Frontiers of Quantum and Mesoscopic Thermodynamics

14 - 20 July 2019, Prague, Czech Republic

Under the auspices of

Ing. Miloš Zeman
President of the Czech Republic

Jaroslav Kubera
President of the Senate of the Parliament of the Czech Republic

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

Prof. RNDr. Eva Zažímalová, CSc.
President of the Czech Academy of Sciences

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Archbishop of Prague

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

Topics

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

Scientific Committee

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Organized by

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

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The conference is dedicated to Marlan Scully for his lifetime achievements in physics

Marlan Scully has enriched the field of quantum physics, and in particular our meetings. With this in mind, it is with great pleasure we dedicate the FQMT'19 conference to him.

Marlan O. Scully

A true pioneer in quantum optics and laser physics, Marlan O. Scully (Texas A&M, Baylor, and Princeton), among his many accomplishments, developed the first quantum theory of the laser with Willis Lamb, validated lasing without inversion, demonstrated ultraslow light in hot gases, and used quantum coherence to detect anthrax in real time. His work in quantum coherence and correlation effects shed new light on the very foundations of quantum mechanics, in particular his most remarkable "quantum eraser".

Marlan Scully is devoted to theoretical physics. He has often used methods of quantum field theory, statistical physics and quantum optics, and his works have impacted experimental physics and technology. He has been concerned with different fields, in many of which he made seminal contributions: foundations of quantum mechanics; laser physics and quantum optics; theory of measurement; decoherence processes; quantum teleportation; quantum computation; information and entropy in statistical mechanics; quantum heat engines; spectroscopy, especially Raman; imaging; photonic crystals; cold atom systems; ultraslow light in hot gases; solar cells; the use of quantum coherence to detect anthrax in real time; astrophysics, e.g. black hole physics.

He has been elected to the National Academy of Sciences, American Academy of Arts and Sciences, Academia Europaea, and Max Planck Society. He has won numerous awards including the APS Schawlow prize, OSA Townes Award, IEEE Quantum Electronics Award, Franklin Institute's Elliott Cresson Medal, OSA Lomb Medal, and Humboldt Senior Faculty Prize. More recently, he was named Harvard Loeb Lecturer, received an honorary doctorate from Universität Ulm, and was awarded the OSA/DPG Hebert Walther Award. Most recently, he has been awarded the OSA Frederic Ives Medal / Quinn Prize, the highest award of the Society, and was named C.N. Yang Visiting Professor in Hong Kong.

He has authored about 900 scientific articles, as well as standard textbooks such as "Laser Physics (with W. Lamb and M. Sargent) and "Quantum Optics (with M. S. Zubairy).

Marlan Scully has participated in the FQMT conferences from the very beginning and has delivered a number of invited talks. What deserves to be especially mentioned are his FQMT public lectures in 2008 and 2015. On the occasion of his second public lecture Marlan was awarded a medal by the Senate of the Parliament of the Czech Republic for his exceptional achievements in physics.

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

Preface

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

A good understanding of the time evolution of both classical and quantum systems is essential for an explanation of many observations and experiments of contemporary physics. Observed systems must be often treated as non-equilibrium, open systems in which their behavior is influenced not only by their inner parameters, but also by properties of their environment and time dependent external fields. The theory of non-equilibrium behavior of quantum many-body systems is, however, far from complete. Important problems include such questions as irreversible behavior of real systems in comparison with reversible microscopic laws, emergence of classical macroscopic behavior from microscopic quantum behavior, charge (electron), spin and heat transport, limits to "phenomenological" thermodynamic descriptions, and the problem of how to describe properly open quantum systems far from equilibrium, especially in the case of strong interaction between a small system and reservoirs. Thus, further experimental as well as theoretical studies of short to long time dynamics (via transport as well as optical properties) and the influence of initial and boundary conditions (e.g., in quenched or annealed systems) are needed.

The conference will be therefore focused on a better understanding of the behavior of quantum systems out of equilibrium. To reach this aim we also need to improve our knowledge of systems in equilibrium and steady state situations. The conference will thus address also foundations of quantum physics, quantum many body physics, statistical physics, and thermodynamics relying on the theoretical and experimental methods of condensed matter physics and quantum optics. The systems considered will be mainly on the order of mesoscopic (nanoscale) size, and include those of both natural and artificial origin. Special attention will be given to non-equilibrium quantum systems, physics of quantum information and manifestation of quantum effects in biological systems. Subjects from astrophysics, gravitation or cosmology related to the above scope will also be included.

FQMT'19 is a follow-up to the six previous, successful Prague conferences "Frontiers of Quantum and Mesoscopic Thermodynamics" (FQMT'04, FQMT'08, FQMT'11, FQMT'13, FQMT'15, and FQMT'17). For the details of their programs and the history of the FQMT conferences see the www pages https://fqmt.fzu.cz/. The contributions from the previous conferences have been published in Physica E (vol. 29, issues 1-2, 2005, and vol. 42, issue 3, 2010), Physica Scripta (vol. T151, 2012), Fortschritte der Physik (Progress of Physics, vol. 65, issue 6-8, 2017), and European Physical Journal-Special Topics (vol. 227, issue 15-16, 2019).

As in the foregoing FQMT conferences, the aim of FQMT'19 is to create a bridge between the fields of non-equilibrium statistical physics, quantum many body physics, foundations of quantum physics, quantum thermodynamics, quantum optics, physics of quantum information, astrophysics, condensed matter physics, physics of mesoscopic systems, chemical physics and biophysics.

Following the tradition of the FQMT conferences, FQMT'19 will again bring together a unique combination of both young and experienced scientists across a disciplinary spectrum covering the above mentioned topics. The interdisciplinary character of the conference will be supported by the choice of key speakers who, apart from their specializations, are not only able to report specific results within their fields, but are also able to discuss the state of the art of their fields from the standpoint of a broader perspective of overlap with other fields. It is an objective to gather important scientists from overlapping branches of physics who can mutually benefit from the exchange of different views and ideas, experiences from studies of many different systems and various theoretical and experimental approaches to the study of current problems in physics. It is intended that this arrangement of the scientific program of the conference will again significantly contribute to the formulation of challenging questions and problems, as well as their related answers that are nowadays essential to improve the understanding of the foundations of quantum physics, many body physics, quantum statistical physics of systems far from equilibrium, the physics of nanoscale and biological systems, and further, will motivate new collaboration and intensive discussions between experts from differing fields of physics, chemistry, and biology.

To this end, the organizers have endeavored to create a program which is encompassing while simultaneously achieves an "equilibrium" between theoretically and experimentally orientated talks to stimulate the discussion between the experimentalists and the theorists as much as possible. In keeping with the multidisciplinary character of the scientific program, the cultural richness of the City of Prague and the tradition of the previous FQMT conferences, the FQMT'19 program will feature four concerts of classical music performed by world-class musicians, held at outstanding venues of the city. Both the scientific program and the musical program are intended as a complement to one another, where scientists and musicians are encouraged to mingle and share their knowledge and experience.

The organizers are particularly delighted that the FQMT'19 conference is dedicated to Marlan Scully for his lifetime achievements in physics. The state-of-the-art and perspectives of the fields in which Marlan has been active will be overviewed during Thursday sessions and the following round table discussion. We are very glad that Marlan will attend the conference since his he is 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'19 conference and we hope you will enjoy your stay in Prague.

On behalf of the organizers,

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

Contents

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

Important Information

Contact address

FQMT'19
Dr. Václav Špička
Institute of Physics, Czech Academy of Sciences
Cukrovarnická 10, CZ-162 00 Praha 6, Czech Republic
E-mail: fqmt19@fzu.cz
Phone: (+420) 220 318 446
Mobile: +420 777 326 724
WWW: https://fqmt.fzu.cz/19

Emergency phone numbers (free calls):

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

Conference sites

The FQMT'19 conference will take place at the following sites:

Regular talks, the poster session, the public lecture of William Phillips with concert, and the round table will take place at:
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

Public lectures of Wolfang Ketterle and Rainer Weiss with concert will take place at:
Mayakovsky Hall of National House of Vinohrady
address: Náměstí Míru 9, Praha 2 - Vinohrady

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

Conference dinner and concert will take place at:
Strahov Monastery
address: Strahovské nádvoří 1/132, Praha 1

Limitations related to the Wallenstein Palace

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

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

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

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

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

All visitors of the Prague Castle area have to pass the security check and possibly metal detection frame and their things have to be screened by x-rays similarly as at airports.
Important: Participants are, therefore, kindly asked to come to the Prague Castle not at the last moment before the beginning of the concert in the St. Vitus Cathedral.

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

Rooms and facilities available for the participants

Pyramida Hotel

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

- Lecture Hall C (ground floor) and Lecture Hall D (first floor) will also be used for parallel sessions.

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

- Several other rooms will be available for the FQMT'19 participants, e.g., study and computer rooms on the first floor.

Posters

Poster session will be held on Tuesday (July 16, from 4:40 p.m.). Posters can be fixed already from 7:30 a.m. on Tuesday on the first floor (corridors) of the Pyramida Hotel and can be exhibited till Friday 10 a.m.

Social events

- Welcome party: Wallenstein Palace Garden, Monday July 15
- Public lecture: Pyramida Hotel Lecture Hall, Tuesday July 16
  This evening lecture will be given by William Phillips.
- Classical music concert: Pyramida Hotel Lecture Hall, Tuesday July 16
- Public lecture: Mayakovsky Hall of National House of Vinohrady, Wednesday July 17
  This evening lecture will be given by Rainer Weiss
- Public lecture: Mayakovsky Hall of National House of Vinohrady, Wednesday July 17
  This evening lecture will be given by Wolfgang Ketterle
- Classical music concert: Mayakovsky Hall of National House of Vinohrady, Wednesday July 17
- Classical music concert: St. Vitus Cathedral, Thursday July 18
- Tour of Strahov Monastery: Strahov Monastery, Friday July 19
- Conference dinner: Strahov Monastery, Friday July 19
- Classical music concert: Basilica of the Assumption of the Virgin Mary of the Strahov Monastery, Friday July 19

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 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:** Buffet during the poster session in the **Pyramida Hotel**.
- **Wednesday:** Refreshment will be provided after the last sessions.
- **Thursday:** Refreshment will be provided after the round table discussion.
- **Friday:** Conference dinner in **Strahov Monastery**.
  Price: 60 EUR per person - tickets for this dinner will be available during the registration.

PROGRAM

Sunday, 14 July 2019

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

Monday, 15 July 2019

07:50 – 08:20	**Opening addresses**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Václav Špička)	
08:20 – 09:50	**1 session: Nonequilibrium statistical physics**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Michael Thorwart)	
08:20 – 08:50	Joachim Ankerhold:	*Out-of-equilibrium operation of a quantum heat engine beyond weak thermal contact*
08:50 – 09:20	Jianshu Cao:	*Quantum coherence and thermodynamics of non-equilibrium transport*
09:20 – 09:50	Sebastian Erne:	*Universal dynamics far from equilibrium*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session: Quantum transport**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Oren Tal)	
10:10 – 10:40	Peter Hänggi:	*Anomalous heat diffusion*
10:40 – 11:10	Jukka P. Pekola:	*Quantum heat transport via a superconducting qubit*
11:10 – 11:40	Uri Peskin:	*Towards mechanical stabilization of molecular tunneling devices: Cooling by heating, high voltage, and more*
11:40 – 12:10	Jan van Ruitenbeek:	*Advances and challenges in single-molecule electron transport*
12:10 – 13:00	Lunch	
13:00 – 15:10	**3 session - A parallel: Many body physics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Thomas Vojta)	
13:00 – 13:30	Fernando Sols:	*Protected cat states in a driven superfluid boson gas*

13:30 – 14:00	Lea Santos:	*Thouless and relaxation time scales in many-body quantum systems*
14:00 – 14:30	Holger Fehske:	*Exotic criticality and symmetry-protected topological states in dimerised fermion, boson and spin chain models*
14:30 – 14:50	Boris V. Fine:	*Many-body dynamic localization effect in periodically driven finite clusters of spins 1/2 without disorder*
14:50 – 15:10	Sylvain Nascimbene:	*Synthetic Landau levels with atomic dysprosium*

13:00 – 15:10 **3 session - B parallel: Quantum transport, tunneling**

Location: Pyramida Hotel Lecture Hall B

(chairperson: Juan Carlos Cuevas)

13:00 – 13:30	Oren Tal:	*Electronic noise due to temperature differences across nanoscale conductors: Beyond standard thermal and shot noises*
13:30 – 14:00	Alfredo Levy Yeyati:	*Revealing the fine structure of Andreev levels in hybrid nanowires*
14:00 – 14:30	Alessandro Braggio:	*Cooper pair entanglement manipulation in hybrid topological Josephson junctions*
14:30 – 14:50	Efrat Shimshoni:	*Quantum thermal Hall effect of chiral spinons in a Kagome strip*
14:50 – 15:10	Mauro Antezza:	*Giant interatomic energy-transport amplification with nonreciprocal photonic topological insulators*

13:00 – 15:10 **3 session - C parallel: General physics, quantum chemistry**

Location: Pyramida Hotel Lecture Hall C

(chairperson: Jianshu Cao)

13:00 – 13:30	Armin Shayeghi:	*Quantum-assisted molecule metrology*
13:30 – 14:00	Daniel Neuhauser:	*GW0 for > 10K electrons: Stochastic GW*
14:00 – 14:30	Hans A. Schuessler:	*Touching horizons with lasers*
14:30 – 14:50	Yutaka Shikano:	*Statistical cost of interactive quantum phase estimation in quantum chemistry*
14:50 – 15:10	Lawrence S. Schulman:	*Decoherence and the size of a wave packet*

13:00	–	15:10	**3 session - D parallel: Biophysics**	
			Location: Pyramida Hotel Lecture Hall D	
			(chairperson: Shmuel Gurvitz)	
13:00	–	13:30	Stefan Klumpp:	*Propulsion and fluctuations in magnetotactic bacteria*
13:30	–	14:00	Philip Hemmer:	*Nanodiamonds and nanophosphors for quantum enhanced bio-sensing*
14:00	–	14:30	Marcelo Lozada-Cassou:	*Violation of the local electroneutrality condition in an inhomogeneous macroions solution*
14:30	–	14:50	Lev Mourokh:	*Physical models of proton-pumping complexes in mitochondria membranes*
14:50	–	15:10	Jiří J. Mareš:	*The possible role of extracellular tissue in biological neural networks*
15:10	–	15:30	Coffee break	
15:30	–	18:00	**4 session: Light matter interaction**	
			(chairperson: Warwick Bowen)	
15:30	–	16:00	Federico Capasso:	*Metasurfaces: From flat optics to structured light*
16:00	–	16:30	Ortwin Hess:	*Ultrafast quantum nanophotonics: From nanoplasmonic strong coupling to quantum chaos in semiconductor lasers*
16:30	–	17:00	Dirk Bouwmeester:	*Rare earth and DNA nanophotonics*
17:00	–	17:30	Michael Thorwart:	*Nonequilibrium quantum phase transitions in a hybrid atom-optomechanical system*
17:30	–	18:00	Norbert Kroo:	*Surface plasmon assisted room temperature Cooper pair formation in gold films*
18:00	–	19:00	Free time and transfer to Wallenstein Palace	
19:00	–	22:00	**Welcome party**	
			Location: Wallenstein Palace and its Garden	
19:00	–	19:30	Opening	
19:30	–	22:00	Welcome party in the Wallenstein Palace Garden	

Tuesday, 16 July 2019

07:50	–	09:50	**1 session: Physics of quantum information**	

Location: Pyramida Hotel Lecture Hall
(chairperson: Andrew White)

07:50	–	08:20	Yuval Gefen:	*Weak measurement induced geometric phase: A topological transition*
08:20	–	08:50	Giuseppe Falci:	*Adiabatic quantum operations in systems of ultrastrongly coupled matter and radiation*
08:50	–	09:20	Mikko Möttönen:	*Fast measurement and initialization of superconducting qubits*
09:20	–	09:50	Paul G. Kwiat:	*Investigations of quantum superadditivity*
09:50	–	10:10	Coffee break	

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

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

10:10	–	10:40	Wolfgang Belzig:	*Is energy conserved when nobody looks?*
10:40	–	11:10	Nicolas R. Gisin:	*Non-locality in quantum networks*
11:10	–	11:40	Jens Eisert:	*Quantum field simulators: How they evolve in time, how they can be read out, and in what way they may realize quantum thermal machines*
11:40	–	12:10	Andrew N. Jordan:	*Quantum measurement engines*
12:10	–	13:00	Lunch	

13:00	–	15:00	**3 session - A parallel: Molecular junctions, tunneling**	

Location: Pyramida Hotel Lecture Hall A
(chairperson: Alessandro Braggio)

13:00	–	13:30	Juan Carlos Cuevas:	*Peltier cooling in molecular junctions*
13:30	–	14:00	Thierry Martin:	*Finite frequency noise in a normal metal - topological superconductor junction*
14:00	–	14:20	David Sanchez:	*How to distinguish between interacting and noninteracting molecules in tunnel junctions*

14:20	–	14:40	Kristen Kaasbjerg:	*Fluctuation-driven Coulomb drag in interacting quantum dot systems*
14:40	–	15:00	Thibaut Jonckheere:	*Giant shot noise from Majorana zero modes in topological trijunctions*

13:00 – 15:00 **3 session - B parallel: Thermodynamics, general physics**

Location: Pyramida Hotel Lecture Hall B

(chairperson: Saar Rahav)

13:00	–	13:30	Thomas Schmidt:	*A bath with a memory: Initial states in quantum thermodynamics*
13:30	–	14:00	Friedemann Queisser:	*Dynamically assisted nuclear fusion*
14:00	–	14:20	Peter D. Keefe:	*Second law implications of the size dependency in the adiabatic phase transition of Type I superconductors*
14:20	–	14:40	Daniel P. Sheehan:	*Supradegeneracy, thermophotovoltaics, and the second law of thermodynamics*
14:40	–	15:00	Denys I. Bondar:	*Towards a resolution of the Riemann hypothesis via quantum control*

13:00 – 15:00 **3 session - C parallel: General physics**

Location: Pyramida Hotel Lecture Hall C

(chairperson: Andrei Khrennikov)

13:00	–	13:30	Ehtibar N. Dzhafarov:	*Measures of contextuality and noncontextuality*
13:30	–	14:00	Gary G. Rozenman:	*Utilization of surface gravity water waves for the observation of quantum mechanical and optical phenomena*
14:00	–	14:20	Fabrizio Piacentini:	*Quantum optical simulation of entangled particles near open time-like curves*
14:20	–	14:40	Roland E. Allen:	*Black hole entropy, the black hole information paradox, and time travel paradoxes from a new perspective*
14:40	–	15:00	Theo M. Nieuwenhuizen:	*The Standard Model of particle physics with Diracian neutrino sector*

13:00 – 15:00	**3 session - D parallel: Many body physics**	
	Location: Pyramida Hotel Lecture Hall D	
	(chairperson: Efrat Shimshoni)	
13:00 – 13:30	Matteo Brunelli:	*Conditional dynamics of optomechanical back-action evading measurements*
13:30 – 14:00	Jean Etesse:	*Sub-second optical storage in an atomic frequency comb memory using dynamical decoupling*
14:00 – 14:20	Fabio Taddei:	*Failure of conductance quantization in two-dimensional topological insulators due to non-magnetic impurities*
14:20 – 14:40	Dirk Semkat:	*Electron-hole plasma influence on band edge and Rydberg exciton lines in cuprous oxide*
14:40 – 15:00	Gergely Zarand:	*Universal scaling of quantum geometric tensor in disordered metals*
15:00 – 15:20	Coffee break	
15:20 – 16:40	**4 session - A parallel: Quantum thermodynamics**	
	Location: Pyramida Hotel Lecture Hall B	
	(chairperson: Saar Rahav)	
15:20 – 15:50	Kater Murch:	*Exploring quantum thermodynamics with superconducting qubits*
15:50 – 16:20	Eric Lutz:	*Quantum fluctuation theorems beyond two-point measurements*
16:20 – 16:40	Wei-Min Zhang:	*Quantum thermodynamics of single particle systems*
15:20 – 16:40	**4 session - B parallel: Quantum optics**	
	Location: Pyramida Hotel Lecture Hall C	
	(chairperson: Edward Fry)	
15:20 – 15:50	Alexei V. Sokolov:	*Coherent Raman spectroscopy: From stand-off detection to nano-sensing*
15:50 – 16:20	Yuri Rostovtsev:	*Excited quantum coherence: From plasmonically induced transparency to quantum correlation*
16:20 – 16:40	Sebastien Gleyzes:	*Optimal control for quantum metrology*

15:20 – 16:40	**4 session - C parallel: Physics of quantum information**	
	Location: Pyramida Hotel Lecture Hall D	
	(chairperson: Jean Etesse)	
15:20 – 15:50	Andrew N. Cleland:	*Surface acoustic wave phonons: Quantum control and quantum state transfer*
15:50 – 16:20	Amir H. Safavi-Naeini:	*Making hybrid quantum systems on a chip*
16:20 – 16:40	Eytan Katzav:	*Distances in random networks - recent results*

16:40 – 18:40	**Poster session and refreshment**	
	Location: Pyramida Hotel - first floor	
18:40 – 19:00	Break	

19:00 – 22:00	**Evening session: Public lecture of William Phillips and concert**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Václav Špička, Peter Keefe)	
19:00 – 19:15	Music introduction and opening address	
19:15 – 20:30	Public lecture	
19:15 – 20:15	**William D. Phillips:**	***Time, Einstein and the coolest stuff in the universe***
20:15 – 20:30	Discussion after the lecture of William Phillips	
20:30 – 20:45	Break	
20:45 – 22:00	**Concert of classical music**	

Wednesday, 17 July 2019

07:50	–	09:50	**1 session: Thermodynamics and foundations of quantum physics**	
			Location: Pyramida Hotel Lecture Hall	
			(chairperson: Eric Lutz)	
07:50	–	08:20	Udo Seifert:	*The inevitable cost of precision*
08:20	–	08:50	Abraham Nitzan:	*Thermodynamics of strongly coupled driven quantum systems*
08:50	–	09:20	Igor Dotsenko:	*Quantum themodynamics in cavity QED*
09:20	–	09:50	Marco Gramegna:	*A journey through quantum measurement paradigms: From weak measurements to protective measurements, and more*
09:50	–	10:10	Coffee break	
10:10	–	12:10	**2 session - A parallel: Nonequilibrium statistical physics**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: James Freericks)	
10:10	–	10:40	Michael Bonitz:	*Ultrafast dynamics of strongly correlated finite fermion systems*
10:40	–	11:10	Claudio Verdozzi:	*Steering magnetic skyrmions with currents: A nonequilibrium Green's functions approach*
11:10	–	11:40	Pawel Danielewicz:	*Nuclear slabs in terms of Green's functions: Collective oscillations with short-range correlations*
11:40	–	12:10	Frithjof B. Anders:	*Theory of inelastic electron tunneling spectroscopy for probing correlated many-body systems*
10:10	–	12:10	**2 session - B parallel: Quantum thermodynamics**	
			Location: Pyramida Hotel Lecture Hall B	
			(chairperson: Igor Dotsenko)	
10:10	–	10:40	Gershon Kurizki:	*Quantum thermodynamics under control*
10:40	–	11:10	Saar Rahav:	*Against the flow: A colloidal Maxwell's demon*
11:10	–	11:40	Rafael Sánchez:	*Non-equilibrium systems as demons*

11:40	–	12:10	Jerzy Łuczka :	*Quantum analogue of energy equipartition theorem*

10:10 – 12:10 **2 session - C parallel: Light matter interaction**

Location: Pyramida Hotel Lecture Hall C

(chairperson: Federico Capasso)

10:10	–	10:40	Evgenii Narimanov:	*Ballistic metamaterials*
10:40	–	11:10	Radim Filip:	*Quantum and stochastic physics of instable systems*
11:10	–	11:40	Janne Ruostekoski:	*Open quantum dynamics of cooperatively coupled atoms and light*
11:40	–	12:10	Michele Governale:	*Single-atom lasing in normal-superconductor quantum dots*

10:10 – 12:10 **2 session - D parallel: Physics of quantum information**

Location: Pyramida Hotel Lecture Hall D

(chairperson: Denis Vion)

10:10	–	10:40	Thomas Walther:	*Quantum key distribution in a telecom network*
10:40	–	11:10	Andrew G. White:	*Communicating via ignorance & imaging via counting*
11:10	–	11:40	Mario Krenn:	*On computer-inspired science*
11:40	–	12:10	Elisabetta Paladino:	*Critical current 1/f noise in graphene Josephson junction*
12:10	–	13:00	Lunch	

13:00 – 15:30 **3 session - A parallel: Many body physics, Quantum transport**

Location: Pyramida Hotel Lecture Hall A

(chairperson: Jürgen Stockburger)

13:00	–	13:30	Shmuel Gurvitz:	*Directed particle flow at zero bias induced by random versus periodic drive*
13:30	–	14:00	Francesco Petruccione:	*From unitary to open quantum walks*
14:00	–	14:30	Amir O. Caldeira:	*Amplification of the diamagnetic response in small Hubbard rings*
14:30	–	14:50	Michael Ridley:	*Numerically exact full counting statistics of the Anderson impurity model*
14:50	–	15:10	Peter Schmitteckert:	*Learning DFT and inverse mean field theories*

15:10	–	15:30	Yasuhiro Utsumi:	*Full-counting statistics of information content and the optimum capacity*

13:00	–	15:30	**3 session - B parallel: Quantum thermodynamics**

Location: Pyramida Hotel Lecture Hall B
(chairperson: Abraham Nitzan)

13:00	–	13:30	Stefan Nimmrichter:	*Quantum (thermo-)dynamics of randomly probed systems*
13:30	–	14:00	Bei-Lok Hu:	*Quantum thermodynamics from the nonequilibrium dynamics of open systems*
14:00	–	14:30	Konstantin E. Dorfman:	*Quantum heat engine with weak and strong coupled baths*
14:30	–	14:50	Hyunggyu Park:	*Coherence effect in a multi-level quantum-dot heat engine*
14:50	–	15:10	Haitao Quan:	*Path integral approach to quantum thermodynamics*
15:10	–	15:30	Marti Perarnau-Llobet:	*Work fluctuations in slow processes: Quantum signatures and optimal control*

13:00	–	15:30	**3 session - C parallel: Topological states**

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

13:00	–	13:30	Gianluca Rastelli:	*Decoherence and relaxation of topological states in extended quantum Ising models*
13:30	–	14:00	Pascal Simon:	*Topologically protected Majorana zero modes around the edge of a magnetic skyrmion*
14:00	–	14:30	Andrei D. Zaikin:	*Topology-controlled macroscopic quantum coherent effects in multi-terminal Andreev interferometers*
14:30	–	14:50	Llorenç Serra:	*Conductance oscillations and magnetic orbital effects with chiral Majorana modes*
14:50	–	15:10	Jerome Rech:	*Minimal excitations in the fractional quantum Hall regime*
15:10	–	15:30	Walter Hahn:	*Thermalization as an invisibility cloak for fragile quantum superpositions*

13:00	–	15:30	**3 session - D parallel: Foundations of quantum physics**	

Location: Pyramida Hotel Lecture Hall D
(chairperson: Theo Nieuwenhuizen)

13:00	–	13:30	Ana María Cetto:	*On the physical meaning of the spin projection operator*
13:30	–	14:00	Arkady Plotnitsky:	*Something happened: The real, the virtual, and the actual in quantum field theory*
14:00	–	14:30	Joan A. Vaccaro:	*The quantum theory of time: Sources of T violation*
14:30	–	14:50	Bryan Dalton:	*Bell non-locality in macroscopic systems*
14:50	–	15:10	Andrei Khrennikov:	*Getting rid of the nonlocality nonsense: Violation of the Bell's type inequalities as a local expression of incompatibility*
15:10	–	15:30	Luis de la Peña:	*Strong entanglement criterion based on momentum weak values*

15:30	–	17:00	Free time and transfer to National House	

17:00	–	22:00	**Evening session: Public lectures of Rainer Weiss, Wolfgang Ketterle and concert**	

Location: National House of Vinohrady - Mayakovsky Hall
(chairperson: Václav Špička, Wolfgang Schleich, Peter Keefe)

17:00	–	17:15	Music introduction and opening address	
17:15	–	18:30	Public lecture	
17:15	–	18:15	**Rainer Weiss:**	***The beginnings of gravitational wave astronomy***
18:15	–	18:30	Discussion after the lecture of Rainer Weiss	
18:30	–	19:00	Break	
19:00	–	20:15	Public lecture	
19:00	–	20:00	**Wolfgang Ketterle:**	***Cooling close to absolute zero temperature: A recipe for discoveries***
20:00	–	20:15	Discussion after the lecture of Wolfgang Ketterle	
20:15	–	20:30	Break	
20:30	–	22:00	**Concert of classical music**	

Thursday, 18 July 2019

07:50	–	09:50	**1 session: Quantum physics and gravitation**	
			Location: Pyramida Hotel Lecture Hall	
			(chairperson: Michael Guidry)	
07:50	–	08:20	Wolfgang Schleich:	*Quantum waves and gravity*
08:20	–	08:50	Ernst Rasel:	*Space-borne matter-wave interferences*
08:50	–	09:20	Hartmut Abele:	*Gravity resonance spectroscopy and the dark sector*
09:20	–	09:50	Hansjoerg Dittus:	*Quantum technology on GNSS*
09:50	–	10:10	Coffee break	
10:10	–	12:10	**2 session: General physics**	
			Location: Pyramida Hotel Lecture Hall	
			(chairperson: Wolfgang Schleich)	
10:10	–	10:40	William D. Phillips:	*The revolutionary changes to the International System of Units*
10:40	–	11:10	Wolfgang Ketterle:	*Ultracold atoms as quantum simulators for new materials – optical lattices and synthetic gauge fields*
11:10	–	11:40	Rainer Weiss:	*Quantum noise in LIGO*
11:40	–	12:10	Theodor W. Hänsch:	*From the Lamb dip to the proton radius puzzle*
12:10	–	13:00	Lunch	
13:00	–	14:30	**3 session: Quantum optics**	
			Location: Pyramida Hotel Lecture Hall	
			(chairperson: Yuri Rostovtsev)	
13:00	–	13:30	Thomas Udem:	*Challenging QED with atomic hydrogen*
13:30	–	14:00	Olga Kocharovskaya:	*Quantum optics with X-rays: Dynamical control of resonant interaction*
14:00	–	14:30	Edward S. Fry:	*A diffuse reflecting material for optical studies*
14:30	–	14:50	Break	

14:50 – 16:20	**4 session: Foundations of physics**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Andrew Jordan)	
14:50 – 15:20	Gerard ’t Hooft:	*Constructing deterministic models for quantum mechanical systems*
15:20 – 15:50	Stephen A. Fulling:	*Things we are still learning about uniform acceleration*
15:50 – 16:20	Marlan O. Scully:	*From Bose condensates to black holes: Tribute to Bogoliubov*
16:20 – 16:40	Cofee break	
16:40 – 19:00	**Round table discussion**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Václav Špička, Wolfgang Schleich)	
16:40 – 17:00	Opening	
17:00 – 17:30	Tribute to Marlan Scully	
17:30 – 19:00	Disscusion: M. Scully, T. Hänsch, W. Ketterle, W. Phillips, G. ’t Hooft, R. Weiss, and others	
19:00 – 20:00	Transfer to St. Vitus Cathedral	
20:00 – 21:10	**Concert of classical music**	
	Location: Prague Castle - St. Vitus Cathedral	

Friday, 19 July 2019

07:50 – 09:50	**1 session: Cold atoms out of equilibrium**	
	Location: Pyramida Hotel Lecture Hall	
	(chairperson: Wolfgang Ketterle)	
07:50 – 08:20	Yoram Alhassid:	*Precision thermodynamics of the cold atomic unitary Fermi gas*
08:20 – 08:50	Warwick Bowen:	*Vortex dynamics in a strongly interacting two-dimensional superfluid*
08:50 – 09:20	Vanderlei S. Bagnato:	*Out of equilibrium BEC: The quantum turbulence and characteristics*
09:20 – 09:50	Aurel Bulgac:	*Real-time dynamics of fermionic superfluids: From cold atoms, to nuclei and neutron star crust*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session - A parallel: Physics of superfluids**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Vanderlei Bagnato)	
10:10 – 10:40	Björn Sothmann:	*Odd-frequency superconductivity revealed by thermopower*
10:40 – 11:10	Linda E. Reichl:	*Local and nonlocal shot noise in high-Tc superconducting nanowires*
11:10 – 11:40	Nir Navon:	*Scale invariance in a turbulent quantum gas: Cascade front dynamics and nonthermal steady states*
11:40 – 12:10	Frédéric Chevy:	*The 2N+1 body problem: An impurity immersed in a strongly correlated fermionic superfluid*
10:10 – 12:10	**2 session - B parallel: Quantum phase transitions**	
	Location: Pyramida Hotel Lecture Hall B	
	(chairperson: Yoram Alhassid)	
10:10 – 10:40	Sabine Andergassen:	*Quantum phase transition with dissipative frustration*
10:40 – 11:10	Niels Lörch:	*Divergence of predictive model output as indication of phase transitions*

11:10 – 11:40	Joseph Maciejko:	*Exotic quantum phase transitions in Dirac fermion systems*
11:40 – 12:10	Thomas Vojta:	*Integer quantum Hall transition on a tight-binding lattice*

10:10 – 12:10 **2 session - C parallel: Nonequilibrium statistical physics**

Location: Pyramida Hotel Lecture Hall C

(chairperson: Takafumi Kita)

10:10 – 10:40	Ilya Sinayskiy:	*Prediction of the dissipative phase transition using machine learning techniques*
10:40 – 11:10	Doron Cohen:	*Chaos, irreversibility and Hamiltonian hysteresis*
11:10 – 11:40	Michael Galperin:	*Nonadiabatic molecular dynamics at surfaces and interfaces*
11:40 – 12:10	Rudolf Hilfer:	*Quantum probability theory and the arrow of time*

10:10 – 12:10 **2 session - D parallel: Quantum transport, spin dynamics**

Location: Pyramida Hotel Lecture Hall D

(chairperson: Thierry Martin)

10:10 – 10:40	Yaroslav M. Blanter:	*Chiral excitations of spin waves in ferromagnetic films*
10:40 – 11:10	Branislav Nikolic:	*Multiscale quantum-classical micromagnetics: Fundamentals and applications in spintronics*
11:10 – 11:40	Jaroslav Fabian:	*Nonequilibrium spin phenomena in 2D materials*
11:40 – 12:10	Jonne V. Koski:	*Circuit quantum electrodynamics with quantum dot qubits*
12:10 – 13:00	Lunch	

13:00 – 14:30 **3 session: Many body physics**

Location: Pyramida Hotel Lecture Hall

(chairperson: Pawel Danielewicz)

13:00 – 13:30	Eberhard K.U. Gross:	*Potential energy surfaces and Berry phases beyond the Born-Oppenheimer approximation*

13:30	–	14:00	James K. Freericks:	*The minimal effective Gibbs ansatz (MEGA): A quantum computing framework for determining many-body correlation functions at nonzero temperature*
14:00	–	14:30	Christian Glattli:	*A Josephson relation for e/3 and e/5 fractionally charged anyons*

14:30 – 14:50 Coffee break

14:50 – 16:20 **4 session: Nonequilibrium physics**

Location: Pyramida Hotel Lecture Hall

(chairperson: Ortwin Hess)

14:50	–	15:20	Andrew Armour:	*Dynamics of many-body quantum synchronisation*
15:20	–	15:50	Petr Hořava:	*Topological quantum gravity of the Ricci flow*
15:50	–	16:20	Walter Pfeiffer:	*Attosecond dynamics in solids after photoexcitation as a benchmark for our understanding of complex quantum systems*

16:20 – 17:00 Free time and transfer to Strahov Monastery

17:00 – 23:00 **Guided tour, conference dinner and concert**

Location: Strahov Monastery

17:00	–	19:00	Guided tour through Strahov Monastery
19:00	–	19:20	Welcome
19:20	–	21:00	First part of the conference dinner
21:00	–	22:00	Concert of classical music in the Basilica of Assumption of Our Lady
22:00	–	23:00	Second part of the conference dinner

Saturday, 20 July 2019

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

Location: Pyramida Hotel Lecture Hall

(chairperson: David Sanchez)

08:30 – 09:00	Denis Vion:	*Quantum microwaves with a dc-biased Josephson junction*
09:00 – 09:30	Harold U. Baranger:	*Nonequilibrium dissipative quantum dots: I-V curves and quantum critical points*
09:30 – 10:00	Daniel Esteve:	*Hybrid spin-superconducting circuits for quantum technologies*

10:00 – 10:20 Break

10:20 – 11:50 **2 session: Thermodynamics, Nonequilibrium statistical physics**

Location: Pyramida Hotel Lecture Hall

(chairperson: Federico Capasso)

10:20 – 10:50	Ronnie Kosloff:	*The quantum Carnot engine and the inertial theorem*
10:50 – 11:20	Jürgen T. Stockburger:	*Implicit erasure: A universal paradigm of irreversibility*
11:20 – 11:50	Václav Špička:	*Dynamics of open systems, fluctuation-dissipation theorems and quantum transport theory*

11:50 – 13:00 Lunch

13:00 – 14:30 **3 session: Many body physics**

(chairperson: Joseph Maciejko)

13:00 – 13:30	Vladimir Zelevinsky:	*Physics of thermalization and level density in an isolated system of strongly interacting particles*
13:30 – 14:00	Takafumi Kita:	*A renormalization-group study of interacting Bose-Einstein condensates: Absence of the Bogoliubov mode below d=4 (T>0) and d=3 (T=0) dimensions*
14:00 – 14:30	Michael Guidry:	*On the critical temperature for the superconducting transition*

14:30 – 15:00 Cofee break

15:00 – 16:30 **Apollo 11: Celebration of the 50th anniversary of the first Moon landing, July 20, 1969**

Location: Pyramida Hotel Lecture Hall
(chairperson: Václav Špička, Peter Keefe)

16:30 – 17:00 **Closing remarks**

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

Public Lectures

Cooling close to absolute zero temperature: A recipe for discoveries

Wolfgang Ketterle

Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, USA

Why do physicists freeze matter to extremely low temperatures? Why is it worthwhile to cool to temperatures which are a billion times lower than that of interstellar space? In this talk, I will experimentally demonstrate phenomena at low temperature and discuss new forms of matter. Of special interest are superfluids which can flow without dissipation, and quantum phase transitions which occur even at zero temperature. I will illustrate persistent flows using superconductors. Recently, we have observed a supersolid which is gaseous, liquid and solid at the same time.

Time, Einstein and the coolest stuff in the universe

William D. Phillips

Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland, 100 Bureau Drive, Gaithersburg 20899-8424, USA

At the beginning of the 20th century Einstein changed the way we think about Time. Now, early in the 21st century, the measurement of Time is being revolutionized by the ability to cool a gas of atoms to temperatures millions of times lower than any naturally occurring temperature in the universe. Atomic clocks, the best timekeepers ever made, are one of the scientific and technological wonders of modern life. Such super-accurate clocks are essential to industry, commerce, and science; they are the heart of the Global Positioning System (GPS), which guides cars, airplanes, and hikers to their destinations. Today, the best primary atomic clocks use ultracold atoms, achieve accuracies of about one second in 300 million years, and are getting better all the time, while a new generation of atomic clocks is leading us to re-define what we mean by time. Super-cold atoms, with temperatures that can be below a billionth of a degree above absolute zero, use, and allow tests of, some of Einstein's strangest predictions.

This will be a lively, multimedia presentation, including exciting experimental demonstrations and down-to-earth explanations about some of today's hottest (and coolest) science.

The beginnings of gravitational wave astronomy

Rainer Weiss

Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, USA

The first detection of gravitational waves was made in September 2015 with the measurement of the coalescence of two $\sim$30 solar mass black holes at a distance of about 1 billion light years from Earth. The talk will provide a review of more recent measurements of black hole events as well as the first detection of the coalescence of two neutron stars and the beginning of multi-messenger astrophysics. The concepts used in the instruments and the methods for data analysis that enable the measurement of gravitational wave strains of 10^{-21} and smaller will be presented. The talk will end with a discussion of prospects for the field.

Invited Talks

Gravity resonance spectroscopy and the dark sector

Hartmut Abele

TU Wien, Stadionallee, Wien, Austria

This talk focuses on the control and understanding of a gravitationally interacting elementary quantum system using the techniques of resonance spectroscopy. It offers a new way of looking at gravitation at short distances based on quantum interference. The ultra-cold neutron reflects from a mirror in well-defined quantum states in the gravity potential of the earth allowing the application of gravity resonance spectroscopy (GRS). GRS relies on frequency measurements, which provide a spectacular sensitivity. An acoustic Ramsey setup, currently under development, will set new standards in precision for the experiment qBOUNCE in many respects.

Precision thermodynamics of the cold atomic unitary Fermi gas

Yoram Alhassid[1], Scott Jensen[1], and Christopher N. Gilbreth[2]

[1]*Center for Theoretical Physics, Sloane Physics Laboratory, Yale University, New Haven, Connecticut 06520, USA*

[2]*Department of Physics, Central Washington University, Ellensburg,Washington 98926, USA*

Cold atomic quantum gases are of great interest in diverse areas of physics since they provide a clean and well-defined paradigm of strongly interacting systems, and they have been the subject of intensive experimental studies. Of particular interest is the unitary Fermi gas (UFG) of two-component fermions with a contact interaction characterized by the strongest interaction of infinite scattering length. The UFG undergoes a phase transition to a superfluid below a certain critical temperature. Accurate calculation of thermodynamic properties of the UFG across the superfluid phase transition has been a major challenge, with many theories using uncontrolled approximations that lead to widely different results even on a qualitative level.

A fundamental thermodynamic property of the UFG is the contact, measuring the pair correlation at short distances. It also characterizes the tail of the momentum distribution and the high-frequency tail of the shear viscosity spectral function. Various theories have yielded qualitatively different results for the temperature dependence of the contact.

We use canonical-ensemble auxiliary-field Monte Carlo (AFMC) methods [1,2] on a spatial lattice to calculate the temperature dependence of the contact in the UFG [3]. The calculations are accurate up to a controlled statistical error. We extrapolate to the continuum limit by taking increasingly larger lattices at a fixed but large number of particles. We find a dramatic increase of the contact as the temperature decreases below the critical temperature for superfluidity. Our results are in excellent agreement with very recent precision experiments by the Swinburne [4] and MIT [5] groups, both below and above the critical temperature.

We also present novel continuum limit results for the thermal energy of the UFG, and extract the Bertsch parameter using our lowest temperature results.

[1] S. Jensen, C.N. Gilbreth, and Y. Alhassid, arXiv:1801.06163.

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

[3] S. Jensen, C.N. Gilbreth, and Y. Alhassid, preprint (2019).

[4] C. Carcy et al, Phys. Rev. Lett. 122 (2019) 203401.

[5] B. Mukherjee et al, Phys. Rev. Lett. 122 (2019) 203402.

Black hole entropy, the black hole information paradox, and time travel paradoxes from a new perspective

Roland E. Allen

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

Relatively simple but apparently novel ways are proposed for viewing three related subjects: black hole entropy [1,2], the black hole information paradox [3,4], and time travel paradoxes. (1) Gibbons and Hawking [5] have completely explained the origin of the entropy of all black holes, including physical black holes – nonextremal and in 3-dimensional space – if one can identify their Euclidean path integral with a true thermodynamic partition function (ultimately based on microstates). An example is provided of a theory containing this feature. (2) There is unitary quantum evolution with no loss of information if the detection of Hawking radiation is regarded as a measurement process within the Everett interpretation of quantum mechanics. (3) The paradoxes of time travel evaporate when exposed to the light of quantum physics (again within the Everett interpretation), with quantum fields properly described by a path integral over a topologically nontrivial but smooth manifold. This presentation extends a previous article [6].

[1] Don N. Page, "Hawking Radiation and Black Hole Thermodynamics", New J. Phys. 7, 203 (2005).

[2] Marlan O. Scully, Stephen Fulling, David Lee, Don Page, Wolfgang Schleich, and Anatoly Svidzinsky, "Radiation from Atoms Falling into a Black Hole", arXiv:1709.00481 [quant-ph].

[3] William G. Unruh and Robert M. Wald, "Information loss", Rep. Prog. Phys. 80, 092002 (2017).

[4] S. W. Hawking, M.J. Perry, and A. Strominger, "Soft Hair on Black Holes", Phys. Rev. Lett. 116, 231301 (2016).

[5] G.W. Gibbons and S. W. Hawking, "Action integrals and partition functions in quantum gravity", Phys. Rev. 15, 2752 (1977).

[6] Roland E. Allen. "Black hole entropy, the black hole information paradox, and time travel paradoxes from a new perspective", Journal of Modern Optics.
DOI: 10.1080/09500340.2018.1563724, Feb., 2019; arXiv:1901.09096.

Quantum phase transition with dissipative frustration

Sabine Andergassen[1], Dominik Maile[1,2], Wolfgang Belzig[2], and Gianluca Rastelli[2]

[1]*University of Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany*
[2]*University of Konstanz, 78457 Konstanz, Germany*

We study the quantum phase transition of the one-dimensional phase model in the presence of dissipative frustration, provided by an interaction of the system with the environment through two noncommuting operators. Such a model can be realized in Josephson junction chains with shunt resistances and resistances between the chain and the ground. Using a self-consistent harmonic approximation, we determine the phase diagram at zero temperature which exhibits a quantum phase transition between an ordered phase, corresponding to the superconducting state, and a disordered phase, corresponding to the insulating state with localized superconducting charge. Interestingly, we find that the critical line separating the two phases has a nonmonotonic behavior as a function of the dissipative coupling strength. This result is a consequence of the frustration between (i) one dissipative coupling that quenches the quantum phase fluctuations favoring the ordered phase and (ii) one that quenches the quantum momentum (charge) fluctuations leading to a vanishing phase coherence. Moreover, within the self-consistent harmonic approximation, we analyze the dissipation induced crossover between a first and second order phase transition, showing that quantum frustration increases the range in which the phase transition is second order. The nonmonotonic behavior is reflected also in the purity of the system that quantifies the degree of correlation between the system and the environment, and in the logarithmic negativity as an entanglement measure that encodes the internal quantum correlations in the chain.

[1] Phys. Rev. B 97, 155427 (2018).

Theory of inelastic electron tunneling spectroscopy for probing correlated many-body systems

Frithjof B. Anders

Lehrstuhl theo. Physik II, Fakultät Physik, Technische Universtät Dortmund, Otto-Hahn Str 4, 44227 Dortmund, Germany

We present an extension of the tunneling theory for scanning tunneling microcopy to include different types of vibrational-electronic couplings responsible for inelastic contributions to the tunnel current in the strong-coupling limit. It allows for a better understanding of more complex scanning tunneling spectra of molecules on a metallic substrate in separating elastic and inelastic contributions. The starting point is the exact solution of the spectral functions for the electronic active local orbitals in the absence of the scanning tunneling microcopy tip. This includes electron-phonon coupling in the coupled systemcomprising the molecule and the substrate to arbitrary order including the anti-adiabatic strong coupling regime as well as the Kondo effect on a free electron spin of the molecule. The tunneling current is derived in second order of the tunneling matrix element which is expanded in powers of the relevant vibrational displacements. We use the results of an ab-initio calculation for the single-particle electronic properties as a adapted material specific input for a numerical renormalization group approach for accurately determining the electronic properties of a NTCDA molecule on Ag(111) as a challenging sample system for our theory. Our analysis shows that the mismatch between the ab-initio many-body calculation of the tunnel current in the absence of any electron-phonon coupling to the experiment scanning tunneling spectra can be resolved by including two mechanisms: (i) a strong unconventional Holstein term on the local substrate orbital leads to reduction of the Kondo temperature and (ii) a different electron-vibrational coupling to the tunneling matrix element is responsible for inelastic steps in the dI/dV curve at finite frequencies.

Out-of-equilibrium operation of a quantum heat engine beyond weak thermal contact

Michael Wiedmann, Jürgen T. Stockburger, and Joachim Ankerhold

Institute for Complex Quantum Systems, University of Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Thermodynamic processes on quantum mechanical scales have been a subject of major research activities in recent years. Particular focus has been laid on the operation of thermal machines, theoretically to be described within the context of open quantum systems and non-equilibrium quantum dynamics. In contrast to the classical regime, however, the situation is challenging as work medium and surrounding thermal reservoirs constitute correlated agents subject to time-dependent driving protocols. Hence, in order to capture the full dynamical range of quantum engines one must go beyond conventional weak coupling approaches, particularly, to explore the regime of stronger thermal coupling and fast/strong driving.

In this talk I will discuss the subtleties that occur in the deep quantum regime and the consequences due to a lack of time and length scale separation. A non-perturbative platform for the reduced quantum dynamics of the working medium is presented (exact mapping of the Feynman-Vernon path integral representation onto a Stochastic Liouville – von Neumann equation) which allows to simulate quantum thermal devices in all ranges of parameter space (driving, dissipation, temperature) and for single or few continuous or discrete degrees of freedom [1-3]. Thermal reservoirs are not abstracted out invoking approximations or tentative thermodynamics arguments but are explicitly included in the modeling. By way of example and triggered by recent experimental realizations, a finite-time generalization of the four stroke Otto engine is discussed [4]. The work associated with the coupling/de-coupling to/from reservoirs is shown to be a necessary ingredient for the energy balance. Quantum correlations turn out to be instrumental to enhance the efficiency which opens new ways for optimal control techniques.

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Giant interatomic energy-transport amplification with nonreciprocal photonic topological insulators

Pierre Doyeux[1], Ali Hassani Gangaraj[2], George Hanson[2], and Mauro Antezza[1]

[1] *Laboratoire Charles Coulomb, Université Montpellier UMR5221, Place Eugène Bataillon - cc 074, Montpellier, 34095, France*

[2] *Department of Electrical Engineering, University of Wisconsin-Milwaukee, 3200N. Cramer Street, Milwaukee, Wisconsin 53211, USA*

We show [1] that the energy-transport efficiency in a chain of two-level emitters can be drastically enhanced by the presence of a photonic topological insulator (PTI). This is obtained by exploiting the peculiar properties of its nonreciprocal surface plasmon polariton (SPP), which is unidirectional, and immune to backscattering, and propagates in the bulk band gap. This amplification of transport efficiency can be as much as 2 orders of magnitude with respect to reciprocal SPPs. Moreover, we demonstrate that despite the presence of considerable imperfections at the interface of the PTI, the efficiency of the SPP-assisted energy transport is almost unaffected by discontinuities. We also show that the SPP properties allow energy transport over considerably much larger distances than in the reciprocal case, and we point out a particularly simple way to tune the transport. Finally, we analyze the specific case of a two-emitter chain and unveil the origin of the efficiency amplification. The efficiency amplification and the practical advantages highlighted in this work might be particularly useful in the development of new devices intended to manage energy at the atomic scale.

