:10 **2 session: Physics of quantum information**

Location: Pyramida Hotel Lecture Hall

10:20 – 10:50	Andrew Cleland:	*Coupling microwaves and optical light*
10:50 – 11:20	Jens Eisert:	*The ironic situation of boson sampling*
11:20 – 11:50	Andrew G. White:	*Experimental boson sampling*
11:50 – 12:10	Lawrence S. Schulman:	*Signaling between entities with opposite thermodynamic arrows of time*

12:10 – 13:00 Lunch

13:00 – 15:00 **3 session: Non-equilibrium statistical physics**

Location: Pyramida Hotel Lecture Hall

13:00 – 13:30	David Ferry:	*Probing the quantum-classical connection with open quantum dots*
13:30 – 14:00	Wolfgang Belzig:	*Weak measurements and quantum paradoxes in quantum transport*
14:00 – 14:30	Shmuel Gurvitz:	*Single-particle approach to mesoscopic transport*
14:30 – 15:00	Yuval Gefen:	*Edge reconstruction in the fractional quantum Hall regime*

15:00 – 15:20	Coffee break		
15:20 – 17:00	**4 session: Special Roger Balian session** *Location: Pyramida Hotel Lecture Hall*		
15:20 – 15:50	Michel Brune:	*Quantum feedback preparation and stabilization of photon number states of light in a cavity*	
15:50 – 16:20	Amir O. Caldeira:	*Emergence of the pointer basis through the dynamics of correlations*	
16:20 – 17:00	Roger Balian:	*A statistical approach to the quantum measurement problem*	
17:00 – 17:45	Free time and transfer to the Wallenstein palace		
17:45 – 22:30	**Guided tour and Welcome party** *Location: Wallenstein Palace and its Garden*		
17:45 – 19:15	Guided tour through the Wallenstein Palace		
19:30 – 22:30	**Welcome party in the Wallenstein Palace Garden**		

Tuesday, 30 July 2013

08:00 – 10:00	**1 session: Noise and quantum transport**	
	Location: Pyramida Hotel Lecture Hall	
08:00 – 08:30	Jan van Ruitenbeek:	*Inelastic signals in shot noise*
08:30 – 09:00	Kensuke Kobayashi:	*Experimental test of Fluctuation Theorem in quantum regime*
09:00 – 09:30	Oren Tal:	*Relating atomic scale conductance to orbital structure by shot noise measurements*
09:30 – 10:00	Jerzy Łuczka:	*Anomalous transport in Josephson junction induced by non-equilibrium noise*
10:00 – 10:20	Coffee break	
10:20 – 12:10	**2 session - A parallel: Physics of biological systems**	
	Location: Pyramida Hotel Lecture Hall A	
10:20 – 10:50	Reinhard Lipowsky:	*Multiscale motility of molecular motors: From single motor molecules to cooperative cargo transport*
10:50 – 11:20	Bob Austin:	*Quantum transport in proteins: An experimental tale*
11:20 – 11:50	Susana Huelga:	*Exciton transport in light harvesting complexes*
11:50 – 12:10	Stefan Klumpp:	*Bacterial nanomagnets*
10:20 – 12:10	**2 session - B parallel: Astrophysics and cosmology**	
	Location: Pyramida Hotel Lecture Hall B	
10:20 – 10:50	Pavel Kroupa:	*The failure of the standard cosmological model and first steps towards a possible new direction*
10:50 – 11:20	Pavel Naselsky:	*CMB cosmology after the Planck mission*
11:20 – 11:50	Hao Liu:	*CMB large-scale anisotropy and the m=0 modes*
11:50 – 12:10	Theo Nieuwenhuizen:	*Neutrinos: The most standard-model friendly option for dark matter*
12:10 – 13:00	Lunch	

13:00	–	14:40	**3 session: Cold atoms, physics of graphene**	
			Location: Pyramida Hotel Lecture Hall	
13:00	–	13:30	Eric Akkermans:	*Quantum field theory on fractals – from spontaneous emission with a fractal QED vacuum to quantum gravity at the Planck scale. Recent results and experiments.*
13:30	–	14:00	Gilles Montambaux:	*Dirac cones, from graphene to cold atoms*
14:00	–	14:20	Efrat Shimshoni:	*Superfluid-insulator transitions of collective helical modes in the zero quantum Hall state of bilayer graphene*
14:20	–	14:40	Ralf Schuetzhold:	*Strong magneto-photoelectric effect in folded graphene*
14:40	–	15:00	Coffee break	
15:00	–	17:00	**4 session: Non-equilibrium statistical physics, publishing**	
			Location: Pyramida Hotel Lecture Hall	
15:00	–	15:30	Mauro Antezza:	*Elementary quantum systems out of thermal equilibrium: From quantum thermalization to entanglement*
15:30	–	16:00	Irena Knezevic:	*Coupling electrons, phonons, and photons for nonequilibrium transport simulation*
16:00	–	16:20	Avik Ghosh:	*Quantum transport and correlated switching – beating the Landauer limit*
16:20	–	16:40	Andrei Zaikin:	*Quantum decoherence of Cooper pairs*
16:40	–	17:00	Suzy Lidström:	*Peer pressure*
17:00	–	18:30	Free time and transfer to Rudolfinum	

18:30	–	22:30	**Evening session: Public lecture of Serge Haroche and concert**
			Location: Rudolfinum - Dvořák's Hall
18:30	–	18:45	Music introduction and opening address
18:45	–	20:00	Public lecture
18:45	–	19:45	**Serge Haroche:** ***Juggling with photons in a box to explore the quantum world***
19:45	–	20:00	Disscusion after the lecture of Serge Haroche
20:00	–	20:20	Break
20:20	–	21:20	**Concert of classical music - first part**
21:20	–	21:30	Intermission
21:30	–	22:30	**Concert of classical music - second part**

Wednesday, 31 July 2013

08:00 – 10:00	**1 session: Nanomechanical and nanoptical systems**	
	Location: Pyramida Hotel Lecture Hall	
08:00 – 08:30	Dirk Bouwmeester:	*Quantum optomechanics*
08:30 – 09:00	Florian Marquardt:	*Quantum many-body physics of phonons and photons*
09:00 – 09:20	Yaroslav M. Blanter:	*Two-mode interaction and quantum effects in non-linear mechanical resonators*
09:20 – 09:40	Liliana Arrachea:	*Heat transport and cooling in electronic and nanomechanical driven systems*
09:40 – 10:00	Mikko Möttönen:	*Experimental study of work and entropy fluctuations in a single-electron box*
10:00 – 10:20	Coffee break	
10:20 – 12:00	**2 session - A parallel: Physics of quantum information**	
	Location: Pyramida Hotel Lecture Hall A	
10:20 – 10:50	M. Suhail Zubairy:	*Optical communication with invisible photons*
10:50 – 11:10	Radim Filip:	*Non-classical quantum states of light and nonlinear operations*
11:10 – 11:40	Howard Carmichael:	*Quantum trajectories without Lindblad*
11:40 – 12:00	Francesco Petruccione:	*Microscopic derivation of open quantum walks*
10:20 – 12:00	**2 session - B parallel: Quantum transport**	
	Location: Pyramida Hotel Lecture Hall B	
10:20 – 10:50	Peter Schmitteckert:	*Transport through correlated nanostructures: Towards steady state dynamics*
10:50 – 11:10	Sam Carr:	*Full counting statistics in the not-so-long-time limit*
11:10 – 11:40	Ferdinand Evers:	*Invariants of the single impurity Anderson model and implications for conductance functionals*
11:40 – 12:00	Emanuel Gull:	*Diagrammatic Monte Carlo methods for non-equilibrium systems*

10:20	–	12:00	**2 session - C parallel: Foundations of quantum mechanics**	
			Location: Pyramida Hotel Conference Room 3	
10:20	–	10:50	Gerhard Groessing:	*Sub-quantum statistical mechanics and the vacuum fluctuation theorem*
10:50	–	11:10	Ana María Cetto:	*The spin of the electron as an emergent property*
11:10	–	11:40	Andrei Khrennikov:	*Devil is in detectors: Towards classical field model of quantum phenomena*
11:40	–	12:00	Luis de la Pena:	*Generalized quantum Ehrenfest equations including radiative corrections*
12:00	–	13:00	Lunch	
13:00	–	14:40	**3 session - A parallel: Fluctuation and FD theorems**	
			Location: Pyramida Hotel Lecture Hall A	
13:00	–	13:30	Yasuhiro Utsumi:	*Fluctuation theorem for a two-terminal conductor connected to a voltage or a thermal probe*
13:30	–	14:00	Michele Campisi:	*Quantum fluctuation relations. Overcoming the two-measurements issue*
14:00	–	14:20	Doron Cohen:	*Fluctuation dissipation phenomenology away from equilibrium*
14:20	–	14:40	Saar Rahav:	*Detailed balance and nonequilibrium fluctuation theorems*
13:00	–	14:40	**3 session - B parallel: Cold atoms**	
			Location: Pyramida Hotel Lecture Hall B	
13:00	–	13:30	Jeff Steinhauer:	*Sonic black holes and thermal phonons*
13:30	–	14:00	Frédéric Chevy:	*Thermodynamics of ultracold Fermi gases*
14:00	–	14:20	Armen Sedrakian:	*Phase diagram of imbalanced Fermi systems*
14:20	–	14:40	Jean-Philippe Brantut:	*Conduction properties of ultracold fermions*
13:00	–	14:40	**3 session - C parallel: Physics of quantum information**	
			Location: Pyramida Hotel Conference Room 3	
13:00	–	13:30	Julien Laurat:	*Witnessing single-photon entanglement with continuous-variable measurements*

13:30 – 14:00	Giuseppe Falci:	*Design of Lambda systems in superconducting architectures*
14:00 – 14:20	Elisabetta Paladino:	*Entanglement protection in superconducting qubits by dynamical decoupling*
14:20 – 14:40	Markku Stenberg:	*Quantum process tomography of energy and phase relaxation in adaptive bases*

14:40 – 15:00 Coffee break

15:00 – 16:00 **4 session - A parallel: Non-equilibrium statistical physics**

Location: Pyramida Hotel Lecture Hall A

15:00 – 15:20	Alessandro Romito:	*Weak measurement of cotunneling time*
15:20 – 15:40	Katarzyna Roszak:	*Measurement induced enhancement of quantum dot coherence*
15:40 – 16:00	Yaroslav Pavlyukh:	*On the initial stage of quasiparticle decay: A many-body perturbation theory perspective*

15:00 – 16:00 **4 session - B parallel: Mesoscopic systems**

Location: Pyramida Hotel Lecture Hall B

15:00 – 15:20	Thomas Schmidt:	*Interfacing Majorana bound states with harmonic oscillators*
15:20 – 15:40	Fabio Taddei:	*Topological pumping in superconducting wires with Majorana fermions*
15:40 – 16:00	Alexander Shnirman:	*A quantum dot close to Stoner instability: The role of Berry's phase*

15:00 – 16:00 **4 session - C parallel: Quantum transport and statistical physics**

Location: Pyramida Hotel Conference Room 3

15:00 – 15:20	Joachim Ankerhold:	*The bright side of charge transfer through Josephson junctions*
15:20 – 15:40	Boris Fine:	*Absence of exponential sensitivity to small perturbations in nonintegrable systems of spins 1/2*
15:40 – 16:00	Dragos Victor Anghel:	*Fractional exclusion statistics – the method to describe interacting particle systems as ideal gases*

16:00 – 18:00 **Poster session and refreshment**

Location: Pyramida Hotel - first floor

18:00 – 18:30 Free time

18:30 – 20:00 **Special lectures**

Location: Pyramida Hotel Lecture Hall

18:30 – 19:15	Axel Beyer:	*Precision spectroscopy of the 2S-4P transition in atomic hydrogen*
19:15 – 20:00	Roland E. Allen:	*Life in the Higgs condensate, where electrons have mass*
20:00 – 20:20	Discussion	

20:20 – 21:00 Break

21:00 – 23:00 **Jazz concert**

Location: Pyramida Hotel Cinema Hall

Thursday, 1 August 2013

08:00 – 10:00	**1 session: Foundations of quantum physics**	
	Location: Pyramida Hotel Lecture Hall	
08:00 – 08:30	Gregor Weihs:	*Multipath interference tests of quantum mechanics*
08:30 – 09:00	Bernhard Wittmann:	*Loophole-free experiments on different types of nonlocality*
09:00 – 09:30	Joshua A. Slater:	*An experimental test of all theories with predictive power beyond quantum theory*
09:30 – 10:00	Michael Hall:	*Experimental test of universal complementarity relations*
10:00 – 10:20	Coffee break	
10:20 – 12:10	**2 session: Cold atoms**	
	Location: Pyramida Hotel Lecture Hall	
10:20 – 10:50	Randall G. Hulet:	*Hubbard model with ultracold atoms: Observation of antiferromagnetic correlations*
10:50 – 11:20	Yoram Alhassid:	*The trapped cold atomic Fermi gas condensate in the configuration-interaction approach*
11:20 – 11:50	Linda Reichl:	*Transport theory for a dilute Bose-Einstein condensate*
11:50 – 12:10	Fernando Sols:	*Quantum transport of cold atoms: Hawking radiation and synthetic fields.*
12:10 – 13:00	Lunch	
13:00 – 14:40	**3 session - A parallel: Cold atoms**	
	Location: Pyramida Hotel Lecture Hall A	
13:00 – 13:30	Ulrich Schneider:	*Negative absolute temperatures for motional degrees of freedom*
13:30 – 14:00	Claudio Verdozzi:	*Dynamical competition between disorder and interactions in ultracold atoms and transport phenomena*
14:00 – 14:20	Thomas Vojta:	*Strong-randomness phenomena at superfluid phase transitions*

14:20 – 14:40	Franz Xaver Bronold:	*Quantum-kinetics of charge-transferring atom-surface collisions*

13:00 – 14:40 **3 session - B parallel: Foundations of quantum mechanics**

Location: Pyramida Hotel Lecture Hall B

13:00 – 13:30	Raymond Chiao:	*Is communication via gravitational radiation possible?*
13:30 – 14:00	Nadav Katz:	*Tomography and control of superconducting circuits*
14:00 – 14:20	Alex Retzker:	*Towards a large-scale quantum simulator on diamond surface at room temperature*
14:20 – 14:40	Vladimir M. Stojanovic:	*Analog quantum simulators of small-polaron physics*

13:00 – 14:40 **3 session - C parallel: Non-equilibrium statistical physics**

Location: Pyramida Hotel Cinema Hall

13:00 – 13:30	Daniel Neuhauser:	*Stochastic large scale DFT and quantum chemistry: On the road to millions of electrons*
13:30 – 14:00	Jürgen Stockburger:	*Non-locality from local stimuli: Entanglement generation in a dissipative system.*
14:00 – 14:20	Denis Feinberg:	*Coherent DC transport in biased Josephson bijunctions*
14:20 – 14:40	Ivan Rungger:	*Topological surface states scattering from first principles*
14:40 – 15:00	Coffee break	

15:00 – 16:40 **4 session - A parallel: Thermodynamics, Biological physics**

Location: Pyramida Hotel Lecture Hall A

15:00 – 15:30	Gombojav O. Ariunbold:	*Quantum thermodynamics: Increasing quantum heat engine efficiency via quantum coherence*
15:30 – 16:00	Michael Kastner:	*Prethermalisation and thermalisation in long-range quantum spin systems*
16:00 – 16:20	Joan Vaccaro:	*Single-reservoir heat engine: Controlling the spin*

16:20 – 16:40	Wokyung Sung:	*Surmounting the insurmontable: Barrier crossing in biological dynamics at mesoscales*

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

Location: Pyramida Hotel Lecture Hall B

15:00 – 15:30	Yigal Meir:	*Emerging localized states and alternating Kondo effects in quantum point contacts*
15:30 – 16:00	Jan von Delft:	*Microscopic origin of the 0.7-anomaly in quantum point contacts*
16:00 – 16:20	Frank Hekking:	*Quantum jump approach for work and dissipation in a two-level system*
16:20 – 16:40	Artur Slobodeniuk:	*Equilibration of quantum Hall edge states by an Ohmic contact*

15:00 – 16:40 **4 session - C parallel: Foundations of quantum mechanics**

Location: Pyramida Hotel Cinema Hall

15:00 – 15:30	Jean-Daniel Bancal:	*Quantum nonlocality based on finite-speed causal influences leads to superluminal signalling*
15:30 – 16:00	Bruno Sanguinetti:	*Realization of a parametric interaction between two photons from independent sources*
16:00 – 16:20	Yeong-Cherng Liang:	*All entangled states display some hidden nonlocality*
16:20 – 16:40	Marco Gramegna:	*Two-photon spectral amplitude resolved in separable Schmidt modes*

16:40 – 18:30 Free time and transfer to the St. Simon and Juda Church

18:30	–	22:30	**Evening lecture: Public lecture of Pavel Kroupa and concert**
			Location: St. Simon and Juda Church
18:30	–	18:45	Music introduction and opening address
18:45	–	19:45	Public lecture
18:45	–	19:45	**Pavel Kroupa:** ***How astronomers define our world view***
19:45	–	20:00	Discussion after the lecture of Pavel Kroupa
20:00	–	20:20	Break
20:20	–	21:10	**Concert of classical music - first part**
21:10	–	21:30	Intermission
21:30	–	22:30	**Concert of classical music - second part**

Friday, 2 August 2013

08:00 – 10:00	**1 session: Non-equilibrium statistical physics**	
	Location: Pyramida Hotel Lecture Hall	
08:00 – 08:30	Udo Seifert:	*Stochastic thermodynamics of autonomous information machines. From Maxwell's demons to cellular sensing*
08:30 – 09:00	J. Miguel Rubi:	*Mesoscopic thermodynamics for near-field heat transfer*
09:00 – 09:30	Ulrich Weiss:	*Thermodynamic anomaly and reentrant classicality of a damped quantum system*
09:30 – 10:00	Yoseph Imry:	*A simple quantum derivation of the Jarzynski and Crooks equalities*
10:00 – 10:20	Coffee break	
10:20 – 12:00	**2 session - A parallel: Non-equilibrium statistical physics**	
	Location: Pyramida Hotel Lecture Hall A	
10:20 – 10:50	Fabrizio Nichele:	*Transport experiments in InAs/GaSb broken-gap quantum wells*
10:50 – 11:20	Michael Galperin:	*Molecular nanoplasmonics*
11:20 – 11:40	Hyoung Joon Choi:	*Self-energy-corrected scattering-state method for electronic transport in single-molecule junctions*
11:40 – 12:00	Jong Han:	*Interplay of strong correlation and dissipation in nonequilibrium lattice systems*
10:20 – 12:00	**2 session - B parallel: Physics of mesoscopic systems**	
	Location: Pyramida Hotel Lecture Hall B	
10:20 – 10:50	Hugues Pothier:	*Revealing the Andreev degree of freedom in the Josephson effect*
10:50 – 11:20	Gert-Ludwig Ingold:	*Zeno effect for repeated projective and finite-time measurements*
11:20 – 11:40	Branislav Nikolic:	*Gauge-invariant nonequilibrium density matrix with applications to spin torques driven by spin-orbit coupling*
11:40 – 12:00	Antonio Macedo:	*Localization effects in quantum dot networks: A unified approach*

10:20 – 12:00	**2 session - C parallel: Thermodynamics** *Location: Pyramida Hotel Cinema Hall*	
10:20 – 10:50	Vittorio Giovannetti:	*Minimal self-contained quadridot quantum refrigeration machine*
10:50 – 11:20	Lea Santos:	*Relationship between initial state and Hamiltonian as a main factor for thermalization*
11:20 – 11:40	Karen Hovhannisyan:	*The role of entanglement in work extraction*
11:40 – 12:00	Jiří J. Mareš:	*On mathematical structure of physical quantities*
12:00 – 13:00	Lunch	
13:00 – 15:00	**3 session: Non-equilibrium statistical physics** *Location: Pyramida Hotel Lecture Hall*	
13:00 – 13:30	James Freericks:	*Beyond Planck-Einstein quanta: Crossover from frequency driven to amplitude driven excitation in a nonequilibrium many-body system*
13:30 – 14:00	Frithjof Anders:	*Influence of vibrational modes on the quantum transport through a nano-device*
14:00 – 14:30	Gianluca Stefanucci:	*Nonequilibrium Green's function approach to ultrafast electron*
14:30 – 15:00	Juan Carlos Cuevas:	*Heat dissipation in atomic-scale junctions*
15:00 – 15:20	Coffee break	
15:20 – 16:50	**4 session: General physics** *Location: Pyramida Hotel Lecture Hall*	
15:20 – 15:50	Hagen Kleinert:	*Quantum field theory of black-swan events*
15:50 – 16:20	Miles Blencowe:	*Effective field theory approach to gravitationally induced decoherence*
16:20 – 16:50	Norbert Kroo:	*Nonlinear plasmonics*
16:50 – 17:30	Free time and transfer to the Prague Castle	

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

Location: Prague Castle - Archbishop's Palace and St. Vitus Cathedral

17:30	–	18:30	Guided tour through Archbishop's Palace
18:30	–	20:15	First part of the conference dinner
20:15	–	20:30	Transfer to the St. Vitus Cathedral
20:30	–	22:00	**Concert in the St. Vitus Cathedral**
22:00	–	23:30	Second part of the conference dinner

Saturday, 3 August 2013

08:00 – 10:00 **1 session: Quantum information, Foundations of quantum mechanics**

Location: Pyramida Hotel Lecture Hall

08:00 – 08:30	Timothy Ralph:	*Gaussian post-selection and quantum communication*
08:30 – 09:00	Kristel Michielsen:	*Event-by-event simulation of neutron interferometry experiments*
09:00 – 09:30	Philipp Haslinger:	*A universal matter-wave interferometer with optical gratings in the time domain*
09:30 – 10:00	Hans De Raedt:	*Quantum theory as the most robust description of reproducible experiments*

10:00 – 10:20 Coffee break

10:20 – 12:00 **2 session: Quantum optics, Non-equilibrium statistical physics**

Location: Pyramida Hotel Lecture Hall

10:20 – 10:50	Tamar Seideman:	*New directions in strong field coherent control. From spinning tops to ultrafast switches*
10:50 – 11:20	Anil Patnaik:	*Ultrafast saturation of Raman coherence*
11:20 – 11:40	Rudolf Hilfer:	*Time flow in non-equilibrium statistical physics*
11:40 – 12:00	Václav Špička:	*Has a fluctuation dissipation theorem some sense out of equilibrium?*

12:00 – 13:00 Lunch

13:00 – 14:00	**General physics**			
	Location: Pyramida Hotel Lecture Hall			
13:00 – 13:30	Arkady Plotnitsky:	*On the concept of quantum field: From reality to probability*		
13:30 – 14:00	Peter Keefe:	*Bardeen hysteresis: Fact or fiction?*		
14:00 – 14:30	**Closing and refreshment**			
	Location: Pyramida Hotel Lecture Hall			

Public Lectures

Juggling with photons in a box to explore the quantum world

Serge Haroche

École Normale Supérieure, Laboratoire Kastler-Brossel, 24 rue Lhomond, 75005 Paris, France

Collège de France, 11, place Marcelin Berthelot, 75231 Paris Cedex 05, France

Atoms interacting with microwave photons trapped between highly reflecting mirrors realize an ideal system to perform some of the thought experiments imagined by the founding fathers of quantum physics and to illustrate fundamental aspects of the quantum meassurement theory. While photons are generally annihilated when detected, we are able to count light quanta without destroying them. This has allowed us to manipulate and control light fields in novel ways. We have for instance prepared and detected so called “Schrödinger cats” of radiation, in reference to the famous feline that the Austrian physicist imagined to be suspended between life and death. In our experiments, we generate a field made of a few photons which is suspended between two states with opposite phases and we observe how this counterintuitive superposition vanishes under the effect of decoherence. The study of this kind of strange states, impossible to comprehend by classical logic, is now developing in many laboratories around the world in a very active and fast expanding domain of research called quantum information science. By controlling and manipulating simple atomic or photonic systems in state superpositions, scientists hope to develop new devices which will use the principles of quantum physics to improve the precision of measurements, the secrecy of communications or the power of computer simulations.

L2

How astronomers define our world view

Pavel Kroupa

Argelander Institute for Astronomy (AIfA), University of Bonn, Auf dem Huegel 71, D-53121 Bonn, Germany

The interpretations of astronomical observations influenced our world views at every age, and at the same time the latest observations led to a refinement and ultimately the collapse of theories. I will venture from antiquity to the future thereby outlining how standard models of the universe were created and replaced. I will emphasise that today this process continues such that we are most likely very far from a true understanding of what the universe really is. The latest results again suggest a major revision of our current standard ideas.

Invited Talks

Quantum field theory on fractals – from spontaneous emission with a fractal QED vacuum to quantum gravity at the Planck scale. Recent results and experiments.

Eric Akkermans

Department of Physics, Technion-Israel Institute of Technology, Technion, Haifa, Israel

Fractals define a new and interesting realm for a discussion of basic phenomena in quantum field theory (QFT) in general and in QED in particular. This interest results from specific properties of fractals, e.g., their dilatation symmetry as opposed to the translation symmetry of Euclidean space and the corresponding absence of Fourier mode decomposition. Moreover, the existence of a set of distinct (usually non integer) dimensions characterizing the physical properties (spatial or spectral) of fractals make them a useful testing ground for dimensionality dependent physical problems.

After presenting general features of QFT on fractals, we shall discuss in more details basic QED physics such as spontaneous emission of a quantum emitter coupled to a fractal vacuum. We will present and discuss recent experimental results.

We shall then turn to the case of massive bosons and discuss the nature of Bose-Einstein condensation and the onset of superfluidity in fractal structures. The existence of distinct fractal dimensions characterizing spatial and spectral properties is instrumental in understanding the dimensionality dependence of the BEC and the existence of a superfluid order either through the existence of an "Off Diagonal Long Range Order" (ODLRO) or the generalization of the Mermin-Wagner theorem on long range order and its implication on the existence of topological defects.

Finally, we shall present recent results obtained in quantum Einstein gravity and discuss short scale fractal structure of the quantum universe.

[1] E. Akkermans, G.V. Dunne and A. Teplyaev, Europhys. Lett. 88, 40007, 20089

[2] E. Akkermans, G.V. Dunne and A. Teplyaev, Phys. Rev. Lett. 105, 230407, 2010

[3] E. Akkermans and G.V. Dunne, Phys. Rev. Lett. 108, 030401, 2012

[4] E. Akkermans and D. Gittelman, to be published, 2013

[5] E. Akkermans, Statistical Mechanics and Quantum Fields on Fractals, in "Applications of Fractals and Dynamical Systems in Science and Economics", D. Carfi, M.L. Lapidus, E.J. Pearse, and M. van Frankenhuijsen eds., Contemporary Mathematics (CONM) b

T2

The trapped cold atomic Fermi gas condensate in the configuration-interaction approach

Yoram Alhassid and Christopher Gilbreth

Center for Theoretical Physics, Sloane Physics Laboratory, Yale University, New Haven, Connecticut 06520, USA

The trapped cold atomic Fermi gas provides a strongly interacting system that is well defined and offers physicists an unprecedented opportunity to assess theoretical techniques that cross the disciplinary boundaries. The interaction strength between the atoms can be experimentally tuned to produce a wide range of systems, including a Bose-Einstein condensate (BEC) and a Bardeen-Cooper-Schrieffer (BCS) regime, as well as a non-perturbative unitary regime, in which the interaction is strongest. We have used the configuration-interaction (CI) approach, widely used in atomic, molecular and nuclear spectroscopy, to study the cold atomic condensate.

(i) New effective interaction for the trapped Fermi gas.

The interaction is often described by a contact interaction that is ill-defined and has to be regularized (by, e.g., a momentum cutoff). However, the convergence of the many-particle energies in the regularization (truncation) parameter is slow. A new effective interaction was introduced in Ref. [1] for the unitary gas in the CI framework that dramatically improves the convergence of the many-particle energies in the regularization parameter. More recently, we have generalized such an effective interaction to the complete BEC to BCS crossover [2]. We have used this effective interaction to calculate accurately the spectra of few-atom systems.

(ii) Superfluidity in the finite-size trapped unitary gas.

Superfluidity in the cold atomic unitary Fermi gas remains incompletely understood. In particular, a pseudogap phase has been proposed to exist above the superfluid critical temperature. We have implemented the auxiliary-field Monte Carlo method to study the thermodynamics of the finite-size system with a fixed number of particles using the CI approach [3]. We have performed the first ab initio calculations of the temperature dependence of three quantities – the energy-staggering pairing gap, the condensate fraction and the heat capacity in a trapped finite-size cold atom system. We have observed clear signatures of the superfluid phase transition in all three quantities, including a signature of the recently measured lambda peak in the heat capacity, but find no evidence of a pseudogap effect in the energy-staggering pairing gap for the finite-size system.

[1] Y. Alhassid, G.F. Bertsch, and L. Fang, Phys. Rev. Lett. 100, 230401 (2008).

[2] C.N. Gilbreth and Y. Alhassid, Phys. Rev. A 85, 033621 (2012).

[3] C.N. Gilbreth and Y. Alhassid, arXiv:1210:4131.

Life in the Higgs condensate, where electrons have mass

Roland E. Allen

Texas A&M University, Department of Physics and Astronomy, College Station, USA

The particle recently discovered by the CMS and ATLAS collaborations at CERN is almost certainly a Higgs boson, fulfilling a quest that can be traced back to three seminal high-energy papers of 1964, but which is intimately connected to ideas in other areas of physics that go back much further. In 1935, Fritz and Heinz London effectively gave mass to the photon in a superconductor, and thereby provided a macroscopic explanation of the Meissner effect – the expulsion of a magnetic field from a superconductor. In 1963, Philip Anderson pointed out another important aspect: A would-be zero-mass Nambu-Goldstone boson in a superconductor is effectively eaten by the photon to become a finite-mass longitudinal mode, which appears as a plasmon in a nonrelativistic treatment. In 1964, realistic models with Lorentz invariance and nonabelian gauge fields were formulated by Englert and Brout, by Higgs, and by Guralnik, Hagen, and Kibble. Finally, Weinberg recognized that a Yukawa interaction with the Higgs field would give masses to fermions like the electron in the fully developed electroweak theory. The Higgs condensate is thus responsible for the masses both of the gauge bosons which are carriers of the weak nuclear force and of fermions like electrons, but in different ways. The radius of an electron's orbit in the ground state of a hydrogen atom is inversely proportional to the electron mass, and similar results hold for other atoms. So if the mass of an electron were zero there would be no atoms, and the formation of ordinary matter would be impossible without the Higgs condensate. (However, about 99% of the mass of an atom or human body results from the kinetic energy of quarks and gluons as they whiz around relativistically inside the protons and neutrons.) It is a true demonstration of the unity of physics that the Meissner effect in a superconducting metal and the short range of the weak nuclear force in the universe have the same origin: In each case the vector bosons (photons or W and Z bosons) grow masses because they are coupled to a field which forms a condensate at low temperature, as the metal is cooled in the laboratory or the universe expands and cools after the Big Bang. Because of a quadratic divergence of radiative corrections to its mass, the Higgs boson appears to require new physics such as supersymmetry, potentially opening the door to a plethora of new effects and new particles, such as a dark-matter candidate. It is also connected to grand unification of the forces of nature, with various high-energy symmetry breakings which presumably involve condensation of Higgs-like fields. Finally, the cosmological constant and dark energy problems are yet again associated with the Higgs field, whose condensation should produce an enormous negative vacuum energy. Instead of acting as an endpoint for physics, and a mere capstone of the Standard Model, the Higgs boson is thus a harbinger of exciting new physics.

T4

Influence of vibrational modes on the quantum transport through a nano-device

Frithjof Anders

Lehrstuhl für Theoretische Physik II, Fakultät Physik, Technische Universtät Dortmund, Otto-Hahn Str 4, 44227 Dortmund, Germany

We employ the scattering states numerical renormalization group (SNRG) approach to calculate I(V) and the differential conductance through a single molecular level coupled to a local molecular phonon using the spinless Anderson-Holstein model. We also discuss the equilibrium physics of the model and demonstrate that the low-energy Hamiltonian is given by an effective interacting resonant level model. From the NRG level flow, we directly extract the effective charge transfer scale U_{eff} and the dynamically induced capacitive coupling U_{eff} between the molecular level and the lead electrons, which turns out to be proportional to the polaronic energy shift E_p for the regimes investigated here. The equilibrium spectral functions for the different parameter regimes are discussed. The additional phonon peaks at multiples of the phonon frequency ω_0 correspond to additional maxima in the differential conductance. Nonequilibrium effects, however, lead to significant deviations between a symmetric junction and a junction in the tunnel regime. The suppression of the current for particle-hole asymmetric junctions with increasing electron-phonon coupling, the hallmark of the Franck-Condon blockade, is discussed.

Fractional exclusion statistics – the method to describe interacting particle systems as ideal gases

Dragos Victor Anghel

Horia Hulubei National Institute of Physics and Nuclear Engineering, 30 Reactorului Street, Magurele, Ilfov, Romania

I will give a brief introduction into the formalism of fractional exclusion statistics (FES) and I will show how this can be applied to describe general interacting particle systems as ideal gases. To form the ideal FES gas we have to define a type of quasiparticles of energies which do not depend on the populations and such that the total energy of the system is equal to the sum of the quasiparticle energies – notice that for typical quasiparticles, e. g. Landau's quasiparticles in the Fermi liquid theory, neither of these conditions is satisfied. The FES description is physically equivalent to other descriptions of the system in terms of quasiparticles and I will show how we can make the correspondence between such descriptions.

T6

The bright side of charge transfer through Josephson junctions

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

Institute for Theoretical Physics, University of Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany

The coupling of photonic and charge degrees of freedom has recently been explored in experiments [1,2] where voltage-biased Josephson junctions (JJ) strongly interact with microwave cavities. The JJ can either be operated in the Coulomb blockade regime (incoherent transfer of Cooper pairs) with low photon population in the cavity or in the coherent domain with high photon population and strong emitted radiation. This is related to a quantum-classical correspondence of the JJ-cavity system. In this talk we present a theoretical description and specific results for various observables of experimental relevance such as current, current noise, photon distribution, emitted radiation [3]. Further, extensions of present set-ups towards the generation of entangled photon pairs are discussed.

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

[2] M. P. Blencowe et al, in: Fluctuating Nonlinear Oscillators, M. Dykman (ed.), 33 (2012)

[3] V. Gramich, S. Rohrer, B. Kubala and J. Ankerhold, in preparation

Elementary quantum systems out of thermal equilibrium: From quantum thermalization to entanglement

Mauro Antezza

Laboratoire Charles Coulomb, Université Montpellier 2 - CNRS, Place Eugène Bataillon - cc 074, Montpellier, France

We study the internal dynamics, the quantum thermalization and the entanglement of elementary quantum systems (one or two atoms) placed close to a body held at a temperature different from that of the surrounding radiation.

Concerning the single atom dynamics [1,2], we derive general expressions for lifetime and density matrix valid for bodies of arbitrary geometry and dielectric permittivity. Out of equilibrium, the thermalization process and steady states become both qualitatively and quantitatively significantly different from the case of radiation at thermal equilibrium. For the case of a three-level atom close to a slab of finite thickness, we predict the occurrence of population inversion and an efficient cooling mechanism for the quantum system, whose effective internal temperature can be driven to values much lower than both involved temperatures. Our results show that non-equilibrium configurations provide new promising ways to control the state of an atomic system.

We also consider two two-level atomic quantum systems (qubits) [3]. While at thermal equilibrium the two-qubit dynamics is characterized by not entangled steady thermal states, we show that absence of thermal equilibrium may bring to the generation of entangled steady states. Remarkably, this entanglement emerges from the two-qubit dissipative dynamic itself, without any further external action on the two qubits, suggesting a new protocol to produce and protect entanglement which is intrinsically robust to environmental effects.

[1] Bruno Bellomo, Riccardo Messina, and Mauro Antezza, Europhys. Lett. 100, 20006 (2012).

[2] Bruno Bellomo, Riccardo Messina, Didier Felbacq, and Mauro Antezza, Phys. Rev. A 87, 012101 (2013).

[3] Bruno Bellomo, and Mauro Antezza, arXiv:1304.2864 (2013).

T8

Heat transport and cooling in electronic and nanomechanical driven systems

Liliana Arrachea

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

The study of electronic transport in mesoscopic devices and nano-structures has attracted much interest for many years now. More recently, this field has been enriched with the study of the concomitant energy dissipation and the search for novel cooling mechanisms.

In this talk, two mechanisms for cooling nonomechanical systems will be discussed. The first one is based on driving with a moving back gate, and constitutes a realization of a phonon pump which transfers heat from a cold body to a hotter one. The second mechanism resorts to electron-phonon coupling and consists in cooling vibrational modes by means of an electron current. In both cases we propose microscopic models, we analyze the relevant operational regimes and we estimate the efficiency of the refrigerator.

Quantum transport in proteins: An experimental tale

Bob Austin

Princeton University, 122 Jadwin Hall, Princeton, USA

Modern non-linear science got started in 1952 when Enrico Fermi, John Pasta, Stan Ulam and Mary Tsingou Menzel discovered a remarkable effect about non-linear system dynamics while exploring the dynamics of a chain of masses connected by anharmonic springs via a computer simulation (in 1952!). To their great surprise, the system was not ergodic under certain initial conditions but periodically returned to its original conditions. The Fermi-Pasta-Ulam-Tsingou discovery of what could be called non-thermalization took awhile to get into the public domain, and during this time the mathematician Martin Kruskal at Princeton with Norman Zabusky at Bell Labs discovered that there were integrable solutions to a nonlinear differential equation called the Korteweg–de Vries equation (KdV) equation that came out of studies of nonlinear dispersive waves [1]. These solutions had remarkably robust properties and Kruskal coined the term "soliton" to describe them, a wonderful term that immediately entered the public domain. Solitons are particularly interesting phenomena and important to physics at many different levels because they act as "particles" with an identity as they move through an anharmonic region. An excellent introduction to solitons can be found in the book by Drazin and Johnson [2].

I'll present a summary of picosecond pump-probe and photon echo experiments in the mid-IR at 6 microns on the protein myoglobin looking for these solitons [3,4]. The intriguing temperature dependence of the amide I band in Mb is rather similar to the temperature dependence of the amide I band of acetanilide, the molecule that launched Al Scott done the road of looking for Davydov solitons in biology. Alas, after much effort we believe the data shows that there is no long-lived Davydov soliton at least in myoglobin, but perhaps I am wrong [5].

[1] Zabusky, N.J., Kruskal, M.D., Interaction of Solitons in a Collisionless Plasma and Recurrence of Initial States. Phys. Rev. Lett. 15, 240-244 (1965)

[2] Drazin, P.G., Johnson, R.S., Solitons: An Introduction, Cambridge Texts in Applied Mathematics (1989)

[3] Xie, A., van der Meer, L., Hoff, W., Austin, R.H., Long-Lived Amide I Vibrational Modes in Myoglobin. Phys. Rev. Lett. 84, 5435-5438 (2000)

[4] Xie, A., van der Meer, L., Austin, R.H., Excited-State Lifetimes of Far-Infrared Collective Modes in Proteins. Phys. Rev. Lett. 88, 018102-1 - 018102-4 (2002)

[5] Penrose, R. The Emperors New Mind - Concerning Computers, Minds, and the Laws of Physics. Behavioral and Brain Sciences 13, 643-654 (1990)

T10

A statistical approach to the quantum measurement problem

Roger Balian

IPhT, Saclay, CEA, Centre de Saclay, F-91191 Gif-sur-Yvette Cx, France

Courses of quantum mechanics usually present the properties of ideal measurements as specific postulates which supplement the standard ones. In order to prove these properties and not postulate them, we treat here a measurement as a set of hamiltonian dynamical processes where the tested system S interacts with a macroscopic apparatus A; this implies the use of quantum statistical mechanics. The theory relies on a minimalist formulation of quantum mechanics, where a state, represented by a density operator (or even by a pure state), does not refer to an individual object but to a statistical ensemble in which this object is embedded. The Hamiltonian that governs the evolution of S+A during the measurement should have some specific properties to ensure that the repeated process behaves as an ideal measurement. The expected final state of S+A in a repeated measurement can then be identified, for a large set of runs as well as for arbitrary subsets, as a thermodynamic equilibrium state. The study, in the framework of quantum statistical dynamics, of the relaxation towards such a state exhibits several time scales. A severe difficulty arises, due to a quantum ambiguity: the knowledge of the final state of S+A for the full large set of runs of the measurement does not allow us to identifiy, among the various mathematically allowed candidates, the final states associated with physical subensembles of runs. This specifically quantum difficulty is overcome owing to a special type of relaxation which holds for any subensemble. By relying on the structure of the final states thus found for all possible subensembles of runs, we infer the uniqueness of the outcome of each individual run, providing a solution of the "quantum measurment problem". The "reduction of the state" of S follows, and a frequency interpretation is given to Born's rule.

[1] A. Allahverdyan, R. Balian and Th. Nieuwenhuizen, arXiv:1303.7257

[2] A. Allahverdyan, R. Balian and Th. Nieuwenhuizen, Physics Reports, 525 (2013)

Quantum nonlocality based on finite-speed causal influences leads to superluminal signalling

Jean-Daniel Bancal[1], Stefano Pironio[2], Antonio Acín[3, 4], Yeong-Cherng Liang[5], Valerio Scarani[1, 6], and Nicolas Gisin[5]

[1] *Center for Quantum Technologies, National University of Singapore, Singapore*

[2] *Laboratoire d'Informatique Quantique, Universite Libre de Bruxelles, Belgium*

[3] *Institut de Ciencies Fotoniques, Castelldefels (Barcelona), Spain*

[4] *Institucio Catalana de Recerca i Estudis Avancats, Barcelona, Spain*

[5] *Group of Applied Physics, University of Geneva, Switzerland*

[6] *Department of Physics, National University of Singapore, Singapore 117542*

The results observed when measuring two entangled quantum particles separated from each other can be correlated in a way that cannot be explained by past causes common to both measurements [1,2]. Still, common causes supplemented by the exchange of influences between distant measurements could explain these results.

Since the measurement events can be space-like separated, any such type of explanation must involve faster than light influences, which could yet remain hidden in the sense of not allowing observable correlations to be used to communicate faster than light. This is what led Abner Shimony to name the situation as "peaceful coexistence" between hidden influences behind the quantum and no signalling at the level of correlations [3].

Here we show that any such model gives, for any finite $v > c$, predictions that can be used to communicate faster than light. This answers a long-standing question on the plausibility of these models [4], on which progress was recently made in [5].

Given that all the correlations we are confronted with in our daily life can be explained by causal influences propagating at a finite speed, this result highlights more than ever the exceptional nature of quantum correlations, and sets the advantage offered by quantum communications and quantum information processing on firmer grounds.

[1] J. S. Bell, Speakable and Unspeakable in Quantum Mechanics: Collected papers on quantum philosophy (Cambridge University Press, Cambridge, 2004).

[2] A. Aspect, Nature 398, 189 (1999).

[3] A. Shimony. In Philosophical Consequences of Quantum Theory, pages 25-37 (University of Notre Dame Press, Notre Dame, 1989).

[4] V. Scarani and N. Gisin, Phys. Lett. A 295, 167 (2002).

[5] B. Cocciaro, S. Faetti and L. Fronzoni, Phys. Lett. A 375, 379 (2011).

T12

Weak measurements and quantum paradoxes in quantum transport

Wolfgang Belzig[1] and Adam Bednorz[2]

[1] *University of Konstanz, Department of Physics, 78457 Konstanz, Germany*

[2] *Faculty of Physics, University of Warsaw, Hoża 69, PL-00681 Warsaw, Poland*

The difficulty in measuring non-commuting quantum mechanical observables is one of the most fascinating consequences of the quantum mechanical postulates, relevant for correlation measurements of the electric current [1]. Hence, the investigation of quantum measurement and projection is a fundamentally interesting topic. We study the concept of a weak measurement of non-commuting observables using a quasiprobabilistic description [2] relevant for mesoscopic transport experiments, resembling the Wigner function or other quasiprobabilities [3]. The possible negativity of a quasiprobability is a fundamental quantum mechanical property and can be tested by violation of classically derived inequalities. We discuss as first example how to detect nonlocal quantum correlations (entanglement) in mesoscopic junctions, which do not permit detection of single events [4]. Furthermore we discuss how non-classical correlations similar to squeezing in quantum optics can be observed in a current fluctuation measurement scheme using a detector at a lower temperature [3].

Partially in collaboration with Christoph Bruder (University of Basel) and Bertrand Reulet (University of Sherbrooke).

[1] A. Bednorz and W. Belzig, Phys. Rev. Lett. 101, 206803 (2008)

[2] A. Bednorz and W. Belzig, Phys. Rev. B 81, 125112 (2010)

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

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

Precision spectroscopy of the 2S-4P transition in atomic hydrogen

Axel Beyer[1], Ksenia Khabarova[2], Randolf Pohl[1], Thomas Udem[1], Theodor W. Hänsch[1, 3], and Nikolai Kolachevsky[1, 4]

[1]*Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany*

[2]*National Research Institute of Physical, Technical and Radiotechnical Measurements, 141570 Mendeleevo, Russia*

[3]*Ludwig Maximilian University, 80799 Munich*

[4]*P.N. Lebedev Physical Institute, 119991 Moscow, Russia*

The comparison between experimental and theoretical values of transition frequencies in atomic hydrogen, the most simple atomic system, provides stringent tests of bound state quantum electro dynamic (QED) calculations. For more than one decade, this comparison has been limited by insufficient knowledge about the size of the proton, strictly speaking its r.m.s. charge radius r_p. In 2010, a value for r_p ten times more accurate than any previous measurement has been determined by laser spectroscopy of muonic hydrogen [1]. However, this value deviates from the one extracted from regular hydrogen spectroscopy by four combined standard deviations. The muonic hydrogen value has been confirmed and improved in a recent publication [2] while the source of the discrepancy remains unclear and suggested solutions to this 'proton size puzzle' range from experimental shortcomings to physics beyond the Standard Model [3].

In this talk, we will report on an experiment aiming to contribute to a more precise determination of the Rydberg constant and the proton charge radius from regular atomic hydrogen spectroscopy: Our measurement of the 2S-4P transition is the first precision experiment of its kind utilizing a cryogenic source of hydrogen atoms [4]. Optical excitation to the meta-stable 2S state preserves the atoms' low thermal velocity and allows for preparation of 2S atoms in only one hyperfine state. In our apparatus, systematic effects such as the Doppler effect, ac Stark effect and different line pulling effects present in previous work are significantly reduced. Preliminary results of our latest measurements of the 2S-4P$_{1/2}$ and 2S-4P$_{3/2}$ transitions will be discussed and a reproducibility of the line center extraction of a few parts in 10^{12} is demonstrated. The study of different systematic effects is underway and will be discussed as well.

[1] R. Pohl *et al.*, Nature **466** (7303), 213-216, 2010.

[2] A. Antognini *et al.*, Science **339**, 417-420, 2013.

[3] R. Pohl *et al.*, arXiv:1301.0905 [physics.atom-ph], 2013.

[4] A. Beyer *et al.*, accepted in Ann. Phys. (Berlin), 2013.

T14

Two-mode interaction and quantum effects in non-linear mechanical resonators

Yaroslav M. Blanter

Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, Delft, Netherlands

Non-linear resonators is the mainstream research direction of nanomechanics. They facilitate engineering back-action and creation of self-sustained oscillations. They also couple different excitation modes and thus facilitate information transfer, both of classical and quantum information. In this talk, we will cover two topics. First, we consider interaction between two mechanical modes in a non-linear resonator (exemplified as a suspended beam). We will show that if only one of the modes is driven, the other one exhibits parametric resonance-like behavior. Classically, it does not get excited at all, if the driving force is below the parametric resonance threshold. We also solved the problem quantum-mechanically, and found that the response of the non-driven mode below the threshold is finite. Thus, the observation of mechanical oscillations in this regime can serve as an indicator of quantum-mechanical behavior. Next, we will consider Josephson parametric amplifier (JPA) coupled to a mechanical resonator. JPA is an inherently non-linear, bistable system. We will show how the interaction considerably modifies the properties of the oscillator and the JPA.

Effective field theory approach to gravitationally induced decoherence

Miles Blencowe

Dartmouth College, Department of Physics, 6127 Wilder Laboratory, Hanover, USA

Adopting the viewpoint that the standard perturbative quantization of general relativity provides an effective description of quantum gravity that is valid at ordinary energies, we show that gravity as an environment induces the rapid decoherence of stationary matter superposition states when the energy differences in the superposition exceed the Planck energy scale.

T16

Quantum optomechanics

Dirk Bouwmeester

Department of physics, University of California, Santa Barbara, USA

Huygens Laboratory, Leiden University, the Netherlands

Quantum mechanics has been formulated over hundred years ago and many experiments have supported this extraordinary theory. It remains however unclear how quantum mechanics can be combined with general relativity in a 4 dimensional space-time structure. Furthermore the emergence of the classical world from the underlying quantum mechanics, often discussed in connection with the collapse of the quantum wavefuntion, leaves open questions. Prof. R. Penrose has been one of the leading theorists in the past 50 years who addressed these fundamental issues. I will discuss some of his ideas leading to far reaching predictions that could be tested in future experiments. In particular I will discuss quantum optomechanical experiments that are designed to test the notion of quantum superpositions for macroscopic objects [1,2]. The ultimate goal is to bring a tiny optical mirror into a quantum superposition and to investigate it's decoherence.

