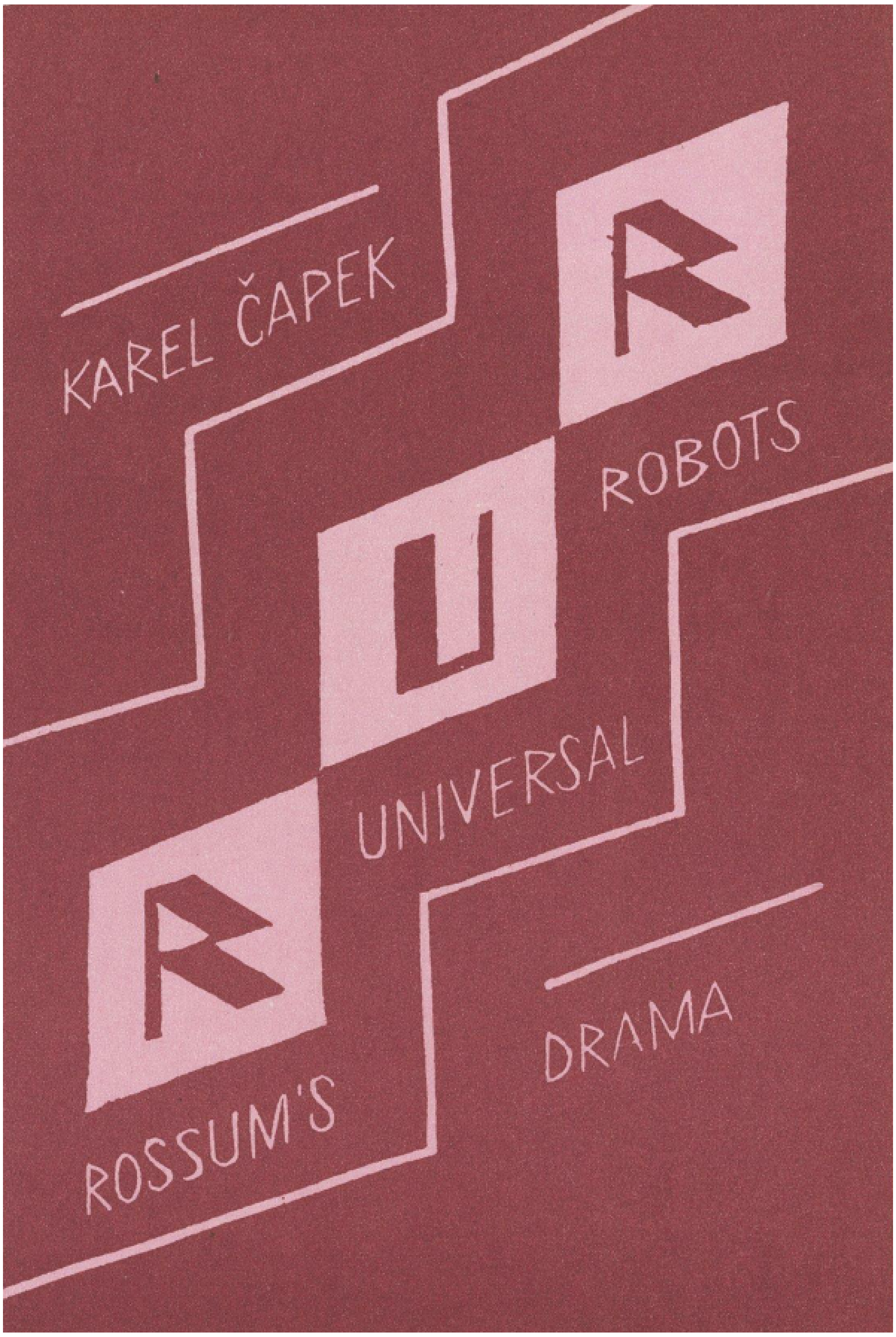
Frontiers of Quantum and Mesoscopic Thermodynamics

21 - 27 July 2024, Prague, Czech Republic



Cover of the first edition of Karel Čapek's play R.U.R., designed by Josef Čapek (Aventinum, Prague, 1920)

Under the auspices of

RNDr. Miloš Vystrčil
President of the Senate of the Parliament of the Czech Republic

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

Supported by

- Committee on Education, Science, Culture, Human Rights and Petitions of the Senate of the Parliament of the Czech Republic
- Institute of Physics, the Czech Academy of Sciences
- Institute for Quantum Science and Engineering, Colleges of Science and Engineering, Texas A&M University, USA
- Institute for Theoretical Physics, University of Amsterdam, the Netherlands
- College of Engineering and Science, University of Detroit Mercy, USA

Topics

- Non-equilibrium quantum phenomena
- Foundations of quantum physics
- Quantum measurement, vacuum, entanglement, coherence
- Dissipation, dephasing, noise and decoherence
- Many body physics, quantum field theory
- Quantum simulations
- Quantum optics
- Optoelectronics, plasmonics
- Imaging, quantum sensors
- Physics of quantum information and computing
- Statistical physics, thermodynamics, quantum heat engines
- Physics of active matter, molecular motors
- Topological states of quantum matter, quantum phase transitions
- Macroscopic quantum behavior, cold atoms and molecules
- Cold atoms and molecules, Bose-Einstein condensates
- Mesoscopic, nano-electromechanical and nano-optical systems
- Biological systems, organoids and quantum biology
- Neural networks, artificial intelligence
- Cosmology, gravitation and astrophysics

Scientific Committee

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Organized by

- Institute of Physics of 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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Preface

FQMT’24 is a follow-up to the nine previous, successful Prague conferences “Frontiers of Quantum and Mesoscopic Thermodynamics” (FQMT’04, FQMT’08, FQMT’11, FQMT’13, FQMT’15, FQMT’17, FQMT’19, FQMT’21, and FQMT’22). For the details of their programs and the history of the FQMT conferences see the www pages https://fqmt.fzu.cz/.

FQMT’24 will thus celebrates double jubilee: The 20th Anniversary of the FQMT conferences and at the same time the FQMT’24 will be the 10th FQMT conference. In the 20 years since the first FQMT conference, the scientific and social program of the conference has changed substantially.

Scientific program of the FQMT’04 conference covered the following, quite limited, number of topics: Quantum, mesoscopic and (partly) classical thermodynamics; Quantum limits to the second law; Quantum measurement; Quantum decoherence and dephasing; Mesoscopic and nanomechanical systems; Classical molecular motors, ratchet systems and rectified motion; Quantum Brownian motion; Quantum motors; Physics of quantum computing; Relevant experiments from the nano- to the macro-scale.

Cultural and social program of the FQMT’04 conference covered only one public lecture, one concert of classical music apart from now traditional FQMT conference welcome party in the Wallenstein Palace garden.

Gradually the number of social events has increased and the FQMT conferences have developed into the event with several public lectures and concerts. The scientific, the fine arts, and the musical programs are intended as a complement to one another, where scientists, artists and musicians are encouraged to mingle and share their knowledge and experience.

The number of topics discussed during the FQMT conferences has also been gradually increasing. Thus the title of the FQMT conference series is now only historical and survives due to tradition. Today its meaning corresponds only partly to the actual topics of the FQMT’24 conference.

The shift to the bigger variety of topics of the FQMT conferences during the last 20 years mirrors the enormous (and fascinating) development of theoretical as well as experimental methods and technologies and their mutual stimulation and improvements. This includes, e.g., more detailed imaging of various structures (including biological ones) and increased observation possibilities in astronomy.

Recent advances in technologies have led to an enormous boost in the possibility to create new, well-defined structures, including e.g. neural networks or organoids, measurement, simulations, sensors, imaging and observation techniques at microscopic, mesoscopic and macroscopic scales. At the same time, various methods allow us to investigate not only equilibrium features of complex many body systems, but also time evolution of these 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.

The present FQMT'24 program will thus be focused on a better understanding of the behavior of quantum systems out of equilibrium, on conceptual and experimental challenges of non-equilibrium statistical physics, quantum many body physics, quantum thermodynamics, quantum optics, physics of quantum information, biophysics, foundations of quantum mechanics, and quantum field theory.

To reach this aim, we seek to improve our understanding of 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.

Following the tradition of the FQMT conferences, FQMT'24 will attempt to bring together a unique combination of both young and experienced scientists across a broad disciplinary spectrum covering the above mentioned topics. The interdisciplinary character of the conference will be supported by the choice of key speakers who are not only able to report specific results within their fields, but can also 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.

As in the foregoing FQMT conferences, the aim of FQMT'24 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. Moreover, the organizers have endeavored to create a program which encompasses all these fields, while simultaneously achieves an “equilibrium” between theoretically and experimentally orientated talks to stimulate discussion between the experimentalists and the theorists as much as possible.

The public lectures will be again the part of the conference program. On Tuesday (July 23) late afternoon there will be a public lecture by Peter Hänggi “The ring of Brownian motion: Its beneficial use for physics and elsewhere”.This lecture will be followed by the two very special lectures complementing each other: The first one by Theo Geisel, a leading expert in the field of non-linear dynamics, on Musical Synchronization and the Secrets of Swing and the second one, Fundamental Aspects of the Physics of Music, by Allen M. Hermann, physicist successfully dealing with a wide range of solid-state topics, who is also an excellent trombone player and professor of jazz music. On Thursday (July 25) evening, there will be the next exceptional lecture: Discoveries with the James Webb Space Telescope by John Mather, the astrophysicist and cosmologist, Nobel Prize laureate, and the key person of the Cosmic Background Explorer and James Webb Space Telescope projects.

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'24 program will feature one concert of jazz music and three concerts of classical music performed by world-class musicians; two of them will be held in exceptionally outstanding venues of the city, in the Gothic Church of Our Lady before Týn, where Tycho Brahe is burried, and in the beautiful Baroque church of the Břevnov Monastery. 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.

On the occasion of the 20th anniversary two special parts of the program will be organized:

1. The special plenary session of the scientific program on Monday afternnon. The speakers of this session will be the physicists who attended already the first FQMT conference and then have visited the FQMT conferences regularly.

2. Taking into account the recently increasing interests in robots and artificial intelligence issues, we will organize an exhibition devoted to the brothers Čapek who introduced to the word 'robot'. The exhibition of some works of Josef Čapek in the Pyramida hotel (he was the foremost Czech painter as well as a writer and journalist and was very instrumental also for texts of his brother) will be accompanied by the exhibition of some books of Karel Čapek. Karel Čapek wrote several influential books dealing with important ethical problems which are especially important nowadays. As already Arthur Miller pointed out: "It is time to read Čapek again for his insouciant laughter and the anguish of human blindness that lies beneath it". Especially significant is the play Rossum's Universal Robots (known worldwide as R.U.R), where the word Robot (designed by Čapek brothers during their discussions about the play) appeared for the first time. As Kurt Vonnegut said about this play: "One of the great plays of the twentieth century by a great writer of the past who speaks to the present in a voice brilliant, clear, honorable, blackly funny and prophetic".

We believe that all participants will enjoy the scientific as well as cultural program of the conference.

Dear colleagues, we welcome you to the FQMT'24 conference and we hope you will enjoy the conference program.

On behalf of the organizers,

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

Contents

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

Important Information

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Emergency phone numbers (free calls):

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

Conference sites

The FQMT'24 conference will take place at the following sites:

Regular talks, the poster session, public lectures and some concerts will take place at:
Pyramida Hotel
address: Bělohorská 24, Praha 6-Břevnov, phone: +420 233 102 111

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

Concert will take place at:
Church of Our Lady before Týn
address: Staroměstské náměstí, Praha 1-Staré Město

Conference dinner and concert will take place at:
Břevnov Monastery
address: Markétská 1/28, 169 00 Praha 6-Břevnov

Limitations related to the Wallenstein Palace

There are some limitations related to the Wallenstein Palace due to the two facts:
1. the Wallenstein Palace is the seat of the Senate of the Czech Republic
2. the Wallenstein Palace is a historical building

Please, read carefully the following text to know about these limitations:

The entrance to the Wallenstein Palace: it is controlled 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 your passport could be an admission problem**.

Rooms and facilities available for the participants

Pyramida Hotel

- Lecture Hall A (ground floor): Plenary and some parallel sessions, the jazz concert, and the public lectures with the concert will be there.
- Lecture Hall B (first floor) and Lecture Hall C (first floor) will 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'24 participants, e.g., study and computer rooms on the first floor.

Posters

Poster session will be held on Thursday July 25, from 4:20 p.m. Posters can be fixed already from 7:30 a.m. on Wednesday on the first floor (corridors) of the Pyramida Hotel and can be exhibited till Friday 9 a.m.

Social events

- Welcome party: Wallenstein Palace Garden, Monday July 22
- Public lecture: Pyramida Hotel Lecture Hall A, Tuesday July 23
  This afternoon lecture will be given by Peter Hänggi.
- Public lectures: Pyramida Hotel Lecture Hall A, Tuesday July 23
  These evening lectures will be given by Theo Geisel and Allen M. Hermann.

- Jazz concert: Pyramida Hotel Lecture Hall A, Tuesday July 23
- Classical concert: Church of Our Lady before Týn, Wednesday July 24
- Public lecture: Pyramida Hotel Lecture Hall A, Thursday July 25
  The evening lecture will be given by John C. Mather.
- Classical concert: Pyramida Hotel Lecture Hall A, Thursday July 25
- Conference dinner: Břevnov Monastery, Friday July 26
- Classical music concert: St. Margaret Church of the Břevnov Monastery, Friday July 26

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 25 EUR.

  or

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

Dinners:

- **Monday:** Welcome party in the **Wallenstein Palace Garden**.
- **Tuesday:** There will be enough time to go for dinner before the evening sessions, either in the Pyramida Hotel or to various restaurants in the vicinity of the Pyramida Hotel.
- **Wednesday:** Refreshment will be provided after the last session.
- **Thursday:** Buffet during the poster session in the **Pyramida Hotel**.
- **Friday:** Conference dinner in **Strahov Monastery**.
  Price: 75 EUR per person - tickets for this dinner will be available during the registration.