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Dynamics of many-body quantum synchronisation

Claire Davis-Tilley, Chen Teoh, and Andrew Armour

University of Nottingham, University Park, Nottingham, United Kingdom

The spontaneous synchronisation of limit-cycle oscillators is a fascinating example of a phase transition which occurs far from equilibrium. Limit-cycle oscillators have a non-zero average amplitude, but no preferred phase, and are extremely common in both the physical and biological sciences. Synchronisation has been studied in a wide range of classical systems as well as in systems such as lasers where semiclassical descriptions prove accurate. Over the last few years experiments have begun to investigate synchronisation in smaller-scale oscillator systems, including micron-sized mechanical oscillators and lasers operating in the few-photon regime. This has stimulated theorists to explore synchronisation in oscillators where a fully quantum mechanical description becomes essential. We analyse the properties of the synchronisation transition in a many-body system consisting of quantum van der Pol oscillators with all-to-all coupling using a self-consistent mean-field method. We find that the synchronised state, which the system can access for oscillator couplings above a critical value, is characterised not just by a lower phase uncertainty than the corresponding unsynchronised state, but also a higher number uncertainty. Just below the critical coupling the system can evolve to the unsynchronised steady state via a long-lived transient synchronised state. We investigate the way in which this transient state eventually decays and show that the critical scaling of its lifetime is consistent with a simple classical model.

Out of equilibrium BEC: The quantum turbulence and characteristics

Vanderlei S. Bagnato

IFSC-University of São Paulo, Av. Trabalhador São Carlense, 400, São Carlos, Brazil

The notion of turbulence in the quantum world was conceived long ago, but the occurrence of turbulence in ultracold gases has been studied in the laboratory only very recently. The topic offers new pathways and perspectives on the problem of turbulence. The finite size effects create specific characteristics observed. In this presentation, we review the general properties of quantum gases at ultralow temperatures paying particular attention to vortices, their dynamics and turbulent behavior. Measurement of the energy spectrum using two techniques will be discussed and related to the present understanding of the theory. Identification of turbulence type based on energy spectrum determination will be explained. Applications of the turbulent cloud, when in an expansion, with the creation of a matter wave speckle field will be demonstrated. The appearance of exponential velocity distribution, as indicative of non-thermalization effect, will be interpreted in different views. Work supported by FAPESP - program CEPID and CNPq - program INCT. Work with contribution from P. Tavares, G. Telles, E. M. Gutierrez, K. Magalhaes, G. Roati, A. Orozco, P. Mazo, G. Neto, A. Marino, M. Miotti, M. Hemmerling, E. Santos, M. Caracanhas and L. Madeira. Recommended papers: http://cepof.ifsc.usp.br

Nonequilibrium dissipative quantum dots: I-V curves and quantum critical points

Harold U. Baranger

Duke University, Dept of Physics, Science Dr, Durham 27708-0305, USA

Many-body systems that are driven far from equilibrium exhibit a complex interplay between the many-body correlations and the driven degrees of freedom. I shall discuss quantum dot systems that are particularly advantageous for studying these effects: they exhibit impurity quantum criticality, they are amenable to detailed experimental study, and they are simple enough theoretically that detailed numerical results (as well as some analytical results) can be obtained. First, I present the experimental system: it consists of a quantum dot or metallic grain connected to resistive leads via tunable tunnel barriers. A quantum critical point (QCP) occurs when a level in the dot is resonant with the leads and the dot is symmetrically coupled to them. Second, I present a summary of our theoretical results for the nonlinear I-V curve, both as the system flows into the QCP and for the crossover away from the QCP. The theory and experiment are compared in a parameter free way, and the agreement is excellent.

Is energy conserved when nobody looks?

Wolfgang Belzig[1], Stanisław Sołtan[2], Mateusz Fraczak[2], and Adam Bednorz[2]

[1]*University of Konstanz, Universitätsstr. 10, 78457 Konstanz, Germany*
[2]*Faculty of Physics, University of Warsaw, ul. Pasteura 5, PL02-093 Warsaw, Poland*

Conservation principles are essential to describe and quantify classical and quantum mechanical processes. Classically, the conservation holds objectively because of the description of reality can be considered independent of observation. In quantum mechanics, however, invasive observations change quantities drastically, even if they are expected to be conserved classically. One may hope to overcome this problem by considering weak, non-invasive quantum measurements. Interestingly, we find that the non-conservation of some quantity Q is manifest even in weakly measured correlations, if some of the observables don't commute with the conserved quantity. The non-conservation shows up in third-order correlation functions of the conserved observable Q with two observables non-commuting with Q, which then depends on the order of measurements. At finite temperatures, the non-conservation becomes negligible pointing out its intrinsic quantum origin. Beyond elementary examples like a harmonic oscillator or a two-level system, we suggest measuring an apparent violation of angular momentum in a free-space electron beam experiment, detecting transverse positions and angular momentum of the electron. On a fundamental level, the observed non-conservation of "conserved" quantities can be related to a violation of a Leggett-Garg-type inequality. Therefore, our finding casts some doubt on the compatibility of conservation laws and quantum objectivity.

Chiral excitations of spin waves in ferromagnetic films

Tao Yu[1], Chuanpu Liu[2], Haiming Yu[2], Yaroslav M. Blanter[1], and Gerrit E. W. Bauer[1,3]

[1]*Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, Delft, the Netherlands*
[2]*Fert Beijing Institute, BDBC, School of Microelectronics, Beihang University, Beijing 100191, China*
[3]*Institute for Materials Research & WPI-AIMR & CSRN, Tohoku University, Sendai 980-8577, Japan*

We theoretically investigate the interlayer dipolar and exchange couplings for an array of metallic magnetic nanowires grown on top of an extended ultrathin yttrium iron garnet film. The calculated interlayer dipolar coupling agrees with observed anticrossings, concluding that the interlayer exchange coupling is suppressed by a spacer layer between the nanowires and film. The Kittel mode in the nanowire array couples chirally to spin waves in the film, even though Damon-Eshbach surface modes do not exist. This chirality is suppressed when the interlayer exchange coupling becomes strong.

[1] T. Yu et at, Arxiv:1901.09182.

Towards a resolution of the Riemann hypothesis via quantum control

Denys I. Bondar[1] and Alexander Pechen[2,3]

[1] *Tulane University, 2001 Percival Stern Hall, New Orleans, USA*
[2] *Steklov Mathematical Institute of Russian Academy of Sciences, Moscow 119991, Russia*
[3] *National University of Science and Technology "MISIS", Moscow 119049, Russia*

An equivalence is established between optimal quantum control and Diophantine equations, polynomial equations with integer coefficients and integer unknowns. This implies that quantum control can be directly used to assess a rich variety of logical conjectures including the celebrated Riemann hypothesis. The negative resolution of Hilbert's tenth problem physically implies that quantum control problems are not algorithmically solvable in general. These findings reveal a deep connection between quantum evolution and the number theory.

Ultrafast dynamics of strongly correlated finite fermion systems

Michael Bonitz

Institute for Theoretical Physics and Astrophysics, Universiy Kiel, Germany, Leibnizstr. 15, 24098 Kiel, Germany

The correlated dynamics of fermions following an external excitation is of interest in many fields, in particular strongly correlated materials, dense plasmas and ultracold atoms. Excitations include laser pulses, rapid changes (quenches) of confinement potentials or the impact of charged particles. The situation is even more complex if the system is finite and spatially inhomogeneous.

During the past decade we have systematically developed nonequilibrium Green functions (NEGF) simulations for such problems [1, 2]. Combined with the use of advanced selfenergy approximations [3], computational optimization and GPU computing long propagations of quite large systems of any geometry are possible where other methods fail or are unreliable.

I will present three examples. The first concerns the dynamics of ultracold fermionic atoms following a confinement quench where we observe excellent agreement with experiments [4]. The second is the stopping of energetic ions in correlated finite graphene-type clusters [5, 6]. The third is laser pulse excitation of graphene nanoribbons where nontrivial correlation effects, such as carrier multiplication are observed [7].

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[2] M. Bonitz, “Quantum Kinetic Theory”, 2nd ed. Springer 2016.

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[6] K. Balzer, M. R. Rasmussen, N. Schlünzen, J.-P. Joost, and M. Bonitz, Phys. Rev. Lett. 121, 267602 (2018).

[7] J.-P. Joost, N. Schlünzen, and M. Bonitz, phys. stat. sol. (b) 1800498 (2019).

Rare earth and DNA nanophotonics

Dirk Bouwmeester[1,2], Donny de Bruin[1], Maria Gotz[1], and Dorris Heinrich[1]

[1]*Huygens Laboratory, Department of Physics, Leiden University, NilesBohrweg 2, Leiden, Netherlands*
[2]*University of California, Santa Barbara, Department of Physics, US*

We present two nanophotonic systems. The first system concerns rare earth ions embedded in an amorphous Silicon Nitride optical micro-resonator. We show how photon echo measurements reveal the role of two-level systems in glass in determining the quantum decoherence properties of the rare earth ions. The second nanophotonic systems is based on 5 to 20 silver atoms forming a nanocluster on DNA. The DNA base sequence determines the size and shape of the clusters which act as single photon emitters. This in turn determines the optical properties, such as the wavelength, the intensity and even the polarization. The optical properties of Ag:DNA are so sensitive that also a change in environmental conditions can be detected by analyzing the fluorescence. The binding strength of the silver atoms to the DNA also varies with the DNA host and some DNA constructs "leak out" silver inside cells while other constructs are stable. Since silver atoms in general interfere destructively with the functionality of RNA this can leads to tunable toxicity. There are a wide range of potential applications in medicine and biology.

T16 Fri, 19 July, 8:20 - 8:50, 1 session

Vortex dynamics in a strongly interacting two-dimensional superfluid

Yauhen Sachkou[1], Christopher Baker[1], Glen Harris[1], Oliver Stockdale[1], Stefan Forstner[1], Matthew Reeves[1], Xin He[1], Andreas Sadawsky[1], Yasmine Sfendla[1], David McAuslan[1], Ashton Bradley[2], Matthew Davis[1], and Warwick Bowen[1]

[1]*University of Queensland, St Lucia, Australia*
[2]*University of Otago, Dunedin, New Zealand*

Kosterlitz and Thouless were awarded the Nobel Prize for discovering that two-dimensional superfluidity occurs due to a topological phase transition involving the binding of quantized vortices. Quite remarkably, however, even after almost a half century, coherent vortex dynamics have yet to be directly seen in any strongly-interacting two-dimensional superfluid. Here, we address this longstanding challenge, observing the coherent dynamics of nonequilibrium clusters of vortices in two-dimensional helium as they evolve, dissipate and annihilate [1].

The importance of strongly-interacting superfluids ranges from string theory to astrophysics; including dark matter, the quark-gluon plasma in the early universe, and neutron star physics. However, progress is impeded by the lack of an underpinning microscopic theory. There is contentious debate, even at the most basic level. For instance, proposed values for the effective mass of a vortex range from zero to infinity, while it remains unclear whether an Iordanskii force exists between vortices and colocalized normal fluid. Our ability to observe vortex dynamics allows direct tests of these questions in the laboratory. We conclude that, for our experiments, neither a vortex mass nor an Iordanskii force is required.

It had generally been thought that surface interactions would prohibit experiments such as ours in two-dimensional helium. We overcome them by greatly enhancing the coherent interactions between vortices. This is achieved by confining the superfluid orders-of-magnitude more strongly than has previously been possible on the atomically smooth surface of a silicon chip. We further show that thermal vortex diffusion is suppressed by six orders-of-magnitude, verifying a thirty-year-old prediction, and realize laser control and imaging of vortex clusters for the first time in helium, leveraging techniques from quantum optomechanics [2].

By observing coherent vortex dynamics in a strongly-interacting two-dimensional superfluid, and achieving this on a silicon-chip with integrated laser observation and control capabilities, our research opens a pathway to explore the rich dynamics of vortices in strongly-interacting systems, to build new matter-wave quantum technologies on a chip, for laboratory tests of astrophysical phenomena, and to test predictions from quantum turbulence.

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Cooper pair entanglement manipulation in hybrid topological Josephson junctions

Gianmichele Blasi, Fabio Taddei, Vittorio Giovannetti, and Alessandro Braggio

Istituto Nanoscienze CNR, NEST, Scuola Normale Superiore, Piazza San Silvestro 12, Pisa 56127, Italy

We investigate the supercurrent of hybrid topological Josephson junction done by two superposed layer of 2D topological insulator which allows local (LAR) and crossed (CAR) Andreev reflections with the s-wave leads [1]. We show that by simply applying gate potentials or magnetic flux to the junction one can uniquely affect the dissipationless current. We demonstrated that the gating, thanks to its symmetry with respect to time-reversal and its differential action between upper an lower layer, is capable to change the spin symmetry of non-local Cooper pairs from singlet to triplet. We establish both analytically and numerically the connection between the Josephson current-phase relationship and the manipulation of external potentials to local and nonlocal components. We discuss notable limits, such as the single-shot regime, which clearly demonstrate that entanglement symmetry is manipulated and that can be identified in the critical current. We examine the universal behavior of the critical current, how it depends on the amplitude ratio between the CAR and LAR processes and on the external potential manipulations. Finally we clarify the role of the multiple Andreev reflection in the presented phenomenology.

The proposed setup and the simple signature in the dependence from external potentials are expected to be experimental accessible with the measurement of the critical currents which one the most basic characterization of a Josephson junctions.

[1] G. Blasi, F. Taddei, V. Giovannetti and A. Braggio, Phys. Rev. B 99 (2019) 064514.

Conditional dynamics of optomechanical back-action evading measurements

Matteo Brunelli and Andreas Nunnenkamp

University of Cambridge, JJ Thomson Ave, Cambridge, UK

Since early works in gravitational wave detection it has been known that the precision attainable in a continuous measurement of the position of a harmonic oscillator is fundamentally limited. The limit, known as the standard quantum limit, is quantum- mechanical in nature. Besides being of fundamental interest, the existence of the standard quantum limit has become of practical relevance for ultra-sensitive measurements. Indeed, current experiments in cavity optomechanics have entered a regime where the dominant noise source comes from the quantum measurement backaction.

A strategy to elude the standard quantum limit is to restrict the measurement to a single quadrature of motion, which realizes a so-called backaction-evading (BAE) measurement. BAE measurements of mechanical motion can in principle achieve arbitrarily small uncertainties, which can be accessed via the conditional dynamics.

In this talk (1) I will provide an exact description of the conditional dynamics of an optomechanical system subjected to a BAE measurement. I will discuss the case of both continuous (two-tone) and stroboscopic BAE measurements. Results are simple and yet very informative, e.g. the existence of an optimal sensitivity (in terms of the system's parameters), which was not known so far. Unlike previous descriptions based on the adiabatic approximation, quantum features induced by the measurement on the whole optomechanical system can be accessed, e.g. conditional entanglement. (2) I will show how the presence of spurious terms in the interaction (so-called counter-rotating terms) usually considered detrimental, can favour the appearance of robust quantum features, such as conditional cavity squeezing and entanglement. (3) I will finally discuss how to extend BAE measurements (continuous and stroboscopic) to multi-mode optomechanical systems. This offers a strategy to efficiently entangle mechanical motion and study the multipartite entanglement structure induced by the measurement on an optomechanical system.

Real-time dynamics of fermionic superfluids: From cold atoms, to nuclei and neutron star crust

Aurel Bulgac

University of Washington, Department of Physics, 3910 15th Ave NE, Seattle, USA

In cold atoms and in the crust of neutron stars the pairing gap can reach values comparable with the Fermi energy. While in nuclei the neutron gap is smaller, it is still of the order of a few percent of the Fermi energy. The pairing mechanism in these systems is due to short range attractive interactions between fermions and the size of the Cooper pair is either comparable to the inter-particle separation or it can be as big as a nucleus, which is still relatively small in size. Such a strong pairing gap is the result of the superposition of a very large number of particle-particle configurations, which contribute to the formation of the Copper pairs. These systems have been shown to be the host of a large number of remarkable phenomena, in which the large magnitude of the pairing gap plays an essential role: quantum shock waves, quantum turbulence, Anderson-Higgs mode, vortex rings, domain walls, soliton vortices, vortex pinning in neutron star crust, unexpected dynamics of fragmented condensates and role of pairing correlations in collisions on heavy-ions, Larkin-Ovchinnikov phase as an example of a Fermi supersolid, role pairing correlations control the dynamics of fissioning nuclei, self-bound superfluid fermion droplets of extremely low densities.

Amplification of the diamagnetic response in small Hubbard rings

Thais V. Trevisan, Gustavo M. Monteiro, and Amir O. Caldeira

Universidade Estadual de Campinas, Rua Sergio Buarque de Holanda 777, Cidade Universitária, Campinas, 13083-859, SP, Brazil

In this presentation, we study the magnetic properties of electrons in small discrete rings with $3 \leq N \leq 6$ sites and $N_e = N$ electrons, which can be regarded as a simplified version of real aromatic molecules. In particular, the ring with six sites and six electrons is our prototype of the benzene molecule. Aiming at that goal we employ the Hubbard model with appropriate parameters t and U, and confirm it cannot account for the anisotropy of the diamagnetic susceptibility of some aromatic molecules, which is observed when they are subjected to an external magnetic field perpendicular to their basal plane. Benzene is a standard example of that. Therefore, we propose an extension of the Hubbard model with an extra interelectronic momentum-momentum coupling which is an effective two-body interaction between the itinerant electrons mediated by virtual transitions of the binding electrons of our pseudo molecules. Our results show that this extension of the Hubbard model is able to cause an enhancement of the anisotropic diamagnetic susceptibility in some specific cases.

Quantum coherence and thermodynamics of non-equilibrium transport

Jianshu Cao

MIT, 77 Mass. Ave. 6-237A, Cambridge, USA

Nano-scale systems often display an intriguing quantum mechanical effect due to system-bath couplings, i.e. polaron effect. We demonstrate this non-trivial effect using the non-equilibrium spin-boson model [1-3] and three-level heat engine model [4-5]. Our analysis will shed light on the coherent nature in quantum transport and will be relevant for the design and control of nano-scale quantum devices. To carry out the above analysis, we adopt the polaron transformation [6] as a non-perturbative method for treating open quantum systems. In the polaron frame, the equilibrium distribution presents a deviation from the canonical distribution. Our polaron transformed Redfield equation (PTRE) bridges smoothly between the Redfield-Bloch equation in the weak coupling limit or Fermi's golden rule in the strong coupling limit, and provides a reliable and analytical method to calculate the non-equilibrium steady state [1-4].

[1] Nonequilibrium energy transfer at nanoscale: A unified theory from weak to strong coupling. C. Wang, J. Ren, and J. Cao, Sci. Rep. 5, p11787 (2015).

[2] Tuning the Aharonov-Bohm effect with dephasing in non-equilibrium transport. G. Engelhardt and J. Cao, Phys. Rev. B 99 (7), p075436 (2019).

[3] Frequency-dependent current noise in quantum heat transfer with full counting statistics. J. Liu, C.-Y. Hsieh, and J. Cao, JCP 148, p234104 (2018).

[4] Polaron effects on the performance of light-harvesting systems: A quantum heat engine perspective. D. Xu, C. Wang, Y. Zhao, and J. Cao, New J. Phys. 18, p023003 (2016).

[5] Efficiency at maximal power of laser quantum heat engine enhanced by quantum coherence. K. Dorfman, D. Xu, and J. Cao, PRE97 p042120 (2018).

[6] Non-canonical distribution and non-equilibrium transport beyond weak system-bath coupling regime: A polaron transformation approach. D. Xu and J. Cao, Front. Phys. 11, p1 (2016).

Metasurfaces: From flat optics to structured light

Federico Capasso

School of Engineering and Applied Sciences, Harvard University, 29A Oxford St., Cambridge 02138, USA

Subwavelength structured surfaces known as metasurfaces are leading to a fundamental reassessment of optical design with the emergence of optical components that circumvent the limitations of standard ones and with entirely new functionalities such as the ability to shape wavefronts in unprecedented ways by means of flat optics [1-4]. I will present recent advances on structured light: spin-to-total angular momentum converters (J-plates), which create complex helical beams with potential for applications in quantum optics and other fields [5], followed by resent research on polarization optics, broad band achromatic planar lenses and wavelength-controlled focusing and orbital angular momentum generation.

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On the physical meaning of the spin projection operator

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

Instituto de Física, UNAM, Mexico, Circuito de la Investigación Científica, CU, 04510 México, DF, Mexico

Spin is a fundamental property of the electron, and yet its physical essence remains nearly as enigmatic as it was a century ago. The successful use of the abstract matrix formalism in terms of Pauli matrices has somehow served to set aside the task of understanding its meaning. Dirac's relativistic generalization adds little to this situation. With the purpose of contributing to a local, realist description of the quantum phenomenon associated with spin, in this work we set out to delve into the physical meaning of the spin projection operator. The image obtained—on the basis of a careful reading of the quantum expressions—leads to relevant conclusions about the assumptions normally made in connection with the spìn correlation for the entangled bipartite singlet spin state, which severely restrict the range of applicability of the CHSH inequality.

The 2N+1 body problem: An impurity immersed in a strongly correlated fermionic superfluid

Frédéric Chevy

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

In my talk I will discuss some properties of an impurity immersed in a fermionic superfluid, a problem that generalizes the Fermi-polaron model that was studied extensively in the context of spin-imbalanced superfluid. I will present experimental and theoretical results on the lifetime and the energy of the impurity and I will highlight the role of three-body physics in the phase diagram of the system.

Surface acoustic wave phonons: Quantum control and quantum state transfer

Andrew N. Cleland

University of Chicago, Institute for Molecular Engineering, 5640 S Ellis Ave - Rm 235, Chicago 60637, USA

I will report on a recent experiment [1] using a superconducting qubit to probe the 4 GHz fundamental mode of a surface acoustic wave (SAW) resonator. This experiment builds on prior work coupling superconducting qubits to mechanical devices, here achieving full quantum control over the SAW resonant phonon mode and exceeding the control achieved over earlier bulk acoustic resonator-qubit experiments. The SAW device, fabricated on a lithium niobate substrate, was designed to have a single SAW mode centered at 4 GHz, with higher order modes outside the stop band of the SAW resonator mirrors. A superconducting qubit, coupled to the SAW resonator through an electrically controlled coupler element, was fabricated on a separate sapphire substrate, with the SAW device flip-chip bonded to the qubit chip. We used the qubit to characterize the SAW resonator admittance; measure the mode occupation with no excitation, in other words a quantum thermometry measurement; and generate one- and two-phonon Fock states, as well as measure the Wigner tomograms of the resonator in its ground state; with one phonon; and with a superposition state of zero and one phonons.

In more recent work, we have coupled two superconducting qubits to a long SAW resonator with a 500 ns phonon bounce time. We used this device to release and recapture individual itinerant phonons using one of the two qubits, as well as transfer quantum states between the two qubits. By sharing half a phonon between the two qubits (in other words, generating the qubit-phonon-qubit entangled state $|e0g\rangle+|g1g\rangle$, that on catching the itinerant phonon with the second qubit, transitions to the Bell state $|e0g\rangle+|g0e\rangle$), we were able to acoustically generate a high-fidelity Bell state between the two qubits [2].

[1] K. J. Satzinger et al., “Quantum control of surface acoustic wave phonons”, Nature 563, 661–665 (2018).

[2] A. Bienfait et al., “Phonon-mediated quantum state transfer and remote qubit entanglement”, submitted (2019).

Chaos, irreversibility and Hamiltonian hysteresis

Doron Cohen

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

In thermodynamics, irreversibility is invariably linked to non-adiabatic evolution. Consider a piston moving out and then back into a cylinder filled with gas. The extreme case is an abrupt process that leads to "free expansion" of the gas. Due to lack of adiabaticity, the evolving state expands into a thicker energy shell in phase-space (increase of entropy). Chaos is conceived as an essential ingredient, leading to the second law of thermodynamics: the growth of the entropy implies that no Hamiltonian driving protocol can restore the system to its original state.

Is chaos really a necessary ingredient, as conjectured by Boltzmann, in order to witness irreversibility in the quasi-static limit? Somewhat surprisingly, the answer is "No". Irreversibility can be obtained even for an integrable (non-chaotic) one degree of freedom system through a "separatrix-crossing" mechanism. The question arises what is the role of Chaos in irreversibility [1-3], and whether it can be probed experimentally.

We highlight the role of chaos in the analysis of Bose-Hubbard circuits. Specifically, we address themes that are related to BEC metastability [4], and irreversibility of quasi-static sweep processes. For non-linear adiabatic passage [2,3] the failure of adiabaticity is related to chaotic spreading away from the followed stationary point. In hysteresis experiment [1,5], the irreversibility of the backward-sweep process can be due to separatrix crossing (non-chaotic scenario), or due to interplay between different mechanisms for adiabatic evolution (Landau vs Ott), or due to diffusion across the energy surface (Kubo dissipation).

We clarify what are the distinct experimental fingerprints of each mechanism.

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[2] A. Dey, D. Cohen, A. Vardi, Adiabatic passage through chaos, Phys. Rev. Lett. 121, 250405 (2018).

[3] A. Dey, D. Cohen, A. Vardi, Many-body adiabatic passage: quantum detours around chaos, Phys. Rev. A 99, 033623 (2019).

[4] G. Arwas, D. Cohen, Monodromy and chaos for condensed bosons in optical lattices, Phys. Rev. A 99, 023625 (2019).

[5] R. Burkle, A. Vardi, D. Cohen, J.R. Anglin, How to probe the microscopic onset of irreversibility with ultracold atoms, arXiv 1903.04834.

Peltier cooling in molecular junctions

Juan Carlos Cuevas

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

With the advent of novel fabrication techniques in the 1980s and 1990s, it became possible to explore many physical phenomena at the nanoscale. Since then, a lot of progress has been done in the understanding of the electronic transport, mechanical, and optical properties of nanoscale devices. However, thermal transport in these systems has remained relatively unexplored because of the experimental difficulty to measure the flow of heat and energy at this small scale. In this talk, I will review our theoretical and experimental efforts to establish the fundamental laws that govern nanoscale thermal transport by using atomic and molecular junctions as a playground. In particular, I will discuss basic phenomena such as Joule heating [1] and Peltier cooling in molecular junctions [2].

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Bell non-locality in macroscopic systems

Bryan Dalton

Centre for Quantum and Optical Science, Swinburne University of Technology, John St, Melbourne, Victoria 3122, Australia
School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK

Focusing on bipartite systems, a brief review will be given of categorizing quantum states as either separable or entangled [1], or alternatively as Bell local or Bell non-local states based on local hidden variable theory (HVT) [2]. Various sub-categories of states display different features regarding EPR steering and Bell non-locality [2]. Finding states that are Bell non-local has long been recognised as important in regard to the long standing controversy between the Copenhagen quantum interpretation of the measurement process involving "collapse of the wave-function" and the alternative interpretation based on pre-existing hidden variables. Although experiments demonstrating Bell non-local in microscopic systems have now been carried out [3], there is current interest in finding Bell non-locality in quantum systems on a macroscopic scale, since in this regime a HVT might be expected to apply. Theoretical approaches towards finding macroscopic quantum states that violate Bell inequalities (such as in [4-8]) will be reviewed. A new test for Bell non-locality [9] applying when the sub-system measured quantities are spin components with large outcomes will be described, and applied to four mode systems of identical massive bosons in Bose-Einstein condensates.

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Nuclear slabs in terms of Green's functions: Collective oscillations with short-range correlations

Pawel Danielewicz[1], Hao Lin[1], Hossein Mahzoon[1,2], and Arnau Rios[3]

[1] *NSCL Cyclotron Laboratory, Michigan State University, 640 South Shaw Lane, East Lansing, 48824, USA*
[2] *Washington University in St. Louis, One Brookings Dr., St. Louis, MO 63130, USA*
[3] *University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom*

Nonequilibrium Green's functions (NGF) seem ideally suited for describing central nuclear reactions, but their use poses serious computational challenges. The attraction of NGF is in the opportunity to include on par the effects of short-range correlations, or collisions between nucleons, and the mean-field effects, in a consistent quantal framework. The computational challenge is in the double-space and double-time integrations within the approach. To progress with the application of NGF to the reactions, we start with nuclear systems modeled in one dimension and seek to develop approximations that may be carried over to two and three dimensions. We first switch on correlations adiabatically in infinite uniform systems at different densities and develop a combination of correlations and mean field that can yield systems saturated at normal density corresponding to the centers of nuclei. Upon constructing finite nuclear slabs, again through adiabatic switching, we study collective oscillations for these slabs, where neutrons move against protons, as common in highly excited nuclei. We compare the progress of oscillations between the situations with mean field only and mean field combined with short-range correlations. Finally, upon preparing two cold nuclear slabs, we slam them against each other, again without and with short-range correlations.

Strong entanglement criterion based on momentum weak values

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

Instituto de Física, UNAM, Apartado postal 20-364, Ciudad Universitaria, 01000 Mexico, DF, Mexico

Weak values have been used in recent years to explore various quantum features in novel ways. In this work we present a separate analysis of the real and imaginary parts of the weak value of the linear momentum operator, which are associated with the flow and the diffusive velocity, respectively. We then establish an entanglement criterion for a bipartite system, based on weak momentum correlations, which allows us to discern whether the entanglement is encoded in the amplitude and/or the phase of the wave function. Our results throw light on the physical role of the real and imaginary parts of the weak values, and serve to stress the relevance of the latter in the multi-particle scenario.

Quantum technology on GNSS

Hansjoerg Dittus

German Aerospace Center, Hansestr. 115, 51149 Koeln, Germany

More than 160 spacecrafts for global and regional navigation services (GNSS) are orbiting the Earth presently. As a result of fundamental research (quantum optics and gravitational physics), quantum technology are directly applied to the future GNNS-fleets and -constellations, vice versa the increasing precision of GNNS-systems can be used for fundamental physics experiments as well.

But quantum technology is not only used for navigation satellites. It is even applied on space platforms for carrying out many experiments for fundamental research, e.g. the ultra-precise observation of gravitational fields which has to be determined by measuring time, distances and accelerations, and by comparing the results in different inertial frames. During the last 15 years quantum optics and quantum engineering seemed and seems to become a powerful tool for inertial sensing in space. Space provides the possibility of carrying out quantum experiments over very large distances, along spacecraft orbits with highly varying velocities, and under weightlessness conditions resulting in long interrogation times. On the other side, quantum technology whose development has been mainly driven by scientific needs is expected to be used even for earth observation, satellite communication, and satellite geodesy.

The talk will focus on present and future application fields of quantum sensors and quantum technology in space and will give an overview of recent and past experiments in space.

Quantum heat engine with weak and strong coupled baths

Konstantin E. Dorfman

State Key Laboratory of Precision Spectroscopy, Department of Physics, East China Normal University, 3663, North Zhongshan Road, Shanghai, 200062, China

We investigate the effect of interplay between strong and weak coupling between the quantum system and the phonon bath. Typically multiple baths are coupled to the same energy transitions in a quantum heat engine. A four-level laser quantum heat engine has various transitions coupled to different baths. Polaron master equation is used and all the other components of dynamics such as dissipation, heat and work are also transformed to the polaron frame consistently. Asymptotic analytical formalism allows to understand the system dynamics and steady state behavior in the limiting cases of the strong and weak coupling. Power, efficiency and efficiency at maximum power show the effect of strong coupled bath and significantly enhanced bounds of the performance compared to the weak coupling regime.

Quantum themodynamics in cavity QED

Igor Dotsenko, Valentin Metillon, Michel Brune, and Jean-Michel Raimond

Laboratoire Kastler Brossel, Collège de France, 11 place Marcelin Berthelot, 75005 Paris, France

In my talk, I will present our latest results on quantum thermodynamics experiments realized in a cavity QED system. First, I will introduce our flexible cavity QED setup. We use two high-quality microwave cavities as "batteries" or "reservoirs", whose charge or temperature can be measured by a sequence of circular Rydberg atoms adjusted to measure the number of stored photons in a quantum non-demolition way. The batteries can be prepared either in a coherent or thermal state by means of an external microwave source with the controllable phase. Resonant atoms, crossing both cavities, are used to transfer heat from one cavity to the other. Depending on the experimental sequences, they can serve us as thermal reservoirs with variable temperature. The experimental apparatus allows us for the auxiliary manipulation of atoms at different moments during the experiment, eg before, in between and after the cavities. Atomic states are finally detected with high precision.

Our first experiment aims on realizing a variant of a "Maxwell's demon", where the heat from the colder reservoir is transferred to the hotter one by using demon's information on quantum fluctuations. The simplest scheme uses an autonomous demon – a resonant atom transferring a photon from cavity 1 to cavity 2 if and only if it carries a photon. Otherwise, it is transferred to an atomic level not coupled to the cavity 2 thus keeping the cavity-2 temperature unchanged without absorbing already present heat. In this way, we can unbalance the two cavity temperatures. The careful measurement of the transfers of energy, entropy and information between simple quantum entities, provides us an entropy budget in accordance with the second law. More generally, we target to derive and measure generalized fluctuation theorems in this new scenery, bringing new quantitative evidences of the energetic and entropic footprints associated to classical and quantum correlations.

Measures of contextuality and non-contextuality

Ehtibar N. Dzhafarov[1] and Janne V. Kujala[2]

[1]*Purdue University, 703 Third Street, West Lafayette 47907, USA*
[2]*University of Turku, FI-20014 Turun yliopisto, Finland*

(Non)contextuality is a basic property of any system of random variables labeled by their contents (that which they measure) and contexts (under what conditions they measure it). A system is consistently connected (obeys the "no-disturbance" or "no-signaling" requirement) if any two random variables with the same content are identically distributed. Empirical systems of random variables are usually inconsistently connected. The Contextuality-by-Default (CbD) theory provides a principled way of determining if a system, generally inconsistently connected, is contextual. We discuss different ways of constructing measures of (the degree of) contextuality for arbitrary systems of random variables. Two of them are developed within the framework of the CbD. We propose a third such measure, whose distinguishing feature is that it can be naturally extended to a measure of (the degree of) noncontextuality for systems found to be noncontextual.

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Quantum field simulators: How they evolve in time, how they can be read out, and in what way they may realize quantum thermal machines

Jens Eisert

FU Berlin, Arnimallee 14, Berlin 14195, Germany

Quantum systems out of equilibrium pose some of the most intriguing problems in quantum many-body physics, and presumably they constitute the basis for notions of quantum statistical mechanics [1, 2]. In this talk, we discuss in what precise way quantum many-body systems tend to equilibrium and provably relax to instances of maximum entropy states [3, 4]. Challenged by questions how such a behavior can be observed in the laboratory with quantum field simulators allowing for high levels of control, we will look at new ways of reading out such devices to achieve instances of quantum measurements [5]. We will end the talk by investigating the potential of using such quantum systems to realize genuinely quantum thermal machines [6].

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Universal dynamics far from equilibrium

Sebastian Erne[1,2,3], Robert Bücker[2,4], Thomas Gasenzer[3,5], Jürgen Berges[3], and Jörg Schmiedmayer[2]

[1] *University of Nottingham, School of Mathematical Sciences, University Park, Nottingham, NG7 2QL, United Kingdom*
[2] *Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, 1020 Vienna, Austria*
[3] *Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany*
[4] *Max Planck Institute for the Structure and Dynamics of Matter, Luruper Chaussee 149, Building 99 (CFEL), 22761 Hamburg, Germany*
[5] *Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany*

Understanding the behaviour of isolated quantum systems far from equilibrium and their equilibration concerns one of the most pressing open problems in quantum many-body physics. Here we report on the first experimental observations [1,2] of universal scaling dynamics far from equilibrium. In [1], following a strong cooling quench transferring a 3D ultra-cold Bose gas into a one-dimensional quasicondensate, the systems, during the course of its relaxation, exhibits universal scaling in time and space, associated with the approach of a non-thermal fixed point. The time evolution within the scaling period is described by a single universal function and scaling exponent, independent of the specifics of the initial state. The non-equilibrium evolution features the transport of an emergent conserved quantity in the scaling region, finally leading to the build-up of a quantum degenerate quasicondensate. Our results provide a quantum simulation in a regime, where to date no theoretical predictions are available and constitute a crucial step in the verification of universality far from equilibrium. If successful, this will provide a conceptually new access to time evolution based on a comprehensive classification of systems according to their universal properties far from equilibrium. This can be the basis for a new type of non-equilibrium quantum simulation relevant for a large variety of systems, including the early Universe after inflation, quark-gluon matter generated in heavy-ion collisions, and cold quantum gases.

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Hybrid spin-superconducting circuits for quantum technologies

Jessica Fernanda Da Silva Barbosa, Bartolo Albanese, Emanuele Albertinale, Marianne le Dantec, Moonjoo Lee, Milos Rancic, Vishal Ranjan, Emmanuel Flurin, Denis Vion, Patrice Bertet, and Daniel Esteve

Quantronics group, SPEC, CEA, CNRS, Université Paris-Saclay, CEA Saclay, 91191 Gif-sur-Yvette, France

Hybrid structures that combine spins and superconducting quantum circuits offer an appealing playground for developing various quantum technologies using the powerful tools of circuit Quantum Electrodynamics, noticeably high quality factor superconducting micro-resonators and Josephson parametric amplifiers that operate at the quantum limit when cooled at 20 mK [1]. We report a sizeable increase of the sensitivity of inductively detected Electron Spin Resonance (ESR), and we investigate a new resonance regime in which the quantum nature of the microwave field plays a role. We demonstrate the detection of 300 Bismuth donor spins in silicon with a signal-to-noise ratio of 1 in a single echo experiment [2-3], and a detection sensitivity of 10 spin/sqrt(Hz) achieved by making spin relaxation by spontaneous emission through the cavity, i.e. the Purcell effect, the dominant relaxation mechanism [4]. We show that the sensitivity can be further enhanced by using quantum squeezed states of the microwave field. Applications of this new regime to ultra-high-sensitivity nuclear spin detection and electron spin hyperpolarization will be also presented. For implementing quantum bits, electro-nuclear levels of spin impurities in insulators could provide quantum bits with excellent quantum coherence, which would alleviate the challenge of quantum error correction when operating a quantum processor. A preliminary experiment aiming at controlling a single electronic spin coupled to a microwave resonator will be described. The perspectives of hybrid routes for quantum computing will also be discussed in a broad perspective.

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Sub-second optical storage in an atomic frequency comb memory using dynamical decoupling

Adrian Holzäpfel, Jean Etesse, Kristov Kaczmarek, Alexey Tiranov, Nicolas Gisin, and Mikael Afzelius

Group of Applied Physics, Chemin de Pinchat, 22, Genève 4, 1211, Switzerland

The developement of devices like quantum memories is nowadays very active, as their existence opens prospects as well for the implementation of a quantum network as for the possibility to synchronize quantum resources [1]. However, the information stored in those memories always suffers from limited lifetime due to inevitable interactions with the environment.

Rare-earth ion doped crystals are very good candidates to implement these quantum memories, as the information can be stored in very protected degrees of freedom, limiting the aforementioned loss mechanisms. Even further, it has been recently shown that coherence times of up to 6 hours could be reached in europium doped YSO [2], by using dynamical decoupling sequences under specific magnetic field configurations called 'ZEFOS' points.

Following these observations, we have investigated the effect of dynamical decoupling sequences on an optical storage sequence using the atomic frequency comb protocol [3] under weak magnetic field configurations, and have shown that the storage time can be pushed from 1 ms up to 400 ms. These observations open new prospects in the possibility to use rare-earth ion doped crystals for long-term quantum information manipulation.

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Nonequilibrium spin phenomena in 2D materials

Jaroslav Fabian

University Regensburg, Department of Physics, 93040 Regensburg, Germany

2D materials such as graphene and transition-metal dichalcogenides offer excellent prospects for investigating spin dynamics and spin relaxation. A great variety of spin interactions is offered: spin-orbit coupling with the lattice ions and with impurities, exchange coupling with magnetic impurities, as well as spin-dependent coupling with phonons. In addition, there are proximity effects with other materials, changing the spin dynamics due to emergence of novel interactions, such as coupled Zeeman and valley spin-pseudospin dynamics. I will review the status of the field, introduce the basic mechanisms of spin dynamics and spin relaxation in 2d materials, and present recent examples of theoretical and experimental accomplishments. In particular, I will focus on the significant spin relaxation anisotropy and the effects of resonant scattering on spin relaxation.

Adiabatic quantum operations in systems of ultrastrongly coupled matter and radiation

Giuseppe Falci[1,2,3], Alessandro Ridolfo[1,3], Giuliano Benenti[4], and Elisabetta Paladino[1,2,3]

[1] *Dipartimento di Fisica e Astronomia "Ettore Majorana", Universita' di Catania, Via Santa Sofia 64, Catania I-95125, Italy*
[2] *CNR-IMM MATIS Catania, Via Santa Sofia 64, Catania I-95125, Italy*
[3] *INFN Sezione di Catania, Via Santa Sofia 64, Catania I-95125, Italy*
[4] *Center for Nonlinear and Complex Systems, Dipartimento di Scienza e Alta Tecnologia, Università dell'Insubria, Como, Italy*

Ultrastrong coupling (USC) between light and matter has been recently achieved in architectures of solid state artificial atoms coupled to cavities. In this regime new phenomena related to the highly entangled eigenstates appear. They contain virtual photons whose detection is a key issue in the field. A protocol basrd on STIRAP [1] is proposed to achieve coherent amplification of the conversion of virtual to real photons in present-day superconducting hardware [2]. Our protocol also provides a feasible road to demonstrate another "holy grail" in the field, namely dynamics in real USC structures,

Such architectures may provide new building blocks for quantum state processing, where ultrafast quantum gates can be performed. However in the USC regime the dynamical Casimir effect (DCE) poses severe limits on the fidelity of quantum operations based on quantum Rabi oscillations [3], used for processing in strongly coupled (SC) circuit-QED systems, since multiphoton generation deteriorates the fidelity even in absence of decoherence [3]. We show that a STIRAP-like adiabatic protocol overcomes this problem [4]. Ideally the cavity is never populated, operating as a virtual bus, thus it is expected to greatly reduce the impact of DCE. Indeed we show that high fidelity operations can be performed for moderate couplings in the USC regime [3], and that properly crafted control extends the high fidelity performance to even larger couplings. The protocol is extremely robust agaist DCE, in the absence of decoherence yields almost 100% fidelity for remote population and state transfer. It is also resilient to decay due to leakage from the cavity, which is the main decoherence mechanism for present USC architectures [3]. In this more realistic scenario it is seen that for larger coupling (entering the deep strong coupling regime) the fidelity decreases due to the interplay between decoherence and DCE. Our results suggest that adiabatic manipulations, may be a promising tool for quantum state processing in the USC regime.

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Exotic criticality and symmetry-protected topological states in dimerised fermion, boson and spin chain models

Satoshi Ejima[1], Fabian H. L. Essler[2], Florian Lange[1], Yukinori Ohta[3], Koudai Sugimoto[3], Tomoki Yamaguchi[3], and Holger Fehske[1]

[1]*Institute of Physics, University Greifswald, 17489 Greifswald, Germany*
[2]*Rudolf Peierls Centre for Theoretical Physics, Oxford University, Oxford OX1 3NP, UK*
[3]*Center for Frontier Science, Chiba University, Chiba 263-8522, Japan*

Combining numerical density-matrix renormalisation group techniques and field theory we analyse the ground-state properties of several paradigmatic dimerised quantum lattice models in one dimension. First, we explore the quantum phase transition (QPT) between Peierls and density-wave (DW) states in the half-filled, extended Hubbard model with explicit bond dimerisation. We show that the critical line of the continuous Ising transition terminates at a tricritical point, belonging to the universality class of the tricritical Ising model with central charge c=7/10. Above this point, the QPT becomes first order. The entanglement spectrum shows that dimerised Peierls insulator is a symmetry-protected topological (SPT) state. By menas of bosonisation we describe the transition region in terms of a triple sine-Gordon model. The field theory predictions for the power-law (exponential) decay of the density-density (spin-spin) and bond-order-wave correlation functions are in excellent agreement with our numerical data. Secondly, we consider the dimerised extended Bose-Hubbard model and show that an SPT Haldane insulator appears between dimerised Mott and DW insulating phases, at weak Coulomb interactions, for filling factor one. Analysing the critical behaviour of the model, we prove that the phase boundaries of the Haldane phase to Mott insulator and DW states belong to the Gaussian and Ising universality classes with c=1 and c=1/2, respectively, and merge in a tricritical point. Furthermore we demonstrate a direct Ising QPT between the dimerised Mott and DW phases above the tricritical point. Thirdly, we demonstrate that a nontrivial SPT Haldane phase also exists in dimerised spin-1 XXZ chain with single-ion anisotropy D, up to a critical dimerisation above which the Haldane phase disappears. In addition the ground-state phase diagram exhibits large-D and antiferromagnetically ordered phases. Again, for weak dimerisation, the phases are separated by Gaussian and Ising QPTs. One of the Ising transitions terminates in a critical point in the universality class of the dilute Ising model. We comment on the relevance of our results to experiments on quasi-one-dimensional anisotropic spin-1 quantum magnets.

[1] S. Ejima, F. H. L. Essler, F. Lange, and H. Fehske, Phys. Rev. B 93, 235118 (2016).

[2] S. Ejima, T. Yamaguchi, F. H. L. Essler, F. Lange, Y. Ohta, and H. Fehske, SciPost Phys. 5, 059 (2018).

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T42 Wed, 17 July, 10:40 - 11:10, 2 session - C parallel

Quantum and stochastic physics of instable systems

Radim Filip

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

The talk will present recent theoretical and experimental results in stochastic and quantum analysis of highly unstable systems including stochastic and quantum interference phenomena in cubic potential. The experimental data from quantum optics and optomechanics will be discussed.

Many-body dynamic localization effect in periodically driven finite clusters of spins 1/2 without disorder

Boris V. Fine[1,2] and Kai Ji[1,3]

[1] *Skolkovo Institute of Science and Technology, Skolkovo Innovation Center, Nobel Str. 3, Moscow, Russian Federation*
[2] *Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany*
[3] *Department of Physics, Shanghai Normal University, No. 100 Guilin Road, 200234 Shanghai, China*

We investigate numerically and analytically the heating process in ergodic clusters of interacting spins 1/2 subjected to periodic pulses of an external magnetic field. Our findings indicate that many-body dynamic localization manifests itself as a cluster-size-dependent threshold for the pulse strength below which the heating is suppressed. This threshold decreases with the increase of the cluster size, approaching zero in the thermodynamic limit. Nevertheless, it should be observable in clusters with fairly large Hilbert spaces. We obtain the above threshold quantitatively as a condition for the breakdown of the golden rule in the second-order perturbation theory.

[1] K. Ji and B. V. Fine, Phys. Rev. Lett. 121, 050602 (2018).
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T44 Fri, 19 July, 13:30 - 14:00, 3 session

The minimal effective Gibbs ansatz (MEGA): A quantum computing framework for determining many-body correlation functions at nonzero temperature

James K. Freericks[1], Jeffrey Cohn[1], Forest Yang[2], Khadijeh Najafi[1,3], and Barbara A. Jones[4]

[1] *Georgetown University, Department of Physics, 37th and O St, Georgetown University, Washington, USA*
[2] *University of California, Berkeley, Departments of Computer Science and Physics, Berkeley, CA, USA*
[3] *Virginia Tech, Department of Physics, Roanoke, VA, USA*
[4] *IBM Almaden Research Center, Almaden, CA, USA*

Quantum Gibbs state sampling algorithms generally suffer from either scaling exponentially with system size or requiring specific knowledge of spectral properties a priori. These algorithms also require a large overhead of bath or scratch/ancilla qubits. We propose a method, termed the minimal effective Gibbs ansatz (MEGA), which uses a quantum computer to determine a minimal ensemble of pure states that accurately reproduce thermal averages of an objective dynamic correlation function. This technique employs properties of correlation functions that can be split into a lesser and greater parts; here, we primarily focus on single-particle Green's functions and density-density correlators. When properly measured, these correlation functions provide a simple test to indicate how close a given pure state or ensemble of pure states are to providing an accurate thermal expectation values. Further, we show that when properties such as the eigenstate thermalization hypothesis hold, this approach leads to accurate results with a sparse ensemble of pure states; sometimes only one suffices. We illustrate the ansatz using exact diagonalization simulations on small clusters for the Fermi-Hubbard and Hubbard-like models. Even if MEGA becomes as computationally complex as other Gibbs state samplers, it still gains an advantage due to its ease of implementation without any a priori information about the Hamiltonian and in the efficient allocation of available qubits by eliminating bath qubits and using a minimal number of ancilla.

[1] Jeffrey Cohn, Khadijeh Najafi, Forest Yang, Barbara Jones, James K. Freericks, Minimal Effective Gibbs Ansatz (MEGA): A simple protocol for extracting an accurate thermal representation for quantum simulation, arxiv:1812.03607 (2018).

A diffuse reflecting material for optical studies

Edward S. Fry and John Mason

Texas A&M University, 4242 TAMU, College Station 77843, USA

Our laboratory developed a new diffuse reflecting material several years ago. It has significantly higher diffuse reflectivity in the visible than that of the best previous diffuse reflector known as Spectralon. At 532 nm this new diffuse reflector has provided a 99.92% diffuse reflectivity, compared to only 99.4% for Spectralon. At first glance that may not seem much better, but the relevant parameter is 100% minus the reflectivity; and on that basis, the new material is a factor of 8 better! In the near ultraviolet the improvement is even better. At 250 nm Spectralon has a diffuse reflectivity of 94%, whereas this new diffuse reflecting material has a reflectivity that exceeds 99.6% at 250 nm.

This new material is opening new research vistas. It can be used to make a state-of-art integrating cavity (a closed container whose wall is the diffuse Lambertian reflector). When a sample is placed in an integrating cavity and illuminated by a beam of light, the result of the multiple reflections of the light from the cavity walls is that the light makes many, many transits through the sample, i.e. the effective path length through the sample far exceeds the dimensions of the sample. For example, the effective path length through a sample that fills a spherical cavity of radius 7.5 cm is about 100 meters when the wall reflectivity is 99.9%. The result is a very high sensitivity to very weak absorption as well as to other light-matter interactions. In addition, since the diffuse reflecting walls of the cavity produce an isotropic illumination of the sample, the spectral absorption measurements are not affected by light scattering in the sample. The latter is very important in many cases; e.g. measurements of water samples, biological samples, etc. This technique was recently used to make the first reliable measurements of the optical absorption of pure water into the UV down to 250 nm.

In another research direction, integrating cavities made from this new diffuse reflecting material have been used to significantly enhance both the excitation and the 4 π collection of the Raman fluorescence from a sample. The detection of sub-femto molar concentrations of urobilin were demonstrated (this corresponds to a capability of detecting the presence of 10 ml of urine in a typical swimming pool).

An exceptionally high sensitivity technique for absorption spectroscopy is cavity ring down spectroscopy (CRDS) in a 2 mirror cavity. Due to the high diffuse reflectivity of this new material, CRDS in an integrating cavity (ICRDS) is now possible. ICRDS opens another new research capability by providing extremely sensitive and accurate direct spectral absorption measurements of both a sample and any particulates suspended in it, while being unaffected by the scattering in the sample. ICRDS has recently been demonstrated in measurements of the very weak spectral absorption of highly scattering biological samples (e.g. at 600 nm the scattering coefficient was more than 500 times larger than the absorption coefficient).