The proposed experiments are technically very challanging and will require optomechanical systems at low mechanical resonator frequencies ($\sim$10-100 kHz) to be cooled to the quantum-mechanical ground state. The various cooling techniques, including optical cooling, will be discussed [3]. Furthermore the experimental challanges associated to the use of mirrors, as small as 10 micrometer in diameter, attached to mechanical resonators will be addressed [4].

[1] W. Marshall, C. Simon, R. Penrose, and D. Bouwmeester, Phys. Rev. Lett. 91, 130401 (2003).

[2] B. Pepper, R. Ghobadi,E. Jeffrey, C. Simon, D. Bouwmeester, Phys. Rev. Lett. 109, 023601 (2012).

[3] D. Kleckner and D. Bouwmeester, Nature, 444, 75 (2006).

[4] D. Kleckner, W. T. W. Irvine, S. S. R. Oemrawsingh, and D. Bouwmeester, Phys. Rev. A. 81, 043814 (2010).

Conduction properties of ultracold fermions

Jean-Philippe Brantut, Jakob Meineke, David Stadler, Sebastian Krinner, and Tilman Esslinger

ETH Zürich, Schafmattstrasse 16, ZURICH, Switzerland

We experimentally study the conduction of ultracold fermionic atoms through a mesoscopic, quasi two-dimensional channel connecting macroscopic reservoirs. By observing the current response to a bias applied between the reservoirs, we directly access the transport coefficients of the channel. The influence of disorder and/or interactions between particles on the conduction processes are discussed.

T18

Quantum-kinetics of charge-transferring atom-surface collisions

Franz Xaver Bronold, Johannes Marbach, and Holger Fehske

Ernst-Moritz-Arndt-University Greifswald, Felix-Hausdorff-Str. 6, 17489 Greifswald, Germany

Charge-exchange between an atomic projectile and a surface plays a central role in applied surface science. Many advanced surface diagnostics utilize surface-based charge-transfer processes. This type of collision is however also of fundamental interest since it couples a system with a finite number of discrete states–the atomic projectile–to a large electron reservoir with a continuum of states–the target surface. Irrespective of the coupling between the two, either due to tunneling or due to Auger-type Coulomb interaction, charge-transferring atom-surface collisions are thus perfect realizations of time-dependent quantum impurity systems. By a judicious choice of the projectile-target combination as well as the collision parameters Kondo-type features due to Coulomb-blockades can be realized as in any other quantum impurity system, with the advantage, however, of being able to control the time scale on which the impurity couples to the reservoir. We will be concerned with the theoretical description of this type of collisional system beyond the saddle-point (semiclassical) approximation. Using an Anderson-Newns-type model in the pseudo-particle representation [1] which allows us to treat strong intra-projectile Coulomb interactions we will show how the time development of the occupancies of the projectile states can be obtained from Keldysh's integral equations for contour-ordered Green functions. Our approach utilizes an exponential resummation to iteratively solve for the double-time retarded Green function [2]. Inserting cumulant-type expressions for the retarded (advanced) Green function into the integral equation for the double-time less-than (larger-than) Green function provides a framework for calculating corrections to the saddle-point approximation, which is usually the method of choice for reducing the double-time quantum-kinetics of Green functions to the single-time quantum-kinetics of occupancies. The saddle-point approximation misses however important non-adiabatic effects, in particular those which drive the Kondo-type features of the collision process. Having a method at hand for going beyond the saddle-point approximation without the necessity of solving the full two-time quantum-kinetic equations [3] is thus of great practical value. We present results for the infinite-U Anderson-Newns model describing resonant charge-transfer but the approach is not restricted to this particular case.

[1] J. Marbach, F.X. Bronold, and H. Fehske, Phys. Rev. B **86**, 115417 (2012)

[2] J. Marbach, F.X. Bronold, and H. Fehske, Phys. Rev. B **84**, 085443 (2011)

[3] H. Shao, D. C. Langreth, and P. Nordlander, Phys. Rev. B **49**, 13929 (1994)

Quantum feedback preparation and stabilization of photon number states of light in a cavity

Michel Brune[1], Clément Sayrin[2], Bruno Peaudecerf[1], Theo Rybarczyk[1], Stefan Gerlich[1], Igor Dotsenko[1], Sébastien Gleyzes[1], Jean-Michel Raimond[1], and Serge Haroche[3]

[1]*Laboratoire Kastler Brossel, ENS, UPMC–Paris 6, CNRS, 24 rue Lhomond, 75005 Paris, France*

[2]*Vienna Center for Quantum Science and Technology TU Wien - Atominstitut Stadionallee 2 1020 Wien Austria*

[3]*Collège de France, 11 place Marcelin Berthelot, 75231 Paris Cedex 05, France*

The stabilization of complex classical systems requires feedback. A sensor performs measurements of the system's state whose result is fed into a controller, which decides on an action bringing the system closer to a target state. Operating feedback for preparing and stabilizing against decoherence a quantum state is a promising tool for quantum control. It is however much more demanding than its classical counterpart, since a quantum measurement by the sensor changes the measured state. We present the first continuous operation of a closed feedback-loop for preparing and stabilizing photon number states of a microwave field stored in a high Q superconducting cavity. The field is probed by non-resonant Rydberg atoms performing Quantum Non-Demolition photon counting [1]. The feedback action consists either in the injection of a small coherent field pulse with a controlled amplitude and phase or in the emission and absorption of single photons with individual resonant atoms [2,3]. The atomic measurement results are fed into a real-time controller, which performs an estimation of the field's state before deciding on the actuator action bringing it closer to the target. We stabilize number states up to 7. We discuss further improvements of the non demolition photon counting method as well as other perspectives.

[1] C. Guerlin, J. Bernu, S. Deléglise, C. Sayrin, S. Gleyzes, S. Kuhr, M. Brune, J.M. Raimond, and S. Haroche, "Progressive field-state collapse and quantum non-demolition photon counting", Nature 448, 889–894 (2007)

[2] C. Sayrin, I. Dotsenko, X. Zhou, B. Peaudecerf, T. Rybarczyk, S. Gleyzes, P. Rouchon, M. Mirrahimi, H. Amini, M. Brune, J.M. Raimond, and S. Haroche, "Real-time quantum feedback prepares and stabilizes photon number states", Nature 477, 73–77 (2011)

[3] X. Zhou, I. Dotsenko, B. Peaudecerf, T. Rybarczyk, C. Sayrin, S. Gleyzes, J.M. Raimond, M. Brune, and S. Haroche, "Field locked to a Fock state by quantum feedback with single photon corrections", Phys. Rev. Lett. 108, 243602 (2012).

T20

Emergence of the pointer basis through the dynamics of correlations

Amir O. Caldeira[1], Marcio F. Cornelio[1], Osvaldo Jiménez Farías[2, 3], Felipe F. Fanchini[4], Irenée Frerot[5], Gabriel H. Aguilar[2], Malena O. Hor-Meyll[2], Marcos C. de Oliveira[1, 6], Stephen P. Walborn[2], and Paulo H. Souto Ribeiro[2]

[1] *Universidade Estadual de Campinas, Sergio Buarque de Holanda 777, Cidade Universitária, Campinas, Brazil*

[2] *Instituto de Física, Universidade Federal do Rio de Janeiro, Caixa Postal 68528, Rio de Janeiro, RJ 21941-972, Brazil*

[3] *Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México (UNAM), Apdo. Postal 70-543, México 04510 D.F.*

[4] *Departamento de Física, Faculdade de Ciências, Universidade Estadual Paulista, Bauru, SP, CEP 17033-360, Brazil*

[5] *Département de Physique, Ecole Normale Supérieure, 24, rue Lhomond. F 75231 PARIS Cedex 05*

[6] *Institute for Quantum Information Science, University of Calgary, Alberta T2N 1N4, Canada*

We use the classical correlation between a quantum system being measured and its measurement apparatus to analyze the amount of information being retrieved in a quantum measurement process. Accounting for decoherence of the apparatus, we show that these correlations may have a sudden transition from a decay regime to a constant level. This transition characterizes a non-asymptotic emergence of the pointer basis, while the system-apparatus can still be quantum correlated. We provide a formalization of the concept of emergence of a pointer basis in an apparatus subject to decoherence. This contrast of the pointer basis emergence to the quantum to classical transition is demonstrated in an experiment with polarization entangled photon pairs.

Quantum fluctuation relations. Overcoming the two-measurements issue

Michele Campisi

University of Augsburg, Universitätsstr. 1, Augsburg D-89135, Germany

In the last two decades the field of nonequilibrium statistical mechanics has received a renewed and intense momentum in its development due to the discovery of exact results, known as fluctuation relations, which are valid independent of how far a system is driven out of equilibrium. These relations offer a powerful tool for the investigation of thermodynamic properties of nano-system even in the quantum regime [1,2]. One major obstacle to the experimental verification of quantum fluctuation relations comes from the requirement of performing two projective measurements on the system (or on the system plus environment, if the system is open) at the beginning and end of the driving protocol. We discuss two strategies to overcome this difficulty. The first strategy is based on the observation that fluctuation theorems are robust to intermediate, possibly weak, measurements [3]. Its application to bi-directional electron counting statistics will be illustrated [4]. The second strategy employs an interferometric measurement on an ancilla-qubit appropriately coupled to the system [5,6]. We will discuss its advantages and its implementation in a circuit QED set-up [7].

[1] M. Campisi, P. Hänggi, and P. Talkner, *Colloquium. Quantum Fluctuation Relations: Foundations and Applications*, Rev. Mod. Phys. **83**, 771 (2011), *ibid.*, **83**, 1653 (2011).

[2] M. Campisi, P. Talkner, and P. Hänggi, *Fluctuation theorem for Arbitrary Open Quantum Systems*, Phys. Rev. Lett. **102**, 210401 (2009).

[3] M. Campisi, P. Talkner, and P. Hänggi, *Influence of measurements on the statistics of work performed on a quantum system*, Phys. Rev. E **83**, 041114 (2011).

[4] M. Campisi, P. Talkner, and P. Hänggi, *Fluctuation Theorems for continuously monitored quantum fluxes*, Phys. Rev. Lett. **105**, 104601 (2010).

[5] R. Dorner, S. R. Clark, L. Heaney, R. Fazio, J. Goold, and V. Vedral, *Extracting quantum work statistics and fluctuation theorems by single qubit interferometry*, Phys. Rev. Lett. **110**, 230601 (2013).

[6] L. Mazzola, G. De Chiara, and M. Paternostro, *Measuring the characteristic function of work distribution*, Phys. Rev. Lett. **110**, 230602 (2013).

[7] M. Campisi *et. al*, in preparation

T22

Quantum trajectories without Lindblad

Howard Carmichael and Simon Whalen

Department of Physics, University of Auckland, Auckland 1142, New Zealand

Quantum trajectory simulations based on jumps are widely used in quantum optics, as a path to the numerical solution of a master equation, and for the physical insight they provide in the form of simulated photoelectron counting sequences for output fields. In their most commonly encountered version [1,2,3], quantum trajectory methods are tied to the Lindblad propagator of a Markov open system dynamic [4] and simulate a Davies photon counting process [5]. Although various non-Markovian trajectory equations have been written down [6,7], these are less widely used and, more importantly from a fundamental point of view, lack an immediate measurement interpretation drawn from photoelectron counting theory [8,9]. In this talk we formulate quantum trajectories for a subset of non-Markovian open systems where the non-Markov character arises from coherent feedback with time delay, as, for example, in a cascaded system [10] with backscatter and coupling in both directions. The formulation builds upon the standard treatment of photoelectron counting for free outgoing fields [11] and thus retains a clear measurement interpretation. The main idea is to numerically model both the open system and that part of the environment required to transmit the feedback signal; only those photons that have without doubt irreversibly escaped the system are viewed from the point of view of jumps. In broad terms the approach is the one taken by Imamoğlu [12] but allows for the fact that photons eventually leave the system through propagation rather than Lindblad/Davies-style absorption.

[1] H. J. Carmichael, An Open Systems Approach to Quantum Optics, Lecture Notes in Physics, Vol. m-18 (Springer, Berlin, 1993)

[2] J. Dalibard, Y. Castin, and K. Moelmer, Phys. Rev. Lett. 68, 580 (1992)

[3] R. Dum, P. Zoller, and H. Ritsch, Phys. Rev. A 45, 4879 (1992)

[4] G. Lindblad, Commun. Math. Phys. 48, 119 (1976)

[5] E. B. Davies, Quantum Theory of Open Systems (Academic Press, London, 1976)

[6] W. T. Strunz, L. Diósi, and N. Gisin, Phys. Rev. Lett. 82, 1801 (1999)

[7] J. Piilo, S. Maniscalco, K. Härkönen, K.-A. Suominen, Phys. Rev. Lett. 100, 180402 (2008)

[8] J. Gambetta and H. M. Wiseman, Phys. Rev. A 66, 012108 (2002)

[9] J. Gambetta and H. M. Wiseman, Phys. Rev. A 68, 062104 (2003)

[10] H. J. Carmichael, Phys. Rev. Lett. 70, 2273 (1993)

[11] P. L. Kelly and W. H. Kleiner, Phys. Rev. 136, A316 (1964)

[12] A. Imamoğlu, Phys. Rev. A 50, 3650 (1994)

Full counting statistics in the not-so-long-time limit

Sam Carr

University of Kent, School of Physical Sciences, Ingram Building, Canterbury CT2 7NH, United Kingdom

The full counting statistics of transport encodes all moments of the non-equilibrium process, and obtaining this distribution for different systems is one of the goals of theorists and experimentalists alike. The usual thing calculated is the cumulant generating function in the long measurement time limit; however neither numerical studies nor experiments have the luxury of measuring for an infinite time; and in certain situations the finite time effects can be very large compared with the eventual long-time result. Here, we present the leading finite-time correction to the cumulant generating function of steady state transport at zero temperature and show that it obeys a remarkably simple scaling relation, at least for a wide class of systems. We back this up with numerical simulations for both the non-interacting and interacting resonant level models.

[1] Sam T. Carr, Dmitry A. Bagrets, Peter Schmitteckert, Phys. Rev. Lett. 107, 206801 (2011)

[2] Peter Schmitteckert, Hubert Saleur, Sam T. Carr, preprint

T24

The spin of the electron as an emergent property

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

Instituto de Física, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510 México, DF, Mexico

The electron spin is presented as one more emergent property arising from the interaction of the electron with the random electromagnetic zero-point radiation field. For this purpose, it is taken into account that the particle interacts separately with modes of right- and left-handed circular polarization of the background field, which gives rise to corresponding rotational motions of the particle. These mean rotations are identified with the two degrees of freedom proper to the spin. Finally, the correct value g = 2 is obtained for the electron g-factor associated with its spin magnetic moment.

Thermodynamics of ultracold Fermi gases

Frédéric Chevy

Laboratoire Kastler Brossel, Ecole Normale Supérieure, 24 rue Lhomond, Paris, France

Understanding the properties of strongly correlated quantum many-body systems is one of the most challenging problems in modern physics. In the recent years, ultracold atomic gases have emerged as new quantitative testbeds for the theoretical paradigms developped in the study of condensed matter phenomena: they provided the first experimental demonstration of the BEC-BCS crossover scenario connecting Bose-Einstein condensation of pairs and BCS theory, probed the Clogston-Chandrasekhar limit of superconductivity or confirmed the 50-year old prediction for the beyond-mean field corrections to the equation of state of dilute Bose and Fermi gases.

In this talk, I will review the recent results obtained in the quantitative study of the thermodynamic properties of strongly interacting gases. I will discuss how the advent of new experimental tools have led to an accurate determination of the equation of state of dilute Bose and Fermi gases, and how these results could be compared quantitatively to the most advanced theoretical calculations.

T26

Is communication via gravitational radiation possible?

Raymond Chiao

University of California at Merced, P.O. Box 2039, Merced, CA 945344, USA

There is a widely held belief in the general relativity community that generating gravitational radiation in the laboratory is, for all practical purposes, impossible. Hence communication via gravitational radiation, unlike the case of radio, is impossible. This belief is based on an orders-of-magnitude argument given by Misner, Thorne, and Wheeler (MTW), who, in their book, "Gravitation", in Chapter 36 on the generation of gravitational (or general relativistic (GR)) waves, concluded that GR waves could be generated with any significance solely by astrophysical sources, and that any laboratory sources of this kind of radiation would, for all practical purposes, be impossible.

MTW's argument begins with the fact that Einstein's field equation contains within its coupling constant only two of the fundamental constants of physics, viz., G, Newton's constant of universal gravitation, and c, the speed of light, but does not contain Planck's constant $\hbar$. By dimensional analysis, they showed that from G and c, one can form the quantity c^5/G, which has units of power, and which turns out to be an astronomically huge quantity. This indicates that the only place in the Universe where gravitational radiation can be generated with any significance is in astronomical sources, such as when two solar-scale masses orbit around each other near the speed of light in an extremely tight orbit, but not in laboratory sources.

However, one can think of at least four possible quantum loopholes in MTW's argument. These four loopholes are connected with the following four questions:

(I) Can Planck's constant alter MTW's argument?

(II) Can mesoscopic, Planck-mass-scale mirrors for gravitational radiation exist?

(III) Can effectively relativistic motions occur within the context of mesoscopic, Planck-mass-scale, opto-mechanical laboratory settings?

(IV) Can the amplification of gravitational waves occur, for example, by the stimulated emission of radiation, like in a laser?

Here we suggest affirmative answers to the above four questions based on some proposed, mesoscopic-scale quantum-gravitational experiments. (See arXiv:1301.4270, 1303.4020).

Self-energy-corrected scattering-state method for electronic transport in single-molecule junctions

Hyoung Joon Choi

Department of Physics, Yonsei University, Seoul, Korea

First-principles scattering-state method [1,2] for electronic transport is an efficient method to perform transport simulations of several hundred atoms. For electronic transport through molecular junctions, the conventional density functional method with LDA or GGA is not accurate enough to describe molecular energy levels from the Fermi energy of metallic contacts. To achieve the required accuracy, the self-energy correction to the molecular energy levels is necessary. Here we consider a GW-based self-energy correction, and obtain both electrical and thermal transport properties of single-molecular junctions [3-5]. The calculated conductance and thermopower of molecular junctions are in good agreement with available experimental data, demonstrating the validity of our theoretical description of molecular junctions. We also extend our self-energy correction method for nonlinear electronic transport at finite bias voltage [6]. This work was supported by NRF of Korea (Grant No. 2011-0018306) and KISTI supercomputing center (Project No. KSC-2012-C3-046). This work was done in collaboration with S. Y. Quek, P. Darancet, J. B. Neaton, D. Strubbe, S. G. Louie, M. S. Hybertsen, J. R. Widawsky, and L. Venkataraman.

[1] H. J. Choi and J. Ihm, Phys. Rev. B 59 (1999) 2267.

[2] H. J. Choi, M. L. Cohen, and S. G. Louie, Phys. Rev. B 76 (2007) 155420.

[3] S. Y. Quek *et al.*, Nano Lett. 7 (2007) 3477.

[4] S. Y. Quek, H. J. Choi, S. G. Louie, and J. B. Neaton, Nano Lett. 9 (2009) 3949.

[5] S. Y. Quek, H. J. Choi, S. G. Louie, and J. B. Neaton, ACS Nano 5 (2011) 551.

[6] P. Darancet *et al.*, Nano Lett. 12 (2012) 6250.

T28

Coupling microwaves and optical light

Andrew Cleland

University of California - Santa Barbara, Department of Physics, Santa Barbara 93106, USA

At UC Santa Barbara, we have been developing a new quantum optomechanical device which allows the direct control of an optical signal at 1550 nm with a microwave-frequency electronic signal. This for example can be used to encode the electrical signal on the optical signal, by generating optical sidebands at the electronic drive frequency, thus providing a type of microwave-to-optical frequency up-conversion. This is achieved using a photonic one-dimensional optomechanical crystal fabricated from a piezoelectric material, the latter converting electrical signals to phonons; the phonon mode is co-localized with the photonic mode, giving strong optomechanical coupling between the two modes.

We plan to use this device to generate optical-frequency entangled sideband photons using a superconducting qubit as a source of entangled microwave frequency photons, thus enabling the coherent transfer of quantum information from a millikelvin cryostat to a fiber optic transmission line, with the potential of coupling hybrid quantum systems.

I will report on our progress in developing this novel device.

Fluctuation dissipation phenomenology away from equilibrium

Doron Cohen

Ben-Gurion University, Physics Department, Beer-Sheva 84105, Israel

The fluctuation dissipation phenomenology, in essence, is a relation $A = D/T$ that connects the rate of energy absorption to its diffusive spreading, where T is the canonical temperature. We explain how this relation can be generalized in circumstances away from equilibrium. In [1] we propose a minimal Fokker-Planck theory for the thermalization of mesoscopic subsystems, without having any baths. In [2,3] the flow of energy from a work agent to a bath is mediated by a "sparse" system whose non-equilibrium steady state has "glassy" features. In both cases we explain how to formulate the fluctuation dissipation relation, and what "temperature" to use.

[1] I. Tikhonenkov, A. Vardi, J.R. Anglin, D. Cohen, Phys. Rev. Lett. 110, 050401 (2013)

[2] D. Hurowitz, D. Cohen, Europhysics Letters 93, 60002 (2011)

[3] D. Hurowitz, S. Rahav, D. Cohen, Europhysics Letters 98, 20002 (2012)

T30

Heat dissipation in atomic-scale junctions

Woochul Lee[1], Kyeongtae Kim[1], Wonho Jeong[1], Linda Angela Zotti[2], Fabian Pauly[3], Juan Carlos Cuevas[2], and Pramod Reddy[1, 4]

[1]*Department of Mechanical Engineering, University of Michigan, Ann Arbor, Michigan, 48109, USA*

[2]*Departamento de Fisica Teorica de la Materia Condensada, Universidad Autonoma de Madrid, Tomas y Valiente 7, 28049 Madrid, Spain*

[3]*Department of Physics, University of Konstanz, D-78457 Konstanz, Germany*

[4]*Department of Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan, 48109, USA*

Atomic and single-molecule junctions represent the ultimate limit to the miniaturization of electrical circuits [1]. They are also ideal platforms to test quantum transport theories that are required to describe charge and energy transfer in novel functional nanodevices. Recent work has successfully probed electric and thermoelectric phenomena in atomic-scale junctions. However, heat dissipation and heat transport in atomic-scale devices remain poorly characterized due to experimental challenges. In this talk, I will present our recent experimental and theoretical efforts to elucidate how heat dissipation takes place in metallic atomic-size contacts and single-molecule junctions [2]. In particular, I will describe how, by using novel scanning probes with integrated nanoscale thermocouples, we have been able to show that heating in the electrodes of molecular junctions, whose transmission characteristics are strongly dependent on energy, is asymmetric, i.e. unequal and dependent on both the bias polarity and the identity of majority charge carriers (electrons vs. holes). In contrast, atomic contacts whose transmission characteristics show weak energy dependence do not exhibit appreciable asymmetry. Our results unambiguously relate the electronic transmission of nanoscale junctions to their heat dissipation properties proving a central prediction of Landauer theory that has remained untested despite its relevance to a range of nanoscale and mesoscopic systems where transport is elastic. Moreover, the techniques developed in our work will enable the study of Peltier effects and other heat transport phenomena at the atomic scale.

[1] J.C. Cuevas and E. Scheer, Molecular Electronics: An Introduction to Theory and Experiment. (World Scientific, 2010).

[2] W. Lee, K. Kim, W. Jeong, L.A. Zotti, F. Pauly, J.C. Cuevas, P. Reddy, Nature 498, 209 (2013).

Generalized quantum Ehrenfest equations including radiative corrections

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

Instituto de Física, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510 Mexico, DF, Mexico

Within the framework of our programme on the Foundations of Quantum Theory, a central role is played by the generalized (phase-space) Fokker-Planck equation of Stochastic Electrodynamics. This equation is established on the assumption that the random zero-point field is the source of the stochasticity of the particle motion leading to their quantum behavior.

From the Fokker-Planck equation a series of average balance equations can be derived, which apply to the mechanical system in the quantum regime, i.e. when the Schrödinger equation holds. Valuable information about the average behavior of dynamical quantities is thus obtained, reminiscent of the Ehrenfest equations of quantum mechanics, but containing additional terms that represent radiative corrections. Without the need of conventional perturbative methods, one can thus obtain the set of formulas for the first-order radiative corrections of nonrelativistic QED, including: the atomic radiative lifetimes, the Lamb shift, and modifications to these due to changes that affect the background radiation field.

T32

Quantum theory as the most robust description of reproducible experiments

Hans De Raedt[1], Mikhail Katsnelson[2], and Kristel Michielsen[3]

[1]Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, Groningen, Netherlands

[2]Radboud University Nijmegen, Institute for Molecules and Materials, Heyendaalseweg 135, NL-6525AJ Nijmegen, The Netherlands

[3]Institute for Advanced Simulation, Jülich Supercomputing Centre, Forschungszentrum Jülich, D-52425 Jülich, Germany and RWTH Aachen University, D-52056 Aachen, Germany

It is shown that the basic equations of quantum theory can be obtained from a straightforward application of logical inference to experiments for which there is uncertainty about individual events and for which the frequencies of the observed events are robust with respect to small changes in the conditions under which the experiments are carried out.

The ironic situation of boson sampling

Jens Eisert

FU Berlin, Arnimallee 14, Berlin 14195, Germany

The boson sampling problem is a task that can – at least in principle – be efficiently realised with linear optical quantum circuits, but which is presumably a computationally hard problem classically. Such quantum circuits are hence candidates for quantum simulators that genuinely outperform classical computers. Recently, a rush of experimental activity has led to the development of a number of linear optical experiments that implement such devices, with enormous visibility.

In this work we show that in this setup, with probability exponentially close to one in the number of bosons, no symmetric algorithm can distinguish the boson sampling distribution from the uniform one from fewer than exponentially many samples. This means that the two distributions are operationally indistinguishable without detailed a priori knowledge. In this precise sense, the quantum devices are classically efficiently simulable. We carefully discuss the prospects of efficiently using knowledge about the implemented unitary for devising non-symmetric algorithms that could potentially improve upon this. We conclude that due to the very fact that Boson-Sampling is believed to be hard, efficient classical certification of boson sampling devices seems to be out of reach.

T34

Invariants of the single impurity Anderson model and implications for conductance functionals

Ferdinand Evers[1] and Peter Schmitteckert[2]

[1]*Karlsruhe Institute of Technology, Inst. of Nanotechnology & Inst. f. Theorie d. Kond. Materie, Hermann-von-Helmholtzplatz 1, 76344 Eggenstein-Leopoldshafen, Germany*

[2]*Karlsruhe Institute of Technology, Inst. of Nanotechnology*

The single impurity Anderson model (SIAM) is one of the key laboratories for theoretical investigations of correlated fermions systems. Analytical solutions of several ground state properties, such as the spin- and charge-susceptibilities are available. In addition, many numerical studies – predominantly employing the numerical renormalization group – have revealed important additional information, most notably on the impurity's spectral function and associated transport properties.

In our presentation we will investigate a new observable, RR, that has not been addressed before. RR denotes a ratio of density changes, that occur in the left and right leads after coupling to the impurity. RR has several interesting invariance properties. They can be derived from lead-invariants of the SIAM that seem to have not received a lot of attention, before. For instance, RR does not depend on microscopic model parameters, such as the interaction strength. Most importantly, however, RR equals the conductance of the SIAM at maximum transmission. Therefore, similar to the Friedel phase shift, RR establishes a parameter-free link between the ground-state density and the transport current.

The second part of the talk is devoted to the fate of RR under modifications of the SIAM that break the symmetries protecting the lead invariants. Our focus will be on lead disorder. A DMRG-study will be presented that strongly suggests that even under moderate disorder strength RR retains much of its (clean) properties. Therefore, we propose to put our theoretical arguments to an experimental test.

Design of Lambda systems in superconducting architectures

Giuseppe Falci[1, 2], Elisabetta Paladino[1, 2], Antonio D'Arrigo[2], and P. Di Stefano[1]

[1]*Dipartimento di Fisica e Astronomia, Universita' di Catania, Viale A. Doria 6, Edificio 10, Catania I-95125, Italy*

[2]*CNR-IMM MATIS Catania, Italy*

The implementation of a Lambda scheme in superconducting artificial atoms could allow detection of STimulated Raman Adiabatic Passage (STIRAP) and other quantum manipulations in the microwave regime. Despite many proposals this problem is still experimentally unsettled. We have shown [1] that implementing an efficient Lambda system in a qutrit depends on the tradeoff between efficient coupling and non-Markovian (low-frequency 1/f [2]) components of noise. Indeed protection from noise and suppression of pump coupling depend on the same symmetry and are conflicting issues. Substantial efficiency can be achieved within present fabrication technology by exploiting tuning of symmetry breaking. We find results [2] uniquely due to non-Markovianity of noise, namely: (a) the efficiency for STIRAP depends essentially on noise channels in the qubit trapped subspace; (b) a physically motivated figure of merit for evaluation of design and operating prescriptions is derived; (c) a scheme of dynamical decoupling related to symmetries of the three-level band-structure of the device is found [3].

We next study two ingredients towards the implementation of population transfer and quantum state engineering in solid-state Circuit-QED or nanomechanichal architectures. The first is a 2+1-photon scheme allowing for a Lambda configuration at the symmetry point [3]. Pump coupling and noise protection now both increase for increasing Josephson energy, this advantage being however limited by leakage from the three-level subspace in a more and more harmonic spectrum. The second issue is a protocol where usual STIRAP is triggered by a suitable modulation of detunings, allowing to operate with an always on field. The absence of an exact dark state makes non trivial achieving destructive interference. This operation mode may allow to switch couplings to quantized modes in solid-state architectures.

We finally comment about possible applications to Quantum Technologies, as single-photon generation and light harvesting.

[1] G. Falci et al., arXiv:1305.0204, Phys. Rev. B, June 2013.

[2] E. Paladino, Y. Galperin, G. Falci, B. Altshuler, "1/f noise: implications for quantum information", arXiv:1304.7925, subm. to Rev. Mod. Phys.

[3] G. Falci et al., Physica Scripta T151, 014020 (2012).

T36

Coherent DC transport in biased Josephson bijunctions

Denis Feinberg[1], Régis Mélin[1], Thibaut Jonckheere[2], Jérome Rech[2], Thierry Martin[2], Benoît Douçot[3], Andreas Pfeffer[4], François Lefloch[4], and Hervé Courtois[1]

[1]Institut NEEL, CNRS and Université Joseph Fourier, Grenoble, France

[2]CPT, CNRS and Aix-Marseille University, Marseille, France

[3]LPTHE, CNRS and Université Paris 6,7, Paris

[4]SPSMS/LaTEQS, CEA-INAC and Université Joseph Fourier, Grenoble

The Josephson effect couples two superconductors by a weak link. At equilibrium (zero bias), DC phase-coherent Cooper pair transport is controlled by the junction phase. With a voltage bias, the AC Josephson effect appears together with DC subgap quasiparticle transport. The present work considers novel devices (Bijunctions) where three superconductors are coupled by a common weak link. Then new DC Josephson transport channels appear. Biasing independently two contacts, commensurate combinations of voltage lead to multipair resonances, like two pairs (a nonlocal quartet) simultaneously crossing to different leads while conserving the energy [1]. At lowest order, quartets coexist as a phase-coherent DC channel, together with dissipative DC quasiparticle channels. Therefore, phase and voltage are independent control parameters for a DC quartet current. In addition, phase-sensitive DC quasiparticle currents are possible.

I will present theoretical results for bijunctions made of: i) tunneling contacts with arbitrary transparency; ii) quantum dots where a dramatic enhancement of the multipair resonances can be obtained by tuning the dot energies [2]; iii) metallic contacts. I will also present the first experimental results for long diffusive Aluminium-Copper bijunction [3]. Strong resonances in the bijunction conductance when one contact is a zero voltage, and the others at V and -V, manifest for V well above the Thouless energy. This rules out a possible synchronization of otherwise AC currents and points towards the quartet channel as a phase-coherent coupling of all three superconductors. I will briefly mention the high potential of multipair processes in bijunctions, in terms of electronic entanglement and microwave photon quantum correlations.

[1] A. Freyn, B. Douçot, D. Feinberg, and R. Mélin, Phys. Rev. Lett. 106, 257005 (2011)

[2] T. Jonckheere, J. Rech, T. Martin, B. Douçot, D. Feinberg, and R. Mélin, to appear (Physical Review B)

[3] A. H. Pfeffer, J. E. Duvauchelle, H. Courtois, R. Mélin, D. Feinberg, and F. Lefloch, submitted

Probing the quantum-classical connection with open quantum dots

David Ferry

Arizona State University, School of Electrical, Computer, and Energy Engineering, Box 875706, Tempe 85287-5706, USA

Open quantum dots provide a natural system in which to study both classical and quantum features of transport. From the classical point of view these dots possess a mixed phase space which yields families of closed, regular orbits as well as an expansive sea of chaos. As a closed test bed, they provide a natural system with a very rich set of eigen-states. When coupled to the environment through a pair of quantum point contacts, each of which passes several modes, the original quantum environment evolves into a set of decoherent and coherent states, which eventually couple to the classical states discussed above. The manner of this connection is governed strongly by decoherence theory. The remaining coherent states possess all the properties of pointer states. These states are naturally studied via traditional magnetotransport at low temperatures. More recently, we have used scanning gate (conductance) microscopy to probe the nature of the coherent states, and have shown that families of states exist through the spectrum in a manner consistent with quantum Darwinism.

T38

Non-classical quantum states of light and nonlinear operations

Radim Filip[1], Petr Marek[1], and Akira Furusawa[2]

[1]*Department of Optics, Palacky University Olomouc, 17. listopadu 1192/12, 77146 Olomouc, Czech Republic*

[2]*Department of Applied Physics, School of Engineering, The University of Tokyo*

We will present a proposal on deterministic implementation of weak cubic nonlinearity, which is a basic building block of a full scale CV quantum computation. Our proposal relies on preparation of a specific ancillary state being the superposition up to three photons and transferring its nonlinear properties onto the desired target by means of the deterministic Gaussian operations and quantum feed-forward. We show that, despite the imperfections arising from the deterministic nature of the operation, the weak quantum nonlinearity can be implemented and verified with the current level of technology. We will describe an experimental scheme based on a continuous-wave (cw) laser for generating arbitrary superposition of photon number states up to three photons. In this experiment, we successfully generate superposition states up to three photons, namely advanced versions of superposition of two and three coherent states. They are fully compatible with developed quantum teleportation and measurement-based quantum operations with cw lasers. Due to achieved high detection efficiency, we observe, without any loss correction, multiple areas of negativity of Wigner function, which confirm strongly nonclassical nature of the generated states. We will present the experimentally generated quantum resource state which could be the product of cubic nonlinear dynamics, which can be used as a resource for the measurement-induced implementation of the cubic gate. We analyze the generated quantum state of light and, despite the weakness of the nonlinearity, confirm its cubic nonlinear nature.

Absence of exponential sensitivity to small perturbations in nonintegrable systems of spins 1/2

Boris Fine[1], Tarek Elsayed[1], Chahan Kropf[1, 2], and Astrid de Wijn[3]

[1] *Instute for Theoretical Physics, University of Heidelberg, Philosophenweg 19, 69120 Heidelberg, Germany*

[2] *Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany*

[3] *Department of Physics, Stockholm University, 106 91 Stockholm, Sweden*

The notion of chaos is frequently invoked in the foundations of quantum statistical physics. Yet, the definition of quantum chaos for many-particle systems is still not fully understood. Here we show that nonintegrable lattices of spins 1/2, which are often considered to be chaotic, do not exhibit the basic property of classical chaotic systems, namely, exponential sensitivity to small perturbations. We compare the responses of chaotic lattices of classical spins and nonintegrable lattices of spins 1/2 to imperfect reversal of spin dynamics known as Loschmidt echo. In the classical case, Loschmidt echoes exhibit exponential sensitivity to small perturbations characterized by twice the value of the largest Lyapunov exponent of the system. In the case of spins 1/2, Loschmidt echoes are only power-law sensitive to small perturbations. Our findings imply that it is impossible to define Lyapunov exponents for lattices of spins 1/2 even in the macroscopic limit. At the same time, the above absence of exponential sensitivity to small perturbations is an encouraging news for the efforts to create quantum simulators. The power-law sensitivity of spin 1/2 lattices to small perturbations is predicted to be measurable in nuclear magnetic resonance experiments.

[1] B. V. Fine, T. A. Elsayed, C. M. Kropf and A. S. de Wijn, arXiv:1305.2817

T40

Beyond Planck-Einstein quanta: Crossover from frequency driven to amplitude driven excitation in a nonequilibrium many-body system

James Freericks[1], Wen Shen[1], and Tom Devereaux[2]

[1]*Department of Physics, Georgetown University, 37th and O Sts. NW, Washington, USA*

[2]*Stanford Institute for Materials and Energy Science, SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*

In 1901, Planck introduced the idea of light quanta to calculate the spectrum for black body radiation, which was employed by Einstein in 1905 to explain the mysterious quantum properties of the photoelectric effect. Later in the 1950s, Kubo and Greenwood independently derived the linear response of a quantum system to an applied external field, and found that the energy available for excitation was determined by the frequency of the driving field as given by the Planck-Einstein relation. As the magnitude of the driving field is further increased into the nonlinear regime, one expects that there will be a crossover from frequency-driven excitation of the quantum system to amplitude-driven excitation. The first hint of such a quantum effect comes from the solution of the Landau-Zener tunneling problem in the 1930s, where a tunneling excitation is determined by the speed at which the minimal excitation gap is approached, which is proportional to the amplitude of an effective driving field. Here we use the exact quantum solution of a charge-density-wave system driven by an electric field to show generically how such a crossover occurs in solid state systems. We find that the behavior is quite complex due to excitation and de-excitation processes, so that it is no longer true that tunneling is optimized when the field amplitude is the highest. When the field amplitude becomes very large, there is a novel quantum oscillatory behavior in the excitation spectroscopy that appears to describe a new regime for quantum phenomena in strong fields.

This work was supported by the National Science Foundation for the development of the algorithms and by the Department of Energy for the application to the quantum excitation problem. JKF was also supported by the McDevitt bequest at Georgetown University.

Molecular nanoplasmonics

Michael Galperin

University of California San Diego, Department of Chemistry & Biochemistry, 9500 Gilman Dr., La Jolla, CA 92093-0340, USA

Advances in optical techniques, in particular nearfield optical microscopy, combined with molecular fabrication techniques, make optical spectroscopy methods an important observation and diagnostic tool in molecular electronics. The molecular optical response in close proximity to plasmonic materials is greatly enhanced by surface plasmon-polariton modes leading to the discovery of the single-molecule spectroscopy. A natural combination of nanoplasmonics and molecular response to the generated field started to appear as molecular nanoplasmonics. In particular, it is a natural ingredient in any study of molecular junctions interaction with light. The small size of molecules implies necessity of quantum treatment ofmolecular junctions response to external driving, while macroscopic size of contacts (nanoparticles) requires to rely on the tools of classical electrodynamics in simulation of plasmon excitations in the leads.

Within simple models we present simulations of time-dependent transport and optical response of molecular junctions driven by external laser fields. First we persent results of simulations employing combination of nonequilibrium Green functions for description of the molecule and finite difference time-domain approach for numerical integration of Maxwell equations on a spatial grid [1]. We demonstrate effects of pulse chirping ond energy relaxation on charge pumping properties in molecular junctions [2], and study local field formation due to both surface plasmon-polariton excitations in the contacts and the molecular response [3]. In the second part of the talk we discuss a possible route for quantum description of the coupling between plasmons and molecular excitons in junctions. In particular, we employ a pseudoparticle nonequilibrium Green function formalism to study the sensitivity of the molecule-plasmon Fano resonance to junction bias and intramolecular interactions, and compare our predictions to previous studies [4].

[1] M. Sukharev and M. Galperin, Phys. Rev. B 81, 165307 (2010).

[2] B. D. Fainberg, M. Sukharev, T.-H. Park, and M. Galperin, Phys. Rev. B 83, 205425 (2011).

[3] A. J. White, M. Sukharev, and M. Galperin, Phys. Rev. B 86, 205324 (2012).

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

T42

Edge reconstruction in the fractional quantum Hall regime

Jianhui Wang[1, 2], Yigal Meir[1], and Yuval Gefen[2]

[1] *Department of Physics, Ben-Gurion University of the Negev, Beer Sheva 84105, Israel*

[2] *The Weizmann Institute, Department of Condensed Matter Physics, Herzl St, Rehovot 76100, Israel*

The edge structure of the ν= 2/3 fractional quantum Hall state has been studied for several decades but recent experiments, exhibiting upstream neutral mode(s), a plateau at a Hall conductance of 1/3 e^2/h through a quantum point contact, and a crossover of the effective charge, from e/3 at high temperature to 2e/3 at low temperature, could not be explained by a single theory. We have developed such a theory, based on edge reconstruction due to a confining potential with finite slope, that admits an additional ν= 1/3 incompressible strip near the edge. Renormalization group analysis of the effective edge theory due to disorder and interactions results in a flows in parameter space, dominated by an intermediate temperature fixed point and a low temperature fixed point. The interplay between these two explains the experimental observations.

Quantum transport and correlated switching – beating the Landauer limit

Avik Ghosh

University of Virginia, 351 McCormick Rd, Charlottesville, USA

It is generally believed that the biggest challenge to the continued scaling of semiconductor electronics is the high cost of binary switching. In the quest for the ultimate switch, there has been a happy emergence of sophisticated 'first principles' computational models on how electrons flow at the atomic scale. Much of nanoscale quantum transport can now be reduced to two limiting cases – for weakly correlated systems, the Landauer-Keldysh Non-Equilibrium Green's Function (NEGF) formalism describes the self-consistent time evolution of the one-electron states through a combination of interference and scattering pathways. The challenge here is to capture the relevant non-equilibrium many-body diagrams with a proper self-energy matrix that must be nonlocal in time. The opposite, strongly correlated regime requires a multi-electron master equation that describes the time evolution of the nonequilibrium occupancies (more generally, the density matrix) in their many-body Fock space. The challenge here, beyond the sheer numerical grunt work, is to capture the broadening of the one-electron transitions by the ensemble of non-interacting contact states.

Simulation plays a critical role in deconstructing the intricate physics above, as well as guiding material and device design. On the material front, we can use 'first principles' theory to scan through entire classes of materials in order to identify promising behavior, such as high magnetic polarization. On the device front, we now understand what digital switches may need to look like in order to operate at very low power, namely, employ alternate state variables beyond uncorrelated charges. The energy dissipated in today's devices is governed by the number of redundant charges set by interconnect 'drivability', and the switching energy per unit charge set by the Shannon-Landauer thermal limit of kTln2. Accordingly, one way to circumvent these limitations is to design 'correlated switches' - embodied in nano-magnetic logic and metal insulator transitions, where many spins or charges lock up through internal exchange-correlation fields and cut down the overall energy cost. An alternate class is 'subthermal switches' where each degree of freedom operates near a phase transition point below the classical 'Boltzmann-Landauer' kTln2 limit. One example is a nano-mechanical relay with a Van der Waals pull-in force that shuts off the current abruptly. A more topical example is chiral electron tunneling across graphene PN junctions, where we can engineer a gate tunable transport gap using geometry alone, thereby preserving the mobility while achieving a high ON-OFF ratio and a steep subthermal switching below the Landauer limit.

T44

Minimal self-contained quadridot quantum refrigeration machine

Vittorio Giovannetti, Davide Venturelli, and Rosario Fazio

Scuola Normale Superiore, Piazza dei Cavalieri, Pisa, Italy

We present a theoretical study of an electronic quantum refrigerator based on four quantum dots arranged in a square configuration, in contact with as many thermal reservoirs. We show that the system implements the minimal mechanism for acting as a self-contained quantum refrigerator, by demonstrating heat extraction from the coldest reservoir and the cooling of the nearby quantum-dot.

The increasing interest in quantum thermal machines has its roots in the need to understand the relations between thermodynamics and quantum mechanics. The progress in this field may as well have important applications in the control of heat transport in nano-devices. In a series of recent works the fundamental limits to the dimensions of a quantum refrigerator have been found. It has been further demonstrated that these machines could still attain Carnot-efficiency thus launching the call for the implementation of the smallest possible quantum refrigerator. The major difficulty in the realization of self-contained refrigerators (SCRs) is the engineering of the crucial three-body interaction enabling the coherent transition between a doubly excited state in contact with a hot (H) and cold (C) reservoir, and a singly-excited state coupled to an intermediate (or "room" - R) temperature bath. We get around this problem by proposing an experimentally feasible implementation of a minimal SCR with semiconducting quantum dots (QDs) operating in the Coulomb blockade regime. We are thus able to establish a connection between the general theory of quantum machines and the heat transport in nanoelectronics

Quantum thermodynamics: Increasing quantum heat engine efficiency via quantum coherence

Gombojav O. Ariunbold[1, 2], Philip Vetter[1, 3], Dmitri V. Voronine[1, 2], and Marlan Scully[1, 2, 3]

[1] *Texas A&M University, College Station, TX 77843-4242, USA*

[2] *Baylor University, Waco, TX 76706, USA*

[3] *Princeton University, Princeton NJ 08544, USA*

Laser and photocell quantum heat engines (QHEs) are powered by thermal light and governed by the laws of quantum thermodynamics. To appreciate the deep connection between quantum mechanics and thermodynamics we need only recall that in 1901 Planck introduced the quantum of action to calculate the entropy of thermal light, and in 1905 Einstein's studies of the entropy of thermal light led him to introduce the photon.

We here show how to use quantum coherence induced by external coherent fields [1] or by quantum noise [2] to improve the efficiency of a laser or photocell QHE. Surprisingly, this coherence can be induced by the same noisy (thermal) emission and absorption processes that drive the QHE. Furthermore, this noise-induced coherence can be robust against environmental decoherence. Applications of these ideas to photosynthesis [3,4] will also be discussed.

[1] M.O. Scully, "Quantum Photocell: Using Quantum Coherence to Reduce Radiative Recombination and Increase Efficiency", Physical Review Letters, 104, 207701 (2010).

[2] M.O. Scully, K.R. Chapin, K.E. Dorfman, M.B. Kim, and A. Svidzinsky, "Quantum heat engine power can be increased by noise-induced coherence", PNAS, 108, 15097 (2011).

[3] G.S. Engel et al., "Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems", Nature, 446, 782-786 (2007).

[4] K.E. Dorfman, D.V. Voronine, S. Mukamel, and M.O. Scully, "Photosynthetic reaction center as a quantum heat engine", PNAS, 110, 2746 (2013).

T46

Two-photon spectral amplitude resolved in separable Schmidt modes

Marco Gramegna[1], Alessio Avella[1, 2], Alexander Shurupov[1], Maria V. Chekhova[3, 4], Giorgio Brida[1], and Marco Genovese[1]

[1]*INRiM - Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce, 91, Torino - 10135, Italy*

[2]*Dipartimento di Fisica, Università degli Studi di Torino, via P. Giuria 1, 10125 Torino, Italy*

[3]*Max-Planck Institute for the Science of Light, G.-Scharowsky Str 1/Bldg 24, 91058, Erlangen, Germany*

[4]*M. V. Lomonosov Moscow State University, 119992 GSP-2, Moscow, Russia*

The ability to access high dimensionality in Hilbert spaces [1] represents a demanding keystone for state-of-art quantum information. The manipulation of entangled states in continuous variables, wavevector as well frequency, represents a powerful resource in this sense. The number of dimensions of the Hilbert space that can be used in practical information protocols can be determined by the number of Schmidt modes that is possible to address separately [2]. For wavevector variables it is possible losslessly filter Schmidt modes using single-mode fibre and a spatial light modulator [3] but no similar procedure exists for the frequency space. Aim of this work is to present a method of engineering spectral property of biphoton light, emitted via ultrafast spontaneous parametric down conversion, in such a way that the Two-Photon Spectral Amplitude (TPSA), that fully characterizes a biphoton sate [4], contains several non-overlapping Schmidt modes, each of which can be filtered losslessly in frequency variables. Such TPSA manipulation is operated by a fine balancing of parameters like the pump frequency, the shaping of pump pulse spectrum, the dispersion dependence of SPDC crystals as well as their length. Measurements have been performed exploiting the group velocity dispersion induced by the passage of optical fields through dispersive media [5], operating a frequency to time two dimensional Fourier transform of the TPSA [6]. Exploiting this kind of measurement we experimentally demonstrate the ability to control the Schmidt modes structure in TPSA manipulating the pump spectrum.