PROGRAM

Sunday, 21 July 2024

17:00 – 21:00 Registration and welcome refreshment

Location: Pyramida hotel - lobby

Monday, 22 July 2024

07:50 – 08:20	**Opening address**	
	Location: Pyramida Hotel Lecture Hall A	
08:20 – 09:50	**1 session: Stochastic and quantum thermodynamics**	
	Location: Pyramida Hotel Lecture Hall A	
08:20 – 08:50	Udo Seifert:	*Stochastic thermodynamics: From concepts to model-free inference*
08:50 – 09:20	Eran Sela:	*Measuring stochastic thermodynamics in mesoscopic systems using a quantum work agent*
09:20 – 09:50	Gershon Kurizki:	*Quantum nonlinear thermodynamics from polaritons and spins to black holes*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session: Quantum measurement**	
	Location: Pyramida Hotel Lecture Hall A	
10:10 – 10:40	Andrew N Jordan:	*Quantum Measurement: Theory and Practice*
10:40 – 11:10	Jasper van Wezel:	*Spontaneous unitarity violation as a model for quantum state reduction*
11:10 – 11:40	Dirk Bouwmeester:	*Quantum optomechanics for investigating the collapse of the quantum wave function*
11:40 – 12:10	Yuval Gefen:	*Measurement-assisted quantum cooling*
12:10 – 13:00	Lunch	
13:00 – 15:10	**3 session - A parallel: Quantum dynamics**	
	Location: Pyramida Hotel Lecture Hall A	
13:00 – 13:30	Emanuel Gull:	*Denoising and Extension of Real- and Imaginary-time Green's Functions*
13:30 – 14:00	Michael Bonitz:	*Accelerating nonequilibrium Green functions simulations: the G1-G2 scheme*
14:00 – 14:30	Ilya Sinayskiy: online	*Quantum Simulation of Markovian Open Quantum Systems*

14:30	–	14:50	David Edward Bruschi:	*Towards exact factorization of quantum dynamics via Lie algebras*
14:50	–	15:10	Rafael Sánchez:	*Scattering theory of thermal and thermoelectric diodes*

13:00	–	15:10	**3 session - B parallel : Quantum optics**

Location: Pyramida Hotel Lecture Hall B

13:00	–	13:30	Anil K Patnaik:	*Reconstructing the Quantum State of Photon Propagating Through Atmospheric Turbulence Simulator*
13:30	–	14:00	Radim Filip:	*Quantum non-Gaussian coherence and correlation of light and atoms*
14:00	–	14:30	Maciej A. Nowak: online	*Eikonal formulation of large dynamical random matrix models*
14:30	–	14:50	Matthias Krüger:	*Theory of thermal transport via photons within media*
14:50	–	15:10	Evgeniy Narimanov: online	*The Effective Permittivity of a Composite Material*

13:00	–	15:10	**3 session - C parallel: Many body physics**

Location: Pyramida Hotel Lecture Hall C

13:00	–	13:30	Thomas Vojta:	*Critical Behavior and Collective Modes at the Superfluid Transition in Amorphous Systems*
13:30	–	14:00	Mauro Antezza:	*Spontaneous Breaking of Time Reversal Symmetry and Time-Crystal States in Chiral Atomic Systems*
14:00	–	14:30	Grégoire Ithier:	*Typicality and unconventional stationary states of a system of interacting spinless fermions*
14:30	–	14:50	Clément Sayrin:	*Interacting laser-trapped circular Rydberg atoms*
14:50	–	15:10	Jeremy R Armstrong:	*Static properties of an asymmetric impurity in a dipolar BEC*
15:10	–	15:30	Coffee break	

15:30	–	16:00	**Opening address: 20th Anniversary of the first FQMT conference**

Location: Pyramida Hotel Lecture Hall A

16:00 – 18:00	**4 session: 20th Anniversary of the first FQMT conference**		
	Location: Pyramida Hotel Lecture Hall A		
16:00 – 16:30	Marlan O. Scully: online	*Entanglement in Unruh and Hawking radiation from a quantum optical perspective*	
16:30 – 17:00	Heiner Linke:	*Symmetry-breaking as a tool for increasing power and efficiency in thermal-to-electric energy conversion*	
17:00 – 17:30	Amir O. Caldeira:	*Exact Solution for the Heat Conductance in Harmonic Chains*	
17:30 – 18:00	Peter Hänggi:	*Aspects of Quantum Thermodynamics: Facts, debatable issues and unsolved issues*	

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, 23 July 2024

07:50 – 09:50	**1 session: Nonequilibrium, quantum dynamics**	
	Location: Pyramida Hotel Lecture Hall A	
07:50 – 08:20	Ankerhold Joachim:	*A Universal Framework for Quantum Dissipation: Minimally Extended State Space and Exact Time-Local Dynamics*
08:20 – 08:50	Tapio Ala-Nissilä:	*Unraveling correlation in quantum master equations for open system dynamics*
08:50 – 09:20	Aurel Bulgac:	*Non-Markovian character, irreversibility, and entanglement entropy of real-time quantum many-body dynamics*
09:20 – 09:50	Jens Eisert:	*Typical thermalization*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session: Quantum computing and simulation**	
	Location: Pyramida Hotel Lecture Hall A	
10:10 – 10:40	Richard Jozsa:	*Classically simulatable quantum computations*
10:40 – 11:10	Franco Nori: online	*Machine Learning Techniques Applied to Quantum Physics*
11:10 – 11:40	Giuseppe A. Falci:	*Adiabatic passage in solid state: from ultrastrong coupling to noise sensing*
11:40 – 12:10	P. Zapletal:	*Quantum convolutional neural networks for the recognition of many-body topological phases of matter*
12:10 – 13:00	Lunch	
13:00 – 15:10	**3 session - A parallel: Foundations of quantum mechanics**	
	Location: Pyramida Hotel Lecture Hall A	
13:00 – 13:30	Bryan Dalton: online	*Can quantum theory be underpinned by a non-local hidden variable theory?*
13:30 – 14:00	Ana Maria Cetto:	*Physical explanation for the emergence of the quantum operator formalism and its connection with linear response theory*
14:00 – 14:30	Stephen A. Fulling:	*Detailed Semiclassical Propagators for Simple but Nontrivial Systems*

14:30	–	14:50	Yutaka Shikano:	*On Observer-Dependent Description of Quantum State on Identical Particles*
14:50	–	15:10	Nicole Yunger Halpern:	*Beyond the first law: Peculiarly quantum conservation laws in thermodynamics*

13:00 – 15:10

3 session - B parallel: Quantum dynamics

Location: Pyramida Hotel Lecture Hall B

13:00	–	13:30	Yigal Meir:	*Backaction and Anderson overlap catastrophe in quantum dots*
13:30	–	14:00	Michael Thoss:	*Quantum transport and thermodynamics using the hierarchical equations of motion method*
14:00	–	14:30	Elisabetta Paladino:	*Heat transport in the quantum Rabi model: Universality and ultrastrong coupling effects*
14:30	–	14:50	Mark Mitchison:	*Optimal time estimation and the clock uncertainty relation for Markovian stochastic processes*
14:50	–	15:10	Klaus Ensslin:	*Graphene quantum devices*

13:00 – 15:10

3 session - C parallel: Topological states, Anyons

Location: Pyramida Hotel Lecture Hall C

13:00	–	13:30	Ady Stern: online	*The return of the Anyons - news from the fractional quantum Hall effect*
13:30	–	14:00	Eric Akkermans:	*Topological Defects: Creating and Imaging Quantum Matter*
14:00	–	14:30	Marcelo Lozada-Cassou:	*Impact of nanopore's topology on the electrical double layer and capacitance*
14:30	–	14:50	Flavio Ronetti:	*Finite width of anyons changes their braiding signatures*
14:50	–	15:10	Frédéric Chevy:	*The quasi-1D polaron problem. When is 1D still 1D?*

15:10 – 15:30 Coffee break

15:30 – 16:30

Afternoon session: Public lecture of Peter Hanggi

Location: Pyramida Hotel Lecture Hall A

15:30	–	16:20	Public lecture	
15:30	–	16:20	**Peter Hänggi:**	***The ring of Brownian motion: Its beneficial use for physics and elsewhere***

16:20 – 16:30 Discussion after the lecture of Peter Hanggi

16:30 – 17:45 Free time

17:45 – 22:00 **Evening session: Public lectures of Theo Geisel, Allen Hermann and concert**

Location: Pyramida Hotel Lecture Hall A

17:45 – 18:00 Opening address
18:00 – 18:50 Public lecture
18:00 – 18:50 **Theo Geisel:** ***Musical Synchronization and the Secrets of Swing***
18:50 – 19:00 Discussion after the lecture of Theo Geisel

19:00 – 19:15 Break
19:15 – 20:05 Public lecture
19:15 – 20:05 **Allen Hermann:** ***Fundamental Aspects of the Physics of Music***
20:05 – 20:15 Disscusion after the lecture of Allen Hermann

20:15 – 20:30 Break
20:30 – 22:00 Concert of jazz music

Wednesday, 24 July 2024

07:50	–	09:50	**1 session: Bose Einstein condensation, Gravity, Sensors**	
			Location: Pyramida Hotel Lecture Hall A	
07:50	–	08:20	Vanderlei S. Bagnato:	*Time evolution of a far-from-equilibrium BEC: turbulence, scalability, reversing cascade, and thermalization*
08:20	–	08:50	Ernst Maria Rasel:	*Interferometry with Bose-Einstein condensates in microgravity*
08:50	–	09:20	Hansjörg Dittus:	*Quantum sensors in spacetime*
09:20	–	09:50	Frank Narducci:	*Measuring the period of a pendulum with a tall atom interferometer*
09:50	–	10:10	Coffee break	
10:10	–	12:10	**2 session: Quantum optics, plasmons**	
			Location: Pyramida Hotel Lecture Hall A	
10:10	–	10:40	Wolfgang Schleich:	*Equivalence of Hamiltonians in Atom Optics*
10:40	–	11:10	Ortwin Hess:	*Quantum Coherent Perfect Absorption in Nanoplasmonic Cavities*
11:10	–	11:40	Walter Pfeiffer:	*Quantumness in plasmon assisted multiphoton photoemission*
11:40	–	12:10	Norbert Kroo:	*High field nanoplasmonics (On the way to nuclear fusion)*
12:10	–	13:00	Lunch	
13:00	–	14:40	**3 session - A parallel: Quantum optics**	
			Location: Pyramida Hotel Lecture Hall A	
13:00	–	13:30	Yuri Rostovtsev:	*Correlated quantum photon states generated by vacuum fields*
13:30	–	14:00	Nir Navon:	*Many-body physics with Fermions in an Optical Box*
14:00	–	14:20	Vincenzo Macrì:	*Spontaneous scattering of Raman photons from cavity-QED systems in the ultrastrong coupling regime*

13:00 – 14:40	**3 session - B parallel: Quantum transport**	
	Location: Pyramida Hotel Lecture Hall B	
13:00 – 13:30	Eugene Sukhorukov:	*Charge-conserving equilibration of quantum Hall edge states*
13:30 – 14:00	Alessandro Braggio:	*Nonlocal thermoelectric detection of interaction and correlations in Quantum Hall edge states*
14:00 – 14:20	Efrat Shimshoni:	*New view on the quantum Hall phase diagram of bilayer graphene*
14:20 – 14:40	Michael Kastner:	*Cooling towards a quantum critical point: Universality and scaling in open quantum systems*

13:00 – 14:40	**3 session - C parallel: Quantum structures and dynamics**	
	Location: Pyramida Hotel Lecture Hall C	
13:00 – 13:30	Peter Samuelsson:	*Quantum measurement and control of a Maxwell demon in double quantum dots*
13:30 – 14:00	Björn Sothmann:	*Higgs-like pair amplitude dynamics in superconductor-quantum dot hybrids*
14:00 – 14:20	H. B. Chan:	*Controlled asymmetric Ising model implemented with parametric micromechanical oscillators*
14:20 – 14:40	Gergely Zaránd:	*Loss-induced quantum information jet in an infinite temperature Hubbard chain*

14:40 – 15:00 Coffee break

15:00 – 17:10	**4 session - A parallel: Quantum transport**	
	Location: Pyramida Hotel Lecture Hall A	
15:00 – 15:30	Shmuel Gurvitz:	*New approach beyond Floquet to tunneling current under external periodic drive of arbitrary shape*
15:30 – 16:00	Fernando Sols:	*Simultaneous symmetry breaking in spontaneous Floquet states: Floquet-Nambu-Goldstone modes, Floquet thermodynamics, and the time operator*
16:00 – 16:30	Oren Tal:	*Experimental demonstration of an atomic-scale heat pump*
16:30 – 16:50	Thomas L Schmidt:	*Quantum geometry and semiclassical dynamics in inhomogeneous fields*

16:50	–	17:10	Jakub Spiechowicz:	*Effective mass approach to memory in non-Markovian systems*

15:00 – 17:10 **4 session - B parallel: Out of equilibrium systems, Active matter**

Location: Pyramida Hotel Lecture Hall B

15:00	–	15:30	Kimball A Milton: online	*Quantum Self-Propulsion of an Inhomogeneous Object out of Thermal Equilibrium*
15:30	–	16:00	Hartmut Löwen:	*Nonequilibrium phase transitions in active matter*
16:00	–	16:30	Saar Rahav:	*Can auxiliary sites accelerate enzymatic reactions?*
16:30	–	16:50	Daniel M Dantchev:	*On ensemble dependence of fluctuation-induced forces: Exact results for Casimir and Helmholtz forces*
16:50	–	17:10	Ido Siovitz:	*Non-linear excitations and low-energy effective theories of spinor gases far from equilibrium*

15:00 – 17:10 **4 session - C parallel: General physics - models and methods**

Location: Pyramida Hotel Lecture Hall C

15:00	–	15:30	Ofer Biham:	*The distribution of first passage times of random walks on random regular graphs*
15:30	–	16:00	Gianluca Rastelli:	*Entangled photon-pair emission in circuit QED from a Cooper pair splitter*
16:00	–	16:30	Peter Schmitteckert:	*NMR: From Molecules to Spectra*
16:30	–	16:50	Alexandre Zagoskin: online	*Generalized Pechukas-Yukawa formalism for quantum systems with discrete energy spectra*
16:50	–	17:10	Mauro Paternostro:	*Informational steady-states and conditional entropy production in continuously monitored systems*
17:10	–	19:00	Free time and transfer to the Church of Our Lady before Týn	
19:00	–	20:30	**Concert of classical music**	

Location: Church of Our Lady before Týn

Thursday, 25 July 2024

07:50 – 09:50	**1 session: Foundations of quantum physics**	
	Location: Pyramida Hotel Lecture Hall A	
07:50 – 08:20	Thomas Udem:	*Fundamental Physics with atomic Hydrogen*
08:20 – 08:50	Georgi Gary Rozenman:	*Quantum Mechanical and Optical Inspirations in Surface Gravity Water Waves: An Analogy Exploration*
08:50 – 09:20	Fabrizio Piacentini:	*Entanglement-preserving single-pair measurement of the Bell parameter*
09:20 – 09:50	Dana Zachary Anderson:	*Maxwell Matter Waves: Coherence Properties, Generation, and Applications*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session - A parallel: Biophysics**	
	Location: Pyramida Hotel Lecture Hall A	
10:10 – 10:40	Philip Hemmer:	*Engineering Nanodiamonds for Quantum-enhanced Bio-sensing*
10:40 – 11:10	Lev Mourokh:	*VitaCrystallography: Old Approach to New Challenges*
11:10 – 11:40	Yaroslav M. Blanter:	*Electron transport in cable bacteria*
11:40 – 12:10	Václav Špička:	*Physical processes controlling biological neural networks*
10:10 – 12:10	**2 session - B parallel: Thermodynamics**	
	Location: Pyramida Hotel Lecture Hall B	
10:10 – 10:40	Eric Lutz:	*Nonequilibrium thermodynamics of quantum coherence beyond linear response*
10:40 – 11:10	Ewa Gudowska-Nowak: online	*Non-orthogonal eigenvectors, fluctuation-dissipation relations and entropy production*
11:10 – 11:40	David A Kessler:	*Stretched Exponential Relaxation of Weakly-Confined Brownian Particles*
11:40 – 12:10	Gabriele De Chiara:	*Thermodynamics of quantum time crystals*

10:10 – 12:10	**2 session - C parallel: Quantum computing**		
	Location: Pyramida Hotel Lecture Hall C		
10:10 – 10:40	Matthias Zimmermann:	*Quantum computing with continuous quantum systems*	
10:40 – 11:10	Ivan Rungger:	*Modelling non-Markovian noise in superconducting qubits*	
11:10 – 11:40	Paolo Piergentili:	*Low Noise Opto-Electro-Mechanical Modulator for RF-to-Optical Transduction in Quantum Communications*	
11:40 – 12:10	Thomas Walther:	*A scalable quantum key distribution network based on time-bin entanglement - reloaded*	
12:10 – 13:00	Lunch		
13:00 – 14:30	**3 session: Biophysics**		
	Location: Pyramida Hotel Lecture Hall A		
13:00 – 13:30	Michael Thorwart:	*Unraveling quantum coherences in photosynthetic protein complexes at ultralow temperatures*	
13:30 – 14:00	J. M. Rubi:	*Optimal transport of active particles induced by substrate concentration oscillations*	
14:00 – 14:30	Stefan Klumpp:	*Patterns of active filaments*	
14:30 – 14:50	Coffee break		
14:50 – 16:20	**4 session: Non-equilibrium statistical physics**		
	Location: Pyramida Hotel Lecture Hall A		
14:50 – 15:20	Uri Peskin:	*Emergence of Boltzmann subspaces in open quantum systems far from equilibrium*	
15:20 – 15:50	Rudolf Hilfer:	*Statistical Ensembles for Unstable Quantum and Classical Systems*	
15:50 – 16:20	Aneta Stefanovska:	*Stability in multiscale oscillatory systems away from equilibrium*	
16:20 – 18:10	**Poster session and refreshment**		
	Location: Pyramida hotel - first floor		

18:10	–	18:30	Free time

18:30	–	22:00	**Evening session: Public lecture of John Mather and concert**
			Location: Pyramida Hotel Lecture Hall A
18:30	–	18:45	Opening address and music introduction
18:45	–	19:45	Public lecture
18:45	–	19:45	**John C Mather:** ***Discoveries with the James Webb Space Telescope***
19:45	–	20:00	Discussion after the lecture of John Mather
20:00	–	20:30	Break
20:30	–	22:00	Concert of classical music