T46 Thu, 18 July, 15:20 - 15:50, 4 session

Things we are still learning about uniform acceleration

Stephen A. Fulling

Texas A&M University, Mathematics Dept., 3368 TAMU, College Station 77843-3368, USA

Radiation by an accelerated charge, especially a uniformly accelerated one, has been the subject of debate for almost a century. It obviously must have some connection with the Unruh-Wald radiation from an accelerated detector, and with the Moore-DeWitt radiation from an accelerated mirror, but the details of those relationships have never been entirely clear. In the early '90s, Higuchi, Matsas, and Sudarsky, and then Ren and Weinberg, studied the quantum radiation from a prescribed c-number charge by perturbation theory in both inertial and uniformly accelerated frames; they found that consistency requires that in the latter case a contribution of the Unruh thermal bath (via absorption and stimulated emission) must be included. Recently, Landulfo, Matsas, and I have reopened the investigation, using the basis of "Unruh modes" that factors the Bogolubov transformation between Minkowski and Rindler modes into a unitary transformation and a diagonal one. This analysis makes the consistency between classical radiation and quantum transition amplitudes more manifest. An important observation is that the radiation is visible as such only outside the Rindler wedge, in the sense that inside the wedge the retarded and advanced solutions coincide; this is the classical counterpart of the quantum observation that the transition probability vanishes except for Rindler zero-frequency modes, which are localized on the horizon. The final state is a coherent state whose field expectation value equals the classical retarded solution. If time permits, I will review "ancient" and modern developments concerning accelerated mirrors, accelerated detectors, and atoms falling into or supported near black holes.

Nonadiabatic molecular dynamics at surfaces and interfaces

Abraham Nitzan[1,2] and Michael Galperin[3]

[1]*University of Pennsylvania, USA*
[2]*Tel Aviv University, Israel*
[3]*University of California San Diego, USA*

Nonadiabatic molecular dynamics is a fundamental problem related to breakdown of the usual timescale separation between electron and nuclear dynamics. It plays an important role in many processes from chemistry and photochemistry to spectroscopy and nonradiative electronic relaxation and from electron and proton transfer to coherent control and photo-induced energy transfer. The significance of the problem stems from both the complexity of its fundamental theoretical description and applicational importance for development of optoelectronic and optomechanical molecular devices.

A crucial part of formulating nuclear dynamics at surfaces and interfaces is the definition of nuclear forces induced by the electronics subsystem. We present general first-principles derivation of the expression for current-induced forces. The expression is applicable in nonequilibrium molecular systems with arbitrary intramolecular interactions and for any form and strength of electron-nuclei coupling. It provides a controlled consistent way to account for quantum effects of nuclear motion around a classical trajectory, accounts for electronic non-Markov character of the electronic friction tensor, and suggests a method for treatment beyond strictly adiabatic approximation. Results of previous considerations are obtained form our general expression as particular limiting cases. We discuss effective ways to evaluate electronic friction tensor using recently introduced by us nonequilibrium Hubbard diagrammatic technique. The discussion is illustrated with numerical simulations employing a generic junction model.

Because full quantum mechanical solution of electron-nuclear dynamics is prohibitively expensive, one has to rely on quasi-classical approximations. Two most popular approaches are the Ehrenfest dynamics and the fewest switches surface hopping (SH) method. While the former can be obtained as expansion around classical solution, the latter is formulated in an ad hoc manner. We argue that one can overcome difficulties in derivation of the SH by employing a many-body flavor of the nonequilibrium Green's function technique. We derive a set of equations which reproduce the SH formulation in the limit of small metal-molecule coupling and the Ehrenfest dynamic when information on different charging states is traced out. This provides, for the first time, a theoretical basis for the surface hopping method as a limiting case of an exact equation of motion.

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Weak measurement induced geometric phase: A topological transition

Valentin Gebhart[1], Kyrylo Snizhko[2], Thomas Wellens[1], Andreas Buchleitner[1], Alessandro Romito[3], and Yuval Gefen[2]

[1]*Physikalisches Institut, Albert-Ludwigs-Universitat Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany*

[2]*Department of condensed Matter, Weizmann Institute, Rehovot, 76100, Israel*

[3]*Department of Physics, Lancaster University, Lancaster LA1 4YB, United Kingdom*

The state of a quantum system, adiabatically driven in a cycle, may acquire a measurable phase depending only on the closed trajectory in parameter space. Such geometric phases are ubiquitous, and also underline the physics of robust topological effects such as the quantized Hall conductance. Equivalently, a geometric phase may be induced through a cyclic sequence of quantum measurements. Here we show that the application of a sequence of weak measurements renders the closed trajectories, hence the geometric phase, stochastic. We study the probability distribution of the geometric phase induced by a suitably designed sequence of measurements of a qubit. We show that the mapping between the sequence of measurements and the geometric phase undergoes a topological transition as function of the measurement strength. Our finding will impact the study of measurement-induced state distillation, trajectory manipulation, and active error correctionlall crucial directions in the field of quantum information processing.

Non-locality in quantum networks

Nicolas R. Gisin

University of Geneva, 22 chemin de Pinchat, Carouge, 1227, Switzerland

Quantum non-locality, i.e. the violation of some Bell inequality, has proven to be an extremely useful concept in analyzing entanglement, quantum randomness and cryptography, among others. In particular, it led to the fascinating field of device-independent quantum information processing. Historically, the idea was that the particles emitted by various quantum sources carry additional variables, known as local hidden variables. The more modern view, strongly influenced by computer science, refers to these additional variables merely as shared randomness. This, however, leads to ambiguity when there is more than one source, as in quantum networks. Should the randomness produced by each source be considered as fully correlated, as in most common analyses, or should one analyze the situation assuming that each source produces independent randomness, closer to the historical spirit? The latter is known, for the case of n independent sources, as n-locality. For example, in entanglement swapping there are two sources, hence "quantumness" should be analyzed using 2-locality (or, equivalently, bi-locality). The situation when the network has loops is especially interesting. Recent results for triangular networks will be presented.

T50

Fri, 19 July, 14:00 - 14:30, 3 session

A Josephson relation for e/3 and e/5 fractionally charged anyons

Christian Glattli[1], Maelle Kapfer[1], Preden Roulleau[1], Matthieu Santin[1], Ian Farrer[2], and David Ritchie[2]

[1]*Service de Physique de l'Etat Condensé, Un. Paris-Saclay, CEA Saclay, 91191 Gif-sur-Yvette, France*
[2]*Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, UK.*

Anyons occur in two-dimensional electron systems as excitations with fractional charge in the topologically ordered states of the fractional quantum Hall effect (FQHE). Their dynamics are of utmost importance for topological quantum phases and possible decoherence-free quantum information approaches, but observing these dynamics experimentally is challenging.

Here, we report on a dynamical property of anyons: the long-predicted Josephson relation fJ = e*V/h for charges e* = e/3 and e/5, where e is the charge of the electron and h is Planck's constant [1]. The relation manifests itself as marked signatures in the dependence of photo-assisted shot noise (PASN) on voltage V when irradiating contacts at microwaves frequency fJ. The validation of FQHE PASN models indicates a path toward realizing time-resolved anyon sources based on levitons. The method may be of interest to provide a demonstration of anyonic statistics, a pre-requisite for topological quantum computing.

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Optimal control for quantum metrology

Sebastien Gleyzes[1], Arthur Larrouy[1], Sabrina Patsch[2], Rémi Richaud[1], Jean Michel Raimond[1], MIchel Brune[1], and Christiane Koch[2]

[1]*Laboratoire Kastler Brossel, College de France, CNRS, ENS-Universite PSL, Sorbonne Universite, 11 Place Marcelin Berthelot, 75005 Paris, France*
[2]*Theoretical Physics, University of Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany*

Rydberg atoms are extremely sensitive to their electromagnetic field environment, which make them a very promising tools for metrology. Rydberg atoms can be described by the model of the hydrogen atom. By applying a small static electric field, it is possible to partially lift the degeneracy between same n levels. The new sublevel forms a regular structure. It is possible to manipulate the state of the atom using a rf field with a well-defined polarization to prepare states with large electric or magnetic dipole. In our experiment, we generate Schrödinger cat states of the Rydberg atom of rubidium by preparing quantum superposition of two trajectories with very different classical property. The relative phase of the superposition is very sensitive to the variations of the probe environment, which allows us to measure electric or magnetic field with a very good sensitivity. However, the preparation fidelity is limited by the actual energy structure of rubidium, which is much more anharmonic than that of hydrogen. I will show how implementing RF pulse shape that have been optimized by the University of Kassel using Optimal Control Theory allowed us to drastically improve the efficiency of our pulses.

Single-atom lasing in normal-superconductor quantum dots

Michele Governale[1] and Gianluca Rastelli[2]

[1] *Victoria University of Wellington, Wellington, New Zealand*
[2] *Universität Konstanz and Zukunftskolleg, Konstanz, Germany*

Nanostructures coupled to quantum resonators have recently attracted a large theoretical [1,2] and experimental interest [3,4]. Quantum dots, due to their tunability and the availability of highly advanced fabrication and characterisation techniques, are an ideal platform to explore single-atom lasing [5]. The possibility of inducing superconducting correlations in the dot opens up new routes to achieve lasing in these nanoscale systems. We study a single-level quantum dot strongly coupled to a superconducting lead and tunnel coupled to a normal electrode, which can exchange energy with a single-mode resonator. This device can be experimentally realised either as an electromechanical system or as a photon cavity. By means of the Linblad-equation formalism, we present a theory for lasing in this hybrid nanostructure. We find that the semiclassical mean-field equations differ from the text-book result. We derive the threshold coupling and the saturation occupation of the resonator mode, as well as the full Fock-state occupation distribution. The onset of lasing is clearly identifiable in the transport characteristics of the quantum dot.

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A journey through quantum measurement paradigms: From weak measurements to protective measurements, and more

E. Rebufello[1], S. Virzì[1], A. Avella[1], F. Piacentini[1], R. Lussana[2,4], El. Cohen[4], G. Brida[1], L. Vaidman[3], A. Tosi[2,4], Marco Gramegna[1], I. P. Degiovanni[1], and M. Genovese[1]

[1]*INRiM - Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce, 91, Torino - 10135, Italy*
[2]*Politecnico di Milano, Italy*
[3]*Tel Aviv University, Israel*
[4]*University of Ottawa, Canada*

The Measurement Problem represents a fundamental aspect in quantum theory. Quantum mechanics allows for different measurement protocols. In recent years a peculiar paradigm has gained interest among physicist, namely, the weak measurements (WMs), in which the measurement is operated with an interaction sufficiently weak not to collapse the original state. These kind of measurements result firstly in weak values [1-4], exploited in experiments spanning from fundamental [5-7] to applied physics, and resulting as a powerful tool for quantum metrology [8]. Moreover, protective measurements (PMs) [8] have been experimentally demonstrated [9] as a new technique able to extract information on the expectation value of an observable even from a single measurement on a single (protected) particle. In addition, other novel measurement protocols have stemmed from these measurement paradigms, exploiting a recursive measurement paradigm where some analogies with the typical mechanisms of genetic algorithms [10] appear, yielding uncertainties even below the level fixed by the quantum Cramer-Rao bound for the traditional prepare-and-measure scheme. We present the first experimental implementation of PM [9], together with preliminary experimental results related to aforementioned new protocols actually under investigation in our laboratories.

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Potential energy surfaces and Berry phases beyond the Born-Oppenheimer approximation

Eberhard K.U. Gross

Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle (Saale), Germany
Fritz Haber Center for Molecular Dynamics, Institute of Chemistry, The Hebrew University of Jerusalem, 1904 Israel

Some of the most fascinating phenomena in Chemistry and Physics, such as the process of vision, exciton dynamics in photovoltaic systems, as well as phonon-driven superconductivity occur in the regime where the non-adiabatic coupling of electronic and nuclear motion is essential. To tackle such situations, one has to face the full Hamiltonian of the complete system of electrons and nuclei. We deduce an exact factorization [1] of the full electron-nuclear wavefunction into a purely nuclear part and a many-electron wavefunction which parametrically depends on the nuclear configuration and which has the meaning of a conditional probability amplitude. The equations of motion for these wavefunctions lead to a unique definition of exact potential energy surfaces as well as exact geometric phases, both in the time-dependent and in the static case. We discuss a case where the exact Berry phase vanishes although there is a non-trivial Berry phase for the same system in Born-Oppenheimer approximation [2], implying that in this particular case the Born-Oppenheimer Berry phase is an artifact. In the time-domain, whenever there is a splitting of the nuclear wavepacket in the vicinity of an avoided crossing, the exact time-dependent surface shows a nearly discontinuous step [3]. This makes the classical force on the nuclei jump from one to another adiabatic surface, reminiscent of Tully surface hopping algorithms. Based on this observation, we propose novel mixed-quantum-classical algorithms whose unique feature is that the trajectories are coupled. Without recourse to Tully surface hopping and without any added decoherence correction, the new algorithm provides a rather accurate, (much improved over surface hopping) description of decoherence [4]. This is demonstrated for the photo-induced ring opening of oxirane [5]. We present a multi-component density functional theory [6] that provides an avenue to make the fully coupled electron-nuclear system tractable for very large systems.

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On the critical temperature for the superconducting transition

Michael Guidry

University of Tennessee, Department of Physics and Astronomy, 3552 Navigator Pointe, Knoxville, USA

Recently it has been demonstrated that certain compounds under high pressure exhibit a more conventional Migdal-Eliashberg-BCS type of superconductivity, with remarkably high critical temperatures for the superconducting transition. Practically this has kindled new interest in the possibility of room-temperature superconductors, and more fundamentally has put a renewed focus on understanding the physics controlling the critical temperature for a transition to superconductivity in particular compounds. I will argue that there are two fundamental principles that govern the temperature of this transition in a given compound: (1) The intrinsic strength of the pair-binding coupling, and (2) the effect of the many-body environment on the efficiency of that coupling. Most discussions take into account only the first, but I will argue that the essential properties of unconventional superconductors are governed more by the second. Understanding the interplay of these effects is essential to charting a path to the highest-temperature superconductors.

Directed particle flow at zero bias induced by random versus periodic drive

Shmuel Gurvitz

Weizmann Institute, Rehovot 76100, Israel

Using a new developed Single-Electron approach, we derive the Landauer-type formula for electron transport in arbitrary time-dependent potentials. This formula is applied for randomly fluctuating potentials represented by a dichotomic noise. It is found that the noise can induce dc-current in quantum system under zero-bias voltage by breaking the time-reversal symmetry of transmission coefficients. We show that this effect is a result of decoherence, produced by the noise, and therefore can be found in many different systems. In the case of periodic drive, our approach yields the same dc-current in the adiabatic limit, as known in the literature. However, in the asymptotic (steady-state) limit, beyond the adiabatic approximation, our approach predicts no directed net current, but only periodic oscillations of the average current around zero. This result is demonstrated analytically on particular examples and it is proven for general case by using Floquet expansion and time-reversal symmetry of transmission coefficients for time-independent Hamiltonian.

Thermalization as an invisibility cloak for fragile quantum superpositions

Walter Hahn[1,2] and Boris V. Fine[2,3]

[1]*QuTech, Delft University of Technology, Lorentzweg 1, Delft, Netherlands*
[2]*Skolkovo Institute of Science and Technology, Skolkovo Innovation Centre, Nobel Street 3, Moscow 143026, Russia*
[3]*Institute for Theoretical Physics, Philosophenweg 12, 69120 Heidelberg, Germany*

We propose a method for protecting fragile quantum superpositions in many-particle systems from dephasing by external classical noise. We call superpositions “fragile” if dephasing occurs particularly fast, because the noise couples very differently to the superposed states. The method consists of letting a quantum superposition evolve under the internal thermalization dynamics of the system, followed by a time-reversal manipulation known as Loschmidt echo. The thermalization dynamics makes the superposed states almost indistinguishable during most of the above procedure. We validate the method by applying it to a cluster of spins 1/2.

Anomalous heat diffusion

Peter Hänggi

University of Augsburg, Department of Physics, Universitätsstrasse 1, 86135 Augsburg, Germany

In low dimensional systems the transport of heat in form of diffusive spread or heat flux between reservoirs of differing ambient temperatures typically may exhibit anomalous features such as the violation of the Fourier Law with length-dependent heat conductivities or the diffusive spread of heat that occurs faster than normal. Here we will discuss results and open issues (!) how the dynamics of energy spread occur-ring in one-dimensional nonlinear lattices relates to anomalous diffusion behavior and heat conductivities. Moreover we explain how the carriers of heat, typically referred to as phonons, may be given meaning in a regime with nonlinear interaction forces beyond the ballistic behavior originating from solely harmonic (linear) interaction forces. The underlying physical mechanism of scattering then renders corresponding mean free paths of such effective phonons finite.

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From the Lamb dip to the proton radius puzzle

Theodor W. Hänsch

Faculty of Physics, Ludwig-Maximilian-University, Munich, Germany
Max-Planck Institute of Quantum Optics, Garching, Germany

The discovery of the Lamb dip in the early days of the laser inspired Doppler-free saturation spectroscopy of atomic and molecular gases. Since the first Doppler-free laser spectroscopy of the Hydrogen Balmer-alpha line in 1972, the accuracy of laser-spectroscopic measurements in atomic hydrogen has advanced by 8 orders of magnitude, approaching the limit set by the definition of the unit of time. Spectroscopic measurements of hydrogen resonances permit tests of quantum electrodynamic theory, they yield values of the Rydberg constant and the proton charge radius, and they provide a reference for laser spectroscopy of antihydrogen and of other hydrogen-like exotic atoms, notably muonic hydrogen and muonic deuterium. The rms proton charge radius as derived from laser measurements of the 2s-2p Lamb shift in muonic hydrogen some years ago is about 4% smaller than that obtained from hydrogen spectroscopy or electron scattering experiments. This “proton size puzzle” has not yet been resolved. Current experiments in our laboratory aim to confirm or resolve this puzzle.

Nanodiamonds and nanophosphors for quantum enhanced bio-sensing

Philip Hemmer

Texas A&M University, 3128 TAMU, College Station, USA

In this talk I highlight new ways to grow diamond that promise near-deterministic design of fluorescent color-centers, optimized for quantum-enhanced sensing. Briefly, diamonds are grown around diamond-like organic seed molecules to give unprecedented control over the number and placement of color centers. I also discuss our plans to grow complete quantum registers, inside nanodiamonds, by this technique. Finally I show how nanophosphors, primarily those employing upconversion, can be combined with nanodiamonds for multi-modal biosensing applications, using the example of local temperature sensing.

Ultrafast quantum nanophotonics: From nanoplasmonic strong coupling to quantum chaos in semiconductor lasers

Ortwin Hess

Imperial College London, The Blackett Laboratory, Department of Physics, South Kensington Campus, London, United Kingdom

Enabled by progress in nanoscience and nanomaterials technology, nanoplasmonics and metamaterials have in the last 15 years inspired scientists to think about waves beyond traditional constraints imposed by materials in which they propagate to conceive functionalities. Concurrently, photonic quantum science is, particularly through a link with nano-plasmonics, progressing from its predominantly lab-based science base involving simple systems into the practical world, vividly evident through breakthroughs such as the recent demonstration of nanoplasmonic and near-field strong coupling at room temperature [1,2] and nanoscale ultraslow light [3]. Using the optical near-field with active quantum materials opens up new domains for science, materials physics and engineering, providing the foundation for novel photonic quantum technologies while linking up with the engineering, communication, security, energy and health care sciences and technologies. The talk will highlight some of the compelling new opportunites: (1) Ultrafast nanoplasmonic near-field photonics. Strong coupling of single quantum emitters (active molecules, quantum dots, etc) with light is of key importance for all photonic quantum technologies and may lead to new types of quantum sensors. Nanoplasmonics offers an innovative route route to realistic photonic quantum technologies, particularly strong coupling quantum technologies [1,2], quantum spectroscopy and ultrafast nano-chemistry. (2) Topological quantum metamaterials: Designing photonic and electronic metamaterials with topological near-field protection against disorder and materials-level functionalities provides the blue-print for symmetry protected near-zero-index materials and technologies [4]. (3) Chaotic near-field laser-dynamics: Combining concepts from the fields of (semiconductor) laser chaos and near-field wave-dynamical chaos providing a pathway to fight (chaotic) semiconductor laser instabilities by near-field optical chaos. We will show that this whole new research direction which will impact many fields dealing with complex spatio-temporal dynamics [5].

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Quantum probability theory and the arrow of time

Rudolf Hilfer

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

The nature of (macroscopic) events and decoherence in quantum probability theory is believed to be closely related to the arrow of time and incomplete information about the past [1]. Contrary to this quantum arrow of time in quantum probability theory a quantum and classical arrow of time arises from coarse graining time evolution operators while also restricting them to a subset of states of vanishing measure [2]. The resulting coarse grained time evolution operators are convolution operators forming a semigroup. The infinitesimal generator of the resulting semigroup has applications to experiment [3].

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Topological quantum gravity of the Ricci flow

Petr Hořava

Berkeley Center for Theoretical Physics, University of California, Berkeley & Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

We present a topological quantum gravity associated with the Hamilton-Perelman theory of Ricci flows on Riemannian manifolds. This construction leads to a nonrelativistic quantum gravity of the Lifshitz type, quantized as a topological theory using the BRST formalism. In its most primitive form, the theory reproduces Hamilton's original Ricci flow. When extended into a gauge theory of foliation-preserving diffeomorphisms of nonrelativistic spacetime, the theory leads to Perelman's Ricci flow, with the role of Perelman's dilaton played by the nonprojectable lapse function. Perelman's entropy F- and W-functionals appear as our superpotential. Precise mathematical results in the literature about Ricci flows (especially in 3+1 dimensions) can be imported into this physical theory, and interpreted in terms of topology changing amplitudes and other far-from-equilibrium phenomena in controllable quantum theory of gravity and cosmology. Since there is no spin-statistics theorem in nonrelativistic systems, our theory can be interpreted after continuation to real time as a theory of propagating nonrelativistic supergraviton degrees of freedom on time-dependent backgrounds.

Quantum thermodynamics from the nonequilibrium dynamics of open systems

Bei-Lok Hu and Jen-Tsung Hsiang

University of Maryland, College Park, USA

Quantum Thermodynamics [1] in a stricter sense is the study of the thermodynamical properties of quantum many-body systems. In fusing the two terms quantum and thermodynamics together it exposes the intrinsic dislocations or even contradictions, namely, while quantum deals with the microscopic world and quantum features manifest usually at low or zero temperatures, thermodynamics is formulated mainly in the context of classical phenomena, restricted to the macroscopic realm, and functions better at high enough temperatures where thermal properties prevail over quantum. What makes quantum thermodynamics interesting is precisely because of these dislocations. They bring out foundational issues at the micro-macro (m-M) and the quantum-classical (q-C) interface. A basic approach which can unify these aspects and enables one to see the emergence of thermodynamics for quantum systems is by studying the nonequilibrium dynamics of open quantum systems. Using a Brownian motion model which is exactly solvable [2] we come to a better understanding of several foundational issues at the m-M/q-C interface from this broader perspective [3] such as the conditions for the applicability of the canonical ensemble, the extensivity of energy, the positivity of the heat capacity at absolute zero and the validity of the Third Law. Many open questions remain such as the definition of thermodynamic potentials and the validity of thermodynamics laws at strong coupling [4-6].

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Giant shot noise from Majorana zero modes in topological trijunctions

Thibaut Jonckheere[1], Jérôme Rech[1], Alex Zazunov[2], Reinhold Egger[2], Alfredo Levy Yeyati[3], and Thierry Martin[1]

[1]*Centre de Physique Théorique - CNRS, Campus de Luminy, case 907, 13009 Marseille, France*
[2]*Institut für Theoretische Physik, Heinrich Heine Universität, D-40225 Düsseldorf, Germany*
[3]*Departamento de Física Teórica de la Materia Condensada C-V, Universidad Autònoma de Madrid, E-28049 Madrid, Spain*

The clear-cut experimental identification of Majorana bound states in transport measurements still poses experimental challenges. I will show that the zero-energy Majorana state formed at a junction of three topological superconductor wires is directly responsible for giant shot noise amplitudes, in particular at low voltages and for small contact transparency. The only intrinsic noise limitation comes from the current-induced dephasing rate due to multiple Andreev reflection processes.

Quantum measurement engines

Andrew N. Jordan and Cyril Elouard

University of Rochester, Bausch and Lomb Hall, Rochester, USA

I will present a new type of purely quantum engine design, whose fuel is the quantum measurement process. An elevator and battery concept will be given, where the system Hamiltonian does no work, and yet the engines function as desired. Conditions for optimal efficiency will be shown, which can approach unity. Unpublished results on an interaction-free measurement version of the engine will also be presented.

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Fluctuation-driven Coulomb drag in interacting quantum dot systems

Miguel A. Sierra[1], David Sánchez[1], Antti-Pekka Jauho[2], and Kristen Kaasbjerg[2]

[1]*Instituto de Física Interdisciplinar y Sistemas Complejos IFISC (UIB-CSIC), E-07122 Palma de Mallorca, Spain*
[2]*Department of Physics, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark*

Coulomb drag between nanoscale conductors is of both fundamental and practical interest. Here, we theoretically study drag in a double quantum-dot (QD) system consisting of a biased drive QD and an unbiased drag QD coupled via a direct interdot Coulomb interaction. We demonstrate that the Coulomb drag is driven by the charge fluctuations in the drive QD, and show how the properties of the associated quantum noise allow to distinguish it from, e.g., shot-noise driven drag in circuits of weakly interacting quantum conductors. In the strong-interaction regime exhibiting an orbital ("pseudospin") Kondo effect, the drag is governed by charge fluctuations induced by pseudospin-flip cotunneling processes. The quenching of pseudospin-spip processes by Kondo correlations are found to suppress the drag at low bias and introduce a zero-bias anomaly in the second-order differential transconductance. Finally, we show that the drag is maximized for values of the interdot interaction matching the lead couplings. Our findings are relevant for the understanding of drag in QD systems and provide experimentally testable predictions in different transport regimes.

Distances in random networks - recent results

Eytan Katzav

The Racah Institute of Physics, The Hebrew University of Jerusalem, Edmond J. Safra Campus, Jerusalem, Israel

The theory of complex networks provides a useful conceptual framework for the study of a large variety of systems and processes in science, technology and society. These studies are based on network models, in which the nodes represent physical or virtual objects, while the edges represent the interactions between them. Typically, these networks exhibit random structures, which can be characterized by their statistical properties at the local and global scales. The local structure of a network is captured by the degree distribution and by certain correlations between nearby nodes. The large scale structure is captured by the spectrum of path lengths between random pairs of nodes. The shortest path between each pair of nodes is of particular importance because it provides the strongest interaction and fastest response between these nodes. While the average distance has been studied extensively, the analytical calculation of the entire distribution has received much less attention. In this presentation I will describe a a novel suite of analytical approaches for the calculation of the DSPL in a wide range of random networks both in and out of equilibrium, including Erdos-Renyi networks, random regular graphs and more generally, configuration model networks, as well as node-duplication networks. The results are found to be in agreement with numerical simulations for a broad range of networks, sizes and connectivities.

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[3] C. Steinbock, O. Biham and E. Katzav, The distribution of shortest path lengths in a class of node duplication network models, Phys. Rev. E 96, 032301 (2017).

[4] H. Bonneau, A. Hassid, O. Biham, R. Kühn and E. Katzav, Distribution of shortest cycle lengths in random networks, Phys. Rev. E 96, 062307 (2017).

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Second law implications of the size dependency in the adiabatic phase transition of Type I superconductors

Peter D. Keefe

University of Detroit Mercy, College of Engineering and Science, 4001 W. McNichols Road, Detroit, MI 48221, USA

The phase transition of a mesoscopic Type I superconductor involves thermal and electrodynamic relaxation processes of the control variables, the electrodynamic relaxation being three orders of magnitude faster than the thermal relaxation. This potentially renders the time differences of the control variables observable and non-isentropic, but only if the phase transition is abrupt. [1-7] An experiment [8] investigating the phase transition of macroscopic wires and mesoscopic whiskers discovered the mesoscopic sized phase transition is abrupt, whereas the macroscopic sized phase transition is continuous.

The talk will discuss the Second Law implications.

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

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

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

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

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Ultracold atoms as quantum simulators for new materials – optical lattices and synthetic gauge fields

Wolfgang Ketterle

Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, USA

When atoms are cooled to nanokelvin temperatures, they can easily be confined and manipulated with laser beams, and new Hamiltonians can be engineered. Crystalline materials are simulated by placing the atoms into an optical lattice, a periodic interference pattern of laser beams. With the help of laser beams, neutral atoms can move around in the same way as charged particles subject to the magnetic Lorentz force. This has been used to realize synthetic magnetic fields and spin-orbit coupling. These and other tools are now applied towards various spin Hamiltonians and topological physics.

Getting rid of the nonlocality nonsense: Violation of the Bell's type inequalities as a local expression of incompatibility

Andrei Khrennikov

Linnaeus University, Center for Math Modeling in Physics and Cognitive Science, P.G. Vägen, Växjö, Sweden

By filtering out the philosophic component we can be said that the EPR-paper was directed against the straightforward interpretation of the Heisenberg's uncertainty principle or more generally the Bohr's complementarity principle. The latter expresses contextuality of quantum measurements: dependence of measurement's output on the complete experimental arrangement. However, Bell restructured the EPR-argument against complementarity to justify nonlocal theories with hidden variables of the Bohmian mechanics' type. Then this Bell's kind of nonlocality - subquantum nonlocality - was lifted to the level of quantum theory - up to the terminology "quantum nonlocality". The aim of this short talk is to explain that Bell's test is simply a special test of local incompatibility of quantum observables, similar to interference experiments, e.g., the two-slit experiment [1].

[1] A. Khrennikov, https://arxiv.org/abs/1902.07070 .

A renormalization-group study of interacting Bose-Einstein condensates: Absence of the Bogoliubov mode below d=4 (T>0) and d=3 (T=0) dimensions

Takafumi Kita

Hokkaido University, Sapporo, Kita 10 Nishi 8, Sapporo 060-0810, Japan

We derive exact renormalization-group equations for the n-point vertices ($n = 0, 1, 2, \cdots$) of interacting single-component Bose-Einstein condensates based on the vertex expansion of the effective action. They have a desirable feature of automatically satisfying Goldstone's theorem (I), which yields the Hugenholtz-Pines relation $\Sigma(0) - \mu = \Delta(0)$ as the lowest-order identity. Using them, it is found that the anomalous self-energy $\Delta(0)$ vanishes below $d_{\rm c} = 4$ ($d_{\rm c} = 3$) dimensions at finite temperatures (zero temperature), contrary to the Bogoliubov theory predicting a finite "sound-wave" velocity $v_{\rm s} \propto [\Delta(0)]^{1/2} > 0$. In other words, Bose-Einstein condensates are free from interactions at the excitation threshold. It is also shown that the one-particle density matrix $\rho(\mathbf{r}) \equiv \langle\hat{\psi}^\dagger(\mathbf{r}_1)\hat{\psi}(\mathbf{r}_1 + \mathbf{r})\rangle$ for $d < d_{\rm c}$ dimensions at finite temperatures approaches the off-diagonal-long-range-order value N_0/V asymptotically as $r^{-d+2-\eta}$ with an exponent $\eta > 0$. The exponent η at finite temperatures is predicted to behave for $d = 4 - \epsilon$ dimensions ($0 < \epsilon \ll 1$) as $\eta = 0.181\epsilon^2$. Thus, the interacting Bose-Einstein condensates are subject to long-range fluctuations similar to those at the second-order transition point, and their excitations in the one-particle channel are distinct from the Nambu-Goldstone mode with a sound-wave dispersion in the two-particle channel.

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Propulsion and fluctuations in magnetotactic bacteria

Stefan Klumpp

University of Goettingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Magnetotactic bacteria are microbes that orient in magnetic fields with the help of an intracellular compass needle, the magnetosome chain. They provide a unique opportunity to study the interplay of generic physical processes with specific biological control mechanisms and to understand how physics enables new biological functions, but also imposes constraints on them. Specifically, I will discuss their swimming patterns while directed by a magnetic field and their orientation fluctuations, which have been shown to have a non-thermal contribution.

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Quantum optics with X-rays: Dynamical control of resonant interaction

Olga Kocharovskaya

Department of Physics and Astronomy, Texas A&M University, TX:77843-4242, College Station,USA

Recently a new, rapidly expanding field of research, X-ray quantum optics, has been formed due to the development of the coherent X-ray sources, including X-ray plasma based lasers, high harmonic generation sources and X-ray Free Electron Lasers (XFEL). We discuss how to control the spectral/temporal characteristics of an X-ray radiation produced by these sources via variation in time/space of the parameters of its resonant interaction with a medium (atomic or nuclear transitions in gases, plasmas or solids) driven by a sufficiently strong optical or IR laser field. Several applications of this technique are considered, including (i) control of single X-ray photon waveform and realization of quantum interfaces between single photons and nuclear ensembles, (ii) generation of intense attosecond pulses in the "water window" range (promising for dynamical microscopy and imaging of material and biological nano-structures, including proteins in living cells), (iii) spectral enhancement of XFEL radiation (promising for development of long-lived quantum nuclear memory, ultrahigh resolution nuclear spectroscopy, and nuclear frequency standards).

Circuit quantum electrodynamics with quantum dot qubits

Jonne V. Koski

ETH Zurich, Laboratory for Solid State Physics, Otto-Stern-Weg 1, 8093, Zurich, Switzerland

Utilizing single electrons in quantum dot devices as qubits is appealing due to the readily available knowledge on industry-scale semiconductor fabrication. In particular, electron spins are promising candidates for storing quantum information due to their long coherence time. To scale up the number of qubits, it is desirable to enable long-range interaction between qubits, for example by using virtual photons as quantum information mediators in a circuit quantum electrodynamics (cQED) platform. This talk will cover our recent work on this topic, focusing on the demonstration of strong coupling between a single microwave photon in GaAs triple quantum dots.

The quantum Carnot engine and the inertial theorem

Ronnie Kosloff and Roie Dann

Hebrew University Jerusalem, givat Ram, Jerusalem 91904, Israel

Quantum thermodynamics follows the tradition of learning by example. The Carnot cycle would be a primary candidate. Previous attempts to model the four stroke quantum Carnot cycle failed due to the difficulty to model the isothermal branches, where the working medium is driven while in contact to the thermal bath. Motivated by this issue we derived a time dependent Non Adiabatic Master Equation (NAME) with an explicit constant adiabatic speed time dependent driving protocol. This master equation is consistent with thermodynamic principles. We then were able to generalise to protocols with small acceleration with respect to the constant speed protocols. This approach was confirmed experimentally for a qubit composed of a driven Ytterbium ion in a Paul trap. Utilising the NAME and the inertial theorem we are able to construct shortcuts to an isothermal transformation. Unlike unitary transformations the shortcut map changes entropy. These fast protocols have a price in dissipated work. After this journey, we are able to obtain a Carnot type cycle with finite power. We explore the tradeoff between power and efficiency in a shortcut engine and in an endo-reversible model. The role of coherence in the cycle is emphasised. We are able to identify the quantum signature of a Carnot type cycle with global coherence.

On computer-inspired science

Mario Krenn

Department of Chemistry, University of Toronto, Canada
Vector Institute for Artificial Intelligence, Toronto, Canada
Faculty of Physics, University of Vienna, Austria
Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Austria

Where do good ideas come from? As many scientists, I am wondering about this question for several years. After all, our ideas identify us as a researcher and – more importantly – are to a large extent responsible for the happiness in our professional endeavor. Here I will discuss two methods, how we can use computer algorithms to inspire new ideas for science – in particular in quantum physics.

One is based on the **automated design of new quantum experiments** [1]. For several years, we use computer algorithm to design novel quantum experiments, as our intuitions for complex quantum phenoma are limited [2,3]. Surprisingly, solutions found these computer algorithms have inspired new ideas for generating quantum entanglement that could have been identified by human scientists 25 years ago [4,5].

Secondly, inspired by fantastic work in the field of biochemistry [6], I am creating a rudimentary **semantic network of quantum physics** and use neural network to draw conclusions about its future evolution. I use 750.000 physics papers published by APS since 1919, and show attempts to suggest new unconventional personalized ideas in quantum physics.

I hope this talk inspires many enlightening discussion about what good, creative and unexpected ideas might be.

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Surface plasmon assisted room temperature Cooper pair formation in gold films

Norbert Kroo

Wigner Physics Research Center, Hungarian Academy of Sciences, Galgoczy str 51/B, Budapest, Hungary

A set of unique results of the study of nonlinear surface plasmon (SPP) phenomena are presented. The SPP-s have been excited in a gold film by intense femtosecond Ti:Sa laser pulses in the Kretschman geometry and spectra of SPP assisted electron emission have been measured by the time-of-flight (TOF) technique. Smooth and nanostructured gold films have been studied A set of these room temperature experimental observations is described. The TOF spectra show a high energy maximum, which is present only in a laser intensity range around 80 GW/cm^2. In addition to this high energy peak , intensive periodic narrow peaks have been detected on the top of the TOF spectra, copying the periodic oscillations of the plasmonic near field, but streched out in time by the ratio of the length of the flight path of the electrons and the height above the surface of the decay of the plasmonic near field,which is about one million , and so detecting femtosecond processes on the nanosecond scale .The plasmonic field enhancement effect in the structured sample is significantly higher, and so is the number of emitted electrons. Narrow periodic "resonances" have been found in the time-of-flight spectra of electrons with anomalies in the high energy peak, i.e. in the laser intensity range where electron pairing has been found earlier [1]. Significant differences have been found, however, in the nanostructured samples compared to those of the smooth surfaces. They are also more intense. In the laser intensity range, where the high energy peak is present, some of the (also periodic in time) but less frequent narrow peaks are about twice as large as the remaining ones, indicating the simultaneous detection of 2 electrons (Cooper pairs) within the resolution time of the TOF spectrometer. Detailed analysis of these findings is presented.

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Quantum thermodynamics under control

Gershon Kurizki

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

Over the past few years we have endeavored to merge the fields of quantum control and thermodynamics, by examining the effects of control fields on quantum thermodynamic machines. This endeavor has resulted in the formulation of general principles that nonequilibrium thermodynamics must abide by in the quantum domain [1-3]. These principles dispel much of the confusion in the literature concerning the questions: What are work and heat in the quantum domain? Can a quantum machine surpass the Carnot bound on efficiency, as previously claimed? What (if any) quantum advantage can we expect from machines that operate in the quantum domain? I will illustrate our answers to these questions for our designs of heat engines, refrigerators, diodes and transducers/ transistors based on quantum systems [4-7].

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[3] W. Niedenzu and G. Kurizki, NJP 20, 113038 (2018).

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Investigations of quantum superadditivity

Paul G. Kwiat

University of Illinois at Urbana-Champaign, 1110 W. Green St., Urbana, 61874, USA

Certain noisy quantum communication channels exhibit a property known as superadditivity, through which the amount of information the channel is capable of faithfully transmitting scales nonlinearly with channel use, e.g., using the channel twice can more than double the amount of information transferred, violating the usual additivity principle of classical communication. These channels rely on a special balance of noise: too much or too little and any improvement is quickly lost. However, in these regions, superadditivity can allow for improvements over classical communication when finite use is a consideration. We report on progress demonstrating superadditivity in the dephrasure channel, a channel which combines probabilistic dephasing and erasure. The dephrasure channel is used because of its simplicity and low-use requirements, a rarity among superadditive channels.

Revealing the fine structure of Andreev levels in hybrid nanowires

Alfredo Levy Yeyati

Universidad Autónoma de Madrid, Campus de Cantoblanco, Madrid, Spain

In atomic physics the fine structure refers to the splitting of the spectral lines due to relativistic effects, leading to the spin-orbit interaction. Analogously, the Andreev bound states in a weak link between two superconducting leads connected through a semiconducting nanowire are expected to exhibit a splitting due to the Rashba spin-orbit interaction in the wire.

In a recent work [1] we provide evidence of this effect through microwave spectroscopic measurements. We have developed a simple model which allows us to fit the transition lines in terms of a few parameters, like the effective junction length and its transparency. A basic ingredient in the model is to account for the nanowire multichannel structure [2]. Our theoretical analysis allows to get an estimate on the size of the spin-orbit interaction in the nanowire, which is found to be in agreement with values reported in the literature. It also allows to describe with high accuracy the effect on the Andreev levels of an applied Zeeman field along an arbitrary orientation.

I shall discuss several open issues connected to understanding the excitation and detection mechanisms of the Andreev transitions in a circuit QED geometry like the one used in the experiments. This knowledge constitutes a basic requirement towards the development of an Andreev spin qubit based on this setup.

[1] L. Tosi, C. Metzger, M.F. Goffman, C. Urbina, H. Pothier, Sunghun Park, A. Levy Yeyati, J. Nygard and P. Krogstrup, Phys. Rev. X 9, 011010 (2019).

[2] Sunghun Park and A. Levy Yeyati, Phys. Rev. B 96, 125416 (2017).

Divergence of predictive model output as indication of phase transitions

Frank Schäfer and Niels Lörch

Unibversity of Basel, Klingelbergstrasse 82, Basel, Switzerland

We introduce a new method to identify phase boundaries in physical systems. It is based on training a predictive model such as a neural network to infer a physical system's parameters from its state. The deviation of the inferred parameters from the underlying correct parameters will be most susceptible and diverge maximally in the vicinity of phase boundaries. Therefore, peaks in the divergence of the model's predictions are used as indication of phase transitions. Our method is applicable for phase diagrams of arbitrary parameter dimension and without prior information about the phases. Application to both the two-dimensional Ising model and the dissipative Kuramoto-Hopf model show promising results.

[1] Frank Schäfer, Niels Lörch, arxiv:1812.00895.

Violation of the local electroneutrality condition in an inhomogeneous macroions solution

Marcelo Lozada-Cassou

Renewable Energies Institute, UNAM, Priv. Xochicalco s/n, Temixco, Mexico

A simple model for a macroions solution next to charged membrane is studied through a well-established integral equations theory, as a function of the macroions and membrane's charge. The macroions adsorption to the surface shows an atypical electrical double layer structure, which implies a violation of the local electroneutrality condition. A breakdown of the charge neutrality in confined, charged fluids, has been theoretically predicted in the past through an integral equation theory [1,2], and recently corroborated with a density functional theory, computer simulations [3], and experimentally [4]. In this presentation we show a charge neutrality breakdown, in *unconfined*, inhomogeneous fluids. Our results are in qualitative agreement with experimental results for Langmuir films of amphiphilic molecules with ionizable head groups [5].

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Quantum fluctuation theorems beyond two-point measurements

Kaonan Micadei[1], Gabriel Landi[2], and Eric Lutz[1]

[1]*University of Stuttgart, Institute for Theoretical Physics I, 70550 Stuttgart, Germany*
[2]*Instituto de Fisica da Universidade de Sao Paulo, 05314-970 Sao Paulo, Brazil*

We derive detailed and integral quantum fluctuation theorems for heat exchange in a quantum correlated bipartite system using the framework of dynamic Bayesian networks. Contrary to the usual two-projective-measurement scheme that is known to destroy quantum features, these fluctuation relations fully capture quantum correlations and quantum coherence at arbitrary times.

Quantum analogue of energy equipartition theorem

Paweł Bialas, Jakub Spiechowicz, and Jerzy Łuczka

University of Silesia (Katowice), 41-500 Chorzów, Poland

One of the fundamental laws of classical statistical physics is the energy equipartition theorem which states that for each degree of freedom the mean kinetic energy E_k equals $E_k = k_B T/2$, where k_B is the Boltzmann constant and T is temperature of the system. Despite the fact that quantum mechanics has already been developed for more than 100 years still there is no quantum counterpart of this theorem. We attempt to fill this far-reaching gap and consider the simplest system, i.e. the Caldeira-Leggett model for a free quantum Brownian particle in contact with thermostat consisting of an infinite number of harmonic oscillators. We prove that the mean kinetic energy E_k of the Brownian particle equals the mean kinetic energy $\langle \mathcal{E}_k \rangle$ per one degree of freedom of the thermostat oscillators, i.e. $E_k = \langle \mathcal{E}_k \rangle$. The symbol $\langle ... \rangle$ denotes two-fold averaging: (i) over the Gibbs canonical state for the thermostat and (ii) over thermostat oscillators frequencies ω which contribute to E_k according to the probability distribution $\mathbb{P}_k(\omega)$. The same formula holds true for a dissipative quantum oscillator and we specify conditions for validity of this relation also for other systems. We show that this relation can be obtained from the fluctuation-dissipation theorem derived within the linear response theory.

Exotic quantum phase transitions in Dirac fermion systems

Joseph Maciejko

Department of Physics, University of Alberta, Edmonton, Alberta, Canada
Theoretical Physics Institute, University of Alberta, Edmonton, Alberta, Canada
Canadian Institute for Advanced Research, Toronto, Ontario, Canada

Critical points of classical second-order phase transitions are thermodynamic phenomena of particular interest, driven by thermal fluctuations and characterized by emergent scale invariance and universal power-law correlations. At zero temperature quantum fluctuations can similarly drive sharp phase transitions between qualitatively distinct many-body ground states, but can potentially produce a richer phenomenology than at classical phase transitions due to intrinsically quantum effects such as quantum statistics, interference, and entanglement. A key problem in the field of quantum criticality is to understand the nature of quantum phase transitions in systems of interacting itinerant fermions, motivated by experiments on a variety of strongly correlated materials. In particular, much attention has been paid in recent years to materials in which itinerant fermions acquire a pseudo-relativistic Dirac dispersion, such as topological insulators and semimetals and certain spin liquids. In this talk I will discuss the rich phenomenology of quantum phase transitions in systems of Dirac fermions, which includes non-Fermi liquid behavior, emergent supersymmetry, universal optical properties, finite-randomness quantum critical points in the presence of quenched disorder, and oscillatory corrections to scaling.

The possible role of extracellular tissue in biological neural networks

Jiří J. Mareš, Václav Špička, and Pavel Hubík

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

As we have recently shown [1], the transfer of action potential via the nervous fibre is ultimately controlled, in contrast to standard theory [2] but in agreement with experiments, by the quantum diffusion of Na^+ and K^+ ions. Accordingly, the diffusion of polarization wave along the axon membrane inevitably excites the response in surrounding extracellular (EC) medium, where equalizing currents are induced. It results in temporal potential distribution in EC tissue biasing the synapses and dendrites of all vicinal neurons. We propose that just this, so called, ephaptic coupling [3,4] between neighbouring neurons, completes the local neural network and is responsible for information processing. Such an idea is obviously incompatible with current models of neural networks of McCulloch-Pitts' [5] and Rosenblatt's [6] type, which assume only the synaptic interactions and are thus convenient merely for artificial networks. In this paper, we are making an attempt to describe mathematically electric interactions within a cluster of neurons imbedded in EC medium with the aim to show, how the information passing through such a system is modified.

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Finite frequency noise in a normal metal - topological superconductor junction

Didier Bathellier[1], Laurent Raymond[1], Thibaut Jonckheere[1], Jérôme Rech[1], Alex Zazunov[2], and Thierry Martin[1]

[1]*Centre de Physique Théorique, Aix Marseille Université, 163 av de Luminy, Marseille 13009, France*
[2]*Institut fur Theoretische Physik, Heinrich Heine Universitat, D-40225, Germany*

A topological superconductor nanowire bears a Majorana bound state at each of its ends, leading to unique transport properties. As a way to probe these, we study the finite frequency noise of a biased junction between a normal metal and a topological superconductor nanowire. We use the non-equilibrium Keldysh formalism to compute the finite frequency emission and absorption noise to all order in the tunneling amplitude, for bias voltages below and above the superconducting gap. We observe noticeable structures in the absorption and emission noise, which we can relate to simple transport processes. The presence of the Majorana bound state is directly related to a characteristic behavior of the noise spectrum at low frequency. We further compute the noise measurable with a realistic setup, based on the inductive coupling to a resonant LC circuit, and discuss the impact of the detector temperature. We have also computed the emission noise for a non-topological system with a resonant level, exhibiting a zero-energy Andreev bound state, in order to show the specificities of the topological case. Our results offer an original tool for the further characterization of the presence of Majorana bound states in condensed matter systems.

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Fast measurement and initialization of superconducting qubits

Joni Ikonen[1], Jan Goetz[1], Matti Silveri[3], Shumpei Masuda[1], Vasilii Sevriuk[1], Jesper Ilves[1], Aarne Keränen[1], Andras M. Gunyho[1], Matti Partanen[1], Kuan Y. Tan[1], Fabian Hassler[4], Russell E. Lake[1], Dibyendu Hazra[1], Leif Grönberg[2], Visa Vesterinen[2], Slawomir Simbierowicz[2], Juha Hassel[2], and Mikko Möttönen[1]

[1]*QCD Labs, Aalto University, Aalto, Finland*
[2]*VTT Technical Research Centre of Finland, VTT, Finland*
[3]*Research Unit of Nano and Molecular Systems, University of Oulu, Oulu, Finland*
[4]*JARA Institute for Quantum Information, RWTH Aachen University, Aachen, Germany*

In this talk, I will cover two very recent results from the QCD Labs, namely, a method and implementation of fast qubit readout [1] and on-demand controllable dissipation and Lamb shift in a superconducting resonator [2]. The latter work is based on our recently developed quantum-circuit refrigerator which is has great potential in becoming a standard initialization tool in circuit quantum electrodynamics and especially in the superconducting quantum computer.

[1] J. Ikonen et al., Phys. Rev. Lett. 122, 080503 (2019).
[2] M. Silveri et al., Nat. Phys. https://doi.org/10.1038/s41567-019-0449-0 (2019).
[3] K. Y. Tan et al., Nat. Commun. 8, 15189 (2017).

Physical models of proton-pumping complexes in mitochondria membranes

Lev Mourokh

Queens College of CUNY, 65-30 Kissena Blvd, Queens, USA

Living objects at the nanoscale can be viewed as molecular complexes, whose dynamics is often controlled by the transfer of single charges or single-photon absorption events. In many senses, it is similar to the principles of operation of semiconductor nanostructures and elements of molecular electronics. Correspondingly, well-established methods of condensed matter and statistical physics can be applied. In this talk, I address proton-pumping complexes and proton-driven nanomotor of the mitochondria membranes. These systems convert the energy obtained from the food to the proton gradient across the membrane, to the mechanical rotation of the nanomotor, and, finally, to the energy of chemical compounds. We propose simple physical models for these complexes which not only allow the quantitative description but can inspire the implementations in nanoelectronics as well.

Exploring quantum thermodynamics with superconducting qubits

Kater Murch[1], Patrick Harrington[1], Mahdi Naghiloo[1], Andrew Jordan[2], Eric Lutz[3], and Alessandro Romito[4]

[1]*Physics Department, Washington University in St. Louis, Campus Box 1105, St. Louis, USA*
[2]*University of Rochester, USA*
[3]*University of Stuttgart, Germany*
[4]*Lancaster University, United Kingdom*

Superconducting circuits offer an interesting platform with which to explore thermodynamics at the quantum level. In particular, the ability to perform high efficiency quantum measurements and track quantum evolution enables novel experiments in measurement and feedback which form the basis of Maxwell's Demon. These experiments elucidate the role of quantum information in thermodynamics. Furthermore, the quantum dynamics associated with continuous measurement allow us to characterize the arrow of time by examining the statistical likelihood of certain measurement processes. By experimentally tracking individual weak measurement trajectories, we compare the path probabilities of forward and backward-in-time evolution to develop an arrow of time statistic associated with measurement dynamics. We show that the arrow of time statistic obeys both detailed and integral fluctuation theorems thus establishing the consistency between microscopic and macroscopic measurement dynamics.