[1] C. K. Law, I. A. Walmsley, and J. H. Eberly, Phys. Rev. Lett. 84, 5304 (2000)

[2] I. N. Agafonov, et al., Phys. Rev. A 82, 011801(R) (2010)

[3] S. S. Straupe et al., Phys. Rev. A 83, 060302(R) (2011)

[4] Yu. M. Mikhailova, et al., Phys. Rev. A 78, 062327 (2008)

[5] W. P. Grice and I. A. Walmsley, Phys. Rev. A 56, 1627 (1997)

[6] M. Avenhaus, et al., Opt. Lett. 34, 2873 (2009)

Sub-quantum statistical mechanics and the vacuum fluctuation theorem

Gerhard Groessing[1], Siegfried Fussy[1], Johannes Mesa Pascasio[1, 2], and Herbert Schwabl[1]

[1] *Austrian Institute for Nonlinear Studies, Akademiehof, Friedrichstr. 10, Vienna 1010, Austria*

[2] *Institute for Atomic and Subatomic Physics, Vienna University of Technology, Operng. 9, Vienna 1040, Austria*

It is assumed that a quantum "particle" may actually be a dissipative system emerging from the dynamical coupling between a local oscillator ("bouncer") and its thermal environment. Consequently, some of the universal properties of nonequilibrium thermodynamics can be applied with regard to a hypothesized sub-quantum medium. In fact, with this rather general ansatz (i.e., independent of many model details), it is possible to derive the exact Schroedinger equation from classical physics. [1]

Moreover, with a more particular model gleaned from the analoguous behavior of classical bouncers in Couder's experiments, it is also possible to show that free particle motion can be exactly described with the aid of anomalous (i.e., "ballistic") diffusion processes on the sub-quantum level. [2]

Both the general ansatz and the more particular one entail the possibility of arbitrarily large momentum fluctuations, or particle drifts, respectively. One version of a formal representation of such effects is given by a "vacuum fluctuation theorem", i.e., a fluctuation theorem applicable on the sub-quantum level. Consequences are discussed with respect to quantum mechanical nonlocality.

[1] G. Groessing, Phys. Lett. A 372 (2008) 4556

[2] See, e.g., G. Groessing et al., Physica A 389 (2010) 4473

T48

Diagrammatic Monte Carlo methods for non-equilibrium systems

Emanuel Gull[1], David R. Reichman[2], and Andrew J. Millis[3]

[1] *University of Michigan, Ann Arbor, 450 Church St, Ann Arbor, 48109, USA*

[2] *Department of Chemistry, Columbia Unversity, New York, NY 10027*

[3] *Department of Physics, Columbia Unversity, New York, NY 10027*

‘Diagrammatic’ or ‘continuous-time’ quantum Monte Carlo algorithms are computational methods based on a stochastic sampling of convergent perturbation series. We present some of these methods and their applications and focus on recently developed ‘bold-line’ algorithms for non-equilibrium (Keldysh) diagrammatics that allow numerically exact access to the Kondo regime of interacting quantum impurities.

Single-particle approach to mesoscopic transport

Shmuel Gurvitz

Weizmann Institute, Rehovot 76100, Israel

We develop a new approach to transport in mesoscopic systems by using single-particle basis. Although this basis generates redundant many-particle amplitudes, it greatly simplifies the treatment. Applying our method to transport of non-interacting particles we generalize the Landauer-type formula to transient currents and to time-dependent potentials. We demonstrate that our approach can be extended for interacting case. As an example, we applied it for study a qubit interacting with a single-electron transistor (representing a measurement device). We investigated the qubit's decoherence (decay-rate of Rabi oscillations) as a function of the bias voltage. Using our method we also obtained the particle-resolve master equations, valid for any bias voltage and temperature. These equations can be very useful for many applications, in particular for counting-statistic analysis.

T50

Experimental test of universal complementarity relations

Morgan Weston, Michael Hall, Matthew Palsson, Howard Wiseman, and Geoff Pryde

Centre for Quantum Dynamics, Griffith University, Nathan QLD 4111, Australia

The principle of complementarity, considered by Niels Bohr to lie at the heart of quantum theory, asserts that the respective experimental arrangements for accurately measuring two quantum observables are, in general, physically incompatible. Thus, it restricts the degree to which *joint* information about the observables can be obtained, from a single experimental setup.

The complementarity principle is quantified by *complementarity relations*, which limit the accuracy with which two observables A and B can be simultaneously measured. For example, suppose that a simultaneous measurement of two compatible observables, $A_{\rm est}$ and $B_{\rm est}$, is used to estimate A and B, and define the *inaccuracy* of $A_{\rm est}$ by the root-mean-square error $\epsilon(A_{\rm est}) := \langle (A_{\rm est} - A)^2 \rangle^{1/2}$. If the estimates are 'globally unbiased', i.e., $\langle A_{\rm est} \rangle = \langle A \rangle$ and $\langle B_{\rm est} \rangle = \langle B \rangle$ for all states, then [1]

$$\epsilon(A_{\rm est})\,\epsilon(B_{\rm est}) \geq c := |\langle [A, B] \rangle|/2. \tag{1}$$

However, Eq. (1) is not universally valid. For example, it fails for joint estimates of the position and momentum of a particle that shares Einstein-Podolsky-Rosen (EPR) correlations with a second particle [2].

More recently, universally-valid complementarity relations have been obtained by Hall [2] and Ozawa [3], such as $\epsilon(A_{\rm est})\,\epsilon(B_{\rm est}) + \epsilon(A_{\rm est})\,\Delta B_{\rm est} + \Delta A_{\rm est}\,\epsilon(B_{\rm est}) \geq c$. This relation implies one can tailor joint estimation schemes to a specific state of interest, so as to reduce the inaccuracies. However, the *spreads* of such tailored estimates must be correspondingly large. The relation is saturated by suitable position and momentum estimates on Gaussian EPR states [2].

Here the first experimental test of such universally-valid relations—as well as of a new and stronger complementarity relation—is reported, in a scenario in which the Arthurs-Kelly relation (1) is violated [4]. It exploits EPR-type correlations between two photonic qubits, to simultaneously estimate complementary polarisation observables X and Y of one of the qubits. To determine the inaccuracies that appear in the complementarity relations, a new method is used that does not rely on state tomography or weak measurements, but on a semi-weak measurement of arbitrary strength.

[1] E. Arthurs and J. L. Kelly, Jr., *Bell Syst. Tech. J.* **44**, 725 (1965).

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

[3] M. Ozawa, *Phys. Lett. A* **320**, 367 (2004).

[4] M. Weston et al., arXiv:1211.0370 [quant-ph].

Interplay of strong correlation and dissipation in nonequilibrium lattice systems

Jong Han

SUNY at Buffalo, 239 Fronczak Hall, Buffalo, USA

Nonequilibrium in electron lattices driven by a uniform electric field is discussed. Contrary to quantum dot systems, dissipation mechanism and its interplay with many-body interaction are one of the central questions. In nonequilibrium lattice systems, the dissipation cannot be simply taken as an implicit medium of providing thermal steady-state, but should be explicitly included as a part of the time-evolution. We reformulate the nonequilibrium problem by a time-independent Coulomb gauge Hamiltonian. The scattering-state formalism is applied to a tight-binding lattice coupled to fermionic baths. We establish the exact solution to the model, and then incorporate the Hubbard interaction within the dynamical mean-field theory. We present the Dyson equation for inhomogeneous lattice and show that the implementation reproduces the linear response theory accurately. We discuss whether the DC conductivity is renormalized by Hubbard interaction. The linear response theory breaks down much earlier than expected, at the inter-site voltage drop much smaller than the quasi-particle bandwidth, in a stark contrast to the conventional wisdom in Kondo physics of quantum dot models. It is argued that the dominating physics in lattice nonequilibrium is not the field vs quasi-particle energy, but it is rather the Joule heat vs the quasi-particle energy. Furthermore, we show that the destruction of the quasi-particle states is immediately followed by a current saturation phenomenon, which has been observed in nano-device experiments.

T52

On the use and abuse of thermodynamic entropy

Peter Hänggi

University of Augsburg, Department of Physics, Universitätsstr. 1, 86135 Augsburg, Germany

Let us elaborate on the notion of *thermodynamic* entropy S (Clausius 1865) and its consequences. Gibbs put forward two notions entropy that I commonly will refer to as the volume entropy (involving the integrated density of states) and as the surface entropy, being proportional to the density of states, commonly also known (incorrectly) as the Boltzmann entropy. The absolute temperature, i.e. $T^{-1} = \partial S/\partial E$, is then related to the thermodynamic entropy; – but which "S" to use? – The consistency for thermodynamics, i.e. dS = an exact differential, singles out the volume entropy [1, 2].

I shall address shortcomings that relate to the thermodynamics of small systems when sticking to the (Boltzmann)-surface entropy [2, 3]. Most of all, the uncritical use of Boltzmann entropy for microcanonical systems may formally yield *negative* values of absolute temperatures. This is not only physically incorrect for the concept of an absolute temperature [1], but also would violate thermodynamic stability if the system is brought into (weak) contact with an omnipresent sort of environment of radiation source or otherwise. Particularly, this criticism applies to the concept of absolute negative (spin) temperatures and, as well, to the negative absolute temperature interpretation of most recent (otherwise correct) experiments with ultra-cold atomic gases [4].

Next, we address canonical entropy when describing quantum systems that interact *strongly* with an environment. Then, the canonical specific heat can in fact assume negative (!) values away from absolute zero temperature [5, 6, 7]. Likewise, the thermodynamic entropy for a strongly coupled system, assuming a form which mimics a conditional entropy (but not quite) can be negative away from absolute $T = 0$ [6, 7].

[1] J. Dunkel and S. Hilbert, *Inconsistent thermostatics and negative absolute temperatures*, arXiv:1304:2066.

[2] M. Campisi, Stud. Hist. & Phil. Mod. Phys. **36**, 275 (2005).

[3] J. Dunkel and S. Hilbert, Physica A **370**, 390 (2006); M. Campisi, arXiv 0709:1082.

[4] S. Braun, *et al.*, *Negative absolute T for motional DoF*, Science **339**, 52 (2013).

[5] P. Hänggi, G.L. Ingold, and P. Talkner, New J. Phys. **10**, 115008 (2008); *ibid*, Phys. Rev. E **79**, 061105 (2009).

[6] M. Campisi, P. Talkner, and P. Hänggi, *Thermodynamics and fluctuation theorems for a strongly coupled open quantum system: an exactly solvable case*, J. Phys. A **42**, 392002 (2009).

[7] M. Campisi, D. Zueco, and P. Talkner, Chem. Phys. **375**, 187 (2010).

A universal matter-wave interferometer with optical gratings in the time domain

Philipp Haslinger[1], Nadine Dörre[1], Jonas Rodewald[1], Stefan Nimmrichter[1, 2], Klaus Hornberger[2], and Markus Arndt[1]

[1] *University of Vienna, VCQ, Boltzmanngasse 5, 1090 Vienna, Austria*

[2] *University of Duisburg-Essen, Lotharstraße 1-21, 47048 Duisburg, Germany*

Over the last century matter-wave interferometry has been an enormously growing research field. New experimental schemes and setups have been developed. On the one hand, atomic matter-waves have been coherently split, guided and recombined [1] with laser pulses for up to 0.5 seconds with a separation distance of 8.8 mm. On the other hand, high contrast interference patterns of massive molecules (6910 amu, consisting of 430 atoms) have shown that quantum superposition of complex structures with more than 1000 internal degrees of freedom can be realized [2]. New experimental advances have allowed us to devise new molecular sources [3], interferometer arrangements [4], diffraction structures [4] and detection methods [3] that enable new experiments to test the linearity of quantum mechanics for massive macroscopic particles. Our recent demonstration of the all optical time-domain ionizing matter-wave (OTIMA) interferometer [4] showed the merits of time-domain interferometry for complex particles. Grating structures made by standing light waves, unlike material gratings, don't create dispersive potentials (particle-grating wall interaction - van der Waals force), which were up to now a main drawback for matter-wave interferometry with massive molecules. Standing light waves of λ = 157 nm ionize the neutral particles in the antinodes and form a transmission grating in time and space. The optical ionization gratings in the VUV range are nearly independent of any specific internal level structure and are therefore universal applicable. These pulsed gratings are applied three times with a well-define pulse delay on the free falling molecules in order to prepare a sufficiently wide spatial coherence (1st grating), to diffract them (2nd grating) and to resolve/detect the appearing interference pattern (3rd grating). In time-domain interferometry, quantum interference is not only imprinted in the sinusoidal interference pattern but also in the mass dependent transmission through the interferometer, which strongly depends on the delays between the laser gratings. On the applied side, time-domain interference patterns are not influenced by the particles velocities and provide therefore a tool for velocity-independent high-precision deflectometry experiments.

[1] S.-Y Lan et al. Physical Review Letters 108, 090402 (2012)

[2] S. Gerlich et al. Nature communications 2, 263 (2011)

[3] P. Haslinger et al. Nature Physics 9, 144–148 (2013)

[4] T. Juffmann et al. Nature nanotechnology 7, 297–300 (2012)

T54

Quantum jump approach for work and dissipation in a two-level system

Frank Hekking[1] and Jukka Pekola[2]

[1]LPMMC-CNRS, Joseph Fourier University, 25 avenue des Martyrs, BP 166, 38042 Grenoble cedex 09, France

[2]Low Temperature Laboratory, Aalto University, School of Science, P.O. Box 13500, 00076 Aalto, Finland

We apply the quantum jump approach to address the statistics of work in a driven two-level system coupled to a heat bath. We demonstrate how this question can be analyzed by counting photons absorbed and emitted by the environment in repeated experiments. We find that the common non-equilibrium fluctuation relations are satisfied identically. The usual fluctuation-dissipation theorem for linear response applies for weak dissipation and/or weak drive. We point out qualitative differences between the classical and quantum regimes.

T55

Time flow in non-equilibrium statistical physics

Rudolf Hilfer

ICP, Universitaet Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

The time evolution of macroscopic states (or mixtures) for classical and quantum many body systems need not correspond to a translation group or semigroup. Instead a special class of convolution semigroups appears generically. The presentation will discuss the implications of this finding for the foundations of nonequilibrium statistical physics as well as possible applications to experiment.

T56

The role of entanglement in work extraction

Karen Hovhannisyan[1], Martí Perarnau Llobet[1], Marcus Huber[1, 2, 3], and Antonio Acín[1, 4]

[1] *ICFO - The Institute of Photonic Sciences, Av. Carl Friedrich Gauss, 3, Castelldefels, 08860, Spain*

[2] *University of Bristol, Department of Mathematics, Bristol, BS8 1TW, U.K.*

[3] *Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain*

[4] *ICREA-Institució Catalana de Recerca i Estudis Avançats, Lluis Companys 23, 08010 Barcelona, Spain*

We consider reversible work extraction from N identical quantum batteries. From an ensemble of individually passive states work can be produced only via global unitary (and thus entangling) operations. We find, though, that the maximal work can be extracted without creating entanglement between batteries at any time during the process. Yet, the protocols requiring less time for the same output are shown to entangle the ensemble. We find a connection between the amount of (multipartite) entanglement and extractable work. Our analysis suggests a general relation between entanglement generation and power of work extraction.

Exciton transport in light harvesting complexes

Susana Huelga

Institute of Theoretical Physics, University of Ulm, Albert Einstein Allee 11, Ulm, Germany

Recent observations of beating signals in the excitation energy transfer dynamics of a range of photosynthetic complexes have been interpreted as evidence for sustained quantum coherence that is sufficiently long-lived to coexist with significant energy transfer [1]. The possibility that coherence may be actively exploited in biological processes has opened up new avenues of exploration at the interface of physics and biology. The detailed microscopic origin of these long-lived coherences, however, remains to be uncovered. Here we present such a mechanism and verify it by numerically exact simulations of system-environment dynamics [2]. Crucially, the non-trivial spectral structures of the environmental fluctuations and particularly discrete vibrational modes can lead to the generation and sustenance of both oscillatory energy transport and electronic coherence on timescales that are comparable to excitation energy transport. This suggests that the non-trivial structure of protein environments plays a very significant role in facilitating coherent processes of biological relevance and may hold the key for their persistence at ambient temperatures.

[1] G.S. Engel, T. Calhoun, E. Read, T. Ahn, T. Mancal, Y. Cheng, R. Blankenship, and G.R. Fleming, Evidence for wavelike energy transfer trough quantum coherence in photosynthetic systems, Nature 446, 782-786 (2007).

[2] A.W. Chin, J. Prior, R. Rosenbach, F. Caycedo-Soler, S.F. Huelga, and M.B. Plenio, Vibrational structures and long-lasting electronic coherence, Nature Physics 9, 113-118 (2013).

T58

Hubbard model with ultracold atoms: Observation of antiferromagnetic correlations

Randall G. Hulet, Russell A. Hart, Pedro M. Duarte, and Tsung-lin Yang

Rice University, Dept of Physics and Astronomy, MS61, 6100 Main St, Houston 77005, USA

Some of the most complex and vexing issues in electronic materials are modeled by extremely simple Hamiltonians. High-temperature superconductors, for example, may arise from magnetic interactions in a Mott insulating state, described by the simple Hubbard model. The Hubbard model stipulates that particles (electrons in the case of superconductors) are distributed in a square lattice where they can hop from site to site with a tunneling energy t, and where they may interact with occupied nearest neighbor sites with interaction energy U. No one knows whether this simple model actually gives rise to the d-wave pairing underlying the cuprate superconductors.

I will describe an experiment that uses ultracold atoms in an optical lattice as stand-ins for the electrons in ionic lattices to realize the Hubbard model in 3D. In high-Tc materials, an anti-ferromagnetic Mott insulating state exist above the superconducting transition when there is exactly one-atom per lattice site. We have used Bragg scattering of near-resonant light to characterize the lattice by scattering of a (0 0 1) Bragg plane, and a spin-sensitive variant of this tool to detect antiferromagnetic correlations on the (1/2 1/2 1/2) plane. We will report on the angular distribution of the Bragg scattering which is a sensitive probe to the correlation length scale.

T59

A simple quantum derivation of the Jarzynski and Crooks equalities

Yoseph Imry

Weizmann Institute, Herzel Str., Rehovot, Israel

We [1] obtain the Crooks and the Jarzynski non-equilibrium fluctuation relations using a direct quantum-mechanical approach for a finite system that is either isolated or coupled not too strongly to a heat bath. These results were hitherto derived mostly [2,3] in the classical limit. The two main ingredients in the picture are the time-reversal symmetry and the application of the first law to the case where an "agent" performs work on the system. No further assumptions regarding stochastic or Markovian behavior are necessary, neither a master equation or a classical phase-space picture are required. The simplicity and the generality of these non-equilibrium relations are demonstrated, giving very simple insights into the Physics.

[1] D. Cohen and Y. Imry, Phys. Rev. E 86, 011111 (2012).

[2] see, however, e.g. J. Kurchan, arXiv:cond-mat/0007360; P. Talkner and P. Hanggi, J. Phys. A 40, F569 (2007).

[3] C. Jarzynski and D. K. Wojcik, Phys. Rev. Lett. 92, 230602 (2004).

T60

Zeno effect for repeated projective and finite-time measurements

Gert-Ludwig Ingold[1], Andreas Prinz-Zwick[1], Peter Talkner[1], and Juyeon Yi[2]

[1] *Institut für Physik, Universität Augsburg, Universitätsstraße 1, 86135 Augsburg, Germany*

[2] *Department of Physics, Pusan National University, Busan 609-735, Korea*

The decay of an unstable state can be slowed down by frequently repeated measurements and even be stopped completely under continuous observation. This so-called quantum Zeno effect has been studied for a single particle on a one-dimensional chain subject to repeated projective measurements on the first lattice site [1]. In contrast to previous work, we keep track of all possible measurement outcomes. While the Zeno effect is obtained for short times, asymptotically the system approaches a uniform state. As an extension, we have considered non-projective measurements where the system is coupled to a measurement apparatus as introduced in [2]. The Zeno effect is studied as a function of the duration of the measurement τ_m and the time between measurements τ_a. An optimal measurement is achieved by appropriately choosing the coupling strength as a function of τ_m. It is found that for not too large duration of the measurement, the Zeno effect becomes more pronounced when τ_m is increased [3].

[1] J. Yi, P. Talkner, G.-L. Ingold, Phys. Rev. A 84, 032121 (2011)

[2] W. Zurek, Ann. Phys. (N.Y.) 9, 855 (2000)

[3] A. Prinz-Zwick, Master thesis (Universität Augsburg, 2012)

Prethermalisation and thermalisation in long-range quantum spin systems

Michael Kastner

National Institute for Theoretical Physics, 10 Marais Street, Stellenbosch 7600, South Africa

Institute of Theoretical Physics, Stellenbosch University, Stellenbosch 7600, South Africa

Recent studies of isolated quantum systems have led to an improved understanding of conditions necessary and/or sufficient for thermalisation to occur (see [1] and references therein). Less is known about the time scales on which thermalisation takes place. Here, analytic results on the relevant time scales are reported for long-range interacting Ising systems on one-, two-, and three-dimensional lattices [2]. The results have applications to experiments on ultrcold polar molecules, and the are presently used for refined benchmarking of trapped-ion quantum simulators.

Different to the exponential relaxation of expectation values known from the nearest-neighbour Ising chain, we find stretched or compressed exponential decay in time towards the corresponding equilibrium values. For sufficiently long-ranged interactions, a wide separation of time scales occurs, leading to pronounced prethermalisation plateaus of correlation functions prior to their relaxation to equilibrium. We discuss the implications of these findings for trapped-ion quantum simulation [4].

[1] P. Reimann and M. Kastner, Equilibration of isolated macroscopic quantum systems, New J. Phys. **14**, 043020 (2012).

[2] M. Kastner, Diverging equilibration times in long-range quantum spin models, Phys. Rev. Lett. **106**, 130601 (2011).

[3] M. van den Worm, B.C. Sawyer, J.J. Bollinger, and M. Kastner, Relaxation timescales and decay of correlations in a long-range interacting quantum simulator, arXiv:1209.3697.

[4] J. W. Britton, B. C. Sawyer, A. C. Keith, C.-C. J. Wang, J. K. Freericks, H. Uys, M. J. Biercuk, and J. J. Bollinger, Engineered two-dimensional Ising interactions in a trapped-ion quantum simulator with hundreds of spins, Nature **484**, 489 (2012).

T62

Tomography and control of superconducting circuits

Nadav Katz

Hebrew University of Jerusalem, Givat Ram, Jerusalem, 91904, Israel

Multi-level superconducting circuits are a remarkable platform for quantum control and tomography. I will present several new control tools, including chirped microwave drive and the associated quantum-classical transition in the response of the circuit. Open loop optimization (by genetic algorithm) of the quantum response will be presented. Finally a mapping, based on group-theoretical considerations, will demonstrate control of the 4-level system. We experimentally benchmark our control tools by direct Wigner tomography.

Bardeen hysteresis: Fact or fiction?

Peter Keefe

University of Detroit Mercy, 24405 Gratiot Avenue, Eastpointe, 48021, USA

The adiabatic phase transition of a Type I superconductor particle of size d, where ξ(T) $\leq$ d $\leq$ 5λ(T), has been predicted to be accompanied by a latent heat evolution inconsistent with the second law of thermodynamics.[1] In response to this prediction, 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 latent heat evolution into consistency with the second law of thermodynamics. This magnetic hysteresis, referred to herein as "Bardeen Hysteresis", has not been reported in the literature, and therefore, its existence is unproven and its causation, if it exists, is undetermined.[3]

[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).

T64

Devil is in detectors: Towards classical field model of quantum phenomena

Andrei Khrennikov

Linnaeus University, P.G. Vägen, Växjö, Sweden

We show that (opposite to rather common opinion) quantum theory can be considered as emergent from theory of "prequantum random fields" – classical random fields having spatial and temporal scales which are essentially finer than the corresponding scales of quantum mechanics. In our model, so called prequantum classical statistical field theory (PCSFT), quantum density operators appear as normalized (by the trace) covariance operators of the prequantum random fields; e.g., an electron in the state rho is nothing else as (spatially and temporally distributed) random (e.g., Gaussian) field which covariance operator B reproduces rho=B/Tr B. Quantum observables correspond to quadratic forms of the prequantum random fields. Averages and covariances of these quadratic forms coincide with quantum quantities, including even the EPR-Bohm correlations and hence violating Bell's inequality [1].

Recently PCSFT was completed by measurement theory based on usage of detectors of the threshold type (threshold detection theory, TSD). In this model a detector clicks when it "eats" energy from the prequantum field which exceeds the threshold. TSD gives quantum probabilities as probabilities of discrete events – clicks of detectors. In this way we model even the coincidence probabilities for the EPR-Bohm experiment [2,3].

[1] Andrei Khrennikov, Masanori Ohya, Naboru Watanabe, Classical Signal Model for Quantum Channels. Journal of Russian Laser Research, v. 31, N 5, 401-407, 2010; arxiv.org/abs/1008.3772.

[2] Andrei Khrennikov, Börje Nilsson, Sven Nordebo, Classical signal model reproducing quantum probabilities for single and coincidence detections. Journal of Physics: Conference Series, 361, art N 012030 (2012); arxiv.org/abs/1112.5591.

[3] Andrei Khrennikov, Quantum probabilities and violation of CHSH-inequality from classical random signals and threshold type properly calibrated detectors. arxiv.org/abs/1111.1907.

Quantum field theory of black-swan events

Hagen Kleinert

FU Berlin, Fabeckstr, 60, Berlin, Germany

Free and weakly interacting particles are described by a secondquantized nonlinear Schrödinger equation, or relativistic versions of it. They describe Gaussian random walks with collisions. By contrast, the fields of strongly interacting particles are governed by effective actions, whose extremum yields fractional field equations. Their particle orbits perform universal Lévy walks with heavy tails, in which rare events are much more frequent than in Gaussian random walks. Such rare events are observed in exceptionally strong windgusts, monster or rogue waves, earthquakes, and financial crashes. While earthquakes may destroy entire cities, the latter have the potential of devastating entire economies.

T66

Bacterial nanomagnets

Stefan Klumpp

Max Planck Institute of Colloids and Interfaces, Am Muehlenberg, 14424 Potsdam, Germany

Magnetotactic bacteria orient in the magnetic field of the earth with the help of a chain of magnetic organelles. These organelles are called magnetosomes and contain magnetic nanoparticles [typically built from magnetite, Fe_3O_4], enclosed by membranes. Based on model for the intracellular dynamics of magnetosomes and comparison to experiments with iron-starved cells, we argue that the magnetitc attraction of aligned magnetosomes has to be coordinated with active transport of magnetosomes for the formation of the magnetosome chain. Active transport is likely driven by the polymerization or depolymerization of a cytoskeletal structure. Furthermore, we discuss the response of immobilized cells to external magnetic fields.

Coupling electrons, phonons, and photons for nonequilibrium transport simulation

Irena Knezevic

University of Wisconsin - Madison, USA

Time-dependent nonequilibrium transport in nanostructures offers a number of exciting basic science challenges, as well as real-world applications. While the low-field and steady-state quantum transport in nanostructures is theoretically well understood, there is incomplete theoretical understanding and a dearth of efficient computational techniques that can address time-dependent quantum transport in nanostructures, where electrons are excited either electrically (by applying a time-varying bias) or optically (by illumination with electromagnetic waves) and transport far from equilibrium that results from large applied biases or electromagnetic waves of high intensity. Simulation of the three-pronged interplay between electrons, lattice, and electromagnetic fields, where simulations proceed in parallel at every time-step and drive each other, is what makes theoretical treatment of realistic transport problems far from equilibrium very different from the linear-regime transport and very challenging.

In this talk, I will present my group's recent work on developing a general and efficient multiphysics simulation framework where electron transport, phonon transport, and electrodynamics will be coupled self-consistently to provide insight into the time-dependent and nonlinear transport in optically or electrically excited low-dimensional electron systems. To achieve this objective, electronic transport [simulated by the ensemble Monte Carlo (EMC) technique] will be self-consistently coupled with the transport of phonons (described by EMC) and electromagnetic field dynamics [described by the finite-difference time-domain (FDTD) technique and molecular dynamics (MD) for subgrid Coulomb interactions]. In particular, I will present our recent work on investigating (1) THz-frequency electronic response of graphene and (2) far-from-equilibrium electron and phonon transport in quantum cascade lasers.

[1] N. Sule, K. J. Willis, S. C. Hagness, and I. Knezevic, "Correlated impurities and carrier transport in supported graphene," submitted (2013).

[2] Y. B. Shi, Z. Aksamija, and I. Knezevic, "Self-Consistent Thermal Simulation of GaAs/Al0.45Ga0.55As Quantum Cascade Lasers," J. Comput. Electron. 11, 144 (2012).

[3] K. J. Willis, S. C. Hagness, and I. Knezevic, "Multiphysics simulation of high-frequency carrier dynamics in conductive materials," J. Appl. Phys. 110, 063714 (2011).

T68

Experimental test of Fluctuation Theorem in quantum regime

Kensuke Kobayashi

Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560-0043, Japan

Since 1980's mesoscopic conductors have been serving as an ideal test stage to investigate the quantum scattering problem, as electron transport through a single quantum site can be precisely probed in electric measurements. The Landauer-Büttiker formalism embodies this advantage of mesoscopic physics, and it has been successfully applied to many mesoscopic conductors such as electron interferometer (Aharonov-Bohm ring), quantum point contact, and quantum dot (artificial atom), through which the mesoscopic physics has been established.

Not only the current, but also the current noise (fluctuation) has been an important topic in this field [1]. Particularly these days, the current noise is invoking more interest: As the electron transport can be viewed as the electron exchange process between the reservoirs via the conductor, it serves as a well-defined test stage for nonequilibrium quantum statistical physics. In this talk, I will discuss the experimental test of the "Fluctuation Theorem" by using an electron interferometer [2].

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

[2] S. Nakamura, Y. Yamauchi, M. Hashisaka, K. Chida, K. Kobayashi, T. Ono, R. Leturcq, K. Ensslin, K. Saito, Y. Utsumi, and A. C. Gossard, Phys. Rev. Lett. 104, 080602 (2010); Phys. Rev. B 83, 155431 (2011) [Editors' suggestion].

Nonlinear plasmonics

Norbert Kroo, Peter Racz, and Sandor Varro

Wigner Physics Research Center of the Hungarian Academy of Sciences, Budapest, Hungary

Surface plasmons (SPO) and localized surface plasmons (LSPO) have a broad spectrum of specific properties, opening up the field for a large number of applications. This is why the interest for plasmonics is exploding both in research and applications.

The lecture selects some of those properties, which are of nonlinear character. The concentration of electromagnetic energy on some metallic surfaces, field enhancement on the surface of small (nano) metallic particles and between particle dimers (hot spots) form the base of the described phenomena. High harmonic generation, multiplasmon electron emission are also discussed in some detail.

Each of the mentioned properties are illustrated by concrete experimental observations and compared with model calculations. Three type of experimental facilities have been used for this purpose. SPO near field STM has been one of them, where the near field of SPO-s has been generated by semiconductor CW and fs Ti:Sa lasers. High intensity fs laser excited SPO emitted light has also been analyzed as well as electron beams emitted by multi-plasmon processes

Findings on some of the non-classical properties of SPO-s, as seen in different experimental observations are also presented.

T70

The failure of the standard cosmological model and first steps towards a possible new direction

Pavel Kroupa

Argelander Institute for Astronomy (AIfA), University of Bonn, Auf dem Huegel 71, D-53121 Bonn, Germany

The current cosmological model rests on Einstein's theory of general relativity. In order for it to be consistent with large-scale structure data, the existence of cosmologically relevant physical processes need to be postulated: inflation, cold dark matter (CDM) particles and dark energy (L). Each of these is not well understood, but assuming the resulting mathematical "LCDM" description is a representation of cosmological reality, this representation can be tested in a different regime, namely on the scales of the Local Volume of galaxies down to individual galaxies. It is found that each test which has been designed shows the LCDM description to fail such that the LCDM model needs to be discarded. In particular, the Dual-Dwarf-Galaxy Theorem, which must be true in the standard model, is falsified. The data on star-forming galaxies suggest a different cosmological model, but a definite final description is yet to be found.

Work and cooling bounds in quantum thermodynamics

Gershon Kurizki

The Weizmann Institute of Science, 2 Herzl Str., Rehovot 76100, Israel

In traditional thermodynamics the Carnot cycle yields the ideal performance bound of heat engines and refrigerators. We propose and analyze a minimal model of a heat machine that can play a similar role in quantum regimes. The minimal model consists of a single two-level system with periodically modulated energy splitting that is permanently, weakly, coupled to two spectrally-separated heat baths at different temperatures. The equation of motion allows to compute the stationary power and heat currents in the machine consistently with the second-law of thermodynamics. This dual-purpose machine can act as either an engine or a refrigerator (heat pump) depending on the modulation rate. In both modes of operation the maximal Carnot efficiency is reached at zero power. We study the conditions for finite-time optimal performance for several variants of the model. Possible realizations of the model are discussed. A minimal model of a quantum refrigerator (QR), i.e. a periodically phase-flipped two-level system permanently coupled to a finite-capacity bath (cold bath) and an infinite heat dump (hot bath), is introduced and used to investigate the cooling of the cold bath towards the absolute zero (T=0). Remarkably, the temperature scaling of the cold-bath cooling rate reveals that it does not vanish as $T \to 0$ for certain realistic quantized baths, e.g. phonons in strongly disordered media (fractons) or quantized spin-waves in ferromagnets (magnons). This result challenges Nernst's third-law formulation known as the unattainability principle.

Work extraction from a heat engine in a cycle by a quantum mechanical device (quantum "piston") and its efficiency bound are shown to crucially depend on the capacity of the quantum state of the piston to accumulate useful work. Energy gain (e.g. in lasing) is shown to drastically differ from work gain. These general results are applied to atoms in a cavity where one mode serves as the piston.

[1] M.Kolar, D. Gelbwasser, R. Alicki and G.Kurizki, Quantum bath refrigeration towards absolute zero: Challenging the unattainability principle, Phys. Letters 109 090601 (2012)

[2] D. Gelbwasser, R. Alicki and G. Kurizki, Minimal universal quantum heat machine Phys. Rev. E 012140 (2013)

T72

Witnessing single-photon entanglement with continuous-variable measurements

Julien Laurat

Laboratoire Kastler Brossel, Universite P. et M. Curie, ENS and CNRS, Case 74, 4 place Jussieu, 75252 Paris Cedex 05, France

Quantum information protocols are commonly based on two kinds of encoding. Some experiments are performed with 'discrete-variables', where the information is encoded in a two dimensional Hilbert space, for instance on the presence or absence of single-photons. Other experiments focus on the 'continuous-variable' approach, where the information is encoded in an infinite-dimensional Hilbert space, for instance on the quadrature components of light. Both encodings have advantages and drawbacks when they come to sophisticated protocols. Mixing the two approaches has recently led to a so-called 'hybrid quantum information' aiming at merging the best properties of both [1]. After a general overview of this approach, I will focus here on a novel hybrid protocol for witnessing single-photon entanglement using the continuous-variable toolbox.

Single-photon entangled states, i.e. states describing two optical paths sharing a single-photon, constitute the simplest form of entanglement. Yet they provide a valuable resource in quantum information. Specifically, they lie at the heart of quantum networks, as they can be used for quantum teleportation, swapped and purified with linear optics. The main drawback of such entanglement is the difficulty in measuring it. Existing methods have at least three drawbacks: they require assumptions on the size of the Hilbert space, they use post-selection or they need to recombine the entangled modes, which is difficult in the context of large-scale networks.

In Ref. [2], we recently proposed and experimentally tested a hybrid entanglement witness that avoids these drawbacks. Significantly, it uses local homodyning only and does not rely on assumption about the Hilbert space dimension of the measured system. We performed this demonstration using as a primary resource a high-fidelity single-photon source recently developed in our group and based on a type-II optical parametric oscillator [3].

[1] P. van Loock, Optical hybrid approaches to quantum information, Laser and Photonics Review 5, 167 (2010).

[2] O. Morin, J.-D. Bancal, M. Ho, P. Sekatski, V. D'Auria, N. Gisin, J. Laurat, N. Sangouard, Witnessing trustworthy single-photon entanglement with local homodyne measurements, Phys. Rev. Lett. 110, 130401 (2013).

[3] O. Morin, V. D'Auria, C. Fabre, J. Laurat, A high-fidelity single-photon source based on a type-II optical parametric oscillator, Optics Letters 37, 17 (2012).

All entangled states display some hidden nonlocality

Yeong-Cherng Liang[1, 3], Lluís Masanes[2], and Denis Rosset[3]

[1]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland

[2]ICFO-Institut de Ciències Fotòniques, Av. Carl Friedrich Gauss 3, E-08860 Castelldefels (Barcelona), Spain

[3]University of Geneva, Chemin de Pinchat 22, CH-1211 Genève 4, Switzerland

A well-known manifestation of quantum entanglement is that it may lead to correlations that are inexplicable within the framework of a locally causal theory – a fact that is demonstrated by the quantum violation of Bell inequalities. The precise relationship between quantum entanglement and the violation of Bell inequalities is, however, not well understood. While it is known that entanglement is necessary for such a violation, it is not clear whether all entangled states violate a Bell inequality, even in the scenario where one allows joint operations on multiple copies of the state and local filtering operations before the Bell experiment. In this talk we show that all entangled states, or more precisely, all not-fully-separable states of arbitrary Hilbert space dimension and arbitrary number of parties, violate a Bell inequality when combined with another state which on its own cannot violate the same Bell inequality. This result shows that quantum entanglement and quantum nonlocality are in some sense equivalent, thus giving an affirmative answer to the aforementioned open question. It follows from our result that two entangled states that are apparently useless in demonstrating quantum nonlocality via a specific Bell inequality can be combined to give a Bell violation of the same inequality. Explicit examples of such activation phenomenon are provided.

T74

Peer pressure

Suzy Lidström

Physica Scripta, Royal Swedish Academy of Sciences, Box 50005, SE 140-05, Sweden

Winnie-the-Pooh [1] opens with the memorable words, “Here is Edward Bear, coming downstairs now, bump, bump, bump, on the back of his head, behind Christopher Robin. It is, as far as he knows, the only way of coming downstairs, but sometimes he feels that there really is another way, if only he could stop bumping for a moment and think of it. And then he feels that perhaps there isn’t.”

Conventional academic journals are an interesting phenomenon. They receive gratuitous submissions from researchers, whereupon the manuscripts received are assessed by unpaid, hopefully disinterested, researchers. If read at all, published papers are read by yet more researchers. Thus all value-adding contributions are made by willing members of the academic community who invest their time for the benefit of all; yet the end product is sold by publishing houses to librarians who purchase it on behalf of the very people who have done all the work. Or have they?

The ease and speed of archiving and the ability to promote one’s work could indicate that there is little demonstrable value to be gained from publishing in traditional journals. If this were true, submissions would be declining. Are they?

Persistent growth in submissions indicates that conventional journals offer a service academics consider of worth. Journal prestige is coupled to the perceived quality of the peer review; so one might deduce that journals would seek to improve this service. Overseeing peer review and the quality stamp provided by this review are the services most valued by scientists. Yet, without the willing participation of already overburdened researchers, peer review would collapse. In this respect, it is noteworthy that peer review impinges increasingly on academics’ time, directly affecting researchers. Thus, a healthy discourse should be taking place between scientists, editorial boards and publishing houses with the aim of designing the service academics desire and addressing researchers’ concerns. This does not appear to be happening.

Are you too busy being bumped down those stairs to give the matter much thought, or would you prefer to hear about recent developments in peer review and to make a central contribution to the evolution of a service provided by you and for you?

[1] A.A. Milne “Winnie-the-Pooh”, Puffin, 1988.

Multiscale motility of molecular motors: From single motor molecules to cooperative cargo transport

Reinhard Lipowsky

MPI of Colloids and Interfaces, Dept of Theory and Bio-Systems, Science Park Golm, 14424 Potsdam, Germany

Within all eukaryotic cells, including those of our body, we encounter heavy traffic of cargo particles such as vesicles, organelles, or filaments. The associated cargo transport covers mesoscopic or even macroscopic distances and is performed by teams of molecular motors, which make discrete nanometer steps along cytoskeletal filaments.

During the last decade, we have developed a multiscale approach, by which one can understand the cooperative behavior of these motors [1,2] in terms of their single motor properties [3]. Here, I will focus on three issues that have been recently addressed within this general framework:

(i) The free energy transduction and kinetics of a single team of two identical motors that are elastically coupled via their common cargo. The corresponding stochastic process explores a complex chemomechanical network but involves only two additional parameters apart from the single motor properties [4];

(ii) The different transport regimes for such a single motor team. These regimes exhibit different forms of motor-motor interference and arise from the competition between spontaneous unbinding, mutual strain-induced unbinding, and mutual strain-induced stalling of the motors [5]; and

(iii) The cooperative transport by two teams of molecular motors, a slow and a fast team that differ in their transport velocity [6].

In all cases, our theories are in good agreement with available experimental data and make predictions that are accessible to future experiments.

[1] M. J. I. Müller, S. Klumpp, and R. Lipowsky, PNAS 105, 4609 (2008)

[2] R. Lipowsky, J. Beeg, R. Dimova, S. Klumpp, and M. J. I. Müller, Physica E 42, 649 (2010)

[3] R. Lipowsky, S. Liepelt, and A. Valleriani, J. Stat. Phys. 135, 951 (2009)

[4] C. Keller, F. Berger, S. Liepelt, and R. Lipowsky, J. Stat. Phys. 150, 205 (2013)

[5] F. Berger, C. Keller, S. Klumpp, and R. Lipowsky, Phys. Rev. Lett. 108, 208101 (2012)

[6] Xin Li, R. Lipowsky, and J. Kierfeld, Biophys. J. 104, 666 (2013)

T76

CMB large-scale anisotropy and the m=0 modes

Hao Liu[1, 2, 3], Anna Mette Frejsel[1, 2], and Pavel Naselsky[1, 2]

[1]*Niels Bohr Institute, Blegdamsvej 17, 2100 København Ø, Denmark*

[2]*Discovery center*

[3]*Institute of High Energy Physics*

We extend the curvaton scenario presented by Erickcek et al. (2008, 2009), to explain how the even-odd multipole asymmetry of the Cosmic Microwave Background (CMB) (also called parity asymmetry, (Kim & Naselsky 2010)) and power anisotropies can be generated by the curvaton field, which acts as an extra component to the spectrum of adiabatic perturbations in the inflationary epoch. Our work provides a possible cosmic explanation to the CMB large-scale asymmetry problems besides systematics and unknown residuals.

Anomalous transport in Josephson junction induced by non-equilibrium noise

Jerzy Łuczka[1], Jakub Spiechowicz[1], and Peter Hänggi[2]

[1]*Institute of Physics, Univeristy of Silesia, Uniwersytecka 4, 40-007 Katowice, Poland*

[2]*Institute of Physics, University of Augsburg, 86135 Augsburg, Germany*

Absolute negative mobility (ANM) is a counterintuitive phenomenon: particles move in a direction opposite to a static bias force. It seems to be in contradiction to the Newton equation of motion, the second law of thermodynamics and observations of motion at a macroscopic scale. However, under non-equilibrium conditions, there is no fundamental principle which excludes ANM. What are essential ingredients for the occurrence of ANM? The minimal model can be formulated in terms of a one-dimensional Newton equation for a Brownian classical particle moving in a symmetric spatially periodic potential, driven by an unbiased harmonic force and biased by a static force F [1]. The ANM response in a symmetric priodic potential is so that an average particle velocity $\langle v(F)\rangle$ obeys the relation: $\langle v(F)\rangle = -\langle v(-F)\rangle$, which follows from the symmetry arguments. In particular, $\langle v(0)\rangle = 0$. So, for $F = 0$ there is no directed transport in the long-time regime. The non-zero static force F breaks the symmetry and therefore induces a directed motion of particles. In the lecture, we replace the static force F by a random force $\eta(t)$ of a time-independent non-zero mean value $\langle \eta(t)\rangle = \eta_0$ [2]. We assume that the particle is coupled to its environment (thermostat) of temperature T and thermal fluctuations $\xi(t)$ are included as well. As an example of the random force $\eta(t)$, we consider non-equilibrium Poissonian shot noise, which is composed of a random sequence of δ-shaped pulses with random amplitudes. We analyze the dependence of the long-time average velocity $\langle v\rangle$ on parameters of both random forces $\eta(t)$ and $\xi(t)$. We find a rich variety of anomalous transport regimes including the absolute negative mobility regime around zero biasing Poissonian noise, the emergence of a negative differential mobility and the occurrence of a negative nonlinear mobility (for values of bias η_0 far from zero). As a feasible physical system, we propound a setup consisting of a single resistively and capacitively shunted Josephson junction driven by both a time periodic current and a noisy current. In this case the phase difference between the macroscopic wave functions of the Cooper electrons in both sides of the junction translates to the Brownian particle coordinate and the voltage across the junction translates to the particle velocity. For such a system, the anomalous transport characteristics can be measured, thus putting our predictions to a reality check.

[1] L . Machura, M. Kostur, P. Talkner, J. Łuczka and P. Hänggi, Phys. Rev. Lett. 98 (2007) 040601

[2] J. Spiechowicz, J. Łuczka and P. Hänggi, J. Stat. Mech. (2013) P02044

T78

Localization effects in quantum dot networks: A unified approach

Antonio Macedo[1], Victor Cavalcanti[1], Marcone Sena[1], and Francisco Almeida[2]

[1] *Universidade Federal de Pernambuco, Departamento de Física, Av. Prof. Luiz Freire, Recife, Brazil*

[2] *Universidade Federal de Sergipe, Departamento de Física, São Cristovão, Sergipe, Brazil*

We study quantum transport in a network of chaotic quantum dots. We propose a nonperturbative formalism that has the potential to unify the three most common approaches to quantum transport: random matrix theory, the nonlinear sigma model and the trajectory based semiclassical approach. Our formalism builds on the construction of appropriate representations for a generating function that contains detailed information on charge transfer processes. Some of the representations are well suited for numerical simulations, while others are best used in analytical calculations. We shall discuss two types of localization effects: weak and strong localization. We found that changes in the dot-dot coupling and in the topology of the network can have significant effects on transport properties. The quantum chain quantum wire crossover will be described in detail.

Observational quantum-thermodynamics: Fluctuation of intensive thermodynamic variables

Guenter Mahler

Institut fuer Theoretische Physik I, Universitaet Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

Quantum thermodynamics is able to show that the partitioning of a closed quantum system into a smaller and a significantly larger part typically gives rise to thermal properties for the former part, even though the system as a whole continues to exhibit unitary motion [1]. This picture differs substantially from the classical (statistical) description: It is not the system as such, which is thermal; rather it is made thermal by its environment. But this setting does not yet include the observer; this is reminiscent of the scenarios studied in abstract quantum theory, i.e., based on isolated systems. In both cases quantum measurements provide a link between classical and quantum descriptions [2].

Thermodynamic variables have a special status, they are no quantum observables. Any estimation has thus to be based on an indirect strategy. But eventually a quantum measurement model of a substitute observable and its characteristic uncertainties serves as an input. Surprisingly, the resulting fluctuations are in accord with simple fluctuation theories of classical thermo-statistics [3]. Concrete results are shown for temperature-and pressure-fluctuations. We close with a brief comment on work fluctuations.

[1] J. Gemmer, M. Michel, G. Mahler, Quantum Thernodynamics, Lecture Notes in Physics 768, Springer 2009 (2nd. ed.)

[2] Th. Jahnke, G. Mahler, Eur. Phys. Lett. 90, 50008 (2010)

[3] Th. Jahnke, S. Lanery, G. Mahler, Phys. Rev. E 83, 011109 (2011)

T80

On mathematical structure of physical quantities

Jiří J. Mareš, Pavel Hubík, and Václav Špička

Institute of Physics ASCR, v.v.i., Cukrovarnická 10, 162 00 Praha 6, Czech Republic

In the present contribution we have analyzed various aspects, epistemological and mathematical, of the fundamental entity of physics – physical quantity. It has been shown that for the description of physical reality the mathematical concepts of continuity and actual infinity intrinsic to real numbers are irrelevant and redundant. Instead, the set of rational numbers which is countable and dense was proved to be quite sufficient for such a purpose. It is further shown using a formalism of continued fractions that all results of physical measurements ever made can be transformed into the form of finite ordered sets of integers. Since in the frame of this formalism the metric properties of the corresponding physical quantity are apparent at first glance, some important conclusions can be made. For example, the requirement that the physical quantities, which are otherwise represented by rational numbers with limited accuracy, are exact, leads immediately to the conclusion that these quantities must constitute a discrete finite system. As we believe, similar considerations may open the way to describe the classical and quantum phenomena by algebraic theory and so resuscitate Pythagoras' dream in which the Nature was a marvelous play of integers.

Quantum many-body physics of phonons and photons

Florian Marquardt

Institute for Theoretical Physics II, University of Erlangen-Nuremberg, Staudtstr. 7, 91058 Erlangen, Germany

During the past few years, the interaction of nanomechanical vibrations and light has seen rapid progress. A whole zoo of so-called "cavity optomechanical" systems have been developed. The light field has been exploited to measure the mechanical vibrations down to the limits allowed by quantum mechanics and to laser-cool this motion down to the quantum ground state.