Friday, 26 July 2024

07:50 – 09:50 **1 session: Topological states, Non-equilibrium physics**

Location: Pyramida Hotel Lecture Hall A

07:50 – 08:20	Wolfgang Belzig:	*Topology, Weyl physics and quartets in multi-terminal superconducting structures*
08:20 – 08:50	Daniele Di Miceli:	*Quantum-anomalous-Hall current patterns and interference in thin slabs of chiral topological superconductors*
08:50 – 09:20	Linda E Reichl:	*Particle-hole thermalization in a composite super and normal conducting nanowire*
09:20 – 09:50	Jian-wei Pan: online	*From multi-photon entanglement to quantum computational advantage*

09:50 – 10:10 Coffee break

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

Location: Pyramida Hotel Lecture Hall A

10:10 – 10:40	Jiří J. Mareš:	*On the Nature of Physical Constants*
10:40 – 11:10	Sreenath K. Manikandan:	*Detecting single gravitons with quantum sensing*
11:10 – 11:40	Yanbei Chen:	*Toward Experimental Signatures of Semi-classical Gravity*
11:40 – 12:10	Gerard Kennedy:	*Blackbody Friction on a Moving Nanoparticle: An Exactly Soluble Model*

10:10 – 12:10 **2 session - B parallel: Nonequilibrium physics**

Location: Pyramida Hotel Lecture Hall B

10:10 – 10:40	Yaroslav Pavlyukh:	*Time-Linear Quantum Transport Simulations: Electroluminescence rectification and high harmonic generation in molecular junctions*
10:40 – 11:10	Frithjof Anders:	*Restoring the continuum limit in the time-dependent numerical renormalization group approach*

11:10	–	11:40	Yasuhiro Utsumi:	*Spin states at the edges of a finite p-orbital helical atomic chain attached to a ferromagnetic substrate*
11:40	–	12:10	Branislav K. Nikolic:	*Schwinger-Keldysh nonperturbative quantum field theory for driven-dissipative spin systems*

10:10	–	12:10	**2 session - C parallel: Quantum thermodynamics**
			Location: Pyramida Hotel Lecture Hall C

10:10	–	10:40	Michael Galperin:	*Quantum Thermodynamics of Nanoscale Molecular Systems.*
10:40	–	11:10	Karen Hovhannisyan:	*Long-time equilibration can determine transient thermality*
11:10	–	11:40	Gerard McCaul:	*Thermal States via Quantum Dynamical Emulation*
11:40	–	12:10	Themistoklis Mavrogordatos:	*Wave-particle correlations and quantum-fluctuation asymmetry in multiphoton Jaynes-Cummings resonances*

12:10	–	13:00	Lunch

13:00	–	14:30	**3 session: Non-equilibrium statistical physics**
			Location: Pyramida Hotel Lecture Hall A

13:00	–	13:30	Doron Cohen:	*Quantum Irreversibility*
13:30	–	14:00	Jürgen T. Stockburger:	*Entropy augmentation through subadditive excess: a sane introduction of irreversibility into micro-dynamics*
14:00	–	14:30	Vlatko Vedral: online	*Emergence of Constructor-Based Irreversibility in Quantum Systems*

14:30	–	14:50	Coffee break

14:50	–	16:50	**4 session: Many body physics, Quantum Hall effect**
			Location: Pyramida Hotel Lecture Hall A

14:50	–	15:20	E.K.U. Gross:	*Mechanisms of decoherence, an ab-initio perspective*
15:20	–	15:50	Christian D. Glattli:	*Probing the 2/3 fractional Quantum Hall edge channel using electronic Hong Ou Mandel shot noise correlation.*

15:50	–	16:20	Thierry Martin:	*Anyon braiding and interferometry in the Fractional Quantum Hall effect*
16:20	–	16:50	Yoram Alhassid: online	*Exploring the Fermi polaron problem with canonical-ensemble quantum Monte Carlo*
16:50	–	18:00	Free time and transfer to Břevnov monastery	
18:00	–	23:00	**Guided tour, conference dinner and concert** *Location: Břevnov Monastery*	
18:00	–	19:00	Guided tour through Břevnov monastery	
19:00	–	19:20	Welcome	
19:20	–	20:30	First part of the conference dinner	
20:30	–	21:30	**Concert of classical music**	
21:30	–	23:00	Second part of the conference dinner	

Saturday, 27 July 2024

08:20 – 09:50	**1 session: Gravity, Cosmology**	
	Location: Pyramida Hotel Lecture Hall A	
08:20 – 08:50	Daine L Danielson:	*Black Holes Decohere Quantum Superpositions*
08:50 – 09:20	Ron Folman and the Atom Chip Group:	*Can a Rock be a Wave? From 100 years of De-Broglie's Wave-Particle Duality, to Quantum-Gravity.*
09:20 – 09:50	John C Mather:	*Discoveries with the JWST, and what comes next*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session: Cold atoms**	
	Location: Pyramida Hotel Lecture Hall A	
10:10 – 10:40	Peter McClintock:	*Experiments on quantum turbulence in superfluid He-4*
10:40 – 11:10	Christopher G Baker:	*Nonlinear hydrodynamics on a chip: wave breaking and multisoliton fission in a superfluid waveflume*
11:10 – 11:30	Milan Radonjić:	*Nanomechanically-induced nonequilibrium quantum phase transition in a Bose-Einstein condensate*
11:30 – 11:50	Nicola Grani:	*Dynamics of vortices in strongly interacting Fermi gases*
11:50 – 12:10	Alberto Imparato:	*A quantum thermodynamics approach to optimization in complex systems*
12:10 – 13:00	Lunch	
13:00 – 15:30	**3 session: General physics**	
	Location: Pyramida Hotel Lecture Hall A	
13:00 – 13:30	James K Freericks:	*A Modernizing View of Heisenberg's Matrix Mechanics*
13:30 – 14:00	Eliahu Cohen:	*Uncertainty relations and flow of time in inertial and non-inertial quantum reference frames*

14:00 – 14:30	Theo M. Nieuwenhuizen:	*How the vacuum explains the Lorentz electron, regular black hole interiors and the dark matter*
14:30 – 15:00	Cyril Elouard:	*Extending the Laws of Thermodynamics for Arbitrary Autonomous Quantum Systems*
15:00 – 15:30	Peter D. Keefe:	*Reflections on the 200th Anniversary of the Second Law*

15:30 – 16:00 **Closing remarks**

Location: Pyramida Hotel Lecture Hall A

Public Lectures

Musical Synchronization and the Secrets of Swing

Theo Geisel

Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany
Bernstein Center for Computational Neuroscience, Göttingen, Germany

It is a widespread opinion that musicians who are interacting together in a performance should perfectly synchronize their timing. This view was challenged for the swing feel, a salient feature of jazz, which has eluded scientific clarification for a century. For much of this period it was considered arcane, arguing that swing can be felt but not explained, until a theory of 'participatory discrepancies' raised the controversial claim that swing is caused by microtiming deviations between different participating musicians [1] and put a question mark on the synchronization of jazz musicians.

In several projects we have clarified the controversy on the central role of microtiming deviations for the swing feel using data analytics [2] and experiments [3,4] in which we manipulated the timing of different instruments and measured the resulting swing feel through ratings of professional jazz musicians. We thereby showed that involuntary random microtiming deviations are irrelevant for swing [3], but found that a particular systematic microtiming deviation between musicians enhances the swing feel and is a key component of swing in jazz [4]. It consists in phase shifts, where downbeats of soloists are slightly delayed with respect to a rhythm section, but offbeats remain strictly in phase.

This effect was unknown to professional jazz musicians, who were able to perceive the differences, but unable to determine their nature. Thus musicians apparently use the effect intuitively and unconsciously, as our data analysis of 456 renowned jazz solos revealed the use of downbeat delays in almost all cases [4].

[1] C. Keil, Cultural Anthropology 2, 275 (1987)

[2] M. Sogorski, T. Geisel, and V. Priesemann, PLoS One 13(1), e0186361 (2018)

[3] G. Datseris, A. Ziereis, T. Albrecht, Y. Hagmayer, V. Priesemann, and T. Geisel, Sci. Rep. 9, 19824 (2019)

[4] C. Nelias, E.M. Sturm, T. Albrecht, Y. Hagmayer, and T. Geisel, Commun. Phys. 5, 237 (2022)

The ring of Brownian motion: Its beneficial use for physics and elsewhere

Peter Hänggi

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

Since the turn of the 20-th century Brownian noise has continuously disclosed a rich variety of phenomena in and around physics. The understanding of this jittering motion of suspended microscopic particles has undoubtedly helped to reinforce and substantiate those pillars on which the basic modern physical theories are resting: Its formal description provided the key to great achievements in statistical mechanics, the foundations of quantum mechanics and also astrophysical phenomena, to name but a few. Recent progress of Brownian motion theory involves the description of relativistic Brownian motion and its impact for relativistic thermodynamics, or its role for fluctuation theorems and symmetry relations in recent developments for equilibrium and nonequilibrium thermodynamics/statistical mechanics.

Although noise commonly is hold as the enemy of order, it in fact also can be of constructive influence. The phenomena of *Stochastic Resonance* and *Brownian motors* present two such archetypes wherein random Brownian dynamics together with unbiased nonequilibrium forces beneficially cooperate in enhancing detection and/or in facilitating directed transmission of information. The applications range from information processing devices in physics, chemistry, and physical biology to new hardware for medical rehabilitation. Particularly, additional nonequilibrium disturbances enable the rectification of haphazard Brownian noise so that quantum and classical objects can be directed along on *a priori* designed routes (such as with Brownian motors). We conclude with an outlook for potential new applications and unsolved issues occurring with the theory of Quantum Brownian and Quantum Thermodynamics.

Fundamental Aspects of the Physics of Music

Allen Hermann

University of Colorado, Department of Physics, Campus Box 390, Boulder (80309-0390), USA

In this lecture, we delve into the production of musical sounds and their organization into Western musical scales, beginning with an examination of the piano keyboard to establish musical nomenclature. For string instruments, wave motion and standing waves are fundamental, as these principles are universal to all instruments. We then explore the historical development of musical scales, starting with Pythagoras in the sixth century B.C.E., who devised a scale based on eight notes between the tonic and the octave, where the octave's frequency is twice that of the tonic. The other notes in this scale are determined by the consonance between the tonic and the fifth. We introduce the just scale, founded on the consonance between the tonic, the third, and the fifth, followed by the tempered scale with equal intervals.

While the physics of string instruments is often intuitive, understanding wind instruments can be more complex. We explain the basic principles of simple tubes, like flutes and clarinets, which can be open at both ends or closed at one end. Brass instruments, such as trumpets and trombones, involve more advanced concepts and typically play higher harmonics, unlike strings and woodwinds that predominantly play the fundamental harmonic. Throughout the lecture, we use real-world and plastic "toy" instruments to demonstrate these concepts, concluding with a jazz performance to illustrate their application.

Discoveries with the James Webb Space Telescope

John C Mather

NASA GSFC, 8800 Greenbelt Road, Greenbelt, MD 20772 USA

The James Webb Space Telescope was launched on Dec. 25, 2021, and commissioning was completed in early July 2022. With its 6.5 m golden eye, and cameras and spectrometers covering 0.6 to 28 μm, Webb is already producing magnificent images and surprises about galaxies, active galactic nuclei, star-forming regions, and planets. It extends the scientific discoveries of the great Hubble, and ties the most distant galaxies to their origin story from the fluctuations of the cosmic microwave background radiation. Scientists are hunting for some of the first objects that formed after the Big Bang, the first black holes (primordial or formed in galaxies), and beginning to observe the growth of galaxies, the formation of stars and planetary systems, individual exoplanets through coronography and transit spectroscopy, and all objects in the Solar System from Mars on out. It could observe a 1 cm^2 bumblebee at the Earth-Moon distance, in reflected sunlight and thermal emission. I will show how we built the Webb, why we study infrared, and the most exciting current discoveries. Webb is a joint project of NASA with the European and Canadian space agencies.

Invited Talks

Topological Defects: Creating and Imaging Quantum Matter

Eric Akkermans, Amit Goft, Yuval Abulafia, and Nadav Orion

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

The tenfold classification of insulators and superconductors provides a useful and elegant framework to study topological features. It allows to characterise quantum materials according to specific symmetries (e.g. time reversal, particle-hole and chiral) and spatial dimension. We show that it is possible to build on demand topological quantum materials by introducing specific and properly tailored defects and textures (e.g vortices, kinks, domain walls, vacancies) so as to navigate on the tenfold classification through modifications of symmetries and of effective spatial dimensions.

To that purpose, we propose a new theoretical framework since spatial defects prevent using the powerful Bloch representation for Hamiltonians. We build upon a deep analogy with the classification of topological defects in thermodynamic phase transitions. This analogy paves the way to a theory for topological phase transitions. While important to predict new topological phases, it is essential to observe them. We show how to directly measure topological numbers by analysing dislocation patterns easily accessible from imaging methods such as STM and resulting from a novel mesoscopic interference effect. Finally, we will show how defect-induced and topologically protected states can be engineered to create and manipulate inter-particle quantum entanglement.

Unraveling correlation in quantum master equations for open system dynamics

Tapio Ala-Nissilä

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Department of Mathematical Sciences, Interdisciplinary Centre for Mathematical Modelling, Loughborough University, Loughborough LE11 3TU, Leicestershire, UK

In this talk I will discuss the range of validity of commonly used quantum master equations for reduced dynamics of open quantum systems [1]. I will use our recently developed correlation picture [2] to unravel the exact form of correlation appearing in such equations [3].

[1] Vasilii Vadimov, Jani Tuorila, Jurgen Stockburger, Tapio Ala-Nissila, Joachim Ankerhold, and Mikko Mottonen, Phys. Rev. B 103, 214308 (2021).

[2] S. Alipour, A.T. Rezakhani, A.P. Babu, K. Molmer, M. Mottonen, and T. Ala-Nissila, Phys. Rev. X 10, 041024 (2020).

[3] A. P. Babu, S. Alipour, A.T. Rezakhani, and T. Ala-Nissila, to appear in Phys. Rev. Res. (2024).

Exploring the Fermi polaron problem with canonical-ensemble quantum Monte Carlo

Yoram Alhassid[1], Shasta Ramachandran[1], and Scott Jensen[2]

[1]*Center for Theoretical Physics, Sloane Physics Laboratory, Yale University, New Haven, Connecticut 06520, USA*
[2]*Department of Physics, University of Illinois, Urbana, Illinois 61801, USA*

The behavior of a mobile impurity that interacts strongly with a Fermi sea, first discussed by Landau, is of fundamental importance in quantum many-body physics. This system has been realized experimentally in ultra-cold atomic Fermi gases with tunable attractive short-range interactions. In the so-called unitary limit of infinite scattering length, there is a crossover from a dressed quasiparticle, known as the Fermi polaron, at low temperatures to a classical Boltzmann gas at high temperatures. As a function of the inverse scattering length at a low temperature, there is a transition from a Fermi polaron to a dressed molecule.

Theoretical explorations of the Fermi polaron have thus far relied mostly on uncontrolled approximations. We carried out controlled calculations of the Fermi polaron thermodynamics [1] using canonical-ensemble auxiliary-field Monte Carlo (AFMC) [2] methods on a discrete lattice and extrapolating to the continuum limit [3,4]. Our canonical-ensemble AFMC methods are particularly suitable for exploring the Fermi polaron by projecting on an N-particle Fermi sea of spin-up particles and on one spin-down particle. The spin-imbalanced Fermi gas has a Monte Carlo sign problem but we find it to be moderate at and beyond unitarity.

We present results for the energy gap and for the contact, a fundamental property of quantum many-body systems with short-range correlations. Our AFMC results for the temperature dependence of the contact at unitarity agree with recent experiments but we find discrepancies between theory and experiment in the dependence of the contact on the inverse scattering length.

[1] S. Ramachandran, S. Jensen, and Y. Alhassid, in preparation (2024).

[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, pp. 267 - 298.

[3] S. Jensen, C. N. Gilbreth, and Y. Alhassid, Phys. Rev. Lett. 124 (2020) 090604.

[4] S. Jensen, C. N. Gilbreth, and Y. Alhassid, Phys. Rev. Lett. 125 (2020) 043402.