Ballistic metamaterials

Evgenii Narimanov

Purdue University, 465 Northwestern Ave, West Lafayette, USA

Metamaterials are artificial composites structured on a subwavelength scale, where the effect of the subwavelength pattern controls the average electromagnetic response of the medium, leading to many properties that are not readily available in natural materials. On the microscopic level, this behavior generally originates from the plasmon resonance in subwavelength metallic elements incorporated in the unit cell of the composite.

In the theoretical description of metamaterials, electromagnetic response of the metallic inclusions is generally treated using the formalism of the local dielectric permittivity, that corresponds to the material at the given spatial position. While adequate for bound electrons, this approach however neglects the inherent mobility of the free charge carriers. Furthermore, the actual free electron dynamics in the metallic constituents, may be qualitatively different – from the diffusive behavior to ballistic regime. Although in the diffusive and in the quantum regimes, the standard description in terms of the local dielectric permittivity may be adequate, the ballistic case shows qualitatively different behavior, with the resonant response due to the interplay of the electromagnetic field period and the ballistic round-trip time.

As we show in the present work, when the round-trip time of the electron motion is equal to the period of the electric field, the resulting electromagnetic response is enhanced, leading to the negative effective permittivity in the direction normal to the metal-dielectric interface, even above the plasma frequency. As the in-plane permittivity component in this regime remains positive, the composite shows the hyperbolic behavior, with its many exciting manifestation - from the negative refraction and diffraction-free propagation to the enhanced quantum and nonlinear effects due to the density of states singularity in hyeprbolic media.

Hyperbolic response of the planar metal-dielectric metamaterials well above the plasma frequency of its "metallic" component, shows the potential of ballistic metamaterials to extend the applications of the existing material platforms: e.g. the use of the high-quality doped semiconductors originally introduced as "designer metals" for mid- and far-infrared frequencies, can now be extended well into the near-IR range.

Synthetic Landau levels with atomic dysprosium

Thomas Chalopin, Jean Dalibard, Alexandre Evrard, Raphael Lopes, Vasiliy Makhalov, Sylvain Nascimbene, and Tanish Satoor

CNRS - Laboratoire Kastler Brossel, Collège de France, 11 place Marcelin Berthelot, Paris, France

We present a realization of synthetic Landau levels using ultracold dysprosium atoms. We use the large electronic spin $J = 8$ to encode a synthetic spatial dimension, along which motion is induced by laser couplings. An effective gauge field arises from the momentum imparted on the atoms upon laser-driven spin flips. We probe the main topological features of the lowest Landau levels: presence of propagating edge modes, quantification of the Hall conductance.

Scale invariance in a turbulent quantum gas: Cascade front dynamics and nonthermal steady states

Nir Navon

Yale University, Prospect Street, New Haven, USA

The recent production of homogeneous Bose gases [1] has opened exciting possibilities to study far-from-equilibrium many-body dynamics in clean uniform quantum fluids. In this talk, I will present our study of the emergence of a turbulent cascade in a homogeneous Bose fluid forced out of equilibrium on a large scale using a spatially-uniform force [2]. In contrast to classical fluids where the dissipation scale is set by the viscosity of the fluid, the turbulent cascade of our quantum gas ends when the particles kinetic energy exceeds the laser-trap depth. This simple mechanism allows us to effectively tune the dissipation scale where particles (and energy) are lost. Using this new knob, we directly measure turbulent fluxes and observe in real time the propagation of the cascade front in momentum space [3]. Once the cascade front has reached the dissipation scale, a scale-invariant steady state is established over the entire inertial range.

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[2] N. Navon et al., Nature 539, 72 (2016).

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GW0 for > 10K electrons: Stochastic GW

Daniel Neuhauser

Department of Chemistry and Biochemistry, UCLA, Los Angeles CA 90095-1569 USA

Stochastic Quantum Chemistry (SQC) is a new paradigm we developed for electronic structure and dynamics, which rewrites traditional quantum chemistry as stochastic averages, avoiding the steep power law scaling of traditional methods. As an example I will discuss Stochastic GW (SGW). The GW technique is known to achieve high accuracy, with only a 0.1-0.3 eV experiment-theory deviation for affinities and ionization energies. SGW reproduces the results of traditional deterministic GW for small systems, but also handles very large systems; as an example, we easily calculated affinities, charging energies, and photoelectron spectroscopy for Si clusters and Si and P platelets with up to 11000 valence electrons, for polymers with thousands of atoms, and for periodic systems with very large supercells. These systems are significantly bigger than any calculable in existing approaches, so that SGW makes a quantum jump in the ability to calculate accurate electronic affinities and potential energies for large molecules. We will specifically discuss recent improvements in the algorithm and implementation which makes SGW superior to traditional techniques already for tetracene, and reduces experiment-theory deviations to $\sim$0.1 eV. These include a post-processing G0W0 –> GW0 partial-self consistency, as well as a new stochastic-compression approach for efficiently representing giant sets of data, as appear in stochastic GW.

The Standard Model of particle physics with Diracian neutrino sector

Theo M. Nieuwenhuizen

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

The minimally extended standard model contains three right handed or sterile neutrinos, coupled to the active ones by a Dirac mass matrix and mutually by a right-handed Majorana mass matrix. In the pseudo-Dirac case, the Majorana masses are small and maximal mixing of active and sterile states occurs, which is generally excluded by solar neutrinos.

We introduce a "Diracian" limit wherein the 6 physical masses become pairwise degenerate and the neutrinos attain a Dirac signature. Within each pair the maximal mixing then does not lead to oscillation and can be circumvented. Since 2 Majorana phases become physical Dirac phases and 3 extra Majorana masses occur, a better description of data is possible. The standard neutrino model is recovered in the limit of vanishing Majorana masses.

Oscillation problems are worked out in vacuum and in matter, as are pion, neutron and muon decay. The model exhibits a very weak rate of neutrinoless double beta decay. It naturally allows the large mixing angles that explain the 2 ultra high energy upward EeV events detected by ANITA in terms of Earth traversing mostly-sterile neutrinos.

[1] T. M. Nieuwenhuizen, The Standard Model of particle physics with Diracian neutrino sector, arXiv:1810.04613.

Multiscale quantum-classical micromagnetics: Fundamentals and applications in spintronics

Branislav Nikolic and Utkarsh Bajpai

University of Delaware, Department of Physics & Astronomy, Newark, DE 19716, USA

This talk introduces recently developed [1,2] multiscale and self-consistent computational tool which combines time-dependent nonequilibrium Green function (TDNEGF) algorithms, scaling linearly in the number of time steps and describing quantum-mechanically conduction electrons in the presence of time-dependent fields of arbitrary strength or frequency, with classical description of the dynamics of local magnetic moments based on the Landau-Lifshitz-Gilbert (LLG) equation. Such TDNEGF+LLG approach can be applied to a variety of problems where current-driven spin torque induces the dynamics of magnetic moments as the key resource for next generation spintronics. Previous approaches for describing such nonequilibrium many-body system have neglected noncommutativity of quantum Hamiltonian of conduction electrons at different times and, therefore, the impact of time-dependent magnetic moments on electrons which can lead to pumping of spin and charge currents that, in turn, can self-consistently affect the dynamics of magnetic moments themselves including introduction of non-Markovian damping and magnetic inertia terms into the LLG equation [2]. Thus, TDNEGF+LLG can be viewed as "quantum-classical micromagnetics" which captures numerous effects missed by widely utilized purely classical micromagnetics. We use examples of current- or magnetic-field-driven motion of domain walls within magnetic nanowires (including their annihilation observed in very recent experiments) to illustrate novel insights that can be extracted from TDNEGF+LLG simulations. In particular, TDNEGF+LLG as a nonperturbative (i.e., numerically exact) framework allows us to establish the limits of validity of simpler theories, such as the so-called spin-motive force theory for pumped charge current by time-dependent noncollinear and noncollinear magnetic textures which turns out to be just the lowest order of the result predicted by TDNEGF+LLG.

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Quantum (thermo-)dynamics of randomly probed systems

Stefan Nimmrichter[1,4], Stella Seah[2], Kiran E Khosla[3], and Valerio Scarani[2,4]

[1] *Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany*
[2] *Department of Physics, National University of Singapore, 2 Science Drive 3, Singapore 117542*
[3] *Center for Engineered Quantum Systems, University of Queensland, St Lucia 4072, Australia*
[4] *Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543*

We study the dynamics of open quantum systems subjected to random repeated probing by external degrees of freedom in the framework of coarse-grained monitoring master equations. They capture the system's dynamics in the natural regime where interactions with different probes do not overlap, but are otherwise valid for arbitrary values of the interaction strength and mean interaction time. The framework can be used to study equilibration and energy exchange with thermal or non-thermal reservoirs, or to model processes driven by random measurements and feedback operations.

For example, collisional channels with identical probes prepared in Gibbs states have been used to describe thermalisation: while this is the case for many choices of parameters, for others one finds out-of-equilibrium states including inverted Gibbs and maximally mixed states. Gapless probes can be interpreted as pointers performing an indirect measurement, which may require an external work supply to mediate the interaction.

We show how random measurement-feedback channels can be employed to construct continuous, self-contained models of measurement-driven engines without the notion of a predefined engine cycle. On a separate note, we show how to use these channels to describe Newtonian gravity as a fundamentally classical interaction.

Thermodynamics of strongly coupled driven quantum systems

Abraham Nitzan

University of Pennsylvania, Department of Chemistry, 231 S 34th St, Philadelphia, USA
Tel Aviv University, School of Chemistry, Tel Aviv, 69978, Israel

The driven resonance level model (a driven molecular level coupled to one or more fermionic baths) has been recently used to study thermodynamic aspects of energy conversion in simple mechanically driven strongly coupled quantum systems. Our original treatment of this problem was based on the non-equilibrium Green function (NEGF) approach [1]. In this talk I will discuss this model using other methodologies that reveal different physical aspects of this problem. First, I will describe an approach [2] based on an expansion of the full system-bath density matrix as a series in powers of the modulation rate, from which the functional form of work, heat, and entropy production rates can be obtained. This approach allows for the inclusion of electron-electron interaction in an approximate way. Second, I repeat the derivation by expressing the density matrix in terms of the asymptotic eigenstates of the system by employing Moller transition operators [3]. The resulting expression, which coincides with results from the steady-state theories of McLean – Zubarev and Hershfield, can reproduce the standard NEGF results for the dot population and the current and, when extended to include driving of the dot energy level and/or the dot-leads coupling, yields the non-adiabatic (second order to the driving speed) corrections to the power, energy and heat production obtained from the NEGF formalism. Using this approach we can easily go beyond the wide band approximation and consider models where the dot is coupled to many leads held at different temperatures and under different chemical potentials. Finally, we employ a numerical solution based on the driven-Liouville-von Neumann approach [4], which reproduces the results obtained from the analytical approaches for slow driving and can be used to investigate systems subjected to high driving speeds.

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Critical current 1/f noise in graphene Josephson junction

Francesco M. D. Pellegrino[1,2], Giuseppe Falci[1,2,3], and Elisabetta Paladino[1,2,3]

[1]*DFA University of Catania, Via Santa Sofia 64, Catania, Italy*
[2]*INFN Sezione di Catania, Via Santa Sofia 64, Catania, Italy*
[3]*CNR-IMM UOS Catania (Università), Via Santa Sofia 64, Catania, Italy*

Short ballistic graphene Josephson junctions (GJJ) sustain superconducting current with a strongly non-sinusoidal current-phase relation (CPR) up to a critical current threshold. The CPR, arising from proximitized superconductivity, is gate-voltage tunable and exhibits peculiar skewness observed in high-quality graphene-superconductors heterostructures with clean interfaces. These properties make GJJ promising sensitive quantum probes of microscopic fluctuations underlying relativistic transport in 2D. We demonstrate that fluctuations with 1/f power spectrum of the critical current of a short ballistic GJJ directly probe carrier density fluctuations of the graphene channel. Tunability with the chemical potential, close to and far from the charge neutrality point, and temperature dependence of the noise amplitude are clear fingerprints of the underlying material-inherent processes. These results provide also relevant figure of merits in view of the envisaged implementation of coherent quantum circuits in hybrid quantum information architectures.

Coherence effect in a multi-level quantum-dot heat engine

Jaegon Um[2], Konstantin Dorfman[3], and Hyunggyu Park[1]

[1]*Korea Institute for Advanced Study, 85 Hoegiro Dongdaemun-gu, Seoul 02455, Republic of Korea*

[2]*BK21PLUS Physics Division, Pohang University of Science and Technology, Pohang 37673, Republic of Korea*

[3]*State Key Laboratory of Precision Spectroscopy, East China Normal University, Shanghai 200062, China*

We study the quantum coherence effect in thermodynamics using the two-level quantum dot coupled to heat reservoirs with temperature and chemical potential gradients, evolving through the Lindblad master equation. Unlike a single level quantum-dot system, the coherence of the levels can be induced by interaction between the bath and system. We find that the coherence remains finite even in the long-time limit, when couplings to baths are asymmetric. We report an anomalous behavior of the engine efficiency and power in this coherent steady state. In particular, the efficiency can exceed the ideal Carnot efficiency with an extra entropy production besides the conventional Clausius one.

T102 Mon, 15 July, 10:40 - 11:10, 2 session

Quantum heat transport via a superconducting qubit

Jukka P. Pekola

Aalto University, Helsinki, Finland

I describe experiments where heat is transported in superconducting quantum circuits by thermal microwave photons.

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Work fluctuations in slow processes: Quantum signatures and optimal control

Matteo Scandi[1], Harry J. D. Miller[2], Janet Anders[2], and Marti Perarnau-Llobet[1]

[1] *Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching bei München, Germany*

[2] *Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, UK*

An important result in classical stochastic thermodynamics is the work fluctuation-dissipation relation (FDR), which states that the dissipated work done along a slow process is proportional to the resulting work fluctuations. Here we show that slowly-driven quantum systems violate this FDR whenever quantum coherence in the energy basis is generated along the protocol, and derive a quantum generalisation of the work FDR. The additional quantum terms on the FDR are shown to uniquely imply a non-Gaussian work distribution, in contrast to the Gaussian shape found in classical slow processes. Fundamentally, our result shows that quantum fluctuations prohibit finding slow protocols that minimise both dissipation and fluctuations simultaneously. Instead, we develop a quantum geometric framework to find processes with an optimal trade-off between the two quantities.

Towards mechanical stabilization of molecular tunneling devices: Cooling by heating, high voltage, and more

Uri Peskin

Department of Chemistry, Technion - Israel Institute of Technology, Technion city, Haifa, Israel

The promise for future realization of single molecule-based electronic devices relies, to a large extent, on the ability to mechanically stabilize the molecular bonds, while making use of efficient resonant charge transport through the molecules. In single molecule junctions, resonant charge transport involves excessive charging of the molecule (transiently, at least). For most organic molecules this is likely to lead to vibrational heating, conformation changes or bond rupture, which hinder the mechanical stability of the junction. Accounting for vibronic coupling during resonant charge transport is therefore essential for the realization of single molecule devices. In the talk we shall discuss several mechanisms for transport induced mechanical instability in molecular junction, and focus in particular on vibrational heating due to inelastic charge transport through the molecule, and on the analysis of the phenomenon of vibrational instability. This analysis leads to new strategies for overcoming the excessive vibrational heating during resonant transport, including counter-intuitive effects, such as high-voltage assisted mechanical stabilization [1], and high temperature stabilization ("cooling by heating" [2]). These results are explained using an analytical model and are demonstrated to hold beyond the model limitations using numerical simulations. This work provides some guidelines for cooling nano-scale conductors operating in the resonant tunneling regime, as well as some practical suggestions with respect to experimentally controlled parameters that can be tuned in order to enhance the mechanical stability of nano-electronic devices.

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[2] R. Härtle, C. Schinabeck, M. Kulkarni, D. Gelbwaser-Klimovsky, M. Thoss and U. Peskin, Cooling by heating in nonequilibrium nanosystems, PRB 98, 081404(R) (2018).

From unitary to open quantum walks

Francesco Petruccione

University of KwaZulu-Natal, Private Bag X54001, Durban 4000, South Africa

Open quantum walks (OQWs) [1] were introduced as quantum analogues to classical Markov chains. In contrast to unitary quantum walks [2], OQWs are driven by the dissipative interaction with the environment and are formulated in the language of open quantum systems [3]. OQWs demonstrate rich dynamical behaviour [1,4] and can be used to perform efficient dissipative quantum computation and state engineering [5]. Another benefit of OQWs is in the well-defined classical limit [6]. The unitary quantum walks are gaining computational power from the quantum interference between the nodes of a walk and the asymptotic behaviour of them is highly non-gaussian [2].

In this talk, we will introduce a generalization of the QWs, which includes OQWs and unitary quantum walks as limiting cases. In this generalization, one can naturally identify an order parameter ξ = (characteristic time)/(characteristic length) and perform characteristic length a "thermodynamic" limit in the characteristic parameters while keeping ξ a constant. As a result, the asymptotic distribution of the position of the walker for the small values of ξ corresponds to a unitary quantum walk and for the large values of ξ to an OQWs, respectively.

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Attosecond dynamics in solids after photoexcitation as a benchmark for our understanding of complex quantum systems

Walter Pfeiffer

Bielefeld University, Universitaetsstr. 25, Bielefeld, Germany

In recent years, time-resolved spectroscopy advanced to the attosecond regime, i.e. on the time scale on which electron motion occurs on an atomic scale. In such experiments an extreme ultraviolet (EUV) pulse with durations of typically a few 100 as is used to excite the system and the response is probed by correlating this excitation with a field in the near infrared (NIR). One example of such a technique is attosecond time-resolved streaking spectroscopy of solid state photoemission [1]. In these experiments a photoelectron is excited in the solid and starts interacting with the NIR field when it crosses the solid-vacuum interface. Slight differences of this photoemission time result in different correlations with the NIR field and hence relative photoemission times for different emission channels can be timed with few-attosecond resolution.

Using this technique we were recently able to demonstrate that the present theoretical model of solid state photoemission misses an essential effect that significantly affects such photoemission delays [2]. Intra-atomic delays determined by the involved angular momentum of the photoelectron affect the photoemission times and are not accounted for in present theoretical models of solid state photoemission. In our present approach to describe the observations we dissect the photoemission process artificially in an intra-atomic and a propagation part that are modeled based on theoretical concepts from atomic physics and solid state physics, respectively. To overcome this artificial dissection new theoretical models of the photoemission process are needed and, hence, attosecond time-resolved spectroscopy provides new benchmarks for a further development of a complex quantum system, i.e. the dynamics of the many-body problem of a photoelectron interacting with the remaining photohole and the other electrons.

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The revolutionary changes to the International System of Units

William D. Phillips

Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland, 100 Bureau Drive, Gaithersburg 20899-8424, USA

Since the beginning of the Metric System of measurement, during the French Revolution, the definitions of units has been changing in response to changing demands of science and technology. As of 20 May 2019, the International System of Units (SI) has undergone its greatest revolution since the French revolution, with the definitions of the kilogram, ampere, kelvin, and mole now based on fixed values of Planck's constant, the electron charge, Boltzmann's constant, and Avogadro's number. As a result, the International Prototype Kilogram, the last artifact standard, no longer defines the unit of mass. This talk will explain why these changes were needed and how they work.

Quantum optical simulation of entangled particles near open time-like curves

Fabrizio Piacentini

INRIM, strada delle Cacce 91, Turin 10135, Italy

Quantum optical systems present several interesting properties, thus becoming a precious tool for simulating physical phenomena otherwise subject of theoretical speculation only, as Bose-Einstein condensation for Hawking radiation [1] or Page-Wootters model [2-6]. Closed Time-like Curves (CTCs), one of the most striking predictions of general relativity, may give rise to paradoxes (e.g. the grandfather's paradox) that can anyway be solved in a quantum network model [7], where a qubit travelling back in time interacts with its past copy. However, the price to pay for the resolution of the causality paradoxes is the breaking of quantum theory's linearity, leading to quantum cloning, uncertainty principle violation and other issues. Interestingly, violations of linearity occur even in open time-like curves (OTCs), when the qubit is initially entangled with another, chronology-respecting, qubit. In this case, non-linearity is needed to avoid entanglement monogamy violations. To preserve linearity and avoid all other drastic consequences, we discuss how the state of the qubit in the OTC is not described by a density operator, but by a pseudo-density operator (PDO) - a recently proposed generalization of density operators, unifying the description of temporal and spatial quantum correlations. Here we present the results obtained with an OTC experimental simulation exploiting polarization-entangled photons [8], providing the first full quantum tomography of the PDO describing the OTC and verifying the violation of the monogamy of entanglement induced by the chronology-violating qubit. At the same time, we show that linearity is preserved, since the PDO already contains both the spatial degrees of freedom and the linear temporal quantum evolution.

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Something happened: The real, the virtual, and the actual in quantum field theory

Arkady Plotnitsky

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

This article addresses a thorny subject of the nature and the very existence of virtual particles, or of elementary particles in the first place, a subject concerning which is difficult and even impossible to be definitive, and the present article does not aim to be. Instead, in contrast to most attempts addressing this subject, which are realist in nature, this article aims to offer a nonrealist viewpoint on this subject—a particular nonrealist viewpoint, as there is no single form of nonrealism any more than a single form of realism. This viewpoint is defined by the concept of "reality without realism" (RWR), introduced by the present author previously, and is, I shall argue, at least practically justified in considering all quantum objects. On the other hand, as I shall also argue, no other justification than practical may be possible in considering the ultimate constitution of reality in quantum theory.

Path integral approach to quantum thermodynamics

Haitao Quan and Ken Funo

Peking University, 5 Yiheyuan Road, Haidian District, Beijing, 100871, China

Work belongs to the most basic notions in thermodynamics but it is not well understood in quantum systems, especially in open quantum systems. By introducing a novel concept of work functional along individual Feynman path, we invent a new approach to study thermodynamics in the quantum regime. Using the work functional, we derive a path-integral expression for the work statistics. By performing the $\hbar$ expansion, we analytically prove the quantum-classical correspondence of the work statistics. In addition, we obtain the quantum correction to the classical fluctuating work. We can also apply this approach to an open quantum system in the strong coupling regime described by the quantum Brownian motion model. This approach provides an effective way to calculate the work in open quantum systems by utilizing various path integral techniques. As an example, we calculate the work statistics for a dragged harmonic oscillator in both isolated and open quantum systems.

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Dynamically assisted nuclear fusion

Friedemann Queisser[1,2,3] and Ralf Schützhold[1,2,3]

[1]*Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany*
[2]*Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany*
[3]*Fakultät für Physik, Universität Duisburg-Essen, Lotharstrasse 1, Duisburg 47057, Germany*

We consider the prototypical deuterium-tritium fusion reaction. At intermediate initial kinetic energies (in the keV regime), a major bottle-neck of this reaction is the Coulomb barrier between the nuclei, which is overcome by tunneling. Here, we study whether the tunneling probability can be enhanced by an additional electromagnetic field, such as an x-ray free electron laser (XFEL). We find that this dynamical assistance should be feasible with present-day or near future technology.

Against the flow: A colloidal Maxwell's demon

Tamir Admon[1], Saar Rahav[2], and Yael Roichman[1]

[1]*Raymond and Beverly Sackler School of Chemistry, Tel Aviv University, Tel Aviv, Israel*
[2]*Schulich Faculty of Chemistry, Technion - Israel Institute of Technology, Technion City, Haifa 32000, Israel*

The connection between information and thermodynamics has been fascinating scientists ever since Maxwell envisioned his celebrated demon. Technological progress now allows realizing lab this celebrated idea that was originally conceived as a thought experiment. Indeed, recent years have seen experimental realizations of several types of information engines.

In this talk, I will describe a realization of Maxwell's demon in which a colloidal particle is “directed” against a fluid flow. Beyond its appealing simplicity, our experimental setup also exhibits an almost full conversion of information to useful work, since it allows to control how much work is applied directly on the particle. Another feature of the setup is a frequent repeated measurement of the particle location, resulting in nontrivial correlations between the outcomes of consecutive measurements. The effect of these correlations on the useful information acquired is investigated with the help of computer simulations.

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Space-borne matter-wave interferences

Ernst Rasel

Institute of Quantum Optics and QUEST-LFS, Leibniz Universität Hannover, Germany

Bose-Einstein condensation (BEC)was awarded with the Nobel prize only 18 years ago. At that time one only could "speculate on areas for the application of BEC. The new "control" of matter which this technology involves is going to bring revolutionary applications in such fields as precision measurement and nanotechnology."

Today BEC interferometry is a cornerstone for applications of cold atoms on ground and in space and represents a new field in matter wave optics. These interferometers strive to increase the sensitivity by coherently spitting and separating wave packets over macroscopic spatial and temporal scales. Bose-Einstein condensates (BECs), representing a textbook example for a macroscopic wave packet, are the ideal source for performing this kind of interferometry in very long baseline interferometers stretching out over seconds on ground and during even longer interferometry times in space.

Indeed, BEC interferometry was exploited for the first time in the extended free fall with a chip-based atom laser for Rubidium ^{87}Rb in the QUANTUS collaboration. The design was successfully employed for a rocket based test of such an BEC interferometer. In the talk, I will present the first interferometry experiments performed on the sounding rocket mission MAIUS-1 in space.

The experiment pave the way for future space experiments by NASA's CAL II and the envisioned DLR-NASA project of "BECCAL", a multi-user facility for experiments on quantum matter, quantum optics and BEC interferometry. Among others, they will demonstrate important techniques necessary for satellite based quantum tests of Einsteins principle of equivalence as pursued by the STE-QUEST mission, for satellite gravimetry and future gravitational wave detection based on ultracold atoms.

The QUANTUS cooperation comprises the group of C. Lämmerzahl (Univ. Bremen), A. Peters (Humboldt Univ. Berlin/Ferdinand Braun Institut), T. Hänsch/J.Reichel (MPQ/ENS), K. Sengstock/P. Windpassinger (Univ. Hamburg/Univ. Mainz), R. Walser (TU Darmstadt), and W.P. Schleich (Univ. Ulm).

This project is supported by the German Space Agency Deutsches Zentrum für Luft- und Raumfahrt (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWI) under grant number DLR 50 WM 0346. We thank the German Research Foundation for funding the Cluster of Excellence EXC2123 Quantum Frontiers.

Decoherence and relaxation of topological states in extended quantum Ising models

Hannes Weisbrich[1], Wolfgang Belzig[1], and Gianluca Rastelli[1,2]

[1]*University of Konstanz, Fachbereich Physik, Fach 703, Universitätsstraße, 78457, Konstanz, Germany*
[2]*Zukunftskolleg, University of Konstanz, 78457, Konstanz, Germany*

We study the decoherence and the relaxation dynamics of topological states in an extended class of quantum Ising chains which can present a degenerate ground state subspace.

The leading interaction of the spins with the environment is assumed to be the local fluctuations of the transverse magnetic field. By deriving the Lindblad equation using the many-body states, we investigate the relation between decoherence, energy relaxation and topology. In particular, in the topological phase and at low temperature, we analyze the dephasing rates between the different degenerate ground states. We derive a formula for the dephasing rate, in a given parity subspace, that incorporate two Majorana zero modes. We show that the topology also affects the relaxation dynamics of excited states. Here we found that a “secondary gap” (which appears for topological number g=2) determines the relaxation behavior of the excited states and the resulting occupation imbalance of the ground states in a given parity subspace.

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Minimal excitations in the fractional quantum Hall regime

Jerome Rech[1], Dario Ferraro[2,3], Flavio Ronetti[2,3], Luca Vannucci[2,3], Matteo Acciai[2,3], Thibaut Jonckheere[1], Maura Sassettti[2,3], and Thierry Martin[1]

[1]*Centre de Physique Theorique, 163 avenue de Luminy, 13009 Marseille, France*
[2]*Dipartimento di Fisica, Università di Genova, Via Dodecaneso 33, 16146, Genova, Italy*
[3]*CNR-SPIN, Via Dodecaneso 33, 16146, Genova, Italy*

Single electron sources have opened up the way to the realization of electronic interferometers involving the controlled preparation, manipulation and measurement of single electron excitations in ballistic conductors, therefore emulating quantum optics experiments to the realm of mesoscopic physics.

One such source consists in applying properly quantized Lorentzian voltage pulses to the contacts of a quantum conductor, thus emitting electrons in the form of minimal excitations states, called "levitons" [1]. Their peculiar properties offer exciting new applications in quantum physics. However, their fate in the presence of interactions is still an open problem.

We propose to study the minimal excitation states of fractional quantum Hall edges, extending the notion of levitons to interacting systems. Interaction and quantum fluctuations strongly affect low dimensional systems leading to dramatic effects like spin-charge separation and fractionalization. This is particularly true when the ground-state is a strongly correlated state, as are the edge channels of a fractional quantum Hall (FQH) system.

Using both perturbative and exact calculations, we show that minimal excitations arise in response to a Lorentzian potential with quantized flux [2]. They carry an integer charge, thus involving several Laughlin quasiparticles (anyons), and leave a Poissonian signature in a Hanbury-Brown and Twiss partition noise measurement at low transparency.

They are further characterized in the time domain using Hong-Ou-Mandel interferometry, revealing some peculiar features in the case of multiply charged Levitons in the form of additional side dips in the computed noise. These dips are concomitant with a regular pattern of peaks and valleys in the charge density, reminiscent of analogous self-organization recently observed for optical solitons in nonlinear environments, ultimately suggesting some kind of crystallization mechanism [3].

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Local and nonlocal shot noise in high-Tc superconducting nanowires

Linda E. Reichl and Corey Ostrove

University of Texas at Austin, Physics Department, 1 University Station, Austin, 78712, USA

We obtain exact expressions for the local current and shot noise and the nonlocal shot noise in the first propagating channel of an NSN (normal-superconducting-normal) nanowire. Using high-T_c cuprate superconductors (HTS) as our model systems we utilize a scattering theory approach to derive the scattering matrix for the systems in the high transparency limit and without the Andreev approximation. The local current and shot noise spectrum is calculated and plotted. In view of recent work in the area of cooper-pair splitting (CPS) devices, we investigate the nonlocal shot noise and relate the behavior of the noise as we change parameters such as the system size, the orientation of the order parameter and the biasing of the junction in the HTS NSN system. The nonlocal shot noise show bunching between electrons and holes that emerge from apposite sides of the superconducting segment.

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Numerically exact full counting statistics of the Anderson impurity model

Michael Ridley

School of Chemistry, Tel Aviv University, Tel Aviv - Yafo 69978, Israel, United Kingdom

The full characterization of charge and energy transfer processes in molecular junctions requires techniques for evaluating higher-order statistical cumulants of the different transfer processes. The complete set of cumulants gives access to the full counting statistics (FCS) through the so-called cumulant generating function (CGF) [1].

Previously, the computation of the CGF for the evaluation of FCS in fermionic systems has been restricted to either noninteracting [2] systems or to specific limiting parameter ranges in correlated systems [3]. Despite the existence of various approximation methods, only very few numerically exact results exist in this field. In this talk, I present a new method [4] for calculating the FCS of a generic nonequilibrium interacting fermionic model, valid for arbitrary temperatures, voltages and interaction strengths. This method is based on the recently-developed inchworm diagrammatic quantum Monte Carlo (iQMC) method [5]. It will be discussed how, using a modified hybridization expansion [6] of the generating function for the FCS in the Anderson impurity model (AIM), the problem of FCS can be mapped to an equivalent problem in iQMC.

To test the method, we present noninteracting benchmarks against path integral techniques [2]. We then go on to discuss the effect of electron-electron interactions on time-dependent charge cumulants, the first passage time distribution (FPTD) and probability distributions for the transfer of n-electrons, as well as the heat current and associated noise. We find ‘queuing‘ behaviour in the FPTD caused by electronic correlations, and discuss how this is manifested in the n-particle probability distribution functions. We observe a fascinating crossover in the shot noise from Coulomb blockade to Kondo effect – dominated physics. Finally, we show how the quantum master equation (QME) approach to FCS fails to capture finite bandwidth effects in the current-voltage and noise-voltage characteristics of the AIM [7].

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Excited quantum coherence: From plasmonically induced transparency to quantum correlation

Yuri Rostovtsev

Department of Physics, University of North Texas, 1155 Union Circle, #311427, Denton, USA

Spectroscopy of materials can be enhanced by the quantum coherent effects [1,2]. Quantum coherent effects are demonstrated to have an all-optical control, on ultrafast time scales, over the photonic topological transition [3]. Localized plasmon interaction in quantum confined structures strongly modify the optical and electronic properties with potential for manipulating light on the nanoscale [4]. Transient pump-probe spectroscopy demonstrate that the coherent absorption in quantum dots is modified by phonon-assisted plasmon induced transparency. A theoretical model has been developed to quantitatively demonstrate that the dark states can be still formed at ultrashort time scale corresponding to the dephasing time of the carriers in the quantum dots. The demonstrated results are important for developing new sensors based on high nonlinearities and their applications to optoelectronic devices. Another approach to demonstrate quantum coherent and cooperative effects is to study the Bi-exponential decay of dye fluorescence near the surface of plasmonic metamaterials and core-shell nanoparticles that has been shown to be an intrinsic property of the coupled system [5]. Our theory shows that the relaxation leads to the population of the sub-radiant states by dephasing the super-radiant Dicke states giving rise to the bi-exponential decay in agreement with the experiments. We use a set of metamaterial samples consisting of gratings of paired silver nanostrips coated with Rh800 dye molecules, having resonances in the same spectral range. We have demonstrated the spectroscopy of nanomaterials and metamaterials, where the quantum coherent effects are able to have an all-optical control, on ultrafast time scales, over the photonic topological transition, for applications as varied as quantum sensing, quantum information processing, and quantum simulations using metamaterials.

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Utilization of surface gravity water waves for the observation of quantum mechanical and optical phenomena

Gary G. Rozenman[1], Lev Shemer[2], Matthias Zimmermann[3], Maxim A. Efremov[3], Wolfgang P. Schleich[3], and Ady Arie[1]

[1]*Faculty of Engineering, Tel-Aviv University, Tel-Aviv, Israel*
[2]*School of Mechanical Engineering, Faculty of Engineering, Tel-Aviv University, Tel-Aviv 6997801, Israel*
[3]*Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89081 Ulm, Germany*

Since the early days of Newtonian mechanics, scientists were interested in the motion of bodies in different potentials. For instance, a massive point-like particle accelerating in a linear potential. In 1927, Kennard [1] has shown that within the quantum-mechanical description, the wave function corresponding to this particle accumulates a position-dependent phase, associated with the momentum change in the linear potential, as well as a position-independent phase that scales with the third power of time (t^3) during which the particle experienced the linear potential [1]. This cubic phase is also accumulated in other physical systems[2]. However, although being a fundamental property of quantum mechanics, so far, no observation of the Kennard phase has been reported, owing to the fact that any setup providing us only with the probability density is insensitive to any global position-independent phase.

The time evolution of a wave function in quantum mechanics is analogous, in many ways, to that of surface gravity water wave pulses. Thus, we utilize this analogy and study the propagation of surface gravity water waves in an effective linear potential, realized by means of a time-dependent homogeneous and well-controlled water flow. In our experiments, we have measured the Kennard cubic phase, for the first time for Gaussian and both normal and inverted Airy wave packets [3].

Motivated by these successful experiments, we have been already studying other analogies between quantum mechanics, optical physics and hydrodynamics, including (i) quantum carpets for periodic input wave packets (Talbot effect), (ii) propagation dynamics of solitary wave packets in an effective linear potential, as well as (iii) different time-dependent flows and black holes.

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Open quantum dynamics of cooperatively coupled atoms and light

Robert Bettles[2], Lewis Williamson[1], Mark Lee[1], Magnus Borgh[3], Simon Gardiner[2], and Janne Ruostekoski[1]

[1]*Lancaster University, Physics Department, Lancaster, United Kingdom*
[2]*Durham University, United Kingdom*
[3]*University of East Anglia, United Kingdom*

We simulate the coupled quantum dynamics of closely-spaced atoms and light by solving the quantum many-body master equation. In the forward scattering of light from planar arrays and uniform slabs of cold atoms we identify quantum many-body effects that are robust to position fluctuations and strong dipole-dipole interactions. This is obtained by comparing the full quantum solution to a semiclassical model that ignores quantum fluctuations. We also evaluate various time correlation functions that illustrate the emergence of quantum effects in the light-mediated many-body interactions between the atoms.

Making hybrid quantum systems on a chip

Patricio Arrangoiz-Arriola, E. Alex Wollack, Jeremy D. Witmer, Timothy P. McKenna, Marek Pechal, Zhaoyou Wang, Wentao Jiang, Felix Mayor, Raphael Van Laer, Agnetta Cleland, Christopher Sarabalis, and Amir H. Safavi-Naeini

Stanford University, 348 Via Pueblo Mall, Stanford, USA

In this talk I will present three platforms that are at the interface of superconducting, phononic (mechanical), and photonic devices.

I will first present our results on coupling superconducting qubits to nanomechanical resonators. We strongly coupled a mechanical system 2.4 GHz to a superconducting qubit at the same frequency. The coupling is sufficiently large that we can resolve different phonon number states through the off-resonant shift they induce on the qubit frequency. This allows us to resolve the energy levels of a mechanical resonator.

Secondly, I will discuss measurements at the interface of superconducting qubits and photonics. I will discuss our platform for quantum electro-optics. I will present a platform where we have co-integrated photonic circuits with microwave resonators and discuss recent measurement results.

Finally, I will discuss new measurements on optomechanical systems that are can provide an alternate scheme for coupling light, sound, and microwaves, on the same chip.

How to distinguish between interacting and noninteracting molecules in tunnel junctions

David Sanchez

University of the Balearic Islands, IFISC (UIB-CSIC), Crta. Valldemossa, km 7.5, E07122-Palma de Mallorca, Spain

Recent experiments demonstrate a temperature control of the electric conduction through a ferrocene-based molecular junction. Here we examine the results in view of determining means to distinguish between transport through single-particle molecular levels or via transport channels split by Coulomb repulsion. Both transport mechanisms are similar in molecular junctions given the similarities between molecular intralevel energies and the charging energy. We propose an experimentally testable way to identify the main transport process [1]. By applying a magnetic field to the molecule, we observe that an interacting theory predicts a shift of the conductance resonances of the molecule whereas in the noninteracting case each resonance is split into two peaks. The interaction model works well in explaining our experimental results obtained in a ferrocene-based single-molecule junction, where the charge degeneracy peaks shift (but do not split) under the action of an applied 7-Tesla magnetic field. This method is useful for a proper characterization of the transport properties of molecular tunnel junctions.

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Non-equilibrium systems as demons

Rafael Sánchez[1], Janine Splettstoesser[2], and Robert S. Whitney[3]

[1]*Universidad Autónoma de Madrid, Francisco Tomás y Valiente, 7, Madrid 28049, Spain*
[2]*Chalmers University of Technology, S-412 96 Göteborg, Sweden*
[3]*Université Grenoble Alpes and CNRS, BP 166, 38042 Grenoble, France*

Maxwell demons cause an apparent violation of the second law of thermodynamics, typically based on detailed detection of internal dynamics and feed-back mechanisms. We show theoretically that non-equilibrium systems can act as much simpler demons with the same effect. These are much more amenable for experimental applications than the Maxwell version, because there is no requirement for the detection of individual particle dynamics in the macroscopic working fluid, nor for feedback. A simple experimental implementation is proposed based on quantum Hall edge states, but can be analogously tested in optical setups.

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Thouless and relaxation time scales in many-body quantum systems

Lea Santos[1], Mauro Schiulaz[1], and Jonathan Torres-Herrera[2]

[1]*Yeshiva University, 245 Lexington Ave, New York City, New York, USA*
[2]*Benem'erita Universidad Autonoma de Puebla, Puebla, Mexico*

Using physical observables, we study numerically and analytically the Thouless time and the relaxation time of realistic interacting many-body quantum systems. The Thouless time refers to the point beyond which the dynamics acquires universal features and becomes purely quantum. Relaxation happens when the evolution reaches a stationary state. These two time scales are not necessarily equal. For chaotic systems, the Thouless time is much smaller than the relaxation time, while for systems approaching a many-body localized phase, they merge together. Both times increase exponentially with system size, while the much smaller characteristic time for the fast initial depletion of the initial state decreases with system size. Our results are compared with those for random matrices, which corroborates their generality. These studies are relevant to experiments with cold atoms and ion traps, where the unitary dynamics of isolated interacting many-body quantum systems is becoming accessible for an ever longer time.

Quantum waves and gravity

Wolfgang Schleich

Institut für Quantenphysik, Universität Ulm, Albert Einstein Allee 11, D-89081 Ulm, Germany
Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm, Germany
Hagler Institute for Advanced Study at Texas A&M University, College Station, TX 77843, USA
Texas A&M AgriLife Research, Texas A&M University, College Station, TX 77843, USA
Institute for Quantum Science and Engineering (IQSE), Texas A&M University, College Station, TX 77843, USA
Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843, USA

Atom interferometry represents a powerful tool to probe the interface of quantum and gravity. It is conventional wisdom that the corresponding phase shift caused by gravity scales quadratically with the time the atom spends in the interferometer. The recent experimental realization of the Stern-Gerlach interferometer [1] displays a cubic rather than a quadratic phase shift. We illustrate this phenomenon in quantum phase space using the Wigner function [2] and, in particular, compare and contrast the sensitivity of this device to uncertainties to the one predicted in the Humpty-Dumpty discussion [3].

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A bath with a memory: Initial states in quantum thermodynamics

Patrick Haughian, Edvin Idrisov, Massimiliano Esposito, and Thomas Schmidt

University of Luxembourg, 162a, avenue de la Faiencerie, L-1511 Luxembourg, Luxembourg

The Markov approximation is a common simplification for open quantum systems and involves neglecting memory effects in the thermal bath. Although this approximation is often justified for systems weakly coupled to a bath, a finite coupling strength makes a more careful study of bath memory effects necessary. To address this question, we examine the role of initial-state contributions for the driven resonant-level model, an exactly solvable prototypical model for quantum thermodynamics. By solving its equations of motion, we obtain an analytical expression for the work performed on the system given a general drive protocol and arbitrary coupling to a bath for different initial conditions. We establish that our definition of work coincides with the one introduced in stochastic thermodynamics. Moreover, we investigate how the memory of the initial state decays in local correlation functions and to what extent it survives in non-local correlation functions.

Learning DFT and inverse mean field theories

Peter Schmitteckert

HQS Quantum Simulations GmbH, c/o CyberForum Service GmbH, Haid-und-Neu-Straße 18, 76131 Karlsruhe, Germany

We first start with an introduction on how to extract a mean field single particle Hamiltonian from a many body wave function of a fermionic system [1]. While we primarily discuss lattice models we also look at neon in an augccpvdz basis set as an example. Our approach allows us to discuss the result of a many particle wave function in terms of a non-interacting description. In contrast to density functional theory approaches on the lattice this approach allows the extraction of appropriate kinetic terms. In result the extracted mean field theories are closer to the physics of the problem under investigation. Therefore, the extracted mean field Hamiltonians may provide an improved starting point for perturbative approaches. As an application we discuss a self consistent cluster embedding (SCCE), where we extract the inverse mean field Hamiltonian from a cluster in real space which we then use to describe a bath Hamiltonian coupled to the cluster. In addition, the technique can be used to decide whether a density matrix renormalization group calculation for interacting fermions has converged to the true ground state.

Second we discuss how one can apply machine learning techniques to construct density functional theory (DFT) functionals from those calculations and provide an example for disordered, interacting 1D fermions.

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Touching horizons with lasers

Hans A. Schuessler[1,2], Feng Zhu[3], Jinbao Xia[3], James R. James Bounds[1], and Alexandre A. Kolomenskii[1]

[1]*Texas A&M University, MS4242, College Station, USA*
[2]*Science Program, Texas A&M University at Qatar, Doha 23874, Qatar*
[3]*School of Physics and Astronomy, Sun Yat-sen University, Zhuhai, Guangdong 519082, China*
[4]*School of Information Science and Engineering, Shandong University, Jinan 25006, China*

High resolution spectroscopy in the infra-red is being employed for monitoring atmospheric pollutions with a variety of techniques. Our group uses two innovative forms of traditional Fourier transform spectroscopy (FTS) with broadband mid-infrared frequency combs. In dual comb spectroscopy the combination of light from two short pulse lasers with slightly different repetition rates produces interferograms without a moving mirror, yielding million times shorter measuring times than FTS, and unprecedented spectral resolution. In single comb Vernier spectroscopy implementation of cavity enhancement achieves in addition ultra-high sensitivity. We also employ narrow band diode lasers in cavity ring-down and wavelength modulation spectroscopies for the detection of methane in ambient air both in our laboratory, and over km path lengths in the atmosphere. The two mid-infrared frequency combs, based on femtosecond Erbium-doped fiber oscillators, are produced through difference frequency generation with periodically poled MgO doped lithium niobate crystals and stabilized at slightly different repetition rates around 250 MHz [1]. We performed dual frequency comb spectroscopy in the spectral range between 2900 cm-1 and 3150 cm-1 with 0.07 cm-1 resolution using a multipass cell with a path length of 580 meter. The sensitivity was about 7.6E-7 cm-1 with a data acquisition time of 80 ms. With the current setup, we measured a methane concentration of 1.9 ppmv in the ambient air in the laboratory with a minimum detection limit of 60 ppbv. In the remote sensing of greenhouse gases over long atmospheric paths carbon dioxide, methane and water vapor were the main absorbers. For these measurements a portable setup was used at the TAMU RELLIS riverside airport [2]. This research was funded by the Robert A. Welch Foundation, Grant No. A1546 and the Qatar Foundation under Grant No. NPRP 6-465-1-091.

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Decoherence and the size of a wave packet

Lawrence S. Schulman[1] and Bernard Gaveau[2]

[1] *Clarkson University, 8 Clarkson Ave, Potsdam, USA*
[2] *University Paris VI, Paris, France*

Off diagonal elements of the one particle density matrix do not go to zero, but rather (for the ideal gas) go to the thermal wavelength. This density matrix nevertheless is consistent with plane waves for wave functions. A contrary view, one natural to kinetic theory is of particles. Using this view, and taking account the spreading of gaussian wave packets during non-scattering periods, we conclude that wave packet size should be a constant times the square root of [the thermal wavelength times the mean free path]. The constant is order unity, but larger than one.

From Bose condensates to black holes: Tribute to Bogoliubov

Marlan O. Scully

Texas A&M University, College Station, TX 77843, USA
Princeton University, Princeton, NJ 80544, USA
Baylor University, Waco, TX 76704, USA

The interface between statistical and optical physics is rich and full of surprises. The present perspective is based on the analogy between lasers and second order phase transitions [1,2], on the one hand, and radiation emitted by accelerating atoms in the vicinity of a black hole, on the other.

The formalism developed by Bogoliubov in the context of superfluid behavior is a powerful tool in these studies. The dynamics of interacting superfluid Bose condensates [3] is naturally developed in the Bogoliubov formalism in which atom pairs, k and –k, are studied. New insights into the Unruh – Hawking radiation problem come from similar pairing correlations within the Bogoliubov analysis.

This approach to the problem of Unruh – Hawking radiation gives us new insight into Einstein's equivalence principle and into rather subtle aspects of causality associated with acceleration radiation [4].

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The inevitable cost of precision

Udo Seifert

University Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

I will discuss recent progress in stochastic thermodynamics for understanding fundamental limits to the temporal precision of processes. The thermodynamic uncertainty relation provides a universal lower bound on the precision a process can achieve for a given energy budget [1]. A variant of this relation allows us to extract from experimental data a model-free upper bound on the efficiency of molecular motors [2]. Likewise, for heat engines, this relation shows that Carnot efficiency at finite power can be reached,in principle, but at the cost of diverging power fluctuations [3]. Persistent coherent oscillations of autonomous biomolecular networks are constrained by the number of states in the network and the driving force [4]. In contrast, in periodically driven systems, coherent subharmonic oscillations can persist forever [5].

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Electron-hole plasma influence on band edge and Rydberg exciton lines in cuprous oxide

Dirk Semkat[1], Heinrich Stolz[2], Rico Schwartz[2], Julian Heckötter[3], Dietmar Fröhlich[3], Marc Aßmann[3], Manfred Bayer[3], and Holger Fehske[1]

[1]*Ernst-Moritz-Arndt-Universität Greifswald, Institut für Physik, Felix-Hausdorff-Str. 6, 17489 Greifswald, Germany*
[2]*Universität Rostock, Institut für Physik, Albert-Einstein-Str. 23-24, 18051 Rostock, Germany*
[3]*Technische Universität Dortmund, Experimentelle Physik 2, 44221 Dortmund, Germany*

Since their first experimental confirmation [1], Rydberg excitons have proven to be fascinating quantum objects with interesting properties (signatures of quantum coherence [2], quantum chaos [3], to name only two examples). Recently it has been shown that a surrounding plasma of free carriers (electrons and holes) has a significant influence on the absorption spectrum, in particular on the position of the band edge, even though its density is very low [4]. There have been, however, some features of the absorption lines that remained still quite unclear, e.g. the temperature dependence of the maximum observable principal quantum number $n_{\max}$. Moreover, no shifts of the exciton lines could be found so far in spite of the sufficient spectral resolution.

We introduce a many-body approach to the behaviour of bound (exciton) states and the band edge in a surrounding electron-hole plasma and discuss several approximations for the band edge. Measurements of the absorption spectrum are presented and a careful analysis of the exciton lines and the band edge is performed. The comparison of calculated and measured line and band edge shifts rules out widely used models for the latter quantity. It is shown that the shifts cannot be consistently explained by semiclassical models like the Debye approximation. Moreover, the temperature dependence of the maximum observable principal quantum number can only be explained by the improved band edge model.

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Conductance oscillations and magnetic orbital effects with chiral Majorana modes

Llorenç Serra

IFISC (CSIC-UIB) and Physics Department, Universitat de les Illes Balears, E-07122 Palma, Spain

Topological transport in Condensed Matter systems is attracting strong interest. In particular, chiral Majorana edge modes in quantum anomalous Hall strips are presently much discussed, theoretically and experimentally. We predict fundamental conductance oscillations in a quantum-anomalous Hall 2d strip having a superconducting region of length Lx with a chiral Majorana mode. These oscillations require a finite transverse extension of the strip Ly of a few microns or less. Measuring the conductance periodicity with Lx and a fixed bias, or with bias and a fixed Lx, yields the speed of the chiral Majorana mode. The physical mechanism behind the oscillations is the interference between backscattered chiral modes from second to first interface of the NSN double junction. The interferometer effect is enhanced by the presence of side barriers. In presence of a vertical magnetic field, the magnetic orbital effect favours the existence of charged Fermionic modes of chiral edge character. These modes are compatible with the present experiments observing a 0.5 plateau in NSN junctions, although a bias dependence of such plateau is predicted.