In this talk I will explore the myriad opportunities that will arise when one designs structures made up of many coupled mechanical and optical modes. Such structures can be realized on the basis of "optomechanical crystals", where one designs free-standing photonic crystals which can support localized vibrational and optical modes. If an array of such localized modes is implemented, the resulting "optomechanical array" can display interesting behaviour both in the classical and in the quantum regime.

I will discuss the physics of optomechanical arrays first in the regime of small vibrations, where a linearized approach to the dynamics is valid. In that case, one can investigate the "optomechanical bandstructure", as well as quantum operations on localized modes using pulsed schemes. I will then move on to the nonlinear dynamics, where in the classical regime the physics of synchronization can be observed (and where first experiments now exist). Finally, I will discuss the nonlinear quantum regime, where we have predicted a synchronization transition due to the competition between quantum noise and hopping of photons and phonons.

T82

Emerging localized states and alternating Kondo effects in quantum point contacts

Yigal Meir

Ben Gurion University, Department of Physics, Beer Sheva 84105, Israel

Quantum point contacts (QPCs), are the basic building blocks of any mesoscopic structure, and display quantized conductance, reflecting the quantization of the number of transparent channels. An additional feature, coined the "0.7 anomaly", has been observed in almost all QPCs, and has been a subject of intensive debate in the last couple of decades. In the past we have attributed this feature to the emergence of a quasi-localized state at the QPC, which explains all the phenomenology of the effect. In this talk I will describe two new experiments, and relevant theories, one which measured the thermoelectric power through the QPC, and another which measured the conductance through length-tunable QPC. The experimental findings support the picture of the localized state(s). Interestingly, with increasing QPC length, it was found that both the 0.7 anomaly and the zero bias peak in the differential conductance oscillate and periodically split with channel length, supporting the idea that the number of the localized state increases with length, leading to an alternating Kondo effect.

Event-by-event simulation of neutron interferometry experiments

Kristel Michielsen[1], Fengping Jin[1], and Hans De Raedt[2]

[1] *Institute for Advanced Simulation, Jülich Supercomputing Centre, Forschungszentrum Jülich, D-52425 Jülich, Germany*

[2] *Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, NL-9747AG Groningen, the Netherlands*

A discrete-event approach, which has been shown to give a unified cause-and-effect description of many quantum optics experiments [1] is applied to single-neutron interferometry experiments. The simulation algorithm does not require the knowledge of the solution of a wave equation of the whole system, yet reproduces the corresponding statistical distributions by generating detection events one-by-one. It is shown that the simulation method reproduces the results of several single-neutron experiments, including one which has demonstrated a violation of a Bell inequality [2,3] and another one in which the spin, energy and phase of the neutrons were coherently manipulated [4]. Our results show that classical (non-Hamiltonian) systems can exhibit correlations that in quantum theory are associated with an entangled state, even if all particles emitted by the source are accounted for by the detection system (i.e. with 100% efficient detectors, no time window etc).

[1] K. Michielsen, F. Jin, and H. De Raedt, J. Comp. Theor. Nanosci. 8, 1052 (2011)

[2] Y. Hasegawa, R. Loidl, G. Badurek, M. Baron, and H. Rauch, Nature 425, 45 (2003)

[3] H. Bartosik, J. Klepp, C. Schmitzer, S. Sponar, A. Cabello, H. Rauch, and Y. Hasegawa, Phys. Rev. Lett. 103, 040403 (2009)

[4] S. Sponar, J. Klepp, R. Loidl, S. Filipp, G. Badurek, Y. Hasegawa, and H. Rauch, Phys. Rev. A 78, 061604 (2008)

T84

Dirac cones, from graphene to cold atoms

Gilles Montambaux

Université Paris-Sud, Laboratoire de Physique des Solides, 91405 - Orsay, France

The so many fascinating properties of graphene are the subject of an intense research activity. There is also a growing interest for the study of "artificial graphenes", that is totally different and new systems which bear exciting similarities with graphene. The advantage of these structures is that they serve as new playgrounds for measuring and testing physical phenomena which may not be reachable in graphene, in particular the possibility of controlling the position of the pair of Dirac points existing in the electronic spectrum of graphene. In this talk, I will show how Dirac points can be manipulated, created or suppressed [1].

Recently, an experimental team in Zürich realized an ultracold gas of atoms moving in a potential landscape designed by laser fields [2]. Atoms now play the role of electrons and laser fields that of the crystalline lattice. This artificial graphene can be manipulated and deformed at will. Using this trick, the experimentalists managed to reach the required limit to observe the merging transition. By accelerating the atoms and measuring their evolution from low to high energy states, it is possible to follow the scenario of the merging transition. We have given a complete explanation of these experiments thanks to a model developed in our group [3]. We were able to compute the probability for an atom to get transferred from one band to the other as a function of the direction of acceleration. We have studied particularly the situation where atoms are accelerated along the axis of the two Dirac cones and experience two Landau-Zener transitions in a row. In this case, we expect the possibility of quantum interferences in momentum space leading to the yet to be observed Stückelberg oscillations [3].

Work done in collaboration with R. de Gail, P. Delplace, P. Dietl, J.N. Fuchs, M. Goerbig, L.K. Lim, F. Piéchon.

[1] Merging of Dirac points in a two-dimensional crystal, G. Montambaux, F. Piéchon, J.-N. Fuchs, M.O. Goerbig, Phys. Rev. B 80 (2009) 153412

[2] Creating, moving and merging Dirac points with a Fermi gas in a tunable honeycomb lattice, L. Tarruell, D. Greif, T. Uehlinger, G. Jotzu, T. Esslinger, Nature 483 (2012) 302

[3] Bloch-Zener oscillations across a merging transition of Dirac points, L.K. Lim J.-N. Fuchs, G. Montambaux, Phys. Rev. Lett. 108 (2012) 175303

Experimental study of work and entropy fluctuations in a single-electron box

Mikko Möttönen[1, 2], Olli-Pentti Saira[1, 2, 6], Jonne Koski[1], Youngsoo Yoon[1], Takahiro Sagawa[5], Tuomo Tanttu[2], Dmitri Averin[3], Aki Kutvonen[4], Paolo Solinas[1, 4], Tapio Ala-Nissila[4, 7], and Jukka Pekola[1]

[1] *Low Temperature Laboratory (OVLL) Aalto University, POB 13500, 00076 Aalto, Finland*

[2] *QCD Labs, COMP Centre of Excellence, Department of Applied Physics, Aalto University, POB 13500, 00076 Aalto, Finland*

[3] *Department of Physics and Astronomy, Stony Brook University, SUNY, Stony Brook, NY 11794-3800, USA*

[4] *COMP Centre of Excellence, Department of Applied Physics, Aalto University, POB 11100, 00076 Aalto, Finland*

[5] *Department of Basic Science, The University of Tokyo, Komaba 3-8-1, Meguro-ku, Tokyo 153-8902, Japan*

[6] *Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands*

[7] *Department of Physics, Brown University, Providence RI 02912-1843, USA*

We present measurements of the distribution of entropy production [1] and dissipated work [2] in a metallic single-electron box that we subject to an external nonadiabatic gate drive at sub-kelvin temperatures. The experimental gate protocol can be repeated indefinitely without degrading the system, which enables measurements with extremely small statistical uncertainty. When expected, we find our experimentally obtained distributions to obey the integral fluctuation theorem [1] and the Jarzynski equality [2], and the corresponding detailed fluctuation relations. The studies on the entropy production [1] employ two thermal baths at different temperatures, which results in an interesting distinction between the thermodynamic entropy production and the typically measured stochastic entropy production. We show analytically that the stochastic entropy production arises from a specific type of average of the thermodynamic production and compare the experimental results on these two different entropy productions with each other.

[1] J. V. Koski, T. Sagawa, O.-P. Saira, Y. Yoon, A. Kutvonen, P. Solinas, M. Möttönen, T. Ala-Nissila, and J. P. Pekola, submitted to Nature Phys., (2013), arXiv:1303.6405.

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

T86

CMB cosmology after the Planck mission

Pavel Naselsky

Niels Bohr Institute, Blegdamsvej 17, Copenhagen, Denmark

I will present the main results of the ongoing Planck experiment, focusing on the impact of the Planck temperature anisotropy data to the fundamental physics. The Planck best fit cosmological model allow us to constrain the theories of inflation through the measurement of the spectral index of scalar perturbations and tensor/scalar ratio. It gives us a unique opportunity to investigate the cosmological gravitational waves from inflation , which will manifest themselves as non-vanishing component of the magnetic mode of the CMB polarization (so called, B-mode). In addition, the Planck data indicate some anomalies of the CMB sky, localized at low multipole domain. I will discuss possible origin and relationship between some of the anomalies and they importance for the modern cosmology.

Stochastic large scale DFT and quantum chemistry: On the road to millions of electrons

Daniel Neuhauser[1], Roi Baer[2], and Eran Rabani[3]

[1] *Department of Chemistry and Biochemistry, UCLA, 607 Charles E Young dr, Los Angeles 90095, USA*

[2] *Fritz Haber Center for Molecular Dynamics, Institute of Chemistry, Hebrew University, Jerusalem 91904, Israel*

[3] *School of Chemistry, The Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel*

We have developed since 2012 a new paradigm for electronic structure, labeled Stochastic Quantum Chemistry (SQC), with subfields: Stochastic DFT/TDDFT, Stochastic MP2/MP3/MPn, Stochastic RPA, etc. In general, we do not need or find the exact orbitals or density matrix, but instead filter random wavefunctions to occupied and unoccupied parts. This fundamental step then allows to find the density, propagate it with time, and calculate the MPn and RPA expressions, without resorting to the determination of the exact orbitals. The methods scale close to linearly (at times sublinearly) with system (grid) size, and have been demonstrated for systems with thousands of electrons (for both DFT and MPn and RPA, a record for the latter two approaches). Stochastic Quantum Chemistry opens the road to calculations with hundreds of thousands and eventually millions of electrons. The theory is simple to comprehend and will be reviewed along with subtleties such as correlated sampling.

[1] D. Neuhauser, E. Rabani, and R. Baer, J. Chem. Theor. Comp. 9, 24 (2012).

[2] D. Neuhauser, E. Rabani, and R. Baer, J. Phys. Chem. Lett. 4, 1172 (2013).

[3] R. Baer, E. Rabani, and D. Neuhauser, submitted for publication.

T88

Transport experiments in InAs/GaSb broken-gap quantum wells

Fabrizio Nichele, Atindra Nath Pal, Patrick Pietsch, Christophe Charpentier, Werner Wegscheider, Thomas Ihn, and Klaus Ensslin

ETH Zurich, Solid State Physics Laboratory, Schafmattstrasse 16, Zurich, Switzerland

An InAs/GaSb double quantum well sandwiched between two AlSb barriers shows a peculiar type-II band alignment. A quantum well for electrons in InAs and a quantum well for holes in GaSb coexist next to each other. If the quantum wells' thicknesses are small enough a small hybridization gap can open for finite k-vectors. Depending on the quantum wells thicknesses and on the perpendicular electric field applied to the structure, a rich phase diagram is predicted. It should be possible to electrically tune the sample from standard conducting phases to insulating, semimetallic or topological insulator phases [1,2]. Recent work on InAs/GaSb quantum wells showed the presence of a residual conductivity in micron-sized Hall bars and interpreted with the existence of helical modes [4,5], as expected for the quantum spin Hall insulator phase [6].

We present transport measurements performed on ambipolar InAs/GaSb double quantum wells at cryogenic temperatures. The large dimension of the devices in use does not allow us to resolve the presence of helical modes at zero magnetic field. We focus our attention on magnetotransport phenomena that allow us to better understand the peculiarity of the band structure under study. Similarly to what was observed in graphene [7] and in semimetallic HgTe quantum wells [8,9], the resistivity at the charge neutrality point strongly increases in a high perpendicular magnetic field. The resistivity increase is accompanied by a giant non-local response that has been interpreted as resulting from counter-propagating electron and hole edge channels. Here we show that the above cited effects are visible in InAs/GaSb as well and we study them as a function of top gate voltage, magnetic field and temperature. Particular attention is given to the nature of the giant non-local response and to its dependence on temperature and distance between Ohmic contacts.

[1] Y. Naveh and B. Laikhtman, Appl. Phys. Lett. 66, 1980 (1995)
[2] C. Liu et al. Phys. Rev. Lett. 100, 236601 (2008)
[3] I. Knez et al. Phys. Rev. Lett. 107, 136603 (2011)
[4] I. Knez et al. Phys. Rev. Lett. 109, 186603 (2012)
[5] M. König et al. Science 18, 766 (2007)
[6] D. A. Abanin et al. Phys. Rev. Lett. 98, 196806 (2007)
[7] G. M. Gusev et al. Phys. Rev. Lett. 104, 166401 (2010)
[8] G. M. Gusev et al. Phys. Rev. Lett. 108, 226804 (2012)

Neutrinos: The most standard-model friendly option for dark matter

Theo Nieuwenhuizen

Institute for Theoretical Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, Netherlands

Searches at the Large Hadron Collider have so far not yielded any beyond-the-standard-model physics. In particular, supersymmetry is not found and neither its WIMP dark matter particle. Likewise, many direct searches in mines, under mountains or with satellites like Fermi, yield at best hints, but no proof, of a WIMP. Heavy (GeV mass) particles like the WIMP would call for a strong revision of the Standard Model (SM) of elementary particles, for which there is at present no direct indication. Also standard axions appear to be ruled out.

Another case deals with (sterile) neutrinos as dark matter particles. Due to neutrino oscillations, right-handed partners must exist. They are "sterile", i. e., they do not couple to SM processes. Sterile neutrinos would lead to a minimal extension of the SM, in particular, they would not affect the gauge symmetry and renormalizability. If the masses have a Dirac structure, the masses of left- and right-handed partners are just equal. An additional Majorana matrix may split this degeneracy. Sterile masses can be considered from sub-eV to TeV scales.

It is well known that solar and atmospheric oscillations imply very small mass-squared differences. Taken together with reactor experiments which point at eV^2 differences, the case of eV-scale neutrino masses is well motivated. This will be tested at the 2015 Katrin experiment, which searches down to 0.2 eV. A discovery would pose severe questions to ΛCDM, the standard model of cosmology. Even though the latter works rather well, Planck has shown that it does not work really well, while it also contains many ill understood features, and may appear to be an effective model only.

Analysis of very precise weak and strong lensing data for the galaxy cluster Abell 1689 is compatible 1.5 eV neutrinos [1,2]. Next to reactor experiments, this supports the case of (light) neutrino hot dark matter. The scenario will be constrained by nucleosynthesis, while the needed non-linear galaxy structure formation, related to turbulence, is poorly understood.

[1] Theo M. Nieuwenhuizen, Do non-relativistic neutrinos constitute the dark matter? Europhysics Letters 86, 59001 (2009)

[2] Theo M. Nieuwenhuizen and Andrea Morandi, Are observations of the galaxy cluster Abell 1689 consistent with a neutrino dark matter scenario? MNRAS, to appear

T90

Gauge-invariant nonequilibrium density matrix with applications to spin torques driven by spin-orbit coupling

Branislav Nikolic[1, 3], Farzad Mahfouzi[1], and Naoto Nagaosa[2, 3]

[1] *University of Delaware, Department of Physics & Astronomy, Newark DE 19716, USA*

[2] *Department of Applied Physics, University of Tokyo, Tokyo 113-8656, Japan*

[3] *Cross-Correlated Materials Research Group (CMRG) and Correlated Electron Research Group (CERG), RIKEN-ASI, Wako, Saitama 351-0198, Japan*

Experiments observing spin density and spin currents (responsible for, e.g., spin-transfer torque) in spintronic devices measure only the nonequilibrium contributions to these quantities, typically driven by injecting unpolarized charge current or by applying external time-dependent fields. On the other hand, theoretical approaches to calculate these quantities operate with both the nonequilibrium (carried by electrons around the Fermi surface) and equilibrium (carried by the Fermi sea electrons) contributions to them. Thus, an unambiguous procedure should remove the equilibrium contributions (as exemplified by non-zero field-like spin torque in magnetic tunnel junctions at zero bias voltage), thereby rendering the nonequilibrium ones which are measurable and satisfy the gauge-invariant condition according to which expectation values of physical quantities should not change when electric potential everywhere is shifted by a constant amount. Using the framework of nonequilibrium Green functions, we delineate such procedure [1] which yields the proper gauge-invariant nonequilibrium density matrix in the linear-response and elastic transport regime for current-carrying steady state of an open quantum system connected to two macroscopic reservoirs. Its usage is illustrated [2] by computing unconventional spin torque driven by spin-orbit coupling (SOC) in vertical N/TI/F or lateral TI/F heterostructures involving normal metal (N) layers, ferromagnetic (F) layers, and layers of recently discovered three-dimensional topological insulators which introduce SOC into the system.

[1] F. Mahfouzi and B. K. Nikolic, http://arxiv.org/abs/1305.3180

[2] F. Mahfouzi, N. Nagaosa, and B. K. Nikolic, Phys. Rev. Lett. 109, 166602 (2012)

Entanglement protection in superconducting qubits by dynamical decoupling

Elisabetta Paladino[1, 2], Antonio D'Arrigo[1, 2], and Giuseppe Falci[1, 2]

[1]*Dipartimento di Fisica e Astronomia, Via S. Sofia 64, 95123 Catania, Italy*

[2]*CNR-IMM UoS Catania (Univeristà), Via Santa Sofia 64, 95123 Catania, Italy*

Superconducting circuits are a promising technology for the realization of quantum information on a solid state platform. The coherence times of the present generation of devices ($\sim \mu$s) are about three orders of magnitudes larger than the first implementations. However, further improvement of the coherence times at least of one order of magnitude would be required to reach the level for practical quantum error correction. In particular, a major question currently unsolved is establishing the best strategy to maintain long-enough a sufficient degree of entanglement.

Solid-state noise sources are often characterized by broad-band and non-monotonic power spectrum. Usually, the spectrum of at least one of the noise sources is 1/f at low-frequencies, at the system's eigen-frequencies instead indirect measurements indicate white or ohmic spectrum. We have investigated and characterized the effects of solid state broad-band noise in various architectures, from single/coupled quantum bits to artificial multilevel atoms, also in the presence of time-dependent external driving fields. A general route to identify optimal operating conditions of reduced sensitivity to 1/f noise sources in complex architectures has been proposed [1] and applied to an entangling two-qubit gate realized by a capacitive coupling of two transmons in a circuit-QED architecture in [2].

Complementary to optimal tuning, dynamical decoupling strategies are a promising tool to suppress the effect of 1/f noise [3]. In this presentation we will illustrate that entanglement between superconducting qubits can be preserved by proper sequences of echo pulses, feasible with current experimental equipments. Our analysis suggests a possible way to simultaneously store entanglement and perform high-fidelity two-qubit gates [4].

[1] E. Paladino, A. Mastellone, A. D'Arrigo and G. Falci, Phys. Rev. B 81, 052502 (2010); E. Paladino, A. D'Arrigo, A. Mastellone and G. Falci., New J. Phys. 13, 093037 (2011).

[2] E. Paladino and A. D'Arrigo New J. Phys. 14, 053035 (2012).

[3] G. Falci, A. D'Arrigo, A. Mastellone, E. Paladino Phys. Rev. A 70, 040101 (2004).

[4] R. Lo Franco, A. D'Arrigo, G. Compagno, G. Falci, E. Paladino, in preparation 2013.

T92

Ultrafast saturation of Raman coherence

Anil Patnaik[1, 2], Sukesh Roy[3], and James Gord[1]

[1]*Aerospace Systems Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433 USA*

[2]*Department of Physics, Wright State University, Dayton, OH 45435 USA*

[3]*Spectral Energies, LLC, 5100 Springfield Street, Ste. 301, Dayton, OH 45431 USA*

A strong laser field can drive an atomic or molecular transition to saturation when the associated Rabi frequency exceeds the decays and dephasing associated with the transitions of interest. The dynamics of saturation exhibit typical Rabi oscillations at a rate that is proportional to the square root of the intensity of the driving field. If the pulse duration of the driving field is longer than the Rabi period of oscillation, steady-state saturation can be obtained. However, if the pulse duration is shorter than the Rabi period and the decay timescale, the saturation dynamics become more complex. By increasing the intensity of the driving laser to such an extent that the Rabi period becomes shorter than the pulse duration, an ultrafast non-equilibrium saturation of the transition can be achieved.

The same reasoning applies to Raman coherence, where a pair of pump and Stokes fields can generate the steady-state saturation if the two-photon Rabi frequency is higher than the decay and dephasing rates. This has been shown in the regime of nanosecond-pulse-based excitation [1]. However, if the coupling lasers are short-duration pulses on the order of femtoseconds (fs), this laser can couple multiple rotational states simultaneously in addition to its role as pump laser [2]. We observed that the saturation dynamics are then determined primarily by the saturation of the rotational Raman coherence. Also, the Raman coherence may exhibit saturation-like behavior if a strong probe resonantly couples the Raman-excited state to another electronic transition in the long-pulse regime [3] – of course in the non-equilibrium sense. Note that the saturation thus observed is on a time scale of the vibrational period of molecules and is orders of magnitude faster than state-of-art electronic switches. A very intuitive understanding of the saturation in these ultrashort-pulse regimes is obtained by calculating the pulse area associated with the pulse. This study gives predictive capability for the intensity threshold to avoid Raman and CARS saturation, which is very important for ultrafast spectroscopic measurements.

[1] A. K. Patnaik, S. Roy, J. R. Gord, R. P. Lucht, and T. B. Settersten, J. Chem. Phys. 130, 214304 (2009).

[2] A. K. Patnaik, S. Roy, and J. R. Gord, Phys. Rev. A 87, 043801 (2013).

[3] A. K. Patnaik, J. R. Gord, and S. Roy (in preparation, 2013).

On the initial stage of quasiparticle decay: A many-body perturbation theory perspective

Yaroslav Pavlyukh

Martin-Luther-University, Halle-Wittenberg, Heinrich-Damerow-Str.4, Halle, Germany

Generally, the addition or removal of a single particle in a many-body system does not correspond to an exact eigenstate of the system. Thus the resulting coherent excitation evolves in time. As discussed here, the evolution at short times upon the excitation with the energy ε exhibits a quadratic decay [with the rate constant $\sigma^2(\varepsilon)$]. Later on, after some time $\tau(\varepsilon)$, the exponential decay sets in. It is governed by another rate constant $\gamma(\varepsilon)$. This behavior is generic for many realistic finite and extended systems [1]. For a finite system it is possible to assess this behavior full numerically using an exact solution of the many-body problem. We present a simple model for the electron spectral function that links together all three aforementioned parameters and give a prescription for how the energy uncertainty $\sigma^2(\varepsilon)$ can be computed within the many-body perturbation theory. Our numerical results demonstrate that the model approach accurately reproduces the exact spectral function in a large range of energies even in the case of fragmented many-body states. We show that the central quantity of this study $\sigma^2(\varepsilon)$ can easily be computed exactly or from approximate theories [2] and, hence, can be used for their validation. We also point out how the set in time can be tested by means of attosecond spectroscopy.

As another application of our theory we inspect the initial and the long-time evolution of excitations in Fermi liquids by analyzing the time structure of the electron spectral function. Focusing on the short-time limit we study the electron-boson model for the homogeneous electron gas and apply the first-order (in boson propagator) cumulant expansion of the electron Green's function. In addition to a quadratic decay in time upon triggering the excitation, we identify nonanalytic terms in the time expansion similar to those found in the Fermi edge singularity phenomenon. We also demonstrate that the exponential decay in time in the long-time limit is inconsistent with the GW approximation for the self-energy. The background for this is the Paley-Wiener theorem of complex analysis. To reconcile with the Fermi liquid behavior an inclusion of higher order diagrams (in the screened Coulomb interaction) is required [3].

[1] Y. Pavlyukh, J. Berakdar, and A. Rubio, Phys. Rev. B 87, 125101 (2013)

[2] Y. Pavlyukh, J. Berakdar, J. Chem. Phys. 135, 201103 (2011)

[3] Y. Pavlyukh, A. Rubio, and J. Berakdar, Phys. Rev. B 87, 205124 (2013)

T94

Microscopic derivation of open quantum walks

Francesco Petruccione[1, 2] and Ilya Sinayskiy[1, 2]

[1] *University of KwaZulu-Natal, Private Bag X54001, Durban 4000, South Africa*

[2] *National Institute for Theoretical Physics (NITheP), KwaZulu-Natal, South Africa*

Recently, a formalism for discrete time open quantum walks was introduced [1]. The formalism suggested is similar to the formalism of quantum Markov chains and rests upon the implementation of appropriate completely positive maps. The formalism of the open quantum random walks (OQW) includes the classical random walk and through a physical realization procedure a connection to the unitary quantum walk can be established. Furthermore, the OQW allows for an unravelling in terms of quantum trajectories. It was shown [2] that open quantum walks can perform universal quantum computation and can be used for quantum state engineering

Here, we present the microscopic derivation of open quantum walks. A walk on a graph is considered and transitions between vertices are mediated by the interaction of the walker with a shared bosonic environment. The reduced dynamics of the walker is shown to be described in terms of a generalised Markovian master equation. The time discretization of the master equation gives raise to an open quantum walk. Based on the class of microscopic models considered here possible physical implementations are discussed. Also, the potential application of the walks to quantum biology is indicated.

[1] S. Attal, F. Petruccione, C. Sabot, and I. Sinayskiy, J. Stat. Phys., 147 (2012) 832

[2] I. Sinayskiy and F. Petruccione, QIP 11 (2012) 1301

On the concept of quantum field: From reality to probability

Arkady Plotnitsky

Purdue University, 500 Oval Drive, West Lafayette, IN, 47907, USA

This paper is a contribution to the long-standing debate concerning the question "What is a quantum field?" In particular, this debate has to do with the status of the standard mathematical formalism, essentially that of a Hilbert-space over complex numbers, associated with the concept of quantum field (from quantum electrodynamics to the set of frameworks comprising the standard model) as representing, or not representing, the ultimate nature of quantum reality. The argument of this paper is that it is difficult to maintain that this formalism represents the nature of the ultimate quantum reality—the behavior of the quantum objects responsible for the data observed in the corresponding (high-energy) experiments. The possibility that such a framework is able to do so cannot be excluded, and arguments to that effect have been and continue to be advanced, including vis-à-vis those for the particle-like picture of quantum reality, a view, as I shall argue in this paper, is equally difficult to maintain, although it cannot be excluded either. Rather, however, than considering alternative to the standard formalism of quantum field theory, this paper will examine an alternative way of relating this formalism to nature and, thus, an alternative interpretation of quantum field theory, specifically, as a way of predicting the probabilities of the outcomes of the relevant quantum experiments, observed in the measuring instruments involved, as opposed to describing quantum objects themselves and their behavior. This view has profound implications for our understanding of the character of the ultimate elementary constituents of nature, sometimes known as "elementary particles"—photons, electrons, quarks, gluons, and so forth—but equally considered in terms of fields. Indeed, this view implies the possibility of a new concept of "quantum field" and a new concept of "elementary particle," and a new way of relating them, thus also posing and relating the questions "What is a quantum field?" and "What is an elementary particle?" in a new way. I shall conclude by considering, from the perspective developed in this paper, a recent discovery of the Higgs boson, and the complexities of the process of this discovery, including the role of computer models in it.

T96

Revealing the Andreev degree of freedom in the Josephson effect

Hugues Pothier, Landry Bretheau, Çağlar Girit, Daniel Esteve, and Cristian Urbina

Quantronics Group, SPEC, CEA-Saclay, Gif-sur-Yvette, France

The Josephson effect describes the flow of supercurrent in a weak link – such as a tunnel junction, nanowire, or molecule – between two superconductors. Microscopically this current is carried by peculiar pair states localized at the weak link. These Andreev states come in doublets with energies symmetric about the Fermi energy, and carry supercurrent in opposite directions. We present photon absorption spectroscopy revealing the transitions between Andreev states in the simplest Josephson element, a superconducting one-atom contact. Our results demonstrate the accessibility of a spin-like internal degree of freedom in Josephson junctions.

[1] Reference: arXiv:1305.4091; to be published in Nature

Detailed balance and nonequilibrium fluctuation theorems

Saar Rahav[1] and Christopher Jarzynski[2]

[1] *Schulich Faculty of Chemistry, Technion - Israel Institute of Technology, Technion City, Haifa 32000, Israel*

[2] *Department of Chemistry and Biochemistry and Institute of Physical Science and Technology, University of Maryland, College Park, MD 20742, U.S.A.*

Fluctuation theorems are a group of exact relations comparing the probabilities of time reversed realizations of out of equilibrium processes. Although their simple structure and general applicability have generated great interest and a vigorous research effort, an intuitive understanding of why such results hold has proven elusive. Should we have expected them?

We point out that in many cases the out of equilibrium process of interest can be viewed as a carefully designed limit of a rare fluctuations in a suitably defined equilibrium system. Fluctuation theorems then emerge naturally from a combination of the principle of detailed balance and the aforementioned limit. This perspective suggests that fluctuation theorems can be viewed a consequence of Onsager's regression hypothesis in the limit of large (and extremely rare) fluctuations, just as the classical fluctuation-dissipation theorem is a consequence of the regression hypothesis for small fluctuations. We use a stochastic jump process with a finite number of states as an instructive example to elucidate these considerations.

T98

Gaussian post-selection and quantum communication

Timothy Ralph and Nathan Walk

University of Queensland, School of Mathematics and Physics, Brisbane, 4072, Australia

Post-selection is a standard part of discrete variable QKD and other quantum communication protocols, however attempts to prove security when post-selection is deployed in continuous variable QKD protocols have until now been limited. Here, by using a carefully tailored Gaussian post-selection protocol, we prove unconditional security and show that significant performance improvements are achieved. We discuss applications to other communication protocols.

Transport theory for a dilute Bose-Einstein condensate

Linda Reichl and Erich Gust

University of Texas at Austin, Center for Complex Quantum Systems and Physics Department, 1 University Station, Austin, 78712, USA

For a non-condensed (T>Tc) dilute monatomic gas of bosons, five slowly varying hydrodynamic variables govern the relaxation to equilibrium. These five variables correspond to quantities conserved during elastic collisions between the particles; the particle number, momentum (three components), and kinetic energy of the particles. Above Tc, relaxation is governed by three transport coefficients; shear viscosity, thermal conductivity, and bulk viscosity (which is zero for the dilute gas). Below the critical temperature Tc for Bose-Einstein condensation, the boson gas has six hydrodynamic modes, but the microscopic collision processes occur between Bogoliubov excitations (bogolons) and only four quantities are conserved; bogolon momentum and energy. The additional modes are due to the broken gauge symmetry and the presence of the condensate. Below Tc, relaxation to equilibrium is governed by six transport coefficients; shear viscosity, thermal conductivity, and four bulk viscosities (which appear to be negligible for a dilute BEC).

We have derived microscopic and macroscopic expressions for the six hydrodynamic modes of a dilute Bose-Einstein condensate; two transverse (shear) modes, and four longitudinal modes corresponding to first sound (elastic waves) and second sound (temperature waves). Our microscopic expressions include both the speed of the two types of sound and the rate of relaxation of the sound waves. The relaxation of both types of sound appears to be governed primarily by shear viscosity and thermal conductivity.

[1] L.E. Reichl and Erich D. Gust, "Transport Theory for a Dilute Bose-Einstein Condensate" (submitted to PRA).

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

[3] Erich D. Gust and L.E. Reichl, "Relaxation Modes and collision integrals for Bose-Einstein condensates," J. Low Temp. Phys. 170 43 (2013).

T100

Towards a large-scale quantum simulator on diamond surface at room temperature

Alex Retzker[1], Jianming Cai[2], Fedor Jelezko[2], and Martin Plenio[2]

[1] *The Hebrew University, Racah Institute of Physics, Jerusalem 91904, Israel*

[2] *Universität Ulm, Albert-Einstein Allee 11, D-89069 Ulm, Germany*

Strongly-correlated quantum many-body systems exhibit a variety of exotic phases with long range quantum correlations, such as spin liquids and supersolids. Despite the rapid increase in computational power of modern computers, the numerical simulation of these complex systems becomes intractable even for a few dozens of particles. Feynman's idea of quantum simulators offers an innovative way to bypass this computational barrier. However, the proposed realizations of such devices either require very low temperatures (ultracold gases in optical lattices, trapped ions, super conducting devices) and considerable technological effort, or are extremely hard to scale in practice (NMR, linear optics). In this work, we propose a new architecture for a scalable quantum simulator that can operate at room temperature. It consists of strongly-interacting nuclear spins attached to the diamond surface by its direct chemical treatment, or by means of a functionalized graphene sheet. The initialization, control and read-out of this quantum simulator can be accomplished with nitrogen-vacancy centers implanted in diamond. The system can be engineered to simulate a wide variety of interesting strongly-correlated models with long-range dipole-dipole interactions. Due to the superior coherence time of nuclear spins and nitrogen-vacancy centers in diamond, our proposal offers new opportunities towards large-scale quantum simulation at room temperatures.

Weak measurement of cotunneling time

Alessandro Romito[1] and Yuval Gefen[2]

[1]*Freie Universität Berlin, Dahlem Center for Complex Quantum Systems, Arnimallee 14, 14195 Berlin, Germany*

[2]*Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel*

Quantum mechanics allows for the existence of virtual states that have no classical analogue. While they are forbidden by energy conservation in classical mechanics, their presence within quantum mechanics as short-lived states is allowed by the time-energy uncertainty principle. Virtual state, being volatile, defy direct observation through strong measurement that would collapse the states itself.

Here we show how a virtual state of an interacting many-body system can be detected via weak measurements. Specifically we employ a composite measurement protocol called Weak Value (WV) [1], consisting of a weak measurement followed by a strong measurement for the determination of the time it takes an electron to tunnel through a virtual state of a quantum dot (QD). Such a cotunneling process [2] is strikingly different from a single particle tunneling under the barrier, since here transport of an electron involves a virtual many-body correlated state on the QD.

We introduce a realistic system-detector setup, which employs a quantum point contact (QPC) as charge detector and is valid both in the sequential and cotunneling regimes. We relate the correlation function of the system-detector currents to the sequential tunneling and cotunneling traversal time. We show that contrary to classical intuition, the cotunneling time is independent of the strength of the dot-lead coupling, and the expectations based on either the uncertainty principle, or on analogy with a single particle tunneling ("imaginary velocity" under the barrier) are unfounded. In fact we find that the cotunneling time depends parametrically on whether the cotunneling is dominated by elastic or inelastic processes.

[1] Y. Aharonov, D. Z. Albert, and L. Vaidman, Phys. Rev. Lett. 60, 1351 (1988).

[2] D. V. Averin and Y. V. Nazarov, Phys. Rev. Lett. 65, 2446 (1990).

T102

Measurement induced enhancement of quantum dot coherence

Katarzyna Roszak[1], Radim Filip[2], and Tomáš Novotný[3]

[1] *Institute of Physics, Wrocław University of Technology, Wyb. Wyspianskiego 27, 50-370 Wroclaw, Poland*

[2] *Department of Optics, Palacký University, 17. listopadu 50, 77207 Olomouc, Czech Republic*

[3] *Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, 12116 Prague, Czech Republic*

Excitonic states in semiconductor self assembled quantum dots (QDs) are one of the solid state candidates for the implementation of quantum computation [1]. Due to the atomic structure of QD energy levels, it is easy to single out a subset of excitonic states to encode the logical qubit values. Being artificial, their properties can be tailored to a very high extent through growth conditions and the choice of materials used. Initialization, manipulation and readout techniques via ultrafast laser spectroscopy are experimentally accessible. The single, but serious drawback on the way to QD based quantum computatopm is the fact that being embedded in bulk semiconductor, excitons in QDs interact with phonon modes of the surrounding crystal. This interaction leads to an unavoidable partial pure dephasing effect on picosecond timescales [2,3].

We address the problem of inhibiting phonon-induced partial pure dephasing of an exciton confined in a QD and show that intermediate measurements on the QD system generically decrease the level of decoherence caused by pure dephasing due to the phonon bath. We explain this counter-intuitive effect by identifying subtle correlations imposed into the reservoir, rather than the qubit itself, by the measurement process and eventually transferred during the non-Markovian dynamics to the asymptotic state of the qubit. It turns out to be advantageous, if the measurements are well separated in time from the initialization of the QD state and from each other. Although the measurements may cause both increase and loss of asymptotic coherence depending on the measurement times and outcomes, we show for the single measurement case that performing a measurement at any time after the initialization of the state is favorable, due to the interplay of given-outcome probabilities and corresponding dephasing values.

[1] P. Zanardi and F. Rossi, Phys. Rev. Lett. 81, 4752 (1998).

[2] A. Vagov, V. M. Axt, T. Kuhn, W. Langbein, P. Borri, and U. Woggon, Phys. Rev. B 70, 201305(R) (2004).

[3] A. Vagov, V. M. Axt, and T. Kuhn, Phys. Rev. B 67, 115338 (2003).

Mesoscopic thermodynamics for near-field heat transfer

J. Miguel Rubi[1], Agustin Perez-Madrid[1], and Luciano Lapas[2]

[1] *University of Barcelona, Faculty of Physics, Diagonal 647, Barcelona, Spain*

[2] *Universidade Federal da Integraçao Latino-Americana, Foz do Iguaçu, Paraná, Brasil*

Radiative heat exchange at the nanoscale presents a challenge for several areas due to its scope and nature. Here, we provide a thermokinetic description of microscale radiative energy transfer including phonon-photon coupling manifested through a non-Debye relaxation behavior. We show that a lognormal-like distribution of modes of relaxation accounts for this non-Debye relaxation behavior leading to the thermal conductance. We also discuss the validity of the fluctuation-dissipation theorem. The general expression for the thermal conductance we obtain fits existing experimental results with remarkable accuracy. Accordingly, our approach offers an overall explanation of radiative energy transfer through micrometric gaps regardless of geometrical configurations and distances.

T104

Topological surface states scattering from first principles

Ivan Rungger, Awadhesh Narayan, and Stefano Sanvito

Trinity College Dublin, College Green, Dublin 2, Ireland

Materials with topologically protected surface states are gaining growing attention due to their potential for device applications, which is rooted in the fact that the current carried by such states is expected to be largely “protected” from scattering. For example, while the conducting properties of graphene usually deteriorate significantly if defects are present, the conductance of topological surfaces is expected to be largely independent on the amount of defects. Our aim is to quantitatively study the scattering properties of such systems in presence of different types of perturbations. Specifically, we study the scattering properties of topologically protected states on the Sb(111) and $Bi_2Se_3(111)$ surfaces by using the ab initio electron transport code SMEAGOL [1]. We consider different types of defects, such as adatoms and extended barriers. In the presence of a strong surface perturbation in the form of a step separating surface terraces we obtain standing-wave states resulting from the superposition of spin-polarized surface states. By Fourier analysis, we identify the underlying two dimensional scattering processes and the spin texture [2]. We find evidence of resonant transmission across the surface barrier at quantum well state energies and evaluate their lifetimes. Our results are in good agreement with experimental findings [3,4].

[1] A. R. Rocha, V. M. Garcia-Suarez, S. Bailey, C. Lambert, J. Ferrer, and S. Sanvito, Phys. Rev. B 73, 085414 (2006).

[2] A. Narayan, I. Rungger, and S. Sanvito, Phys. Rev. B 86, 201402(R) (2012).

[3] J. Seo, P. Roushan, H. Beidenkopf, Y. S. Hor, R. J. Cava, and A. Yazdani, Nature (London) 466, 343 (2010).

[4] Z. Alpichshev, J. G. Analytis, J.-H. Chu, I. R. Fisher, Y. L. Chen, Z. X. Shen, A. Fang, and A. Kapitulnik, Phys. Rev. Lett. 104, 016401 (2010).

Realization of a parametric interaction between two photons from independent sources

Bruno Sanguinetti[1], Thiago Guerreiro[1], Enrico Pomarico[1], Nicolas Sangouard[1], Jason S. Pelc[2], Carsten Langrock[2], Martin M. Fejer[2], Hugo Zbinden[1], Rob Thew[1], and Nicolas Gisin[1]

[1]*GAP Optique, University of Geneva, Chemin de Pinchat 22, Carouge CH-1227, Switzerland*

[2]*E. L. Ginzton Laboratory, Stanford University, Stanford, California 94305, USA*

Photons are ideal carriers of quantum information, as they can be easily created and manipulated and can travel long distances without being affected by decoherence [1]. They are the workhorse of quantum communication. However, under normal circumstances, they do not interact with each other. Realising such an interaction is not only fundamentally fascinating but holds great potential for emerging technologies. In fact, even a weak interaction between single photons can be used to perform quantum communication tasks more efficiently than what can be achieved with ideal linear optics and probabilistic sources [2]. For example, one could herald entanglement over a long distance, and move a step closer to futuristic applications such as device-independent quantum key distribution. Nonlinear interactions at the single-photon level are mainly being explored in atomic systems. However, the wavelengths, bandwidth, temperature and scale of these atomic systems make them incompatible with quantum communication applications. Here we take a different approach and use a state-of-the-art nonlinear waveguide to demonstrate a parametric interaction between a single photon and a single-photon-level coherent state from independent sources. The measured system efficiency is 1.5×10^{-8}, made up for by a high repetition rate of 4.3×10^{8}/s . This provides an integrated, room-temperature, high-bandwidth device operating at telecom wavelengths.

[1] Nicolas Gisin and Robert Thew, Quantum communication. Nature Photonics, 2007, 1(3) 165-171

[2] Nicolas Sangouard, Bruno Sanguinetti, Noé Curtz, Nicolas Gisin, Rob Thew and Hugo Zbinden. Faithful Entanglement Swapping Based on Sum-Frequency Generation. Physical Review Letters, 2011, 106(12) 120403

T106

Relationship between initial state and Hamiltonian as a main factor for thermalization

Lea Santos

Yeshiva University, 245 Lexington Ave, New York, USA

Thermalization of isolated quantum systems initially far from equilibrium holds under two conditions: (i) the fluctuations of the observables about the infinite time average are small and vanish in the thermodynamic limit; (ii) the infinite time average and the thermal average are very close in finite systems and eventually coincide in the thermodynamic limit. Both conditions are strongly dependent on the structure of the initial state with respect to the Hamiltonian that evolves it [1,2]. Thermalization may not occur in the chaotic regime if the initial state is close to the edge of the system spectrum, and it may occur in integrable systems provided the initial state is chaotic. Our approach puts emphasis on the initial state also instead of on the regime of the Hamiltonian only.

The level of 'chaoticity' of the initial state is determined by the filling of the energy shell. Better filling occurs to states close to the middle of the spectrum of both integrable and chaotic systems. For such states, the time fluctuations of few-body observables after relaxation decay faster with system size than for initial states with very low energies. The infinite time averages also get closer to the thermal results.

[1] Pablo R. Zangara, A. D. Dente, E. J. Torres-Herrera, H. M. Pastawski, A. Iucci, and L. F. Santos, Time Fluctuations in Isolated Quantum Systems of Interacting Particles, arXiv:1305.6937

[2] E. J. Torres-Herrera and L. F. Santos, Relationship between Initial State and Hamiltonian as a main factor for Thermalization, arXiv:1305.4640

Interfacing Majorana bound states with harmonic oscillators

Thomas Schmidt

University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

Majorana bound states have been predicted to exist at the edges of one-dimensional topological superconductors. These can be realized, for instance, using a semiconducting wire with spin-orbit coupling placed on top of an s-wave superconductor. These states have extraordinary topological properties which makes their detection and manipulation desirable experimental goals. We explore detection and manipulation schemes based on coupling the Majorana bound states to harmonic oscillators of two kinds: nanomechanical resonators and microwave photons.

In the first part of the talk, we propose a way to detect Majorana bound states using a nanomechanical device [1]. It consists of an oscillating electrode, which can be realized using a doubly-clamped metallic beam, tunnel-coupled to one edge of the topological superconductor. We find that the oscillations of the electrode induce side peaks in the differential conductance as a function of bias voltage, which could allow a unique identification of Majorana bound states.

Majorana bound states have also been proposed as building blocks for topologically protected qubits. In the second part of the talk, we show that such Majorana based qubits can be manipulated in a microwave cavity [2,3]. The cavity photons induce Rabi oscillations between different qubit states, which can be harnessed to implement a single-qubit gate. Supplemented with braiding operations, this gate makes it possible to perform arbitrary single-qubit rotations, and provides a step towards universal quantum computation with Majorana fermions.

[1] S. Walter, T. L. Schmidt, K. Borkje, and B. Trauzettel, Phys. Rev. B 84, 224510 (2011)

[2] T. L. Schmidt, A. Nunnenkamp, and C. Bruder, New J. Phys. 15, 025043 (2013)

[3] T. L. Schmidt, A. Nunnenkamp, and C. Bruder, Phys. Rev. Lett. 110, 107006 (2013)

T108

Transport through correlated nanostructures: Towards steady state dynamics

Peter Schmitteckert

Karlsruhe Institute of Technology, Institute of Nanotechnology,
Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

Recent advances in simulating the time evolution of correlated electron systems led to progress, even giving access to the full counting statistics of charge transport [1]. However, in order to treat strongly correlated systems numerically one has to resort to lattice models with a finite number of sites. In this talk I will start with discussing finite size and finite time effects resulting from the finite character of the model systems. The most obvious finite size effect is the finite transit time of the leads. By adding absorbing terms to the time evolution operator one can actually achieve a quasi stationary state, which is not interrupted by the the finite transit time.

While this presents a step forward towards steady state dynamics on finite systems, this approach does not solve the problem of finite time effects which are not induced by the finiteness of the system [2]. In order to circumvent those one should resort to scattering approaches like the Lippmann-Schwinger equation [3]. There, one switches on the perturbation adiabatically in the distant past which leads to a resolvent equation for the scattering state. However, the finite model systems always posses a finite size gap leading to a breakdown of this so called adiabatic state evolution. Here I present an adiabatic state evolution scheme which allows to track states in the spirit of the adiabatic state evolution of the scattering theory which can be applied to finite size systems.

[1] Sam T. Carr, Dmitry A. Bagrets, and Peter Schmitteckert, Phys. Rev. Lett. 107, 206801 (2011).

[2] Peter Schmitteckert, Hubert Saleur, and Sam T. Carr, preprint.

[3] B.A. Lippmann and Julian Schwinger, Phys. Rev. 79, 469 (1950).

[4] Marion Moliner and Peter Schmitteckert, preprint.

T109

Negative absolute temperatures for motional degrees of freedom

Ulrich Schneider

LMU Munich, Schellingstrasse 4, 80799 Munich, Germany

Max-Planck-Institute of Quantum Optics, Garching near Munich, Germany

Absolute temperature, that is the fundamental temperature scale in thermodynamics, is usually bound to be positive. Under special conditions, however, negative temperatures – where high-energy states are more occupied than low-energy states – are also possible. So far, such states have been restricted to localized systems with finite, discrete spectra. In this talk, I will present a negative temperature state for motional degrees of freedom [1]: By tailoring the Bose-Hubbard Hamiltonian we created an attractively interacting ensemble of ultracold bosons at negative temperature, which is stable against collapse for arbitrary atom numbers. In this state, the quasi-momentum distribution develops sharp peaks at the upper band edge, revealing thermal equilibrium and bosonic coherence over several lattice sites. Negative temperatures imply negative pressures and open up new parameter regimes for cold atoms, enabling fundamentally new many-body states and counterintuitive effects such as Carnot engines above unity efficiency.

[1] S. Braun et al., Science 339, 52 (2013).

T110

Strong magneto-photoelectric effect in folded graphene

Ralf Schuetzhold and Friedemann Queisser

Universität Duisburg-Essen, Fakultät für Physik, Lotharstr. 1, 47048 Duisburg, Germany

We study electronic transport in graphene under the influence of a transversal magnetic field $B(x)\mathbf{e_z}$ with the asymptotics $B(x \to \pm\infty) = \pm B_0$, which could be realized via a folded graphene sheet in a constant magnetic field, for example. By solving the effective Dirac equation, we find robust modes with a finite energy gap which propagate along the fold – where particles and holes move in opposite directions. Exciting these particle-hole pairs with incident (optical or infrared) photons would then generate a nearly perfect charge separation and thus a strong magneto-photoelectric or magneto-thermoelectric effect – even at room temperature.

Signaling between entities with opposite thermodynamic arrows of time

Lawrence S. Schulman[1] and Marcos G. E. da Luz[2]

[1] *Physics Department, Clarkson University, Potsdam, New York 13699-5820, USA*

[2] *Departamento de Fisica, Universidade Federal do Parana, 81531-990 Curitiba, Brazil*

With appropriate boundary conditions systems can interact while maintaining opposite thermodynamic arrows of time [1]. One can now raise two questions: are there regions of the universe where the thermodynamic arrow points oppositely, and if there are, would we notice? If the answer to the second question is "no," there would be no way to investigate the first. As in [1], the issue is studied using models. The models are variations of the cat map and baker's transformation. The scheme in [1] was to consider systems A and B and to give A a low entropy state at parameter time 0, and B low entropy at T. With no coupling, in the interval $t \in [0, T]$ this gives them opposite thermodynamic arrows. With weak coupling the arrows persist and the main effect is a speedup of equilibration. In considering signals our goal is to answer an extreme question: if an opposite arrow supernova went off nearby, would we notice? This is modeled by considering paired exemplars of the time evolution, differing from one another in that (say) A has two very different propagation rules at some particular intermediate time. We than look for specific effects on B. The short answer is, yes, we do see effects on B. This will be illustrated in our presentation. Does this mean that one can contemplate the cat paradoxes of [1]? (We avoid the politically incorrect reference to "grandfathers.") We don't know, but we believe that the supernova would do more than simply make us sweat.