Restoring the continuum limit in the time-dependent numerical renormalization group approach

Frithjof Anders

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The continuous coupling function in quantum impurity problems is exactly partitioned into a part represented by a finite-size Wilson chain and a part represented by a set of additional reservoirs, each coupled to one Wilson chain site. These additional reservoirs represent high-energy modes of the environment neglected by the numerical renormalization group and are required to restore the continuum limit of the original problem. We present a hybrid time-dependent numerical renormalization group approach which combines an accurate numerical renormalization group treatment of the nonequilibrium dynamics on the finite-size Wilson chain with a Bloch-Redfield formalism to include the effect of these additional reservoirs. Our approach overcomes the intrinsic shortcoming of the time-dependent numerical renormalization group approach induced by the bath discretization with a Wilson parameter $\Lambda>1$. For the numerical solution of this master equation, a Lanczos method is employed which couples all energy shells of the numerical renormalization group. The presented hybrid approach is applied to the real-time dynamics in correlated fermionic quantum impurity systems.

Maxwell Matter Waves: Coherence Properties, Generation, and Applications

Dana Zachary Anderson

Inflection & University of Colorado, 3030 Sterling Circle, Boulder, USA

This talk introduces a class of matter waves that are temporally coherent, and that are particularly useful for applications such as inertial and other kinds of sensing. The coherence of these waves is of the same type that characterizes electromagnetic fields, such as those associated with a laser or a radio wave emitter. Maxwell's equations tell us that an oscillating electric current gives rise to an oscillating electromagnetic field. Certain ultracold atoms, such as ^{87}Rb, interact through s-wave scattering and repel each other in a manner somewhat reminiscent of the repulsion of identical charges. One wonders if an oscillating current of atoms, then, give rise to something analogous to an oscillating electromagnetic field. The answer is, perhaps surprisingly, "yes". Among the revolutions in physics of the past 50 years was the recognition that Maxwell's equations can be derived from a gauge-field treatment of interacting identical charges. That is, the electromagnetic field is the gauge field associated with interacting massive, charged particles. In the same way, there is a gauge field that can be associated with any set of identical interacting atoms. We refer to this gauge field as the Maxwell matter wave field. We are certainly familiar with matter waves - the de Broglie waves that are the quantum-mechanical wave description associated with massive particles, whose wavelength is inversely proportional to the particle velocity. We show that de Broglie waves are the special case of the Maxwell matter wave field at "DC". The "AC" fields correspond to the coherent matter waves of interest. Our topic of Maxwell matter waves is introduced from a practical perspective to utilize these waves for inertial and other classes of atomic sensors. Methods for generating Maxwell matter waves involve the design of open quantum systems in which energy is supplied by a Bose-Einstein condensate, a triple-well atomic potential introduces nonlinear behavior, in particular gain, and output coupling to the vacuum provides a means of energy dissipation along with the emission of the coherent matter waves.

A Universal Framework for Quantum Dissipation: Minimally Extended State Space and Exact Time-Local Dynamics

Meng Xu, Stockburger Jürgen, and Ankerhold Joachim

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Open quantum systems exchange energy or particles with their environments and constitute a generic setting in all fields of physics. One prevalent scenario involves a system of interest embedded in thermal reservoirs, a situation that is not only of fundamental relevance. Indeed, the optimization and design of advanced quantum technologies demands efficient, versatile, and precise theoretical simulation schemes that go beyond perturbative treatments of the reduced density such as Lindblad and Master equations. Crucial questions are thus: Is it possible to derive a uniform framework in form of an *exact* time-local equation for quantum dissipation that is numerically efficient and applicable for arbitrary bath spectral densities and across the whole temperature range? Can one relate other established approaches to this uniform theoretical framework through 'simple' transformations?

We recently developed a theoretical platform (QD-MESS) which provides positive answers to both questions [1]. It is directly derived from the Feynman-Vernon path integral expression and exploits that the reservoir can be modelled in a mathematically consistent way through a *finite* set of harmonic modes with complex-valued frequencies and complex valued amplitudes. The consequences are far-reaching: In Fock state representation, this leads to an extended version of the Hierarchical Equations of Motion (HEOM) approach for any given bosonic [2, 3] and fermionic [4] noise spectra. Further, equations of motion in phase space, stochastic unravelings, and pseudomode-Lindbladian formulations can be derived via appropriate 'rotations' in Fock space. Recent applications to spin-systems will be discussed.

[1] Meng Xu, V. Vadimov, M. Krug, J. T. Stockburger, and J. Ankerhold, arXiv: 2307.16790 (2023).

[2] Meng Xu, Yaming Yan, Qiang Shi, J. Ankerhold, J. T. Stockburger, Phys. Rev. Lett. 129, 230601 (2022).

[3] Meng Xu, J. T. Stockburger, G. Kurizki, and J. Ankerhold, New J. Phys. 24, 035003 (2022).

[4] Xiaohan Dan, Meng Xu, J. T. Stockburger, J. Ankerhold, Qiang Shi, Phys. Rev. B 107, 195429 (2023).

Spontaneous Breaking of Time Reversal Symmetry and Time-Crystal States in Chiral Atomic Systems

Mauro Antezza

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We present a theoretical study [1] of the interaction between an atom characterized by a degenerate ground state and a reciprocal environment, such as a semiconductor nanoparticle, without the presence of external bias. Our analysis reveals that the combined influence of the electron's intrinsic spin magnetic moment on the environment and the chiral atomic dipolar transitions may lead to either the spontaneous breaking of time-reversal symmetry or the emergence of time-crystal-like states with remarkably long relaxation times. The different behavior is ruled by the handedness of the precession motion of the atom's spin vector, which is induced by virtual chiral-dipolar transitions. Specifically, when the relative orientation of the precession angular velocity and the electron spin vector is as in a spinning top, the system manifests time-crystal-like states. Conversely, with the opposite relative orientation, the system experiences spontaneous symmetry breaking of time reversal symmetry. Our findings introduce a mechanism for the spontaneous breaking of time-reversal symmetry in atomic systems, and unveil an exciting opportunity to engineer a nonreciprocal response at the nanoscale, exclusively driven by the quantum vacuum fluctuations.

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Static properties of an asymmetric impurity in a dipolar BEC

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To understand the relaxation dynamics in closed quantum systems, we investigate the interaction of a impurity with a quantum environment. We present a three-dimensional physical model in which the static impurity is introduced into a Bose-Einstein condensate of dipolar gas. The modified Gross-Pitaevskii equation is solved numerically employing the split-step Crank-Nicolson method. This allows us to calculate various properties of the static impurity, including self-energy and density. Additionally, we investigate the effects of asymmetry by deforming the impurity, leading to variations in density results. Exploring changes in the impurity's orientation for different deformation scenarios yields density results at various angles. The obtained density results reveal interesting non-uniform variations in response to these changes, demonstrating the between the impurity and the surrounding Bose-Einstein condensate of dipolar gas.

Time evolution of a far-from-equilibrium BEC: turbulence, scalability, reversing cascade, and thermalization

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In this presentation, we combine many of the experiments carried out in Brazil related to the production and characterization of a Bose Condensate of Rb atoms, far- from equilibrium. The trapped BEC after excitation, can evolve, promoting a migration of energy/particles from the largest to the smallest scales in a cascade process. We perform temporal excitations that consist of deformation and potential rotation, causing the system to evolve into a turbulent regime. Simulations demonstrated the generation of solitons, vortices, and waves in the sample. Using time-of-flight techniques, we measure the distribution of moments, n(k,t) and from this, we obtain the energy spectrum E(k,t). This allows identifying the inertial regions, where E(k, t) is dependent on the power law (inertial region) characteristic of the turbulent regime, and measuring the energy flow that migrates between the scales and its preservation from the absence of dissipation. We have developed a new way of analyzing the problem by looking at the distribution of lower-moment modes. Using differential equation analysis based on the spatial-time variation of the moment distribution, many properties are determined and compared to the experiment, including the power law relationship with the presence of scalability. The temporal evolution of the moment distribution for the lower modes allows the determination of different intervals where process specifics in the route to equilibration occur. We observe the establishment of turbulence, and it decays, taking the system back to pre-thermalization followed by final thermalization, recovering the condensate in its final conditions. Interpretations are offered for all stages of the time evolution to offer more interpretation to the challenge problem of the time evolution of a non-equilibrium quantum many-particle system.

Nonlinear hydrodynamics on a chip: wave breaking and multisoliton fission in a superfluid waveflume

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In this talk I will present research interfacing cavity optomechanics and superfluid physics for the study of nonlinear wave phenomena.

Building upon our previous work in superfluid optomechanics [1], I will present a novel sensor architecture formed by covering nanofabricated silicon photonic crystal beams with a thin superfluid helium-4 film. This creates an optically addressable quasi-one-dimensional wave tank containing a few femtoliters of superfluid helium, upon which waves can be generated, propagate and be readout.

Superfluid helium's characteristics present a unique opportunity for the study of nonlinear wave propagation. Indeed, thanks to superfluid helium's vanishing viscosity, the depth of the film h can readily be made as small as a few nanometers without wave attenuation–something impossible to do with classical fluids. Our platform thus enables us to generate waves whose aspect ratio (defined as the wavelength over depth λ/h) exceeds 10,000:1, two orders of magnitude larger than that achievable in the world's largest wave tanks and exceeding that of the most extreme terrestrial phenomena such as tsunamis. This, combined with our recently developed ability to engineer strong fountain pressure forces [2], now allows us to combine within a single device high spatial and temporal resolution along with strong actuation capabilities.

Leveraging these unique characteristics, I will show how our superfluid wave tank enables us to generate and measure (within a sub-millimetre-sized device in a laboratory setting) a rich variety of superfluid nonlinear wave phenomena for the first time, including wavebreaking, multisoliton fission and optomechanical dissipative solitons [3] - opening up the way for the study of extreme regimes of nonlinear hydrodynamics on a chip.

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Topology, Weyl physics and quartets in multi-terminal superconducting structures

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Topology ultimately unveils the roots of the perfect quantization observed in complex systems. The 2D quantum Hall effect is the celebrated archetype. Remarkably, topology can manifest itself even in higher-dimensional spaces defined by control parameters playing the role of synthetic dimensions. However, so far, a very limited number of implementations of higher-dimensional topological systems have been proposed, a notable example being the so-called 4D quantum Hall effect. In this talk show how to engineer non-trivial topological signatures like Weyl-nodes in synthetic dimensions created by multi-terminal superconductors and how Berry spectroscopy can be used to extract information about the systems quantum geometry [1]. Furthermore, I will show that mesoscopic superconducting systems can implement higher-dimensional topology and represent a formidable platform to study a quantum system with a purely nontrivial second Chern number [2]. I discuss that these systems also admit a non-Abelian Berry phase. Hence, they also realize an enlightening paradigm of topological non-Abelian systems in higher dimensions. Furthermore, such systems can host exotic topological signatures like tensor monopoles [3]. Finally, I comment on recent experimental progress to implement synthetic dimensions in semiconductor-superconductor heterostructures [4] and the analysis revealing Cooper pair quartet [4].

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The distribution of first passage times of random walks on random regular graphs

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We present analytical results for the distribution of first passage times of random walks (RWs) on random regular graphs (RRGs) [1]. RRGs are random networks, consisting of N nodes, in which all the nodes are of the same degree $c \geq 3$ and the connections are random and uncorrelated. Starting from a random initial node i at time $t = 0$, at each time step $t \geq 1$ an RW hops into a random neighbor of its previous node. For an RW starting from an initial node i, the first-passage (FP) time $T_{\rm FP}$ from i to a target node j is the first time at which the RW visits the target node j. The first-passage time varies between different instances of the RW trajectory. The distribution of first-passage times may depend on the choice of the initial node i and the target node j. In particular, it may depend on the length ℓ_{ij} of the shortest path (also referred to as the distance) between i and j. Averaging over all possible choices of the initial node i and the target node j one obtains the distribution of first-passage times $P(T_{\rm FP} = t)$.

We distinguish between the case in which the first-passage trajectory from the initial node i to the target node j follows the shortest path (SPATH) between i and j and the case in which it does not follow the shortest path (non-SPATH). The SPATH trajectories are characterized by the property that the subnetwork that consists of the nodes and edges along the trajectory is a tree network and the distance ℓ_{ij} between i and j in this subnetwork is the same as in the whole network. The SPATH scenario takes place mainly for pairs of nodes for which the distance ℓ_{ij} is small, while most of the first passage trajectories follow the non-SPATH scenario.

The special case in which the initial node i is also chosen as the target node ($i = j$) is called the first return (FR) problem. The distribution $P(T_{\rm FR} = t)$ of first return times of RWs on RRGs was studied in Ref. [2]. The characteristic time scale of first passage processes (when i and j are not too close to each other) is of order $t \sim N$. Another important event, which occurs at much longer time scales, is the step at which the RW completes visiting all the nodes in the network. The time at which this happens is called the cover time, which scales like $t \sim N \ln N$ [3].

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Electron transport in cable bacteria

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It was recently discovered experimentally that cable bacteria exhibit electric conduction, and that the temperature behaviour of electrical conducnptance is different at high and low temperatures. We show that the main features of this behaviour can be explained using the model of a hopping chain, choosing the hopping rates to be classical Marcus rates at high temperatures and quantum analog of the Marcus expression for low temperatures. There are however some experimental details which are not accounted for in this model and require further investigation.

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Accelerating nonequilibrium Green functions simulations: the G1-G2 scheme

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Full two-time NEGF simulations suffer from a cubic scaling of the CPU time with the simulation duration. Recently we have introduced the G1-G2 scheme that exactly reformulates the Hartree-Fock-GKBA into time-local equations, allowing for a dramatic reduction to time-linear scaling [1]. Remarkably, this scaling is achieved quickly, and also for high-level selfenergies, including nonequilibrium GW and T-matrix appro-ximation [2]. Even the dynamically screened ladder approximation is now feasible [3]. I will present applications to nonequilibrium situations including laser excitation of graphene nanoribbons [4] and ion stopping and neutralization by graphene and TMDC monolayers [5].

The scaling advantage of the G1-G2 scheme comes at a price, and I will discuss how these problems can be solved: i) for strong coupling situations and long simulations, the scheme becomes unstable which can be cured using purification schemes [3,4] ii) It is necessary to store the time-diagonal two-particle Green function which rapidly grows with system size. This can be overcome, for the GW approximation, using a recently developed quantum fluctuations approach [6]. Another promising concept to reduce the simulation size is the use of embedding selfenergies. Here, we demonstrate how the embedding concept can be introduced into the G1-G2 scheme, allowing us to drastically accelerate NEGF embedding simulations [7]. A recent review on the G1-G2 scheme can be found here [8].

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Quantum optomechanics for investigating the collapse of the quantum wave function

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Understanding the apparent collapse of the quantum wave function upon a measurement is still a challenge for modern science. Of course, environment induced decoherence is an important aspect of this problem, but leads to the notion of a multi-universe. Scientists, including Roger Penrose, have argued that the notion of a single universe is restored if there is an additional physical mechanism, possibly including gravity, that underlies the collapse process. This leads to experimentally testable predictions for large mass systems, and we proposed such an experiment many years ago [1].

We will present the experimental progress towards testing the collapse of macroscopic quantum superpositions. We make use of optomechanical systems in order to transfer photon superposition states into macroscopic mechanical superposition states. In multimode optomechanical systems, the mechanical modes can be coupled via the radiation pressure of the common optical mode, but the fidelity of the state transfer is limited by the optical cavity decay. We demonstrate stimulated Raman adiabatic passage (STIRAP) in optomechanics, where the optical mode is not populated during the coherent state transfer between the mechanical modes, thus avoiding this decay channel [2]. We show a state transfer of a coherent mechanical excitation between vibrational modes of a membrane in a high-finesse optical cavity with a transfer efficiency of 86%. Combined with high mechanical quality factors, STIRAP between mechanical modes can enable generation, storage, and manipulation of long-lived mechanical quantum states, which is important for quantum information science and for the investigation of macroscopic quantum superpositions. A crucial aspect of exploring the quantum regime in optomechanics is the ability to detect individual photons that have been up or down converted in frequency from the optical pump frequency by the absorption or emission of a phonon. This requires a narrow bandwidth optical frequency filter that passes the up or down converted photons while suppressing the pump beam well below the detection-rate of the converted photons. We demonstrate a four coupled cavity filter system that can filter out, with 40% overall detection efficiency, individual photons up or down converted by 1 MHz via optomechanics from a pump source.