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Quantum-assisted molecule metrology

Armin Shayeghi and Markus Arndt

Vienna Center for quantum science and technology, University of Vienna, Boltzmanngasse 5, Wien, Austria

The wave nature of molecules is a perfect example of the peculiarities of quantum physics. Molecular quantum optics deals with phenomena related to this wave nature and in particular the interaction of molecules with light [1]. Modern molecule interferometry can further test the notions of macroscopicity and the speculative limits of the linearity of quantum physics by observing quantum effects in massive particles and more recently also biologically relevant molecules [2,3]. Intrinsically, molecule interferometers generate nanoscale fringes in the density distribution of molecular beams which can be shifted by external perturbations and be read with nanometre accuracy. This high sensitivity to beam shifts and wave dephasing can in turn be used to extract a variety of interesting molecular electronic properties [4]. Molecular matter-wave experiments hence open a wide field of research at the interdisciplinary interface between quantum optics and chemical physics. Complex many-body systems further offer a vast variety of electric, magnetic and optical properties that render quantum decoherence interesting and may be technologically useful for future applications.

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Supradegeneracy, thermophotovoltaics, and the second law of thermodynamics

Daniel P. Sheehan

Dept. of Physics, University of San Diego, 5998 Alcala Park, San Diego, USA

Recently, a new thermodynamic phenomenon has been investigated – supradegeneracy [1] – in which the statistical degeneracy of a system increases more rapidly with energy than its Boltzmann exponential decreases such that its higher energy levels can be more populated than its lower ones, thus creating something akin to population inversion – at equilibrium! (Population inversion is typically associated with nonequilibrium systems like lasers.) Although supradegenerate systems do not occur in Nature, they appears possible to create in the laboratory. This presentation reviews recent experimental attempts to generate this phenomenon in the bandgap of silicon. By doping with multiple acceptor impurities having increasing energy with respect to silicon's valence band edge (i.e., B (0.045 eV); Ga (0.072 eV); In (0.16 eV)), but each in exponentially increasing concentrations, we are attempting to create a supradegenerate energy ladder (SDEL) up which electrons can climb into the bandgap, via roughly thermal energy increments, to energies that they would normally would be unable to attain using individual thermal transitions. Such energy ladders could improve the efficiency of thermophotovoltaics. Additionally, SDELs could provide sensitive experimental tests of the second law [2] when incorporated into thermophotovoltaic diodes constructed from narrow-gap semiconductors (e.g., HgCdTe, InSb). In this scenario, electrons would ford the entire band gap of the narrow-gap semiconductor via a 3-4 rung SDEL, transforming thermal energy into dc electric current.

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T136 Mon, 15 July, 14:30 - 14:50, 3 session - C parallel

Statistical cost of interactive quantum phase estimation in quantum chemistry

Yutaka Shikano

Keio University, Quantum Computing Center, 3-14-1 Hiyoshi, Kohoku, Yokohama, Japan
Chapman University, Institute for Quantum Studies, 1 University Dr., Orange, CA, USA

Interactive quantum phase estimation is essentially used in solving the several computational problems, especially, quantum chemistry calculation. In quantum chemistry calculation, a eigenvalue of a given Hamiltonian can be computed with high probability. On calculating the computational speed, we should discuss how many trials we need to solve the eigenvalue of the Hamiltonian, which is hardly verified. In this work, we evaluate the statistical cost of interactive quantum phase estimation via the statistical hypothesis testing to affirm that the solved eigenvalue is the desired one. This work is collaborated with Shintaro Niimura, Aruto Hosaka, and Fumiaki Kannari.

Quantum thermal Hall effect of chiral spinons in a Kagome strip

Pavel Tikhonov and Efrat Shimshoni

Dept. of Physics, Bar-Ilan University, Bar-Ilan University campus, Ramat Gan 52900, Israel

We develop a theory for the thermal Hall effect in a spin-1/2 system on a strip of Kagome lattice, where a chiral spin-interaction term is present. To this end, we model the Kagome strip as a three-leg XXZ spin-ladder, and use Bosonization to derive a low-energy theory for the spinons in this system. Introducing further a Dzyaloshinskii-Moriya interaction (D) and a tunable magnetic field (B), we identify three distinct B-dependent quantum phases: a valence-bond crystal (VBC), a "metallic" spin liquid (MSL) and a chiral spin liquid (CSL). In the presence of a temperature difference between the top and the bottom edges of the strip, we evaluate the net heat current generated along the strip, and consequently the thermal Hall conductivity. We find that the VBC-MSL-CSL transitions are accompanied by a pronounced change in the behavior of thermal Hall coefficient as a function of B. In particular, analogously to the quantum Hall effect, in the CSL phase the thermal Hall conductivity exhibits a quantized plateau centered around a commensurate value of the spinon 'filling factor' B/D.

Topologically protected Majorana zero modes around the edge of a magnetic skyrmion

Maxime Garnier, Andrej Mesaros, and Pascal Simon

University Paris Sud, Laboratoire de Physique des Solides, Bat 510, LPS, Orsay, 91405, France

Magnetic skyrmions are topological spin textures currently at the forefront of research in spintronics because of their fundamental properties as well as their possible applications for memory devices. From another perspective, the question of the interplay of magnetic textures and superconductivity has naturally arisen as attempts to engineer topological superconductivity intensify. In that context, previous work has shown that magnetic skyrmions can host a Majorana zero mode (MZM) in their core when proximitized by a conventional s-wave superconductor. In constrast, we find a highly degenerate flat band of Majorana zero modes on the edge of the skyrmion that is robust to local perturbations be they electronic or geometric. We show that these states can be interpreted as the topologically protected end states of Rashba wires. In addition, the number of MZMs in the flat band surprisingly grows linearly with the perimeter of the edge of the texture, irrespective of its precise shape. In turn, this implies that the MZM are localized on the nanometer scale which potentially allows for their individual adressing. We finally argue that the system considered here implements a Majorana island suitable for the experimental realization of the topological Kondo effect and of electron "teleportation" and suggest possible physical realizations.

Prediction of the dissipative phase transition using machine learning techniques

Ilya Sinayskiy[1,2], Anesan Reddy[1], and Francesco Petruccione[1,2,3]

[1]*University of KwaZulu-Natal, Westville campus, Durban, South Africa*
[2]*National Institute for Theoretical Physics (NITheP), KZN, South Africa*
[3]*School of Electrical Engineering, KAIST, Daejeon 34141, Republic of Korea*

In the last decade, there was tremendous progress in the application of machine learning techniques for various tasks, namely, image recognition, natural language processing, recommending systems. Technologically this progress is due to substantial development of GPU (graphics processing unit) technology which allowed to train deep CNN (convolutional neural network) with millions of parameters in a relatively short time. Recently, researchers have begun to apply machine learning techniques to mathematically ill-defined problems in physics, for example, the prediction of phase transitions. One could identify a few ways of using machine learning for problems in statistical physics. One way is to use neural networks (deep CNN and Restricted Boltzmann Machines - RBMs) as an efficient representation of the quantum state of the system. The other way is more typical for machine learning, where user supply labeled/unlabelled training data (for example spin configurations corresponding to different phases) and the algorithm performs classification/clustering tasks. In this presentation, we will demonstrate the application of the deep CNNs to a prediction of the steady-state properties of the in the dissipative-driven spin chain. It is shown that well tuned and trained ML architecture is capable of performing the thermodynamic limit and predicting dissipative phase transition. Possible application and generalizations will be discussed, as well.

Coherent Raman spectroscopy: From stand-off detection to nano-sensing

Alexei V. Sokolov

Institute for Quantum Science & Engineering, Texas A&M Univ., College Station, TX 77843, and Baylor Research and Innovation Collaborative, Baylor Univ., Waco, TX 76704, USA

Quantum coherence is the central feature of multiple techniques, and corresponds to a situation where atoms or molecules of a sample are prepared in a coherent superposition state. High degree of coherence can lead to remarkable results. Atomic coherence has earlier been used in electromagnetically induced transparency, ultraslow light propagation, and lasing without inversion. Recent work has shown that an increased and cleverly manipulated molecular coherence enables improvements in optical detection and sensing [1], including the possibility of remote sensing via femtosecond laser filaments and optically-pumped atmospheric lasing [2]. At the nanoscale, an additional (multiplicative) improvement can be obtained due to enhancement via plasmonic resonances and nanoantenna effects [3]. Another example is a technique termed molecular modulation, which enables generation of a coherent optical bandwidth spanning infrared, visible, and ultraviolet spectral regions, producing bursts of light synchronized with respect to the molecular oscillations [4]. Controlled spectral, temporal, and spatial shaping of the generated multi-color waveform may lead to arbitrary ultrafast space- and time-tailored sub-cycle optical field synthesis.

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Protected cat states in a driven superfluid boson gas

Fernando Sols, Gregor Pieplow, and Charles E Creffield

Universidad Complutense de Madrid, Dpto. Física Materiales, Plaza de las Ciencias 1, E-28040 Madrid, Spain

We investigate the behavior of a one-dimensional Bose-Hubbard gas whose kinetic energy is made to oscillate with zero time average. The effective dynamics is governed by an atypical many-body Hamiltonian where only even-order hopping processes are allowed. At a critical value of the driving, the system passes from a Mott insulator to a superfluid formed by two quasi-condensates with opposite nonzero momenta. In some parameter range the system has similarities to the Richardson model, which permits a detailed understanding of its key features. The ground state is a cat-like superposition of two macroscopically occupied one-atom states of opposite momentum. Interactions give rise to a reduction (or modified depletion) cloud that is common to both macroscopic branches. Symmetry arguments permit a precise identification of the two orthonormal, macroscopically distinguishable many-body states yielding the cat state, each involving a large number of momentum configurations. In the ring, the system is sensitive to variations of the effective flux but in such a way that the macroscopic superposition is preserved. We discuss other physical aspects that contribute to protect the cat-like nature of the ground state.

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Odd-frequency superconductivity revealed by thermopower

Sun-Yong Hwang[1], Pablo Burset[2], and Björn Sothmann[1]

[1]*Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany*

[2]*Department of Applied Physics, Aalto University, FIN-00076 Aalto, Finland*

Superconductivity is characterized by a nonvanishing superconducting pair amplitude. It has a definite symmetry in spin, momentum, and frequency (time). While the spin and momentum symmetry have been probed experimentally for different classes of superconductivity, the odd-frequency nature of certain superconducting correlations has not been demonstrated yet in a direct way. Here, we propose the thermopower as an unambiguous way to assess odd-frequency superconductivity [1]. This is possible since the thermoelectric coefficient given by Andreev-like processes is only finite in the presence of odd-frequency superconductivity. We illustrate our general findings with a simple example of a superconductor-quantum-dot-ferromagnet hybrid.

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Dynamics of open systems, fluctuation-dissipation theorems and quantum transport theory

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

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

[2]*Dep. of Condensed Matter Physics, Charles University, 121 16 Praha 2, Czech Republic*

This talk will deal with the problem of the proper description of electron dynamics of open quantum systems out of equilibrium from a finite time initial state over the transient period to the long time asymptotic.

The formulation of a simplified transport theory of non-equilibrium dynamics of electrons in quantum systems, based on the Fluctuation-Dissipation (FD) theorem, will be addressed. The FD theorem will be formulated within the Non-Equilibrium Green Function (NEGF) formalism. The relation of the simplified Generalized Master Equation (GME) description to non-equilibrium generalization of FDT will be shown independently on the chosen model.

The possibility of such a simplified description will be first discussed on non-equilibrium dynamics of the molecular bridge model represented by calculations of transient magnetic currents between two ferromagnetic electrodes linked by tunneling junctions to a molecular size island of an Anderson local center type. This model can be treated by using the full set of equations for NEGF, which can be solved numerically.

This provides a reference framework for testing the possibility of a simpler and physically more transparent solution based on a Non-Markovian GME as an approximation of the full set of NEGF equations, which can be derived by using the Generalized Kadanoff-Baym Ansatz (GKBA) [1,2]. The limitations and possible improvements of the GKBA type of approximations, as well as an improved GME, based on the use of a corrected GKBA, will be discussed [2,3].

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Implicit erasure: A universal paradigm of irreversibility

Jürgen T. Stockburger

Universität Ulm, Institute for Complex Quantum Systems, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Irreversibility is manifest in phenomena throughout physics – a fact not accounted for in the reversible dynamics at a microscopic level: Standard Gibbs-Shannon-von-Neumann Entropy is a constant of motion. In order to bring dynamics into contact with thermodynamics, this constraint must be lifted, allowing entropy to increase [1]. Some established approximations to dynamical laws lead to entropy "production" as a by-product, which is typically diagnosed a posteriori. I will argue that entropy production can alternatively be viewed as *implicit erasure* of information [2,3] – information which is not pertinent to a limited set of (typically macroscopic) observables under study. This concept will be formalized, allowing great flexibility to find erasure-modified equations of motion compatible with given sets of observables. Boltzmann's program of irreversibility is thus generalized far beyond gas particles in the weak interaction limit, using information theory instead of scattering theory as its basis. Numerical simulations in both classical and quantum regimes illustrate the approach.

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Failure of conductance quantization in two-dimensional topological insulators due to non-magnetic impurities

Pietro Novelli[2,3], Fabio Taddei[1], Andre K. Geim[4], and Marco Polini[2,4]

[1] *NEST, Istituto Nanoscienze-CNR & Scuola Normale Superiore, Piazza dei Cavalieri, 7, I-56126, Pisa, Italy*

[2] *Istituto Italiano di Tecnologia, Graphene Labs, Via Morego 30, I-16163 Genova, Italy*

[3] *NEST, Scuola Normale Superiore, I-56126 Pisa, Italy*

[4] *School of Physics & Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL, United Kingdom*

Despite topological protection and the absence of magnetic impurities, two-dimensional topological insulators display quantized conductance only in surprisingly short channels, which can be as short as 100 nm for atomically-thin materials. We show that the combined action of short-range non-magnetic impurities located near the edges and onsite electron-electron interactions effectively creates non-collinear magnetic scatterers, and, hence, results in strong back-scattering. The mechanism causes deviations from quantization even at zero temperature and for a modest strength of electron-electron interactions. Our theory provides a straightforward conceptual framework to explain experimental results, especially those in atomically-thin crystals, plagued with short-range edge disorder.

Electronic noise due to temperature differences across nanoscale conductors: Beyond standard thermal and shot noises

Ofir Shein Lumbroso[1], Lena Simine[2,3], Abraham Nitzan[4,5], Dvira Segal[2], and Oren Tal[1]

[1] *Weizmann Institute of Science, Rehovot, Israel*
[2] *University of Toronto, Toronto, Ontario, Canada*
[3] *McGill University Montreal, Quebec, Canada*
[4] *University of Pennsylvania, Philadelphia, Pennsylvania, USA*
[5] *Tel Aviv University, Tel Aviv, Israel*

Since the discovery of electronic thermal (Johnson–Nyquist) noise and shot noise about a century ago, these two forms of fundamental electronic noise have had an enormous impact on science and technology. Here, we report on a new version of electronic noise that is generated by temperature differences across nanoscale conductors, which we term "delta-T noise" [1,2]. We experimentally demonstrate this noise in atomic and molecular junctions, and analyze it theoretically using the Landauer formalism. The delta-T noise reveals a peculiar combination of characteristics that makes it different from the known thermal noise and voltage-activated shot noise. This noise can be used to detect temperature differences across nanoscale conductors without the need for fabricating sophisticated local probes. Furthermore, delta-T noise should be considered when designing modern nanoscale electronics, since temperature gradients are often generated unintentionally across electronic components.

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Constructing deterministic models for quantum mechanical systems

Gerard 't Hooft

Universiteit Utrecht, Institute for Theoretical Physics, Princetonplein 5, Utrecht, 3584CC, Netherlands

In principle one can construct deterministic models that allow for a description in terms of superimposed quantum states in Hilbert space. At first sight, this does seem to clash with locality, and the question is whether one may suspect that more complex structures exist that are more realistic. As is well-known, Bell's theorem suggests that there must be severe limitations for such constructions, but we point out that a conservation law can resolve such issues: the "conservation of ontology".

Nonequilibrium quantum phase transitions in a hybrid atom-optomechanical system

Niklas Mann[1], Axel Pelster[2], M. Reza Bakhtiari[1], and Michael Thorwart[1]

[1] *Universität Hamburg, I. Institut für Theoretische Physik, Jungiusstr. 9, 20355 Hamburg, Germany*

[2] *Physics Department and OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany*

We consider a hybrid quantum many-body system formed by a vibrational mode of a nanomechanical membrane, which interacts optomechanically with light in a cavity, and an ultracold atom gas in the optical lattice of the out-coupled light [1]. A competition occurs between the force localizing the motional state of the atoms in the optical lattice and the membrane displacement. At a critical atom-membrane interaction, we find a nonequilibrium quantum phase transition from a localized symmetric state of the atom cloud to a shifted symmetry-broken state. A strong atom-membrane entanglement arises. The effect occurs when the atoms and the membrane are non-resonantly coupled.

In addition, also the internal degrees of freedom of the atoms can be addressed [2,3]. We show that this hybrid atom-optomechanical system not only undergoes a nonequilibrium quantum phase transition between phases of different collective behavior, but also that the order of the phase transition can be tuned. The coupling between atoms and membrane can tuned by changing the intensity of a common laser. The order of the phase transition is determined by the imbalance of the population of internal atomic states and the transition frequency. Moreover, hysteresis is found by adiabatically tuning the coupling strength in the regime of a first-order phase transition. Finally, we show [3] that the mechanical mode can be squeezed by the backaction of internal excitations of the atoms in the gas. A Bogoliubov approach reveals that these internal excitations form a fluctuating environment of quasiparticle excitations for the mechanical mode with a gaped spectral density. Nanomechanical squeezing arises due to quasiparticle excitations in the interacting atom gas when the mechanical frequency is close to resonance with the internal atomic transitions. Interestingly, nanomechanical squeezing is enhanced by atom-atom interactions.

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Challenging QED with atomic hydrogen

Lothar Maisenbacher, Axel Beyer, Vitaly Andreev, Alexey Grinin, Arthur Matveev, Ksenia Khabarova, Nikolai Kolachevsky, Randolf Pohl, Dylan Yost, Theodor W. Hänsch, and Thomas Udem

Max-Planck Institute of Quantum Optics, Hans-Kopfermann Strasse 1, Garching, Germany

Precise determination of transition frequencies of simple atomic systems are required for a number of fundamental applications such as tests of quantum electrodynamics (QED), the determination of fundamental constants and nuclear charge radii. The sharpest transition in atomic hydrogen occurs between the metastable 2S state and the 1S ground state with a natural line width of only 1.3 Hz. Its transition frequency has been measured with almost 15 digits accuracy using an optical frequency comb and a cesium atomic clock as a reference [1]. A measurement of the Lamb shift in muonic hydrogen is in significant contradiction to the hydrogen data if QED calculations are assumed to be correct [2]. In order to shed light on this discrepancy the transition frequency of one of the broader lines in atomic hydrogen has to be measured with very good accuracy. For this purpose we have employed our previous 1S-2S apparatus as a cold source of laser excited 2S atoms in order to perform spectroscopy on the 2S-4P transitions. With a natural line width of 12.7 MHz, large Doppler effects, quantum interference etc. a good line shape analysis is mandatory to identify the true transition frequency. Our result on this transition yields a value for the proton radius that is compatible with the value obtained from muonic hydrogen with an uncertainty that is comparable to the previous hydrogen world data [3]. Meanwhile H. Fleurbaey and her team at the Laboratoire Kastler Brossel, Paris have re-measured the 1S-3S transition frequency with a significantly improved accuracy and find the previous "regular hydrogen charge radius" [4]. At our lab we have also been working on this transition with a different method. We hope to be ready to report a result soon. This will provide a unique opportunity to compare two highly accurate measurements obtained at different labs.

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Full-counting statistics of information content and the optimum capacity

Yasuhiro Utsumi

Mie University, 1577, Kurimamachiya-cho, Tsu, 514-8507, Japan

Through a mesoscopic quantum conductor, one bit of information content can be conveyed by the arrival or non-arrival of an electron. The performance of communication through such conductor is limited by laws of physics and has been discussed since 1960s. The optimum channel capacity, the maximum rate at which information can be transmitted under a given signal power, i.e. heat current, relates the theory of communication, thermodynamics and quantum physics. We revisit this issue by considering a bipartite quantum conductor and analyzing fluctuations of self-information associated with the reduced density matrix of a subsystem subjected to a constraint of the local heat quantity [1]. The operator of the self-information introduced in this way may be formally regarded as the entanglement Hamiltonian. By exploiting the multi-contour Keldysh technique [2,3], we calculate the Renyi entropy, or the infor-mation generating function, from which the probability distribution of the conditional self-information is derived. We present a Jarzynski-equality like universal relation, that relates the optimum capacity, the Renyi entropy of order 0, which is the number of eigenvalues of the entanglement Hamiltonian, and the number of integer partitions into different positive integers. We apply our theory to a two terminal quantum dot and analyze the probability distributions. We point out that at the steady state, the reduced density matrix and the operator of the local heat quantity of the subsystem may be commutative.

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The quantum theory of time: Sources of T violation

Toshio Croucher and Joan A. Vaccaro

Centre for Quantum Dynamics, Griffith University, 170 Kessels Road, Nathan, Australia

The violation of the discrete symmetries of charge conjugation (C), parity inversion (P), and time reversal (T) observed in high energy physics are clearly fundamental aspects of nature. A new quantum theory [1,2] has been introduced to demonstrate the possibility that the violations have large-scale physical effects. The new theory does not assume any conservation laws or equations of motion. In particular, if T violation is turned off, matter is represented in terms of virtual particles that exist momentarily only. However, with T violation turned on, what was the mathematical representation of a virtual particle now traces out an unbounded world line that satisfies conservation laws and an equation of motion. The theory is then analogous to the 5 dimensional "proper time" formalism introduced by Feynman [3], extended by Nambu [4] in the 1950's, and developed as "parameterized relativistic quantum theories" [5]. The important point here is that time evolution and conservation laws are not built into the new theory, but rather they emerge *phenomenologically* from T violation. In other words, the new theory proposes that T violation is the *origin of dynamics and conservations laws*. It has experimentally testable predictions and offers new insight into the quantum nature of time.

The talk will present results of our analysis of known and expected sources of T violation such as mesons, neutrinos, and the Higgs field. We will show how, in each case, the commutator of $\hat{H}_F$ and $\hat{H}_B$, the time-reversed versions of the associated T violating Hamiltonian, approaches the canonical form [1,2]

$$[\hat{H}_F, \hat{H}_B] = i\lambda\hat{1}$$

in the limit of many particles or field modes, where $\hat{H}_B = \hat{T}\hat{H}_F\hat{T}^{-1}$, $\hat{T}$ is Wigner's time reversal operator, $\hat{1}$ is the identity, and real number λ represents the amount of T violation.

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Advances and challenges in single-molecule electron transport

Sumit Tewari[1,4], Richard Korytár[2], Ferdinand Evers[3], and Jan van Ruitenbeek[4]

[1] *Department of Materials, University of Oxford, OX1 3PH, Oxford, United Kingdom*
[2] *Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, 121 16 Praha 2, Czech Republic*
[3] *Institut für Theoretische Physik, Universität Regensburg, D-93053 Regensburg, Germany*
[4] *Huygens-Kamerlingh Onnes Laboratory, Leiden University, Niels Bohrweg 2, 2333CA Leiden, Netherlands*

Electronic transport properties for single-molecule junctions have been widely measured by several techniques, including mechanically controllable break junctions, electromigration break junctions or by means of scanning tunneling microscopes. In parallel, many theoretical tools have been developed and refined for describing such transport properties and for obtaining numerical predictions. Most prominent among these theoretical tools are those based upon density functional theory. In this review, theory and experiment are critically compared and this confrontation leads to several important conclusions. The theoretically predicted trends nowadays reproduce the experimental findings quite well for series of molecules with a single well-defined control parameter, such as the length of the molecules. The quantitative agreement between theory and experiment usually is less convincing, however. Many reasons for quantitative discrepancies can be identified, from which one may decide that qualitative agreement is the best one may expect with present modeling tools. For further progress, benchmark systems are required that are sufficiently well-defined by experiment to allow quantitative testing of the approximation schemes underlying the theoretical modeling. Several key experiments can be identified suggesting that the present description may even be qualitatively incomplete in some cases. Such key experimental observations and their current models are also discussed here, leading to several suggestions for extensions of the models towards including dynamic image charges, electron correlations, and polaron formation.

Steering magnetic skyrmions with currents: A nonequilibrium Green's functions approach

Claudio Verdozzi

Lund University, Professorgatan 1, Lund, 22100, Sweden

We present a mixed quantum-classical scheme to describe how magnetic skyrmions can be manipulated with currents. Our approach is based on a microscopic treatment of the skyrmion-current interaction, where we treat the currents via nonequilibrium Green's functions (NEGF), the skyrmions in terms of classical localized spins, and describe the skyrmion motion within the Ehrenfest dynamics. This mixed quantum-classical scheme is then employed to gain insight into how time-dependent currents, and electron-electron and spin-orbit interactions in a current-carrying wire affect skyrmion dynamics. In the second part of the talk, we address scope and limitations of this approach, and speculate on possible ways forward. This is done using examples and concepts borrowed from NEGF treatments of molecular motors and density functional approaches for multi-component systems.

Quantum microwaves with a dc-biased Josephson junction

Ambroise Peugeot[1], Chloé Rolland[1], Olivier Paralvechio[1], Marc Westig[1], Gerbold Ménard[1], Iouri Moukharski[1], Bjorn Kubala[2], Carles Altimiras[1], Max Hofheinz[1], Patrice Roche[1], Philippe Joyez[1], Denis Vion[1], Pascal Simon[3], Joachim Ankerhold[2], Daniel Esteve[1], and Fabien Portier[1]

[1]*CEA Saclay (France), Orme des merisiers Bd772, F91191 Gif sur Yvette Cedex, France*
[2]*Institue for complex Quantum Systems, University of Ulm, 89068 Ulm, Germany*
[3]*Laboratoire de Physisque des Solides, Université Paris-Saclay, 91405 Orsay, France*

By dc-voltage biasing a Josephson junction in series with one or two high-impedance microwave resonators, we generate different bright non-classical states of propagating microwaves. The physics behind is simple and non-dissipative (Hamiltonian): the energy of a Cooper pair tunneling accross the junction and flowing accross the circuit is conserved by creation of one or several correlated photons. We first demonstrate the equality between the Cooper pair tunneling rate and the photon production rates [1]. Then we demonstrate a blockade regime for which the presence of a single photon blocks the next tunneling event, leading to a continuous beam of anti-bunched photons [2]. Finally, using two resonators with different frequencies, we demonstrate photon pair production [3], as well as two-mode entanglement.

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Integer quantum Hall transition on a tight-binding lattice

Thomas Vojta[1], Martin Puschmann[1], Philipp Cain[2], and Michael Schreiber[2]

[1]*Missouri University of Science and Technology, Department of Physics, 1315 North Pine Street, Rolla, MO 65409, USA*
[2]*Chemnitz University of Technology, 09107 Chemnitz, Germany*

Even though the integer quantum Hall transition has been investigated for nearly four decades its critical behavior remains a puzzle. The best theoretical and experimental results for the localization length exponent ν differ significantly from each other, casting doubt on our fundamental understanding. While this discrepancy is often attributed to long-range Coulomb interactions, Gruzberg et al. [1] recently suggested that the semiclassical Chalker-Coddington model, widely employed in numerical simulations, is incomplete, questioning the established central theoretical results. To shed light on the controversy, we perform a high-accuracy study of the integer quantum Hall transition for a microscopic model of disordered electrons. We find a localization length exponent $\nu = 2.58(3)$ validating the result of the Chalker-Coddington network.

This work was supported by the National Science Foundation under Grant Nos. DMR-1828489, DMR-1506152, PHY-1607611, and PHY-1125915. We thank Ferdinand Evers, Ilya Gruzberg, and Ara Sedrakyan for helpful discussions.

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Quantum key distribution in a telecom network

Oleg Nikiforov, Erik Fitzke, and Thomas Walther

TU Darmstadt, Institute for Applied Physics, Schlossgartenstr. 7, Darmstadt, Germany

In this talk we present the current status of our experiment on a quantum key distribution (QKD) system.

First, we briefly review the key elements of our QKD system based on time-bin entanglement. The entangled photons are provided by spontaneous parametric down-conversion of a 775-nm pulsed source consisting of frequency doubled and fibre amplified radiation from a DFB laser operating at 1550 nm.

After characterizing our source of entangled photons in terms of count rate as well as spectrum, we describe our setup using the time-bin entanglement to exchange a key between Alice and Bob employing Franson interferometers. First tests of this source in a telecom environment provided by the Deutsche Telekom will be discussed.

The future goal of this experiment is the extension of the system towards a small quantum hub where any two of four parties can exchange a key using WDM equipment.

Quantum noise in LIGO

Rainer Weiss

Massachusetts Institute of Technology, Cambridge, NW22-283,MIT,185 Albany St, Cambridge, 02139, USA

The understanding of how the noise due to the quantum nature of light and matter enters the interferometric detection of gravitational waves came slowly. The work of Horace Yuen, Carlton Caves and Marlan Scully in the late 1970's and early 1980's provided the insight into how the vacuum fluctuations enter the instrument. They also showed how the generation of paired photon states derived from the vacuum fluctuations could be used to suppress the quantum noise. The talk will describe some of this history and subsequent experimental work. The development of practical techniques to reduce the quantum noise, first on the GEO detector at the Albert Einstein Institute in Hannover and at the Australian National University, are now being applied to both the LIGO and VIRGO detectors. The sensitivity improvements are significant.

T158 Wed, 17 July, 10:40 - 11:10, 2 session - D parallel

Communicating via ignorance & imaging via counting

K. Goswami[1], L. A. Howard[1], Y. Cao[2], G. G. Gillett[1], G. A. Paz-Silva[2], M. E. Pearce[3], R. A. Abrahão[1], P. Kok[3], J. Romero[1], and Andrew G. White[1]

[1]*Centre for Engineered Quantum Systems, University of Queensland, Brisbane, Australia*
[2]*Centre for Quantum Dynamics, Griffith University, Brisbane, Australia*
[3]*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*

Communicating via ignorance. Intuitively, no information can be sent through a completely noisy channel. However quantum physics defies this intuition, enabling information to be sent either via superposition of path, or superposition of causal order. Previous work has shown that: *path superposition*—placing two completely noisy channels in different arms of an interferometer—allows up to 0.16 bits to be communicated; *order superposition*—placing two completely noisy channels in a superposition so we are ignorant of channel order—allows up to 0.049 bits can be communicated. Here we improve on this, showing that perfect information transmission is possible, but *only* in the case of order superposition [1]. Experimentally we use a quantum switch [2] to achieve indefinite causal order, achieving for path and order superposition respectively 0.0341 ± 0.0015 bits and 0.636 ± 0.017 bits, the latter a capacity not possible with simple path superposition. Our results offer intriguing possibilities in applications ranging from communication through to imaging in turbulent media.

Imaging via counting. Physical limits to imaging precision are well known, less well know are ways to circumvent them, e.g. using super-resolution techniques that exploit the physical structure of the object, or object illumination with entangled states of light. However, in many applications—e.g. when the object is very far away—we cannot directly interact with the object, or illuminate it with entangled light: the quantum state of the light field is <i>all</i> that is accessible to the observer. We show the best way to extract the spatial characteristics of the light source, given a finite size imaging system in the far field, is to measure the complex degree of coherence. We do this with linear optics and photon number resolving detectors, measuring the size and position of a small distant source of pseudo-thermal light. Our method outperforms traditional imaging by an order-of-magnitude in precision. Additionally, a lack of photon-number resolution in the detectors has only a modest detrimental effect on measurement precision, highlighting the practicality of this method for a wide range of imaging applications.

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Topology-controlled macroscopic quantum coherent effects in multi-terminal Andreev interferometers

Pavel E. Dolgirev[1], Mikhail S. Kalenkov[2], and Andrei D. Zaikin[2,3]

[1]*Department of Physics, Harvard University, Cambridge Massachusetts 02138, USA*
[2]*I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physical Institute, 119991 Moscow, Russia*
[3]*Institute of Nanotechnology, Karlsruhe Institute of Technology, 76021, Karlsruhe, Germany*

Proximity induced long range quantum coherence of electrons in multi-terminal voltage-driven hybrid normal-superconducting (NS) nanostructures may result in a non-trivial interplay between topology-dependent Josephson and Aharonov-Bohm effects. Further intriguing phenomena emerge due to the combination of quantum coherence and electron-hole asymmetry generated by the mechanism of sequential Andreev reflection at different NS interfaces [1]. In this talk I will elucidate several recent developments [2-4] associated with the above effects. In particular, I will demonstrate that a trade-off between voltage-dependent Josephson (I_J) and Aharonov-Bohm (I_{AB}) currents may yield a novel topology-controlled ϕ_0-junction behavior [2]. An even richer physical picture emerges if one accounts for the competition between stimulation of I_J due to non-equilibrium effects and reduction of both I_J and I_{AB} caused by quantum dephasing of quasiparticles. Finally, I will address quantum coherent topology-dependent oscillations of the thermopower in Andreev interferometers [4] and formulate predictions possibly resolving several long-standing experimental puzzles. Our results may be employed for engineering superconducting nanocircuits with controlled quantum properties.

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Universal scaling of quantum geometric tensor in disordered metals

Miklos Antal Werner[1], Arne Brataas[2], Felix von Oppen[3], and Gergely Zarand[1]

[1]*Exotic Quantum Phases "Momentum" Research Group, Department of Theoretical Physics, Budapest University of Technology and Economics, 1111 Budapest, Budafoki ut 8, Hungary*
[2]*Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway*
[3]*Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universitat Berlin, 14195 Berlin, Germany*

The geometrical structure of the Hilbert space continues to receive a lot of attention. The Fubini-Study metric tensor of the Hilbert space, also referred to as Fisher information metric, provides a natural measure of distance in the Hilbert space, related to quantum fidelity – a fundamental concept in quantum information science. Interestingly, the concepts of the Fubini-Study metric tensor and the Berry phase can be unified through the so-called quantum geometric tensor (QGT).

In the present work [1], we demonstrate that the quantum geometric tensor offers deep insight into a long-standing problem in condensed matter physics, Anderson's disorder-driven metalinsulator (MI) transition in small external magnetic fields. In particular, the structure of the QGT reflects the universality class of the Anderson transition. Elements of the QGT display universal finite size scaling close to the metal-insulator transition, and capture the flow between the orthogonal ($B = 0$) and unitary ($B \neq 0$) universality classes. At the transition, the elements of the QGT have universal distributions, characteristic of the underlying symmetry of the transition, but, surprisingly, independent of the direction of the external field. We predict that these universal fluctuations show up as universal and isotropic Hall conductance fluctuations at the metal-insulator transition.

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Physics of thermalization and level density in an isolated system of strongly interacting particles

Vladimir Zelevinsky

Michigan State University, 640 South Shaw Lane Cyclotron, East Lansing 48824, USA

Statistical physics of isolated systems of strongly interacting constituents is an important part of all practical applications, including astrophysics and technology. Two aspects will be discussed: level density and time-dependent process of thermalization. Recent experiments in nuclear reactions show that the nuclear level density is well described, up to some excitation energy, by a pure exponential function of energy (the so-called "constant temperature model"). The same conclusion follows from the exact shell-model diagonalization. The underlying physics is related to the process of chaotization of many-body dynamics. The role of superfluid pairing, collective modes, random spin coupling, and incoherent collision-like interactions is discussed. The time-dependent evolution of an initial non-equilibrium state shows an analogy to the radioactive decay of unstable systems. The majority of initial states undergo the typical decoherence process similar to what is characteristic for random ensembles.

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Quantum thermodynamics of single particle systems

Wei-Min Zhang, Md. M. Ali, and Wei-Ming Huang

National Cheng Kung University, No.1 University Road, Tainan, Taiwan

Thermodynamics is built with the concept of equilibrium states. However, it is less clear how equilibrium thermodynamics emerges through the dynamics that follows the principle of quantum mechanics. In this paper, we develop a theory of quantum thermodynamics that is applicable for arbitrary small systems, even for single particle systems, in contact with a reservoir. We generalize the concept of temperature into non-equilibrium regime that depends on the detailed dynamics of quantum states. We apply the theory to a single-mode cavity system and a two-level atomic system interacting with a reservoir, the results unravels (1) the emergence of thermodynamics naturally from the exact quantum dynamics in the weak system-reservoir coupling regime without introducing the hypothesis of equilibrium between the system and the reservoir from the beginning; (2) the emergence of thermodynamics in the intermediate system-reservoir coupling regime where the Born-Markovian approximation is broken down; (3) the breakdown of thermodynamics in the strong coupling regime due to the long-time non-Markovian memory effect; (4) the occurrence of dynamical quantum phase transition characterized by inflationary dynamics associated with negative non-equilibrium temperature. The corresponding dynamical criticality provides a border separating classical and quantum thermodynamics. The inflationary dynamics may also provide a simple picture for the origin of big bang and universe inflation; (5) the third law of thermodynamics, allocated in the deep quantum realm, is naturally proved.

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Invited Posters

Time-dependent Ginzburg-Landau-McMillan models for light-induced ultrafast phase transitions in cuprates and other complex materials

Roland E. Allen and M. Ross Tagaras

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

It has become increasingly apparent that the experiments of Cavalleri, Först, Kaiser, and coworkers have indeed demonstrated light-induced superconductivity. Focusing on these experiments, but also inspired to consider the complex phases of other materials, we are fitting time-dependent Ginzburg-Landau-McMillan models, with multiple competing phases, to the static phase diagrams, and then performing simulations of the response to femtosecond-scale laser pulses. Comparison with the experiments can then provide information about the relevant time scales and other properties of the phases. In the first simulations [1], with only two phases schematically representing the stripe and superconducting phases considered in Refs. [2-5], we obtained the same basic qualitative results as observed in the experiments: For strong enough laser pulses, there is a nonthermal “melting'” of an initial stripe phase. Then the superconducting phase will emerge, as observed, if it couples more weakly. But there is a reciprocity inherent in the free energy: The superconducting phase is just as effective in blocking the stripe phase as vice-versa. This can explain why the superconducting phase persists for an extremely long time in the low-temperature results of Refs. [2] and [4]. In more recent simulations, corresponding to other parts of the static phase diagram for LESCO, and with more competing phases, we observe more complex behavior.

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I2

Global thermodynamic variables to describe non-homogeneous quantum systems

Arnol Orozco[1], Marcos Miotti[1], Michael Hemmerling[1], Gustavo Telles[1], Vanderlei S. Bagnato[1], and Victor Romero-Rochin[2]

[1]*IFSC-University of São Paulo, Av. Trabalhador São Carlense, 400, São Carlos, Brazil*
[2]*Physics Department, UNAM, Mexico City, Mexico*

The field of quantum gases has evolved very rapidly in recent years, exceeding the expectation of many researchers. Experiments are mostly done with trapped samples, where atoms present an inhomogeneous density distribution. In such situation quantities like pressure and volume, normally easy interpreted inhomogeneous systems, find difficulties to be applied. The determination of those thermodynamic variables is achieved using the local density approximation (LDA). Alternatively, one can consider the Global behavior of the system, defining a new approximation called Global Variables (GV). In this approximation, a single pressure and a single volume are assigned to the system, and their relations constitute an overall equation of state. While the local density approximation has been proposed by, the global variable has been explored in a few published papers. In this presentation we consider the BEC transition observed from the Global Variable approach. We start presenting the fundaments of the methods and applications to the determination of compressibility, State Equation, Thermal expansion coefficient, Heat capacity. Finally, a treatment to analyze the critical exponent is performed. Work supported by FAPESP and CNPq. Recommended papers can be found at http://cepof.ifsc.usp.br

Entanglement generation and single photon storage using waveguide QED

Harold U. Baranger

Duke University, Dept of Physics, Science Dr, Durham 27708-0305, USA

Strong coupling between a local quantum system (qubit or atom) and one-dimensional bosonic states has recently become experimentally feasible in a variety of plasmonic, photonic, circuit-QED, and cold-atom contexts. This has opened up a new field dubbed "waveguide QED". The key ingredient in the many new effects in this area is inelastic scattering into the one-dimensional continuum. Using such inelastic scattering as a unifying theme, I shall discuss our results on (i) photon correlations, (ii) capture of a photon into a bound state in the continuum, and (iii) photon production when the coupling is ultrastrong.

I4

Microwave spectroscopy reveals the quantum geometric tensor of topological Josephson matter

Wolfgang Belzig[1], Raffael Klees[1], Gianluca Rastelli[1], and Juan Carlos Cuevas[2]

[1] *Fachbereich Physik, Universität Konstanz, Universitätsstr. 10, 78457 Konstanz, Germany*
[2] *Departamento de Fisica Teorica de la Materia Condensada and Condensed Matter Physics Center , Universidad Autonoma de Madrid, E-28049 Madrid, Spain*

Quantization effects due to topological invariants such as Chern numbers have become very familiar. However, key quantities as the quantum geometric tensor providing local information about quantum states remain experimentally difficult to access. Recently, it has been shown that multiterminal Josephson junctions constitute an ideal platform to synthesize topological systems in a controlled manner. We theoretically study properties of Andreev states in topological Josephson matter and demonstrate that the quantum geometric tensor of Andreev states can be extracted by synthetically polarized microwaves. The integrated absorption provides direct evidence of topological quantum properties of the Andreev states.

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Ab initio results for the dynamical structure factor of the finite temperature electron gass

Simon Groth[1], Tobias Dornheim[2], Jan-Philip Joost[1], and Michael Bonitz[1]

[1]*Institute for Theoretical Physics and Astrophysics, Universiy Kiel, Germany, Leibnizstr. 15, 24098 Kiel, Germany*
[2]*Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany*

The accurate description of electrons at high density and finite temperature is of paramount importance for, e.g., the understanding of astrophysical objects and correlated materials. In this context, the dynamic structure factor $S(q, \omega)$ constitutes a key quantity as it is directly measured in X-ray Thomson (XRTS) scattering experiments. We have recently [1] obtained the first ab initio results for $S(q, \omega)$ by carrying out extensive path integral Monte Carlo simulations and developing a new method for the required analytic continuation, which is based on the stochastic sampling of the dynamic local field correction $G(q, \omega)$. A particularly interesting result is the confirmation of a negative plasmon dispersion in the correlated liquid regime. This extends our recent work on the ab initio thermodynamic results of the warm dense electron gas [2] to dynamic quantities. These results are compared with an independent approach that is based on nonequilibrium Green functions [3].

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I6

Thermodynamic cycles in Josephson junctions

Francesco Vischi[1,2], Matteo Carrega[1], Pauli Virtanen[1], Elia Strambini[1], Alessandro Braggio[1], and Francesco Giazotto[1]

[1] *Istituto Nanoscienze CNR, NEST, Scuola Normale Superiore, Piazza San Silvestro 12, Pisa 56127, Italy*
[2] *Dipartimento di Fisica, Universitaa' di Pisa, Pisa 56127, Italy*

A superconductor/normal metal/superconductor Josephson junction is a coherent electron system where the thermodynamic entropy depends on temperature and difference of phase across the weak-link. Here, exploiting the phase-temperature thermodynamic diagram of a thermally isolated system, we argue that a cooling effect can be achieved when the phase drop across the junction is brought from 0 to π in a iso-entropic process [1]. We show that iso-entropic cooling can be enhanced with proper choice of geometrical and electrical parameters of the junction, i.e. by increasing the ratio between supercurrent and total junction volume. We present extensive numerical calculations using quasi-classical Green function methods for a short junction and we compare them with analytical results. Interestingly, we demonstrate that phase-coherent thermodynamic cycles can be implemented by combining iso- entropic and iso-phasic processes acting on the weak-link, thereby engineering the coherent version of thermal machines such as engines and cooling systems. We therefore evaluate their performances and the minimum temperature achievable in a cooling cycle.

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Contextuality in human decision making

Ehtibar N. Dzhafarov and Victor H. Cervantes

Purdue University, 703 Third Street, West Lafayette 47907, USA

(Non)contextuality is a characteristic of any system of random variables labeled by what they measure and under what conditions. This notion is not restricted to quantum systems. In particular, it is applicable to systems of random variables describing human responses to stimuli/questions. However, until recently, all available data were showing that human choice behavior is noncontextual. These systems grossly violate the no-disturbance principle, so they can only be analyzed by a theory that is not predicated on this principle. Contextuality-by-Default is such a theory. We present a series of results from both crowdsourcing and individual experiments that do reveal contextuality in human choice behavior.

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I8

Detecting ultrastrong coupling by nonequilibrium photon distributions

Alessandro Ridolfo[1,3], Jishnu Rajendrar[1,3], Elisabetta Paladino[1,2,3], and Giuseppe Falci[1,2,3]

[1]*Dipartimento di Fisica e Astronomia "Ettore Majorana", Universita' di Catania, Via Santa Sofia 64, Catania I-95125, Italy*
[2]*CNR-IMM MATIS Catania, Via Santa Sofia 64, Catania I-95125, Italy*
[3]*INFN Sezione di Catania, Via Santa Sofia 64, Catania I-95125, Italy*

Fabrication techniques have recently allowed to produce ultra-strong coupling (USC) between light and matter, a regime where previously unexplored non-perturbative phenomena emerge. The highly entangled light matter states are responsible for the peculiar phenomena in this regime thus one of the key issues in the field is the detection of virtual photon pairs.

We introduce several proposals based on the use of a ancillary third atomic level which provides a channel for photon-pair production, only in the presence of USC. We discuss the implementation of such schemes in specific systems, as different superconducting structures of artificial atoms or semiconductor nanostructures, suitably controlled by external drives and accounting for thermal and quantum fluctuations.

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Attraction induced by mutual quantum measurements of velocity

Walter Hahn[1,2] and Boris V. Fine[1,3]

[1] *Skolkovo Institute of Science and Technology, Skolkovo Innovation Center, Nobel Str. 3, Moscow, Russian Federation*
[2] *QuTech, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands*
[3] *Institute for Theoretical Physics, University of Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany*

We define the notion of mutual quantum measurements of two macroscopic objects and investigate the effect of these measurements on the velocities of the objects. We show that multiple mutual quantum measurements can lead to an effective force emerging as a consequence of asymmetric diffusion in the velocity space. We further show that, under a certain set of assumptions involving the measurements of mutual Doppler shifts, the above force can reproduce Newton's law of gravitation. such a mechanism would explain the equivalence between the gravitational and the inertial masses. For a broader class of measurements, the emergent force can also lead to corrections to Newton's gravitation.

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I10

Auxiliary master equation for nonequilibrium dual fermion approach

Feng Chen[1], Guy Cohen[2], and Michael Galperin[1]

[1]*University of California San Diego, USA*
[2]*Tel Aviv University, Israel*

We introduce an auxiliary quantum master equation dual fermion method (QME-DF) and argue that it presents a convenient way to describe steady-states of correlated impurity models. The scheme yields an expansion around a reference that is much closer to the true nonequilibrium state than that in the original dual fermion formulation. In steady-state situations, the scheme is numerically inexpensive and avoids time propagation. The Anderson impurity model is used to test the approach against numerically exact benchmarks.

Propagation of two entangled identical particles

Gastón García-Calderón[1], Roberto Romo[2], and Miguel Ángel Terán[1]

[1]*Instituto de Física, UNAM, Ciudad Universitaria, México City , 04510, Mexico*
[2]*Facultad de Ciencias, UABC, Ensenada, B. C., 22800, Mexico*

An exact analytical non-Hermitian formulation based on the properties of the outgoing Green's function to the problem in the momentum plane [1,2,3] is presented for treating the propagation, along the external potential region, first, by the sake of comparison, of the probability density profile of a single decaying particle, at a fixed value of the position of the particle as a function of time; and then, in a similar fashion, of two identical noninteracting decaying particles which are entangled by spatial symmetry at fixed values of the positions of each particle as a function of time. Using a generic solvable model we study the corresponding probability densities aimed to find possibly signatures of the symmetric and antisymmetric solutions. We find, however, that the symmetric and antisymmetric probability densities exhibit a similar profile, except at long times where they display in general the distinct inverse power in time behavior found for the corresponding survival and nonescape probabilities [4].

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I12

Nonlocal thermoelectricity in a Cooper-pair splitter

Robert Hussein[1], Michele Governale[2], Kohler Kohler[3], Wolfgang Belzig[1], Francesco Giazotto[4], and Alessandro Braggio[4]

[1]*Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany*
[2]*Victoria University of Wellington, Wellington, New Zealand*
[3]*Instituto de Ciencia de Materiales de Madrid, CSIC, Cantoblanco, E-28049 Madrid, Spain*
[4]*NEST, Istituto Nanoscienze-CNR, Piazza S. Silvestro 12, Pisa I-56127, Italy*

We investigate the nonlocal thermoelectric transport in a Cooper-pair splitter based on a double-quantum-dot-superconductor three-terminal hybrid structure. We find that the nonlocal coupling between the superconductor and the quantum dots gives rise to nonlocal thermoelectric effects which originate from the nonlocal particle-hole breaking of the system. We show that Cooper-pair splitting induces the generation of a thermocurrent in the superconducting lead without any transfer of charge between the two normal-metal leads. Conversely, we show that a nonlocal heat exchange between the normal leads is mediated by nonlocal Andreev reflection. We discuss the influence of finite Coulomb interaction and study under which conditions nonlocal power generation becomes possible, and when the Cooper-pair splitter can be employed as a cooling device.

Quantum time: Experimental multi-time correlations

Ekaterina Moreva[1], Marco Gramegna[1], Giorgio Brida[1], Lorenzo Maccone[2,3], and Marco Genovese[1,4]

[1]*INRiM - Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce, 91, Torino - 10135, Italy*
[2]*Dipartimento Fisica " Alessandro Volta " - University of Pavia, Italy*
[3]*INFN Sezione Pavia, Italy*
[4]*INFN Sezione di Torino, Italy*

In this poster we provide an experimental illustration of Page and Wootters' quantum time mechanism [1-2] that is able to describe two-time quantum correlation functions. This allows us to test a Leggett-Garg inequality, showing a violation from the "internal" observer point of view. The "external" observer sees a time-independent global state. Indeed, the scheme is implemented using a narrow-band single photon where the clock degree of freedom is encoded in the photon's position [3-4]. Hence, the internal observer that measures the position can track the flow of time, while the external observer sees a delocalized photon that has no time evolution in the experiment time-scale.

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I14

Induced fractional charges on the domain wall and the skyrmion-like dot

Ikuzo Kanazawa and Ryota Maeda

Department of Physics,Tokyo Gakugei University, Nukuikitamachi 4-1-1,Koganeishi, Tokyo 184-8501, Japan

One (I.K.) of the present authors has reported the importance of hole-induced domain wall and the hedgehog-like magnetic soliton in magnetoresistance in diluted magnetic semiconductors [1,2], and doped manganites [3]. In addition, the present authors [4,5] have proposed exotic quasiparticles with fractional charges in a semiconductor-dot from collectively induced-charge effect on a domain wall shell. In this study, we have discussed in detail the anomalous excitations such as dyons and Majorane fermions on the domain wall in the topological materials and the skyrmion-like dot, and the relation to low-energy hadrons in QCD, from viewpoints of a field-theoretical fromula.