[1] L. S. Schulman, *Opposite Thermodynamic Arrows of Time*, Phys. Rev. Lett. **83**, 5419-5422 (1999).

T112

Phase diagram of imbalanced Fermi systems

Armen Sedrakian

Institute for Theoretical Physics, Max-von-Laue str. 1, Frankfurt am Main, Germany

I will report on a comprehensive study of the phase structure of paired fermionic system featuring a condensate at non-zero imbalance between two species at finite temperature. We find a rich phase diagram comprising three superfluid phases, namely a Larkin-Ovchinnikov-Fulde-Ferrell phase, the ordinary BCS phase, and a heterogeneous, phase-separated BCS phase, with associated crossovers from the latter two phases to a homogeneous or phase-separated Bose-Einstein condensate of dimers. The phase diagram contains two tricritical points (one a Lifshitz point), which may degenerate into a single tetra-critical point for some degree of imbalance.

New directions in strong field coherent control. From spinning tops to ultrafast switches

Tamar Seideman, Benjamin Ashwell, Maxim Artamonov, and Sai Ramakrishna

Northwestern University, 2145 Sheridan Rd, Evanston 60208, USA

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 17 years 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 review of the essential physics underlying alignment, we consider the case of asymmetric top molecules, where alignment overcomes the mechanisms that render the rotations unstable in the classical limit [1]. Next we focus on dissipative media, and illustrate the application of rotational wavepackets as a probe of the decohering properties of the environment [2]. We extend alignment to control the torsional motions of polyatomic molecules, and apply torsional control to manipulate charge transfer events in solutions [3], 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 [4]. 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 [5]. 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, suggesting intriguing potential applications in material design [6].

[1] J.J. Larsen, K. Hald, N. Bjerre, H. Stapelfeldt and T. Seideman, Phys.Rev.Lett. 85, 2470 (2000).

[2] S. Ramakrishna and T. Seideman, Phys.Rev.Lett. 95, 113001 (2005).

[3] S. Ramakrishna and T. Seideman, Phys.Rev.Lett. 99, 103001 (2007).

[4] I. Nevo et al, J.Chem.Phys. 140, 144704 (2009); Science, “Molecular Choreography in Next Generation Nanofilms” (highlight).

[5] M.G. Reuter, M. Sukharev, and T. Seideman, Phys.Rev.Lett. 101, 208303 (2008); Nature Photonics 3, 4-5 (2009) “Our Choice from the Recent Literature” (highlight).

[6] M. Artamonov and T. Seideman, Phys.Rev.Lett. 109, 165408 (2012).

T114

Stochastic thermodynamics of autonomous information machines. From Maxwell's demons to cellular sensing

Udo Seifert

University Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

The framework of stochastic thermodynamics can be applied to Brownian information machines for which information about the system acquired in a measurement is used to extract work from a single heat bath. Fluctuation theorems have been generalized to such feedback-driven non-autonomous machines following an almost standard recipe also allowing to discuss their efficieny and efficiency at maximum power [1]. After briefly recalling this (reasonably well-understood) class, I will describe our recent work dealing with autonomous machines. First, I will discuss a fully stochastic, reversible variant of the demon recently introduced by Mandal and Jarzynski [PNAS 109, 11641, 2012]. Our generalization which includes genuine equilibrium allows to identify Onsager coefficients and the linear response theory of such a demon [2]. Second, within a minimal model for cellular sensing, I will discuss the relation between information-theoretic and thermodynamic entropy production. While one could naively expect the rate of information to be bounded by the thermodynamic cost of acquiring it, based on our new bound on the rate of mutual information for time-continuous processes, I will show that there is no such inequality [3].

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

[2] AC Barato and US, EPL 101, 60001, 2013.

[3] AC Barato, D. Hartich and US, Phys. Rev. E 87, 042104, 2013.

Superfluid-insulator transitions of collective helical modes in the zero quantum Hall state of bilayer graphene

Efrat Shimshoni[1], Victoria Mazo[1], Chia-Wei Huang[1], Herbert Fertig[2], and Samuel Carr[3]

[1]*Dept. of Physics, Bar-Ilan University, Bar-Ilan University campus, Ramat Gan 52900, Israel*

[2]*Dept. of Physics, Indiana University, Bloomington, IN 47405, USA*

[3]*Institut fur Theorie der Kondensierten Materie, Universitat Karlsruhe, 76049 Karlsruhe, Germany*

We derive an effective field-theoretical model for the one-dimensional collective modes associated with domain walls in a quantum Hall ferromagnetic state, as realized in bilayer graphene systems at zero filling subject to a kink-like perpendicular electric field. In particular, it is demonstrated that two pairs of collective helical modes are formed at opposite sides of the kink, each pair consisting of modes with identical helicities. The coupling between modes implies a description in terms of anisotropic quantum spin-ladders, whose parameters are tunable by varying the magnetic and electric fields. We show that this system possesses a rich phase diagram, which due to the helical nature of the modes implies a diversity of charge conduction properties. Most notably, we find that the helical ladders may undergo a transition from a superfluid to an insulating phase, manifested by a jump in the two-terminal conductance as well as the drag trans-conductance.

T116

A quantum dot close to Stoner instability: The role of Berry's phase

Alexander Shnirman

Karlsruhe Institute of Technology, Wolfgang-Gaede-Str. 1, Karlsruhe 76131, Germany

Physics of a quantum dot with electron-electron interactions is well captured by the so called "Universal Hamiltonian" if the dimensionless conductance of the dot is much higher than unity. Within this scheme interactions are represented by three spatially independent terms which describe the charging energy, the spin-exchange and the interaction in the Cooper channel. We concentrate on the exchange interaction and generalize the functional bosonization formalism developed earlier for the charging energy [1]. This turned out to be challenging as the effective bosonic action is non-Abelian due to the non-commutativity of the spin operators. We develop a geometric approach which is particularly useful in the mesoscopic Stoner regime, i.e., when the strong exchange interaction renders the system close the the Stoner instability. We show that it is sufficient to sum over the adiabatic paths of the bosonic vector field and, for these paths, the crucial role is played by the Berry phase. Using these results we were able to calculate the magnetic susceptibility of the dot. The latter, in close vicinity of the Stoner instability point, matches very well with the exact solution [2]. Furthermore, we extend our formalism for the case of an open quantum dot coupled to a non-magnetic lead and generalize the well known Ambegaokar-Eckern-Schoen formalism. Whereas the original AES effective action was developed for the U(1) phase related to the charge degree of freedom, ours describes the dynamics of a large spin in terms of the SU(2) Euler angles. Using the real-time Keldysh technique we derive the Landau–Lifshitz–Gilbert equations with unusual Langevin terms. Finally, we discuss how our theory could be confirmed, e.g., by performing spin resonance experiments.

[1] A. Kamenev and Y. Gefen, Phys. Rev. B 54, 5428 (1996).

[2] I.S. Burmistrov, Y. Gefen, and M.N. Kiselev, Pis'ma v ZhETF 92, 202 (2010).

An experimental test of all theories with predictive power beyond quantum theory

Terence Stuart[1], Joshua A. Slater[1], Roger Colbeck[2], Renato Renner[2], and Wolfgang Tittel[1]

[1] *Institute for Quantum Information Science, University of Calgary, Calgary, Canada*

[2] *Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland*

For almost a century much debate has surrounded the probabilistic nature and lack of predictive power of quantum theory with regards to measurement outcomes. Even with all the information available within quantum mechanics, the outcomes of certain experiments on members of entangled pairs are generally not predictable, which begs the question, can this probabilistic nature be alleviated by supplementing the wavefunction with additional information? A few specific models (e.g. Bell [1], Leggett [2]) have suggested a hidden parameter that would, if accessible, improve upon these predictions. The existence of such hidden variables has been falsified by numerous experiments [3,4].

We give a more general answer by experimentally bounding the predictive power, about measurements on members of entangled particles, of any alternative model [5,6]. As is the case in all falsifications of alternative models, our conclusions are based on the strength of correlations between measurement outcomes of entangled particles. Our experiment employs polarization-entangled photon pairs generated through SPDC and correlation measurements in up to fourteen bases [5,6]. We find that an alternative theory could improve the quantum predictionsby at most 16.5 percentage points.

Our experimental results are incompatible with any already known and yet-to-be-proposed alternative theories that could predict the outcomes of measurements on entangled particles with significantly higher probability than quantum theory, suggesting that quantum theory is optimal. Our conclusion is based on the natural assumption that all measurement settings have been chosen freely, which we precisely define, and that the presence of the detection loophole did not affect the measurement outcomes.

[1] J.S. Bell. Physics 1, 195-200 (1964).

[2] A.J. Leggett. Foundations of Physics 33, 1469-1493 (2003).

[3] S.J. Freedman and J.F. Clauser. Phys. Rev. Lett. 28, 938-941 (1972); A. Aspect, P. Grangier and G. Roger. Phys. Rev. Lett. 49, 91-94 (1982); W. Tittel et al. Phys. Rev. A 57, 3229-3232 (1998); G. Weihs et al. Phys. Rev. Lett. 81, 5039-5043 (1998).

[4] S. Groblacher et al. Nature 446, 871 (2007); T. Paterek et al. Phys. Rev. Lett. 99, 210406 (2007); C. Branciard et al. Nat. Phys. 4, 681 (2008).

[5] R. Colbeck and R. Renner. Nat. Commun. 2, 411 (2011).

[6] T. Stuart et al. Phys. Rev. Lett. 109, 020402 (2012).

T118

Equilibration of quantum Hall edge states by an Ohmic contact

Artur Slobodeniuk[1, 2], Ivan Levkivskyi[2, 3], and Eugene Sukhorukov[1]

[1]*University of Geneva, Department of Theoretical Physics, 24 quai Ernest-Ansermet, Geneva 1211, Switzerland*

[2]*Bogolyubov Institute for Theoretical Physics, 14-b Metrolohichna Street, Kiev 03680, Ukraine*

[3]*Department of Physics, Harvard University, Cambridge, MA 02138, USA*

Ohmic contacts are crucial elements of electron optics that have not received a clear theoretical description yet. We propose a model of an Ohmic contact as a piece of metal of the finite capacitance C attached to a quantum Hall edge. It is shown that charged quantum Hall edge states may have weak coupling to neutral excitations in an Ohmic contact. Consequently, despite being a reservoir of neutral excitations, an Ohmic contact is not able to efficiently equilibrate edge states if its temperature is smaller than $\hbar\Omega_c$, where Ω_c is the inverse RC time of the contact. This energy scale for a floating contact may become as large as the single-electron charging energy e^2/C.

Quantum transport of cold atoms: Hawking radiation and synthetic fields.

Fernando Sols

Universidad Complutense de Madrid, Avda. Complutense s/n, E-28040 Madrid, Spain

Cold atom systems permit the exploration of novel forms of quantum transport. The analog of Hawking radiation can be emitted at a sonic horizon where condensate atom flow becomes supersonic. That scenario also involves the boson analog of Andreev reflection [1] . Due to coherent quasiparticle scattering, double-barrier structures generate zero-point Hawking radiation that peaks at non-zero frequencies [2]. Near those resonant peaks, classical Cauchy-Schwarz (CS) inequalities are violated that can only be associated with spontaneous radiation [3]. This decisive CS violation cannot occur near the conventional zero-frequency peak displayed by non-resonant structures. We also explore the generation of synthetic gauges by controlling the switching conditions of the driving force [4,5]. A method for generating synthetic magnetic fields without the need to use the switching or the atom internal structure is proposed [6].

[1] I. Zapata and F. Sols, "Andreev reflection in bosonic condensates", Phys. Rev. Lett. 102, 180405 (2009).

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

[3] J. R. M. de Nova, F. Sols and I. Zapata, "Violation of Cauchy-Schwarz inequalities by spontaneous Hawking radiation in resonant boson structures", arXiv:1211.1761 (2012).

[4] C. E. Creffield, F. Sols, "Controlled generation of coherent matter-currents using a periodic driving field", Phys. Rev. Lett. 100, 250402 (2008).

[5] C. E. Creffield, F. Sols, "Directed transport in driven optical lattices by gauge generation", Phys. Rev. A 84, 023630 (2011).

[6] C. E. Creffield, F. Sols, "Generation of synthetic magnetic fields for cold atoms without internal structure", to be published (2013).

T120

Has a fluctuation dissipation theorem some sense out of equilibrium?

Václav Špička[1], Anděla Kalvová[1], and Bedřich Velický[2]

[1] *Institute of Physics, v.v.i., Academy of Sciences of the Czech Republic, Cukrovarnická 10, 162 00 Praha 6, Czech Republic*

[2] *Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, 121 16 Praha 2, Czech Republic*

The fluctuation-dissipation (FD) theorems are known to be a constitutive aspect of thermal equilibrium. One FD theorem is a part of the linear response theory and relates the response functions to their counterpart equilibrium correlation functions. Here, we address the other FD theorem, equivalent with the KMS boundary condition, which permits to write all components of the equilibrium one particle equilibrium Green's function in terms of the spectral density and a thermal factor. Out of equilibrium, such reduction is not possible and the non-equilibrium Green's function has two independent components, typically the Kadanoff-Baym pair $G^<$ and $G^>$ [1].

There are two closely related hints for a possible generalization of the FD theory to non-equilibrium. One is the early Kadanoff-Baym Ansatz valid for weakly non-equilibrium Fermi liquid: $G^<$ is factorized into the spectral density and the quasi-particle distribution function. This has been used to obtain the Boltzmann Equation [1]. Second, the FD property is physically based on the detailed balance in a canonical ensemble. Out of equilibrium, this may be weakened to a Master equation or even to a Generalized Master equation. Significantly, the KB Ansatz and its later sequel, centered around the generalized KBA [2], were devised to reduce the full GF equations of motion to kinetic equations for a single-time distribution function. We follow both lines. It has been analyzed, to which extent GKBA can be considered an extension of the FD theorem to non-equilibrium [3]. On the formal side, this can be given an exact formulation in terms of reconstruction equations building the correlation functions $G^<$ and $G^>$ from the propagators and the non-equilibrium distribution function [4]. On the physical side, it is found that a useful extended FDT applies, if the non-equilibrium process obeys a kinetic equation and can be visualized as a swarm of flying non-equilibrium quasi-particles.

[1] L. P. Kadanoff, G. Baym, Quantum Statistical Physics, W. A. Benjamin, NY 1962.

[2] K. Balzer, M. Bonitz, Nonequilibrium Green's function Approach to Inhomogeneous Systems, Springer, Heidelberg 2013.

[3] V. Špička, A. Kalvová, B. Velický, Physica E29, 154 (2005).

[4] V. Špička, A. Kalvová, B. Velický, Physica E42, 525 (2010).

Nonequilibrium Green's function approach to ultrafast electron

Gianluca Stefanucci

Universita' di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy

We describe a many-body approach to correlated electron dynamics based on the solution of the Kadanoff-Baym equations (KBE). The main advantages of the method are (1) correlation effects can be included in a nonperturbative manner through the self-energy, (2) important conservation laws are satisfied at all times, (3) initial correlations effects are properly taken into account, and (4) nonlinear transient responses as well as responses to arbitrary time-dependent driving fields are accessible. Numerical results in the fully self-consistent second-Born and GW approximations are presented and discussed. We also propose an efficient approximate method based on the Generalized Kadanoff-Baym Ansatz to speed up the KBE time propagation.

T122

Sonic black holes and thermal phonons

Jeff Steinhauer, Shahar Rinott, Alex Blumkin, Ran Schley, Ilanit Shammass, Oren Lahav, Amir Itah, Carmit Gordon, Alona Zayats, and Amit Berkovitz

Technion – Israel Institute of Technology, Technion City, Haifa, 32000, Israel

We have created an analogue of a black hole in a Bose-Einstein condensate. A step-like potential accelerates the flow of the condensate to velocities which cross and exceed the speed of sound by an order of magnitude. The Landau critical velocity is therefore surpassed. The predicted Hawking temperature is given by the gradient of the velocity at the horizon, and is thus determined from the measured profiles of the velocity and speed of sound. A simulation finds negative energy excitations, which are required for Hawking radiation. Furthermore, we observe the Planck distribution of thermal phonons in a 3D Bose-Einstein condensate. This observation provides an important confirmation of the basic nature of quantized excitations in the condensate. In contrast to the bunching effect, the density fluctuations are seen to increase with increasing temperature. This is due to the non-conservation of the number of phonons. When the quench time drops below the measured thermal equilibration time, the phonon temperature is out of equilibrium with the surrounding thermal cloud. Thus, for rapid cooling rates, a Bose-Einstein condensate is not as cold as previously thought. These measurements are enabled by our in situ k-space technique.

Quantum process tomography of energy and phase relaxation in adaptive bases

Markku Stenberg[1] and Frank Wilhelm[1, 2]

[1]Saarland University, Theoretical Physics, 66123 Saarbrücken, Germany

[2]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, 200 University Avenue West, Waterloo, ON, N2L 3G1, Canada

Quantum process tomography tends to be very time-consuming when multiple degrees of freedom are studied simultaneously. We present a method of efficient quantum process tomography to estimate the energy and phase relaxation rates in qubits. In a sequence of measurements, the method adaptively chooses the basis for the next measurement based on the previously obtained measurement outcomes in the sequence. This is accomplished by applying Bayesian inference. We adopt sequential Monte-Carlo approach to perform the updates of the Bayesian probability distributions and make use of a fast numerical implementation of the algorithm. We compare the performance of our method to conventional offline strategies (that are implemented after experimental data collection) and illustrate how our method can speed up quantum process tomography.

T124

Non-locality from local stimuli: Entanglement generation in a dissipative system.

Jürgen Stockburger, Rebecca Schmidt, and Joachim Ankerhold

Universität Ulm, Institut für Theoretische Physik, Albert-Einstein-Allee 11, 89069 Ulm, Germany

External driving can induce non-trivial qualitative changes such as increased purity [1] or generation of entanglement [2] in a quantum state. We demonstrate this for simple damped harmonic modes, using optimal control techniques to define suitable signals.

In a system consisting of two Gaussian harmonic modes sharing a heat bath, tailored local driving is used to initiate entanglement generation. The shared bath, normally a source of decoherence and other detrimental effects, becomes instrumental in this process. In numerical simulations, we observe entanglement generation over a wide range of temperatures.

Special care is needed in evaluating the dynamics, since standard Lindblad-type techniques for open quantum systems yield misleading results in strongly driven systems. We outline the key features of alternative techniques with no strong-driving artifacts for open-system dynamics [3].

[1] Schmidt, R., Negretti, A., Ankerhold, J., Calarco, T., and Stockburger, J.T.: Optimal Control of Open Quantum Systems: Cooperative Effects of Driving and Dissipation, Phys. Rev. Lett. 107, 130404 (2011)

[2] Schmidt, R., Stockburger, J.T., and Ankerhold, J.: Quasi-local generation of EPR entanglement in non-equilibrium, arXiv:1305.6566

[3] Stockburger, J.T. and Grabert, H.: Exact c-Number Representation of Non-Markovian Quantum Dissipation, Phys. Rev. Lett. 88, 170407 (2002)

Analog quantum simulators of small-polaron physics

Vladimir M. Stojanovic

University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

The small-polaron problem – that of an excess carrier (electron or a hole) whose kinetic energy is heavily suppressed due to a self-induced deformation of the host-crystal lattice – is typically addressed within the framework of the Holstein molecular-crystal model. In this talk, two analog quantum simulators for the one-dimensional version of this model will be discussed, based on arrays of trapped ions and superconducting transmon qubits (circuit-QED setup) as their respective physical platforms [1,2]. We show that in both cases the strong excitation-phonon coupling regime – characterized by small-polaron formation – can be reached using realistic values of the underlying-system parameters. We propose state-preparation schemes, as well as experimental probes for validating the polaronic character of the phonon-dressed excitations in both physical platforms. We perform a comparative analysis of the two realizations of the Holstein model, and conclude by underlining their potential use for studying the dynamics of small-polaron formation and density-driven destabilization of such excitations.

[1] V. M. Stojanovic, T. Shi, C. Bruder, and J. I. Cirac, Phys. Rev. Lett. 109, 250501 (2012).

[2] F. Mei, V. M. Stojanovic, I. Siddiqi, and L. Tian, unpublished.

T126

Surmounting the insurmontable: Barrier crossing in biological dynamics at mesoscales

Wokyung Sung

Pohang University of Science & Technology, Hyoja Dong, Pohang, Republic of Korea

Due to structural connectivity and flexibility, many biological systems in meso-scale manifest interesting cooperative dynamics under the barriers caused by external fields, confining and constraining environments. Its cooperative dynamics is important, no only in understanding how a biological system self-organizes by manipulating its flexible degrees of freedom, but also in a multitude of biotechnological applications. Nature utilizes the ambient fluctuations in such biological soft-condensed matter to facilitate crossing seemingly insurmountable barriers, which is typically assisted by shape changes and coupling of the collective modes of the fluctuations. I will talk about a number of subjects we have studied in this vein, such as biopolymer dynamics under potential barriers, and associated stochastic resonance, and kink formation in mechanically constrained double-stranded DNA.

Topological pumping in superconducting wires with Majorana fermions

Fabio Taddei[1], Marco Gibertini[2], Marco Polini[1], and Rosario Fazio[1]

[1]*NEST, Istituto Nanoscienze-CNR & Scuola Normale Superiore, Piazza dei Cavalieri, 7, I-56126, Pisa, Italy*

[2]*École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland*

A periodic modulation of two or more independent parameters in a quantum system may give rise to a dc flow of charge in the absence of any applied bias voltage. This transport mechanism is known as charge pumping and it is termed adiabatic when the pumping period is much larger than any characteristic time scale of the system. In his pioneering work, Thouless [1] showed that quantized adiabatic pumping can occur through one-dimensional insulating systems as a consequence of the topological properties of the Hamiltonian. In this work we study adiabatic pumping in a class-D topological superconductor which support Majorana fermions.

It has been recently suggested that class-D superconductors can be realized in spin-orbit coupled semiconducting nanowires in a magnetic field with proximity-induced s-wave superconducting pairing [2,3]. Here we show that topological adiabatic pumping of charges occurs in a class-D superconducting nanowire connected to a metallic lead, provided that a single mode of the latter is affected by the presence of Majorana fermions present at the endpoints of the superconducting nanowire [4]. This is the case, for example, when the lead supports a single propagating mode or when the nanowire is coupled to the lead through a quantum point contact. The topological nature of pumping consists in the fact that any continuous deformation of the pumping path in parameter space does not change the charge pumped in a cycle. The necessary condition to achieve a finite quantized value of the pumped charge is that the phase diagram presents a non-simply connected structure, where isolated non-topological regions are surrounded by connected topological ones. This is possible by allowing both a non-uniform pairing amplitude and a tilted Zeeman field. Non-contractible pumping paths in parameter space can thus be identified within the topological phase. We have furthermore verified that the quantization of the pumped charge is robust against disorder.

[1] D. J. Thouless, Phys. Rev. B 27, 6083 (1983).

[2] R. M. Lutchyn, J. D. Sau, and S. Das Sarma, Phys. Rev. Lett. 105, 077001 (2010).

[3] Y. Oreg, G. Refael, and F. von Oppen, Phys. Rev. Lett. 105, 177002 (2010).

[4] M. Gibertini, R. Fazio, M. Polini, and F. Taddei, arXiv:1302.2736.

T128

Relating atomic scale conductance to orbital structure by shot noise measurements

Oren Tal, Ran Vardimon, Tamar Yelin, and Marina Klionsky

Weizmann Institute of Science, 234 Herzl St., Rehovot 76100, Israel

When an electric current is transmitted through atomic or molecular junctions, the transport properties are very sensitive to the orbital structure of these atomic scale conductors. Using detailed analysis, we can take advantage of this sensitivity to reveal the relation between orbital structure and transport properties. The direct link between the available transmission channels across an atomic scale conductor and its orbital structure, led us to develop a numerical procedure that extracts the distribution of channels from measurements of conductance and shot noise. We use this approach to identify the orbital origin of conductance oscillations measured during the elongation of platinum and gold monatomic chains. Our findings provide useful information about the structure of the examined atomic chains and demonstrate that electronic transport at the atomic scale can be tuned by controlled overlap of specific orbitals.

Fluctuation theorem for a two-terminal conductor connected to a voltage or a thermal probe

Yasuhiro Utsumi[1], Ora Entin-Wohlman[2, 3], Amnon Aharony[2, 3], Toshihiro Kubo[4], and Yasuhiro Tokura[4]

[1]*Mie University, 1577, Kurimamachiya-cho, Tsu, 514-8507, Japan*

[2]*Physics Department, Ben Gurion University, Beer Sheva 84105, Israel*

[3]*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel*

[4]*Graduate School of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8571, Japan*

We analyze the full-counting statistics of current through a three-terminal quantum conductor characterized by energy-dependent S-matrix including a voltage/thermal probe and subject to a magnetic field. Particle-hole excitations inside the probe relax quickly and cause slow energy and charge fluctuations in the probe electrode. We account for the slow stochastic dynamics of the chemical potential/temperature of the voltage/thermal probe and demonstrate that the full-counting statistics satisfies the fluctuation theorem. Furthermore, we calculate the two-terminal non-linear transport coefficients and point out that for the energy dependent S-matrix vertex corrections are necessary to satisfy universal relations imposed by the fluctuation theorem. Our result is particularly relevant for the non-linear thermoelectric transport, where the energy dependence of the S-matrix is crucial for the non-vanishing heat current in the linear response regime.

T130

Single-reservoir heat engine: Controlling the spin

Joan Vaccaro[1] and Stephen Barnett[2]

[1] *Centre for Quantum Dynamics, Griffith University, Brisbane, Australia*

[2] *Department of Physics, University of Strathclyde, Glasgow, UK*

Thermodynamical equilibrium is usually associated with thermalisation and thermal reservoirs. However, it is now possible to engineer spin-polarised atomic gases to act as reservoirs of spins and replace the traditional thermal reservoirs. In the absence of magnetic fields, the internal spin states of the atoms are energy degenerate. This means that in reaching statistical equilibrium, conservation of spin angular momentum takes on a dominant role and energy conservation is satisfied trivially. Not surprisingly, new feats are now possible. Indeed, we have recently argued that information can be erased at a cost in terms of spin angular momentum and no energy [1]. This result would contradict Landauer's erasure principle which asserts that information erasure is associated with an energy cost. Given that Landauer's principle is equivalent to the Second Law of thermodynamics, it would also call for a revision of thermodynamics at the nanoscale. Here we describe an experimental proposal to convert the thermal energy of a single reservoir (a gas of trapped atoms) into useful work (as coherent radiation).

The working fluid of the engine is a cloud of cold atoms trapped in an optical dipole trap. The atoms have a ground electronic state with hyperfine quantum number $F=1$ and are prepared in the $M=-1$ state. A red-detuned coherent Raman π pulse acting between the $M=-1$ and $M=1$ states via an excited state extracts thermal energy. The extracted energy appears as increased coherent light via stimulated Raman emission. Hot atoms are transferred by the pulse from the $M=-1$ to the $M=1$ state. As such, the internal spin degree of freedom of the atoms plays the role of Maxwell's demon in remembering which atoms were the hot ones. In order to complete a thermodynamic cycle these atoms need to be returned to their original $M=-1$ state. A spin reservoir comprising a cloud of cold atoms trapped in a separate optical dipole trap is used for this. Let its atoms have a hyperfine $F=\frac{1}{2}$ ground state with atoms initially prepared in the $M=-\frac{1}{2}$ state. The working fluid and the spin reservoir clouds are brought together, allowing spin angular momentum to be redistributed among the atoms by collisions, and then separated. As a result the atoms of the working fluid are returned (nearly) to their $M=-1$ state at a loss of polarisation of the spin reservoir. Essentially entropy is decoupled from the motional degree of freedom of the atoms and transferred into the spin degree of freedom as the thermal energy is extracted as coherent light. The heat engine demonstrates the use of the new means of erasing information at a cost of spin angular momentum [1]. Implications for the Second Law will be discussed.

[1] J.A. Vaccaro and S.M. Barnett, Proc. R. Soc. A **467** (2011) 1770-1778.

Inelastic signals in shot noise

Jan van Ruitenbeek[1], Manohar Kumar[1], Remi Avriller[2, 3], and Alfredo Levy Yeyati[2]

[1]*Leiden University, Kamerlingh Onnes Laboratory, Niels Bohrweg 2, 2333CA Leiden, Netherlands*

[2]*Departamento de Fisica Teorica de la Materia Condensada C-V, Universidad Autonoma de Madrid, E-28049 Madrid, Spain*

[3]*Donostia International Physics Center (DIPC), Paseo Manuel de Lardizabal 4, E-20018 San Sebastian, Spain*

We present shot noise measurements on Au nanowires showing very pronounced vibration-mode features. In accordance to recent theoretical predictions the sign of the inelastic signal, i.e., the signal due to vibration excitations, depends on the transmission probability becoming negative below a certain transmission value. We argue that the negative contribution to noise arises from coherent two-electron processes mediated by electron-phonon scattering and the Pauli exclusion principle. These signals can provide unique information on the local phonon population and lattice temperature of the nanoscale system.

[1] M. Kumar et al., PRL 108, 146602 (2012)

T132

Dynamical competition between disorder and interactions in ultracold atoms and transport phenomena

Claudio Verdozzi

Mathematical Physics, Lund University, Solvegatan 14A, Lund 22100, Sweden

We investigate the nonequilibrium behavior of lattice model systems via time-dependent density-functional theory and via the non-equilibrium Green's function technique. Results from specific applications will be shown (namely, quantum transport through short chains contacted to semi-infinite leads, and the expansion of fermionic clouds into a optical lattice), along with a mention to work in progress.

Strong-randomness phenomena at superfluid phase transitions

Thomas Vojta

Missouri University of Science and Technology, Department of Physics, 1315 North Pine Street, Rolla, MO 65409, USA

Quenched disorder or randomness can dramatically change the properties of thermal and quantum superfluid phase transitions.

In the first part of the talk, we discuss the effects of one-dimensional (layered) disorder on the thermal phase transition of a bulk superfluid. We find an anomalously elastic "sliding" phase between the conventional normal and superfluid phases. In this intermediate phase, the stiffness parallel to the layers remains finite while the stiffness perpendicular to the random layers vanishes, and the elastic free energy exhibits anomalous scaling behavior [1].

The second part of the talk is devoted to large-scale Monte-Carlo simulations of the superfluid-insulator quantum phase transition of one-dimensional bosons with off-diagonal disorder. For weak disorder, we find the transition to be in the same universality class as the superfluid-Mott insulator transition of the clean system. The nature of the transition changes for stronger disorder. Beyond a critical disorder strength, we find nonuniversal, disorder-dependent critical behavior [2].

[1] P. Mohan, P.M. Goldbart, R. Narayanan, J. Toner and T. Vojta, Phys. Rev. Lett. 105, 085301 (2010).

[2] F. Hrahsheh and T. Vojta, Phys. Rev. Lett. 109, 265303 (2012).

T134

Microscopic origin of the 0.7-anomaly in quantum point contacts

Jan von Delft[1, 2], Florian Bauer[1, 2], Jan Heyder[1, 2], Enrico Schubert[1], David Borowsky[1], Daniela Taubert[1], Benedikt Bruognolo[1, 2], Dieter Schuh[3], Werner Wegscheider[4], and Stefan Ludwig[1]

[1]*Center for NanoScience, Ludwig-Maximilians-Universität München, Geschwister-Scholl-Platz, D-80539 München, Germany*

[2]*Arnold Sommerfeld Center for Theoretical Physics, Theresienstr. 37, D-80333 München, Germany*

[3]*Institut für Angewandte Physik, Universität Regensburg, D-93040 Regensburg, Germany*

[4]*Laboratory for Solid State Physics, ETH Zürich, CH-8093 Zürich, Switzerland*

Quantum point contacts, elementary building blocks of semiconductor-based quantum circuits, are narrow one-dimensional constrictions usually patterned in a two-dimensional electron system, e.g. by applying voltages to local gates. It is one of the paradigms of mesoscopic physics that the linear conductance of a point contact, when measured as function of its channel width, is quantized in units of $G_Q = 2e^2/h$. However, its conductance also exhibits an unexpected shoulder at $\simeq 0.7G_Q$, known as the "0.7-anomaly", whose origin is still subject to controversial discussions. Proposed theoretical explanations have evoked spontaneous spin polarization, ferromagnetic spin coupling, the formation of a quasi-bound state leading to the Kondo effect, Wigner crystallisation and various treatments of inelastic scattering. However, explicit calculations that fully reproduce the various experimental observations in the regime of the 0.7-anomaly, including the zero-bias peak that typically accompanies it, are still lacking. Here we offer a detailed microscopic explanation for both the 0.7-anomaly and the zero-bias peak: their common origin is a smeared van Hove singularity in the local density of states at the bottom of the lowest one-dimensional subband of the point contact, which causes an anomalous enhancement in the Hartree potential barrier, magnetic spin susceptibility and inelastic scattering rate. We present theoretical calculations and experimental results that show good qualitative agreement for the dependence of the conductance on gate voltage, magnetic field, temperature, source-drain voltage (including the zero-bias peak) and interaction strength. We also clarify how the low-energy scale governing the 0.7-anomaly depends on gate voltage and interactions. For low energies we predict and observe Fermi-liquid behavior similar to that known for the Kondo effect in quantum dots. At high energies, however, the similarities between 0.7-anomaly and Kondo effect cease.

T135

Multipath interference tests of quantum mechanics

Gregor Weihs, Thomas Kauten, Benjamin Gschösser, Patrick Mai, and Zoltán Vörös

Universität Innsbruck, Institut für Experimentalphysik, Technikerstrasse 25, 6020 Innsbruck, Austria

Several possible generalizations of quantum mechanics would show their deviation from the standard variant through their interference behavior in multipath interference experiments. These generalizations include representations based on hypercomplex numbers and on density cubes. Further, in some nonlinear versions of quantum mechanics one also would expect deviations.

In order to test for such deviations with high precision, we have constructed a very stable five-path interferometer with individually controllable phases and individual shutters for the five beams. We use quantum dots and heralded single photon sources as well as detectors with extremely low nonlinearity to reduce the systematic uncertainties in the experiment as much as possible.

We will present our experimental results that allow us to put a new and reduced upper bound on any hypothetical higher-order interference.

T136

Thermodynamic anomaly and reentrant classicality of a damped quantum system

Ulrich Weiss[1], Gert-Ludwig Ingold[2], and Benjamin Spreng[2]

[1]II. Institute for Theoretical Physics, University of Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany

[2]Institute for Physics, University of Augsburg, D-86135 Augsburg, Germany

We study thermodynamics of open quantum systems based on the reduced partition function. We are interested in general features pertaining to linear environments with spectral densities of the coupling proportional to ω^s at low frequencies, and algebraic cut-off at high frequencies. The low-energy features of a damped system are determined by the low-frequency characteristics of the Laplace transform $\hat{\gamma}(z)$ of the damping kernel. Generally, we have $\hat{\gamma}(z) = [\gamma/\sin(\pi s/2)]z^{s-1} + (\Delta M/M)z$, where the first term describes damping, and the second term conveys mass renormalization. For super-Ohmic baths with $s > 2$, the dressed mass $M_{\rm dr} = M + \Delta M$ is generally larger than the bare mass M, whereas in the regime $0 < s < 2$ the dressed mass is always smaller than the bare mass, and even becomes negative when the damping parameter γ exceeds a critical damping strength. The fact that ΔM is negative for $s < 2$ largely escaped notice, since the term $(\Delta M/M)z$ is usually a sub-leading contribution to $\hat{\gamma}(z)$. Interestingly, mass renormalization of a free Brownian particle in the range $0 < s < 2$ is a major effect and leads to anomalous thermodynamic behavior, when $M_{\rm dr}$ falls below zero.

We present a study of the thermodynamics of a free Brownian particle. For $s < 2$, the specific heat at zero temperature increases linearly with s from $-k_{\rm B}/2$ at $s = 0$ to $k_{\rm B}/2$ at $s = 2$. Hence it is negative in the sub-Ohmic regime $s < 1$. The Ohmic bath, $s = 1$, thus represents the only case where the specific heat vanishes at zero temperature. The specific heat at low T is decreasing with T, when $M_{\rm dr}$ falls below zero, and can even become negative in the entire range $0 < s < 2$. For $M_{\rm dr} > 0$, the specific heat increases monotonically with T towards the classical value $C = k_{\rm B}/2$.

For a super-Ohmic bath with $s \geq 2$, we find a reentrant classical behavior. As the temperature is lowered, the specific heat decreases from the classical value $C = k_{\rm B}/2$, thereby indicating the appearance of quantum effects. However, the classical value $k_{\rm B}/2$ is restored, as the temperature approaches zero.

For all s, the flow into the classical regime at high temperatures is universally described by an algebraic tail of inverse power 2, $C/k_{\rm B} = \frac{1}{2} - a/T^2$, where a depends linearly on the damping parameter γ.

Experimental boson sampling

Matthew A. Broome[1, 2], Alessandro Fedrizzi[1, 2], Saleh Rahimi-Keshari[2], Justin Dove[3], Scott Aaronson[3], Timothy C. Ralph[2], and Andrew G. White[1, 2]

[1] *Centre for Engineered Quantum Systems, Physics, University of Queensland, 4072, Australia*

[2] *Centre for Quantum Computer and Communication Technology, Physics, University of Queensland, 4072, Australia*

[3] *Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

The extended Church-Turing thesis posits that any computable function can be calculated efficiently by a probabilistic Turing machine. If this thesis held true, the global effort to build quantum computers might ultimately be unnecessary. The thesis would however be strongly contradicted by a physical device that efficiently performs a task believed to be intractable for classical computers. BosonSampling—the sampling from a distribution of n photons undergoing some linear-optical process—is a recently developed, and experimentally accessible example of such a task [1].

Here we report an experimental verification of one key assumption of BosonSampling: that multi-photon interference amplitudes are given by the permanents of submatrices of a larger unitary describing the photonic circuit. We built a tunable photonic circuit consisting of a central 3x3 fiber beamsplitter, and exploited orthogonal polarization modes to extend the network to 6x6 modes. We developed a direct characterization method [2] to obtain the unitary description of this network and compared theoretical interference patterns predicted from this unitary with an experimental signature obtained via non-classical interference of three single photons [3]. Our results show good agreement with theory, and we can rule out an explanation of the observed interference via classical means. We conclude that small-scale BosonSampling can be performed in the presence of unavoidable optical loss, imperfect photon sources, and inefficient detection [3].

[1] S. Aaronson and A. Arkhipov, Proceedings of the ACM Symposium on Theory of Computing, San Jose, CA pp. 333–342 (2011).

[2] S. Rahimi-Keshari, M. A. Broome, R. Fickler, A. Fedrizzi, T. C. Ralph, and A. G. White, Optics Express, to appear (2013).

[3] M. A. Broome, A. Fedrizzi, S. Rahimi-Keshari, J. Dove, S. Aaronson, T. C. Ralph, and A. G. White, Science 339 (2013).

T138

Loophole-free experiments on different types of nonlocality

Bernhard Wittmann[1, 2] and Anton Zeilinger[1, 2]

[1] *Institute for Quantum Optics (IQOQI), Boltzmanngasse 3, Vienna, Austria*

[2] *University of Vienna, Faculty of Physics, Boltzmanng. 5, Vienna, Austria*

The nonlocality of entangled states was pointed out by Eintein, Podolsky, and Rosen in 1935 [1]. According to quantum theory, when two systems are entangled, a local measurement carried out on one of them instantaneously collapses the state of the other distant one. EPR thus argued that the quantum state cannot describe the real factual situation. There are different types of nonlocality, each constituted by the assumption made on the theory describing the systems. The hierarchy of nonlocality [2] starts with non-separability, showing failure of local hidden state theory. This is followed by EPR-steering nonlocality, an asymmetrical concept similar to the EPR thought experiment. The strongest type is Bell nonlocality, which shows the failure of any conceivable local hidden variable theory. Experimental realizations testing nonlocality can have imperfections that could open so-called loopholes. The three main loopholes are the detection loophole (photon ensemble is a fair sample) [3]. The locality loophole (no hidden communication) [4], and the freedom of choice loophole [5] (measurement is independent of production of the pairs). Invoking any of these assumptions renders an experiment vulnerable to possible explanation by a local realistic theory. The realization of a loophole-free experiment is an important goal for the physics community with strong implications for quantum technologies. Here we give an overview of experiments with photons addressing loopholes on different types of nonlocality. With photons a loophole-free EPR-steering test was possible [6] and for Bell nonlocality all three major loopholes were closed in separate experiments. The locality and freedom of choice loophole were closed by Scheidl et al. [5]. With the recent development of TES detectors and the use of a Bell inequality with only 2/3 detection efficiency the fair sampling assumption was closed recently by Giustina et al. [7], opening up the way to a completley loophole-free Bell test.

[1] A. Einstein, B. Podolsky, and N. Rosen, Phys. Rev. **47**, 777-780 (1935)

[2] H. Wiseman and S. Jones, PRL **98** 140402 (2007)

[3] P.M. Pearl, Phys. Rev. D **2**, 1418-1425 (1970)

[4] A. Aspect, J. Dalibard, and G. Roger, PRL **49**, 1804-1807 (1982)

[5] T. Scheidl, et al., PNAS **107**, 19708-19713 (2010)

[6] B. Wittmann, et al., NJP **14**, 053030 (2012)

[7] M. Giustina, et al., Nature **497**, 227-230 (2013)

Quantum decoherence of Cooper pairs

Andrei Zaikin[1, 2] and Andrew Semenov[2]

[1] *Institute of Nanotechnology, Karlsruhe Institute of Technology, 76021, Karlsruhe, Germany*

[2] *I.E.Tamm Department of Theoretical Physics, P.N. Lebedev Physics Insitute, 119991, Moscow, Russia*

We argue that electron-electron interactions yield dephasing of Cooper pairs penetrating from a superconductor (S) into a diffusive normal metal (N). At low temperatures this phenomenon imposes fundamental limitations on the proximity effect in NS hybrids restricting the penetration length of superconducting correlations into the N-metal to a temperature independent value and thereby defining the new length scale – decoherence length for Cooper pairs.

We evaluate the subgap conductance of NS hybrids in the presence of electron-electron interactions [1] and demonstrate that this new fundamental decoherence length can be directly extracted from conductance measurements in such structures. Our results agree qualitatively with earlier experimental observations [2] showing that the low temperature magnetoconductance of NS structures is determined by phase coherent electron paths with a typical size restricted by the temperature independent dephasing length rather than by the thermal length diverging in the low temperature limit. We also analyze the effect of electron-electron interactions on the critical Josephson current in diffusive hybrid SNS structures and demonstrate [3] that this current gets exponentially suppressed even at zero temperature provided the thickness of the N-layer exceeds the dephasing length for Cooper pairs. This our prediction appears to be consistent with recent experimental observations [4].

It is remarkable that the Coper pair dephasing length established both for NS- and SNS-systems up to a numerical prefactor coincides with zero temperature decoherence length obtained within a totally different theoretical framework [5] for a different physical quantity – weak localization correction to the normal metal conductance. This agreement emphasizes fundamental nature of low temperature dephasing by electron-electron interactions which universally occurs in different types of disordered conductors.

[1] A.G. Semenov, A.D. Zaikin and L.S. Kuzmin, Phys. Rev. B 86, 144529 (2012).

[2] D.A. Dikin, M.J. Black, and V. Chandrasekhar, Phys. Rev. Lett. 87, 187003 (2001).

[3] A.G. Semenov and A.D. Zaikin, in preparation.

[4] M. Möttönen, private communication.

[5] D.S. Golubev and A.D. Zaikin, Phys. Rev. Lett. 81, 1074 (1998); Phys. Rev. B 59, 9195 (1999); Physica E 40, 32 (2007).

T140

Optical communication with invisible photons

M. Suhail Zubairy

Texas A&M University, Department of Physics and Astronomy, College Station, USA

In this paper [1], we present a counterfactual quantum communication protocol in which no real information carriers (photons) are transmitted through the transmission channel. By using the first "chain" version of the quantum Zeno effect, we show how the possibility of a highly efficient direct communication exists through a quantum channel. A double chain version enables us to make the information carriers invisible in the transmission channel. This counterfactual protocol is secure and can survive most of the conventional attacks.

[1] H. Salih, Z. Li, M. Alamri, and M. S. Zubairy, Phys. Rev. Lett. 110, 170502 (2013).

Invited Posters

Predictions of a fundamental statistical picture

Roland E. Allen

Texas A&M University, Department of Physics and Astronomy, College Station, USA

This poster presentation is based on arXiv:1101.0586 [hep-th], with some clarifications and additions, and a greater emphasis on the connection to standard physics. There has always been a remarkably close relationship between the partition function of statistical physics and the path integral of field theory. Here we argue that this is no coincidence, and that nature can be interpreted as a statistical system described by a Euclidean path integral (partition function), but with an action (entropy or free energy) which has Lorentzian form to lowest order. One can then transform to a Lorentzian path integral, Lorentzian propagators, etc., and the fields, operators, classical equations of motion, quantum transition probabilities, propagation of particles, and meaning of time are the same in both formulations. A specific system will be discussed which implies the following: (1) Lorentz invariance is an extremely good approximation at normal energies, but is ultimately broken at high energy. (2) Supersymmetry is inescapable. In other words, the present theory cannot possibly be formulated without susy. (3) Higgs-like bosons are inescapable. (4) The fundamental gauge theory must be SO(N), with SO(10) giving neutrino masses plus the standard model. (5) The usual cosmological constant is zero, but there is a much weaker term involving a factor that is conventionally taken to be constant. (These two points were already made in an earlier version, hep-th/9612041, before the discovery of dark energy.) The fundamental formulation of the theory also accounts for the origin of boson and fermion fields, and of spacetime coordinates, with a gravitational metric necessarily having the form (-,+,+,+). In short, the present theory is far more ambitious than string theory, and also far closer to experiment. However, the deviations from standard physics are subtle and hard to test, and quantitative predictions will also be very difficult because they require a detailed treatment of symmetry-breakings in the early universe, and of the resulting very complex vacuum fields that determine, e.g., the gravitational and gauge coupling constants plus Yukawa couplings.

I2

Thermodynamics of small isolated quantum systems. Rationale for volume entropy and examples

Michele Campisi

University of Augsburg, UniversitaetStr. 1, Augsburg D-89135, Germany

In his seminal book of statistical mechanics [1] Gibbs identifies the volume entropy [i.e. the logarithm of the volume of phase space enclosed by the constant energy shell] as the thermodynamic entropy of isolated systems. We present the seldom discussed rationale behind this identification, which dates back to Helmholtz [2]. Further, we highlight that the volume entropy possesses the properties of thermodynamic entropy regardless of the system size, thus being adequate for the study of the thermodynamics of small isolated system [3,4]. Its property of growing as a consequence of non-equilibrium driving has been shown only recently [5,6], for both classical and quantum systems. This is in close connection with the fluctuation theorem [7]. We illustrate the increase of volume entropy by means of a forced harmonic oscillator [8]. Lastly we show that the volume entropy also increases in a scenario where two small quantum systems (two spin chains) at different initial temperatures are quenched into a single chain [9].

[1] Gibbs, J. W. "Elementary Principles in Statistical Mechanics", Yale U.P. (1902)

[2] Helmholtz, H., von, "Principien der Statik monocyklischer Systeme", Borchardt-Crelle's Journal fur die reine und angewandte Mathematik, 97, 111-140 (1884); also in Wiedemann G. (Ed.) (1895) Wissenschafltliche Abhandlungen. Vol. 3, pp. 142-162, 179-202

[3] Campisi, M., Stud. Hist. Phil. Mod. Phys. 36, 275-290 (2005)

[4] Campisi, M. and Kobe, D. H., Am. J. Phys. 78, 608 (2010)

[5] Campisi, M., Stud. Hist. Phil. Mod. Phys. 39, 181-194 (2008)

[6] Tasaki, H., arXiv:cond-mat/0009206

[7] Campisi, M., Hanggi, P., and Talkner, P., Rev. Mod. Phys. 83, 771 (2011)

[8] Campisi, M., Phys. Rev. E 78, 051123 (2008)

[9] Joshi, D. J. and Campisi, M., Eur. Phys. J. B, 86, 157 (2013)

Quantum-classical correspondence in the dynamics of the Dicke model

Holger Fehske, Andreas Alvermann, and Lutz Bakemeier

Institute of Physics, University Greifswald, Felix-Hausdorff-Str. 6, 17489 Greifswald, Germany

We study the dynamical properties of the Dicke model for moderate to large spin length, close to the classical spin limit of infinite spin length. Our focus is on the general question whether and how the quantum dynamics converges to the classical dynamics. The Dicke model serves as a paradigmatic example where signatures of classical regular and chaotic motion are manifest in the quantum dynamics. Using numerical time-propagation we are able to cover situations with rather large spin lengths, which allow for clear identification of the relevant dynamical signatures. The comparison between quantum and classical time evolution is made in phase space, using spin and oscillator Husimi functions. We also relate the classical orbits and Poincare plots to their suitably defined quantum counterparts, including Husimi functions of full orbits and individual eigenstates. The competition between classical drift and quantum diffusion is quantified through comparison of classical Lyapunov exponents and quantum diffusion rates in phase space. We finally discuss whether classical chaotic motion leads to full coverage of the energy shell and subsequent thermalisation of the quantum state.