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Nonlocal thermoelectric detection of interaction and correlations in Quantum Hall edge states

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Nonequilibrium effects in interacting systems are among the most difficult problems in mesoscopic physics. This is even more crucial in quantum Hall systems where the electronic coherent nature, non-equilibrium features and interactions make the physics very complex[1,2]. Hereafter, we propose the nonlocal thermoelectric response as a direct indicator of the presence of interactions, nonthermal states and the effect of correlations[3]. This is done by assuming a quantum Hall setup where two channels (connected to reservoirs at different temperatures) co-propagate for a finite distance, such that a thermoelectrical response is only expected when the electron-electron interaction mediates heat exchange between the channels. The nonlocal Seebeck response measures the interaction strength. Considering zero-range interactions, we solve the charge and energy currents and noises of a non-equilibrium integrable interacting system, determining the universal interaction-dependent length scale of energy equilibration for a Luttinger liquid. Further, a setup with two controllable quantum point contacts allows thermoelectricity to monitor the interacting system thermalisation as well as the fundamental role of cross-correlations in the heat exchange at intermediate length scales. Finally, the proposed methodology could inspire novel methods in solid-state systems to measure heat currents by direct thermoelectrical conversion of the heat-exchange in electrical current signal.

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Towards exact factorization of quantum dynamics via Lie algebras

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Determining exactly the dynamics of a physical system is the paramount goal of any branch of physics. Quantum dynamics are characterized by the non-commutativity of operators, which implies that the dynamics usually can rarely be tackled analytically. A priori knowledge on the ability to obtain exact results would be of great advantage for many tasks of modern interest, such as quantum computing and quantum control.

We initiate an approach to determine the dimensionality of a Hamiltonian Lie algebra by characterizing its generators. This requires us to develop a new tool to construct sequences of operators that determine the dimension of the algebra itself. Our work is exact and fully general, therefore providing statements on the ultimate ability to exactly control the dynamics or simulate specific classes of physical systems. This work has important implications for theoretical physics, and it aids our understanding of the structure of the Hilbert space, as well as Lie algebras.

Non-Markovian character, irreversibility, and entanglement entropy of real-time quantum many-body dynamics

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In 1872 the Boltzmann introduce an equation which describes the irreversible Markovian dynamics of a classical many-body system in terms of the mass probability where are the coordinates momenta of a "fluid particle." This equation has been extended to quantum many-body systems by Nordheim (1928) and Uehling and Uhlenbeck (1933), by introducing a generalized the collision integral and in the case of quantum systems, where is replaced with the Wigner transform of the one-body density matrix. Either the classical or quantum extension of the Boltzmann equations have an eerie similarity with the Kohn-Sham Time-Dependent Density Functional Theory (TDDFT) equations (extended to fermionic superfluid systems) which are formulated in terms of the one-body density matrix. The main difference between the two formulations is that the quantum Boltzmann equation is formulated in terms of one-body probabilities, while the TDDFT equations are formulated in terms of quantum single-particle amplitudes and thus capable of describing interference and quantum coherence phenomena.

The extension of TDDFT is mathematically equivalent to the time-dependent many-body Schrödinger equation at the one-body density level. The presence of collisions in TDDFT leads to conspicuous a non-Markovian time evolution along with irreversibility and also to quantum entanglement, even though the quantum dynamics is at the same time dissipative, aspect absent in the quantum extension of the Boltzmann equation due to Nordheim and Uehling and Uhlenbeck, which are still widely used in the description of quantum systems, which cannot describe quantum turbulence, when quantum vortices cross and reconnect. I will present several examples of the quantum dynamics of the decay of superfluid vortices in the Unitary Fermi Gas and related phenomena in nuclear systems.

Exact Solution for the Heat Conductance in Harmonic Chains

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We present an exact solution for the heat conductance along a harmonic chain connecting two reservoirs at different temperatures. In this model, the end points correspond to Brownian particles with different damping coefficients. Such analytical expression for the heat conductance covers its behavior from mesoscopic to very long one-dimensional quantum chains and validates the ballistic nature of the heat transport in the latter example. This implies the absence of the Fourier law for classical and quantum harmonic chains. We also provide a thorough analysis of the normal modes of system which helps us to satisfactorily interpret these results.

Physical explanation for the emergence of the quantum operator formalism and its connection with linear response theory

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To address the question of the physical origin of the quantum operator formalism, we follow the approach of stochastic electrodynamics by considering the interaction of matter with the full radiation field, including the zero-point field. We take an atomic system in a stationary state and analyze in detail its linear, resonant response to the driving field. A one-to-one relation is established between the (c-number) response variables and the corresponding operators; the Poisson bracket of the response variables with respect to the driving field amplitudes takes the form of the (x.p) commutator, the response coefficients playing the role of matrix elements. The results obtained allow to establish a natural contact with linear response theory at the fundamental quantum level. To account for the order of the response variables, which is reflected in the non-commutativity of the operators, we introduce the concept of ordered covariance, both for the atomic system and for the field.

Controlled asymmetric Ising model implemented with parametric micromechanical oscillators

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We show that coupled parametric oscillators provide a well-controlled and fully characterizable physical system for implementation of the asymmetric Ising model, where two coupled spins affect each other differently. Each resonator is parametrically modulated so that there are two coexisting states of vibrations with phase difference of π. The presence of noise induces switching between the two states. When the oscillators are weakly coupled, the rate of interstate switching is changed. The change is asymmetric if the oscillators are not identical. Using two non-identical oscillators weakly coupled to each other, we demonstrate that detail balance is broken. A probability current emerges in the stationary state.

Toward Experimental Signatures of Semiclassical Gravity

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Testing the quantum nature of gravity in the laboratory has recently become an active field of research. In this talk, I will discuss two theoretical aspects of this research program.

It has been argued that since Newtonian gravity can be incorporated as a term in the Schroedinger equation, its quantumness does not necessarily require the quantization of the gravitational field. In connection to this, Danielson, Satischandran and Wald considered a series of thought experiments, in which the transfer of quantum information via Newtonian gravity can be viewed as information transfer by gravitons. In the most exciting thought experiment, they showed that gravitating static quantum systems near a Killing horizon will undergo quantum decoherence via soft-graviton emission across the horizon. I will discuss how this effect can also be understood as a form of the Unruh effect.

Another aspect of the research program is to explore "classical" theories of gravity, namely whether a classical field theory can be constructed to describe the effect of gravitational interaction between quantum systems, in a way that recovers the phenomenology of classical gravity. I will describe a "causal-conditional formulation" of semiclassical gravity, which is a causality-preserving extension of the nonlinear Schroedinger-Newton theory. I will make connections between this theory and other semiclassical gravity theories (e.g., by Kafri, Taylor and Milburn and by Oppenheim), as well as the Diosi-Penrose and CSL collapse models.

The quasi-1D polaron problem. When is 1D still 1D?

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Quantum simulation requires excellent knowledge of the Hamiltonian governing the behavior of the simulator. In the case of highly correlated systems, recent developments have suggested that usual models are not applicable and that efforts should be focused on the search and understanding of the effective Hamiltonians describing these systems. In this talk, I will discuss this question in the context of the study of one-dimensional systems with strongly correlated fermionic gases. In particular I will discuss how the interplay between interactions and confinement leads to emergent few body interactions that alter the properties of the system with respect to simple model Hamiltonians.

Quantum Irreversibility

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Quantum mechanically, a driving process is expected to be reversible in the quasistatic limit, aka adiabatic theorem. This statement stands in opposition to classical mechanics, where mix of regular and chaotic dynamics implies irreversibility. A paradigm that demonstrates the emergence of a novel regime of "quantum irreversibility" is introduced [1]. Specifically, an atomtronic superfuild ring is considered. Initially the ring is at rest, and the condensed bosons have zero momentum. The rotation velocity of the ring is increased gradually from zero to a finite value that is large enough to induce flow. Then, the rotation velocity of the ring is gradually decreased back to zero, and the final energy distribution of the particles is probed.

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Uncertainty relations and flow of time in inertial and non-inertial quantum reference frames

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Uncertainty relations play a crucial role in quantum mechanics [1]. On the one hand, we have shown that the locality of generalized uncertainty relations gives rise to both known and hitherto unknown bounds on quantum correlations [2-4]. On the other hand, in a recent work [5] we have emphasized the relational aspects of position uncertainties, clock uncertainties and their influence on each other within the framework of quantum reference frames. In this talk I will address both local and relational aspects of uncertainty relations trying to reconcile them via a properly defined covariance matrix structure. As constructive examples of this approach I will discuss novel time-energy uncertainty relations [6], the appearance of non-unitarity from the perspective of non-inertial quantum clocks [7] and general consequences regarding entanglement and the relational flow of time.

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Can quantum theory be underpinned by a non-local hidden variable theory?

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The description by a Bell-type non-local hidden variable theory of bipartite quantum states with two observables per sub-system is considered. Bell inequalities [1] of the Collins-Gisin -Liden-Massar-Popescu type [2] which involve combinations of the probabilities of related outcomes for measurements for the four pairs of sub-system observables are derived. It is shown that the corresponding quantum theory expressions violate the Bell inequalities in the case of the maximally entangled state of the bipartitite system. This shows that quantum theory can not be underpinned by a Bell-type non-local hidden variable theory. So as a Bell-type local hidden variable theory has already been shown to conflict with quantum theory, it follows that quantum theory can not be understood in terms of any Bell-type hidden variable theory.

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Black Holes Decohere Quantum Superpositions

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We show that if a massive (or charged) body is put in a quantum superposition of spatially separated states in the exterior of a black hole, the mere presence of the black hole will eventually destroy the coherence of the superposition. This occurs because, in effect, the long-range fields sourced by the body radiate soft gravitons/photons through the horizon, allowing the black hole to harvest "which path" information about the superposition. The electromagnetic decoherence arises only when the superposed particle carries electric charge. However, since all matter sources gravity, the quantum gravitational decoherence applies to all superpositions. We provide estimates of the decoherence time for such quantum superpositions.

Based on [1], [2], [3], and work to appear.

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On ensemble dependence of fluctuation-induced forces: Exact results for Casimir and Helmholtz forces

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Fluctuations are ubiquitous; they unavoidably appear in any matter, either due to its quantum nature or due to the nonzero temperature of the material bodies and of the confined medium. If these fluctuations are correlated in space, the dependence of their spectrum on the relative positions and orientations of the bodies generates an effective force and torque, respectively, acting between them. When the degrees of freedom can enter and leave the region between the interacting objects, one speaks about the Casimir force. In the case of the electromagnetic Casimir force, the medium is the vacuum, and the underlying mechanism is the set of quantum zero point or temperature fluctuations of the electromagnetic field. The now widely-investigated critical Casimir force (CCF) results from the fluctuations of an order parameter and, more generally, the thermodynamics of the medium supporting that order parameter in the vicinity of a critical point. Recently, a review of the exact results available for the CCF has been published in Ref. [1]. In a recent Letter [2], and also in [3] we introduced the terms of a Helmholtz fluctuation-induced force and derived some results for it. It is a force in which an integral quantity of the order parameter value (say, the total magnetization) is fixed. We stress that in customarily considered applications of, say, the equilibrium Ising model to binary alloys or binary liquids, if one insists on full rigor, the case with the order parameter fixed must be addressed. In [2] and [3] via deriving there exact results on the example of Ising chain with fixed magnetization and under periodic and antiperiodic boundary conditions, we have shown that the Helmholtz force has a behavior very different from that of the Casimir force. It is interesting to note that the studied Helmholtz force has a behavior similar to the one appearing in some versions of the big bang theory: strong repulsion at high temperatures, transitioning to moderate attraction for intermediate values of the temperature, and then back to repulsion, albeit much weaker than during the initial period of highest temperature. We stress that the definition and existence of Helmholtz force are by no means limited to the Ising chain and can be addressed, in principle, in any model of interest. We note that the issue of the ensemble dependence of fluctuation-induced forces pertinent to the ensemble has yet to be studied. In the envisaged talk, we will review some recent and present some new both exact and numerical results for the behavior of the Casimir and Helmholtz forces.

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Thermodynamics of quantum time crystals

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Time-translation symmetry breaking is a mechanism for the emergence of non-stationary many-body phases, so-called time-crystals, in Markovian open quantum systems. Dynamical aspects of time-crystals have been extensively explored over the recent years. However, much less is known about their thermodynamic properties, also due to the intrinsic nonequilibrium nature of these phases. Here, we consider the paradigmatic boundary time-crystal system, in a finite-temperature environment, and demonstrate the persistence of the time-crystalline phase at any temperature. Furthermore, we analyze thermodynamic aspects of the model investigating, in particular, heat currents, power exchange and irreversible entropy production. Our work sheds light on the thermodynamic cost of sustaining nonequilibrium time-crystalline phases and provides a framework for characterizing time-crystals as possible resources for, e.g., quantum sensing. Our results may be verified in experiments, for example with trapped ions or superconducting circuits, since we connect thermodynamic quantities with mean value and covariance of collective (magnetization) operators.

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Quantum-anomalous-Hall current patterns and interference in thin slabs of chiral topological superconductors

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The chiral topological superconductor, which supports propagating nontrivial edge modes while maintaining a gapped bulk, can be realized hybridizing a quantum-anomalous-Hall thin slab with an ordinary *s*-wave superconductor [1]-[2]. We show that by sweeping the voltage bias in a normal-hybrid-normal double junction, the pattern of differential conductance and electric currents in the normal leads spans three main regimes [3].
At low bias, the differential conductance is half-quantized to the value $e^2/2h$ and the electric current is localized on the edges, due to the presence of unpaired Majorana edge modes. At intermediate voltages, the current remains edge-localized, but the differential conductance exhibits large oscillations between 0 and e^2/h, produced by interference patterns due to the superconducting pairing. Finally, at large bias, the electric transport becomes diffusive, with electric current propagating through delocalized modes within the bulk of the film.

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Quantum sensors in spacetime

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Matter wave interferometry became an interesting tool for experimental gravitational physics for the last 25 years. On one side, quantum objects might be fundamental for an axiomatic approach to space-time geometry, on the other side matter wave interferometry can enable highly precise experiments to test General Relativity and the limits of possible modified theories.

In particular, the application of quantum sensors on space platforms and satellites under conditions of weightlessness brought up a number of new types of gravitational experiments with increasing accuracy.

The presentation will report on new approaches and goals of future experiments in space.

Typical thermalization

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Proving thermalization from the unitary evolution of a closed quantum system is one of the oldest questions that is still nowadays only partially resolved [1]. Several efforts have led to various formulations of what is called the eigenstate thermalization hypothesis, which leads to thermalization under certain conditions on the initial states. These conditions, however, are sensitive to the precise formulation of the hypothesis.

In the core part of this talk [2], we focus on the important case of low entanglement initial states, which are operationally accessible in many natural physical settings, including experimental schemes for testing thermalization and for quantum simulation. We prove thermalization of these states under precise conditions that have operational significance. More specifically, motivated by arguments of unavoidable finite resolution, we define a random energy smoothing on local Hamiltonians that leads to local thermalization when the initial state has low entanglement. Finally we show that such a transformation affects neither the Gibbs state locally nor, under generic smoothness conditions on the spectrum, the short-time dynamics.

In an outlook of the talk, we will look at new classical simulation methods for long time quantum evolution [3], quantum simulations of non-equilibrium quantum field systems with cold atoms [4] including curved background simulations [5], contributions to a generalised linear response theory [6], and ways of measuring out quasi-local integrals of motion from entanglement [7].

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Extending the Laws of Thermodynamics for Arbitrary Autonomous Quantum Systems

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Recent formulations of the law of thermodynamics encompass the case of single quantum systems coupled to macroscopic energy sources. The latter are generally treated either as ideal work sources (treated as a classical entity via a time-dependent Hamiltonian of the system) or assumed to be pure heat sources starting in a thermal equilibrium state. In contrast, implementations show multiple examples of hybrid sources of work and heat. One can also wonder to which extent one can formulate constraints about the energy exchanges between arbitrary quantum systems starting out of equilibrium, under the form of the laws of thermodynamics.
In [1], we address these questions by considering any quantum system as source of both work and heat. Based on the system's entropy, we identify an effective temperature and the fraction of its energy which is of thermal nature. We show that the variation of this thermal energy plays the same role as heat in a universal microscopic formulation of the second law. The latter is valid for an arbitrary set of quantum systems, initially in any quantum state. On the other hand, we identify general resources stored in the quantum states that differ from thermal equilibrium states. The consumption of these resources is equivalent to work, and allows one e.g. to decrease entropy or to induce heat flows against thermal biases. We use these microscopic notions of work and heat to recover known ideal limits of quantum thermodynamics, but also to explore nanoscale quantum machines where even the energy sources can be single quantum systems.
Our results open perspectives to understand and optimize the energetic performances of autonomous quantum setups, from quantum batteries to in-situ refrigerators.