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Quantum-like modeling decision making in linguistics

Andrei Khrennikov[1] and Anja Nertyk[2]

[1]*Linnaeus University, Center for Math Modeling in Physics and Cognitive Science, P.G. Vägen, Växjö, Sweden*
[2]*Chair of Swedish Language, School for Adult Education, Växjö, Sweden*

Recent years the mathematical formalism of quantum theory started to be widely applied outside of physics: in cognitive science, psychology, economics, finances, decision making, geophysics, linguistics (see, e.g. [1]). In this poster, we present a short review of these applications. We concentrate on applications to linguistics, especially to decision making in translation from one language to another. As illustrations, we consider the quantum-like presentation of the process of translations from English to Russian and from Czechish to English.

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I16

Theory of Hall effect in superconductors

Takafumi Kita[1], Hikaru Ueki[2], and Marie Ohuchi[1]

[1]*Hokkaido University, Sapporo, Kita 10 Nishi 8, Sapporo 060-0810, Japan*
[2]*Hirosaki University, Hirosaki, 1 Bunkyo-cho, Aomori 036-8560, Japan*

The Lorentz force on electric currents flowing in magnetic fields has a unique component perpendicular to both the current and field. It generally induces charge redistribution before recovering any steady state to produce the Hall voltage that eventually brings a force balance along the transverse direction. Extensive studies have been performed on this *Hall effect* in metals and semiconductors, especially on the quantum Hall effect in two dimensions over decades.

In contrast, we still have a poor understanding of the phenomena in superconductors. This is because the force on supercurrent itself may easily be overlooked in the presence of the predominant diamagnetic effect by supercurrent obeying Ampère's law. Indeed, the Lorentz force is missing from the Ginzburg-Landau and Eilenberger equations that have been used extensively in the literature, and can only be reproduced microscopically as a next-to-leading order contribution in the expansion of the Gor'kov equations in terms of the quasiclassical parameter $\delta \equiv 1/k_{\rm F}\xi_0$. Hence, physics of the Lorentz force in superconductors remains mostly unexplored theoretically.

We present results of our recent theoretical studies on the Hall effect and charging in superconductors based on the extended quasiclassical equations of superconductivity.

Measurement-induced charging of quantum batteries

Mariia O. Gumberidze, Michal Kolář, and Radim Filip

Palacký University Olomouc, 17. listopadu 1192/12, Olomouc, 771 46, Czech Republic

Quantum batteries are quantum systems capable of storing and exchanging their energy (or other quantities) with the environment. The increase, denoted as the charging process, is usually modeled as application of an unitary transformation to the battery, or by coupling the battery to certain structure of thermal baths.

Our approach relies on charging the battery by application of quantum projective measurement. The building blocks for our battery are identical two-level systems (TLS). We initialize the protocol by taking two independent, noninteracting copies of TLS in state with nonzero, possibly very small, excitation and initial coherence. The TLS can be prepared in such state, e.g., by a suitable interaction with a thermal bath. This pair of TLS subsequently undergoes a global measurement with two possible outcomes. One of these is represented by a ground state projector in the energy eigenbasis of the TLS pair and the remaining one is its complement to unity. These two outcomes represent the failure and success of our protocol, respectively, each happening with appropriate probability. Hence, our protocol is inherently probabilistic, being successful only in a fraction of realizations, in contrast to the deterministic approaches described in the current literature. If the protocol succeeds, we fuse the initially independent pair of TLS into a larger non-separable system with higher energy and coherence, thus create and charge the battery simultaneously. The failure of the protocol results in reducing the initial energy and coherence to zero, by bringing the TLS pair to the product state of their energetic ground states. Thus, these pairs failed to be fused and charged, resulting in not using them further directly. Such probabilistic strategy allows for increase of the battery energy and coherence jointly in the region of small TLS excitation probabilities. We require the increase of the coherence for the sake of strengthening the quantum properties of the battery final state, i.e. to improve the quality of the quantum resource for later use. We study how partial purity of the initial TLS state affects the charging protocol compared to the use of pure initial state. The results show that the partial purity of the initial state decreases the positive effect of the charging but does not prevent the charging in principle.

We study an analogous charging protocol in case of using a generalized measurement (POVM) instead of the projective measurement. We observe an improvement of the results for POVM over the projection case and optimize them over a suitable class of POVM's.

Generalization of the projector-based charging protocol using N-TLS is presented, indicating an overall improvement of the results over the 2-TLS case. These improvements consist of reaching higher values of the coherence measure and of the possibility of obtaining increased coherence for wider range of the initial excitation of single-TLS. Possible optical simulation of the discussed charging protocol is suggested, and its basic structure is discussed.

I18

Towards understanding and realistically modelling consciousness

Suzy Lidström and Roland E. Allen

Texas A&M University, Mail Stop 4242, College Station, USA

Consciousness is only one narrow sector of the full range of neuronal activity in biology, but it is of particular interest because it is our only direct experience of reality. In the first part of this talk we will review the amazing discoveries of recent years regarding the conscious and unconscious activity of human brains, and the closely related phenomena across a wide variety of other species. The 302-neuron nervous system of C. elegans, the 1,000,000-neuron "brain" of a bee, and the 100,000,000,000-neuron human brain have, in a sense, the same basic architecture, but very different capabilities. In the second part we turn to the quest for understanding consciousness, which involves extremely sophisticated experimental and theoretical studies, overlapping neural network models, recent developments in both network theory and control theory, experimental neuroscience, and their intersection with statistical physics. In the third part, we introduce a "brainwide web" picture of consciousness which strongly overlaps previous ideas — principally the global workspace theory — but with emphasis on the features that are needed for physical and biological realism. A broadly testable prediction is that consciousness is bounded within a single system of neurons, spanning most of the relevant volume of the brain, which has many collective excited states. These states can be treated as the modes of a system coupled by nonlinear and retarded electrochemical couplings of the neurons, with a given neuron coupled to N»1 others. The system is open, coupled through both input and output channels. A toy model will be described. We anticipate that detailed simulations will be initiated but not completed at the time of the talk.

Sounds of science – a symphony for many voices and instruments

Gerianne Alexander, Roland E. Allen, Anthony Atala, James E. Baggott, Warwick Bowen, Ana Maria Cetto, Alan A. Coley, Bryan J. Dalton, Edward S. Fry, John Goodenough, Philippe Grangier, Mikhail I. Katsnelson, Eugene V. Koonin, Mario Krenn, Lars Madsen, Martin Månsson, Nicolas Mauranyapin, Art I. Melvin, Douglas Miller, Dimitri Nanopoulos, Ernst Rasel, Linda E. Reichl, Viraj A.A. Sanghai, Roman Yampolskiy, Philip B. Yasskin, Anton Zeilinger, and Suzy Lidström

Diverse

In the spirit of "Light, the Universe and Everything – 12 Herculean tasks for Quantum Cowboys and Black Diamond skiers" [1], the the participants of Frontiers of Quantum and Mesoscopic Thermodynamics in 2017 were invited to propose questions for discussion by leading experts in the field. The fascinating responses of the authors listed above will be reported.

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I20

Dynamical multistability in a quantum-dot laser

Mattia Mantovani[1], Andrew D. Armour[2], Wolfgang Belzig[1], and Gianluca Rastelli[1,3]

[1]*Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany*
[2]*Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems and School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom*
[3]*Zukunftskolleg, Universität Konstanz, D-78457 Konstanz, Germany*

We study the dynamical multistability of a solid-state single-atom laser implemented in a quantum-dot spin valve [1]. The system is formed by a resonator that interacts with a two-level system in a dot in contact with two ferromagnetic leads of antiparallel polarization. We show that a spin-polarized current provides high-efficiency pumping leading to regimes of multistable lasing, in which the Fock distribution of the oscillator displays a multipeaked distribution. The emergence of multistable lasing follows from the breakdown of the usual rotating-wave approximation for the coherent spin-resonator interaction which occurs at relatively weak couplings. The multistability manifests itself directly in the charge current flowing through the dot, switching between distinct current levels corresponding to the different states of oscillation.

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Nonlocal heat transfer between resonators by splitting Cooper pairs

Mattia Mantovani[1], Gianluca Rastelli[1,2], Wolfgang Belzig[1], and Robert Hussein[1]

[1]*Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany*
[2]*Zukunftskolleg Physik, Universität Konstanz, D-78457 Konstanz, Germany*

Hybrid quantum dot-oscillator systems have become attractive platforms to inspect quantum coherence effects and heat transport at the nanoscale [1,2]. Here, we investigate a Cooper-pair splitter setup [3] consisting of two quantum dots, each coupled capacitively to a local resonator. The latter can be realized either by a microwave cavity or a nanomechanical resonator. Focusing on the subgap regime, we demonstrate that cross-Andreev reflection, through which Cooper pairs are split into both dots, can efficiently cool down each resonator into its ground state. Moreover, we show that a nonlocal heat transfer between the two cavities may be enabled by induced coherences. The proposed scheme can, thus, act as a high-performance heat-pump device with potential applications in heat control and cooling of nanoresonators.

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I22

Observation of a broadband Lamb shift in an engineered quantum system

Matti Silveri[2], Shumpei Masuda[1], Vasilii Sevriuk[1], Kuan Y. Tan[1], Máté Jenei[1], Eric Hyyppä[1], Fabian Hassler[3], Matti Partanen[1], Jan Goetz[1], Russell E. Lake[1], Leif Grönberg[4], and Mikko Möttönen[1]

[1]*QCD Labs, Aalto University, Aalto, Finland*
[2]*Research Unit of Nano and Molecular Systems, University of Oulu, Oulu, Finland*
[3]*JARA Institute for Quantum Information, RWTH Aachen University, Aachen, Germany*
[4]*VTT Technical Research Centre of Finland, QTF Center of Excellence, Espoo, Finland*

The shift of the energy levels of a quantum system owing to broadband electromagnetic vacuum fluctuations—the Lamb shift—has been central for the development of quantum electrodynamics and for the understanding of atomic spectra. Identifying the origin of small energy shifts is still important for engineered quantum systems, in light of the extreme precision required for applications such as quantum computing. However, it is challenging to resolve the Lamb shift in its original broadband case in the absence of a tunable environment. Consequently, previous observations in non-atomic systems are limited to environments comprising narrow-band modes. Here, we observe a broadband Lamb shift in high-quality superconducting resonators, a scenario also accessing static shifts inaccessible in Lamb's experiment [1]. We measure a continuous change of several megahertz in the fundamental resonator frequency by externally tuning the coupling strength to the engineered broadband environment, which is based on hybrid normal-metal–insulator–superconductor tunnel junctions. Our results may lead to improved control of dissipation in high-quality engineered quantum systems and open new possibilities for studying synthetic open quantum matter using this hybrid experimental platform.

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Quantum calculation of the nonequilibrium heat capacity in the resonant level transport

Katarzyna Roszak[1,2], Karel Netočný[2], and Tomáš Novotný[3]

[1]*Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, 50-370 Wrocław, Poland*
[2]*Institute of Physics, Czech Academy of Sciences, 182 21 Prague, Czech Republic*
[3]*Faculty of Mathematics and Physics, Charles University, 121 16 Prague, Czech Republic*

Using the so-called thermomechanical field method [1] enabling fully quantum mechanical treatment of nonequilibrium systems with time-dependent thermodynamical (non-Hamiltonian) parameters such as temperature or chemical potential we study the thermal response of a single resonant level in transport regime. The response can be measured by the excess heat, and for slowly varying temperature it is quantified in terms of a nonequilibrium extension of the heat capacity. This work thus generalizes similar previous classical study [2] to the fully quantum regime. We identify various contributions to the (quantum) nonequilibrium heat capacity, in particular the "boundary terms" due to the finite coupling to the electronic leads, and inspect their influence on the thermal response. Eventually, we single out the term which is a direct quantum counterpart of the classical result and thoroughly analyze its dependence on various model parameters.

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I24

On the relaxation dynamics of a stochastic bosonic Josephson junction

Dionisis Stefanatos and Emmanuel Paspalakis

Materials Science Department, University of Patras, Patras 265 04, Greece

A bosonic Josephson junction is a system of two boson ensembles, with each of them occupying a single quantum state, which interact through a tunnel barrier. Mathematically, this system is described as two interacting nonlinear quantum oscillators and it is a general and important model for nanoscale quantum dynamics. The bosonic Josephson junction has been implemented experimentally in various physical settings, including Bose-Einstein condensates confined in optical traps, atom chips, semiconductor microcavities (exciton-polariton systems), superconducting nanocircuits, and nanophotonic systems, and provides an ideal model to study quantum correlations and their time evolution. An important problem with intense recent experimental and theoretical work is the understanding of the relaxation dynamics of bosonic Josephson junctions. Here, we present a new theoretical approach for this problem. We consider a stochastic bosonic Josephson junction where some of the parameters are corrupted by physically meaningful noise processes. These mechanisms represent couplings to the ignored degrees of freedom and cause the relaxation of the system to a prethermalized state, a quasi-stationary state, that differs from the real thermal equilibrium. We obtain the relevant mean field dynamics and compare our findings with the widely used damped nonrigid pendulum model [1]. We also present numerical simulations and show that the described model can essentially capture all the important features observed in recent experiments regarding the relaxation dynamics in one-dimensional bosonic Josephson junctions, namely the damped oscillations of the population imbalance and the relative phase, as well as the large final coherence [2].

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Thermodynamic length in open quantum systems

Matteo Scandi and Marti Perarnau-Llobet

Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching bei München, Germany

The dissipation generated during a quasistatic thermodynamic process can be characterised by introducing a metric on the space of Gibbs states, in such a way that minimally-dissipating protocols correspond to geodesic trajectories. Here, we show how to generalize this approach to open quantum systems by finding the thermodynamic metric associated to a given Lindbladian. The family of obtained metrics can be understood as a perturbation over the background geometry of equilibrium Gibbs states, which is induced by the Kubo-Mori-Bogoliubov (KMB) inner product. We illustrate this construction on the two paradigmatic examples of the Ising chain and of a two-level system.

I26

Genetic quantum measurement

Fabrizio Piacentini[1], Salvatore Virzì[1,2], Alessio Avella[1], Marco Gramegna[1], Rudi Lussana[3], Federica Villa[3], Alberto Tosi[3], Eliahu Cohen[4], Ivo Pietro Degiovanni[1], and Marco Genovese[1]

[1] *INRiM, strada delle Cacce 91, 10135 Torino, Italy*
[2] *Università degli Studi di Torino, via P. Giuria 1, 10125 Torino, Italy*
[3] *Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria, Piazza Leonardo da Vinci 32, 20133 Milano, Italy*
[4] *Faculty of Engineering and the Institute of Nanotechnology and Advanced Materials, Bar Ilan University, Ramat Gan 5290002, Israel*

Following the von Neumann scheme, the measurement process in quantum mechanics can be modelled as a sequence composed of state preparation, strong interaction (represented by a unitary operator) and state detection (typically described with the projective measurements formalism). Here we present a novel measurement protocol, called Genetic Quantum Measurement (GQM), representing a paradigm shift in the quantum measurement framework, since it takes advantage of a genetic-like approach to significantly surpass the performances of conventional (projector-based) measurement techniques. Indeed, GQMs, after the usual initial state preparation, take advantage of a repeated sequence of interaction-recombination steps leading to quantum interference (here taking the role of the crossover in genetic processes) and selective measurements (corresponding to the genetic selection pressure). The quantum superposition principle, at the heart of the quantum parallelism advantage exploited in several of the forthcoming quantum technologies (e.g., quantum computers), plays the role of the mutation mechanism, necessary to explore different evolution paths. Thanks to the quantum parallelism feature, in the GQM approach, all the possible "evolution trajectories" are explored at the same time. In analogy with sequential measurements [1-3], GQMs exploit a sequence of interactions, but they also take advantage of a continuous protection of the quantum state analogous to the one of protective measurements [4,5]. GQM approach consists of a finite number of interaction-selection stages with any interaction intensity, from weak to strong, in order to optimize the trade-off between single quantum system survival probability and measurement uncertainty reduction. In some sense, GQM can be considered as a practical and (astonishingly) powerful version of the general concept of protective measurement, granting a major advantage in several quantum technologies related fields.

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An epistemological review on quantum observation

Claudia Pombo

Amsterdam, Netherlands

Investigations on perception and Plato's foundations of geometry were in the basis of Aristotle's philosophical program [1]. This led to a natural science focusing on movement. Paradoxically, this project was both fruitful and restrictive. On one hand, it resulted in a successful theory for movement. On the other hand, it excluded the treatment of more general classes of phenomena. At the beginning of last century, two theories emerged outside this program: special relativity and quantum physics.

Special relativity modified the geometrical foundations of physics and movement was assimilated within a more general concept of animation. But quantum physics had no similar treatment. Quantum phenomena are not expressions of movement, or similar forms of animation. Thus, in spite of the emergence of a new theoretical formulation, the corresponding phenomenology was not recognized.

This situation also shows that a theory can be formulated without known phenomenology. The history of physics has been telling about the development of theories without touching the process of evolution of observers. In order to investigate this disconnection, we need a suitable epistemology, assuming independence between observational and theoretical expressions as a principle. This separation was suggested by R. Carnap and incorporated in the basis of the epistemology of observational realism, which we adopt [2].

Based on these ideas, we review the foundations of the natural philosophy. We argue that the Greek mathematical approach of nature only included arithmetic and geometry. Despite knowing and using matrices, physical references were not associated to these concepts [3]. We then define physical concepts in matrix form, showing that they are present in the observational domain of quantum physics. As a consequence of this proceeding, we argue that Heisenberg and Schrodinger approaches of quantum physics are not equivalent formulations of the same theory, as usually found in the literature. They are complementary approaches in a broader theoretical domain.

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I28

Experimental test of the differential fluctuation theorem and a generalized Jarzynski equality for arbitrary initial states

Thai M. Hoang[2], Rui Pan[1], Jonghoon Ahn[3], Jaehoon Bang[3], Haitao Quan[1], and Tongcang Li[2,3]

[1] *Peking University, 5 Yiheyuan Road, Haidian District, Beijing, 100871, China*
[2] *Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47907, USA*
[3] *School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN 47907, USA*

Nonequilibrium processes of small systems such as molecular machines are ubiquitous in biology, chemistry and physics, but are often challenging to comprehend. In the past two decades, several exact thermodynamic relations of nonequilibrium processes, collectively known as fluctuation theorems, have been discovered and provided critical insights. These fluctuation theorems are generalizations of the second law, and can be unified by a differential fluctuation theorem. Here we perform the first experimental test of the differential fluctuation theorem, using an optically levitated nanosphere in both underdamped and overdamped regimes, and in both spatial and velocity spaces. We also test several theorems that can be obtained from it directly, including a generalized Jarzynski equality that is valid for arbitrary initial states, and the Hummer-Szabo relation. Our study experimentally verifies these fundamental theorems, and initiates the experimental study of stochastic energetics with the instantaneous velocity measurement.

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Boltzmann relaxation dynamics in strongly interacting quantum lattice systems

Friedemann Queisser[1,2,3] and Ralf Schützhold[1,2,3]

[1]*Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany*
[2]*Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany*
[3]*Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, Duisburg 47057, Germany*

Via the hierarchy of correlations, we study the Fermi-Hubbard model and derive a quantum Boltzmann equation describing the relaxation dynamics of quasi-particle- and hole-excitations. In the strongly interacting limit, the collision terms are solely determined by the hopping matrix elements. This is in stark contrast to the weakly interacting limit which is determined by the on-site interaction strength.

I30

Microwave spectroscopy reveals the quantum geometric tensor of topological Josephson matter

Raffael L. Klees[1], Gianluca Rastelli[1,3], Juan Carlos Cuevas[2], and Wolfgang Belzig[1]

[1]*University of Konstanz, Fachbereich Physik, Fach 703, Universitätsstraße, 78457, Konstanz, Germany*
[2]*Departamento de Física teórica de la materia condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain*
[3]*Zukunftskolleg, University of Konstanz, 78457, Konstanz, Germany*

Topology is providing new insight into condensed matter physics problems. Concepts like Chern numbers and their relation to physical phenomena have become very familiar, but actually, key quantities like the quantum geometric tensor, which provides a much deeper information about quantum states, remain experimentally difficult to access. Recently it has been shown that multiterminal superconducting junctions constitute an ideal playground to mimic topological systems in a controlled manner. Here, we theoretically study the spectrum of Andreev bound states in topological Josephson matter and demonstrate that the full information of the quantum geometric tensor of the ground state manifold can be extracted with the help of microwave spectroscopy [1]. In particular, we develop the concept of artificially polarized microwaves, which can be used to obtain both the quantum metric tensor and the Berry curvature. The quantized integrated absorption provides a direct evidence of topological quantum properties of the Andreev states.

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Quantum mechanical and optical systems explored in surface gravity water-waves

Georgi Gary Rozenman[1], Lev Shemer[1], Matthias Zimmermann[2], Maxim A. Efremov[2], Ady Arie[1], and Wolfgang P. Schleich[2,3]

[1]*Faculty of Engineering, Tel-Aviv University, Tel-Aviv 69978, Israel*
[2]*Institut für Quantenphysik and Center for Integrated Quantum Science and Technology, Universität Ulm, 89081 Ulm, Germany*
[3]*Hagler Institute for Advanced Study at Texas A&M University, Texas A&M AgriLife Research, Institute for Quantum Science and Engineering (IQSE), and Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843-4242, USA*

The concept of analogy is crucial for understanding nature, as it allows finding connections between diverse physical phenomena linked by common properties or similar behavior. In some cases, analogy exists between specific quantum and corresponding classical phenomena. In particular, the Schrödinger equation is crucial since it describes many important discoveries which have dramatically changed the world, like computers or modern communication systems, such as mobile telephones which all depend on quantum technology. Therefore, it is advantageous to apply qualitative and quantitative properties of the Schrödinger equation and extend our understanding of fundamental quantum mechanical problems [1].

As such, one of the most fundamental problems is an accelerating quantum mechanical particle in a linear potential. The wave function corresponding to this particle accumulates not only a position-dependent phase associated with the momentum change in a linear potential, but also a position-independent phase that scales with the third power of time during which the particle experienced the linear potential [2]. Although being a fundamental property of quantum mechanics, so far, no direct observation of the cubic phase exists, since any experimental setup can only provide the probability density is therefore insensitive to any global position-independent phase. The time evolution of a wave function in quantum mechanics is analogous to dynamics of surface gravity water wave pulses. In our experiments, we have utilized this analogy and measured the cubic phase for both Gaussian and Airy wave packets for the first time [1,2].

In present, we study analogies that include quantum carpets, propagation dynamics of solitons in a linear potential and the possibility to perform an experiment which is analogous to a black hole.

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I32

Cooling from Cooper pair splitting

Rafael Sánchez[1], Pablo Burset[2], and Alfredo Levy Yeyati[1]

[1] *Universidad Autónoma de Madrid, Francisco Tomás y Valiente, 7, Madrid 28049, Spain*
[2] *Aalto University, 00076 Aalto, Finland*

Cooper pairs in superconductors are a natural source of non-local electron entanglement. We show that when the two electrons from a pair are split into different reservoirs, the heat flow between the reservoirs can be reverted. A Cooper pair splitter device thus becomes a quantum refrigerator. The process can be also used to define a non-local thermoelectric power generator. In both cases, the system can perform at high efficiencies. This is ultimately possible due to the quantum correlations of the entangled pair. Our proposal thus constitutes the first experimentally accessible proposal of an autonomous entanglement-based quantum heat engine, able to optimally extract thermodynamic work from quantum many body states.

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Monitoring greenhouse gases with long-range open-path wavelength modulation spectroscopy

Carlos Rodrigues[1], Jinbao Xia[2], Feng Zhu[3], Sasa Zhang[2], Alexandre Kolomenskii[1], Jian Dong[1], Kunihiro Okada[4], James Bounds[1], James Strohaber[5], and Hans A. Schuessler [1,6]

[1]*Texas A&M University, MS4242, College Station, USA*
[2]*School of Information Science and Engineering, Shandong University, Jinan 25006, China*
[3]*School of Physics and Astronomy, Sun Yat-sen University, Zhuhai, Guangdong 519082, China*
[4]*Department of Physics, Sophia University, Tokyo, 1028554, Japan*
[5]*Department of Physics, Florida A&M University, Tallahassee, Florida 323073, USA*
[6]*Science Program, Texas A&M University at Qatar, Doha 23874, Qatar*

Analysis of light transmission through atmosphere provides information on its content and turbulence. We have developed a mobile analytical platform for detecting atmospheric variations of the concentrations of methane and carbon dioxide and carried out continuous monitoring of greenhouse gases for several hours over km paths. Our spectroscopic method is based on wavelength modulation spectroscopy [1]. The system was calibrated in the laboratory and then moved to the field for continuous automated measurements. The intensity variations caused by atmospheric turbulence were observed and characterized by comparing the open-path signal with the reference signal.. We conclude by comparing our results with those obtained by other techniques, showing that the developed sensor is a promising tool for monitoring of greenhouse gases. This research was funded by the Robert A. Welch Foundation, Grant No. A1546 and the Qatar Foundation under Grant No. NPRP 6-465-1-091.

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I34

Self-contained measurement driven engine

Stella Seah[1,2], Stefan Nimmrichter[3], and Valerio Scarani[1,2]

[1] *Department of Physics, National University of Singapore, 2 Science Drive 3, Singapore 117542, Singapore*
[2] *Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543, Singapore*
[3] *Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany*

There has been growing interest in understanding the role of measurement in quantum thermodynamics. Previous works [1-3] exploit the stochasticity induced by quantum measurements – more commonly termed as “quantum heat”– to design engines with efficiencies approaching unity. However, a more recent study [4] suggests that the energy change due to “quantum heat” should rather be interpreted as work. Here we adopt a bottom-up approach and propose a self-contained heat engine driven by a continuous measurement-feedback protocol, where the engine system acts as the working medium and is coupled to a hot bath and to a measurement pointer that thermalises with a cold bath. The measurement cost is associated to the interaction Hamiltonian between the system and pointer and vanishes for a gapless pointer. We show that when operated in ideal cycles of distinct measurement, feedback, and erasure strokes, the engine attains Otto efficiency. In a practical scenario of continuous finite-time operation, the efficiency will be lower as the interplay between the thermalisation rates to individual baths, the measurement-feedback rate, and the coupling rate between the system and pointer will then affect the engine performance

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Measurement in dynamic mesoscopic systems

Dalibor Štys and Renata Štysová Rychtáriková

Institute of Complex Systems, FFPW, University of South Bohemia, Zámek 136, Nové Hrady, Czech Republic

Recently we have shown that the Belousov-Zhabotinsky reaction [1] and possibly also all excitable media [2] may be modelled as a mesoscopic system whose stability depends on fine-tuned noise [3]. By comparison with the experiment we found that the spatial element (elementary cell) of such a mesoscopic system contains 10^{14} molecules and is thus well within the thermodynamic limit, i.e., may be considered as a microscopic chemical reactor/tube which communicates with its neighbours by diffusion, possibly of energy, entropy, and chemical potential, in brief Gibbs energy. We have also shown earlier that the size of the elementary cell is dependent on the ratio between the rate of internal excitation, i.e., internal rise of the chemical potential, and the rate of diffusion [4]. García-Ojalvo et al. [5] suggested that the noisy excitable media may be a solution of a long-term unsolved problems such as the onset of turbulence. Consequently, many, if not all, real systems may be in effect mesoscopic.

With the latter suggestion in mind, we have examined the problem of measurement in a general mesoscopic system. For assessment of the measurement outcome we have used the approach of Zampa [6] who introduced the term system event Ω_i as a set of trajectories which pass certain set of variables. In principle the event may be defined arbitrarily. For structured systems, we may use some structure clasifiyers (PIE, PDGE) as system variables. While most experimentalists set the variables defining the system event Ω_i arbitrarily (or better said voluntarily), we decided to use methods of multivariate statistics to determine the most discriminating set of variables. This enabled us to examine the influence of system time $t_i \in T$ which is an ordered set of times at which the value of variables was determined on the objective determination of system events Ω_i. The ultimately correct solution is the measurement (state variables calculation) at each system elementary timesteps. We show that doubling the timestep drastically changes the definition of system events Ω_i.

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I36

CHSH-type inequality involving momentum weak values

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

Instituto de Física, Universidad Nacional Autónoma de México, Apartado Postal 20-364, Ciudad de México, Mexico

The weak value of the linear momentum operator is a complex vector whose real and imaginary parts are, respectively the *flow* and the *diffusive* velocity. Both velocities have been the subject of several efforts aimed at exploring varied quantum features in novel ways, and more recently they have been analyzed in the context of entangled bipartite systems [1]. In particular, it has been shown that the individual diffusive velocities of the two particles —intimately connected with their distinctive quantum properties— play a central role in different entanglement indicators. This suggests new ways of exploring, addressing and attesting entanglement in bipartite pure states. Here we construct a CHSH-type operator involving (continuous and commuting) momentum variables, and establish a corresponding CHSH-type inequality that serves to certify the presence of entanglement in the bipartite system. Our results represent a step towards a deeper and broader understanding of the role of the diffusive velocity as the bearer of quantumness.

The authors gratefully acknowledge financial support from DGAPA-UNAM through project PAPIIT IA101918.

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Necessary and sufficient conditions for the emergence of genuine entanglement in 3-qubit evolving systems

Andrea Valdés-Hernández, Víctor T. Brauer, and Santiago Zamora

Instituto de Física, Universidad Nacional Autónoma de México, Apartado Postal 20-364, Ciudad de México, Mexico

The dynamics and flow of entanglement in multipartite systems constitutes a vast line of research with implications ranging from the development of strategies aimed at increasing the entanglement in specific processes, to the establishment of the global laws that govern the evolution of entanglement in multiparty systems. To take a step further in these directions it becomes necessary to identify the appropriate processes that guarantee the emergence of specific classes of entanglement, particularly of multipartite entanglement, in different scenarios. Here we contribute to the study of the emergence of genuine tripartite entanglement by considering a system of two initially entangled qubits, one of which is let to interact with a third qubit under an arbitrary unitary evolution. Resorting to the formalism of Kraus operators to describe the evolution of the system, we establish the necessary and sufficient conditions on these operators that guarantee that the evolved (pure) state possesses either W- or GHZ-type entanglement, which are the two inequivalent classes of multipartite entanglement in 3-qubit systems. Our results provide a classification of the Kraus operators according to their capacity of producing multipartite correlations, and settle the basis for establishing the type of interactions (or Hamiltonians) that must be implemented in order to create and distribute entanglement in a convenient way.

The authors gratefully acknowledge financial support from DGAPA-UNAM through project PAPIIT IA101918.

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I38

Graphene-edge electrodes for molecular recognition

Sasha Vrbica[1], Amedeo Bellunato[2], Carlos Sabater[1], Federica Galli[1], Norman Blümel[1], Batuhan Can[2], Valeria Saavedra[1,2], Grégory Schneider[2], and Jan van Ruitenbeek[1]

[1]*Huygens-Kamerlingh Onnes Laboratory, Leiden University, Niels Bohrweg 2, 2333CA Leiden, Netherlands*
[2]*Leiden Institute of Chemistry, Leiden University, Einsteinweg 55, 2333CC Leiden, Netherlands*

The investigation of the transport properties of single molecules by flowing tunneling currents across extremely narrow gaps is relevant for challenges as diverse as the development of molecular electronics and sequencing of DNA. The achievement of well-defined electrode architectures remains a technical challenge, especially due to the necessity of high precision fabrication processes and the chemical instability of most bulk metals. Here, we illustrate a continuously adjustable tunneling junction between the edges of two twisted graphene sheets. The unique property of the graphene electrodes is that the sheets are rigidly supported all the way to the atomic edge. By analyzing the tunneling current characteristics, we also demonstrate that the spacing across the gap junction can be controllably adjusted. Finally, we demonstrate the transition from the tunneling regime to contact and the formation of an atomic-sized junction between the two edges of graphene.

Towards lasing without inversion in mercury

Daniel Preißler, Benjamin Rein, Thorsten Führer, and Thomas Walther

TU Darmstadt, Institute for Applied Physics, Schlossgartenstr. 7, Darmstadt, Germany

In this poster we present the current status of our experiment towards Lasing without Inversion in neutral mercury. Goal of this experiment is the generation of 253.7 nm-radiation based on a four-level double-dark scheme in neutral mercury.

A recent theoretical study has shown the principle feasibility of our approach [1]. Our first experimental implementation lead to the observation of Doppler-free three-photon coherences. While our pump was not fully meeting all of the requirements in terms of power and linewidth, we were able to see a reduction in absorption, i.e. a first step towards amplification without lasing [2]. The theoretical model is in good agreement with our results and a prediction for the necessary pump power and linewidth was determined. Furthermore, we report on the technical progress to arrive at higher pump power [3].

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I40

Criteria of quantumness in large quantum coherent structures

Alexandre Zagoskin

Loughborough University, University Rd., Loughborough, United Kingdom

It is currently possible to fabricate, manipulate and maintain in (partially) quantum coherent regime artificial structures, which are too big to be directly simulated using classical computers. Instead one has to rely on a range of indirect approaches to characterization of such systems. Here I discuss dimensionless figures of merit which can be used to characterize the degree of "quantumness" in the operation of a large quantum coherent structure.

Theory of heat statistics in nanograins

Izabella Lovas[1,2], Andras Grabarits[1], and Gergely Zarand[1]

[1]*MTA-BME Exotic Quantum Phases "Momentum" Research Group, Department of Theoretical Physics, Budapest University of Technology and Economics, 1111 Budapest, Hungary*
[2]*Department of Physics, Technical University of Munich, 85748 Garching, Germany*

We investigate the non-equilibrium dynamics and the generation of internal excitations in the presence of external time dependent perturbations in a generic, disordered nanograin, described by random matrix theory. Time varying external perturbations generate a *motion* within the manifold of random matrices. We focus on the distribution of the non-adiabatic part of work during this motion, identified as the heat $\mathcal{Q}$ in usual statistical physics, and study the case where the grain is initially in its ground state. We derive a closed determinant formula for the generating function of heat statistics at time t, $P_t(\mathcal{Q})$, and investigate the latter numerically and analytically for the orthogonal and unitary ensembles.

We find that heat is generated by a diffusive broadening of the Fermi sea, $\langle \mathcal{Q} \rangle \sim Dt$, with the diffusion constant D characterizing the diffusion in energy space. For small velocities (slow deformations), $P_t(\mathcal{Q})$ is universal, and most of its features can be captured by a Markovian model. In this small velocity limit, the diffusion in energy space is generated by Landau-Zener transitions, and the velocity dependence of D reflects the symmetry class and the statistics of avoided level crossings: we find $D \sim v^2$ for the Gaussian Unitary Ensemble, while $D \sim v^{3/2}$ for the Gaussian Orthogonal Ensemble. The probability of adiabatic processes is shown to exhibit a stretched exponential behavior. These results could be experimentally tested by calorimetric measurements in nanoscale systems.

Posters

Analysis of assumptions in Big Bell test

Stanisław Sołtan, Dawid Dopierała, and Adam Bednorz

University of Warsaw, Krakowskie Przedmiescie 26/28, 00-927 Warsaw, Poland

We have analysed the recently published group of quantum tests of local realism, The BIG Bell Test. It was based on human choice of measurement settings. We checked if the no-signaling assumption is confirmed by the data. Mooreover, we check if the results agree with the assumed model and known technical features. The analysis is based on the data from 9 groups, who provided the data, out of all 13 experiments.

P2

Order in complex and simple liquids

Henry Jose Castejon

Wilkes University, Chemistry Department, 80 W. South Street, Wilkes Barre, USA

Molecular Dynamics Simulations were used to study the behavior of a complex liquid and a simple liquid both in a confined environment. Despite the difference in complexity, order parameters, in particular the distribution function along a symmetry axis, for both liquids display a remarkably similar behavior. Both functions are also identical to that of system of non-interacting particles predicted by the Asakura-Oosawa Interaction.

Despite the fact that interactions in one liquid are weak and can be described by a simple central force potential while in the other the strong interactions require a multi-term potential, the distribution functions in both systems are dominated by entropic forces.

Despite the difference in complexity and strength, the thermodynamic response of both systems to confinement appears to be determined solely by entropy.

Proper relativistic operators in relativistic vortex beams

Taeseung Choi[1,2], Yeong Deok Han[3], and Sam Yong Cho[4]

[1] *Seoul Women's University, Hwarangro 621, NowonGu, Seoul 01797, Republic of Korea*
[2] *School of Computational Sciences, Korea Institute for Advanced Study, Seoul 130-012, Republic of Korea*
[3] *Department of Game Contents, Woosuk University, Wanju, Cheonbuk, 565-701, Republic of Korea*
[4] *Centre for Modern Physics and Department of Physics, Chongqing University, Chongqing 400044, China*

Since its discovery, spin describing the intrinsic angular momentum of elementary particles has exposed its fundamental nature and significant roles in wide ranges of (relativistic) quantum phenomena and practical applications for future quantum technology. Its telltale incomplete description, on the other hand, has been also disclosed through emerging inconsistencies, for instance, the so-called proton spin crisis, and the non-conserving spin current due to spin-orbit couplings in spintronics. Originally, finding relativistic spins (operators) of massive particles is a long-standing problem from the beginning of relativistic quantum mechanics. Here, we present the rigorous derivation of proper spin operator for an arbitrary spin massive particle from the spacetime symmetry [1]. And we also suggest the experimental test of this spin operator and its related position operator using the singularity of the relativistic electron vortex beams [2]. We have studied the two sets of relativistic operators, ours and usual Dirac. Our operators predict the same singular circulation for the electron vortex beams as in the nonrelativistic case. On the other hand, the Dirac operators anticipate that the singularity of the circulation is spin-dependent and so can be disappeared for the spin-polarized paraxial beam with spin parallel to the moving direction of the beam. Therefore the experiment for the spin polarized relativistic electron beams will answer which operators are proper relativistic observables for the first time.

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P4

Time-reversed quantum trajectory analysis of micromaser correlation properties and fluctuation relations

James Cresser

University of Glasgow, Glasgow G12 8QQ, United Kingdom
Macquarie University, 2109 NSW, Australia

The micromaser is a device in which a single quantized mode of a high Q cavity is driven by a beam of thermally excited two-level atoms, and in many respects is an exemplar of a collisional or repeated interaction model of an open quantum system. The master equation for the cavity field can be unravelled as quantum trajectories corresponding to measurements performed on the atoms emerging from the cavity. Time-reversed quantum trajectories, defined according to the Crooks approach can then be shown, first of all, to arise naturally in the analysis of micromaser and atomic beam correlations, and second used in the formulation of a fluctuation relation for the probabilities of trajectories and their time-reversed counterparts in terms of the associated entropy flow from the cavity reservoir and atomic beam.

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Behavior of the relativistic Bose gas in a film geometry: Exact results for the free energy and the Casimir force

Daniel Dantchev

Institute of Mechanics, Bulgarian Academy of Sciences, Academic Georgy Bonchev St. building 4, 1113 Sofia, Bulgaria

Since its theoretical prediction by Einstein in 1925, based on the work in 1924 by Bose [2] on photons, and after languishing for decades as a purely academic exercise in textbooks, Bose-Einstein condensation has been observed in the laboratory in laser-cooled, magnetically-trapped ultra-cold bosonic atomic clouds, starting with the pioneering experiment reported in [3] in 1995 based on rubidium atoms. After that, the field enjoys serious attention and numerous works have been devoted to different aspects of the Bose-Einstein condensation.

Bose-Einstein condensation can only occur when the particle number is conserved, i.e., the discussion of the Bose-Einstein condensation for a relativistic Bose gas must also take the antiparticles into account [4]. According to this line, we formulated the corresponding model in the way used in [5]. We derive the exact scaling functions of the free energy and of the Casimir force. Our results are in full conformity with the finite-size scaling theory [6]. We demonstrate analytically that the excess free energy is a monotonically increasing function of the temperature T in the vicinity of T_c. In addition, analytical evidence is also presented to confirm that the Casimir force in the system is negative both below and in the vicinity of the bulk critical temperature T_c. The universal Casimir amplitude Δ_{Cas} is calculated exactly. Finally, we discuss the mathematical connection of the model of the relativistic Bose gas with the classical spherical model [7].

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P6

A quantum-enhanced stimulated emission microscope

Shakib Daryanoosh[1], Gil Triginer Garces[1], Valerian Thiel[1,2], Anna Marchant[1], Raj B. Patel[1], Helen Chrzanowski[1,3], Animesh Datta[4], and Ian Walmsley[1,5]

[1]*University of Oxford, Parks Road, Oxford, United Kingdom*
[2]*University of Oregon, 120 Willamette Hall, Eugene, OR 97403, USA*
[3]*Humboldt University of Berlin, Unter den Linden 6, 10099 Berlin, Germany*
[4]*University of Warwick, Coventry CV4 7AL, United Kingdom*
[5]*Imperial college of London, South Kensington, London SW7 2AZ, United Kingdom*

Microscopy is a conventional method of imaging among others, with sensitivity limited by the shot-noise limit (SNL). However, this limit can be surpassed by exploiting some intrinsic properties of quantum physics such as squeezing of light. In this work we demonstrate sub-shot-noise limited stimulated emission microscopy where pulsed squeezed light probes the sample. This scheme should pave the way for imaging biological samples where they do not have detectable fluorescence due to the presence of non-radiative decay channels.

Generalized 2nd law under non-Markovian feedback control using a levitated particle

Maxime Debiossac[1], David Grass[1], Jose Joaquin Alonso[1], Eric Lutz[2], and Nikolai Kiesel[1]

[1]*University of Vienna, Boltzmanngasse, 5, Vienna, Austria*
[2]*Institute for Theoretical Physics I, University of Stuttgart, D-70550 Stuttgart, Germany*

Feedback control mechanisms are ubiquitous in science and technology and their role in regulating physical, biological and engineering systems, is essential. The close link between feedback protocol and information has raised a fundamental question in thermodynamics: can the knowledge about a system be processed and used to extract more work from the system? To answer this question, most studies so far have extended the second law for discrete, Markovian feedback protocols. However, feedback loops are never instantaneous due to finite time delays. Here we experimentally investigate the thermodynamics of continuous, time-delayed feedback control using a levitated microparticle. Our experimental results are consistent with the most general version of the second law. This results in an improved bound for feedback efficiency when memory effects are included.

P8

Spooky work at a distance: An interaction-free quantum measurement-driven engine

Cyril Elouard[1], Mordecai Waegell[2], Benjamin Huard[3], and Andrew N. Jordan[1,2]

[1]*Department of Physics and Astronomy, University of Rochester, 500 J. C. Wilson Blvd., Rochester, NY 14627, USA*

[2]*Institute for Quantum Studies, Chapman University, One University Dr, Orange, CA 92866, USA*

[3]*Laboratoire de Physique-CNRS 5672, ENS de Lyon 46, allée d'Italie, 69364 Lyon Cedex 7, France*

We revisit the Elitzur–Vaidman bomb-tester [1], a setup that allows to detect the presence of a quantum object in the arm of a single-photon interferometer seemingly without interacting with it. In our case, the bomb is a quantum system whose motional ground state is a superposition of being located inside and outside one of the arms of the interferometer, and able to perfectly absorb the single photon when it is located inside the arm. When the so-called dark port detector fires, the presence of the bomb in the interferometer is confirmed. Moreover, analysis of the weak values involved in the problem allows to conclude that the photon must have taken the other arm in this case. We analyze the energy exchanges between the photon and the bomb, and show that the bomb gains energy due to measurement-induced localization of its wave-function inside or outside the arm. This energy is provided by the photon even though its amplitude of presence in the bomb's arm vanishes and both systems only interact via a local Hamiltonian. Such device allows to build a quantum engine similar to the one proposed in Ref. [2], but extracting work in a non-local way.

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Discontinuities in driven spin-boson systems due to coherent destruction of tunneling: breakdown of the Floquet-Gibbs distribution

Georg Engelhardt[1], Gloria Platero[2], and Jianshu Cao[1,3]

[1]*Beijing Computational Science Research Center, Building 9, East Zone, ZPark II, No.10 East Xibeiwang Road, Beijing 100193, China*
[2]*Instituto de Ciencia de Materiales de Madrid, CSIC, 28049 Madrid, Spain*
[3]*Department of Chemistry, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA*

Periodic driving is a flexible tool for quantum control of various systems. While the dynamics of isolated quantum system is well understood and used in experiments, the behavior of open ac-driven quantum system has gained less attention. This question becomes more important with recent experimental progress in the simulation of open quantum systems [1].

Under special conditions of the ac drive, Floquet-Gibbs states, generalization of Gibbs states to ac-driven systems, arise [2]. These states require that transitions associated with the Mollow triplet [3], appearing due to a nonelastic scattering process of the driving field, vanish.

Here, we investigate possible exotic stationary states in ac-driven open quantum systems which appear after the breakdown of the Floquet-Gibbs states. We show that the probability distribution of the stationary state of a dissipative ac-driven two-level system exhibits discontinuities, i.e. jumps. These jumps are induced by the phenomenon of coherent destruction of tunneling, a genuine quantum localization in ac-driven systems [4]. These discontinuities can be observed as jumps in the emission of the Mollow triplet. Overall, the stationary states depend sensitively on the system-environment coupling operator. The jumps are the consequence of discontinuities in the transition rates, which we calculate numerically and analytically based on the secular Floquet-Redfield formalism [5].

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P10

Quantum work distributions associated with the dynamical Casimir effect

Zhaoyu Fei[1], Rui Pan[1], Tian Qiu[1], Jingning Zhang[2], and H. T. Quan[1,3]

[1]*School of Physics, Peking University, Beijing 100871, China*
[2]*Institute for Interdisciplinary Information Sciences, Tsinghua University, Beijing 100084, China*
[3]*Collaborative Innovation Center of Quantum Matter, Beijing 100871, China*

We study the joint probability distribution function of the work and the change of photon number of the nonequilibrium process of driving the electromagnetic field in a three-dimensional cavity with an oscillating boundary. The system is initially prepared in a grand canonical equilibrium state and we obtain the analytical expressions of the characteristic functions of work distributions in the single-resonance and multiple-resonance conditions. Our study demonstrates the validity of the fluctuation theorems of the grand canonical ensemble in nonequilibrium processes with particle creation and annihilation. In addition, our work illustrates that in the high temperature limit, the work done on the quantized EM field approaches its classical counterpart; while in the low temperature limit, similar to Casimir effect, it differs significantly from its classical counterpart.

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Quantum neural networks to simulate many body quantum systems

Bartlomiej Gardas[1,2,3], Marek Rams[1], and Jacek Dziarmaga[1]

[1]*Jagiellonian University, Faculty of Physics, Astronomy and Applied Computer Science, Lojasiewicza 11, 30-348 Krakow, Krakow, Poland*
[2]*Institute of Physics, University of Silesia, 40-007 Katowice, Poland*
[3]*Theoretical Division, LANL, Los Alamos, New Mexico 87545, USA*

We conduct experimental simulations of many-body quantum systems using a hybrid classical-quantum algorithm. In our setup, the wave function of the transverse field quantum Ising model is represented by a restricted Boltzmann machine. This neural network is then trained using variational Monte Carlo assisted by a D-wave quantum sampler to find the ground-state energy. Our results clearly demonstrate that already the first generation of quantum computers can be harnessed to tackle nontrivial problems concerning physics of many-body quantum systems.

P12

Application of a quantum action principle to the Stern-Gerlach experiment

Alan K. Harrison

Los Alamos National Laboratory, MS T086, P. O. Box 1663, Los Alamos 87545, USA

We propose that a time-symmetric, realistic quantum theory can be based on the principle of stationary action. [1-2] The action is defined as the integral of the Lagrangian between two times t_i and t_f, with the variational analysis resulting in a description of the wavefunction dynamics at intermediate times ($t_i < t < t_f$). Such a theory is applied to describe a typical measurement by imposing the description of the system preparation as a boundary (initial) condition at t_i and using a natural boundary condition [3] as the final condition at t_f. The dependence of dynamics at t on a later condition at t_f (retrocausality) cannot result in a contradiction because it is not possible to observe the system at time t without modifying the action and therefore invalidating the original prediction. (This reasoning does not confer any special status on a *measurement* as opposed to other physical interactions.) We point out that Bell's Theorem does not restrict retrocausal theories, since an independence assumption essential to its derivation does not apply to such theories [4].

We here construct an approximate Lagrangian describing a spin-1/2 neutral particle moving in the $+y$ direction (on the average) through a stationary magnetic field with $\partial B_x/\partial x > 0$ (the Stern-Gerlach experiment [5], except for the spin-1/2 simplification). Applying the action principle as described above, we obtain differential equations for the position of the center of the wavefunction and the coefficients C_+, C_- of the eigenmodes of the S_x operator. Analyzing the equations and using the natural boundary condition at t_f, we show that the particle state collapses into one or the other of the spin eigenstates. We consider whether a naturally arising distribution of a variable or variables not usually controlled in the experimental preparation can produce outcome statistics consistent with Born's rule.

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Spin backflow: A non-Markovian effect on spin pumping

Kazunari Hashimoto[1], Gen Tatara[2], and Chikako Uchiyama[1,3]

[1]*University of Yamanashi, 4-3-11 Takeda, Kofu, 400-8511, Japan*
[2]*RIKEN Center for Emerging Matter Science (CEMS), 2-1 Hirosawa, Wako, 351-0198, Japan*
[3]*National Institute of Informatics, 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo, 101-8430, Japan*

Recently, quick developments in experimental techniques have enabled the miniaturization of nano-scale spintronic devices. To generate spin current in the nano- spintronic devices, one needs also to consider miniaturizing the spin pump to use with the rotating magnetic moment in a quantum dot attached to an electron lead. Conventionally, the Markovian approximation is often used to describe the electron dynamics, which is valid under the strict assumption the system is slowly driven compared with electron relaxation by tunneling. However, we find several implementations in nano-spintronics for which we need to go beyond the Markovian approximation where the relaxation time for the transition to the lead is comparable to the rotation period of the rotating magnetic moment. This situation has led us to examine non-Markovian effects on spin pumping, which is the topic of this presentation.

We analyze electron transport under the non-Markovian dynamics in terms of the full counting statistics and capture a temporal backflow of spin, call spin backflow brevity, in contrast to the one-way-only nature of spin current generation under the Markovian dynamics. We find that the backflow significantly reduces the amount of spin current when the rotation frequency exceeds the relaxation rate. It prevents an unphysical divergence of the spin current in the high frequency limit that occurs under the Markovian approximation. The result indicates that the non-Markovian dynamics is necessary to achieve a physically reasonable description of spin pumping for all frequency range.