I4

Coherent states of Landau-Aharonov-Casher levels

Claudio Furtado, Jilvan Lemos de Melo, and Knut Bakke

Departamento de Fisica-UFPB, Cidade Universitaria, Caixa Postal 5008, Joao Pessoa 58051-970, Brazil

Coherent state is an important physical concept both theoretically and experimentally, because it possesses physical properties that represent many physical systems. Such states can be generated from eigenstates of the Landau levels. The Landau levels are highly degenerate energy levels that arise in the quantum dynamic of a electron in the presence of a uniform constant magnetic field. There are analogous Landau levels to others physical systems, as Landau-Aharonov-Casher levels that are the energy levels of a neutral particle with permanent magnetic dipole moment interacting with a certain electric field, since it satisfies conditions of null torque and effective uniform magnetic field. In this contribution, we study the coherent states of Landau levels and show how to obtain the coherent states of the Landau-Aharonov-Casher levels. We also analyze the coherent state for the analogous Landau levels.

Recovering entanglement by local operations

Elisabetta Paladino[1, 2, 4], Antonio D'Arrigo[1, 2], Rosario Lo Franco[3, 4], Giuliano Benenti[5, 6], and Giuseppe Falci[1, 2, 4]

[1]*Dipartimento di Fisica e Astronomia, University of Catania, Via Santa Sofia 64, Catania, Italy*

[2]*CNR-IMM UOS Catania (Università) Via Santa Sofia 64, 95123 Catania, Italy*

[3]*CNISM and Dipartimento di Fisica, Università di Palermo, via Archirafi 36, 90123 Palermo, Italy*

[4]*Centro Siciliano di Fisica Nucleare e di Struttura della Materia (CSFNSM), Viale S. Sofia 64, 95123 Catania, Italy*

[5]*CNISM and Center for Nonlinear and Complex Systems, Università degli Studi dell'Insubria, Via Valleggio 11, 22100 Como, Italy*

[6]*Istituto Nazionale di Fisica Nucleare, Sezione di Milano, via Celoria 16, 20133 Milano, Italy*

We investigate the non-monotonous dynamics of entanglement in bipartite systems under the action of local operations. In particular, we propose an explanation of the possible entanglement increase when the system interacts with classical environments in the absence of non-local operations. Local operations cannot create entanglement, nor entanglement can be transferred back and forth from/to the environment, as a difference with quantum environments. Therefore, in the considered case, the increase of entanglement must be attributed to the manifestation of quantum correlations already present in the system, but in some sense "hidden". In this perspective, we introduce the concept of "hidden entanglement", proposing a way to quantify it. We discuss several examples. We show that in the case of a low-frequency stochastic environment, hidden entanglement can be recovered by purely local pulses applied to the system. We also propose a simple optical set-up which provides evidence of the concept of hidden entanglement.

[1] A. D'Arrigo, R. Lo Franco, G. Benenti, E. Paladino, G. Falci, Recovering Entanglement by Local Operations, arXiv:1207.3294

I6

Theoretical analysis of the spin dynamics of magnetic adatoms

Michael Schüler, Yaroslav Pavlyukh, and Jamal Berakdar

Martin-Luther-University, Halle-Wittenberg, Heinrich-Damerow-Str.4, Halle, Germany

Inelastic scanning tunneling microscopy (STM) has recently been shown [1] to be extendable to access the nanosecond, spin-resolved dynamics of magnetic adatoms and molecules. Here we analyze this novel tool theoretically by considering the time-resolved spin dynamics of a single adsorbed Fe atom excited by a tunneling current pulse from a spin-polarized STM tip [2]. The adatom spin configuration can be controlled and probed by applying voltage pulses between the substrate and the spin-polarized STM tip. We demonstrate how, in a pump–probe manner, the relaxation dynamics of the sample spin is manifested in the spin-dependent tunneling current. Our model calculations are based on the scattering theory in a wave-packet formulation. The scheme is non-perturbative and, hence, is valid for all voltages. The numerical results for the tunneling probability and the conductance are contrasted with the predictions of simple analytical models and compared with experiments.

[1] S. Loth, M. Etzkorn, C. P. Lutz, D. M. Eigler and A. J. Heinrich, Science 329, 1628 (2010)

[2] M Schüler, Y. Pavlyukh, and J. Berakdar, New J. Physics 14, 043027 (2012)

Coherent states of a generalized nonstationary damped harmonic oscillator

Inácio Pedrosa

Universidade Federal da Praíba, Caixa postal 5008, João Pessoa, 58051-970, Brazil

In this work we study the quantum motion of a generalized harmonic oscillator with arbitrary time-dependent mass and frequency subjected to a linearly velocity-dependent frictional force. Based on the dynamical invariant method and using quadratic invariants, we derive exact nonstationary quantum states for this system and write them in terms of solutions of the Milne-Pinney equation. In addition, we construct coherent states for this quantized system and employ them to investigate its quantum properties. In particular, we show that the product of the quantum fluctuations of the coordinate and the momentum space does not attain its minimum value.

I8

Atomically wired molecular junctions: Connecting a single organic molecule by chains of metal atoms

Tamar Yelin[1, 3], Ran Vardimon[1, 3], Nataly Kuritz[1], Richard Korytár[2], Alexei Bagrets[2], Ferdinand Evers[2], Leeor Kronik[1], and Oren Tal[1]

[1]Weizmann Institute of Science, Rehovot, Israel

[2]Karlsruhe Institute of Technology, Karlsruhe, Germany

[3]These authors contributed equally to this work

Acquiring control over electronic transport at the atomic scale requires the ability to fabricate electronic devices in atomic resolution. Here we show that benzene and larger organic molecules can be electrically connected by the smallest possible conducting wire: a chain of atoms. The wiring process is done in a mechanically controllable break junction setup by pulling atom after atom from platinum electrodes into a molecular junction. The organic molecule is directly connected to atomic chains with no linking groups such as thiols or amines to gain high conductance which is weakly dependent on the chain length. Ab-initio calculations show that wiring benzene molecules with platinum atomic chains leads to the formation of stable hybrid junctions with significant structural flexibility. These hybrid junctions can be a useful testbed for the study of interfaces between low-dimensional structures as organic molecules and chains of metal atoms.

T violation as the cause of the direction of time

Joan Vaccaro

Griffith University, 170 Kessels Road, Nathan, Australia

Nature has been shown to violate the time reversal (T) and charge-parity conjugation (CP) invariances. T violation implies that there are two versions of the Hamiltonian, H_F and the time reversed version H_B. In order to write down the Schrodinger equation we must first choose the direction of time evolution and a specific version, say H_F, of the Hamiltonian. Then by applying the time reversal operation we obtain the Schrodinger equation involving the H_B version of the Hamiltonian for evolution in the opposite direction of time. But we do not have a dynamical equation of motion for the situation where the direction of time evolution cannot be specified and for which there is no argument for favouring one version of the Hamiltonian over the other. This problem becomes critical when we attempt to describe the universe as a closed system because being closed precludes any external clock-like device for use as a reference for the direction of time. There is, therefore, no satisfactory quantum formalism for describing a universe that exhibits T violation processes. The resolution of this problem calls for a major shift in the way we think about time.

To address this issue we allow the universe to take a random walk through time [1]. The path of the walk comprises steps of evolution in a random direction of time, where the evolution is according to H_F or its time reversed version H_B depending on the direction. We use a Feynman path method to sum the amplitudes of different paths. We find destructive interference between different paths for the case where the commutator $[H_F, H_B]$ is nonzero. This corresponds to the universe containing processes that violate time reversal invariance. For particular conditions, the destructive interference eliminates all paths except for two that represent continuously forwards and continuously backwards time evolution. This work suggests that T violation has previously unknown, large-scale physical effects that constrain the universe to follow a fixed direction of time. It appears to provide a view of the quantum nature of time itself.

Recent work has focused on clarifying the nature of the destructive interference between different paths and the conditions for it to occur. The results show that the interference follows a scaling law which is reminiscent of a Wiener process. The mechanism by which the universe can evolve from one state at time A to another state at time B but not the reverse will also be discussed.

[1] J.A. Vaccaro, Found. Phys. **41** (2011) 1569-1596.

Posters

Mapping the dynamics of the spin-boson model

Andreas Alvermann

University of Greifswald, Felix-Hausdorff-Strasse 6, 17489 Greifswald, Germany

The aim of this contribution is to give a detailed study of the spin dynamics in the ohmic and sub-/super-ohmic regimes of the spin-boson model. We therefore propose a numerical method that allows for precise computation of the dissipative non-unitary dynamics of open quantum systems.

The advantage of our method is its long-time stability over large propagation times, without early recurrences arising from a truncation of the number of bath modes. This is achieved through the combination of the sparse polynomial space approach, previously applied to the sub-ohmic quantum phase transition [1], and the dynamical semigroup formalism. Our method works at zero and finite temperatures, and also in situations with long bath memory and pronounced non-Markovian dynamics. It does not involve artificial averaging procedures or restrictive assumptions on the bath spectral function.

We present our method for systems with a coupling to bosonic baths. To demonstrate the general applicability beyond the spin-boson model we include results for several dissipative spins that illustrate the nature of entanglement decay in non-Markovian environments.

[1] A. Alvermann and H. Fehske, Phys. Rev. Lett. 102, 150601 (2009)

P2

Quantum state transfer and routing via resonant tunnelling in spin chains

Tony Apollaro

Dipartimento di Fisica - Universita' della Calabria, via P. Bucci cubo 31 C, 87036 Arcavacata di Rende, Italy

CTAOMP - School of Mathematics and Physics, Queens University, Belfast - UK

Quantum-State Transfer (QST) is an important requisite in many Quantum Information Processing protocols. For short distance communication, interacting spin-1/2 chains as a means of data bus fulfilling faithful QST between a sender and a receiver qubit have been widely investigated and different protocols have been proposed [1-3].

A step forwards would be to allow for the use of the same data bus by many senders and receivers in an independent way. In this poster we go in this direction by designing a protocol for high-fidelity QST from one sender to a selected receiver out of many possible ones with minimal engineering needs.

Two different schemes for such a task to be achieved are presented: in the first one, by weakly coupling the sender/receiver qubits to the data bus and allowing for local/global magnetic field intensity tuning, QST is achieved via resonant coupling; in the second one, the sender/receivers are not directly coupled to the spin bus, but rather via effective 'barrier qubits', on which strong magnetic fields act as knobs for the QST, occuring via a resonant coupling mechanism that allows the spin excitation to tunnel towards the selected receiver. The latter scheme may also be useful for the transfer of an e-bit by locating appropriately the barrier qubits on the spin chain [4, 5].

tony.apollaro@fis.unical.it

[1] L. Banchi, T.J.G. Apollaro, A. Cuccoli, R. Vaia and P. Verrucchi, Phys. Rev. A 82, 052321 (2010)

[2] L. Banchi, T.J.G. Apollaro, A. Cuccoli, R. Vaia and P. Verrucchi, New J. Phys. 13, 123006 (2011)

[3] T.J.G. Apollaro, L. Banchi, A. Cuccoli, R. Vaia and P. Verrucchi, Phys. Rev. A 85, 052319 (2012)

[4] S. Lorenzo, T.J.G. Apollaro, A. Sindona, F. Plastina, Phys. Rev. A 87, 042313 (2013)

[5] S. Paganelli, S. Lorenzo, T.J.G. Apollaro, F. Plastina, G. L. Giorgi, Phys. Rev. A 87, 062309 (2013)

P3

Quantum mechanical analogy of the zeroth law of thermodynamics (On the problem of incorporating thermodynamics into quantum theory)

Olga Golubjeva[1] and Anton Artamonov[2]

[1]*Peoples' Friendship University of Russia, Moscow, Russia*

[2]*Sodankylä Geophysical Observatory, University of Oulu, Oulu Unit, University of Oulu P.O.Box 3000, FIN-90014 Oulu, Finland*

We implement the possibility of explicitly incorporating the zeroth law of stochastic thermodynamics in the form of the saturated Schrödinger uncertainty relation into quantum theory. This allows comparatively analyzing the sets of states of arbitrary vacuums which can be used for the description of thermal equilibrium states.

At the same time, in the case of sufficiently low temperatures where the thermal influence must already be taken into account, the quantum stochastic influence continues to be a significant factor. Thus, quantum and thermal fluctuations are produced simultaneously but they turn out to be non-additive. We introduced the concept of the quantum thermostat (arbitrary vacuum in the quantum language) as a model of the environment to describe such a case at low temperatures.

The most important results. A. In this investigation we have demonstrated that the physically significant subgroups of the group of Bogolyubov (υ,ν)-transformations generate two types of states: real squeezed coherent states providing the saturation of the Heisenberg "coordinate-momentum" uncertainty relationships (UR) at the zero temperature and complex correlated coherent states providing the saturation of the Schrödinger "coordinate-momentum" UR at finite temperatures. B. On the micro level, we have formulated a quantum analogue of the zeroth law of stochastic thermodynamics in the form of the saturated Schrödinger UR. C. We have substantiated the invariance of the saturated Schrödinger UR under the Bogolyubov (υ,ν)-transformations. D. We have proposed regarding the saturated Schrödinger UR as an initial concept of quantum theory at finite temperatures. E. We have shown that in theories using real wave functions or real elements of the density matrix, there is no correlation between the coordinate and momentum fluctuations. Therefore, in this case, the concept of thermal equilibrium occurring as a result of the correlation between coordinate and momentum fluctuations can be introduced only conditionally for the states at the zero temperature, i.e., if there is no thermal environmental influence. F. We have established that in the theory involving complex wave functions of the vacuum, thermodynamics can be incorporated into quantum theory at any temperatures (unlike the Umezawa thermofield dynamics). H. We have shown justice of the quantum analogue of the zeroth law of stochastic thermodynamics in the form of the saturated Schrödinger UR experimentally.

P4

Theory of p-adic dynamical systems with applications to biology

Ekaterina Axelsson

Linnaeus University, Vejdes Plats, 6, 352 52, Växjö, Sweden

P-adic dynamical systems recently found numerous applications in biology, from genetics (p-adic structure of genetic code to molecular motors dynamics), it seems that biological mesoscopic systems have hierarchical structure which can be mathematically described by ultrametric and, in particular, p-adic models.

As a p-adic model we consider a dynamical system $\langle Z_p, \mu_p, f\rangle$, where Z_p is a ring of p-adic integers, μ_p is the normalized Haar measure and $f : Z_p \to Z_p$ is a μ_p-measurable function that is continuous with respect to p-adic metric. As a trajectory of a dynamical system we take $x_{i+1} = f(x_i), i \geq 0.$

One of examples of the p-adic model with an application to biology is the process of DNA-reproduction. In this model the process of DNA-reproduction is described by the action of a 2-adic dynamical system. As we know, the genes contain information for production of proteins. The genetic code is a degenerate map of codons to proteins. This map is modeled as functioning of a polynomial dynamical system.

[1] V. Anashin and A. Khrennikov, Applied Algebraic Dynamics, de Gruyter Expositions in Mathematics, Walter de Gruyter, V. 49 (Berlin – New York, 2009).

[2] A. Khrennikov and S. V. Kozyrev, Genetic code on the diadic plane. Physica A: Statistical Mechanics and its Applications, 381, 265-272 (2007).

[3] A. Khrennikov and S. Kozyrev, 2-adic numbers in genetics and Rumer's symmetry. Doklady Mathematics, 81 (1), 128-130 (2010).

[4] A. Y. Khrennikov, Gene expression from 2-adic dynamical systems. Proc. of the Steklov Inst. of Math., 265, N.1, 131-139 (2009).

[5] A. Khrennikov and A. Kozyrev, J. Theor. Biology, 261, (2009) 396-406.

[6] F. Vivaldi, Algebraic and arithmetic dynamics.
http://www.maths.qmul.ac.uk/˜fv/database/algdyn.pdf

Thermoelectric transport in nanoscale devices, influence of Kondo and Hund

Julien Azema, Anne-Marie Daré, Steffen Schäfer, and Pierre Lombardo

IM2NP - Aix Marseille Université, Av. Escadrille Normandie Niemen, Marseille 13397, France

Thermoelectric effects in nanoscale devices have become an intense field of research during the last decade. The possibility to reconvert wasted heat into useful electric energy represents a major challenge in microelectronics. This issue also requires a significant theoretical effort due the high electron confinement and many-body behavior which take place in these devices. The most famous effect occurring in low dimensional systems is the Coulomb blockade which tends to deteriorate the conductance. A many-body effect overcomes this undesirable effect: indeed low temperature exhibits some resonant spin-flip scattering between conduction electrons in the leads and those in the dot-like channel which restores the conductance: it's the Kondo effect.

We investigate the transport through a nanoscale device consisting of a degenerate double-orbital Anderson dot coupled to two uncorrelated leads [1]. Close to the one-electron Kondo regime, we determine the thermoelectric transport properties. We use a non-equilibrium generalization of the non-crossing approximation based on the Keldysh formalism. In the linear regime we compute transport coefficients such as conductance, Seebeck coefficient and the figure of merit. Whereas power output and efficiency are estimated in the non linear regime. These last quantities are strongly promoted by the presence of a second orbital and we predict an experimentally relevant optimal operating point.

Furthermore, we include a Hund coupling in the double-orbital system leading to a splitting of the energy levels of two electron states. This lift of degeneracy results in inelastic cotunneling processes which are clearly revealed in the differential conductance by threshold effects. These processes strongly affect the density of state at the Fermi level, and have a major impact on transport properties, including Seebeck coefficient and conductance.

[1] J. Azema, A.-M. Daré, S. Schäfer, and P. Lombardo, PRB 86, 075303 (2012)

P6

Paradoxes of noninvasive measurements

Adam Bednorz[1] and Wolfgang Belzig[2]

[1] *Faculty of Physics, University of Warsaw, ul. Hoża 69, 00-681 Warsaw, Poland*

[2] *University of Konstanz, D-78457 Konstanz, Germany*

Standard, projective quantum measurements are invasive, while experimentalists prefer non-invasivess. It is possible to construct a universal model of weak measurements, working both classical and quantum, which becomes noninvasive in a certain limit. The outcome probability is a convolution of inherent detector noise and system's statistics. However, the results of quantum noninvasive measurements are fundamentally different from their classical analogues. The quantum statistics is described by a quasiprobability (real and normalized but sometimes negative) instead of classical probability [1]. Moreover, the quantum noninvasive measurements are not time-symmetric, while the classical are [2]. These unsual properties can be demonstrated on simple quantum systems.

[1] A. Bednorz, W. Belzig, Phys. Rev. Lett. 105, 106803 (2010)

[2] A. Bednorz, K. Franke, W. Belzig, New J. Phys. 15, 023043 (2013)

The Kibble-Zurek mechanism in superconducting loops

Jorge Berger

Ort-Braude College, Snunit 51, Karmiel 21982, Israel

The Kibble-Zurek mechanism (KZM) [1,2] provides a general framework for rapid and continuous phase transitions. KZM divides the phase transition into three stages, and postulates a leading feature at each stage: during the initial stage the system remains in thermal equilibrium, during the stage at which the critical temperature is crossed the system is sluggish and its state remains unchanged, and during the final state the selected state is locked. KZM has been invoked to explain cosmological phenomena, such as the symmetry breaking responsible for the difference between the electromagnetic and the weak interaction, and also a wide range of experiments in condensed matter.

We study the final distribution of persistent currents that spontaneously appear when a superconducting ring is quenched through its critical temperature with no applied magnetic flux [3]. This is an interesting system, because the fluctuations of its order parameter compete with those of the gauge field, and it is not obvious which of them will dominate. Our results are compared with KZM.

Our results are in agreement with KZM, but only in some appropriate limits. The variance of the winding number above T_c agrees with KZM, provided that the coherence length is short compared with a length that is determined by the quartic term in the energy functional. Most states are locked after quenching, provided that we allow for some necessary "incubation time". According to KZM, for a mean field model, the variance of the winding number ought to be proportional to the fourth root of the quenching rate. This is indeed what we find, provided that quenching times are larger than $10^5\hbar/k_BT_c$. When fluctuations of the gauge field are suppressed, this scaling is obeyed over a wider range.

[1] W. H. Zurek, Phys. Rep. **276**, 177 (1996)

[2] T. W. B. Kibble, Phys. Today **60**, 47 (2007)

[3] arXiv:1301.0912

P8

Flux-induced thermoelectric effect

Jorge Berger

Ort-Braude College, Snunit 51, Karmiel 21982, Israel

When a superconducting ring encloses a magnetic flux that is not an integer multiple of half the quantum of flux, a voltage arises in the direction perpendicular to the temperature gradient. We study the dependence of this voltage on the temperature gradient, flux, position, average temperature, BCS coherence length and thermal coherence length.

Weak measurement of Zeno time in the context of dissipative system

Samyadeb Bhattacharya and Sisir Roy

Indian Statistical Institute, 203 B.T. Road, Kolkata, India

A generalized expression for weak value of dwell time in dissipative systems has been constructed using the approach of Caldirola and Montaldi. An approximate measure of Zeno time has been found taking an asymmetric double well potential. Atomic tunneling between two surfaces is taken as a practical example. The formalism can be used for any solvable potential with exact or approximate energy Eigen-values. Extending the calculation further, De-coherence time has been calculated for an optical ion trap of Be atoms in a bistable potential model. Comparison has been made between de-coherence time and Zeno time for double well potential as a special case. Zeno time is considered as a lower limit of de-coherence time for sustainable quantum coherence. Equality of the respective timescales provides a certain transitional temperature, below which de-coherence can be asymptotically minimized.

P10

Nonlinear cavity optomechanics

Kjetil Borkje

Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen, Denmark

We identify signatures of the intrinsic nonlinear interaction between light and mechanical motion in cavity optomechanical systems. These signatures are observable in the resolved sideband regime even when the cavity linewidth exceeds the optomechanical coupling rate. A strong laser drive red-detuned by twice the mechanical frequency from the cavity resonance frequency makes two-phonon processes resonant, which leads to a nonlinear version of optomechanically induced transparency. This effect provides a new method of measuring the average phonon number of the mechanical oscillator. Furthermore, we show that if the strong laser drive is detuned by half the mechanical frequency, optomechanically induced transparency also occurs due to resonant two-photon processes. The cavity response to a second probe drive is in this case nonlinear in the probe power. These effects should be observable with optomechanical coupling strengths that have already been realized in experiments.

[1] K. Borkje, A. Nunnenkamp, J. D. Teufel, S. M. Girvin, arXiv:1304.4155

Third order nonlinear optical effects in a strongly driven semiconductor quantum dot coupled to a metallic nanosphere

John Boviatsis[1], Spyridon Kosionis[2], Andreas Terzis[2], and Emmanuel Paspalakis[3]

[1]Technological and Educational Institute of Patras, Megalou Alexandrou 1, Patras 26334, Greece

[2]Physics Department, University of Patras, Patras 265 04, Greece

[3]Materials Science Department, University of Patras, Patras 265 04, Greece

A relatively new area of active research involves the study of the quantum and nonlinear optical properties of complexes of plasmonic nanoparticles (MNPs) and semiconductor quantum dots (SQDs). One of the structures that have attracted particular attention is composed of a SQD and a spherical MNP that interacts with a weak probe field of varying frequency and a strong pump field of fixed frequency [1-4]. In this system slow light [1], gain without inversion [2] and third order nonlinearity [3,4] have been theoretically studied. These studies have shown that the interparticle distance plays an important role in the optical response of the nanocrystal complex. An important result was found by Sadeghi [2], who showed that when the interparticle distance reaches a critical value, plasmonic meta-resonances are created [5] and an abrupt formation of a significant amount of gain without inversion in the SQD occurs. In this paper we also address theoretically the problem of the nonlinear optical response in a coupled SQD-spherical MNP structure that interacts with a weak probe field of varying frequency and a strong pump field of fixed frequency and give emphasis to the behaviour of the real and imaginary part of the third order nonlinearity of the SQD with the interparticle distance. We find that there is a critical interparticle distance that strongly modifies the third order nonlinearity. The derived spectra show strongly different behaviour above and below the critical distance. This critical distance is the one that creates plasmonic meta-resonances in the hybrid structure [5].

Acknowledgements: This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Archimedes III.

[1] Z. Lu and K.-D. Zhu, J. Phys. B 41, 185503 (2008).

[2] S. M. Sadeghi, Nanotechnology 21, 455401 (2010).

[3] Z. Lu and K.-D. Zhu, J. Phys. B 42, 015502 (2009).

[4] J.-B. Li, N.-C. Kim, M.-T. Cheng, L. Zhou, Z.-H. Hao, and Q.-Q. Wang, Opt. Express, 20, 1856 (2012).

[5] S. M. Sadeghi, Phys. Rev. B 79, 233309 (2009).

P12

A conceptual study on thermal equilibrium states and thermal convections of fluids in nanochannels

Song Ge and Min Chen

Department of Engineering Mechanics, Tsinghua University, Tsinghua Park, Beijing, 100084, China

In recent years, substantial progress in nano-fabrication and operating of nanoscale devices has been made. One group of the typical nanoscale devices is the so called nanoelectromechanical systems (NEMS), where the transport of heat and fluid is often involved within very small dimensions. In this paper, the definition of thermal equilibrium states and the characteristics of thermal convection of fluids in nanochannels are discussed base on molecular dynamics (MD) simulations. In the MD simulations, methodological differences of the temperature calculation, the heat flux calculation and the interfacial temperature jump calculation are carefully compared with each other, and carefully compared with the macroscopic thermodynamics definition. For the thermal convection, the contributions from heat diffusion and advection are respectively calculated, and also compared with macroscopic thermal convection calculations. The differences between the nanoscale thermal convection and the macroscopic thermal convection are summarized.

Quantum correlations and localization of two emitters in the subwavelength regime of the standing field

Nellu Ciobanu[1, 2] and Miguel Orszag[1]

[1] *Facultad de Fisica, Pontificia Universidad Catolica de Chile, Casilla 306, Santiago, Chile*

[2] *Institute of Applied Physics, Academy of Sciences of Moldova, Academiei 5, Chisinau MD-2028, Republic of Moldova*

New experimental achievements based on cold system use the light capacity to control with the motion of the atoms, and allow to establish high resolution measurements of the atomic positions via the optical technique. In this model, we discuss the time dependence of the resonance fluorescence of two three-level atoms dressed in the subwavelength region of the standing field. In particular we observe the appearance of quantum beats (Rabi oscillations) in the fluorescent emission, due to the non-equivalent localization of the emitters in the field. The modification of quantum correlations between the atoms in the anti-node, and the statistical properties of the emitted photons from the dressed-states as function of the position of atoms as well as the laser field parameters are examined. We find a bunched character of the sub-Poissonian statistics, in which the anti-Stokes correlations prevail. For some positions of the atoms, we observe the violation of Cauchy-Schwarz inequality, where the scattered light has a non-classical character. A possibility to estimate the positions of the atoms in the standing field via the strong correlated photons emitted at Stokes and anti-Stokes transitions is discussed.

P14

Evolution of classical and quantum correlations for two qubits in cavity-QED under thermal decoherence

Vitalie Eremeev[1], Nellu Ciobanu[2], and Miguel Orszag[2]

[1] *Universidad Autónoma de Chile, Pedro de Valdivia 641, Providencia, Santiago, Chile*

[2] *Pontificia Universidad Catolica de Chile, Casilla 306, Santiago, Chile*

The quantum correlations between the particles known as entanglement, is a tool very important for applications in quantum information technologies, nevertheless the recent investigations indicate on the alternative measure of the quantum correlations as quantum discord, which is more robust against some decoherences if compared to entanglement. We proposed recently [1] a scheme for generation of long-stable entanglement and quantum discord by the effects of the thermal environments considering a model of two atoms(qbits) trapped in the cavities-fibre network with dissipations to thermal reservoirs. This system was investigated in the context of generation and protection of quantum correlations for initially uncorrelated qbits and considering the approximation of one excitation which may exist in the entire system, including the environments. Here we generalize the mentioned model and propose a versatile study of the correlations for different conditions of the system under evolution, with any number of excitations in the whole system. As results of the study we obtain a various interesting phenomena, such as sudden/sharp transitions [2] in the temporal evolution of the classical and quantum correlations (discord), entanglement sudden-death (ESD) and revivals, stable state of the classical and quantum correlations for a relative long time under the decoherence, etc. Therefore by the proposed model we demonstrate the existence and coexistence of some curious phenomena which were shown separately in the literature [2] by considering some particular models or conditions. This study may bright more light on the understanding of the mentioned effects at general in the case of quantum open systems under distinct kind of decoherence.

[1] V. Eremeev, V. Montenegro, and M. Orszag, Phys. Rev. A 85, 032315 (2012).

[2] J. Maziero et al., Phys. Rev. A 80, 044102 (2009); L. Mazzola, J. Piilo, and S. Maniscalco, Phys. Rev. Lett. 104, 200401 (2010); Jin-Shi Xu et al., Nat. Commun. 1, 7 (2010); R. Lo Franco et al, Phys. Rev. A 85, 032318 (2012).

Coarse-grained master equations and heat transport fluctuation theorems for open quantum systems

James Cresser and Chris Facer

Macquarie University, Herring Road, North Ryde 2019, Australia

An essential step in deriving quantum master equations (QMEs) is the coarse-graining of the system dynamics. Not all derivations of the QME make this explicit; a very early exception is that of Cohen-Tannoudji et al [1] where the coarse-graining time scale appears as a parameter that can be freely chosen, within certain clearly defined limits, the result being a QME that can, in fact, be shown to be of Lindblad form. The QME is insensitive to the choice of this coarse-graining time scale provided it is chosen to be much larger than all inverse transition frequencies of the system, yielding the familiar secular approximation form of the QME, but for systems consisting of interacting subsystems there arises a new time scale, the time scale of this interaction, and a QME can be derived that is insensitive to a choice of coarse-graining on a scale shorter than this interaction time scale. This yields a different, yet valid, master equation for the same system. The physical meaning of this difference is founded on a quantum trajectory measurement interpretation based on time-resolved measurements made on the reservoir(s) with which the system is interacting: the different master equations reflect differences in information gained about the system by these measurements. The idea is explored for a system consisting of a qubit tunneling between two quantum wells, each well a thermal reservoir at a different temperature. Coarse-graining can be either longer or shorter than the tunneling time, yielding two master equations each with a clear quantum jump/measurement interpretation. Heat transfer from one reservoir to the other and, through quantum trajectory simulations, the statistics of fluctuations predicted by fluctuation theorems [2,3], are also studied in a circumstance in which quantum coherence is present, depending on the choice of master equation, which in turn are reflections of the measurement of reservoir energies in determining the heat transport process.

[1] C. Cohen-Tannoudji , J. Dupont-Roc, and G. Grynberg, *Atom-Photon Interactions: Basic Processes and Applications*, Wiley-VCH Verlag GmbH (2004).

[2] M. Esposito, U. Harbola, and Shaul Mukamel, Rev. Mod. Phys. **81** (2009) 1665.

[3] M. Campisi, P. Hänggi, and P. Talkner, Rev. Mod. Phys. **83** (2011) 771.

P16

Swapping of quantum correlations in dissipative environments

Dawid Crivelli and Jerzy Dajka

Institute of Physics, University of Silesia, ul. Uniwersytecka 4, 40-007 Katowice, Poland

Quantum channel teleporting one party of a bipartite entangled state is considered. It is assumed that resource state is coupled to decohering (e.g. thermal, Davis-type) environment. The aim is to study both the fidelity of the channel and its ability to swap the initial correlation to the final state of the system in which subsystems did not interact directly. The correlations are qualified by negativity and quantum discord. It is shown that the correlation loss defined as a difference between values of the correlation measure for the teleported state and the resource state vanishes at certain time instants for certain choice of parameters of the system and its environment.

Spin squeezing and other entanglement tests for two mode systems of identical bosons

Bryan Dalton

Centre for Atom Optics and Ultrafast Spectroscopy, Swinburne University of Technology, Melbourne, Victoria 3122, Australia

Entangled quantum states are considered for systems of identical particles, where inorder to represent physical states, the system density operator must satisfy the symmetrisation principle (SP) and conform to super-selection rules (SSR) that prohibit states with coherences between differing total particle numbers [1]. Both the system and sub-systems are modes (or sets of modes), particles being associated with different mode occupancies [2]. In defining the non-entangled or separable states, the subsystem density operators are also required to satisfy the SP and conform to SSR which forbid states with coherences between differing subsystem particle numbers [3,4] – in contrast to other approaches [5]. The work mainly focuses on two mode entanglement both for massive bosons (e.g. bosonic atoms) and for photons. It is shown here [4] that spin squeezing in at least one of the spin components $\widehat{S}_x = (\widehat{b}^\dagger\widehat{a} + \widehat{a}^\dagger\widehat{b})/2$, $\widehat{S}_y = (\widehat{b}^\dagger\widehat{a} - \widehat{a}^\dagger\widehat{b})/2i$, $\widehat{S}_z = (\widehat{b}^\dagger\widehat{b} - \widehat{a}^\dagger\widehat{a})/2$ ($\left\langle \Delta\widehat{S}_x^2 \right\rangle < \frac{1}{2}|\left\langle \widehat{S}_z \right\rangle|$ and $\left\langle \Delta\widehat{S}_y^2 \right\rangle > \frac{1}{2}|\left\langle \widehat{S}_z \right\rangle|$ for squeezing in $\widehat{S}_x$ compared to $\widehat{S}_y$ etc) is a sufficiency test for entanglement of the modes $\widehat{a}$,$\widehat{b}$. Whilst previous tests for entanglement in two mode systems, such as $(\left\langle \Delta\widehat{S}_x^2 \right\rangle + \left\langle \Delta\widehat{S}_y^2 \right\rangle) < \frac{1}{2}\left\langle \widehat{N} \right\rangle$ related to spin squeezing [6], and strong correlation tests [7] $|\left\langle \widehat{a}^m\,(\widehat{b}^\dagger)^n \right\rangle|^2 > \left\langle (\widehat{a}^\dagger)^m\widehat{a}^m\,(\widehat{b}^\dagger)^n\widehat{b}^n \right\rangle$ $(m,n = 1,2,..)$ still apply for the present concept of entanglement, new tests have been obtained [4] – such as the spin squeezing test and a simple correlation test $|\left\langle \widehat{a}^m\,(\widehat{b}^\dagger)^n \right\rangle|^2 > 0$. For the case of relative phase eigenstates, the new spin squeezing test for entanglement is satisfied (for principle spin operators) [4], whilst the test [6] above is not. In [8] the spin squeezing entanglement test $\left\langle \Delta\widehat{S}_z^2 \right\rangle < \frac{1}{N}(\left\langle \widehat{S}_x \right\rangle^2 + \left\langle \widehat{S}_y \right\rangle^2)$ for BEC was based on a concept of entanglement inconsistent with the SP, but a revised treatment [4] leads to spin squeezing as an entanglement test. The sub-systems are now pairs of internal state modes, not particles – each pair only occupied by one boson.

[1] S. Bartlett, T. Rudolph, and R. Spekkens, Rev. Mod. Phys. **79** (2007) 555.

[2] C. Simon, Phys. Rev. A **66** (2002) 052323.

[3] S. Bartlett et al., Phys. Rev. A **73** (2006) 022311.

[4] B. Dalton, ArXiv Quant-ph 1305.0788 (2013).

[5] F. Verstraete and J. Cirac, Phys. Rev. Letts. **91** (2003) 010404.

[6] M. Hillery and M. Zubairy, Phys. Rev. Letts. **96** (2003) 050503.

[7] M. Hillery, H. Dung and J. Nisbet, Phys. Rev. A **80** (2009) 052335.

[8] A. Sorensen, L.-M. Duan, J. Cirac, and P. Zoller, Nature **409** (2001) 63.

P18

Coulomb blockade microscopy of spin density oscillations and fractional charge in quantum spin Hall dots

Giacomo Dolcetto[1, 2, 3], Niccolò Traverso Ziani[1, 2], Matteo Biggio[4], Fabio Cavaliere[1, 2], and Maura Sassetti[1, 2]

[1] *Dipartimento di Fisica, Università degli Studi di Genova, via Dodecaneso 33, Genova, 16146, Italy*

[2] *CNR-SPIN, Via Dodecaneso 33, Genova, 16146, Italy*

[3] *INFN, Via Dodecaneso 33, Genova, 16146, Italy*

[4] *Dipartimento di Ingegneria Navale, Elettrica, Elettronica e delle Telecomunicazioni, Università degli Studi di Genova, Via Opera Pia 11a, Genova, 16145, Italy*

We evaluate the spin density oscillations arising in quantum spin Hall quantum dots created via two localized magnetic barriers. The combined presence of magnetic barriers and spin-momentum locking, the hallmark of topological insulators, leads to peculiar phenomena: a half-integer charge is trapped in the dot for antiparallel magnetization of the barriers, and oscillations appear in the in-plane spin density, which are enhanced in the presence of electron interactions. Furthermore, we show that the number of these oscillations is determined by the number of particles inside the dot, so that the presence or the absence of the fractional charge can be deduced from the in-plane spin density. We show that when the dot is coupled with a magnetized tip, the spatial shift induced in the chemical potential allows to probe these peculiar features.

Can classical probability account for contextuality in quantum and non-quantum systems alike?

Ehtibar Dzhafarov[1] and Janne Kujala[2]

[1] *Purdue University, 703 Third Street, West Lafayette 47907, USA*

[2] *University of Jyvaskyla, Jyvaskyla, Finland*

From quantum physics to biology to behavioral sciences, one encounters systems with several inputs and several random outputs, such that (A) for each of these outputs only some of the inputs may "directly" influence them, but (B) other inputs provide a "context" for this output by influencing its probabilistic relations to other outputs. These contextual influences are different, say, in classical mechanics and in the entanglement paradigm of quantum physics, being traditionally interpreted as representing different forms of physical determinism. One can mathematically construct systems with other types of contextuality, whether or not they can be empirically observed: those that form special cases of the classical type, those that fall between the classical and quantum ones, and those that violate the quantum type. We propose a mathematical language for describing all possible patterns of contextuality. The central notion of the language is that of all possible couplings for stochastically unrelated outputs indexed by mutually exclusive values of inputs. The set of couplings compatible with the constraints imposed on the outputs (such as Bell-type or Cirel'son inequalities) represents a form of contextuality in the dependence of outputs on inputs with respect to the declared pattern of direct influences. The theory of probability involved is purely classical, Kolmogorovian, with the emphasis on the fact that random variables are not a priori defined on a single, universal sample space (which is a mathematical impossibility to begin with).

[1] Dzhafarov, E.N., & Kujala, J.V. (2013). All-possible-couplings approach to measuring probabilistic context. PLoS ONE 8(5): e61712. doi:10.1371/journal.pone.0061712

[2] Dzhafarov, E.N., & Kujala, J.V. (in press). Selective influences, marginal selectivity, and Bell/CHSH inequalities. Topics in Cognitive Science

[3] Dzhafarov, E.N., & Kujala, J.V. (2013). A qualified Kolmogorovian account of probabilistic contextuality. arXiv:1304.4546

[4] Dzhafarov, E.N., & Kujala, J.V. (2013). No-Forcing and No-Matching theorems for classical probability applied to quantum mechanics. arXiv:1305.3649

P20

Violation of macroscopic Lorentz invariance: Experiment and fundamental consequences

Sergey Emelyanov

Ioffe Institute, Polytechnicheskaya 26, St. Petersburg, Russian Federation

Light-induced spatially-discontinuous transitions of electrons are well-known since the early days of quantum mechanics. They have never been regarded as a peculiar quantum dynamics because their lengthscale was always microscopic and this seems a self-evident thing. Recently, however, a modification of integer quantum Hall (IQH) system was revealed which contains a great number of orbit-like macroscopic states similar to the so-called current-carrying states responsible for conventional IQH effect [1]. We detect light-induced spatially-discontinuous transitions between these states and directly demonstrate that their characteristic lengthscale can be as long as about 1cm or even longer.

Thus, spatially-discontinuous transitions are not a "quantum description" but a real macroscopic dynamics beyond the paradigm of continuous movement and therefore beyond the relativity [2]. This dynamics is clearly incompatible with the fundamental status of Lorentz invariance as well as with the fundamental status of Minkowski spacetime. At the same time, it is consistent with the Lorentz-Poincaré interpretation of relativity where Lorentz invariance has the status of an emergent phenomenon and where absolute simultaneity may occur owing to the notion of "aether". Actually, this notion leaves a room for deeper concepts of space and time. Now this room should be filled by appropriate quantum concepts (see, e.g., [3]) consistent with the dynamics we observe.

Violation of macroscopic Lorentz invariance clearly eliminates the basic argument against realistic (de Broglie-Bohm) quantum theory. As a result, along with the natural solution of the measurement problem, we get a new way to unify quantum and relativity theories [4]. Instead of the number of unsuccessful attempts to find a third "unified" theory, the already existing realistic quantum theory may be just the theory we need. Relativity thus appears to be only a limiting case insofar as it is relevant only to the systems with non-interfered autonomic objects.

[1] S. A. Emelyanov, S. V. Ivanov Proc. 30th Int. Conf. on the Phys. of Semicond. (ICPS2010), Seoul, Korea, 2010 (AIP Conf. Proc. 1399, 1049 (2011))

[2] S. A. Emelyanov Proc. FQMT'11, Prague, 2011 (Phys. Scr. T151, 014012 (2012))

[3] D. Bohm, Wholeness and the Implicate Order (Routledge, London, 1980)

[4] S. A. Emelyanov Proc. Int. Workshop "Spacetime - Matter - Quantum Mechanics" (DICE2012), Castiglioncello, Italy, 2012 (J. Phys.: Conf. Ser. 442, 012035 (2013))

Spin-dependent Landau levels for Λ-type cold atoms in a optically induced gauge field

Bruno Farias[1, 2], Jilvan Lemos[1], and Claúdio Furtado[1]

[1] *Universidade Federal da Paraíba, Cidade Universitária, Joao Pessoa, 58051-970, Brazil*

[2] *Universidade Federal de Campina Grande, Campus Cajazeiras, 58900-000, Brazil*

Ultracold atoms have turned into a powerful experimental platform to study a wide range of condensed matter phenomena, including, e. g., Landau levels and quantum-Hall-like effects [1]. In this respect, the formation of Landau levels requires the generation of an effective magnetic field. These synthetic fields can be implemented for neutral atoms in rotating traps [2] or by using optically induced methods [3]. Interestingly, optically induced arrangements are flexible enough to allow the realization not only of Abelian gauge fields but also non-Abelian gauge fields.

Recently, a plethora of effects for cold atoms subject to synthetic gauge fields have been investigated. In particular, the Landau levels problem have attracted a growing attention [4-6]. In the case of a uniform Abelian magnetic field the single-particle energy spectrum organizes in Landau levels familiar from the quantum mechanics. In contrast, when a non-Abelian term is added to an Abelian gauge field the degeneracy of the Landau levels is broken.

In this work we propose an experimental scheme to observe Landau levels for cold atoms with Λ-level configuration in the presence of an optically induced gauge field. We show that the purely Abelian gauge field breaks the spin degeneracy of the Landau levels in the same way as in the non-Abelian case. In this system the cyclotron frequency is also spin-dependent, a fact which is not observed for other light-induced gauge potential system. Furthermore, the energy spectrum of spin-down component depends explicitly on the transversal momentum, which leads to each Landau level splits into bands.

[1] M. Lewenstein, A. Sanpera, V. Ahufinger, B. Damski, A. Sen De, and U. Sen, Adv. Phys. 56, 243 (2007).

[2] A. L. Fetter, Rev. Mod. Phys. 81, 647 (2009).

[3] J. Ruseckas, G. Juzeliūnas, P. Öhberg, and M. Fleischhauer, Phys. Rev. Lett. 95, 010404 (2005).

[4] Indubala I. Satija, Daniel C. Dakin, J. Y. Vaishnav, and Charles W. Clark, Phys. Rev. A 77, 043410 (2008).

[5] A. Jacob, P. Öhberg, G. Juzeliūnas, and L. Santos, New J. Phys. 10, 045022 (2008).

[6] M. Burrello and A. Trombettoni, Phys. Rev. Lett. 105, 125304 (2010).

P22

Real-time imaging of quantum entanglement

Robert Fickler[1, 2], Mario Krenn[1, 2], Radek Lapkiewicz[1, 2], Sven Ramelow[1, 2], and Anton Zeilinger[1, 2, 3]

[1] *University of Vienna, Blotzmanngasse 5, Vienna 1090, Austria*

[2] *IQOQI Vienna, Austrian Academy of Sciences, Blotzmanngasse 3, Vienna 1090, Austria*

[3] *Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna*

Photonic entanglement of spatial modes is routinely studied in many experiments and offers interesting features for quantum optical and quantum information experiments. To investigate the properties of these complex modes, it is crucial to gain information about the transversal structure with high precision and in an efficient way. We show that modern technology, namely triggered intensified charge coupled device (ICCD) cameras are fast and sensitive enough to image in real-time the effect of the measurement of one photon on the spatial mode of its entangled partner photon. We determine from imaged intensity pattern the number of photons within a certain region, evaluate its error margin and thereby quantitatively verify the non-classicality of the measurements. In addition, the use of the ICCD camera allows us to demonstrate visually the enhanced remote angular sensing and the high flexibility of our setup in creating any desired spatial-mode entanglement [1].

[1] Robert Fickler, Mario Krenn, Radek Lapkiewicz, Sven Ramelow, Anton Zeilinger, Scientific Reports 3, 1914 (2013)

Quantum entanglement of high angular momenta

Robert Fickler[1, 2], Radek Lapkiewicz[1, 2], William N. Plick[1, 2], Mario Krenn[1, 2], Christoph Schaeff[1, 2], Sven Ramelow[1, 2], and Anton Zeilinger[1, 2, 3]

[1] *University of Vienna, Blotzmanngasse 5, Vienna 1090, Austria*

[2] *IQOQI Vienna, Austrian Academy of Sciences, Blotzmanngasse 3, Vienna 1090, Austria*

[3] *Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna*

Orbital angular momentum (OAM) of single photons represents a relatively novel optical degree of freedom for the entanglement of photons [1,2]. One physical realization of OAM carrying light beams are the so called Laguerre-Gaussian modes which have the required helical phase structure. One big advantage over the well known polarization degree of freedom is the possibility of realizing entanglement between two photons with very high quantum numbers and momenta respectively. However, the creation of photonic OAM entanglement by the widely used spontaneous parametric down conversion (SPDC) process is limited by the strongly reduced efficiency for higher momenta. We have realized a novel method to create entanglement between two photons which is not constrained by the SPDC efficiency or conservation law for the OAM degree of freedom. We created and measured the entanglement of two photons with up to $600\hbar$ difference in their angular momentum by transferring the polarization entanglement to the orbital angular momentum degree of freedom within an interferometric scheme [3]. Additionally, we used hybrid entangled biphoton states between polarization and OAM to show the angular resolution enhancement in possible remote sensing applications.

[1] G. Molina-Terriza, J. P. Torres, L Torner, Nature Physics 3, 305 (2007)

[2] A. Mair, A. Vaziri, G. Weihs, A. Zeilinger, Nature 412, 313 (2001)

[3] R. Fickler, R. Lapkiewicz, W.N. Plick, M. Krenn, C. Schaeff, S. Ramelow, A. Zeilinger, Science, 338 (2012)

P24

Spin dynamics in graphene quantum dots

Moritz Fuchs[1], John Schliemann[2], and Björn Trauzettel[1]

[1] *Institut for Theoretical Physics and Astrophysics, University of Wuerzburg, Am Hubland, 97074, Germany*

[2] *Institute for Theoretical Physics, University of Regensburg, D-93040 Regensburg, Germany*

Graphene based quantum dots (QD) constitute interesting systems for both quantum computation and the physics of quantum information [1]. An electron spin confined to such a QD is in contact with a bath of nuclear spins via an anisotropic hyperfine interaction (AHI) [2]. Since in flat graphene the AHI is expected to be the most important interaction of the electron spin with its environment, all spins together form a star-like system with the electron spin in its center. Most interestingly, isotope purification allows to change the ratio of spin carrying ^{13}C with respect spinless ^{12}C and, hence, to control the number N of nuclear spins.