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Graphene quantum devices

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Bilayer graphene is a promising platform for electrically controllable qubits in a two-dimensional material. In general charge, spin and valley states can be used as a starting point for qubits. Of particular interest is the ability to encode quantum information in the valley degree of freedom, a two-fold orbital degeneracy that arises from the symmetry of the hexagonal crystal structure. The use of valleys could be advantageous, as known spin- and orbital-mixing mechanisms are unlikely to be at work for valleys, promising more robust qubits. The Berry curvature associated with valley states allows for electrical control of their energies, suggesting routes for coherent qubit manipulation. In this talk we report about the characteristic relaxation times of these spin and valley states in gate-defined bilayer graphene quantum dot devices. Different valley states can be distinguished from each other with a fidelity of over 99 percent.. The relaxation time between valley triplets and singlets exceeds 500 ms and is more than one order of magnitude longer than for spin states. We also report about quantum devices such as Josephson junctions and SQUIDs in superconducting twisted graphene layers.

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Adiabatic passage in solid state: from ultrastrong coupling to noise sensing

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INFN, Sezione di Catania

Adiabatic passage is a powerful control technique atomic physics which is gaining interest also in the solid-state realm since it implements quantum operations weri robust against parametric fluctuations. We exploit the application of coherent techniques as coherent transport by adiabatic passage (CTAP) or stimulated Raman adiabatic passage (STIRAP) in quantum architectures where the robustness of the protocols may determine key advantages for selected tasks[1,2]. As an example we discuss quantum operation for modular computing in ultrastrongly coupled structures of artificial atoms [3] showing that CTAP-like manipulation ensure the suppression of unrecoverable errors due to the dynamical Casimir effect. A second example is noise classification in multilevel quantum structures where we propose a STIRAP-based supervised learning procedure to recognize energy-correlations of noise and their relation to the Markovianity of the environment [4].

[1] J. Brown,

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[3] G. Falci, preprint; G. Falci, preprint

[4] Shreyasi Mukherjee, Dario Penna, Fabio Cirinnà, Mauro Paternostro, Elisabetta Paladino, Giuseppe Falci, Luigi Giannelli, Noise classification in small quantum networks by Machine Learning

Quantum non-Gaussian coherence and correlation of light and atoms

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The talk will report recent theoretical and experimental achievements opening the door to highly non-Gaussian quantum states of photons and phonons. This territory is challenging for investigation, both theoretically and experimentally. We will present recent achievements, mainly the experimental tests of climbing the hierarchy of quantum non-Gaussian phononic and photonic states suitable for applications. Particular focus will be on new nonclassical and quantum non-Gaussian coherences, their experimental verification and applications in bosonic quantum sensing and error correction. The talk will conclude with other related results and the following challenges in theory and experiments with atoms, mechanical oscillators and superconducting circuits to stimulate discussion and further development of this advancing and prospective field.

Can a Rock be a Wave? From 100 years of De-Broglie's Wave-Particle Duality, to Quantum-Gravity.

Ron Folman and the Atom Chip Group

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It is almost exactly 100 years since De-Broglie made public his outrageous hypothesis regarding Wave-Particle Duality (WPD), where the latter plays a key role in interferometry. In parallel, the Stern-Gerlach (SG) effect, found a century ago, has become a paradigm of quantum mechanics. I will describe the realization of a half- [1-3] and full- [4-5] loop SG interferometer for single atoms [6], and show how WPD, or complementarity, manifests itself. I will then use the acquired understanding to show how this setup may be used to realize an interferometer for macroscopic objects doped with a single spin [5], namely, to show that even rocks may reveal themselves as waves. I emphasize decoherence channels which are unique to macroscopic objects such as those relating to phonons [7,8] and rotation [9]. These must be addressed in such a challenging experiment. The realization of such an experiment could open the door to a new era of fundamental probes, including the realization of previously inaccessible tests of the foundations of quantum theory and the interface of quantum mechanics and gravity, as well as probing exotic theories. Time permitting, and as an anecdote noting De-Broglie's less popular assertion, that the standard description of QM is lacking, I will also present our recent work on Bohmian mechanics, which is an extension of De-Broglie's ideas on the pilot wave [10].

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A Modernizing View of Heisenberg's Matrix Mechanics

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In 1925, Heisenberg, Born, and Jordan developed matrix mechanics as a strategy to solve quantum-mechanical problems. While finite-sized matrix formulations are commonly taught in quantum instruction, the logic and detailed steps of the original matrix mechanics has become a lost art. In preparation for the 100th anniversary of the discovery of quantum mechanics, we present a modernized discussion of how matrix mechanics is formulated, how it is used to solve quantum-mechanical problems, and how it can be employed as the starting point for a postulate-based formulation of quantum-mechanics. We focus on the harmonic oscillator to describe how quantum mechanics advanced from the Bohr-Sommerfeld quantization condition, to matrix mechanics, to the current abstract ladder-operator approach. We show how experiment motivaties a matrix representation via the Rydberg-Reisz combination principle, how the Ehrenfest theorem is motivated by the correspondence principle, and how just these two postulates allow us to derive the canonical commutation relation. Then by moving from matrices to operators and abstract vectors in a Hilbert space, one can finish thepostulate-based formulation of quantum mechanics with the Born rule and a measurement postulate (the Born rule can be strongly motivated via a simple counting approach). This talk will not focus on a historical treatment of the materials, but instead on how we can revive and use a modernized version of these ideas to make the foundations of quantum mechanics clearer, and experimentally motivated.

Detailed Semiclassical Propagators for Simple but Nontrivial Systems

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When applied to a time-dependent Schrodinger equation, the WKB method yields an approximation to the propagator (Green function) as a sum over classical particle trajectories (paths). This much is well known, but one seldom sees a semiclassical propagator worked out in any particular case. With student assistants I have been examining the details in some simple cases and finding them to be more interesting and difficult than one might expect. (1) For “a ball bouncing off a ceiling” (linearly decreasing potential with a reflecting barrier at the origin), for any choice of initial and final position and elapsed time, there are generically either two paths or none. Thus the solution is a sum of two terms, corresponding to paths that do or don’t bounce off the ceiling. In some regions of phase space the approximation is improved by using initial momentum, not position, as the parameter. The rival propagators can be fairly compared by looking at Gaussian wave packets as initial data. (2) For a “soft wall” (a potential equal to 0 left of the origin and a positive power on the right), the classification of paths is more complicated but is topologically similar for all positive values of the exponent. There are 5 classes of paths. For example, if the particle starts and ends on the left side, there is always a path that stays outside, but sometimes there are two more paths that enter the right side and are kicked back out. Because acceleration in this model is never rightward, a particle cannot visit the right side more than once. For momentum initial data some calculation is needed to determine where the initial position is. In any event the action and amplitude for each path can be computed from the Hamilton-Jacobi and transport equations. Momentum-space and position-space results differ by terms of higher order in Planck’s constant.

Quantum Thermodynamics of Nanoscale Molecular Systems.

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We discuss an energy-resolved variant of quantum thermodynamics for open systems strongly coupled to their baths. The approach generalizes the Landauer-Buttiker inside-outside duality method [Phys. Rev. Lett. 120, 107701 (2018)] to interacting systems subjected to arbitrary external driving. It is consistent with the underlying dynamical quantum transport description and is capable of overcoming limitations of the only other consistent approach [New J. Phys. 12, 013013 (2010)]. We illustrate viability of the generalized inside-outside method with numerical simulations for generic junction models.

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Measurement-assisted quantum cooling

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Cooling a quantum system to its ground state is important for the characterization of non-trivial interacting systems, and in the context of a variety of quantum information platforms. In principle, this can be achieved by employing measurement-based passive steering protocols, where the steering steps are predetermined and are not based on measurement readouts. However, measurements, i.e., coupling the system to auxiliary quantum degrees of freedom, is rather costly, and protocols in which the number of measurements scales with system size will have limited practical applicability. We have identified conditions under which measurement-based cooling protocols can be taken to the dilute limit. For two examples of frustration-free one-dimensional spin chains, we show that steering on a single link is sufficient to cool these systems into their unique ground states. We corroborate our analytical arguments with finite-size numerical simulations and discuss further applications.

Probing the 2/3 fractional Quantum Hall edge channel using electronic Hong Ou Mandel shot noise correlation.

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The physics of the 2/3 edge channel is still awaiting a satisfying physical modeling. Inspiring of validating theoretical models requires the input of new type of experimental information. Here, we go well beyond the traditional DC transport and noise studies and, instead, explore the dynamic of the carriers propagating in along a 2/3 edge. New information is obtained by performing photo-assisted shot noise (PASN) measurements and electronic Hong Ou Mandel (HOM) shot noise measurements by sending GHz microwave excitations on the contacts of a Hall bar with a Quantum Point Contact (QPC) in its middle.

Under weak reflection of the inner channel by the QPC, we combine a DC voltage Vds and the rf excitation to probe the possible voltage reduction V_{QPC}QPC is measured via the Josephson relation using the PASN noise singularity occurring when V_{QPC} obeys the Josephson relation $(e/3)V_{QPC}$=hf [1].

Then, applying the same coherent sine-wave rf excitation on both contacts, but with a time-delay, and measuring the cross-correlated partition noise of e/3 charge in the weak reflection regime, we observe HOM noise oscillations similar to that recently observed on the 2/5 and integer edge channel. The finite but weak visibility observed in these two-particle noise interference measurements suggests the existence of a finite quantum coherence of the 2/3 edge channel [2]. Moreover, sending periodic Leviton-like pulses of small 70ps witdh and 5GHz repetition rate, we observe, from the HOM signal, a large broadening of the pulses. This broadening show evidence of a long predicted charge diffusion mode [3] along the 2/3 edge channel.

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Dynamics of vortices in strongly interacting Fermi gases

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At T=0, vortex dynamics is considered dissipationless and vortices move together with the surronding superfluid. At finite temperature, the presence of both a normal and superfluid componets changes this scenario. Vortex acts as a medium for momentum exchange between the normal and superfluid components, and the dynamics of the vortex is modified [1]. In this framework, vortex dynamics can be described by the dissipative Point Vortex Model (PVM), in which the dissipation effects are described by the dissipative coefficients α and α' [1].

In Fermi superfluids, the vortex core can host so-called Andreev bound states, introducing additional mechanisms for dissipation respect to bosonic superfluids and the theoretical microscopic undestanding of these coefficients is still an open problem in gas superfluids [1,2]. In our experiment, we probe the dissipative vortex dynamics in a homogeneous oblate unitary Fermi gas by creating a single vortex dipole [3]. Owning to our exquisite control of single-vortex position, we study the dynamics by tracking the single-vortex trajectories for different temperatures of the system. We analized the trajectories using the PVM and measure the dissipative coefficients as a function of temperature.

We also observe the time evolution of regular arrays of vortices created by the contact of two counter rotating superfluids, that break into vortex clusters [4]. The observed instability grow rates follow universal scaling relations, predicted by both classical hydrodynamics and PVM, suggesting that the observed vortex dynamics is a manifestation of the underlying unstable flow.

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Mechanisms of decoherence, an ab-initio perspective

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Decoherence, i.e. the phenomenon that quantum systems tend to lose their quantumness due to interactions with other degrees of freedom, is ubiquitous. Most prominently, decoherence is responsible for preventing genuine quantum computing at useful scales to this day. It appears desirable to develop a genuine ab-initio theory of decoherence that allows one to make reliable predictions of decoherence times for a given material, and to gain a microscopic understanding of decoherence with the goal to ultimately find ways to control it. For electrons, the principal source of decoherence is the non-adiabatic interaction with nuclear degrees of freedom, i.e. with an "environment" that is strongly coupled to the electronic subsystem. In the paradigm of electronic-structure theory where electrons move in the static Coulomb potential of clamped nuclei, decoherence is absent. In this lecture, a universally applicable approach to the description of decoherence and, in particular, to the prediction of decoherence times will be presented. We start from the exact factorization [1] of the full electron-nuclear wave function into a purely nuclear part and a correlated many-electron wave function which parametrically depends on the nuclear configuration and which has the meaning of a conditional probability amplitude. This gives the exact electron-nuclear wave function an adiabatic-like appearance while decoherence is fully contained in this wave function. The equations of motion for the two factors are then used to calculate measures of decoherence, such as the purity, from first principles, allowing us to identify different mechanisms of decoherence.

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Non-orthogonal eigenvectors, fluctuation-dissipation relations and entropy production

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Celebrated fluctuation-dissipation theorem (FDT) inking the response function to time dependent correlations of observables measured in the reference unperturbed state is one of the central results in equilibrium statistical mechanics. In this work we discuss an extension of the standard FDT to the case when multidimensional matrix representing transition probabilities is strictly non-normal. This feature dramatically modifies the dynamics, by incorporating the effect of eigenvector non-orthogonality via the associated overlap matrix of Chalker-Mehlig type. In particular, the rate of entropy production per unit time is strongly enhanced by that matrix. We suggest, that this mechanism has an impact on the studies of collective phenomena in neural matrix models, leading, via transient behavior, to such phenomena as synchronisation and emergence of the memory. We also expect, that the described mechanism generating the entropy production is generic for wide class of phenomena, where dynamics is driven by non-normal operators. For the case of driving by a large Ginibre matrix the entropy production rate is evaluated analytically, as well as for the Rajan-Abbott model for neural networks.

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Denoising and Extension of Real- and Imaginary-time Green's Functions

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Response functions of quantum systems, such as electron Green's functions, magnetic, or charge susceptibilities, describe the response of a system to an external perturbation. They are the central objects of interest in field theories and quantum computing and measured directly in experiment. Response functions are intrinsically causal. In equilibrium and steady-state systems, they correspond to a positive spectral function in the frequency domain. Response functions define an inner product on a Hilbert space and thereby induce a positive definite function. The properties of this function can be used to reduce noise in measured data and, in equilibrium and steady state, to construct positive definite extensions for data known on finite time intervals, which are then guaranteed to correspond to positive spectra.

New approach beyond Floquet to tunneling current under external periodic drive of arbitrary shape

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We present a novel approach to analyze the electron tunneling current through a time-dependent barrier under external periodic drive. We derive simple and exact analytic expressions for the current generated by periodic pulses of any shape, going beyond the conventional Floquet expansion. These results remain valid in both the adiabatic and non-adiabatic limits. Our findings explicitly reveal that, in the case of Markovian leads, the tunneling current through the barrier mirrors the oscillations of the barrier with no time delay, indicating zero tunneling time. However, a time delay emerges in the case of non-Markovian leads, although it is not directly associated with the concept of tunneling time. We also apply our method to analyze the time-dependent current in various quantum systems driven by ultra-short (femtosecond and attosecond) pulses. The obtained analytical results proved to be highly relevant to recent experimental developments investigating currents in laser-driven junctions.

Aspects of Quantum Thermodynamics: Facts, debatable issues and unsolved issues

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Thermodynamics at the macroscopic scale, considered at *weak* system-bath coupling, together with its Statistical Mechanics in thermal equilibrium are well established theories, as developed by pioneers such as Gibbs, Einstein, Boltzmann and others. However, recent activities in the thermodynamics of small mesoscopic and nanoscopic systems require new in-depth investigations, such as the equivalence between different ensembles. Moreover, this is also the case for concepts such as *work* or *heat* when taken away from the quasi-static regime. The issue becomes even more intriguing in a quantum setting, such as when studying fluctuation relations or the operation of quantum heat engines.

The state of the art of this quite active field is plagued by many subtleties, pitfalls and inconsistencies; some of which even apply at manifest thermal equilibrium, especially beyond weak system-bath coupling. A major challenge, both theoretical and experimental, is the invasive nature of quantum measurements due to its unavoidable impact on the measured system. This aspect becomes essential when several measurements are performed on one and the same system, as for example for the measurement of quantum work and quantum heat, both requiring measurements of a properly defined energy at the beginning and at the end of the process in question. Fact then is: if anything can be said at all – it must be said as clearly as possible (Wittgenstein, 1889-1951).