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P14

Multi-qudit states generated by unitary braid quantum gates based on Temperley-Lieb algebra

Choon-Lin Ho[1] and Tetsuo Deguchi[2]

[1]*Department of Physics, Tamkang University, 151 Yingzhuan Road, Tamsui 25137, Taiwan*
[2]*Department of Physics, Ochanomizu University, Tokyo 112-8610, Japan*

Using a braid group representation based on the Temperley-Lieb algebra, we construct braid quantum gates that could generate entangled n-partite D-level qudit states. D different sets of unitary representation of the braid group generators are presented. With these generators the desired braid quantum gates are obtained. We show that the generalized GHZ states, which are maximally entangled states, can be obtained directly from these braid quantum gates without resorting to further local unitary transformations. We also point out an interesting observation, namely for a general multi-qudit state there exists a unitary braid quantum gate based on the Temperley-Lieb algebra that connects it from one of its component basis states, if the coefficient of the component state is such that the square of its norm is no less than 1/4.

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Generalized Dirac oscillators with position-dependent mass

Choon-Lin Ho[1] and Pinaki Roy[2]

[1]*Department of Physics, Tamkang University, 151 Yingzhuan Road, Tamsui 25137, Taiwan*
[2]*Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City, Vietnam*

Dirac oscillator (DO) is one of a very few relativistic systems which admits exact solutions. After it was introduced, the DO and its various generalizations have been widely studied. One of the areas where the DO has found most applications is quantum optics. It has been shown that the Jaynes-Cummings and some of their generalized versions can be related to the DO system. Recently, the DO in (1 + 1) dimensions has also been realized experimentally, and a proposal for experimentally observing a two dimensional DO system in a single trapped ion has also been put forward. A classical wave analogue of the DO based on light propagation in engineered fiber Bragg gratings has also recently been considered. In this scenario the mass in DO becomes position dependent and is related to the refractive index. In this context we would like to mention that the lower dimensional Dirac equation with a position dependent mass has also found applications in electronic optics in graphene. In this work our objective is obtain solutions of the DO with a position dependent mass with/without an electric field. It will be seen that the effect of the electric field is to destroy the bound states and there exists a critical field beyond which bound states do not exist. Another aspect which we shall explore is the possibility of finding zero energy states. It will be shown that for a number of physically acceptable mass functions, exact zero energy states can be found.

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P16

Non-invasive thermometer based on proximity superconductor

Bayan Karimi and Jukka P Pekola

QTF Centre of Excellence, Aalto University, Finland

We present thermometry based on a tunnel junction between a superconductor and proximitized normal metal. It allows operation in a wide range of biasing conditions with microsecond time resolution. We demonstrate that this thermometer has low dissipation and operates at temperatures down to about 10 mK.

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Thermodynamic behaviors of excitonic emission in CdCrS nanosheets

Dong Jin Lee[1], Yong Deuk Woo[2], and Deuk Young Kim[1]

[1]*Quantum-Functional Semiconductor Research Center, Dongguk University, 30, Pildong-ro 1-gil, Seoul 04623, Republic of Korea*

[2]*Department of Mechanical and Automotive Engineering, Woosuk University, Chonbuk 55338, Republic of Korea*

We investigated the thermodynamic behaviors of excitonic emission properties in chromium-doped cadmium sulfide (CdCrS) diluted magnetic semiconductor (DMS) nanosheets (Cr $\approx$ 2%). The CdCrS nanosheets were prepared by a simple catalyst-free vapor phase epitaxy (VPE) process. The CdCrS nanosheets exhibited a clear luminescence peak from the neutral acceptor-bound exciton (A^0X), which persisted near room temperature. Compared to the CdS diamagnetic nanosheets, the inhomogeneous thermal-broadening of the excitonic-emission line-width in CdCrS DMS nanosheets is dominant at lower temperatures. This is attributed to the increase of ionized impurity scattering from Cr ions and results in the increase of exciton-phonon coupling strength. We have evaluated it through fitting of the Bose-Einstein approximation. As a consequence, Cr dopant can lead to low excitonic emission efficiency of CdS nanosheets, although a larger Cr content is favorable to increase the magnetic moment of a DMS material.

P18

Quantum corrections of work statistics in closed quantum systems

Fei Liu[1], Zhaoyu Fei[2], and Haitao Quan[2]

[1]*Beihang University, Beijing, 100191, China*
[2]*Peking University, Beijing, 100871, China*

We investigate quantum corrections to the classical work characteristic function (CF) as a semiclassical approximation to the full quantum work CF. In addition to explicitly establishing the quantum-classical correspondence of the Feynman-Kac formula, we find that these quantum corrections must be in even powers of $\hbar$. Exact formulas of the lowest corrections ($\hbar^2$) are proposed, and their physical origins are clarified. We calculate the work CFs for a forced harmonic oscillator and a forced quartic oscillator respectively to illustrate our results.

Excited state quantum phase transitions in interacting boson systems

Michal Macek[1], Pavel Stránský[2], Amiram Leviatan[3], and Pavel Cejnar[2]

[1]*The Czech Academy of Sciences, Institute of Scientific Instruments, Kralovopolska 147, Brno, Czech Republic*

[2]*Institute of Particle and Nuclear Physics, Charles University, v Holesovickach 2, Praha*

[3]*Racah Institute of Physics, The Hebrew University in Jerusalem, Jerusalem, Israel*

Phenomena analogous to ground state quantum phase transitions (QPT) have recently been noted to occur in the excitation spectra of certain many-body models [1-5]. These excited state phase transitions (ESQPT) are manifested as simultaneous singularities in the eigenvalue spectrum (including the gap or level density), order parameters, and wave function properties. Concentrating on bosonic lattice systems, we ask whether and how ESQPT singularities occur in condensed matter systems with ground state QPTs. As a general prerequisite, we point out the analogy between ESQPTs and van Hove singularities (vHss) [4]. We study in particular the spectral singularities above the ground-state phase diagram of the boson Hubbard (BH) model and compare the results with the Interacting Boson Model (IBM) of collective dynamics of atomic nuclei [5].

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P20

Entanglement via dissipation in a nonlinear circuit QED system

Dominik Maile[1,2], Sabine Andergassen[1], Wolfgang Belzig[2], and Gianluca Rastelli[2]

[1]*University of Tuebingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany*
[2]*University of Konstanz, Universitätsstraße 10, 78457 Konstanz, Germany*

We discuss a superconducting nanoscale circuit formed by two microwave cavities coupled via a Josephson junction and a joint capacitance to the ground (three contacts capacitance). In addition, the Josephson junction is shunted by a resistance and one plate of the capacitor is in series with a resistance connected to the ground. Such a configuration leads to dissipation in the relative phase difference across the Josephson junction and in the total charge of the two capacitances in parallel [1,2]. We show that, in the steady state, the resonators are in an entangled state and calculate the logarithmic negativity as a measure of entanglement in the harmonic regime. We find that the entanglement grows by increasing both dissipative coupling strengths via simultaneous squeezing of the fluctuations of the total charge and the relative phase difference. Due to the dissipative interaction, the system is not in a pure state. However, in the limit of large squeezing we compare the entanglement generated via dissipation with the one of an effective pure two-mode squeezed state. Increasing the coupling strength between the two oscillators via the Josephson energy also leads to a rise of the entanglement. Here the system enters the nonlinear coupling regime. We analyze the effect of such nonlinear interaction perturbatively.

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The energy level dynamics across many-body localization transition in 1D spin-1/2 XXZ system

Artur Maksymov, Piotr Sierant, and Jakub Zakrzewski

Marian Smoluchowski Institute of Physics, Jagiellonian University, Łojasiewicza 11, Kraków 30-348, Poland

The sensitivity of individual energy level with respect to perturbation was analyzed in terms of the first and the second derivatives of eigenstates with respect to Hamiltonian parameter defined as velocity and curvatures of energy levels. They can be obtained from the following Schrödinger equation

$$\hat{H}\left|\psi_n\right\rangle = E_n\left|\psi_n\right\rangle, \tag{1}$$

where $\hat{H} = \hat{H}_0 + \lambda\hat{V}$; $\hat{V}$ and λ representing perturbation matrix and system parameter. The analytical and numerical investigation of sensitivity of eigenstates to a change of external parameter for Gaussian random matrices (GRM) was done in [1].

For level dynamics studies we considered XXZ Heisenberg spin chain described by the following Hamiltonian

$$\hat{H}_0 = J\sum_{i=1}^{L}\left(S_i^x S_{i+1}^x + S_i^y S_{i+1}^y\right) + J_z\sum_{i=1}^{L} S_i^z S_{i+1}^z + \sum_{i=1}^{L} h_i S_i^z, \tag{2}$$

where J and J_z are the couplings for XY and Z components respectively, and h_i is the random magnetic field uniformly distributed within the range $[-W; W]$.

The two ways of system parametrization are considered: (i) the perturbation is given by a change of interaction term, $\hat{V}_{zz} = \delta J_z \sum_i^L S_i^z S_{i+1}^z$, therefore the system parameter is $\lambda \equiv \delta J_z$; (ii) the perturbation is defined by XY component, $\hat{V}_{xy} = \delta J \sum_i^L (S_i^x S_{i+1}^x + S_i^y S_{i+1}^y)$, thus the system is parametrized by tunneling, i.e. $\lambda \equiv \delta J$. From analysis of velocity and curvature distributions the non-universal behavior in ergodic phase was observed. For both perturbation matrices the curvature distribution in ergodic phase is similar to the one for GRM [2], however in deeply localized phase the statistics of curvatures follow two different laws. The tail of curvature distribution for many-body localized system follow the power-law behavior, but with exponent different from the one for ergodic regime, whereas the bulk of distribution is exponential. Such a complex distribution is observed for both types of perturbation considered here, however for $\hat{V}_{xy}$ matrix the division of curvature distribution into two part is more pronounced. We hope that the dynamical characteristics of energy levels analyzed here could serve as additional criteria that help to describe the ergodic to many-body localization transition in a more comprehensive way.

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P22

The squeezed thermal reservoir as a generalized equilibrium reservoir

Gonzalo Manzano

ICTP, Strada Costiera, 11, 34151, Trieste, Italy
Scuola Normale Superiore, Piazza dei Cavalieri, 7, 56126, Pisa, Italy

I explore the perspective of considering the squeezed thermal reservoir as an equilibrium reservoir in a generalized Gibbs ensemble with two noncommuting conserved quantities [1]. I outline the main properties of such a reservoir in terms of the exchange of energy and entropy. This perspective allows for identifying a new thermodynamic current based on quantum coherence, together with an associated chemical-like potential, which needs to be taken into account for correctly computing heat and work in the setup. Using this idea, I am able to provide an insightful interpretation of all thermodynamic features of the squeezed thermal reservoir, including the characterization of reversibility, and the first and second laws of thermodynamics. The main results may also apply to configurations in quantum thermodynamics using other nonthermal reservoirs, such as e.g. the displaced thermal reservoir.

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Non-equilibrium quantum stochastic thermodynamics: The role of symmetry

Daniel Manzano

University of Granada, Facultad de Ciencias. Av. Fuentenueva, Granada, Spain

Symmetry is a key concept in Physics. In this poster, we discuss how to harness symmetry to control transport and statistics in open quantum systems. Using tools from open quantum systems and large deviation theory, we show that symmetry-mediated control of transport is enabled by a pair of twin dynamic phase transitions in current statistics, accompanied by a coexistence of different transport channels. Other symmetry-mediated control mechanisms are also described. Overall, these results demonstrate the importance of symmetry not only as an organizing principle in physics but also as a tool to control quantum systems.

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P24

Two-level atom driven by a bistable Jaynes-Cummings oscillator

Themistoklis K. Mavrogordatos and Jonas Larson

Stockholm University, AlbaNova University Center, Fysikum, Stockholm SE 106 91, Sweden

The study of nonlinear oscillators interacting with nonclassical light features prominently in quantum optics in order to reveal the importance of quantum fluctuations far from thermal equilibrium. One of the archetypal examples of a quantum nonlinear oscillator is the resonantly-driven two-level atom. The properties of resonance fluorescence show ostensible deviations from classical radiation, as predicted in [1]. Closer to our days, the breakdown of photon blockade [2,3] demonstrates as well the importance of quantum fluctuations with respect to phase transitions substantiated by a semiclassical nonlinearity.

Joining the two ends, in our work, we investigate the interaction of a bistable Jaynes-Cummings oscillator and a single coherently-driven two-level atom. The spatially separated systems interact with the same unidirectional traveling-wave reservoir, similar to the setup of Ref. [4]. In particular, light emanating from the bistable emitter is focused on the external two-state scatterer, which is coupled to the modes of the vacuum and subsequently monitored via one forwards-scattering and three side-scattering channels.

In the semiclassical picture, the JC oscillator reaches steady state independently of its coupling to the external atom. Therefore, in order to assess the effect of the quantum fluctuations in the output cavity field, we present solutions of the master equation and employ quantum trajectories to characterize the emission profile of the external two-level atom. We also find that altering the strength of the coupling to the external atom impacts on the manifestation of amplitude and phase bistability in the cavity field, visible in individual realizations. We pay particular attention to the regimes of photon blockade and its breakdown in the phase portrait of the dissipative quantum phase transition analyzed in [2].

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P25

Asymmetry in energy versus spin transport in certain interacting disordered systems

Juan Jose Mendoza-Arenas[1,2], Marko Znidaric[3], Vipin Varma[4,5], John Goold[6], Stephen Clark[7,8], and Antonello Scardicchio[9,10]

[1] *Physics Department, Los Andes University, Carrera 1 No. 18A-12, Bogotá, Colombia*
[2] *Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, UK*
[3] *Physics Department, Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia*
[4] *College of Staten Island and Graduate Center, CUNY, New York, USA*
[5] *Department of Physics and Astronomy, University of Pittsburgh, PA, USA*
[6] *School of Physics, Trinity College Dublin, Dublin 2, Ireland*
[7] *University of Bath, Claverton Down, Bath BA2 7AY, UK*
[8] *Max Planck Institute for the Structure and Dynamics of Matter, University of Hamburg CFEL, Germany*
[9] *Abdus Salam ICTP, Strada Costiera 11, 34151 Trieste, Italy*
[10] *INFN, Sezione di Trieste, Via Valerio 2, 34126 Trieste, Italy*

Following the prediction of many-body localization [1], a vast amount or research has focused on the interplay between disorder and interactions in correlated systems. While the deep localized state is well understood, the nature of the transport of different conserved quantities remains to be established. Here we study energy conduction in a testbed disordered lattice, namely a XXZ spin-$1/2$ chain with random magnetic field, driven to a nonequilibrium configuration by unequal thermal reservoirs at the boundaries [2]. We discuss the transition between diffusive and subdiffusive transport in sectors of zero and finite magnetization at high temperature, using large-scale matrix product simulations. At strong anisotropies we find that energy diffusion prevails over a wide range of disorder strengths, which is in contrast to spin transport that is subdiffusive in the same regime for weak disorder. However, at finite magnetization both energy and spin currents decay as a function of the system size with the same exponent. We conclude that diffusion of energy is much more pervasive than that of magnetization in these disordered systems, and occurs across a significant range of the interaction-disorder parameter phase-space. We support the existence of this asymmetry, reminiscent of that in the clean limit, by an analytical estimation of diffusion constants for weak disorder.

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P26

Enhancing violations of single-site Leggett-Garg inequalities in nonequilibrium correlated many-body systems by interactions and decoherence

Juan Jose Mendoza-Arenas, Fernando Javier Gómez-Ruiz, Ferney Rodríguez, and Luis Quiroga

Physics Department, Los Andes University, Carrera 1 # 18A-12, Bogotá, Colombia

For several decades, assessing and quantifying quantum coherence have remained as fundamental open problems. A seminal breakthrough in this direction was made by Leggett and Garg [1], who showed that a macroscopic system entirely described by classical physics satisfies a set of inequalities (LGIs). The experimental observation of their violation has been sought intensively and reported in various platforms [2]. To engineer novel setups with strong violations, recent efforts have focused on their properties in open few-body systems. However, given the complex interplay between decoherence and interactions in many-body systems, it is natural to expect that both can be exploited for non-trivial control mechanisms of LGIs violation. In the present work we establish such mechanisms, by assessing genuine quantum transport in open correlated systems [3]. Considering a testbed many-body out-of-equilibrium configuration, we calculate single-site LGIs by performing large-scale matrix product simulations. We show that the steady-state transport transition of this model features a change of direction of the maximal violation, and that the latter increases with interactions in the diffusive regime. Furthermore we show that for strong interactions and large driving, bulk dephasing also enhances the LGI violation. We unravel the basic ingredients of this decoherence-enhanced quantum behavior through the analytical study of a minimal model. The generality of our results indicates that an increase of quantumness by interaction and dephasing can take place in a wide variety of systems.

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The metal-insulator transition in disordered solids: How theoretical prejudices influence its characterization. A critical review of analyses of experimental data

Arnulf Moebius

Leibniz Institute for Solid State and Materials Research, Helmholtzstr. 20, 01069 Dresden, Germany

In a recent experimental study, Siegrist et al. investigated the metal-insulator transition (MIT) induced by annealing in $GeSb_2Te_4$ and related phase-change materials [1]. The authors concluded that these materials exhibit a discontinuous MIT with a finite minimum metallic conductivity. The striking contrast between their work and reports on many other disordered substances from the last 35 years motivated the in-depth study of the influence of the MIT criterion used on the character of the MIT derived Ref. [2], presented in this poster.

First, we discuss inherent biases of various approaches to locating the MIT, that is to discriminating between just metallic and weakly insulating samples. Second, reanalyzing the $GeSb_2Te_4$ data, we show that this material resembles other disordered solids: according to a widely-used approach, its temperature dependences of the conductivity, $\sigma(T)$, may also be interpreted in terms of a continuous MIT. Checking the justification of this analysis, however, uncovers discrepancies rendering a clear interpretation impossible. Third, examining previous experimental studies of nine other solids, among them various doped crystalline semiconductors, we show that substantial problems in the interpretation of $\sigma(T)$ can also be detected in numerous studies which claim the MIT to be continuous: evaluating $w(T) = \mathrm{d}\ln\sigma/\mathrm{d}\ln T$ highlights serious inconsistencies. In part, they are common to all such studies and seem to be generic, in part, they vary from experiment to experiment. Fourth, for four qualitatively different phenomenological models of the temperature and control parameter dependence of the conductivity, we present the respective flow diagrams of $w(T)$. In consequence, the likely generic inconsistencies seem to originate from the MITs being discontinuous and occurring when $\mathrm{d}\sigma/\mathrm{d}T = 0$ at infinitely small T, in contradiction to most of the original interpretations.

Because of the large number and diversity of the experiments considered, the inconsistencies uncovered provide overwhelming evidence against the common, localization theory motivated interpretations, which are based on the assumption that $\sigma(T) \propto T^p$ with $p = 1/2$ or $1/3$ at the MIT. Thus, the question about the character of the MIT in disordered solids has to be considered as still open. The primary challenges now lie in improving the measurement precision and accuracy, rather than in extending the temperature range, as well as in developing a microscopic theory which explains the seemingly generic features of $\mathrm{d}\ln\sigma/\mathrm{d}\ln T$.

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P28

Strong coupling and non-Markovian effects on the statistical notion of temperature

Camilo Alfonso Moreno and Juan Diego Urbina

Regensburg University, Universitätsstraße 31, 93053, Regensburg, Germany

We investigate the emergence of temperature T in the system-plus-reservoir paradigm starting from the fundamental microcanonical scenario at total fixed energy E where, contrary to the canonical approach, T = T (E) is not a control parameter but a derived auxiliary concept. As shown by Schwinger for the regime of weak coupling γ between system and environment, T (E) emerges from the saddle-point analysis that leads to the usual ensemble equivalence in the thermodynamic limit. By extending these ideas for finite γ, we provide a consistent generalization of temperature T (E, γ) in strongly coupled systems and we illustrate its main features for the specific model of Quantum Brownian Motion where it leads to consistent microcanonical thermodynamics. Interestingly, while this T (E, γ) is a monotonically increasing function of the total energy E, its dependence with γ is a purely quantum effect drastically different for Markovian and non-Markovian regimes.

Numerical approach to non-equilibrium quantum thermodynamics: A non-perturbative treatment of the driven resonant level based on the driven Liouville von Neumann formalism

Inbal Oz[1], Oded Hod[1], and Abraham Nitzan[1,2]

[1]*School of Chemistry, Tel Aviv University, 6997801, Israel*
[2]*Department of Chemistry, University of Pennsylvania, Philadelphia, PA, 19104, USA*

We develop a numerical platform to study non-equilibrium thermodynamics in small systems and calculate the density matrix using the Driven Liouville von Neuman method, in which the Liouville von-Neuman equations of motion for an extended system comprising the system of interest plus finite leads is solved with open boundary conditions imposed on the leads. These boundary conditions are enforced by augmenting the equations with non-unitary source/sink terms that drive each lead into its own equilibrium distribution.

As the system is driven far from equilibrium it exhibits new phenomena. While at the regime of low driving rates the numerical and analytical results agree to first order in the deviation from equilibrium [1], they differ for high driving rates, where the perturbative analytical results are not valid. We calculate the dot occupation number and analyze the particle flux from the dot into the lead. Additionally, we study the energy, the work, and the heat flux developed in the lead section and examine the change in their structure for high deriving rates where the dot cannot reach a state of equilibrium with respect to the metal. Finally, we calculate the von Neumann entropy of the different parts of the system and its time dependence, and analyze its far from equilibrium structure and maximum value, shown to deviate from the Fermi level as the driving rate is increased.

This work is the first to develop a numerical platform and study the properties of the system driven far from equilibrium. The general platform developed is applicable for other non-interacting systems and for the calculations of higher moments of the thermodynamic properties.

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When the edge rules: Inter-layer transport in graphene dominated by edge states

Inbal Oz[1], Oded Hod[1], and Elad Koren[2]

[1]*School of Chemistry, Tel Aviv University, 6997801, Israel*
[2]*Department of Materials Science and Engineering, Technion Institute, Haifa 3200003, Israel*

Interlayer transport in graphene is central for its practical application in nano-electronics and sensing devices.

We present new computational results that rationalize recent experimental findings on interlayer transport between microscale graphene surfaces and describe the underlying mechanisms. Notably, we find that pronounced edge states, localized on the zigzag edges of circular flakes, result in edge-currents that scale linearly with the circumference of the system. The corresponding bulk-currents, while originating from a much larger number of atoms, are considerably weaker. This in turns leads to a current which is primarily dominated by the edge at small values of the bias voltage and for systems smaller then $\sim$100nm. For larger systems, the number of atoms in the bulk increases quadratically, eventually resulting in the domination of the bulk.

Our findings enable the development of control schemes for interlayer transport in graphitic systems based on the system size, shape, and interlayer misfit.

Phonon backaction in two-site molecular junctions: Negative differential conductance, interference and super-Poissonian noise

Tae-Ho Park and Han-Yong Choi

SungKyunKwan University, 2066, Seobu-ro, Jangan-gu, Suwon, Republic of Korea

We present a study of the electron transport through two-site molecular junctions employing the full counting statistics (FCS) in combination with the self-consistent Born approximation (SCBA). Here, we consider two different types of electron-phonon coupling in a molecule. One (model A) is the on-site coupling of the molecular vibration to the electrons and the other (model B) is the inter-site coupling of the vibration to the transferring electrons. In the weak coupling regime, both models present the sequential tunneling behavior with exhibiting the bonding and antibonding states as double peaks in the differential conductance as a function of bias voltage. In the presence of the phonon backaction, the super-Poissonian noise emerges and the Fano factor is enhanced as the electron-phonon coupling increases. In the intermediate coupling regime, the differential conductance shows multiple peaks associated with increased number of channels driven by the multiple inelastic scattering from the molecular vibration. Further, the phonon backaction leads to the interference between channels and dips by the reduction of the conductance and peaks with asymmetric line shape are observable. The model B shows that the negative differential conductance (NDC) take place, differently from the model A, in the course of the crossover from the weak electron-phonon coupling to the intermediate coupling. The NDC is accompanied with the abrupt change of the peak position in the charge distribution induced by the bias voltage. It turns out that the current fluctuation suppresses NDC, but induces the quantum interference in molecular conductance.

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Quantum to classical transition of trajectory work in two prototype systems

Tian Qiu[1], Rui Pan[1], Zhaoyu Fei[1], and Haitao Quan[1,2]

[1]*School of Physics, Peking University, No.5 Yiheyuan Road, Haidian District, 100871, China*
[2]*Collaborative Innovation Center of Quantum Matter, Beijing 100871, China*

Work is one of the most basic notions in thermodynamics. Usually the trajectory work in an isolated quantum systems is defined via two-point measurement. While in classical systems, the trajectory work is defined via trajectories in the phase space. How the definitions of work in these two regimes are connected is still unexplored. In this work, we study this problem by employing Feynman's path integral approach. We derive the analytical work distributions of two prototype quantum systems, which can be proved to be equivalent to the Schrödinger's formalism. Then we show the quantum-classical correspondence of individual trajectory. Our results provide good examples to show the effectiveness of path integral approach to quantum thermodynamics, and bring important insights to the understanding of trajectory work in quantum systems.

Global thermodynamics for trapped BEC gases. Critical properties

Victor Romero-Rochin

Instituto de Física, Universidad Nacional Autonoma de Mexico, Mexico City, Mexico

The critical properties of the phase transition from a normal gas to a BEC (superfluid) of a harmonically confined Bose gas are addressed with the knowledge of an equation of state of the underlying homogeneous Bose fluid. It is shown that while the presence of the confinement trap arrests the usual divergences of the isothermal compressibility and heat capacities, the critical behavior manifests itself now in the divergence of derivatives of the mentioned susceptibilities. This result is illustrated with a mean-field like model of an equation of state for the homogeneous particle density as a function of the chemical potential and temperature of the gas. The model assumes the form of an ideal Bose gas in the normal fluid while in the superfluid state a function is proposed such that, both, asymptotically reaches the Thomas-Fermi solution of a weakly interacting Bose gas at large densities and low temperatures and, at the transition, matches the critical properties of the ideal Bose gas. With this model we obtain the *global* thermodynamics of the harmonically confined gas, from which we analyze its critical properties. We discuss how these properties can be experimentally tested.

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Sharp energy determination of macroscopic pure quantum states

Victor Romero-Rochin

Instituto de Física, Universidad Nacional Autonoma de Mexico, Mexico City, Mexico

We show that a very large class of quantum pure states of isolated macroscopic bodies, which are superpositions of energy eigenstates within arbitrary finite energy intervals, have sharply peaked energy distributions, with their width relative to the average, scaling between $\sim N^{-1}$ and $\sim N^{-1/2}$, with $N \gg 1$ the number of atoms conforming the body. The implication of this statement is that closed systems in those states are *microcanonical* in the sense that, in their evolution and relaxation to equilibrium, "visit" only energy eigenstates very near to the mean energy. Since thermodynamics accurately describes processes of macroscopic bodies and requires that closed systems have constant energy, we argue that these pure states are typical of those systems. The main assumption beneath the energy sharpness is that the isolated body can reach thermal equilibrium if left unaltered.

Non-renewal statistics for quantum electron transport

Samuel Rudge and Daniel Kosov

James Cook University, 1 James Cook Drive, Townsville, 4814, Australia

Molecular electronic devices are subject to fluctuations in measurements of the bath variables, such as the stationary single particle current. An important task in mesoscopic physics, therefore, has been developing and applying statistical tools that can characterise these fluctuations. The full counting statistics (FCS), for example, calculates cumulants of the distribution of total transferred charge in a fixed time interval. Some complementary fluctuating time statistics, such as the waiting time distribution (WTD), have the remarkable ability to detect non-renewal transport, thus overcoming the historical long-time limitations of the FCS. Unfortunately, however, the WTD has so far been restricted to unidirectional transport only. Recently, the first-passage time distribution (FPTD), the distribution of times until the net number of detected electrons reaches a specified number, has emerged as an alternative fluctuating time statistic that incorporates bidirectional transitions.

In this poster, we apply the WTD and FPTD to sequential and cotunneling processes in an Anderson impurity, as well as sequential tunneling through the Holstein model. Over a certain voltage range in an Anderson impurity, inelastic cotunneling processes involve a spin-flip that induces telegraphic switching between two transport channels. One would expect that this phenomena would be accompanied by positive correlations in subsequent waiting times; yet the WTD is unable to penetrate this voltage regime due to bidirectional processes [1]. Applying the FPTD, we confirm the non-renewal behaviour but find small negative correlations between successive first-passage times [2].

We have reported [2,3,4] correlations between successive waiting times for transport through the Holstein model, which are largely reproduced in the first-passage times: albeit with a smaller peak. In both transport scenarios, we additionally demonstrate that, unlike WTD cumulants, the cumulants of the FPTD are correctly able to reproduce the FCS for bidirectional transport when the renewal assumption is satisfied [2].

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Quantum coarse-grained entropy and thermodynamics

Dominik Safranek, Joshua M. Deutsch, and Anthony Aguirre

University of California, Santa Cruz, 1156 High St, Santa Cruz, USA

Some people say that entropy of a closed quantum system remains constant. Of course, they have von Neumann entropy in mind. But is this entropy the right quantity to define thermodynamic properties of a closed system? For example, would you say that the entropy does not change when you throw ice into an insulated bottle? And from a macroscopic perspective, should there be really that much of a difference between a pure and a mixed state, when observer can detect change only in the macroscopic observables but not the microscopic ones? I will present framework of Observational entropy, which is based on generalizing Boltzmann entropy rather than Gibbs entropy, providing a new perspective on thermalization of isolated quantum systems. Within this framework, it is possible to define a measure that is well-defined out of equilibrium, grows to thermodynamic entropy as the system thermalizes, and which can be interpreted as a measure of "regions trying to equilibrate with each other". This "dynamical thermodynamic entropy" provides a step towards understanding the long-standing problem of quantum thermodynamics, as to which entropy is relevant for isolated quantum systems.

Active motion in two dimensions

Francisco J Sevilla

Instituto de Física, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica S/N, Coyoacán, Mexico

We study the statistical properties of two-dimensional active motion within a theoretical framework that takes into account an arbitrary pattern of motion of active particles (which absorb energy from the environment and transform it into self-locomotion through complex mechanisms). In other words, we analyze the diffusion in two dimensions of non-interacting self-propelled particles that follow an arbitrary motility strategy (active Brownian motion; run-and-tumble, run-and-reverse, run-reverse-flick dynamics; random walks with random velocities, etc.). Explicit solutions are obtained in Laplace-Fourier domain by solving a generalized transport equation. Analytical expressions for the mean-square displacement and for the kurtosis of the probability distribution function of the particle positions are presented, and the effects of persistence discussed.

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Stationary states of subsystems in the Bose-Hubbard model

Miguel Alejandro Pérez-Contreras, Francisco J Sevilla, and Andrea Valdés-Hernández

Instituto de Física, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica S/N, Coyoacán, Mexico

The stationary states of subsystems of a six-sites lattice with six bosons are studied theoretically within the Bose-Hubbard model when the complete system is in a pure state. We focus our analysis on subsytems composed by just one site, and characterize its stationary states with the ratio of the hopping parameter to the on-site energy interaction. We find that the equilibrium and nonequilibrium nature of the stationary states, can be mapped to an effective temperature defined in terms of the coupling between the site of interest and the rest of the complete system.

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Confinement-induced resonances in two-center problem

Sara Shadmehri[1] and Vladimir S. Melezhik[1,2]

[1]*Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Moscow Region 141980, Russian Federation*
[2]*People Friendship University of Russia (RUDN University) Miklukho-Maklaya st. 6, Moscow, 117198, Russian Federation*

Experimental investigation of quantum gases stimulated the theory development of low-dimensional quantum systems in confined geometry of atomic traps [1-2]. There has been a growing interest in cold hybrid atom-ion, atom-impurity and Rydberg atoms [3]. For example, there is a possibility to model stationary nuclear cores and mobile electrons in a crystal with trapped Rydberg atoms (or ions) and cold atoms [3-4]. This makes it necessary to extend the theoretical analysis to the quantum two-center problem in confined traps. The first step in the study of the discrete spectrum of the confined two-center problem was made in a recent paper [5]. In the present work [6], we study atomic scattering from two centers fixed on the longitudinal axis of a waveguide-like atomic trap via the pseudopotential approach. In this method, we introduce an alternative regularization operator for the zero-range interaction potential leading to consistent results with the corresponding one-center problem when the displacement between the scattering centers approaches zero [7]. In contrast to the confined scattering on a single center in the s-wave pseudopotential approach [7], we show the appearance of two CIRs in the confined two-center problem due to the resonances in the even and odd scattering states at a fixed distance between the centers.

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P40

Quantum-stochastic spreading on a disordered chain

Dekel Shapira and Doron Cohen

Ben-Gurion University, Beer-Sheva, Israel

We study the the spreading of a particle along a tight-binding chain, and the relaxation in a finite segment with periodic boundary conditions (ring geometry). Specifically we address the interplay of coherent and stochastic transitions, with or without bias, and also discuss the implications of introducing disorder. We find that the dependence of the drift velocity on the bias is non-monotonic, and explore the interplay between Anderson-localization and non-Hermitian delocalization. In a sense we study the quantum version of the Sinai-Derrida model, aka random walk in random environment.

Three-level laser heat engine at optimal performance with ecological function

Varinder Singh and Ramandeep Singh Johal

Indian Institute of Science Education and Research, Mohali, Knowledge City, Sector 81, Mohali, 140306, India

Although classical and quantum heat engines work on entirely different fundamental principles, there is an underlying similarity. For instance, the form of efficiency at optimal performance may be similar for both types of engines. In this work, we study a three-level laser quantum heat engine operating at maximum ecological function (EF) which represents a compromise between the power output and the loss of power due to entropy production. We derive analytic expressions for efficiency under the assumptions of strong matter-field coupling and high bath temperatures. Upper and lower bounds on the efficiency exist in case of extreme asymmetric dissipation when the ratio of system-bath coupling constants at the hot and the cold contacts respectively approaches, zero or infinity. These bounds have been established previously for various classical models of Carnot-like engines. We conclude that while the engine produces at least 75% of the power output as compared with the maximum power conditions, the fractional loss of power is appreciably low in case of the engine operating at maximum EF, thus making this objective function relevant from an environmental point of view.

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Dynamics of two-part quasi-distribution function in phase space

Bartłomiej J. Spisak, Damian Kołaczek, and Maciej Wołoszyn

AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, al. Mickiewicza 30, 30-059 Krakow, Poland

The inherent feature of quantum theory is the superposition principle of states which constitutes that sum of any two or more states also describes a possible state of the isolated system [1]. This principle has been tested in many quantum interference experiments involving photons, electrons, neutrons, atoms, and molecules and currently there is no doubt about its existence at least „microscopic" scale. One of the fundamental issues for applications in quantum information processing is generation of highly nonclassical states. One of the examples of such states is the coherent superposition of fairly separated two or more distinguishable localized states of a single system [2].

In this contribution we study the dynamics of the coherent superposition of two localized states generated by the Gaussian wavepackets. We refer to this object as the Schrödinger cat state. The presented studies are based on the phase space formulation of quantum mechanics [3]. The Wigner function is used to characterize the state in the space, and the dynamics of the quasi-distribution function is described by the equation of motion in the Moyal form [4,5]. We concentrate on a scattering process of the considered state on the single barrier using the phase-space methods. Transmission coefficient is determined and quantumness of these kind of states is analysed in terms of the non-classicality parameter.

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Probing measurement induced effects in quantum walks via recurrence

Thomas Nitsche[1], Sonja Barkhofen[1], Regina Kruse[1], Linda Sansoni[1], Martin Stefanak[2], Aurel Gabris[2], Vaclav Potocek[2], Tamas Kiss[3], Igor Jex[2], and Christine Silberhorn[1]

[1]*University of Paderborn, Applied Physics,Warburger Straße 100, 33098 Paderborn, Germany*
[2]*Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Brehova 7, 115 19 Praha 1 – Stare Mesto, Czech Republic*
[3]*Wigner Research Center for Physics, SZFKI, Konkoly-Thege M. u. 29-33, H-1121 Budapest, Hungary*

Measurements on a quantum particle unavoidably affect its state, since the otherwise unitary evolution of the system is interrupted by a non-unitary projection operation. In order to probe measurement-induced effects in the state dynamics using a quantum simulator, the challenge is to implement controlled measurement on a small subspace of the system and continue the evolution from the complementary subspace. A powerful platform for versatile quantum evolution is represented by photonic quantum walks [1] due to their high control over all relevant parameters. However, measurement-induced dynamics in such a platform have not yet been realized. Here [2] we implement controlled measurements in a discrete time quantum walk based on time multiplexing. This is achieved by adding a deterministic out-coupling of the optical signal to include measurements constrained to specific positions resulting in the projection of the walker's state on the remaining ones. With this platform and coherent input light we experimentally simulate measurement-induced single particle quantum dynamics. We demonstrate the difference between the dynamics of a quantum system which is measured only once at the end of the experiment and that which is measured repeatedly during the evolution. To this aim we study recurrence as a figure of merit, i.e. the return probability to the walker's starting position, which is measured in the two cases. We track the development of the return probability over 38 time steps and observe the onset of both recurrent and transient evolution as an effect of the different measurement schemes, a signature which only emerges for quantum systems. Our work serves as an experimental proof that one particle conditional quantum dynamics can be simulated using coherence alone.

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Thermodynamic coupling rule for far-from-equilibrium systems

Shanhe Su, Wei Shen, Jianying Du, and Jincan Chen

Xiamen University, Siming Nan Road, Xiamen, China

The energy conversion efficiency of far-from-equilibrium systems is generally limited by irreversible thermodynamic fluxes that make contact with different heat baths. For complex systems, the states of the maximum efficiency and the minimum entropy production are usually not equivalent. Here we show that the proper adjustments of the interaction between the energy and matter currents offer some important criteria for the performance characterizations of thermal agents, regardless of the system types and transition protocols. The universal thermodynamic coupling rule plays a critical role in irreversible processes. A double quantum dot system is applied to demonstrate that the performances of heat engines or refrigrators can be enhanced by suitably adjusting the coupling strength between thermodynamic fluxes.

Enhanced spin flip rate by two-phonon processes from a hot spot

Yasuhiro Tokura[1], Kazuyuki Kuroyama[2], Sadashige Matsuo[2], and Seigo Tarucha[2]

[1] *Pure and Applied Scienced, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, 305-8571, Japan*

[2] *Department of Applied Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan*

The dynamics of the electrons confined in quantum dot (QD) system is sensitively influenced by the conditions of the environment. For example, when a finite bias is applied to the series QDs containing an electron, the dynamics of the additional electron depends on the polarity of the bias [1]. This phenomenon is originated from Fermi statistics and is called as Pauli-spin blockade (P-SB). The invention of highly sensitive charge sensor adjacent to QD system had enabled detailed studies of the electron (spin) dynamics in real time [2]. Recently, the effect of P-SB on the electron dynamics was examined with this real time charge sensor [3]. Thermal effect on the electron dynamics in nanostructures has been attracting attentions in view of the fundamental research of the thermodynamics. Here, we focus on the effect of the near-by hot spot made of biased single QD, which emits thermal phonons to the coupled QD system. By real time monitoring charge sensor, we found that the spin flip process is accelerated beyond some threshold voltage of the applied bias [4].

In this contribution, we present our theoretical study of the effect of thermal phonons on the electron spin flip rate. In particular, we found that the two-phonon process (phonon absorption and then phonon emission) can explain the threshold behavior. By using the effective phonon temperature T, the spin flip rate is proportional to fifth power of T below the threshold but grows quadratically with T above the threshold. The thermal phonons are possibly in non-equilibrium state and the physical consequences are also studied.

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Non-Markovian effect on quantum Otto engine

Chikako Uchiyama[1,2], Ryuta Tezuka[1], Kazunari Hashimoto[1], Yuji Shirai[3], and Naomichi Hatano[3]

[1] *Univ. of Yamanashi, 4-3-11,Takeda, Kofu, 400-8511,Japan*
[2] *National Institute of Informatics, 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, Japan;*
[3] *Institute of Industrial Science, The University of Tokyo, Komaba, Meguro, Tokyo 153-8505, Japan*

Since the first proposal in 2004 [1], the quantum Otto engine has attracted much attention, including a report on experimental realization with NV centers [2]. In the proposed model [1], the working medium of the conventional four-stroke engine is replaced with a 1/2 spin, two isochroric processes with interaction of the spin with hot and cold reservoirs, and two adiabatic processes with adiabatic expansion and compression of the energy gap of the spin. In addition, description of the infinitesimal transferred heat dQ and work dW are obtained through the infinitesimal change of measured energy as $dQ = \sum_i E_i dp_i$ and $dW = \sum_i p_i dE_i$ with energy levels E_i and the corresponding occupation probabilities p_i [1].

In the conventional studies, the probabilities p_i have been mainly described by using the stationary state [1] or long time (Markovian) approximation [3]. The description in the finite-time region, which is one of the advantages of the Otto engine, has been possible only recently by introducing the non-Markovian effect through relative entropy [4].

In this presentation, we show the direct contribution of transferred energy between the spin and environment by using the Full Counting Statistics with introducing the non-Markovian effect. This treatment enables us to discuss the relation between dQ and the energy flow including back flow [5]. Obtaining a formula for dQ after the infinite repetition of the quantum Otto cycle, we show the concrete condition on intervals to be touched with the hot and cold reservoir to extract net positive work with using the definition of dW as in Ref. [1]. Moreover, we discuss the effect of attaching and detaching of the reservoirs to the extraction of net work.

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Quantum energy transport under environmental engineering

Chikako Uchiyama[1,2] and Kae Nemoto[2]

[1]*Univ. of Yamanashi, 4-3-11,Takeda, Kofu, Japan*
[2]*National Institute of Informatics, 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, Japan*

The experimental studies on energy transfer in photosynthetic bacteria have been attracting intensive attentions in these days [1]. We can find the typical example in the light harvesting antenna of a green sulfur bacteria, called Fenna-Mathews-Olson(FMO) complex [2]. An electron excitation generated by light in the complex is carried to the reaction center through bacteriochlorophyll (BChl) molecules which are surrounded by the protein molecules. In conventional thinking, thermal fluctuation of the protein molecules seems to disturb the energy transfer as noise. But recent studies have opened a new way of thinking: it is found that environmental noise can assist the energy transfer which is called as environmental assisted quantum transfer (ENAQT) [3] or dephasing-assisted transport [4] where the temporal correlation of the noise is described with the delta-function.

In this presentation, we show that we can accelerate quantum energy transport with environmental engineering: by applying stochastic noise with spatial-temporal correlation on a linear chain model [5]. Especially, we show that an extension of the spatial correlation into the negative region (anti-correlation) plays an important role on an acceleration of energy transport. We also show that the time evolution of the population and transfer efficiency measures non-monotonically depend on the correlation time of noise, which means that we need to choose the correlation time of noise to achieve the optimum energy transport. We expect that these results show new possibilities to engineer efficient energy transport as well as to understand the one in nature.

This work was supported in part from the MEXT KAKENHI Grant-in-Aid for Scientific Research on Innovative Areas Science of hybrid quantum systems Grant No.15H05870, and 18H04290.

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Quantum chaos on time series of photons

Benjamín David Mendoza, Diego Alberto Lara, Josué Cantera, Víctor Velazquez, Jehú López, Marcela Dolores Grether, and Enrique López

Facultad de Ciencias, UNAM, Av. Universidad 3000, Mexico, Mexico

Quantum chaos has been studied in nuclear systems and mesoscopic systems, always keeping in mind the classic comparison of balls that move in a non-regular billiard. In this poster we study the chaotic behavior of photons with quantum statistics that are injected into a beam splitter. Depending on the ratio between transmittance and reflectance [1], different photon statistics are obtained in the outputs, ranging from quantum statistics to Poisson statistics. The intermediate statistic between the two previous ones is chaotic. We show this assertion using the criteria of Fano and Wigner surmise.

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Born's rule from second quantization

Fritiof Wallentin

International Center for Mathematical Modeling, Linnaeus University, P G Vejdes väg, 351 95 Växjö, Sweden

We view phase factors not only as redundancies in the quantum formalism but instead as remnants of unitary transformations under which the probabilistic properties of observables are invariant. We postulate that a quantum observable corresponds to unitary representations of an abelian group, the irreducible subrepresentations of which correspond to the observable's outcomes. It is shown that this identification agrees with the conventional identification as self-adjoint operators. The upshot of this formalism is that we may 'second quantize' the representation to which an observable corresponds, thus obtaining the corresponding Fock space representation. This Fock space representation is then too identifiable as an observable in the same sense, the outcomes of which are naturally interpretable as ensembles of outcomes of the corresponding non-second quantized observable. We adopt the frequency interpretation of probability, i.e. as the average occurrence of the outcome in question, from which we deduce Born's rule by enforcing the notion 'average' to such that are invariant under contextual global phase factors of the second quantized initial state.

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Thermal transistor and thermometer based on Coulomb coupled conductors

Jing Yang[1], Cyril Elouard[1], Janine Splettstoesser[2], Björn Sothmann[3], Rafael Sánchez[4], and Andrew N. Jordan[1,5]

[1]*Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627, USA*
[2]*Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, S-412 96 Göteborg, Sweden*
[3]*Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany*
[4]*Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, 28049 Madrid, Spain*
[5]*Institute for Quantum Studies, Chapman University, 1 University Drive, Orange, CA 92866, USA*

We investigate a three-terminal setup consisting of a Coulomb coupled quantum dot and point contact. The source and drain reservoirs are connected to the quantum point contact while the base reservoir is tunnel coupled to the Coulomb blockaded quantum dot, which can contain at most one electron. We show that the setup can act as the nanoscale thermal transistor to control the electric or heat current in the quantum point contact. Alternatively, by detecting the electric current in the quantum point contact, the setup can also act as a sensitive nanoscale thermometer that is noninvasive. For both cases, we analytically calculate the relevant figure of merits. Remarkably, we find that the optimal performance of both the transistor and the thermometer occurs in the same regime where the ratio between the magnitude of the relative charging energy of the dot and the temperature of the base approximately equals to 2.4. Near this optimal regime, both the differential sensitivity of the thermal transistor and the sensitivity of the thermometer are maximized. For fixed applied bias, the differential sensitivity could be further maximized by making the electron on and off the dot correspond to fully closed and open channels respectively, which can be implemented by tuning the parameters of the quantum point contact. The sensitivity of the thermometer in the optimal regime is limited by the zero temperature energy decay rate of the dot and the sensing time and is remarkably independent of the point contact parameters, so long as the telegraph noise is much larger than the shot noise. Our proposal is useful for the control of the electric and heat flow and high precision thermometry at the nanoscale.

The intricate history of magnetite: From loadstone to multiferroicity

Karel Závěta

Institute of Physics, ASCR, v. v. i., Na Slovance 2, Praha 8, Czech Republic

The history of the use of natural magnetite as spontaneously magnetized material will be presented with respect to the claims of various countries or cultural regions for priority. We shall mention the Chinese, Olmec and Greek/Roman demands for priority and further describe various realizations of navigational tools, in particular compass.

The Néel theory of ferrimagnetism explained the magnetic properties of this material and they will be contrasted with the ferromagnetic and antiferromagnetic behaviour. Special attention will be paid to the Verwey transition discovered and described in 1939 and the progress of understanding the changes of structural, electrical and magnetic properties taking place at this transition.

We will finally bring a new look on this material connected to the multiferroic properties of magnetite in a certain temperature range.

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Quantum simulation of a two-level novel system with PT symmetry

Chao Zheng

Department of Physics, College of Science, North China University of Technology, 5 Jinyuanzhuang Road, Beijing 100144, China

We construct a general PT-symmetric two-level subsystem in a four-dimensional Hilbert space using the duality quantum algorithm. Quantum simulation of the evolution of the PT-symmetric system is investigated theoretically, and the quantum circuit is designed for qubit, qutrit and qudit systems. The experimental realizations are analyzed for NMR quantum system and quantum optics. Therefore, the ability of quantum computers is extended to simulate novel quantum system, and future applications can be expected.

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High efficient quantum simulation of the Yang-Baxter equations

Chao Zheng

Department of Physics, College of Science, North China University of Technology, 5 Jinyuanzhuang Road, Beijing 100144, China

We theoretically investigate how to simulate and verify the Yang-Baxter equations (YBE) by a quantum computer high efficiently using the duality quantum algorithm. The two hand sides of the YBE are entangled and simulated simultaneously. Therefore, the YBE is simulated as a whole, and the efficiency of quantum simulation and verification are improved. Quantum entanglements of the two hand sides of the YBE can be studied further, and both the unitary and non-unitary YBE can be simulated in Hermitian quantum systems.