For quantum computation, a minimal N is favorable, which provides improved spin coherence and potentially offers new opportunities such as nuclear spin quantum memories. Moreover, the comparably weak AHI gives rise to long decoherence times and the sufficiency of small external fields, while its anisotropic nature leads to interesting spin dynamics [3].

For the study of quantum information, isotope purification allows for the realization of tunable spin environments in a solid state device, where in principle N can range from 1 to 10^5 for typical QDs. By this means, a quantum-to-classical crossover and an accompanied flow of information from the central (electron) spin to the environment should be observable.

To this end, we study the spin dynamics of small systems containing $N<15$ nuclear spins by exact numerical diagonalization, which reveals the time evolution of all involved spins. By varying certain parameters such as the initial state of the system, the configuration of the nuclei within the QD and the external magnetic field, we aim to identify interesting regimes for both quantum computing and quantum information. Interestingly, we find already for moderate N a (pseudo) relaxation of the central spin to a finite value, which shows a non-trivial dependence on the strength and orientation of the external magnetic field.

[1] B. Trauzettel, D.V. Bulaev, D. Loss, and G. Burkard, Nature Phys. 3, 192 (2007)

[2] J. Fischer, B. Trauzettel, and B. Loss, Phys. Rev. B 80, 155401 (2009)

[3] M. Fuchs, V. Rychkov, and B. Trauzettel, Phys. Rev. B 86, 085301 (2012)

Quantum decay of one and two identical particles

Gaston Garcia-Calderon

Instituto de Física, UNAM, Ciudad Universitaria, México D.F. , 04510, Mexico

An analytical solution to the time evolution of decay of one and two identical noninteracting particles is presented using the formalism of resonant states. It is shown that the time-dependent wave function and hence the survival and nonescape probabilities for the initial state of a single particle and entangled symmetric and antisymmetric initial states of two identical particles evolve in a distinctive form along the exponential and long-time nonexponential decaying regimes. In particular, for the last regime they exhibe different inverse power of time behaviors. The above results are exemplified by considering the s-wave delta-shell potential model.

[1] Gastón García-Calderón, Adv. Quant. Chem. 60, 407 (2010).

[2] Gastón García-Calderón and Luis Guillermo Mendoza-Luna, Phys. Rev. A 84, 032106 (2011).

P26

Dephasing states in two-level open quantum systems

Bartłomiej Gardas and Jerzy Dajka

Institute of Physics, University of Silesia, Bankowa 14, 40-007 Katowice, Poland

It is possible to prepare a composite qubit-environment system so that its time evolution will guarantee the conservation of a preselected qubit's observable. In general, this observable is not associated with a symmetry. The latter may not even be present in the subsystem. The initial states which lead to such a quantity conserved dynamics form a subspace of the qubit–environment space of states. General construction of this subspace is presented and illustrated by two examples. The first one is the exactly solvable Jaynes-Cummings model and the second is the multi-photon Rabi model.

[1] B. Gardas, J. Dajka, J. Phys. A: Math. Theor. 46 235301 (2013)

Dynamics of thermalisation and decoherence of a nanoscale system

Sam Genway[1], Andrew Ho[2], and Derek Lee[3]

[1] *School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, United Kingdom*

[2] *Royal Holloway University of London, Egham, Surrey TW20 0EX, United Kingdom*

[3] *Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom*

We study the decoherence and thermalisation dynamics of a nanoscale system coupled non-perturbatively to a fully quantum mechanical bath. The system is prepared out of equilibrium in a pure state of the complete system. We propose a random matrix model for the subsequent dynamics. We find that the full temporal evolution of the system decays towards a Gibbs ensemble with an initial Gaussian decay followed by an exponential tail. The dynamics of this simple model is consistent with numerical results on small Hubbard-model systems [1].

[1] S. Genway, A. F. Ho and D. K. K. Lee, Phys. Rev. Lett. 105 260402 (2010)

P28

Probing generalised Dicke dynamics in trapped ions through collective quantum jumps

Sam Genway, Weibin Li, and Igor Lesanovsky

School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

Taking inspiration from experiments with cold trapped ions, we propose a non-equilibrium system with a rich phase diagram: a generalised Dicke model with dissipation. We introduce a coupling between the internal ion states an their collective vibrational modes. We demonstrate with numerical simulations and semi-classical descriptions the onset of transitions and phase-coexistence regions not seen in the traditional Dicke model, and show how these may be observed in experiments through photon detection.

Non equilibrium steady state of sparse systems

Daniel Hurowitz

Ben Gurion University of the Negev, Ben Gurion blvd. 84105, Beer Sheva, Israel

We study the steady state of systems that are driven out of equilibrium by a sparse perturbation. Specifically we consider: [1] the energy absorption by a weakly chaotic system due to driving that induces near-neighbor transitions; [2] the current in a ring where the driving induces transitions with rates that are log-wide distributed. In the stochastic case there is an analogy to the physics of percolating glassy systems, and an extension of the fluctuationdissipation phenomenology is proposed. In the mesoscopic case the quantum NESS might differ enormously from the stochastic NESS, with saturation temperature determined by the sparsity. In the case of a ring, detailed balance is broken: An induced current arises, which is controlled by the strength of the driving, and an associated topological term appears in the expression for the energy absorption rate. Due to the sparsity, the crossover from linear response to saturation is mediated by an intermediate regime, where the current is exponentially small in $\sqrt{N}$, which is related to the work of Sinai on "random walk in a random environment".

[1] D. Hurowitz, D. Cohen, EPL 93, 60002 (2011)

[2] D. Hurowitz, S. Rahav, D. Cohen, EPL 98, 20002 (2012)

P30

A map for finding quantum hidden Markovian models

Michael Hush, Juan Garrahan, Igor Lesanovsky, and Andrew Armour

University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

Attaching ancillary systems to markovian systems to generate non-markovian behaviour has been of interests in many fields of physics [1,2], we present the first framework for taking such an approach which establishes precisely what non-markovian evolution can be generated, and how efficiently. We prove that any system which evolves according to a non-markovian master equation which is local in time can be realised as a markovian system with an additional ancillary system. Furthermore we show that this ancilla system is never required to be larger than a two level system. The method is not only constructive, we also determine the precise class of non-markovian evolution that can be generated by coupling a system to an ancilla in general and determine how efficient a physical implementation would be. We apply this framework in the field of non-equilibrium thermodynamics and quantum filtering. Recently it has been shown that biasing quantum jump trajectories using the so-called s-parameter is a useful method to investigate dynamical phase transitions in non-equilibrium thermodynamics [3]. We demonstrate that in certain cases the s-parameter can be implemented as a physical system parameter which can be varied experimentally to induce dynamical phase transitions. In the field of quantum filtering, we prove the converse. Quantum filters can be used to provide a best estimate of the current state of a quantum system given the record from a weak continuous measurement [4]. We demonstrate that it is impossible to efficiently implement a quantum filter with a quantum computer.

[1] H. P. Breuer, Phys. Rev. A 70, 012106 (2004).

[2] J. E. Gough, M. R. James, H. I. Nurdin, and J. Combes, Phys. Rev. A 86, 043819 (2012).

[3] J. P. Garrahan and I. Lesanovsky, Phys. Rev. Lett. 104, 160601 (2010).

[4] H. M. Wiseman and G. J. Milburn, Quantum Measurement and Control (Cambridge, 2010).

Controlling spontaneous-emission noise in measurement-based feedback cooling of a Bose-Einstein Condensate

Michael Hush[1], Stuart Szigeti[2], Andre Carvalho[2], and Joe Hope[2]

[1] *University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom*

[2] *The Australian National University, ACT 0200, Australia*

Bose-Einstein Condensates is set to be the leading platform for simulating quantum fields and precision measurement, the addition of quantum feedback control will provide robust state manipulation which is impossible to match with other techniques. Off-resonant imaging of a condensates is likely to be a key ingredient to developing such feedback, and is also an important tool in its own right [1,2]. A long standing question has been does the spontaneous emission rate induced by off resonant imaging produces a fundamental limit to its applicability. We demonstrate these excitations in the condensate can be entirely damped using a novel feedback control which is tailor made to the measurement being applied. The need for this novel control is multimode in nature as these oscillations are not seen in single particle or mean field models of the same system. Observing these effects was only possible using a number-phase Wigner (NPW) particle filter, which is a hybrid between the leading techniques for simulating non-equilibrium dynamics in condensates and particle filter for simulating high diminutional non gaussian filters in the field of engineering [3-5].

[1] S. S. Szigeti, M. R. Hush, A. R. R. Carvalho, and J. J. Hope, Phys. Rev. A 80, 013614 (2009).

[2] S. S. Szigeti, M. R. Hush, A. R. R. Carvalho, and J. J. Hope, Phys. Rev. A 82, 043632 (2010).

[3] M. R. Hush, A. R. R. Carvalho, and J. J. Hope, Phys. Rev. A 81, 033852 (2010).

[4] M. R. Hush, A. R. R. Carvalho, and J. J. Hope, Phys. Rev. A 85, 023607 (2012).

[5] arXiv:1301.1963

P32

Anomalous excitations and induced-charge in a narrow-gap semiconductor-dot

Ikuzo Kanazawa

Department of Physics,Tokyo Gakugei University, Nukuikitamachi 4-1-1,Koganeishi, Tokyo 184-8501, Japan

Brocke et al. [1] have reported very interesting results in self-assembled quantum dots (SAQD) by resonant inelastic light scattering. They observe excitations, which might be identified as transition of electrons from the s-shell to the p-one (s-p transition) and from the p-shell to the d-one (p-d transition) of the quasi-atoms. Taking into account the effect of Coulomb interactions, they explain the shift and broadening of the s-p transition of collective excitations as additional excitations at lower energies. But the origin of additional excitations is not confirmed so far. Recently the present author [2] has indicated the important of the photo-induced domain-wall in magnetoresistance in diluted magnetic semiconductors. In this study, we will discuss the additional excitations in the quantum dot from collectively induced-charge effects on a domain wall shell around the semiconductor-dot and suggest that one of possible origins of additional excitations might correspond to exotic excitations with fractional charges, extending the previous formula [3] and Callen-Harvey theory [4].

[1] T.Brocke et al., Physica E 22, 478 (2004)

[2] I. Kanazawa, Physica E 40, 277 (2007)

[3] J. Goldstone and F. Wilczek, Phys. Rev. Lett. 47, 986 (1981)

[4] C. G. Callen and J. A. Harvey, Nucl. Phys. B 250, 427 (1985)

Quantized massive collective modes and the short-range spin fluctuations in high-Tc cuprates

Ikuzo Kanazawa and Tomoaki Sasaki

Department of Physics,Tokyo Gakugei University, Nukuikitamachi 4-1-1,Koganeishi, Tokyo 184-8501, Japan

One of the most mysterious and characteristic phenomena in high-Tc cuprates is the so-called pseudogap, which exists well above Tc. The present author [1] proposed that the temperature-evolution of the Fermi arc is strongly related to the restoration of spontaneous symmetry breaking in underdoped cuprates. Furthermore he [2] proposed the evolution mechanism of the Fermi arc with increasing of hole-doping in high-Tc cuprates, from the standpoint of the effect of the quantized massive gauge fields around the hole [3]. Recently Yazdani [4] has suggested that the high-energy (up to about 400 meV) hole-like excitations of the normal state are a direct predictor of the strength of Cooper pairing, although he cannot present a model for the excitations. In this study, we present one model for the high-energy (up to about 400 meV) excitations, which play an important role on the strength of Cooper pairing, and then discuss the characteristic properties of quantized massive gauge fields in high-Tc cuprates.

[1] I. Kanazawa, J. Phys. Chem.Solids 66, 1388 (2005)

[2] I. Kanazawa, Physica C 470, S183 (2010)

[3] I. Kanazawa, J. Phys. A36, 9371 (2003)

[4] A. Yazdani, J. Phys. Condensed Matters 21, 164214 (2009)

P34

Local geometric phase in Aharonov-Bohm loops

Kicheon Kang

Chonnam National University, 300 Yong-Bong-Dong, Gwang-Ju 500-757, Republic of Korea

Quantum state of an Aharonov-Bohm loop will be discussed with particular attention to the local geometric phase. In contrast to the standard viewpoint that the local phase is arbitrary and depends on the choice of gauge, it is shown that the local phase can be fully determined by taking into account the time-reversal symmetry and the Faraday's law of induction [1,2]. It will be shown that the local phase plays a central role in quantum state dynamics by studying some examples of possible flux-switching experiment. Its dynamics is mainly governed by the quantum Faraday effect. Further, I point out that there exists some tension between the standard description of the Aharonov-Bohm effect and the present results.

[1] K. Kang, "Quantum Faraday Effect in Double-Dot Aharonov-Bohm Loop", Europhys. Lett. 99, 17005 (2012).

[2] K. Kang, "Local geometric phase and quantum state tomography in a superconducting qubit", arXiv:1303.7019.

Entanglement in 100 dimensions

Mario Krenn[1, 2], Marcus Huber[3, 4, 5], Robert Fickler[1, 2], Radek Lapkiewicz[1, 2], Sven Ramelow[1, 2], and Anton Zeilinger[1, 2]

[1] *Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria.*

[2] *Institute for Quantum Optics and Quantum Information, Boltzmanngasse 3, A-1090 Vienna, Austria*

[3] *University of Bristol, Department of Mathematics, Bristol BS8 1TW, U.K.*

[4] *ICFO-Institut de Ciencies Fotoniques, E-08860 Castelldefels, Barcelona, Spain*

[5] *Fisica Teorica: Informacio i Fenomens Quantics, Departament de Fisica, Universitat Autonoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain*

Entangled quantum systems have properties that have fundamentally overthrown a classical worldview. Increasing the complexity of entangled states by expanding their dimensionality not only allows the implementation of novel fundamental tests of nature, but also enables genuinely new protocols for quantum information [1].

Spatial modes of photons are a vivid field of research, as they provide a source for high-dimensional entanglement readily available from down-conversion [2-3].

We present an experiment that determines the dimensionality of two-photon entangled state. The photons are created in spontaneous parametric down-conversion, and we use the "full-field" Laguerre-Gauss basis to analyze the photons. To examine high-dimensional entanglement, we develop a novel state-independent entanglement witness. The witness is capable of unambiguously revealing high dimensional entanglement through sub-space correlations.

In the experiment, we analyze a (186*186)-dimensional Hilbert space. With only $\sim$210.000 projective measurements, we were able to demonstrate 100-dimensional entanglement. This result indicates the great potential of high-dimensional entangled systems for various quantum information tasks.

[1] "The angular momentum of light", edited by D.L. Andrews, and M. Babiker (Cambridge University Press, New York, 2013).

[2] A. Vaziri, G. Weihs, and A. Zeilinger, "Experimental Two-Photon, Three-Dimensional Entanglement for Quantum Communication", Phys. Rev. Lett. 89, 240401 (2002).

[3] V. D. Salakhutdinov, E. R. Eliel, and W. Löffler, "Full-Field Quantum Correlations of Spatially Entangled Photons", Phys. Rev. Lett. 108, 173604 (2012).

P36

Spin chain under pulse conditions as quantum data channel

Mikhail Kucherov and Evgeniy Perederiy

Siberian Federal University, Kirensky st., 26, Krasnoyarsk, 660074, Russian Federation

The ability to increase entanglement via transport of quantum correlations across a spin chain does not require macroscopic transport of the polarization. It should be possible to prepare a sample more rapidly to transferring spin coherence with entangled quantum correlations. The quantum channel consists of N spin-$\frac{1}{2}$ particles placed at sites 1 to N of a one-dimensional lattice and interacting through the truncated coupling Hamiltonian

$$H_{int} = \sum_{i=1}^{N} b(I_i^x I_{i+1}^x + I_i^y I_{i+1}^y + \zeta I_i^z I_{i+1}^z),$$

where $\zeta = -2$ for dipolar coupling, $+1$ for Heisenberg coupling, etc. The last zz-coupling term is equivalent to that of an overall uniform magnetic field applied everywhere but at end-points; which implies that dynamics still remains restricted to the zero- and single-exitation sectors of the total Hilbert space. After short$(\pi/2)_y$ pulse of magnetic field, the maximal concurrence C_r between two spins sitting on sites i and j reads [1,2]:

$$C_r = 0.5 \max\{0, C_r^{'}, C_r^{''}\},\ C_r^{'} = K_r^{yy} + K_r^{zz} - \sqrt{(1 + K_r^{xx})^2 - (K_i^x + K_j^x)^2},$$

$$C_r^{''} = K_i^x + K_j^x + K_r^{xx} - 1,$$

where $r = |i - j|$, $K_r^{xx} = \langle I_i^x I_j^x \rangle$ - spin correlation functions, and $K_{i,j}^x = \langle I_{i,j}^x \rangle$ - spin expectation values. We compute numerically the concurrence between initial and some other spins vs. parameter ζ in an array of 100 spins at zero temperature. In series on transverse interactions we discard the terms leading to the changes in z-components while retaining the terms in which transverse interactions lead to correlations between the x-components of neighboring spins. The condition $|\zeta| > 1$ suggests that the nonstationary state, after the pulse which affects the initial spin of lattice, remains in practice exponentially localized over a length $d = \max\{1, 1/\ln(|\zeta|)\}$, and the dynamics may be described by classical system of N first order ODEs for one-quantum coherences [3]. Comparison is made with entanglement resulting in the one-magnon model. Accounting for this effect allows us to get a higher value of quantum correlations that is sent in the spin channel.

[1] U. Glaser, H. Büttner, and H. Fehske, Phys. Rev. A 68 (2003) 032318.

[2] M. Kutcherov, in *Proc. SPIE 7023, Quantum Informatics 2007*, edited by Yu. I. Ozhigov (2008) 70230E.

[3] A. Wokaun, G. Bodenhausen, and R. Ernst in *Principles of N.M.R. in One and Two Dimensions* (Oxford University Press, USA, 1990), Chap. 2.

Cross-relaxation dynamics in isolated spin system after pulse of magnetic field

Evgeniy Perederiy and Mikhail Kucherov

Siberian Federal University, Institute of Space and Information Technology, 26, Kirensky st., Krasnoyarsk, 660074, Russian Federation

Quantum XXZ Heisenberg spin system exhibits long-time periodic dynamics far aside from ergodic behavior. We begin with isolated spin systems, where some of their many-body eigenstates are localized. The method for predicting the cross-relaxation rates in solid state NMR assumes that the Hamiltonian can be written as $H(t) = H_0 + V(t)$. The perturbing term $V(t)$ causes slow evolution of the local integrals of motion toward their equilibrium values. The Hamiltonian of the spin system immersed in a large external magnetic field can be written as

$$H(t) = H_Z + H_M + H_I,$$

where H_Z, H_M, and H_I denote the Zeeman, intramolecular, and intermolecular Hamiltonian. The parts of H_M and H_I, which are nonsecular with respect to H_Z, are neglected. The spin system can be seen as an assembly of small spin clusters [1,2]. By analogy with the treatment of a system with Zeeman and dipolar population only, we consider H_M as an unperturbed Hamiltonian while the small perturbing term H_I plays a role similar to the dipolar Hamiltonian. Then we can neglect the part of H_I nonsecular with respect to H_M. It restricts our calculations to those in which the splitting of absorption lines is much larger than the width of each line. Using the techniques of spin thermodynamics in solids [3] we obtain the mixing rate

$$W \sim \int_0^\infty \mathrm{Tr}\{[H_M, V][\tilde{V}(t), H_M]\}\mathrm{d}t, \tag{1}$$

where $V = H_I - (H_I)^{\mathrm{secular}/M}$, and $\tilde{V}(t) = \exp(iH_M t)V\exp(-iH_M t)$.

Now let's consider a generic many-body localized spin system. We simulate the localization by adding a random magnetic field in the z-direction [4]. We can describe the evolution from the initial state which is rotated in the transverse plane, and estimate the long-time decay rate of coherent multi-spin states. The mixing rate should match (1) in the limiting case of spin pairs. The connection between quantum chaos and nonequilibrium thermodynamics is considered.

[1] H. Eisendrath, W. Stone, and J. Jeener, Phys. Rev. B, 17 (1978) 47.

[2] M. Kucherov, A. Blyumenfeld, Fiz. Tverdogo Tela, 18 (1976) 2838.

[3] M. Goldman in *Spin Temperature and N.M.R. in Solids* (Clarendon Press, 1970), Chap. 6.

[4] E. Canovi, D. Rossini, R. Fazio, et al., Phys. Rev. B, 83 (2011) 094431.

P38

Thermodynamics of periodically driven integrable quantum systems

Achilleas Lazarides[1], Arnab Das[1, 2], and Roderich Moessner[1]

[1]*Max Planck Institute for the Physics of Complex Systems, Dresden, Germany*

[2]*Indian Assoc. for the Cultivation of Science, Kolkata (Calcutta), India*

We analytically show that the long-time steady-state behaviour of a periodically driven quantum system is well described by the maximum entropy approach first proposed by Jaynes and more recently applied to integrable quantum systems. This result implies that the notion of thermalization survives in this far from equilibrium situation.

Quantum refrigerators and the third law of thermodynamics

Amikam Levy[1], Robert Ailicki[2], and Ronnie Kosloff[1]

[1] *Fritz Haber Center, The Hebrew University of Jerusalem, Edmund J. Safra Campus, Givat Ram, Jerusalem 91904, Israel*

[2] *Institute of Theoretical Physics and Astrophysics, University of Gdańsk, Wita Stwosza 57, PL 80-952 Gdańsk, Poland*

The rate of temperature decrease of a cooled quantum bath is studied as its temperature is reduced to the absolute zero. The third law of thermodynamics is then quantified dynamically by evaluating the characteristic exponent ζ of the cooling process $\frac{dT(t)}{dt} \sim -T^{\zeta}$ when approaching the absolute zero, $T \to 0$. A continuous model of a quantum refrigerator is employed consisting of a working medium composed either by two coupled harmonic oscillators or two coupled two-level systems.

The refrigerator is a nonlinear device merging three currents from three heat baths: a cold bath to be cooled, a hot bath as an entropy sink, and a driving bath which is the source of cooling power. A heat/noise driven refrigerator (absorption refrigerator) is compared to a power driven refrigerator. When optimized both cases lead to the same exponent ζ, showing a lack of dependence on the form of the working medium and the characteristics of the drivers. The characteristic exponent is therefore determined by the properties of the cold reservoir and its interaction with the system. Two generic heat baths models are considered, a bath composed of harmonic oscillators and a bath composed from ideal Bose/Fermi gas.

[1] A. Levy and R. Kosloff, Phys. Rev. Lett. 108 07604 (2012)

[2] A. Levy, R. Alicki and R. Kosloff, Phys. Rev. E 85 061126 (2012)

[3] A. Levy, R. Alicki and R. Kosloff, Phys. Rev. Lett. 109, 248901 (2012)

P40

Damping of mechanical vibrations in mesoscopic resonators

Ze'ev Lindenfeld, Eli Eisenberg, and Ron Lifshitz

Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel

We study the damping of externally excited vibrations in two finite-size mesoscopic resonators [1] — metallic nanomechanical beams and semiconducting atomic chains. We examine the damping of vibrations in metallic nanobeams due to electron-phonon interaction [2], and in atomic chains due to phonon-phonon interaction in the presence of mechanical coupling to an outer environment [3]. In both systems the baths with which the excited mode interacts (the electrons of the metallic beam or the phonons of the atomic chain), as well as the interaction Hamiltonian itself, are modified by the finite size of the systems. This leads to deviation from bulk-like damping and to sensitivity to changes in different parameters.

We find that electron-phonon interaction significantly affects the quality factors of longitudinal modes, and may also be of significance to the damping of flexural modes in otherwise high-quality factor nanomechanical beams. The finite geometry of the beam is manifested both in introducing imperfect momentum conservation and in introducing a temperature scale that is determined by the width of the beam. At low temperatures compared to this scale damping is dominated by a few dissipation channels, and is thus strongly sensitive to variations in parameters such as temperature, Fermi energy, beam geometry, mode number, etc. At high temperatures bulk-like behavior is recovered.

In the atomic chain we consider the decay of the excited mode, at zero temperature, into phonons of the finite chain that are broadened by the weak coupling to the environment. The approximately discrete nature of the phonons results in an absence of energy conservation in most decay processes, which leads to weak phonon-mediated damping for most modes. However, for certain modes a decay process that approximately conserves energy is possible, which leads to strong phonon-mediated damping. The approximately discrete nature of the phonons also leads to high sensitivity of the damping to changes in the parameters that characterize the atomic chain and the excited mode.

[1] Ze'ev Lindenfeld, Ph.D. Thesis (Tel Aviv University, 2013) submitted.
[2] Ze'ev Lindenfeld and Ron Lifshitz, Phys. Rev. B 87, 085448 (2013).
[3] Ze'ev Lindenfeld, Eli Eisenberg, and Ron Lifshitz, (2013) in preparation.

On the possibility of electron pairing in small metallic nanoparticles

Ze'ev Lindenfeld, Eli Eisenberg, and Ron Lifshitz

Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel

We investigate the possibility of phonon mediated electron pairing in isolated metallic approximately spherical nanoparticles containing a few hundred atoms at zero temperature [1]. In these particles both phonons and electrons are mesoscopic, i.e. modified by finite size effects. In particular, the electrons of such particles exhibit an energy shell structure, which is modified due to deviations from spherical symmetry. We derive the electron-phonon interaction within the particles and from it the phonon-mediated electron-electron interaction. The Coulomb interaction between the electrons is also calculated. We evaluate the modifications in the electronic spectrum due to the combined effect of pairing and Coulomb interactions.

We find that the phonon-mediated interaction is highly anisotropic and significantly affected by deformations of the spherical particles. Furthermore, the inclusion of Coulomb interaction results in an average interaction that is usually repulsive. Nevertheless, due to the existence of an approximate electronic shell structure and the anisotropy of the interaction, it is possible to find a solution to the BCS gap equations that results in a paired ground state with lower electronic energy compared to the unpaired electronic ground state. The resulting lowest excitation energies are much larger than the bulk energy gap, and form an intermediate energy scale between the electronic inter-shell energy spacing and the electronic intra-shell energy splitting.

[1] Ze'ev Lindenfeld, Eli Eisenberg, and Ron Lifshitz, Phys. Rev. B 84, 064532 (2011).

P42

Realization of a photonic micro-macro entangled state

Anthony Martin, Natalia Bruno, Pavel Sekatski, Nicolas Sangouard, Rob Thew, and Nicolas Gisin

Gap Optic, University of Geneva, Chemin de Pinchat 22, CH-1211 Genève 4, Switzerland

Quantum theory has historically been presented as the theory describing the microscopic world. However, the technological progress of the last decades allows us to experimentally test the theory in different regimes. Many questions can be raised at this point, e.g. whether quantum mechanics applies at any scale, and what is the meaning of “macroscopic”. We experimentally demonstrate the presence of entanglement in a system involving states of light that can be efficiently distinguished using “classical detectors”, i.e. detectors that only resolve large photon number differences. We start generating heralded single photon entanglement between two spatially separated optical modes and subsequently displace one of these modes towards the macroscopic domain. The fact that the resulting entangled state involves a number of photons large enough to be easily seen by the naked eye (provided that the wavelength is in the visible spectrum) make it analogous to an optical Schrödinger cat state. A final displacement back to the single photon regime allows us to experimentally set a lower bound on the concurrence (a measure of entanglement) [1-3]. Our results highlight the idea that although observing macroscopic entanglement with coarse-grained measurements is very challenging, the creation of quantum macro systems can be straightforward. This suggests that quantumness is a concept that extends into our macroscopic world and provides us with renewed motivation to look for quantum effects in Nature.

[1] P. Sekatski, N. Sangouard, M. Stobińska, F. Bussières, M. Afzelius, and N. Gisin, Phys. Rev. A, vol. 86, 060301 (2012).

[2] N. Bruno, A. Martin, P. Sekatski, N. Sangouard, R. T. Thew, and N. Gisin, arXiv:1212.3710 [quant-ph] (2012).

[3] A. I. Lvovsky, R. Ghobadi, C. Simon, A. Chandra, A. S. Prasad, arXiv:1212.3713 [quant-ph] (2012).

Heralded single photon amplifier

Anthony Martin, Natalia Bruno, Rob Thew, and Nicolas Gisin

Gap Optic, University of Geneva, Chemin de Pinchat 22, CH-1211 Genève 4, Switzerland

Device-independent quantum key distribution (DI-QKD) is extremely demanding and, in practice, fundamentally limited by losses. A way to overcome this problem consists of employing a heralded amplifier [1]. This protocol is based on relay configuration experiment where an ancillary photon is mixed with the photon of interest. A herald photon announces that the teleportation has been successful. The protocol depends on the ability to vary the ancilla photon's transmission in the amplifier, thereby increasing the probability of heralding the presence of one photon at the amplifier output. Several experiments have proven the feasibility of this approach [2-4] although only with a low gain ($\sim$5). Our aim was to test the limitation of this approach, and we have been able to demonstrate a gain greater than 100. We have also demonstrated that our setup is able to herald the presence of one photon with a probability greater than 83%, which corresponds to the limit for the DI-QKD protocol, for an input loss up to 90% (i.e. $\sim$40 km). Heralded photon amplifiers, such as this, clearly represent a key technology for the realization of DI-QKD in the real world and over typical network distances.

[1] N. Gisin, S. Pironio, and N. Sangouard, "Proposal for Implementing Device-Independent Quantum Key Distribution Based on a Heralded Qubit Amplifier," Phys. Rev. Lett., vol. 105, no. 7, pp. 1-4, Aug. 2010.

[2] S. Kocsis, G. Y. Xiang, T. C. Ralph, and G. J. Pryde, "Heralded noiseless amplification of a photon polarization qubit," Nat. Phys., vol. 9, no. 1, pp. 23-28, Nov. 2012.

[3] C. Osorio, N. Bruno, N. Sangouard, H. Zbinden, N. Gisin, and R. Thew, "Heralded photon amplification for quantum communication," Phys. Rev. A, vol. 86, no. 2, 023815, Aug. 2012.

[4] G. Y. Xiang, T. C. Ralph, A. P. Lund, N. Walk, and G. J. Pryde, "Heralded noiseless linear amplification and distillation of entanglement," Nat. Photon., vol. 4, no. 5, pp. 316-319, Mar. 2010.

P44

Measuring the characteristic function of work distribution

Laura Mazzola, Gabriele De Chiara, and Mauro Paternostro

Queen's University Belfast, David Bates Building, BT7 1NN, Belfast, United Kingdom

We propose a scheme to detect the characteristic function of the work distribution associated to a time-dependent process experienced by a generic quantum system. Our scheme uses an interferometric setting relying on measurement of an ancillary qubit. An appropriate conditional system-ancilla interaction allows to retrieve entirely the characteristic function of work of the system, by mapping it onto the populations and coherences of the ancilla. We identify how the configuration of the effective interferometer is linked to the symmetries enjoyed by the Hamiltonian ruling the process and provide the explicit form of the operations to implement in order to accomplish our task.

Non-Markovian dynamics of open quantum systems subjected to colored noise

Sithi Muniandy

University of Malaya, Department of Physics, Kuala Lumpur 50603, Kuala Lumpur, Malaysia

The emergence of classical behavior from quantum system due to decoherence induced by the environment has been the focus of many studies based on different approaches. Real open quantum systems interacting with reservoir with memory effects are expected to exhibit non-Markovian evolution characteristics. In this paper, we examined the dissipative dynamics of a quantum Brownian motion subjected to colored noise, parameterized by system-reservoir coupling strength and spectral density of the reservoir. The behavior of the decay rates at different conditions is described.

P46

Violation of Cauchy-Schwarz inequalities by spontaneous Hawking radiation in BEC

Juan Ramón Muñoz, Fernando Sols, and Ivar Zapata

Departamento de Física de Materiales, Universidad Complutense de Madrid, Ciudad Universitaria 28040, Madrid, Spain

The violation of a classical Cauchy-Schwarz (CS) inequality is identified as an unequivocal signature of spontaneous Hawking radiation in sonic black holes. This violation can be particularly large near the peaks in the radiation spectrum emitted from a resonant boson structure forming a sonic horizon. As a function of the frequency-dependent Hawking radiation intensity, we analyze the degree of CS violation and the maximum violation temperature for a double barrier structure separating two regions of subsonic and supersonic condensate flow. We also consider the case where the resonant sonic horizon is produced by a space-dependent contact interaction. In some cases, CS violation can be observed by direct atom counting in a time-of-flight experiment. We show that near the conventional zero-frequency radiation peak, the decisive CS violation cannot occur.

Motional entanglement with trapped ions and a nanomechanical resonator

Fernando Nicacio[1, 2], Kyoko Furuya[2], and Fernando Semião[1]

[1] *UFABC, Av. dos Estados, 5001. Santo André, Brazil*

[2] *UNICAMP, Av. Sergio Buarque de Holanda, 777. Campinas, Brazil*

We study the entangling power of a nanoelectromechanical system (NEMS) simultaneously interacting with two separately trapped ions. To highlight this entangling capability, we consider a special regime where the ion-ion coupling does not generate entanglement in the system, and any resulting entanglement will be the result of the NEMS acting as an entangling device. We study the dynamical behavior of the bipartite NEMS-induced ion-ion entanglement as well as the tripartite entanglement of the whole system (ions+NEMS). We found some quite remarkable phenomena in this hybrid system. For instance, the two trapped ions initially uncorrelated and prepared in coherent states can become entangled by interacting with a nanoelectromechanical resonator (also prepared in a coherent state) as soon as the ion-NEMS coupling achieve a certain value, and this can be controlled by external voltage gate on the NEMS device. By considering the NEMS in an initial thermal state, we numerically show that there is not a temperature threshold above which bipartite ion-ion entanglement ceases. A distinct effect occurs when the NEMS interacts with a thermal reservoir, above a certain value of temperature, the NEMS induction of ion-ion entanglement ceases. We also show that tripartite entanglement presents a more pronounced robustness against the destructive effects of dissipation when compared to the bipartite content.

P48

Theory of single-Josephson-junction-based microwave amplifier

Tomáš Novotný

DCMP, Faculty of Mathematics and Physics, Charles University in Prague, Ke Karlovu 5, 121 16 Praha 2, Czech Republic

I will present a theory describing the recently proposed and realized microwave amplifier based on the negative resistance of a selectively damped Josephson junction [1]. The theory uses the standard linear expansion around the limit cycle and its results are in excellent agreement with the measured as well as simulated gain characteristics of the device. However, the noise temperature calculated within the well-established Gaussian approximation scheme appears to fail to describe the simulations and measurement even qualitatively. I will conjecture the probable reason for the unexpected failure and outline a possible correcting direction. I will also sketch the prospects of semi-analytical approaches and possibilities of optimization of the devices based on the presented theory and its extensions.

[1] P. Lahteenmaki et al., Sci. Rep. 2, 276 (2012)

Ejection fraction of O stars as a function of star cluster mass

Pavel Kroupa and Seungkyung Oh

Argelander Institute for Astronomy (AIfA), University of Bonn, Auf dem Huegel 71, D-53121 Bonn, Germany

Massive stars are effectively shot out from young star clusters by the dynamical ejection process. Here, we study how the ejection fraction of O stars varies with cluster mass using direct N-body calculations. The binary-rich clusters have initially a Kroupa-1995 period distribution function for the O stars. We find that the ejection fraction of O stars exhibits a significant maximum at a cluster mass of 3000 Msun, even though the number of ejected O stars increases with cluster mass. Up to on average 25 per cent of all O stars can be ejected physically from their binary-rich birth clusters, while for clusters with single-O stars only, the ejection fractions are typically reduced by up to a factor of two. Individual clusters with M<3000 Msun can expel more than 80 per cent of their initial O star content. The binary fraction among ejected O stars decreases with cluster mass, but can be substantial. The fraction of ejected O stars and the binary fraction thereof would be larger still for a harder initial binary period distribution function. Our results are in good agreement with the expectation which can be derived from a binary–single star scattering rate.

P50

Entanglement of ultracold atoms in an optical cavity

Krzysztof Pawlowski, Jerome Esteve, Jacob Reichel, and Alice Sinatra

Laboratoire Kastler Brossel, Ecole Normale Superieure, 24, rue Lhomond, 75231 Paris, France

We discuss theoretically schemes to create useful entanglement in an ensemble of atoms trapped inside an optical cavity and interacting with a cavity mode. We consider two schemes: the pulsed scheme analyzed in [1] and a second scheme, where the cavity is continuously pumped with a coherent field. We study fundamental limits of the schemes and determine analytically the scaling of the squeezing after optimization over the squeezing time. We discuss the results in the light of possible experiments.

[1] I. D. Leroux, M. H. Schleier-Smith, H. Zhang, and V. Vuletic, Phys. Rev. A 85, 013803 (2012)

Non-relativistic quantum motion as differentiable random process (Košťál's version of stochastic mechanics)

Bohuslav Rudolf

NBÚ, Jerevanská 2588, Kladno 272 01, Czech Republic

We present description of the non-relativistic quantum motion of the particles, which is based on differentiable random process. Our work is closely related with the well-known (Nelsonian) stochastic mechanics. We also regard the non-relativistic quantum motion as stochastic process, but the trajectories of particles are doubly differentiable in our model. And we also make reasoning for validity of the Schrödinger equation, but we do not introduce any forward and backward components of the motion. Our reasoning starts with kinematical equations for the doubly differentiable random process. Then we tried to add the dynamical equation. Our main heuristic step was requirement that it express the mean conditional acceleration with some polynomial in space partial derivatives of the probability density. Our other requirements for the free particle motion has the physical meaning. We use: the measurement model, group of symmetry and stochasticity. We also introduce some rule for cutting of the polynomial. The generalization of the obtained equations for the motion in some deterministic field is straightforward. We do not regard our model as the fundamental theory of the quantum phenomena. We understand it as plausible approximative description only.

email: b.rudolf@centrum.cz

[1] F. J. Belinfante: A Survey of Hidden Variables Theories, Perg. Press, 1973

[2] E. Nelson: Phys. Rev. 150, 4, 1966

[3] K. Košťál: Czech. Math. Journ. 17, 92, 53, 1967

[4] K. Košťál: Diff. Random process as model of the particles motion, Res. Rep., CTU, 1974, in Czech

[5] K. Košťál: Stoch. Mech. B. on diff. Random funct., in: Sel. Topics in QFT and Math. Phys., Singapore 1990

[6] K. Košťál, B. Rudolf: Non-linear models in quantum phys., in Workshop CTU 1992

[7] B. Rudolf: Stoch. Mech. of Differentiable Random processes, Thesis, 1992

P52

Work distribution in a time-dependent logarithmic–harmonic potential: Exact results and asymptotic analysis

Artem Ryabov[1], Marcel Dierl[2], Petr Chvosta[1], Mario Einax[2], Philipp Maass[2], and Viktor Holubec[1]

[1] *Charles University in Prague, Faculty of Mathematics and Physics, Department of Macromolecular Physics, V Holesovickach 2, Prague, 180 00, Czech Republic*

[2] *Fachbereich Physik, Universitat Osnabruck, Barbarastrasse 7, D-49076 Osnabruck, Germany*

We investigate the distribution of work performed on a Brownian particle in a time-ependent asymmetric potential well. The potential has a harmonic component with a time-dependent force constant and a time-independent logarithmic barrier at the origin. For an arbitrary driving protocol, the problem of solving the Fokker-Planck equation for the joint probability density of work and particle position is reduced to the solution of the Riccati differential equation. For a particular choice of the driving protocol, an exact solution of the Riccati equation is presented. An asymptotic analysis of the resulting expression yields the tail behavior of the work distribution for small and large work values. In the limit of a vanishing logarithmic barrier, the work distribution for the breathing parabola model is obtained.

Quantum phase slips and persistent current noise in superconducting rings

Andrey Semenov[1] and Andrei Zaikin[1, 2]

[1] *I.E.Tamm Department of Theoretical Physics, P.N.Lebedev Physics Institute, 119991 Moscow, Russia*

[2] *Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), 76021 Karlsruhe, Germany*

Fluctuations of the superconducting order parameter may strongly modify the ground state properties of superconducting nanorings giving rise to qualitatively new phenomena in such systems. As a result of such fluctuations, superconductivity may be temporarily disrupted in various parts of the ring and the magnetic flux inside the ring undergoes virtual transitions between the states with different number of flux quanta. At low temperatures the most relevant fluctuations are coherent quantum phase slips (QPS) [1,2]. Such QPS (i) reduce the magnitude of superconducting persistent current (SPC) which becomes exponentially small at ring perimeters L exceeding some fundamental length [1] and (ii) modify the periodic flux dependence of SPC from the saw-tooth form to the sinusoidal one.

QPS can also induce the SPC noise which is the main subject of our present work. In order to analyze the SPC noise we derive the general effective action for superconducting nanorings in presence of QPS and show that the resulting effective theory is of a sine-Gordon type on torus with special boundary conditions. We demonstrate that in small perimeter rings interactions between different QPS can be neglected and our effective theory reduces to that for a quantum particle on the ring in a cosine potential [3]. In this case the SPC noise frequency spectrum consists of a set of sharp peaks which can be tuned by an external magnetic flux piercing the ring. In contrast, in rings with bigger perimeters QPS interactions become crucially important and yield considerable SPC noise reduction in the limit of large L.

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

[2] O.V. Astafiev et al., Nature 484, 355 (2012)

[3] A.G. Semenov and A.D. Zaikin, J. Phys.: Condens. Matter 22, 485302 (2010)

P54

Coupled quantum Otto cycle and friction

George Thomas and Ramandeep Singh Johal

Department of Physical Sciences, Indian Institute of Science Education and Research Mohali, Knowledge City, Sector 81, SAS Nagar, Manauli P.O. 140306, India.

Models of quantum thermodynamic machines are novel tools to study the thermodynamic properties of quantum systems. We study two spin-half systems with one-dimensional isotropic Heisenberg Hamiltonian, as the working medium for quantum Otto cycle [1]. First we assume that quantum adiabatic theorem holds along the adiabatic branches. In the four-step cycle, the adiabatic processes are done by changing the external magnetic field keeping the coupling constant fixed. We find the criterion when efficiency of the coupled model is higher than the uncoupled case. An upper bound for efficiency is derived which is tighter than the Carnot bound. The corresponding four-step cycle of the individual spins is studied using reduced density matrix. Locally it appears that spins cause a flow of heat opposite to the global temperature gradient. This effect has been recently observed in other heat cycles also [2]. This counter-intuitive behavior is explained with aid of local effective temperatures. Then we study the cycle when finite time is allocated to the adiabatic branches. An interesting phenomenon observed in certain models of finite-time heat engines is the friction [3], which arises due to non-commutativity of internal and external Hamiltonians. We find a novel mechanism for friction in our model [4]. We study entropy production and work obtained per cycle in the finite time case. The extreme limit of a sudden adiabatic process where the density matrix remains unchanged, is also investigated.

[1] G. Thomas and R. S. Johal, Phys. Rev. E 83, 031135 (2011).

[2] X. L. Huang, L. C. Wang, and X. X. Yi, Phys. Rev. E 87, 012144 (2013).

[3] R. Kosloff and T. Feldmann, Phys. Rev. E 65, 055102(R) (2002).

[4] G. Thomas and R. S. Johal (2013) - under preparation.

Experimental determination of conduction channels in atomic scale conductors based on shot noise measurements

Ran Vardimon, Marina Klionsky, and Oren Tal

Weizmann Institute of Science, Rehovot 76100, Israel

We present an experimental procedure for obtaining the conduction channels of low-dimensional conductors based on shot noise measurements. The transmission coefficient for each channel is determined numerically from the measured conductance and Fano factor. The channel analysis is demonstrated for atomic contacts of Ag, Au, Al and Pt, showing their channel evolution as a function of conductance and mechanical elongation. This approach can be readily applied to map the conduction channels in a wide range of nanoscale conductors under different conditions.

P56

Non-adiabatic spin orbit torques in magnetic semiconductors

Liviu Zarbo

Institute of Physics ASCR, Cukrovarnicka 10 CZ-162 00, Praha, Czech Republic

The presence of spin-orbit coupling in uniform magnetic materials allows for the electrical generation of nonequilibrium spin polarization of the carriers which couples magnetically to the magnetization, thus generating a spin-orbit torque (SOT). This is to be contrasted to the standard spin transfer torque device which needs a extra magnetic spin polarizing layer to achieve this effect. There are two types of SOT. One is the adiabatic torque which originates in carrier redistribution by electric field on the Fermi surface. The other is the nonadiabatic torque due to the polarization of the carrier wave function in electric field. We calculate this second contribution magnetic semiconductors and show that it has an intrinsic origin, i.e. is disorder independent. We show that the symmetry properties of SOT measured in experiments on (Ga,Mn)As are consistent with the intrinsic SOT.

Elementary phase slip processes in φ Josephson junctions

Martin Žonda and Tomáš Novotný

Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, Praha 2, 121 16, Czech Republic

Modern unconventional Josephson junctions (JJ), can have a current-phase relation $I(\phi) = I_1 \sin\phi + I_2 \sin 2\phi$ where the second harmonic I_2 plays an important role. Typical example of such systems are ϕ junctions, where the second harmonics is negative. We numerically study the influence of the negative second harmonic on the phase dynamics and voltage noise of JJs within the resistively and capacitively shunted junction (RCSJ) model. We evaluate the noise as well as the full counting statistics of the phase dynamics by the matrix continued fraction method. The analysis of the results enables us to identify the various components contributing to the overall noise such as the thermal noise close to equilibrium (small current-bias regime), switching noise for higher biases and the shot noise of (multiple) phase slips in the intermediate range of biases. We focus on the phase-slips regime, characterized by the plateau in the Fano factor (voltage noise normalized by the mean voltage) as a function of the current bias, in more detail. Depending on the relative importance of the first (I_1) and second (I_2) harmonic, we observe the crossover from the unitary Fano factor corresponding to elementary 2π phase slips to the Fano factor value of one half revealing the fractional phase slips just by π. These findings are further supported by the analysis of the full counting statistics also exhibiting the presence of fractional phase slips via the non-trivial analytical properties of the cumulant generating function.