My presentation is based on studies carried out in close collaboration with Peter Talkner, also of the University of Augsburg.

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Engineering Nanodiamonds for Quantum-enhanced Bio-sensing

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Diamond color centers like the nitrogen-vacancy (NV) have shown much promise for nanoscale sensing of magnetic and electric fields and temperature. So far however the quantum properties of the NV have not been used to full advantage, for example quantum entanglement of NV qubits has rarely been used for sensing. In this talk I will review recent advances in the fabrication of NVs, and other magnetic color centers in diamond, and in the growth of high quality nanodiamonds. Combining these advances, I will discuss the future prospects of engineering quantum-enhanced sensors in nanodiamonds.

Quantum Coherent Perfect Absorption in Nanoplasmonic Cavities

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Plasmonic nanoresonators offer the unique ability to confine light to extremely sub-wavelength volumes and strongly enhance local optical fields via resonant surface plasmon modes, thereby constituting exceptional architectures for enhanced light-matter interaction and the exploration of extreme nano-optics for quantum dynamics. In particular, room-temperature strong coupling using single molecules and colloidal quantum dots in nanoplasmonic environments has been realized using ultrathin (1 nm) nanoplasmonic cavities [1] and scanning probe tips [2]. While ultrafast plasmonic near-field evolution can be exploited to achieve high-speed quantum operations [3], including dynamic bi [4]- and tripartite [5] entanglement in quantum dots, it is vital to explore pathways for improving the temporal robustness of strongly coupled plasmon-emitter states under ambient conditions, with the aim of realizing truly room-temperature-viable quantum nanophotonic devices.

Here, a novel strategy for selective preparation and, conceivably, 'immortalization' of selected plasmon-exciton polariton states by means of quantum coherent perfect absorption (qCPA) is discussed. It is shown that under plasmonic nanowire-waveguide driving, the qCPA regime can selectively lock a nanocavity-emitter system in either the upper or lower plasmon-emitter polariton state. Furthermore, in this regime, the intrinsic losses of the nanocavity-emitter device can be precisely compensated for, effectively paving the way towards strongly coupled light-matter states that are robust against decoherence at room temperature. This contrasts sharply with the conventional belief that preserving an individual quantum state requires cryogenic cooling andstrict isolation of the system from environmental influence. In fact, here, dynamic dissipation under ambient conditions is fully embraced, strategically harnessing its interplay with plasmon interference in a specific dressed state to establish the qCPA regime itself. As a novel paradigm for quantum state preparation and preservation in plasmonic cavity quantum electrodynamics (cQED), qCPA offers exciting prospects for innovative and room-temperature-viable quantum nanophotonic technologies.

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Statistical Ensembles for Unstable Quantum and Classical Systems

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Unstable quantum and classical systems are defined by Hamiltonians without an additive lower bound of the ground state energy. Such systems exhibit explosive or implosive behaviour, metastability, transient dynamics, non-equivalence of ensembles and non-existence of the thermodynamic limit for Boltzmann-Gibbs ensembles. Unstable systems are non-equilibrium many-body systems in the sense that their statistical and thermal behavour falls outside the domain of applicability of equilibrium thermodynamics and statistical mechanics. Recently [1] the Boltzmann-Gibbs ensembles were generalized and extended to cover unstable systems. Applying the generalized statistical ensembles leads to normal, extensive thermodynamic potential and existence of the thermodynamic limit.

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Long-time equilibration can determine transient thermality

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When two initially thermal many-body systems start to interact strongly, their transient states quickly become non-Gibbsian, even if the systems eventually equilibrate. To see beyond this apparent lack of structure during the transient regime, we use a refined notion of thermality, which we call g-local. A system is g-locally thermal if the states of all its small subsystems are marginals of global thermal states. We numerically demonstrate for two harmonic lattices that whenever the total system equilibrates in the long run, each lattice remains g-locally thermal at all times, including the transient regime. This is true even when the lattices have long-range interactions within them. In all cases, we find that the equilibrium is described by the generalized Gibbs ensemble, with three-dimensional lattices requiring special treatment due to their extended set of conserved charges. We compare our findings with the well-known two-temperature model. While its standard form is not valid beyond weak coupling, we show that at strong coupling it can be partially salvaged by adopting the concept of a g-local temperature.

A quantum thermodynamics approach to optimization in complex systems

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An optimization problem can be translated into physics language as the quest for the energy minimum of a complex system with a Hamiltonian that encodes the problem itself. Stretching the analogy further, the optimization problem can be seen as the controlled cooling of such a complex system so as it lands in a minimum of its complex energy landscape corresponding to the optimal solution of the given problem. I will introduce and discuss two methods for quantum cooling, and thus for optimization, entailing the use of quantum, non-Markovian baths connected to the system of interest. In the first method the bath is prepared in a suitable low energy initial state that efficiently cools down the system of interest. In the second method the bath is measured, and post-measurement excited states of the bath are selected, that correspond to low energy states for the system of interest.

Typicality and unconventional stationary states of a system of interacting spinless fermions

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Since the end of the nineteenth century, statistical physics has allowed understanding the equilibrium and weakly out-of-equilibrium properties of systems made of a large number of particles. In order to provide theoretical predictions, this framework relies on a probabilistic hypothesis defined by the microcanonical ensemble: all accessible states have the same probability of occurrence. Remarkably, this very simple postulate is now put into question by the recent progress in quantum engineering and simulation. Indeed, in experiments displaying phenomena like Many Body Localization, the interplay between disorder and interactions can prevent the emergence of the usual thermodynamical equilibrium [1]. More generally, these kind of experiments ask two fundamental questions: i) is it possible for a closed quantum system to reach a state of local equilibrium despite being at all times globally in a pure state evolving according to the Schrödinger equation? ii) if yes, what are the properties of this equilibrium state? Does it follow the usual prediction of statistical physics or is it unconventional, i.e. involving some new statistical physics yet to be discovered?

In this talk, I will present results obtained on these two questions using random matrix models and focusing on interacting spinless fermions. First, I will describe a “typicality” property, i.e. the self-averaging of the quantities of interest like occupation numbers, which has important implications for analytical and numerical calculations [2,3]. Then I will describe how the crossover towards thermalisation emerges when increasing the interaction strength between particles.

Finally, I will discuss how to calculate a new partition function [4] involving the Many Body Density of States, a quantity which has been eclipsed for a long time by Single or few Body Density of States due to the success of mean field theories and the concept of quasiparticle [5]. Interestingly, this new partition function recovers the Fermi-Dirac distribution as a particular case.

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Quantum Measurement: Theory and Practice

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This talk will give a selective overview of the advances in the field of quantum measurement theory over the past two decades. I will present selected material from our newly published book on quantum measurement, coauthored with Irfan Siddiqi [1]. Topics covered include weak measurements, quantum measurement reversal, quantum trajectories and the stochastic path integral formalism. The theory and practice of quantum measurement will be discussed, including how to build quantum-limited amplifiers, fundamental noise limits imposed on measurement by quantum mechanics, and the design of superconducting circuits. I will conclude with a reflection on where the field is going and what lessons we should take away about what quantum physics is telling us about the external world and our role as observers.

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Classically simulatable quantum computations

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Quantum computing is usually concerned with processes offering computing power beyond that achievable by classical means. Classically simulatable quantum computations offer no such benefit, but as a restricted class of quantum processes, their special features can nevertheless provide striking insights into fundamental questions of the origins of universal quantum computing power, and into practical issues of its implementation and verification. In this talk we will introduce the classically simulatable classes of Clifford computations and matchgate computations, and discuss some insights that they can offer for these issues.

Detecting single gravitons with quantum sensing

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The quantization of gravity is widely believed to result in gravitons – particles of discrete energy that form gravitational waves. But their detection has so far been considered impossible. Here we show that signatures of single graviton exchange can be observed in laboratory experiments. We show that stimulated and spontaneous single-graviton processes can become relevant for massive quantum acoustic resonators and that stimulated absorption can be resolved through continuous sensing of quantum jumps. We analyze the feasibility of observing the exchange of single energy quanta between matter and gravitational waves. Our results show that single graviton signatures are within reach of experiments. In analogy to the discovery of the photo-electric effect for photons, such signatures can provide the first experimental clue of the quantization of gravity.

Cooling towards a quantum critical point: Universality and scaling in open quantum systems

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Signatures of equilibrium phase transitions can be imprinted into the nonequilibrium dynamics of many-body quantum systems, resulting in the emergence of universal scaling laws out of equilibrium, as exemplified by the Kibble-Zurek mechanism. In a similar spirit, but novel setting, I report scaling and universality in open nonequilibrium quantum systems that are cooled towards a quantum critical point. The excess excitation density, which quantifies the degree of adiabaticity of the dynamics, is found to obey scaling laws in the cooling velocity as well as in the initial and final temperatures of the cooling protocol. The scaling laws are universal, governed by the critical exponents of the quantum phase transition. The validity of these statements is shown analytically for a Kitaev quantum wire coupled to Markovian baths, and subsequently argued to be valid under rather general conditions. Remarkably, these results establish that quantum critical properties can be probed dynamically at finite temperature, without even varying the control parameter of the quantum phase transitions.

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Reflections on the 200th Anniversary of the Second Law

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On June 12, 1824, Sadi Carnot published his book, “Reflections sur la puissance motrice du feu et sur les machines propres a developper cette puissance” [1] at the age of 27. At the time, he was a believer in the caloric theory of heat (he would later realize that heat and motion have an interconnection). Nonetheless, he rightly surmised that the highest possible efficiency of a heat engine occurs when it operates according to a cycle in which there is no conduction of heat among the various parts of the engine. In such a situation, the motive power is independent of the working medium and dependent only on the high and low operating temperatures of the engine.

Carnot’s only publication went largely unnoticed until after his death in 1832. But discovered it was, and while Carnot never articulated the Second Law, he nevertheless became acknowledged as its founding father.

The Second Law of Thermodynamics remains to this day a mysterious, inviolable, fundamental law of nature.

The talk will conclude with an example of how even quantum systems cannot escape the mandates of the Second Law.

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Blackbody Friction on a Moving Nanoparticle: An Exactly Soluble Model

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Quantum electromagnetic field fluctuations can induce a frictional force on a neutral but polarisable particle that is moving uniformly through free space filled with blackbody radiation. If the particle has purely real intrinsic polarisability, before being dressed by radiation, the only dissipative mechanism is through its interaction with the radiation field fluctuations. In this case, the particle is guaranteed to be in the non-equilibrium steady state (NESS), where it absorbs and emits energy at the same rate. However, if the particle is intrinsically dissipative, the corresponding intrinsic dipole fluctuations provide a further dissipative mechanism. In this case, the particle can be out of NESS, where it gains or loses net internal energy; indeed, it will be in NESS only if its temperature is equal to a special NESS temperature, which is a function both of its velocity and of the temperature of the blackbody radiation. Using a Lorentz oscillator model for a spherical nanoparticle, we obtain exact analytical expressions for the frictional force that the particle experiences and for the net radiation power that it absorbs. The frictional force and the NESS temperature derived from these analytical expressions are compared with corresponding numerical results for the case of a gold nanosphere.

Stretched Exponential Relaxation of Weakly-Confined Brownian Particles

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Stretched-exponential relaxation is a widely observed phenomenon found in ordered ferromagnets as well as glassy systems. One modeling approach connects this behavior to a droplet dynamics described by an effective Langevin equation for the droplet radius with an $r^{2/3}$ potential. Here, we study a Brownian particle under the influence of a general confining, albeit weak, potential field that grows with distance as a sublinear power law. We find that for this memoryless model, observables display stretched-exponential relaxation. The probability density function of the system is studied using a rate-function ansatz. We obtain analytically the stretched-exponential exponent along with an anomalous power-law scaling of length with time. The rate function exhibits a point of nonanalyticity, indicating a dynamical phase transition. In particular, the rate function is double valued both to the left and right of this point, leading to four different rate functions, depending on the choice of initial conditions and symmetry

Patterns of active filaments

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Biological structures are often based on filamentous structures, the most important example being the cytoskeleton, a composite network of several filamentous elements, namely microtubules, actin filaments and intermediate filaments. These filaments have length of several to tens of microns and nanometer-size diameters. Importantly such filament are typically active, e.g. because they are driven by molecular motors as in the case of microtubules and actin filaments. This results in a variety of non-equilibrium structures and in unusual rheological properties. On larger scales, filamentous bacteria with lengths of hundreds of microns and diameters of the order of one micron provide other examples for active filaments, due to their larger size more easily accessible to microscopy. These filaments can also active due to their motility such as, for example, gliding on surfaces. In dense monolayers, they form intriguing patterns including nematic order and larger spools or spirals.

High field nanoplasmonics (On the way to nuclear fusion)

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Surface plasmon polaritons are the light of the nanoworld, with a broad spectrum of special properties. These properties open the field for a high number of applications, both in the fields of low and high intensities. The present lecture summarizes the plasmonic properties of localized (LSPP) plasmons. They play asignificant role in many high field applications. Here a special appllication of localized surface plasmons is presented. These plasmons are resonantely excited by ultrashort (n.10 fs) , high intensity (up to n.10^{17} W/cm^2) pulses of a Ti:Sa laser on resonant gold nanoparticles, implanted into a transparent polymer, creating craters in the studied samples. The volume of these craters, produced by the laser pulses in clean and gold nanoparticles implanted polymers has been studied as the function of the exciting laser intensity. Simultaneously the C-H and C-D oscillation Raman scattering lines were also measured on the crater surfaces. Preliminary data indicate fusion energy production due to the nuclear trasmutation (hydrogen to deuterium) in the nanoparticle seeded sample, already at these "relatively low" laser intensities, clearly proving the decisive role of different properties (screening and accelerating protons) of the LSPP-s in both observed phenomena. The roughness, attributed to the nuclear processes on the crater surface is also analyzed. Preliminary data of other techniques (optial and mass spectrometry and some nuclear methods) are also shown. Some results on modelling are also presented.

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Theory of thermal transport via photons within media

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It is well known that photons can cause thermal transport between *isolated* bodies, i.e., via near- and far-field thermal radiation. In contrast, thermal transport *within* media by photons is hardly explored, as it is typically exceeded by other mechanisms, such as electronic or phononic contributions. Furthermore, theoretically determining photonic energy transport in dissipative media has been found challenging, as it, among other things, requires careful treatment of Poynting's theorem. In this contribution, we derive an exact mesoscopic formalism for thermal transport within dissipative media, circumventing Poynting's theorem [1]. We discuss cases where photonic contributions can be dominant such as an interface that supports traveling surface waves. We compare to recent experiments as well as to approximate approaches, e.g., using the Boltzman transport equation.

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Quantum nonlinear thermodynamics from polaritons and spins to black holes

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We introduce a paradigm change in quantum thermodynamics: Instead of the usual *open systems* coupled to thermal baths, with possible modifications due to coherence effects, we resort to *closed systems* with *nonlinear interactions* between thermal noise channels as work and information resources. Nonlinear interferometers fed by thermal noise and filtered by giant polariton-polariton interactions or light-matter interactions in cavities are shown to act as unique heat engines [1], quantum sensors [2] or quantum microscopes [3]. Black holes are shown to be resources for nonlinear heat engines usable for spaceship propulsion [4]. We further show that quantum measurements can be a "poor man's substitute" for nonlinear work and information resources [5-8].

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Symmetry-breaking as a tool for increasing power and efficiency in thermal-to-electric energy conversion

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Thermoelectric systems, which can directly convert a heat gradient into electric current, typically operate in the linear regime described by a well-defined Seebeck coeficient and figure of merit ZT. In this limit, the ratio of actual maximum power relative to the ideal maximum power, the so-called fill factor (FF), is one quarter. By increasing the FF one can potentially drastically increase the maximum power, but this is only possible in the nonlinear regime of transport and has previously rarely been considered. Fundamental symmetry considerations show that the leading order non-linear terms that can increase the FF require devices with broken spatial symmetry. To experimentally demonstrate such a system, we studied nonlinear, thermoelectric transport across an asymmetric energy barrier epitaxially designed in a single semiconductor nanowire and show that we can use symmetry breaking to both increase and decrease the fill factor.

The results will be presented in the context of longterm work to use mesoscopic energy filtering to increase the performance of thermoelectric energy conversion, and I will highlight the potential use of these results in hot-carrier photovoltaics.