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Author Index

D

E

F

G

H

Q

R

S

List of Participants

Prof. Hartmut Abele
TU Wien
Stadionallee
Wien
Austria

Prof. Mauro Antezza
Laboratoire Charles Coulomb, Université Montpellier
UMR5221
Place Eugène Bataillon - cc 074
Montpellier, 34095
France

Prof. Yoram Alhassid
Yale University
Department of Physics
217 Prospect Street
New Haven
USA

Dr. Andrew Armour
University of Nottingham
University Park
Nottingham
United Kingdom

Prof. Roland E Allen
Texas A&M University
Department of Physics and Astronomy
Mail Stop 4242
College Station
USA

Prof. Vanderlei Salvador Bagnato
IFSC-University of São Paulo
Av. Trabalhador São Carlense, 400
São Carlos
Brazil

Prof. Sabine Andergassen
University of Tübingen
Auf der Morgenstelle 14
72076 Tübingen
Germany

Prof. Harold U Baranger
Duke University
Dept of Physics, Science Dr
Durham 27708-0305
USA

Prof. Frithjof Anders
Lehrstuhl theo. Physik II, Fakultät Physik
Technische Universtät Dortmund
Otto-Hahn Str 4
44227 Dortmund
Germany

Dr. Adam Bednorz
University of Warsaw
Krakowskie Przedmiescie 26/28
00-927 Warsaw
Poland

Prof. Joachim Ankerhold
Institute for Complex Quantum Systems
University of Ulm
Albert-Einstein-Allee 11
89069 Ulm
Germany

Prof. Wolfgang Belzig
University of Konstanz
Universitätsstr. 10
78457 Konstanz
Germany

Prof. Yaroslav M. Blanter
Kavli Institute of Nanoscience
Delft University of Technology
Lorentzweg 1
Delft
Netherlands

Prof. Denys I Bondar
Tulane University
2001 Percival Stern Hall
New Orleans
USA

Prof. Michael Bonitz
Institute for Theoretical Physics and Astrophysics
Universiy Kiel, Germany
Leibnizstr. 15
24098 Kiel
Germany

Prof. Dirk Bouwmeester
Huygens Laboratory
Department of Physics, Leiden University
NilesBohrweg 2
Leiden
Netherlands

Prof. Warwick Bowen
University of Queensland
Physics Annex (bld 6), School of Maths and Physics
St Lucia
Australia

Dr. Alessandro Braggio
Istituto Nanoscienze CNR
NEST, Scuola Normale Superiore
Piazza San Silvestro 12
Pisa 56127
Italy

Dr. Matteo Brunelli
University of Cambridge
University of Cambridge
JJ Thomson Ave
Cambridge
United Kingdom

Prof. Aurel Bulgac
University of Washington
3910 15th Ave NE
Seattle
USA

Prof. Amir Ordacgi Caldeira
Universidade Estadual de Campinas
Rua Sergio Buarque de Holanda 777, Cidade Universitária
Campinas, 13083-859
Brazil

Prof. Jianshu Cao
MIT
77 Mass. Ave. 6-237A
Cambridge
USA

Prof. Federico Capasso
School of Engineering and Applied Sciences
Harvard University
29A Oxford St.
Cambridge 02138
USA

Dr. Henry Castejon
Wilkes University
Chemistry Department
80 W. South Street
Wilkes Barre
USA

Prof. Ana María Cetto
Instituto de Física, UNAM, Mexico
Circuito de la Investigación Científica, CU
04510 México, DF
Mexico

Prof. Juan Carlos Cuevas
Departamento de Fisica Teorica de la Materia Condensada
Universidad Autonoma de Madrid
Tomas y Valiente 7
28049 Madrid
Spain

Prof. Frédéric Chevy
Laboratoire Kastler Brossel
Ecole Normale Supérieure, CNRS
24 rue Lhomond
Paris
France

Prof. Bryan Dalton
Centre for Quantum and Optical Science
Swinburne University of Technology
John St
Melbourne 3122
Australia

Prof. Taeseung Choi
Seoul Women's University
Hwarangro 621, NowonGu
Seoul 01797
Republic of Korea

Prof. Pawel Daniel Danielewicz
NSCL Cyclotron Laboratory, Michigan State University
640 South Shaw Lane
East Lansing, 48824
USA

Dr. Andrew Cleland
University of Chicago
Institute for Molecular Engineering
5640 S Ellis Ave - Rm 235
Chicago 60637
USA

Prof. Daniel M Dantchev
Institute of Mechanics
Bulgarian Academy of Sciences
Akad. G. Bontchev St. bl. 4
Sofia
Bulgaria

Prof. Doron Cohen
Ben-Gurion University
Physics Department
Beer-Sheva 84105
Israel

Dr. Shakib Daryanoosh
University of Oxford
Parks Road
Oxford
United Kingdom

Dr. James Cresser
University of Glasgow
University Avenue
Glasgow G12 8QQ
United Kingdom

Prof. Luis de la Peña
Instituto de Física, UNAM
Apartado postal 20-364, Ciudad Universitaria
01000 Mexico, DF
Mexico

Dr. Maxime Debiossac
University of Vienna
Boltzmanngasse, 5
Vienna
Austria

Dr. Cyril Elouard
University of Rochester
500 J. C. Wilson Blvd.
Rochester, 14627
USA

Prof. Hansjoerg Dittus
German Aerospace Center
Hansestr. 115
51149 Koeln
Germany

Dr. Georg Engelhardt
Beijing Computational Science Research Center
Building 9, East Zone, ZPark II, No.10 East Xibeiwang Road
Beijing 100193
China

Prof. Konstantin Dorfman
State Key Laboratory of Precision Spectroscopy,
Department of Physics, East China Normal University
3663, North Zhongshan Road,
Shanghai, 200062
China

Dr. Sebastian Erne
University of Nottingham
School of Mathematical Sciences
University Park
Nottingham, NG7 2QL
United Kingdom

Dr. Igor Dotsenko
Laboratoire Kastler Brossel
Collège de France
11 place Marcelin Berthelot
75005 Paris
France

Dr. Daniel Esteve
SPEC
CEA Paris-Saclay
Orme des Merisiers
91191 Gif-sur-Yvette
France

Prof. Ehtibar Dzhafarov
Purdue University
703 Third Street
West Lafayette 47907
USA

Dr. Jean Etesse
Group of Applied Physics
Chemin de Pinchat, 22
Genève 4, 1211
Switzerland

Prof. Jens Eisert
FU Berlin
Arnimallee 14
Berlin 14195
Germany

Prof. Jaroslav Fabian
University Regensburg
Universitätstrasse
Regensburg
Germany

Prof. Giuseppe Falci
Dipartimento di Fisica e Astronomia
Universita' di Catania and CNR-IMM MATIS Catania
Via Santa Sofia 64
Catania I-95125
Italy

Prof. Edward Fry
Texas A&M University
4242 TAMU
College Station 77843
USA

Prof. Holger Fehske
Institute of Physics, University Greifswald
Felix-Hausdorff-Str. 6
17489 Greifswald
Germany

Prof. Stephen A. Fulling
Texas A&M University
Mathematics Dept.
3368 TAMU
College Station 77843-3368
USA

Mr. Zhaoyu Fei
Peking University
No. 5 Yiheyuan Road
Haidian District, zipcode: 100871
China

Prof. Michael Galperin
University of California San Diego
Dept. Chem. & Biochem., UH 3250, MC 0340
9500 Gilman Drive
La Jolla
USA

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 City , 04510
Mexico

Prof. Boris Fine
Skolkovo Institute of Science and Technology
Skolkovo Innovation Center
Nobel Str. 3
Moscow
Russian Federation

Dr. Bartłomiej Jerzy Gardas
Jagiellonian University
Faculty of Physics, Astronomy and Applied Computer Science
Lojasiewicza 11, 30-348 Krakow
Krakow
Poland

Prof. James Freericks
Georgetown University
Dept of Physics, 37th and O St, Georgetown University
Washington
USA

Prof. Yuval Gefen
The Weizmann Institute
Department of Condensed Matter Physics
Herzl St
Rehovot 76100
Israel

Prof. Nicolas Robert Gisin
University of Geneva
22 chemin de Pinchat
Carouge, 1227
Switzerland

Prof. Michael Guidry
University of Tennessee
Department of Physics and Astronomy
3552 Navigator Pointe
Knoxville
USA

Prof. D. Christian Glattli
CEA Saclay
SPEC, Service de Physique de l'Etat Condensé,Un. Paris-Sacla
CEA Saclay
91191 Gif-sur-Yvette
France

Prof. Shmuel Gurvitz
Weizmann Institute
Herzl
Rehovot 76100
Israel

Dr. Sébastien Gleyzes
Laboratoire Kastler Brossel
CNRS
11 Place Marcelin Berthelot
75005 Paris
France

Mr. Walter Hahn
QuTech, Delft University of Technology
Lorentzweg 1
Delft
Netherlands

Prof. Michele Governale
Victoria University of Wellington
Kelburn Campus
Wellinton
New Zealand

Prof. Peter Hänggi
University of Augsburg
Department of Physics
Universitätsstrasse 1
86135 Augsburg
Germany

Dr. Marco Gramegna
INRiM - Istituto Nazionale di Ricerca Metrologica
Strada delle Cacce, 91
Torino - 10135
Italy

Prof. Theodor W. Wolfgang Hänsch
LMU Faculty of Physics
Schellingstrasse 4/IIIrd floor
München/Munich
Germany

Prof. Eberhard K.U. Gross
Max Planck Institute of Microstructure Physics
Weinberg 2
06120 Halle (Saale)
Germany

Dr. Alan K. Harrison
Los Alamos National Laboratory
MS T086, P. O. Box 1663
Los Alamos 87545
USA

Dr. Jindrich Hasek
Institute of Biotechnology, AV CR
Prumyslova 595
Vestec
Czech Republic

Prof. Petr Hořava
Berkeley Center for Theoretical Physics
University of California, Berkeley
& Lawrence Berkeley National Laboratory
Berkeley
USA

Dr. Kazunari Hashimoto
University of Yamanashi
4-3-11 Takeda
Kofu, 400-8511
Japan

Dr. Jiri Hosek
Nuclear Physics Institute
Hlavni
Rez
Czech Republic

Prof. Philip Hemmer
Texas A&M University
3128 TAMU
College Station
USA

Prof. Bei-Lok Hu
University of Maryland
Campus Dr & Regents Dr, PSC3153
College Park
USA

Prof. Ortwin Hess
Imperial College London
The Blackett Laboratory, Department of Physics
South Kensington Campus
London
United Kingdom

Dr. Pavel Hubík
Institute of Physics CAS, v. v. i.
Cukrovarnická 10
162 00 Praha 6
Czech Republic

Prof. Rudolf Hilfer
ICP
Universitaet Stuttgart
Allmandring 3
70569 Stuttgart
Germany

Dr. Thibaut Jonckheere
Centre de Physique Théorique - CNRS
Campus de Luminy, case 907
13009 Marseille
France

Prof. Choon-Lin Ho
Department of Physics, Tamkang University
151 Yingzhuan Road
Tamsui 25137
Taiwan

Prof. Andrew N. Jordan
University of Rochester
Bausch and Lomb Hall
Rochester
USA

Dr. Kristen Kaasbjerg
Dept. of Physics
Technical University of Denmark
Anker Engelundsvej 1
2800 Kgs. Lyngby
Denmark

Prof. Ikuzo Kanazawa
Department of Physics,Tokyo Gakugei University
Nukuikitamachi 4-1-1,Koganeishi
Tokyo 184-8501
Japan

Miss. Bayan Karimi
Aalto University
Tietotie 3
02150 Espoo
Finland

Prof. Eytan Katzav
The Racah Institute of Physics
The Hebrew University of Jerusalem
Edmond J. Safra Campus
Jerusalem
Israel

Dr. Peter D. Keefe
University of Detroit Mercy
24405 Gratiot Ave.
Eastpointe
USA

Prof. Wolfgang Ketterle
Massachusetts Institute of Technology, Cambridge
MIT
77 Massachusetts Avenue
Cambridge
USA

Prof. Andrei Khrennikov
Linnaeus University
Center for Math Modeling in Physics and Cognitive Science
P.G. Vägen
Växjö
Sweden

Prof. Takafumi Kita
Hokkaido University, Sapporo
Kita 10 Nishi 8
Sapporo 060-0810
Japan

Prof. Stefan Klumpp
University of Goettingen
Friedrich-Hund-Platz 1
37077 Göttingen
Germany

Prof. Olga Kocharovskaya
Department of Physics and Astronomy
Texas A&M University
4018 Decatur Drive
College Station
USA

Dr. Michal Kolář
Palacký University Olomouc
17. listopadu 1192/12
Olomouc, 771 46
Czech Republic

Dr. Richard Korytár
Charles University
Ke Karlovu 3
121 16 Prague
Czech Republic

Dr. Jonne Verneri Koski
ETH Zurich
Laboratory for Solid State Physics
Otto-Stern-Weg 1
8093, Zurich
Switzerland

Prof. Gershon Kurizki
The Weizmann Institute of Science
2 Herzl Str.
Rehovot 76100
Israel

Prof. Ronnie Kosloff
Hebrew University Jerusalem
givat Ram
Jerusalem 91904
Israel

Dr. Paul G Kwiat
University of Illinois at Urbana-Champaign
1110 W. Green St.
Urbana, 61874
USA

Dr. Zdeněk Kožíšek
Institute of Physics
Academy of Sciences of the Czech Republic
Cukrovarnická 10
Praha 6
Czech Republic

Dr. Dong Jin Lee
Dongguk University
30, Pildong-ro 1-gil
Seoul 04623
Republic of Korea

Mr. Mario Krenn
Vector Institute for Artificial Intelligence
661 University Ave., Suite 710
Toronto, ON M5G 1M1
Canada

Prof. Alfredo Levy Yeyati
Universidad Autónoma de Madrid
Campus de Cantoblanco
Madrid
Spain

Prof. Norbert Kroo
Wigner Physics Research Center
Hungarian Academy of Sciences
Galgoczy str 51/B
Budapest
Hungary

Dr. Suzy Lidstrom
Texas A&M University
Mail Stop 4242
College Station
USA

Dr. Karla Kuldová
Institute of Physics ASCR, v.v.i.
Cukrovarnická 10
162 00 Prague 6
Czech Republic

Dr. Fei Liu
Beihang University
Xueyuan Road 37, Haidian District
Beijing, 100191
China

Prof. Yi min Liu
Department of Physics, Shaoguan University
Zhenjiang district university road, 288
Shaoguan 512005
China

Dr. Michal Macek
The Czech Academy of Sciences
Institute of Scientific Instruments
Kralovopolska 147
Brno
Czech Republic

Dr. Jan Loos
Institute of Physics ASCR
Cukrovarnická 10
Praha
Czech Republic

Prof. Joseph Maciejko
University of Alberta
Department of Physics, CCIS
Edmonton
Canada

Dr. Niels Lörch
Unibversity of Basel
Klingelbergstrasse 82
Basel
Switzerland

Mr. Dominik Maile
University of Tuebingen
University of Konstanz
Universitätsstraße 10
78457 Konstanz
Germany

Dr. Marcelo Lozada-Cassou
Renewable Energies Institute
UNAM
Priv. Xochicalco s/n
Temixco
Mexico

Dr. Artur Maksymov
Marian Smoluchowski Institute of Physics
Jagiellonian University
Łojasiewicza 11
Kraków 30-348
Poland

Prof. Eric Lutz
University of Stuttgart
Institute for Theoretical Physics I
Pfaffenwaldring 57
70550 Stuttgart
Germany

Mr. Mattia Mantovani
Universität Konstanz
Universitätsstraße 10
Konstanz
Germany

Prof. Jerzy Łuczka
University of Silesia
75 Pułku Piechoty 1A
41-500 Chorzów
Poland

Dr. Gonzalo Manzano
International Centre for Theoretical Physics (ICTP)
and Scuola Normale Superiore di Pisa
Strada Costiera, 11
34151, Trieste
Italy

Prof. Daniel Manzano Diosdado
University of Granada
Facultad de Ciencias. Av. Fuentenueva
Granada
Spain

Mr. Camilo Alfonso Moreno Jaimes
Regensburg University
Schwabenstrasse 6
Regensburg
Germany

Dr. Jiří J. Mareš
Institute of Physics, v.v.i., Czech Academy of Sciences
Cukrovarnická 10
162 00 Praha 6
Czech Republic

Prof. Mikko Möttönen
Aalto University
QCD Labs
POB 13500
00076 Aalto
Finland

Prof. Thierry Martin
Centre de Physique Théorique, Aix Marseille Université
163 av de Luminy
Marseille 13009
France

Prof. Lev Mourokh
Queens College of CUNY
65-30 Kissena Blvd
Queens
USA

Dr. Themis Mavrogordatos
Stockholm University
AlbaNova University Center
Stockholm SE 106 91
Sweden

Prof. Kater Murch
Physics Department
Washington University in St. Louis
Campus Box 1105
St. Louis
USA

Dr. Juan Jose Mendoza-Arenas
Universidad de los Andes
Carrera 1 # 18A-12
Bogota
Colombia

Prof. Evgenii Narimanov
Purdue University
465 Northwestern Ave
West Lafayette
USA

Prof. Arnulf Moebius
Leibniz Institute for Solid State and Materials Research
Helmholtzstr. 20
01069 Dresden
Germany

Dr. Sylvain Nascimbene
CNRS - Laboratoire Kastler Brossel
Collège de France
11 place Marcelin Berthelot
Paris
France

Prof. Nir Navon
Yale University
Prospect Street
New Haven
USA

Dr. Stefan Nimmrichter
Max Planck Institute for the Science of Light
Staudtstr. 2
91058 Erlangen
Germany

Dr. Karel Netočný
Institute of Physics CAS
Na Slovance 2
Praha 8, CZ-18221
Czech Republic

Prof. Abraham Nitzan
University of Pennsylvania
Department of Chemistry
231 S 34th St
Philadelphia
USA

Prof. Daniel Neuhauser
UCLA
607 Charles E Young dr
Los Angeles 90095
USA

Mrs. Inbal Oz
Tel-Aviv University
Einstein 1
Tel-Aviv
Israel

Dr. Theo M. Nieuwenhuizen
Institute for Theoretical Physics
University of Amsterdam
Science Park 904
1098 XH Amsterdam
Netherlands

Prof. Elisabetta Paladino
DFA University of Catania & CNR-IMM UOS Catania
(Università)
Via Santa Sofia 64
Catania
Italy

Prof. Branislav Nikolic
University of Delaware
Department of Physics & Astronomy
217 Sharp Lab
Newark
USA

Prof. Hyunggyu Park
Korea Institute for Advanced Study
85 Hoegiro Dongdaemun-gu
Seoul 02455
Republic of Korea

Prof. Martin Nikolo
Saint Louis University
221 N. Grand Blvd.
St. Louis
USA

Dr. Tae-Ho Park
SungKyunKwan University
2066, Seobu-ro, Jangan-gu
Suwon
Republic of Korea

Prof. Emmanuel Paspalakis
University of Patras
Rio
Patras
Greece

Prof. William Daniel Phillips
The National Institute of Standards and Technology (NIST)
100 Bureau Drive
Gaithersburg 20899-8424
USA

Prof. Jukka Pekola
Aalto University School of Science
Tietotie 3
Helsinki
Finland

Dr. Fabrizio Piacentini
INRIM
strada delle Cacce 91
Turin 10135
Italy

Dr. Marti Perarnau-Llobet
Max Planck Institute of Quantum Optics
Hans-Kopfermann-Straße 1
85748 Garching bei München
Germany

Prof. Arkady Plotnitsky
Purdue University
500 Oval Drive
West Lafayette, IN, 47907
USA

Prof. Uri Peskin
Technion - Israel Institute of Technology
Technion city
Haifa
Israel

Dr. Claudia Pombo
-
-
Amsterdam
Netherlands

Prof. Francesco Petruccione
University of KwaZulu-Natal
Private Bag X54001
Durban 4000
South Africa

Dr. Tian Qiu
School of Physics, Peking University
No.5 Yiheyuan Road
Haidian District, 100871
China

Prof. Walter Pfeiffer
Bielefeld University
Universitaetsstr. 25
Bielefeld
Germany

Prof. Haitao Quan
Peking University
5 Yiheyuan Road, Haidian District
Beijing, 100871
China

Dr. Friedemann Queisser
Helmholtz-Zentrum Dresden-Rossendorf
Bautzner Landstrasse 400
01328 Dresden
Germany

Dr. Michael Ridley
Tel Aviv University
Chaim Levanon 30
Tel Aviv - Yafo 69978
United Kingdom

Dr. Saar Rahav
Schulich Faculty of Chemistry
Technion - Israel Institute of Technology
Technion City
Haifa 32000
Israel

Dr. Victor Romero-Rochin
Instituto de Física
Universidad Nacional Autonoma de Mexico
Circuito de la Investigacion s/n, Ciudad Universitaria
Mexico City
Mexico

Prof. Ernst Rasel
Leibniz University Hannover
Institute of quantum optics
Welfengarten 1
Hannover
Germany

Dr. Yuri Rostovtsev
Department of Physics, University of North Texas
1155 Union Circle, #311427
Denton
USA

Dr. Gianluca Rastelli
University of Konstanz
Fachbereich Physik, Fach 703
Universitätsstraße
78457, Konstanz
Germany

Mr. Gary Georgi Rozenman
Tel Aviv University
Faculty of Exact Sciences
Kokhavei Yitskhak St 14/9
Tel Aviv, ZIP: 6687176
Israel

Dr. Jerome Rech
Centre de Physique Theorique
163 avenue de Luminy
13009 Marseille
France

Mr. Samuel Louis Rudge
James Cook University
1 James Cook Drive
Townsville, 4814
Australia

Prof. Linda Reichl
University of Texas at Austin
Physics Department, 1 University Station
Austin, 78712
USA

Prof. Janne Ruostekoski
Lancaster University
Physics Department
Lancaster
United Kingdom

Prof. Amir Safavi-Naeini
Stanford University
348 Via Pueblo Mall
Stanford
USA

Prof. Thomas L. Schmidt
University of Luxembourg
162a, avenue de la Faiencerie
L-1511 Luxembourg
Luxembourg

Dr. Dominik Safranek
University of California, Santa Cruz
1156 High St
Santa Cruz
USA

Dr. Peter Schmitteckert
HQS Quantum Simulations
Haid-und-Neu-Straße 18
76131 Karlsruhe
Germany

Dr. David Sanchez
University of the Balearic Islands
IFISC (UIB-CSIC)
Crta. Valldemossa, km 7.5
E07122-Palma de Mallorca
Spain

Prof. Hans A Schuessler
Texas A&M University
MS4242
College Station
USA

Dr. Rafael Sánchez
Universidad Autónoma de Madrid
Francisco Tomás y Valiente, 7
Madrid 28049
Spain

Prof. Ralf Schuetzhold
Helmholtz-Zentrum Dresden-Rossendorf
Bautzner Landstrasse 400
01328 Dresden
Germany

Prof. Lea Santos
Yeshiva University
245 Lexington Ave
New York
USA

Prof. Lawrence S. Schulman
Clarkson University
8 Clarkson Ave
Potsdam
USA

Prof. Wolfgang Schleich
Institut für Quantenphysik
Universität Ulm
Albert Einstein Allee 11
D-89081 Ulm
Germany

Prof. Marlan Scully
Texas A&M University and Princeton University
IQSE, 4242 TAMU
College Station, Texas 77843-4242
USA

Miss. Stella Seah
National University of Singapore
Block S15, 3 Science Drive 2, 117543
Singapore
Singapore

Dr. Sara Shadmehri
Bogoliubov Laboratory of Theoretical Physics
Joint Institute for Nuclear Research
Joliot-Curie
Dubna, Moscow Region 141980
Russian Federation

Prof. Udo Seifert
University Stuttgart
Pfaffenwaldring 57
70550 Stuttgart
Germany

Mr. Dekel Shapira
Ben-Gurion University
Israel

Dr. Dirk Semkat
Ernst-Moritz-Arndt-Universität Greifswald
Institut für Physik
Felix-Hausdorff-Str. 6
17489 Greifswald
Germany

Dr. Armin Shayeghi
Vienna Center for Quantum Science and Technology
University of Vienna
Boltzmanngasse 5
Wien
Austria

Prof. Chulhun Seo
Soongsil University
369 Sangdoro Dongjak
Seoul 06978
Republic of Korea

Prof. Daniel Sheehan
University of San Diego
5998 Alcala Park
San Diego
USA

Prof. Llorenç Serra
Universitat de les Illes Balears
Carretera Valldemossa km 7.5
Palma de Mallorca
Spain

Dr. Yutaka Shikano
Keio University
Quantum Computing Center
3-14-1 Hiyoshi, Kohoku
Yokohama
Japan

Dr. Francisco J Sevilla
Instituto de Física
Universidad Nacional Autónoma de México
Circuito de la Investigación Científica S/N
Coyoacán
Mexico

Prof. Efrat Shimshoni
Dept. of Physics, Bar-Ilan University
Bar-Ilan University campus
Ramat Gan 52900
Israel

Prof. Pascal Simon
University Paris Sud
Laboratoire de Physique des Solides
Bat 510, LPS
Orsay, 91405
France

Dr. Václav Špička
Institute of Physics, v.v.i.
Czech Academy of Sciences
Cukrovarnická 10
162 00 Praha 6
Czech Republic

Dr. Ilya Sinayskiy
University of KwaZulu-Natal, South Africa
National Institute for Theoretical Physics (NITheP), KZN
Westville campus
Durban
South Africa

Dr. Bartlomiej J. Spisak
AGH University of Science and Technology
Faculty of Physics and Applied Computer Science
al. Mickiewicza 30
30-059 Krakow
Poland

Mr. Varinder Singh
Indian Institute of Science Education and Research, Mohali
Knowledge City, Sector 81
Mohali, 140306
India

Prof. Martin Stefanak
FNSPE CTU in Prague
Brehova 7
Prague, 115 19
Czech Republic

Dr. Alexei V. Sokolov
Texas A&M University
Physics Dept. 4242 TAMU
College Station
USA

Dr. Jürgen T. Stockburger
Universität Ulm
Institute for Complex Quantum Systems
Albert-Einstein-Allee 11
89069 Ulm
Germany

Prof. Fernando Sols
Universidad Complutense de Madrid
Plaza de las Ciencias 1
E-28040 Madrid
Spain

Prof. Dalibor Štys
Institute of Complex Systems
FFPW, University of South Bohemia
Zámek 136
Nové Hrady
Czech Republic

Prof. Björn Sothmann
University Duisburg-Essen
Lotharstr. 1
47048 Duisburg
Germany

Dr. Shanhe Su
Xiamen University
Siming Nan Road
Xiamen
China

Dr. Fabio Taddei
NEST, Istituto Nanoscienze-CNR & Scuola Normale Superiore
Piazza dei Cavalieri, 7
I-56126, Pisa
Italy

Prof. Thomas Udem
Max-Planck Institute of Quantum Optics
Hans-Kopfermann Strasse 1
Garching
Germany

Prof. Oren Tal
Weizmann Institute of Science
Herzl 234
Rehovot 7610001
Israel

Prof. Yasuhiro Utsumi
Mie University
1577, Kurimamachiya-cho
Tsu, 514-8507
Japan

Prof. Gerard ’t Hooft
Universiteit Utrecht
Institute for Theoretical Physics
Princetonplein 5
Utrecht, 3584CC
Netherlands

Prof. Joan Vaccaro
Centre for Quantum Dynamics
Griffith University
170 Kessels Road
Nathan
Australia

Prof. Michael Thorwart
Universität Hamburg
I. Institut für Theoretische Physik
Jungiusstr. 9
20355 Hamburg
Germany

Dr. Andrea Valdés-Hernández
Instituto de Física, Universidad Nacional Autónoma de México
Apartado Postal 20-364
Ciudad de México
Mexico

Prof. Yasuhiro Tokura
University of Tsukuba
1-1-1 Tennodai
Tsukuba, 305-8571
Japan

Prof. Jan van Ruitenbeek
Leiden University
Kamerlingh Onnes Laboratory
Niels Bohrweg 2
2333CA Leiden
Netherlands

Prof. Chikako Uchiyama
University of Yamanashi
4-3-11,Takeda
Kofu
Japan

Dr. Víctor Manuel Velázquez
Facultad de Ciencias, UNAM
Av. Universidad 3000
Mexico
Mexico

Dr. Claudio Verdozzi
Lund University
Professorgatan 1
Lund, 22100
Sweden

Prof. Andrew White
University of Queensland
Physics
Brisbane
Australia

Dr. Denis Vion
CEA Saclay (France)
Orme des merisiers Bd772
F91191 Gif sur Yvette Cedex
France

Mr. Jing Yang
University of Rochester
328 Quinby Rd.
Rochester
USA

Prof. Thomas Vojta
Missouri University of Science and Technology
Department of Physics
1315 North Pine Street
Rolla, MO 65409
USA

Prof. Sun Hyun Youn
Chonnam National University
Yongbongdong
Gwangju
Republic of Korea

Mr. Fritiof Wallentin
International Center for Mathematical Modeling,
Linnaeus University
Rundquists Väg 12
352 20 Växjö
Sweden

Dr. Alexandre Zagoskin
Loughborough University
University Rd.
Loughborough
United Kingdom

Prof. Thomas Walther
TU Darmstadt
Institute for Applied Physics
Schlossgartenstr. 7
Darmstadt
Germany

Prof. Andrei Zaikin
Karlsruhe Institute of Technology
76021
Karlsruhe
Germany

Prof. Rainer Weiss
Massachusetts Institute of Technology, Cambridge
NW22-283,MIT,185 Albany St
Cambridge, 02139
USA

Prof. Gergely Zarand
Budapest Univ. Technology and Economics
Budafoki út 8.
Budapest
Hungary

Dr. Karel Závěta
Institute of Physics, ASCR, v. v. i.
Na Slovance 2
Praha 8
Czech Republic

Prof. Vladimir Zelevinsky
Michigan State University
640 South Shaw Lane Cyclotron
East Lansing
USA

Prof. Wei-Min Zhang
National Cheng Kung University
No.1 University Road
Tainan
Taiwan

Dr. Chao Zheng
North China University of Technology
5 Jinyuanzhuang Road
Beijing 100144
China

Prof. Chun long Zheng
Department of Physics , Shaoguan University
Zhenjiang district university road,288
Shaoguan 512005
China

Conference Site Buildings

Pyramida Hotel

Pyramida Hotel was built in 1980 in the neo-functionalist style with an interesting star-like ground plan and pyramid-like outer shape. During 2010-2013, the hotel was modernized and some rooms were upgraded to business class. The hotel offers a wide selection of conference services.

The Pyramida Hotel is situated in the residential area of Prague called Břevnov near the Prague Castle - see map 'Prague center'. It is in the same time very near the historical center of Prague and Prague international airport - about 20 minutes by car. From the Pyramida Hotel you can reach easily many historical and important places of Prague taking trams No. 22 or No. 23 which have their stops nearly in front of the Pyramida Hotel: Prague Castle within about 5 minutes, Lesser Town is about 10 minutes, Charles Bridge area, too, Old Town and New Town centers (in the vicinity of Old Town Square and Wenceslas Square) within about 20 minutes ride.

Wallenstein Palace

Wallenstein Palace (Valdštejnský palác) is situated in the very center of the Lesser Town in close vicinity of the Lesser Town Square and the Charles Bridge. The origin of the settlement in the Lesser Town is directly linked to Prague Castle, which was founded around 880 AD. The oldest settlement of the future city named Prague was concentrated just to places below the castle. In this area the second town of Prague was later formed: the space between the river of Vltava and Prague Castle was fortified in the 13th century and the Lesser Town was founded in 1257 by the Czech King Přemysl Otakar II.

The Wallenstein Palace was built from 1624 to 1630 as a seat of the Imperial Generalissimo, Admiral of the Atlantic Ocean and the Baltic Sea, Albrecht Eusebius of Valdstein (Wallenstein) who was one of the most important figures of the Thirty Year's War. Apart from being famous as a very influential soldier (Commander-in-Chief of the Imperial Army), Wallenstein is also known for his belief in the influence of the stars. It is a very interesting experience to read personal characterization of Wallenstein in the horoscope written for him personally by Johannes Kepler. This link is not the only one which connects Wallenstein Palace with astronomy and physics: inside the Palace there is the astronomical-astrological corridor with allegories of seven planets, the leading architect who designed the Wallenstein Palace and its Sala Terrena in the huge Baroque garden was Italian Giovanni Battisto Pieronni, a student of Galileo Galilei. When designing the huge palace complex of the Wallenstein Palace, Pieronni (together with two other Italian architects A. Spezza and N. Sebregondi) combined elements of the Late Renaissance with those of the Early Baroque. He also hired the most renowned artists to participate on the art works and decoration of the palace. This resulted in the first Baroque palace complex in Prague which became a really representative and up to date as for fashion seat of Albrecht Wallenstein. By this palace the idea of Wallenstein to express his power and glory by building a magnificent palace whose size and decoration even surpassed those of the Prague Castle, was fulfilled.

To imagine the size of the Wallenstein Palace consider the fact that Wallenstein purchased twenty three houses, three gardens and the municipal brick-kiln to gain the place for his palace. The palace complex has a perimeter of almost 750 meters. It is completely separated from the outside world by walls and concentrated around a landscaped garden and five courtyards. The huge garden is famous for its monumental Baroque Sala Terrena with three open arches as well as for a number of bronze statues of ancient gods by Adriano de Vries. As for the palace rooms, the most famous place there is the Main Hall. This hall reaches to the height of two floors and its dimensions are further enlarged optically by mirror windows.

The Wallenstein Palace is nowadays the seat of the Senate of the Parliament of the Czech Republic.

How to get there:
The entrance to the Wallenstein Palace is from the Wallenstein Square which you can reach within five minutes walk either from tram and underground station Malostranská or from tram station on the Lesser Town Square (Malostranské náměstí) - see map 'Prague Castle and Wallenstein Palace neighborhood'.
Special tram will depart from the Pyramida Hotel to the Malostranská station on Monday afternoon to facilitate FQMT'19 participants transfer. Exact departure time will be announced during the Conference.
Stops Malostranská or Malostranské náměstí can also be reached from the Pyramida Hotel by tram No. 22 (23) - 5th or 6th stop.
Alternatively, you can get to the Wallenstein Palace directly from the Pyramida Hotel within 30-40 minutes of a nice walk - see maps 'Pyramida Hotel - access and nearest neighborhood' and 'Prague Castle and Wallenstein Palace neighborhood'.

National House of Vinohrady

The Neo-Renaissance National House of Vinohrady (Národní dům na Vinohradech) was built in 1894. At the end of 19th century the area of Royal Vinohrady (then an independent town) developed rapidly. The construction of the National House became one the symbols of this development. After its completion the National House of Vinohrady served as theatre and seat of various associations and clubs. Nowadays, it is a center where numerous cultural events, conferences and exhibitions take place.

The National House and the closely situated, neo-Gothic Church of St. Ludmila make prominent buildings of the Náměstí Míru (Peace Square), a main square of this part of Prague.

How to get there:
Special tram will depart from the Pyramida Hotel to the Náměstí Míru tram stop on Wednesday afternoon to facilitate FQMT'19 participants transfer. Exact departure time will be announced during the Conference.

For those who will use an **individual transfer**: The easiest way from the Pyramida Hotel is to use tram No. 22 from Malovanka stop to the Náměstí Míru stop (14 stops, about 30-35 minutes) - see the map ‘National House of Vinohrady’.
Alternatively, e.g. if you want to have a dinner in some restaurant located in the Lesser Town, Old Town or New Town areas, or if your prefer speed over convenience, you can reach the Náměstí Míru by underground (metro) line A. Náměstí Míru is one of the underground station of this line - see the map ‘National House of Vinohrady’. In this case, the total traveling time from the Pyramida Hotel to the National House of Vinohrady (with the change from tram No. 22 (23) to underground A at the Malostranská station) should be about 25 minutes.

Prague Castle, St. Vitus Cathedral

The **Prague Castle**, the ancient seat of Czech sovereigns, now the seat of the president of the Czech Republic, is the most important historical and cultural place of Prague. Its palaces, Saint Vitus Cathedral and churches situated at the hill above the Vltava River represent the symbol of the Czech Lands. These palaces, gardens and churches create the largest castle complex in Europe. You can read more about the Prague Castle in various books on the European and Czech history besides much special literature devoted just to the Prague Castle, its history and architecture.

St. Vitus Cathedral (St. Vitus, St. Wenceslas and St. Adalbert Cathedral in full name) has been always considered to be the most important church of the Czech Lands and intimately related to the history of the Czech state. The coronations of Czech kings took place in it, and many kings are buried there.

How to get there:
Special tram will depart from the Pyramida Hotel to the Pražský Hrad tram stop on Thursday afternoon to facilitate FQMT’19 participants transfer. Exact departure time will be announced during the Conference.
For those who will use an **individual transfer**: From the Pyramida Hotel you can reach the Prague Castle (see maps ‘Pyramida Hotel - access and nearest neighborhood’ and ‘Prague Castle and Wallenstein Palace neighborhood’):

1. either by about 20 minutes walk, starting down along the Bělohorská street (the main street where the Pyramida Hotel is situated)
2. or by tram No. 22 or 23 (1 stop, about 2 minutes) down along Bělohorská street from the stop Malovanka to the stop Pohořelec, from where you can reach the Prague Castle within 15 minutes walk
3. or going by tram No. 22 or 23 (3 stops, 5 minutes) to the Pražský Hrad stop from where you can reach the central part of the Prague Castle by a side entrance within 5 minutes walk.

The St. Vitus Cathedral is situated in the central part of the Prague Castle - see map ‘Prague Castle and Wallenstein Palace neighborhood’.

Strahov Monastery

The **Strahov Monastery** (Strahovský klášter) was founded as a Premonstratensian abbey by Jindřich Zdík, Bishop John of Prague, and Vladislaus II, Duke of Bohemia already in 1143. It is located in Strahov in the vicinity of the Prague castle.

The original monastery has been rebuilt many times. The monks began to build their monastery first of wood, with a Romanesque basilica as the center of all spiritual events in Strahov. The building was gradually completed and the construction of the monastery stone buildings continued, in order to replace the provisional wooden living quarters with permanent stone. In 1258, the monastery was heavily damaged by fire and later renewed.

The monastery continued functioning until the period of the Hussites, when it was attacked and plundered in 1420. Consequently, the monastery took a long time to recover. It was not until the arrival of the abbot Jan Lohelius, who became the abbot of Strahov in 1586, that a turn came about. He devoted all his abilities to the renewal of Strahov. He reconstructed the church, renewed the abbey buildings, established workshops, built a new dormitory and refectory, and had the monastery gardens newly laid out. He regained many of the monastery estates in order to build up the material base of the monastery, providing funds for the institution's maintenance and further development.

In 1612, the new abbot, Kašpar Questenberg, continued in the expensive work started by Lohelius, completed the lower cloisters and prelature, and even erected a new building in the form of St. Elizabeth's Hospital, as well as adding out-buildings and a brewery. The financial account of the costs incurred by his building activities was comparable with such builders as his contemporary Albrecht von Wallenstein.

One of the biggest events in the history of the Premonstratensian order was the transfer of the remains of Norbert of Xanten, the founder of the order, from Magdeburg. The reinterring took place under Questenberg's abbacy. This came about in 1627, and since then the remains of the saintly founder have laid at rest in the abbey church.

The abbey was plundered by troops of the Swedish Empire towards the end of the Thirty Years' War. The church and the library were looted. After the departure of the Swedes, the abbot Kryšpin Fuk had the damaged abbey repaired again.

In 1670 Jeroným Hirnheim, a philosopher and theologian, became the abbot of Strahov. His greatest work, which has survived to the present day, was the building of a new library and the so-called Theological Hall which was completed in 1679. During the 17th and early 18th centuries, other abbots continued in the reconstruction of the monastery. In 1779 Václav Mayer became the abbot. His most outstanding work was the building of the new library now in Classical style. Today it is called the Philosophical Hall.

After 1950, the library was incorporated into the Memorial of National Literature. Following events of 1989 the library was, along with the monastery, returned to the Premonstratensians. The Strahov Library contains over 200,000 volumes, including over 3,000 manuscripts and 1,500 first prints stored in a special depository.

The conference dinner will be held in the summer refectory. The refectory dating back to

1691 was designed by Jean Baptiste Mathey, a Burgundy architect. Along the walls there is a portrait gallery with paintings from the end of the 17th century showing significant personalities of the Strahov Monastery. A rood screen is hung on the walls that was used for reading during meals. The vault is decorated with a fresco by Premonstratensian painter Siard Nosecký (1693-1753) and has the theme "Heavenly Feast of the Righteous with the Christ as the Host" dating 1743-1745.

The conference concert will be held in The Basilica of Assumption of Our Lady. The Basilica was constructed as a triple-aisle Romanesque basilica 56 m long and 22 m wide with a transept and two prismatic towers. This design did not last long, because the church was rebuilt in Gothic style after a fire in 1258. The flat wooden ceiling was replaced by a dome and the Chapel of St Ursula was added to the northern transept. After being plundered by the Hussites, the church was reconstructed in Renaissance style. In 17th century, the basilica was extended westwards and the Chapel of Our Lady of Passau was added to the southern transept. In 1742, the Basilica was severely damaged again, this time during the French bombardment of Prague. The building was given a Baroque overhaul under the leadership of Italian architect Anselmo Lurago, and the fruit of this project is today's church. The basilica nave is 63 metres long, 10 metres wide, and 16 metres high. It ends in an apse, which hosts an altar of marble from Slivenec, made by Lauermann in 1768. There are ten side altars located at the pillars which separate the nave from the transepts. The sculptural work on the main altar was made by Ignác Platzer in 1768.

How to get there:

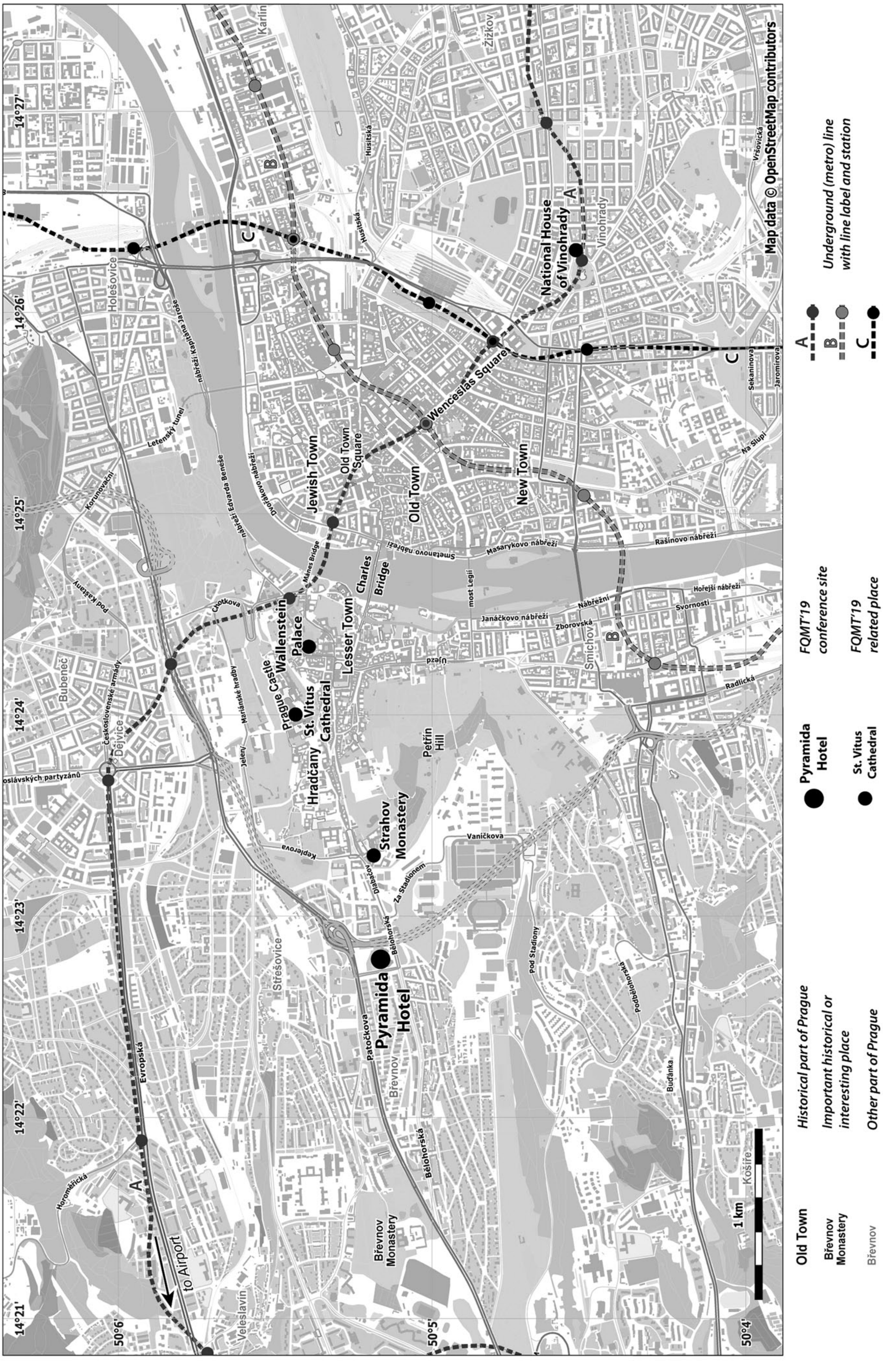
The best way from the Pyramida Hotel is to take a pleasant 10 min walk along the Bělohorská and Dlabačov streets, going left after leaving the hotel. After ca 600 m you will see the narrow road going up to the Strahov Monastery gate.

Alternatively, you can use tram No. 22 or No. 23 (one stop, about 2 minutes) from the stop Malovanka to the stop Pohořelec (towards city center). Then, walk back with respect to the direction in which the tram arrived, cross a wide road and go right using a narrow slightly rising road. After ca 100 m, turn sharply left and you will stand in the front of the Monastery gate.

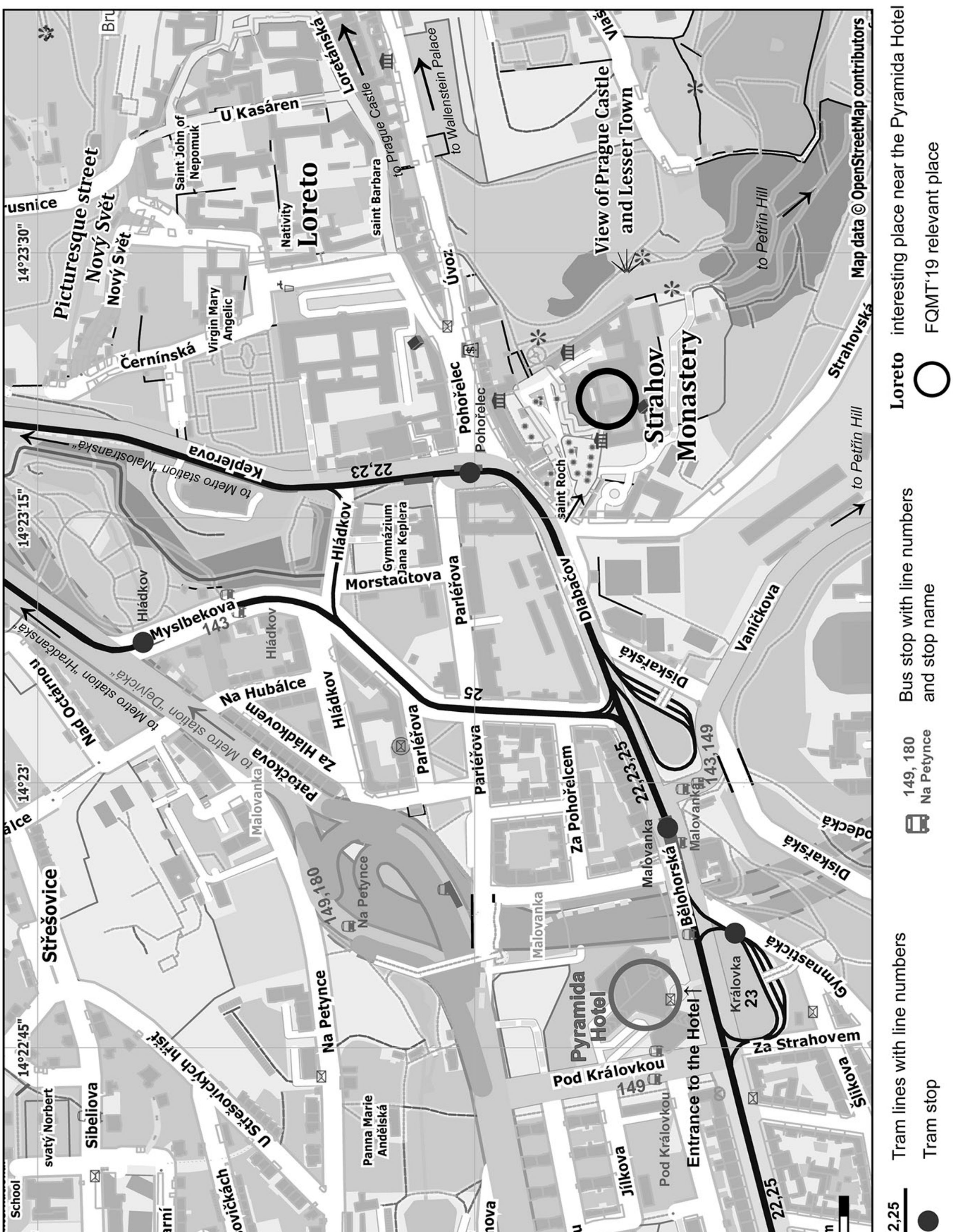
See also map Pyramida Hotel - access and nearest neighborhood

Maps

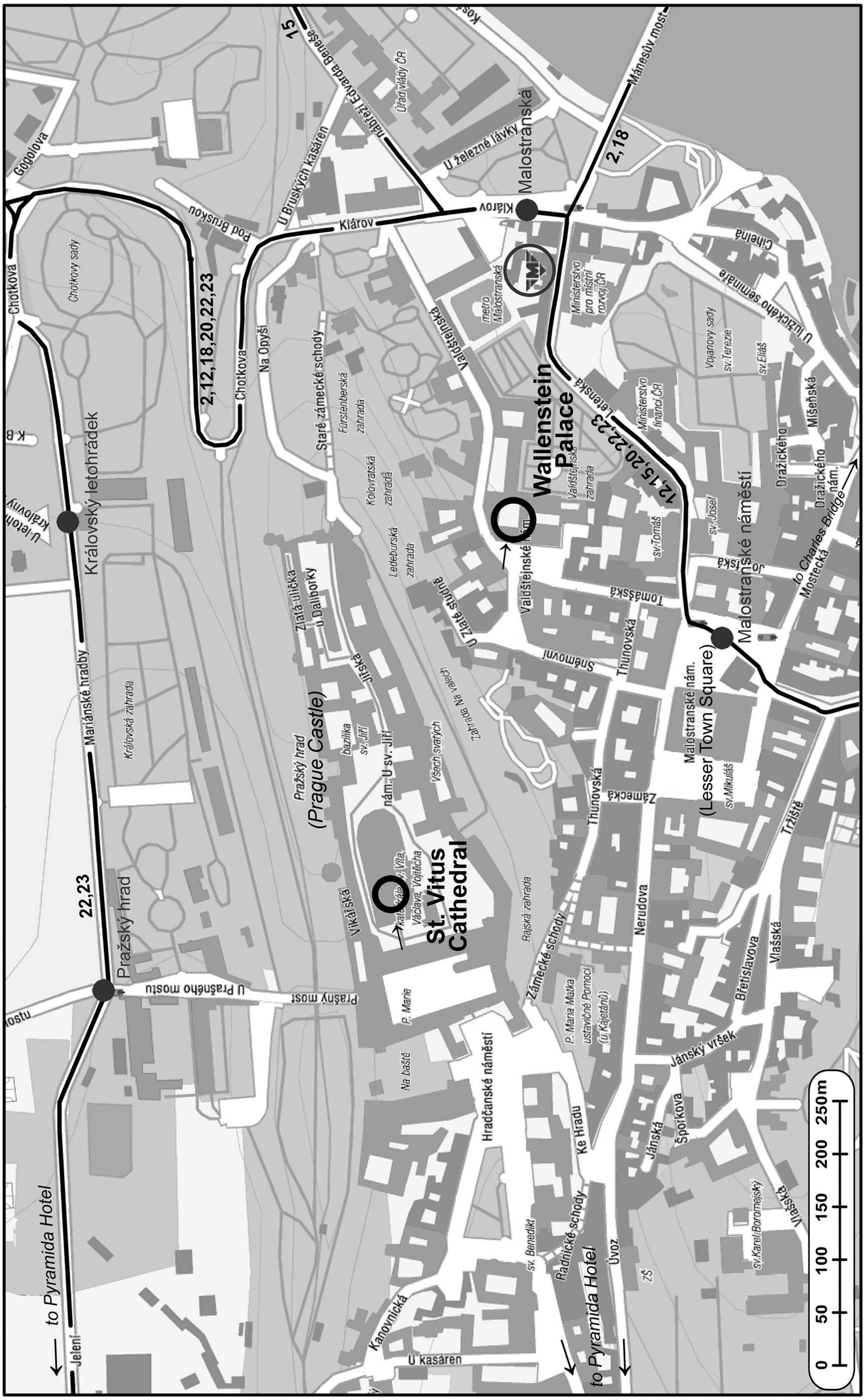
Prague center



Pyramida Hotel - access and nearest neighborhood



Prague Castle and Wallenstein Palace neighborhood



22,23 Tram line with line numbers

Line A underground (= subway, tube, Metro) station

FQMT'19 relevant places

National House of Vinohrady (place of Wednesday's public lectures and concert)