Author Index

A

Aaronson S., 169
Acín A., 43, 88
Aguilar G., 52
Aharony A., 161
Ailicki R., 225
Akkermans E., 33
Ala-Nissila T., 117
Alhassid Y., 34
Allen R., 35, 175
Almeida F., 110
Alvermann A., 177, 187
Anders F., 36
Anghel D., 37
Ankerhold J., 38, 156
Antezza M., 39
Apollaro T., 188
Ariunbold G., 77
Armour A., 216
Arndt M., 85
Arrachea L., 40
Artamonov A., 189
Artamonov M., 145
Ashwell B., 145
Austin B., 41
Avella A., 78
Averin D., 117
Avriller R., 163
Axelsson E., 190
Azema J., 191

B

Baer R., 119
Bagrets A., 182
Bakemeier L., 177
Bakke K., 178
Balian R., 42
Bancal J., 43
Barnett S., 162
Bauer F., 166
Bednorz A., 44, 192
Belzig W., 44, 192
Benenti G., 179
Berakdar J., 180
Berger J., 193, 194
Berkovitz A., 154
Beyer A., 45
Bhattacharya S., 195
Biggio M., 204
Blanter Y., 46
Blencowe M., 47
Blumkin A., 154
Borkje K., 196
Borowsky D., 166
Bouwmeester D., 48
Boviatsis J., 197
Brantut J., 49
Bretheau L., 128
Brida G., 78
Bronold F., 50
Broome M., 169
Brune M., 51
Bruno N., 228, 229
Bruognolo B., 166

C

Cai J., 132
Caldeira A., 52
Campisi M., 53, 176
Carmichael H., 54
Carr S., 55, 147
Carvalho A., 217
Cavalcanti V., 110
Cavaliere F., 204
Cetto A., 56, 63
Charpentier C., 120
Chekhova M., 78
Chen M., 198
Chevy F., 57
Chiao R., 58
Choi H., 59
Chvosta P., 238

Ciobanu N., 199, 200
Cleland A., 60
Cohen D., 61
Colbeck R., 149
Cornelio M., 52
Courtois H., 68
Cresser J., 201
Crivelli D., 202
Cuevas J., 62

D
da Luz M., 143
Dajka J., 202, 212
Dalton B., 203
Daré A., 191
D'Arrigo A., 67, 123, 179
Das A., 224
De Chiara G., 230
de la Pena L., 56, 63
de Oliveira M., 52
De Raedt H., 64, 115
de Wijn A., 71
Devereaux T., 72
Di Stefano P., 67
Dierl M., 238
Dolcetto G., 204
Dörre N., 85
Dotsenko I., 51
Douçot B., 68
Dove J., 169
Duarte P., 90
Dzhafarov E., 205

E
Einax M., 238
Eisenberg E., 226, 227
Eisert J., 65
Elsayed T., 71
Emelyanov S., 206
Ensslin K., 120
Entin-Wohlman O., 161
Eremeev V., 200
Esslinger T., 49
Esteve D., 128
Esteve J., 236
Evers F., 66, 182

F
Facer C., 201
Falci G., 67, 123, 179
Fanchini F., 52
Farias B., 207
Fazio R., 76, 159
Fedrizzi A., 169
Fehske H., 50, 177
Feinberg D., 68
Fejer M., 137
Ferry D., 69
Fertig H., 147
Fickler R., 208, 209, 221
Filip R., 70, 134
Fine B., 71
Freericks J., 72
Frejsel A., 108
Frerot I., 52
Fuchs M., 210
Furtado C., 178, 207
Furusawa A., 70
Furuya K., 233
Fussy S., 79

G
Galperin M., 73
Garcia-Calderon G., 211
Gardas B., 212
Garrahan J., 216
Ge S., 198
Gefen Y., 74, 133
Genovese M., 78
Genway S., 213, 214
Gerlich S., 51
Ghosh A., 75
Gibertini M., 159
Gilbreth C., 34
Giovannetti V., 76
Girit Ç., 128
Gisin N., 43, 137, 228, 229
Gleyzes S., 51
Golubjeva O., 189
Gord J., 124

Gordon C., 154
Gramegna M., 78
Gramich V., 38
Groessing G., 79
Gschösser B., 167
Guerreiro T., 137
Gull E., 80
Gurvitz S., 81
Gust E., 131

H

Hall M., 82
Han J., 83
Hänggi P., 84, 109
Hänsch T., 45
Haroche S., 29, 51
Hart R., 90
Haslinger P., 85
Hekking F., 86
Heyder J., 166
Hilfer R., 87
Ho A., 213
Holubec V., 238
Hope J., 217
Hor-Meyll M., 52
Hornberger K., 85
Hovhannisyan K., 88
Huang C., 147
Huber M., 88, 221
Hubík P., 112
Huelga S., 89
Hulet R., 90
Hurowitz D., 215
Hush M., 216, 217

I

Ihn T., 120
Imry Y., 91
Ingold G., 92, 168
Itah A., 154

J

Jarzynski C., 129
Jelezko F., 132
Jeong W., 62
Jiménez Farías O., 52
Jin F., 115
Johal R., 240
Jonckheere T., 68

K

Kalvová A., 152
Kanazawa I., 218, 219
Kang K., 220
Kastner M., 93
Katsnelson M., 64
Katz N., 94
Kauten T., 167
Keefe P., 95
Khabarova K., 45
Khrennikov A., 96
Kim K., 62
Kleinert H., 97
Klionsky M., 160, 241
Klumpp S., 98
Knezevic I., 99
Kobayashi K., 100
Kolachevsky N., 45
Korytár R., 182
Kosionis S., 197
Koski J., 117
Kosloff R., 225
Krenn M., 208, 209, 221
Krinner S., 49
Kronik L., 182
Kroo N., 101
Kropf C., 71
Kroupa P., 30, 102, 235
Kubala B., 38
Kubo T., 161
Kucherov M., 222, 223
Kujala J., 205
Kumar M., 163
Kuritz N., 182
Kurizki G., 103
Kutvonen A., 117

L

Lahav O., 154
Langrock C., 137
Lapas L., 135

Lapkiewicz R., 208, 209, 221
Laurat J., 104
Lazarides A., 224
Lee D., 213
Lee W., 62
Lefloch F., 68
Lemos de Melo J., 178
Lemos J., 207
Lesanovsky I., 214, 216
Levkivskyi I., 150
Levy A., 225
Levy Yeyati A., 163
Li W., 214
Liang Y., 43, 105
Lidström S., 106
Lifshitz R., 226, 227
Lindenfeld Z., 226, 227
Lipowsky R., 107
Liu H., 108
Lo Franco R., 179
Lombardo P., 191
Łuczka J., 109
Ludwig S., 166

M

Maass P., 238
Macedo A., 110
Mahfouzi F., 122
Mahler G., 111
Mai P., 167
Marbach J., 50
Marek P., 70
Mareš J., 112
Marquardt F., 113
Martin A., 228, 229
Martin T., 68
Masanes L., 105
Mazo V., 147
Mazzola L., 230
Meineke J., 49
Meir Y., 74, 114
Mélin R., 68
Mesa Pascasio J., 79
Michielsen K., 64, 115
Millis A., 80
Moessner R., 224
Montambaux G., 116
Möttönen M., 117
Muniandy S., 231
Muñoz J., 232

N

Nagaosa N., 122
Narayan A., 136
Naselsky P., 108, 118
Nath Pal A., 120
Neuhauser D., 119
Nicacio F., 233
Nichele F., 120
Nieuwenhuizen T., 121
Nikolic B., 122
Nimmrichter S., 85
Novotný T., 134, 234, 243

O

Oh S., 235
Orszag M., 199, 200

P

Paladino E., 67, 123, 179
Palsson M., 82
Paspalakis E., 197
Paternostro M., 230
Patnaik A., 124
Pauly F., 62
Pavlyukh Y., 125, 180
Pawlowski K., 236
Peaudecerf B., 51
Pedrosa I., 181
Pekola J., 86, 117
Pelc J., 137
Perarnau Llobet M., 88
Perederiy E., 222, 223
Perez-Madrid A., 135
Petruccione F., 126
Pfeffer A., 68
Pietsch P., 120
Pironio S., 43
Plenio M., 132
Plick W., 209
Plotnitsky A., 127

Pohl R., 45
Polini M., 159
Pomarico E., 137
Pothier H., 128
Prinz-Zwick A., 92
Pryde G., 82

Q
Queisser F., 142

R
Rabani E., 119
Racz P., 101
Rahav S., 129
Rahimi-Keshari S., 169
Raimond J., 51
Ralph T., 130, 169
Ramakrishna S., 145
Ramelow S., 208, 209, 221
Rech J., 68
Reddy P., 62
Reichel J., 236
Reichl L., 131
Reichman D., 80
Renner R., 149
Retzker A., 132
Rinott S., 154
Rodewald J., 85
Rohrer S., 38
Romito A., 133
Rosset D., 105
Roszak K., 134
Roy S., 124, 195
Rubi J., 135
Rudolf B., 237
Rungger I., 136
Ryabov A., 238
Rybarczyk T., 51

S
Sagawa T., 117
Saira O., 117
Sangouard N., 137, 228
Sanguinetti B., 137
Santos L., 138
Sanvito S., 136
Sasaki T., 219
Sassetti M., 204
Sayrin C., 51
Scarani V., 43
Schaeff C., 209
Schäfer S., 191
Schley R., 154
Schliemann J., 210
Schmidt R., 156
Schmidt T., 139
Schmitteckert P., 66, 140
Schneider U., 141
Schubert E., 166
Schuetzhold R., 142
Schuh D., 166
Schüler M., 180
Schulman L., 143
Schwabl H., 79
Scully M., 77
Sedrakian A., 144
Seideman T., 145
Seifert U., 146
Sekatski P., 228
Semenov A., 171, 239
Semião F., 233
Sena M., 110
Shammass I., 154
Shen W., 72
Shimshoni E., 147
Shnirman A., 148
Shurupov A., 78
Sinatra A., 236
Sinayskiy I., 126
Slater J., 149
Slobodeniuk A., 150
Solinas P., 117
Sols F., 151, 232
Souto Ribeiro P., 52
Špička V., 112, 152
Spiechowicz J., 109
Spreng B., 168
Stadler D., 49
Stefanucci G., 153
Steinhauer J., 154

Stenberg M., 155
Stockburger J., 156
Stojanovic V., 157
Stuart T., 149
Sukhorukov E., 150
Sung W., 158
Szigeti S., 217

T
Taddei F., 159
Tal O., 160, 182, 241
Talkner P., 92
Tanttu T., 117
Taubert D., 166
Terzis A., 197
Thew R., 137, 228, 229
Thomas G., 240
Tittel W., 149
Tokura Y., 161
Trauzettel B., 210
Traverso Ziani N., 204

U
Udem T., 45
Urbina C., 128
Utsumi Y., 161

V
Vaccaro J., 162, 183
Valdés-Hernández A., 56, 63
van Ruitenbeek J., 163
Vardimon R., 160, 182, 241
Varro S., 101
Velický B., 152
Venturelli D., 76
Verdozzi C., 164
Vetter P., 77
Vojta T., 165
von Delft J., 166
Voronine D., 77
Vörös Z., 167

W
Walborn S., 52
Walk N., 130
Wang J., 74
Wegscheider W., 120, 166
Weihs G., 167
Weiss U., 168
Weston M., 82
Whalen S., 54
White A., 169
Wilhelm F., 155
Wiseman H., 82
Wittmann B., 170

Y
Yang T., 90
Yelin T., 160, 182
Yi J., 92
Yoon Y., 117

Z
Zaikin A., 171, 239
Zapata I., 232
Zarbo L., 242
Zayats A., 154
Zbinden H., 137
Zeilinger A., 170, 208, 209, 221
Žonda M., 243
Zotti L., 62
Zubairy M., 172

List of Participants

Prof. Eric Akkermans
Department of Physics
Technion-Israel Institute of Technology
Technion
Haifa
Israel

Prof. Yoram Alhassid
Yale University
Department of Physics
217 Prospect Street
New Haven
USA

Prof. Roland E. Allen
Texas A&M University
Department of Physics and Astronomy
Mail Stop 4242
College Station
USA

Dr. Andreas Alvermann
University of Greifswald
Felix-Hausdorff-Strasse 6
17489 Greifswald
Germany

Prof. Frithjof Anders
Lehrstuhl theo. Physik II, Fakultät Physik
Technische Universtät Dortmund
Otto-Hahn Str 4
44227 Dortmund
Germany

Dr. Dragos Victor Anghel
Horia Hulubei National Institute
of Physics and Nuclear Engineering
Reactorului 30
Magurele
Romania

Prof. Joachim Ankerhold
Institute for Theoretical Physics
University of Ulm
Albert-Einstein-Allee 11
89069 Ulm
Germany

Prof. Mauro Antezza
Laboratoire Charles Coulomb, Université Montpellier 2 - CNRS
Place Eugène Bataillon - cc 074
Montpellier
France

Dr. Tony Apollaro
Dipartimento di Fisica - Universita' della Calabria
via P. Bucci cubo 31 C
87036 Arcavacata di Rende
Italy

Dr. Liliana Arrachea
Universidad de Buenos Aires
Pabellon I, Ciudad Universitaria
1428 Buenos Aires
Argentina

Mr. Anton Artamonov
Sodankylä Geophysical Observatory, University of Oulu
Oulu Unit
University of Oulu P.O.Box 3000
FIN-90014 Oulu
Finland

Dr. Bob Austin
Princeton University
122 Jadwin Hall
Princeton
USA

Dr. Ekaterina Axelsson
Linnaeus University
Vejdes Plats, 6
352 52, Växjö
Sweden

Mr. Julien Azema
IM2NP - Aix Marseille Université
Av. Escadrille Normandie Niemen
Marseille 13397
France

Prof. Roger Balian
IPhT, Saclay, CEA
Centre de Saclay
F-91191 Gif-sur-Yvette Cx
France

Mr. Jean-Daniel Bancal
Center for Quantum Technologies
National University of Singapore
3 Science Drive 2
Singapore 117542
Singapore

Dr. Adam Bednorz
University of Warsaw
ul. Krakowskie Przedmieście 26/28
00-927 Warsaw
Poland

Prof. Wolfgang Belzig
University of Konstanz
Universitätsstr. 10
78457 Konstanz
Germany

Prof. Jorge Berger
Ort-Braude College
Snunit 51
Karmiel 21982
Israel

Mr. Axel Beyer
Max Planck Institute of Quantum Optics
Hans-Kopfermann-Str. 1
D-85748 Garching
Germany

Mr. Samyadeb Bhattacharya
Indian Statistical Institute
203 B.T. Road
Kolkata
India

Prof. Yaroslav M. Blanter
Kavli Institute of Nanoscience
Delft University of Technology
Lorentzweg 1
Delft
Netherlands

Prof. Miles Blencowe
Dartmouth College
Department of Physics
6127 Wilder Laboratory
Hanover
USA

Dr. Kjetil Borkje
Niels Bohr Institute, University of Copenhagen
Blegdamsvej 17
2100 Copenhagen
Denmark

Prof. Dirk Bouwmeester
UCSB & Leiden University
2526 Mesa School lane
Santa Barbara
USA

Prof. John Boviatsis
Technological and Educational Institute of Patras
Megalou Alexandrou 1
Patras 26334
Greece

Dr. Jean-Philippe Brantut
ETH Zürich
Schafmattstrasse 16
Zurich
Switzerland

Dr. Franz Xaver Bronold
Ernst-Moritz-Arndt-University Greifswald
Felix-Hausdorff-Str. 6
17489 Greifswald
Germany

Mr. Howard Brubaker
PO Box 39
St. Clair Shores
USA

Dr. Michel Brune
Laboratoire Kastler Brossel
Ecole Normale Supérieure
24 rue Lhomond
75005 Paris
France

Prof. Amir Ordacgi Caldeira
Universidade Estadual de Campinas
Sergio Buarque de Holanda 777, Cidade Universitária
Campinas
Brazil

Dr. Michele Campisi
University of Augsburg
UniversitaetStr. 1
Augsburg D-89135
Germany

Prof. Howard Carmichael
University of Auckland
38 Princess Street
Auckland 1020
New Zealand

Dr. Sam Carr
University of Kent
School of Physical Sciences
Ingram Building
Canterbury CT2 7NH
United Kingdom

Prof. Ana María Cetto
Instituto de Física, UNAM, Mexico
Circuito de la Investigación Científica, CU
04510 México, DF
Mexico

Prof. Min Chen
Department of Engineering Mechanics
Tsinghua University
Tsinghua Park
Beijing, 100084
China

Prof. Frédéric Chevy
Laboratoire Kastler Brossel
Ecole Normale Supérieure, CNRS
24 rue Lhomond
Paris
France

Prof. Raymond Chiao
University of California at Merced
P.O. Box 2039
Merced, CA 945344
USA

Prof. Hyoung Joon Choi
Yonsei University
Yonsei-ro 50
Seoul 120-749
Republic of Korea

Dr. Nellu Ciobanu
Facultad de Fisica, Pontificia Universidad Catolica de Chile
Casilla 306
Santiago
Chile

Dr. Andrew Cleland
University of California - Santa Barbara
Department of Physics
Santa Barbara 93106
USA

Prof. Doron Cohen
Ben-Gurion University
Physics Department
Beer-Sheva 84105
Israel

Dr. James Cresser
Macquarie University
Herring Road
North Ryde 2019
Australia

Mr. Dawid Crivelli
Institute of Physics, University of Silesia
ul. Uniwersytecka 4
40-007 Katowice
Poland

Prof. Juan Carlos Cuevas
Departamento de Fisica Teorica de la Materia Condensada
Universidad Autonoma de Madrid
Tomas y Valiente 7
28049 Madrid
Spain

Prof. Bryan Dalton
Centre for Atom Optics & Ultrafast Spectroscopy
Swinburne University of Technology
John St
Hawthorn 3122
Australia

Prof. Luis de la Pena
Instituto de Física, UNAM
Apartado postal 20-364
Ciudad Universitaria
01000 Mexico, DF
Mexico

Prof. Hans De Raedt
Zernike Institute for Advanced Materials
University of Groningen
Nijenborg 4
Groningen
Netherlands

Mr. Giacomo Dolcetto
Dipartimento di Fisica, Università degli Studi di Genova
via Dodecaneso 33
Genova, 16146
Italy

Prof. Giuseppe Falci
Dipartimento di Fisica e Astronomia
Universita' di Catania and CNR-IMM MATIS Catania
Viale A. Doria 6, Edificio 10
Catania I-95125
Italy

Dr. Bohuslav Drahoš
Palacký University Olomouc
17. listopadu 1192/12
Olomouc 77146
Czech Republic

Mr. Bruno Farias da Silva
Universidade Federal da Paraíba
Cidade Universitária
Joao Pessoa, 58051-970
Brazil

Prof. Ehtibar Dzhafarov
Purdue University
703 Third Street
West Lafayette 47907
USA

Prof. Holger Fehske
Institute of Physics, University Greifswald
Felix-Hausdorff-Str. 6
17489 Greifswald
Germany

Prof. Jens Eisert
FU Berlin
Arnimallee 14
Berlin 14195
Germany

Dr. Denis Feinberg
Institut NEEL
Centre National de la Recherche Scientifique
BP166
38042 Grenoble Cedex 9
France

Dr. Sergey Emelyanov
Ioffe Institute
Polytechnicheskaya 26
St. Petersburg
Russian Federation

Prof. David Ferry
Arizona State University
School of Electrical, Computer, and Energy Engineering
Box 875706
Tempe 85287-5706
USA

Prof. Ferdinand Evers
Karlsruhe Institute of Technology
Inst. of Nanotechnology & Inst. f. Theorie d. Kond. Materie
Hermann-von-Helmholtzplatz 1
76344 Eggenstein-Leopoldshafen
Germany

Mr. Robert Fickler
University of Vienna / IQOQI Vienna
Blotzmanngasse 5
Vienna 1090
Austria

Prof. Radim Filip
Department of Optics, Palacky University Olomouc
17. listopadu 1192/12
77146 Olomouc
Czech Republic

Dr. Gaston Garcia-Calderon
Instituto de Física, UNAM
Ciudad Universitaria
México D.F. , 04510
Mexico

Dr. Boris Fine
University of Heidelberg
Institute for Theoretical Physics
Philosophenweg 19
69120 Heidelberg
Germany

Mr. Bartłomiej Gardas
Institute of Physics, University of Silesia
Bankowa 14
40-007 Katowice
Poland

Prof. James Freericks
Department of Physics, Georgetown University
37th and O Sts. NW
Washington
USA

Prof. Yuval Gefen
The Weizmann Institute
Department of Condensed Matter Physics
Herzl St
Rehovot 76100
Israel

Mr. Moritz Fuchs
Institut for Theoretical Physics and Astrophysics
University of Wuerzburg
Am Hubland
97074
Germany

Dr. Sam Genway
University of Nottingham
University Park
Nottingham, NG7 2RD
United Kingdom

Prof. Claudio Furtado
Departamento de Fisica-UFPB
Cidade Universitaria, Caixa Postal 5008
Joao Pessoa 58051-970
Brazil

Prof. Avik Ghosh
University of Virginia
351 McCormick Rd
Charlottesville
USA

Dr. Michael Galperin
University of California San Diego
Dept. Chem. & Biochem., UH 3250, MC 0340
9500 Gilman Drive
La Jolla
USA

Dr. Alexei Gilchrist
Macquarie University
Balaclava Road
Sydney
Australia

Prof. Vittorio Giovannetti
Scuola Normale Superiore
Piazza dei Cavalieri
Pisa
Italy

Dr. Michael Hall
Centre for Quantum Dynamics, Griffith University
Science 2, Bldg N.34
Nathan QLD 4111
Australia

Dr. Ariunbold Gombojav
Texas A&M University
4242
College Station
USA

Prof. Jong Han
SUNY at Buffalo
239 Fronczak Hall
Buffalo
USA

Dr. Marco Gramegna
INRiM - Istituto Nazionale di Ricerca Metrologica
Strada delle Cacce, 91
Torino - 10135
Italy

Prof. Peter Hänggi
University of Augsburg
Department of Physics
Universitätsstrasse 1
86135 Augsburg
Germany

Dr. Gerhard Groessing
Austrian Institute for Nonlinear Studies
Akademiehof
Friedrichstr. 10
Vienna 1010
Austria

Prof. Serge Haroche
École Normale Supérieure
Laboratoire Kastler-Brossel
24 rue Lhomond
75005 Paris
France

Prof. Emanuel Gull
University of Michigan, Ann Arbor
450 Church St
Ann Arbor, 48109
USA

Mr. Philipp Haslinger
University of Vienna
VCQ
Boltzmanngasse 5
Wien
Austria

Prof. Shmuel Gurvitz
Weizmann institute
Herzl
Rehovot 76100
Israel

Prof. Frank Hekking
LPMMC-CNRS
Joseph Fourier University
25 avenue des Martyrs, BP 166
38042 Grenoble cedex 09
France

Prof. Rudolf Hilfer
ICP
Universitaet Stuttgart
Allmandring 3
70569 Stuttgart
Germany

Mr. Daniel Hurowitz
Ben Gurion University of the Negev
Ben Gurion blvd. 84105
Beer Sheva
Israel

Mr. Viktor Holubec
Charles university in Prague
Faculty of mathematics and physics
V Holešovičkách 2
Prague, 18000
Czech Republic

Dr. Michael Hush
University of Nottingham
University Park
Nottingham NG7 2RD
United Kingdom

Dr. Karen Hovhannisyan
ICFO - The Institute of Photonic Sciences
Av. Carl Friedrich Gauss, 3
Castelldefels, 08860
Spain

Prof. Yoseph Imry
Weizmann Institute
Herzel Str.
Rehovot
Israel

Dr. Pavel Hubík
Institute of Physics ASCR, v. v. i.
Cukrovarnická 10
162 00 Praha 6
Czech Republic

Prof. Gert-Ludwig Ingold
Institut für Physik
Universität Augsburg
Universitätsstraße 1
86135 Augsburg
Germany

Prof. Susana Huelga
Institute of Theoretical Physics
University of Ulm
Albert Einstein Allee 11
Ulm
Germany

Prof. Ikuzo Kanazawa
Department of Physics,Tokyo Gakugei University
Nukuikitamachi 4-1-1,Koganeishi
Tokyo 184-8501
Japan

Prof. Randall G. Hulet
Rice University
Dept of Physics and Astronomy, MS61
6100 Main St
Houston 77005
USA

Prof. Kicheon Kang
Chonnam National University
300 Yong-Bong-Dong
Gwang-Ju 500-757
Republic of Korea

Prof. Michael Kastner
National Institute for Theoretical Physics
10 Marais Street
Stellenbosch 7600
South Africa

Prof. Irena Knezevic
University of Wisconsin - Madison
Electrical and Computer Engineering
1415 Engineering Dr, Rm 3442
Madison, WI 53706
USA

Dr. Nadav Katz
Hebrew University of Jerusalem
Givat Ram
Jerusalem, 91904
Israel

Prof. Kensuke Kobayashi
Osaka University
1-1 Machikaneyama, Toyonaka
Osaka 560-0043
Japan

Dr. Peter Keefe
University of Detroit Mercy
24405 Gratiot Avenue
Eastpointe, 48021
USA

Dr. Zdeněk Kožíšek
Institute of Physics
Academy of Sciences of the Czech Republic
Cukrovarnická 10
Praha 6
Czech Republic

Prof. Andrei Khrennikov
Linnaeus University
P.G. Vägen
Växjö
Sweden

Mr. Mario Krenn
University of Vienna
Boltzmanngasse 5
1090 Vienna
Austria

Prof. Hagen Kleinert
FU Berlin
Fabeckstr, 60
Berlin
Germany

Prof. Norbert Kroo
Hungarian Academy of Sciences
Roosevelt sq 9, now Szechenyi Istvan sq 9
Budapest
Hungary

Dr. Stefan Klumpp
Max Planck Institute of Colloids and Interfaces
Am Muehlenberg
14424 Potsdam
Germany

Prof. Pavel Kroupa
Argelander Institute for Astronomy (AIfA)
University of Bonn
Auf dem Huegel 71
D-53121 Bonn
Germany

Prof. Mikhail Kucherov
Siberian Federal University
Institute of Space and Information Technology
26, Kirensky st.
Krasnoyarsk, 660074
Russian Federation

Dr. Suzy Lidström
Physica Scripta
Royal Swedish Academy of Sciences
Box 50005
SE 140-05
Sweden

Prof. Gershon Kurizki
The Weizmann Institute of Science
2 Herzl Str.
Rehovot 76100
Israel

Mr. Ze'ev Lindenfeld
Tel Aviv University
Ramat Aviv, P.O.B 39040
Tel Aviv
Israel

Prof. Julien Laurat
Laboratoire Kastler Brossel
Universite P. et M. Curie
Case 74, 4 place Jussieu,
75252 Paris Cedex 05
France

Prof. Reinhard Lipowsky
MPI of Colloids and Interfaces
Dept of Theory and Bio-Systems
Science Park Golm
14424 Potsdam
Germany

Dr. Achilleas Lazarides
Max Planck Institute for the Physics of Complex Systems
Dresden, DE
Noethnitzer Str 38
Dresden
Germany

Dr. Hao Liu
Niels Bohr Institute & Institute of High Energy Physics
& Discovery center
Blegdamsvej 17
2100 København Ø
Denmark

Mr. Amikam Levy
The Hebrew University of Jerusalem
Edmund J. Safra Campus, Givat Ram
Jerusalem 91904
Israel

Prof. Jerzy Łuczka
Univeristy of Silesia
Uniwersytecka 4
40-007 Katowice
Poland

Dr. Yeong-Cherng Liang
University of Geneva/ ETH Zurich
Chemin de Pinchat 22
CH-1211 Genève 4
Switzerland

Prof. Antonio Macedo
Universidade Federal de Pernambuco
Departamento de Física
Av. Prof. Luiz Freire
Recife
Brazil

Dr. Michael MacLachlan
US Army International Technology Center - Atlantic
86 Blenheim Crescent
Ruislip
United Kingdom

Dr. Laura Mazzola
Queen's University Belfast
15 Ashburne Place
Belfast
United Kingdom

Prof. Guenter Mahler
Institut fuer Theoretische Physik I
Universitaet Stuttgart
Pfaffenwaldring 57
70550 Stuttgart
Germany

Prof. Yigal Meir
Ben Gurion University
Department of Physics
Beer Sheva 84105
Israel

Prof. Volodymyr Marenkov
I.I.Mechnikov Odessa National University
2 Dvorjanskaja Str.
65026 Odessa
Ukraine

Prof. Kristel Michielsen
Jülich Supercomputing Centre
Forschungszentrum Jülich GmbH
Wilhelm-Johnen-Straße
D-52425 Juelich
Germany

Dr. Jiří J. Mareš
Institute of Physics ASCR, v.v.i.
Cukrovarnická 10
162 00 Praha 6
Czech Republic

Prof. Gilles Montambaux
Université Paris-Sud
Laboratoire de Physique des Solides
Bat. 510
91405 - Orsay
France

Prof. Florian Marquardt
Institute for Theoretical Physics II
University of Erlangen-Nuremberg
Staudtstr. 7
91058 Erlangen
Germany

Dr. Mikko Möttönen
Aalto University
POB 13500
00076 AALTO
Finland

Dr. Anthony Martin
Gap Optic, University of Geneva
Chemin de Pinchat 22
CH-1211 Genève 4
Switzerland

Dr. Sithi Muniandy
University of Malaya
Department of Physics
Kuala Lumpur 50603
Kuala Lumpur
Malaysia

Mr. Juan Ramón Muñoz
Departamento de Física de Materiales
Universidad Complutense de Madrid
Ciudad Universitaria 28040
Madrid
Spain

Mr. Fabrizio Nichele
ETH Zurich
Solid State Physics Laboratory
Schafmattstrasse 16
Zurich
Switzerland

Dr. José Roberto Nascimento
Universidade Federal da Paraiba
Cidade Universitaria
58051970
Brazil

Dr. Theo Nieuwenhuizen
Institute for Theoretical Physics
University of Amsterdam
Science Park 904
1098 XH Amsterdam
Netherlands

Prof. Pavel Naselsky
Niels Bohr Institute
Blegdamsvej 17
Copenhagen
Denmark

Prof. Branislav Nikolic
University of Delaware
Department of Physics & Astronomy
217 Sharp Lab
Newark
USA

Prof. Paul Nation
Korea University
Asan Science 216, Anam-dong 5
Seoul, 136-713
Republic of Korea

Dr. Tomáš Novotný
DCMP, Faculty of Mathematics and Physics
Charles University in Prague
Ke Karlovu 5
121 16 Praha 2
Czech Republic

Prof. Daniel Neuhauser
UCLA
607 Charles E Young dr
Los Angeles 90095
USA

Miss. Seungkyung Oh
Argelander Institut fuer Astronomie
University of Bonn
Auf dem Huegel 71
Bonn, 53121
Germany

Dr. Fernando Nicacio
UFABC
Av. dos Estados, 5001
Santo André
Brazil

Dr. Alexandra Olaya-Castro
University College London
Gower Street
London
United Kingdom

Dr. Elisabetta Paladino
DFA University of Catania & CNR-IMM UOS Catania (Università)
Via Santa Sofia 64
Catania
Italy

Mr. Evgeniy Perederiy
Siberian Federal University
28 Lazo st. #214
660133 Krasnoyarsk
Russian Federation

Dr. Mauro Paternostro
Queen's University Belfast
David Bates Building
Belfast BT7 1NN
United Kingdom

Prof. Francesco Petruccione
University of KwaZulu-Natal
Private Bag X54001
Durban 4000
South Africa

Dr. Anil Patnaik
Air Force Research Laboratory/
Wright State University
RZTC Bldg 5, 1950 Fifth St
Dayton 45431
USA

Dr. Arkady Plotnitsky
Purdue University
500 Oval Drive
West Lafayette, IN, 47907
USA

Dr. Yaroslav Pavlyukh
Martin-Luther-University, Halle-Wittenberg
Heinrich-Damerow-Str.4
Halle
Germany

Dr. Claudia Pombo
Oosterpark 49
Amsterdam
Netherlands

Dr. Krzysztof Pawlowski
Laboratoire Kastler Brossel
Ecole Normale Superieure
24, rue Lhomond
75231 Paris
France

Dr. Hugues Pothier
CEA-Saclay
SPEC
Orme des Merisiers
Gif-sur-Yvette
France

Dr. Inácio Pedrosa
Universidade Federal da Praíba
Caixa postal 5008
João Pessoa, 58051-970
Brazil

Dr. Saar Rahav
Schulich Faculty of Chemistry
Technion - Israel Institute of Technology
Technion City
Haifa 32000
Israel

Prof. Timothy Ralph
University of Queensland
Department of Physics
Brisbane, 4072
Australia

Dr. Bohuslav Rudolf
NBÚ
Jerevanská 2588
Kladno 272 01
Czech Republic

Dr. Linda Reichl
University of Texas at Austin
Physics Department, 1 University Station
Austin, 78712
USA

Dr. Ivan Rungger
Trinity College Dublin
College Green
Dublin 2
Ireland

Dr. Alex Retzker
The Hebrew University
Racah Institute of Physics
Jerusalem 91904
Israel

Dr. Artem Ryabov
Charles University in Prague
Faculty of Mathematics and Physics
V Holesovickach 2
Prague, 180 00
Czech Republic

Dr. Alessandro Romito
Freie Universität Berlin
Dahlem Center for Complex Quantum Systems
Arnimallee 14
14195 Berlin
Germany

Dr. Bruno Sanguinetti
University of Geneva
Chemin de Pinchat 22
Carouge CH-1227
Switzerland

Dr. Katarzyna Roszak
Institute of Physics, Wrocław University of Technology
Wyb. Wyspianskiego 27
50-370 Wroclaw
Poland

Prof. Lea Santos
Yeshiva University
245 Lexington Ave
New York
USA

Prof. Miguel Rubi
University of Barcelona
Faculty of Physics
Diagonal 647
Barcelona
Spain

Dr. Thomas Schmidt
University of Basel
Klingelbergstrasse 82
CH-4056 Basel
Switzerland

Dr. Peter Schmitteckert
Karlsruhe Institute of Technology
Institute of Nanotechnology
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Germany

Prof. Udo Seifert
University Stuttgart
Pfaffenwaldring 57
70550 Stuttgart
Germany

Dr. Ulrich Schneider
LMU Munich
Schellingstrasse 4
80799 Munich
Germany

Dr. Andrey Semenov
Lebedev Physical Institute, Russian Academy of Sciences
Leninskij prospekt, 53
119991
Russian Federation

Prof. Ralf Schuetzhold
Universität Duisburg-Essen
Fakultät für Physik
Lotharstr. 1
47048 Duisburg
Germany

Prof. Efrat Shimshoni
Dept. of Physics, Bar-Ilan University
Bar-Ilan University campus
Ramat Gan 52900
Israel

Prof. Lawrence S. Schulman
Clarkson University
8 Clarkson Ave
Potsdam
USA

Prof. Alexander Shnirman
Karlsruhe Institute of Technology
Wolfgang-Gaede-Str. 1
Karlsruhe 76131
Germany

Prof. Armen Sedrakian
Institute for Theoretical Physics
Max-von-Laue str. 1
Frankfurt am Main
Germany

Mr. Joshua Slater
Institute for Quantum Information Science
University of Calgary
2500 University Dr NW
Calgary
Canada

Prof. Tamar Seideman
Northwestern University
2145 Sheridan Rd
Evanston 60208
USA

Dr. Artur Slobodeniuk
University of Geneva
Department of Theoretical Physics
24 quai Ernest-Ansermet
Geneva 1211
Switzerland

Prof. Fernando Sols
Universidad Complutense de Madrid
Avda. Complutense s/n
E-28040 Madrid
Spain

Dr. Vladimir M. Stojanovic
University of Basel
Klingelbergstrasse 82
CH-4056 Basel
Switzerland

Dr. Václav Špička
Institute of Physics, v.v.i.
Academy of Sciences of the Czech Republic
Cukrovarnická 10
162 00 Praha 6
Czech Republic

Prof. Wokyung Sung
Pohang University of Science & Technology
Hyoja Dong
Pohang
Republic of Korea

Dr. Gianluca Stefanucci
Universita' di Roma Tor Vergata
Via della Ricerca Scientifica 1
Roma 00133
Italy

Dr. Fabio Taddei
NEST, Istituto Nanoscienze-CNR & Scuola Normale Superiore
Piazza dei Cavalieri, 7
I-56126, Pisa
Italy

Prof. Jeff Steinhauer
Technion – Israel Institute of Technology
Technion City
Haifa, 32000
Israel

Dr. Oren Tal
Weizmann Institute of Science
234 Herzl St.
Rehovot 76100
Israel

Dr. Markku Stenberg
Saarland University
Theoretical Physics
66123 Saarbrücken
Germany

Mr. George Thomas
Indian Institute of Science Education and Research Mohali
Knowledge city, Sector 81
SAS Nagar, Manauli PO 140306
India

Dr. Jürgen Stockburger
Universität Ulm
Institut für Theoretische Physik
Albert-Einstein-Allee 11
89069 Ulm
Germany

Dr. Yasuhiro Utsumi
Mie University
1577, Kurimamachiya-cho
Tsu, 514-8507
Japan

Prof. Joan Vaccaro
Griffith University
170 Kessels Road
Nathan
Australia

Prof. Jan van Ruitenbeek
Leiden University
Kamerlingh Onnes Laboratory
Niels Bohrweg 2
2333CA Leiden
Netherlands

Mr. Ran Vardimon
Weizmann Institute of Science
Hertzel 123
Rehovot 76100
Israel

Prof. Bedřich Velický
Charles University
Faculty of Mathematics and Physics, DCMP
Ke Karlovu 5
121 16 Praha 2
Czech Republic

Dr. Claudio Verdozzi
Mathematical Physics, Lund University
Solvegatan 14A
Lund 22100
Sweden

Prof. Thomas Vojta
Missouri University of Science and Technology
Department of Physics
1315 North Pine Street
Rolla, MO 65409
USA

Prof. Jan von Delft
Ludwig-Maximilians-Universität München
Theresienstr. 37
Munich
Germany

Prof. Gregor Weihs
University of Innsbruck
Institute for Experimental Physics
Technikerstrasse 25
6020 Innsbruck
Austria

Prof. Ulrich Weiss
Institute for Theoretical Physics
University of Stuttgart
Pfaffenwaldring 57
D-70550 Stuttgart
Germany

Prof. Andrew White
University of Queensland
Physics
Brisbane
Australia

Mr. Bernhard Wittmann
Institute for Quantum Optics and Quantum Information
University of Vienna
Boltzmanngasse 3
1090 Vienna
Austria

Prof. Andrei Zaikin
Karlsruhe Institute of Technology
76021
Karlsruhe
Germany

Dr. Liviu Zarbo
Institute of Physics ASCR
Cukrovarnicka 10 CZ-162 00
Praha
Czech Republic

Dr. Karel Závěta
Institute of Physics, ASCR, v. v. i.
Na Slovance 2
Praha 8
Czech Republic

Dr. Martin Žonda
Faculty of Mathematics and Physics, Charles University
Ke Karlovu 5
Praha 2, 121 16
Czech Republic

Prof. M. Suhail Zubairy
Texas A&M University
Department of Physics and Astronomy
College Station
USA

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 bussiness 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 25 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'13 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'.

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 Tuesday afternoon to facilitate FQMT'13 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 Palachovo náměstí (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'.

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 Thursday afternoon to facilitate FQMT'13 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.

Prague Castle, Archbishop's Palace, 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.

Archbishop's Palace is the seat of the Prague's archbishop and the archdiocese administration. It was built in Renaissance style in 16th century, radically reconstructed to early-Baroque palace in the second half of the 17th century and one century later extended and marvelously decorated in late-Baroque and Rococo styles. Interiors of the palace are unique by wood carvings and Rococo stuccoes, beautiful chandeliers, contemporary furniture and plethora of precious glass and porcelain.

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:
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 25 minutes walk, starting down along the Bělohorská street (the main street where the Pyramida hotel is situated)

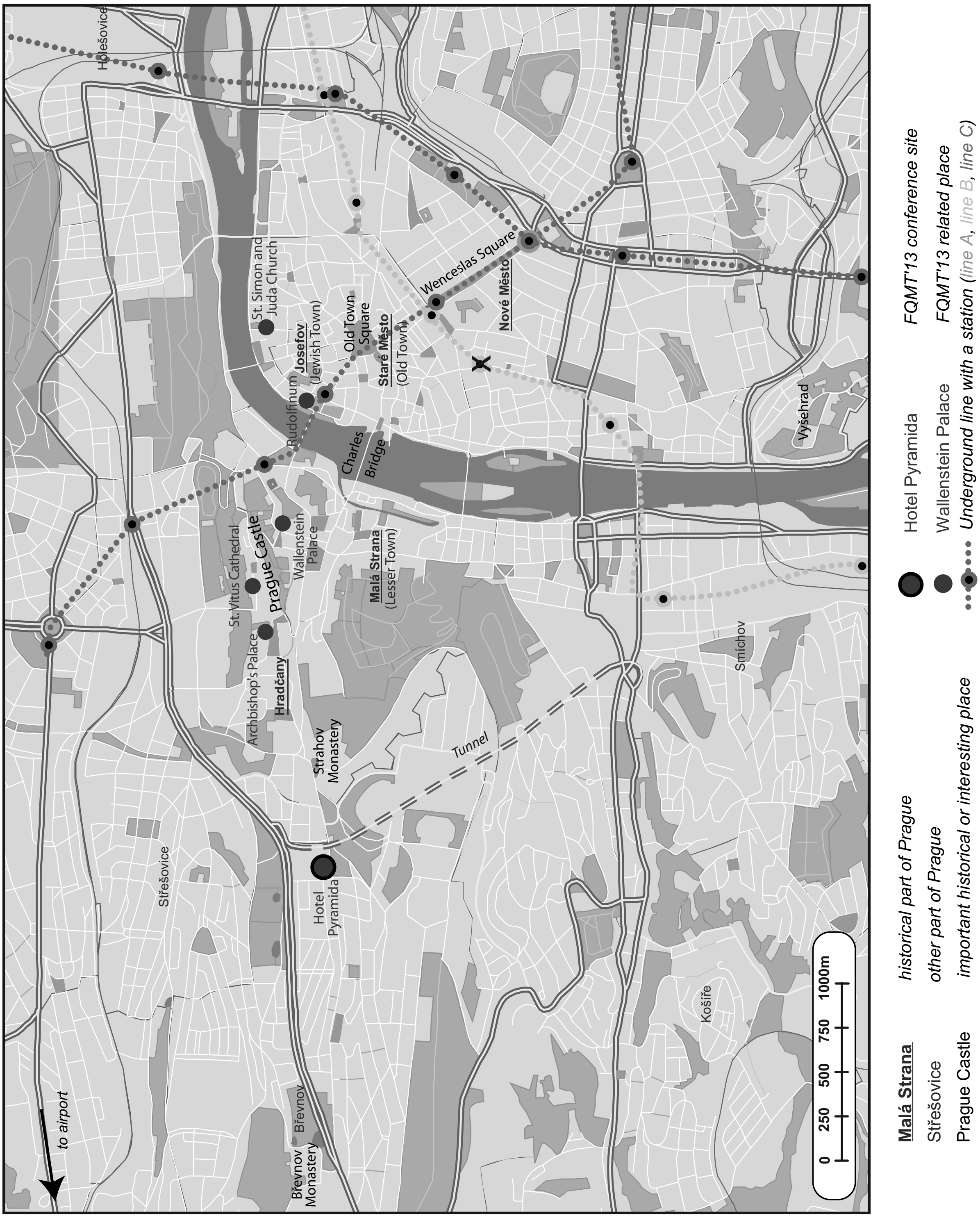
2. or by tram No. 22 (1 stop, about 2 minutes) down along Bělohorská street from the stop Malovanka to the stop Pohořelec, from where you can reach the Prague Castle within 15 minutes walk

3. or going by trams No. 22 (3 stops, 5 minutes) or No. 25 (3 stops, 7 minutes) to the stop Pražský Hrad from where you can reach the central part of the Prague Castle within 5 minutes walk from the different side.

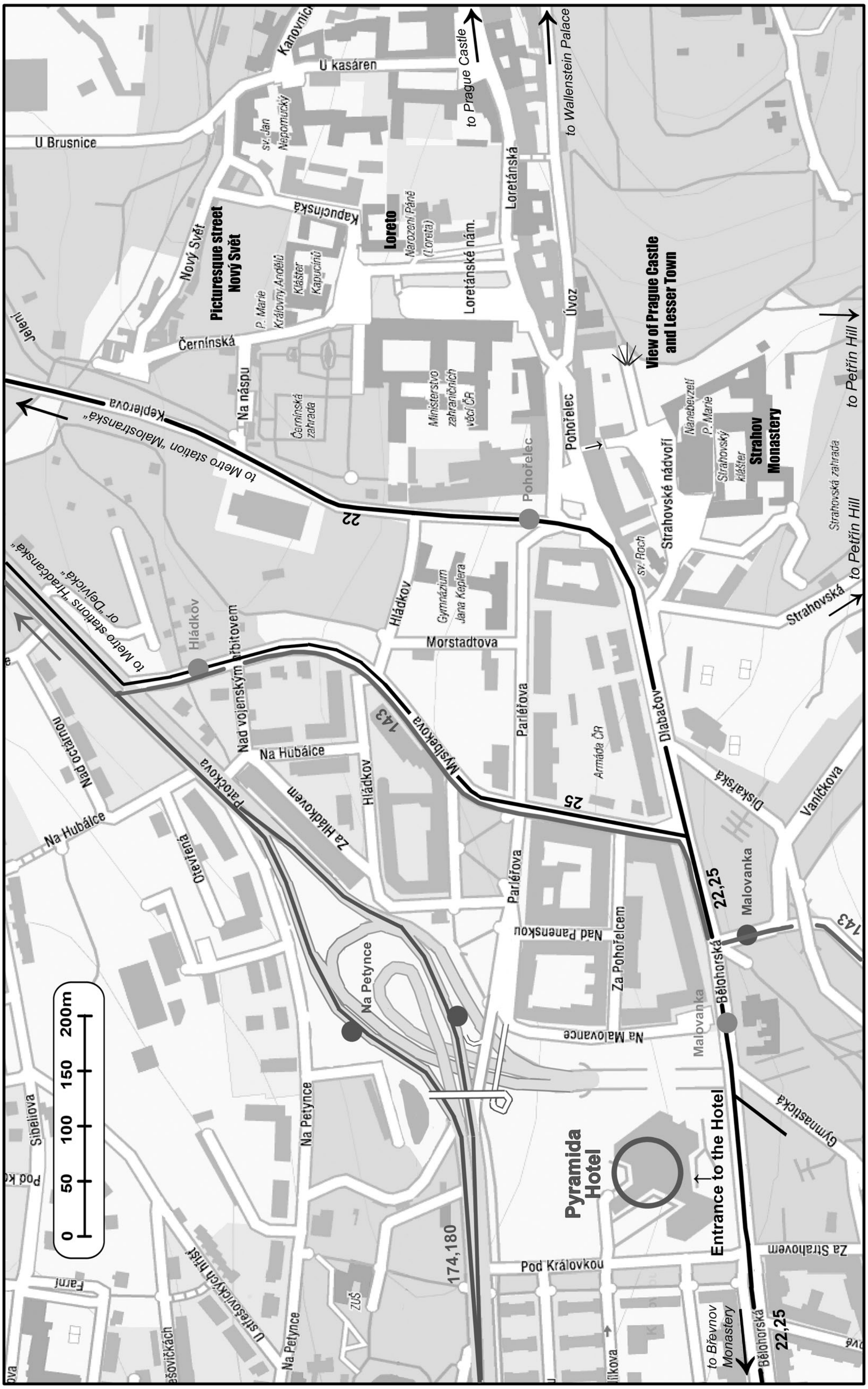
Archbishop's Palace is located on the northern side of Hradčanské náměstí (Hradcany Square, Castle Square) - on your left when you face the main gate to the Castle; the St. Vitus Cathedral is situated in the central part of the Prague Castle - see map 'Prague Castle and Wallenstein Palace neighborhood'.

Maps

Prague center



Pyramida Hotel - access and nearest neighborhood



22,25 Tram lines with line numbers

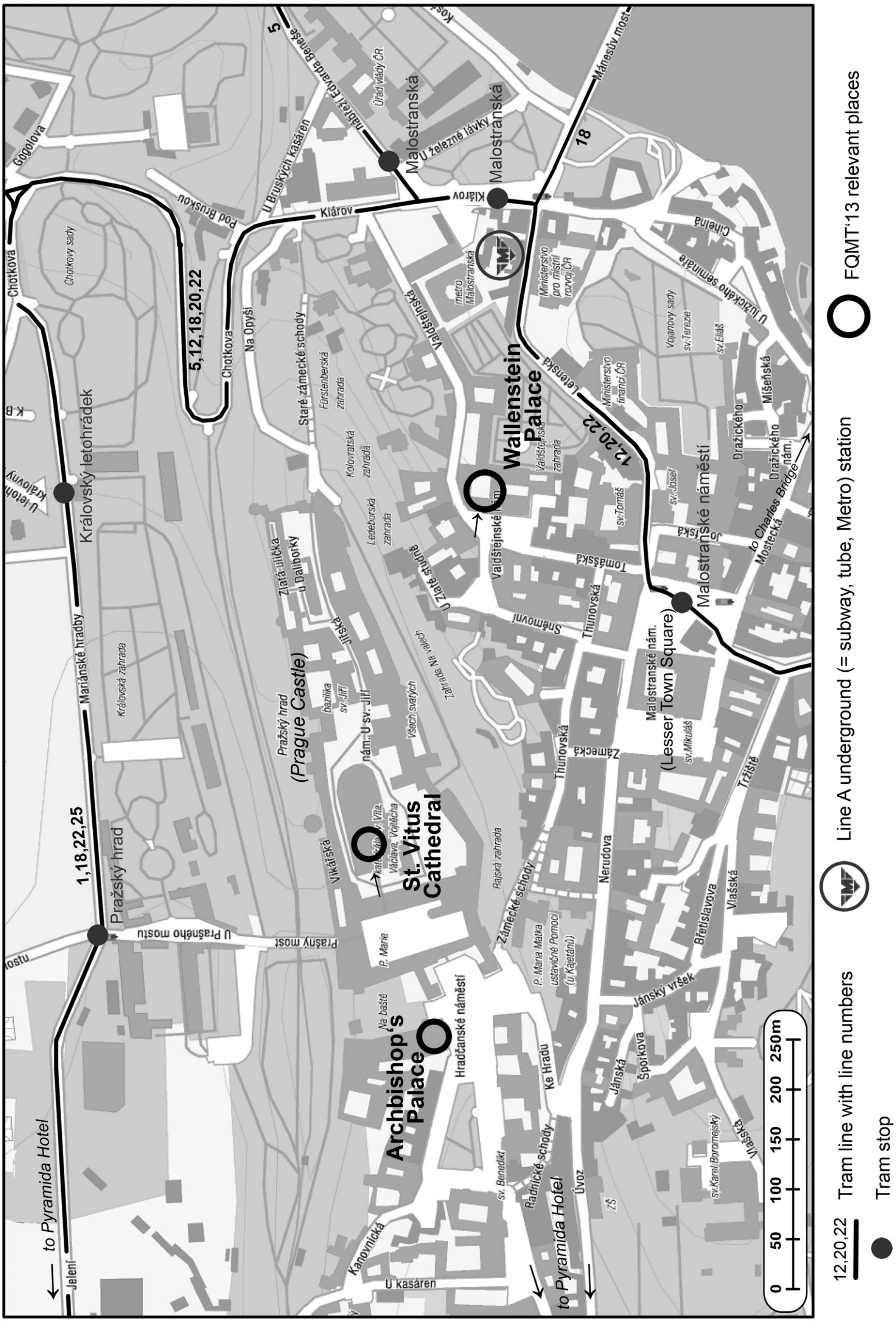
Tram stop

174,180 Bus lines with line numbers

Bus stop

Strahov Monastery interesting place near the Pyramida Hotel

Prague Castle and Wallenstein Palace neighborhood



Places of the Public Lectures