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Nonequilibrium phase transitions in active matter

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While ordinary materials are typically composed of inert ”passive” particles, active matter comprises objects or agents which possess an intrinsic propulsion. Examples are living systems like schools of fish, swarms of birds, pedestrians and swimming microbes but also artificial particles equipped with an internal motor such as robots and colloidal Janus particles. In this talk the statistical mechanics of synthetic artificial self-propelled colloidal particles [1] and possible nonequilibrium phase transitions are discussed and the importance of inertia is highlighted [2,3]. Finally, quantum active matter [4] and its thermodynamic consequences will be proposed. The latter describes ultracold atoms in space-time correlated optical fields.

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Impact of nanopore's topology on the electrical double layer and capacitance

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The electrolyte structure inside and outside of nanopores immersed into a bulk electrolyte is analytically obtained [1]. Three different nanopore topologies are studied, i.e., planar, cylindrical, and spherical. The nanopores are model as nanocavities of wall thickness, d, with equal surface charge density, σ_0, on both surfaces of the nanopores. The electrolyte is model as a point-ion symmetrical electrolyte, at a given concentration, ϱ_0. The dielectric constant of the fluid and the nanopores are taken to be equal to avoid image potentials. The nanopores are considered as electrodes, not directly connected to a power source. The electrical double layer inside and outside the nanopores are attained through the analytical solution of the corresponding linearized Poisson-Boltzmann equation. Thus, analytical formulas for the mean electrostatic potential, electrolyte's reduced concentration, and electrical field profiles, are exhibited. In particular, analytical expressions for the nanopore's differential capacitances are presented. The nanopores are treated as permeable, so the electrolyte outside and inside the electrodes are at the same chemical potential. Analogous analytical formulas for solid nano-electrodes are obtained as a corollary of those for nanopores. In particular, their analytical expressions for the differential capacitance here derived are shown to be consistent with the capacitive compactness proposed in the past by one of us [2]. Numerical results of all of the above functions are analyzed as a function of the nanopores geometrical parameters and the electrolyte's temperature and molar concentration. It is found that the spherical topology, at lower temperatures, has the higher differential capacitance. It is demonstrated that for the three nanopore topologies here considered their capacitances reduce to that of a single planar electrode, in the limit of infinitely wide nanopores. The electrical double layer and mean electrostatic potential of the three topologies are in qualitatively agreement with those from the non-linearized Poisson-Boltzmann, hypernetted chain/mean-spherical approximation (HNC/MSA) equations and computer simulations results presented in the past, within the low mean electrostatic potential assumption. Connection of nanopore capacitance with biological, chemical and medical systems is briefly discussed.

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Nonequilibrium thermodynamics of quantum coherence beyond linear response

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Quantum thermodynamics allows for the interconversion of quantum coherence and mechanical work. Quantum coherence is thus a potential physical resource for quantum machines. However, formulating a general nonequilibrium thermodynamics of quantum coherence has turned out to be challenging. In particular, precise conditions under which coherence is beneficial to or, on the contrary, detrimental for work extraction from a system have remained elusive. We here develop a generic dynamic-Bayesian-network approach to the far-from-equilibrium thermodynamics of coherence. We concretely derive generalized fluctuation relations and a maximum-work theorem that fully account for quantum coherence at all times, for both closed and open dynamics. We obtain criteria for successful coherence-to-work conversion, and identify a nonequilibrium regime where maximum work extraction is increased by quantum coherence for fast processes beyond linear response.

Spontaneous scattering of Raman photons from cavity-QED systems in the ultrastrong coupling regime

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We show that spontaneous Raman scattering of incident radiation can be observed in cavity-QED systems without external enhancement or coupling to any vibrational degree of freedom. Raman scattering processes can be evidenced as resonances in the emission spectrum, which become clearly visible as the cavity-QED system approaches the ultrastrong coupling regime. We provide a quantum mechanical description of the effect, and show that ultrastrong light-matter coupling is a necessary condition for the observation of Raman scattering. This effect, and its strong sensitivity to the system parameters, opens new avenues for the characterization of cavity QED setups and the generation of quantum states of light.

On the Nature of Physical Constants

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Undoubtedly, the most important results of physical science are embodied in numerical values of fundamental constants, while the exact experimental determination of these constants is quite essential for checking of the physical theories and establishment of the firm frame for technological measurements, as well. In fact, the fundamental constants represent a rich blend of physical quantities of very different nature, such as conversion factors, characteristics of certain micro-physical objects or interaction coupling constants. Moreover, there are universal constants, such as c (speed of light) and $\hbar$ (Planck's constant), defining for the quantities of the same kind, the unsurmountable upper or lower bound, respectively. Obviously, the ensemble and numerical values of the fundamental constants are closely related to the system of units used. In addition, in modern physics has appeared a strong "objectivization" trend to construct a system of physical units which would be free of anthropic elements. As an example, Planck's system of *natural units* may serve, reputedly retaining its meaning for all times and civilizations. This program was later completed by, among theoreticians very popular, *non-dimensionalization*, i.e. by putting the fundamental constants to dimensionless unity, $\to 1$. In experimental science, this tendency was in 2019 crowned with the re-definition of International System of Units (SI), consisting of the substitution of all *base units*, depending on material realizations (*étalons*), by *defining constants*, i.e. selected fundamental constants with the fixed numerical values. Such epistemologically deep changes in the approach to the physical metrology have inevitably some unexpected aspects and weak points, the discussion of which is the subject of the present contribution.

Anyon braiding and interferometry in the Fractional Quantum Hall effect

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The fractional quantum Hall effect (FQHE) is known to host anyons, quasiparticles whose statistics is intermediate between bosonic and fermionic. We examine scénarios inspired by quantum optics and translated in a condesed matter setting which demonstrate the braiding of anyons. By injecting anyons on the edges of a quantum Hall bar we show that Hong Ou Mandel interferometry allows to determine the scaling dimension of the quasiparticle operator, which is related to the statistics of anyons. This universal width of the Hong Ou Mandel dip can be related to the anyonic braiding of the incoming excitations with thermal fluctuations created at the quantum point contact. We also examine other interferometric devices such as Fabry Perot to illustrate braiding in the time domain.

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Discoveries with the JWST, and what comes next

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The JWST, with its 6.5 m hexagonal mirror and its 4 infrared instruments, has yielded remarkable surprises. The first galaxies are brighter and hotter than expected, and they aren't round, but are elongated into bananas and cigars. Galaxies and even individual stars are frequently found at high redshift, through gravitational lensing. The first black holes we can find are extremely bright and sometimes surrounded by immense clusters of galaxies. Pairs of Jupiter-mass objects (JMBOs) have been discovered in the Orion nebula, upending theories of planet formation. Some new stars are observed in their dusty cocoons, and some with their orbiting disks of dust are observed edge-on, so we can test our stories of formation. Hot, large exoplanet have atmospheres that we measured in transit spectroscopy, but no small planets around M stars have detectable atmospheres, alas for the search for signs of life elsewhere. I will tie the JWST results to cosmological predictions, with galaxies arising from density fluctuations measured with the cosmic microwave background radiation, discuss the effects of cosmic dark matter and dark energy, and consider the future of astronomy. Miraculous discoveries await.

Wave-particle correlations and quantum-fluctuation asymmetry in multiphoton Jaynes-Cummings resonances

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We discuss the conditional measurement of field amplitudes by a non-classical photon sequence in the Jaynes-Cummings (JC) model under multiphoton operation. We do so by employing a correlator of immediate experimental relevance to reveal a distinct quantum evolution in the spirit of [1], relying on the complementary nature of the pictures obtained from different unravelings of the JC master equation. We demonstrate that direct photodetection entails a conditioned separation of timescales [2], a quantum beat and a semiclassical oscillation, produced by the coherent light-matter interaction in its strong-coupling limit. We single the quantum beat out in the analytical expression for the waiting-time distribution, pertaining to the particle nature of the scattered light, and find a negative spectrum of quadrature amplitude squeezing, relevant to its wave nature for certain operation settings. We then jointly detect the dual aspects of the emitted radiation via the wave-particle correlator, showing an asymmetric regression of fluctuations to the steady state [2, 3] which depends on the quadrature amplitude being measured.

More precisely, the application of quantum trajectory theory in parallel with the master equation and quantum regression formula uncovers various aspects of temporal asymmetry in the quantum fluctuations characterizing the cascaded process through which a multiphoton resonance is established and read out. We also find that monitoring different quadratures of the cavity field in conditional homodyne detection affects the times waited between successive photon counter “clicks”, which in turn trigger the sampling of the homodyne current [3]. The individual realizations thus obtained allow the experimenter to access the distribution and statistics of the light field in a regime of single-atom QED where photon blockade persists for a growing system-size parameter [4].

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Thermal States via Quantum Dynamical Emulation

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We introduce the concept of Quantum Dynamical Emulation, a constructive method for mapping the solutions of non-unitary dynamics to a weighted set of unitary operations. This allows us to derive a new correspondence between real and imaginary time, which we term Imaginary Time Quantum Dynamical Emulation (ITQDE). This enables an imaginary time evolution to be constructed from the overlaps of states evolved in opposite directions in real time. We show that a single trajectory evolved using ITQDE can be used not only to infer ground and thermal states, but also to resolve information about the complete Hamiltonian spectrum. We further employ ITQDE to derive novel thermodynamic results, including a generalisation of the Hubbard-Stratonovich transform. We go on to develop a quantum algorithm for computing the spectra of quantum systems that is based on this premise. We demonstrate the utility of this method through numerical simulation, as well as quantum hardware implementations.

Experiments on quantum turbulence in superfluid He-4

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The physical properties of superfluid ^{4}He are dominated by quantised vortices. They are all identical, with a core of sub-atomic radius around which superfluid flows with a circulation of $\kappa = h/m_4$ where h is Planck's constant and m_4 is the ^{4}He atomic mass. Energy dissipation by e.g. a moving object usually occurs through the production of quantised vortices - a process that occurs at critical velocities that are lower by orders of magnitude than the Landau critical velocity needed for the creation of rotons. Free ends do not exist, so vortices either join back on themselves to form continuous loops, or they terminate on the walls of the container or solid objects within it. In the latter case they are "pinned" to protuberances to minimise their length and thus energy. At higher temperatures towards that of the superfluid transition, thermal energy may be sufficient to shake a vortex off its pinning site, in which case it may slide across the surface until it re-pins to another protuberance. There is some evidence [1, 2] that, astonishingly, the vortices may also de-pin at extremely *low* temperatures. We describe an experiment to try to confirm this unexpected phenomenon, and to explore it, if it really exists. The research is based on a novel kind of oscillator [3] in which, in the absence of vortices, the superfluid remains at rest while the cell surfaces move. Both vortex creation, and the dragging of vortex ends across surfaces, will result in energy dissipation which should be detectable through the resultant changes in the frequency and width of the resonance. The experiment will be described and preliminary results will be reported and discussed.

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Backaction and Anderson overlap catastrophe in quantum dots

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In recent years significant experimental and theoretical progress has been made, enabling the measurements of entropy in mesoscopic systems, in the hope of critically testing the existence of exotic quasi-particles, such as Majorana fermions (MFs), in such systems. Some of these measurements rely on the Maxwell relation $\mathrm{dS}/\mathrm{d}\mu = \mathrm{dN}/\mathrm{dT}$, which requires measuring the charge in the system, using a nearby quantum point contact (QPC) or a quantum-dot detector. In this talk, I will briefly describe such measurements for single and double quantum dots in the Coulomb blockade regime and show how the formalism has been generalized to deduce the entropy from conductance measurements. Applying it to a setup where two and three-channel Kondo physics have been observed, this formalism yields the fractional entropy of a single MF and a single Fibonacci anyon. In the main part of the talk I will concentrate on the backaction of the detector on the system itself, demonstrating that the detector may lead to a localization transition in the measured quantum system, a manifestation of the Anderson overlap catastrophe and the quantum phase transition in the celebrated spin-boson model. We find a Kosterlitz-Thouless flow diagram, leading to a universal jump in the spin-bath interaction, reflected in a discontinuity in the zero temperature QPC conductance. Lastly, I show how by controlling the properties of the detector, one can generate exotic models, yet unrealized experimentally, such as the pseudo-gap Kondo model.

Quantum Self-Propulsion of an Inhomogeneous Object out of Thermal Equilibrium

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Previously, we explored how quantum vacuum torque can arise: a body or nanoparticle that is out of thermal equilibrium with its environment, having a temperature T' different from that the the blackbody background, T, experiences a spontaneous torque. But this requires that the body be composed of nonreciprocal material, which seems to necessitate the presence of an external influence, such as a magnetic field. Then the polarizability of the particle has a real part which is nonsymmetric. This effect occurs to first order in the polarizability. To that order, no self-propulsive force can arise. Here, we consider second-order effects, and show that spontaneous forces can arise in vacuum, without requiring exotic electromagnetic properties. Thermal nonequilibrium is still necessary, but the body need only be inhomogeneous. We consider four examples: a needle composed of distinct halves; a sphere and a ball, each hemisphere being made of a different substance; and a thin slab, each face of which is different. The results found are consistent with previous numerical investigations. Here, we take into account the skin depth of metal surfaces. We consider the frictional forces that would cause the body to acquire a terminal velocity, which might be observable. More likely to be relevant is relaxation to thermal equilibrium, which can still lead to a readily observable terminal velocity. There also arises, in second order, a torque on a body out of equilibrium with its environment, provided the body be inhomogeneous and chiral. The resulting radiation fields reflect both the spontaneous force and torque.

Optimal time estimation and the clock uncertainty relation for Markovian stochastic processes

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Time estimation is a fundamental task that underpins precision measurement, global navigation systems, financial markets, and the organisation of everyday life. Many biological processes also depend on time estimation by nanoscale clocks, whose performance can be significantly impacted by random fluctuations. In this work, we formulate the problem of optimal time estimation for Markovian stochastic processes, and present its general solution in the asymptotic (long-time) limit. Specifically, we obtain a tight upper bound on the precision of any time estimate constructed from sustained observations of a classical, Markovian jump process. This bound is controlled by the mean waiting time between jumps: in simple terms, the more frequently a system transitions between its underlying states, the more precisely it can function as a clock. As a consequence, we obtain a universal bound on the signal-to-noise ratio of arbitrary currents and counting observables in the steady state. This bound is similar in spirit to the kinetic uncertainty relation but provably tighter and we explicitly construct the counting observables that saturate it. Our results establish ultimate precision limits for an important class of observables in non-equilibrium systems, and demonstrate that the mean waiting time, not the dynamical activity, is the measure of freneticity that tightly constrains fluctuations far from equilibrium.

VitaCrystallography: Old Approach to New Challenges

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In the XX century, X-ray diffraction crystallography facilitated a major breakthrough in material sciences allowing the determination of the electron density and, hence, the atomic positions by the angle and intensity of the X-ray scattering. Later, in *biocrystallography*, this approach was extended to biological molecules. After their crystallization, an electron density map can be constructed from the X-ray diffraction patterns, and the molecular structure can be resolved.

In this presentation, I will examine the further extension of the X-ray diffraction approach, which we call VitaCrystallography. It deals with the X-ray scattering on whole living tissues without crystallization. The extracellular matrix (ECM) is not crystalline per se. Still, it contains many elements exhibiting the structural periodicities that can contribute to the X-ray diffraction patterns, such as collagen, keratin, glycoproteins, and adipose.

We will also discuss the perspectives of VitaCrystallography for monitoring the ECM status. ECM plays critical regulatory roles in morphogenesis since it orchestrates cell signaling, functions, properties, and morphology. The ECM structure is constantly being remodeled and altered as a response to various external and internal factors. In this sense, revealing the pathology-induced and, especially, the pathology-causing aberrations in the ECM is crucial. I will present our results on animal and human samples, including nails (keratin) and mammal glands (collagen and adipose), and show that VitaCrystallography leads to very early cancer diagnostics.

Measuring the period of a pendulum with a tall atom interferometer

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Atom interferometers have long been recognized as very powerful tools for precision measurements. Light-pulse atom interferometers allow atoms to freely evolve in-between laser pulses and acquire information about the surrounding potential with a phase that scales as T^2, although proposals and experiments involving higher-order scaling (T^3) have been reported [1, 2, 3]. The quantum sensors group at the Naval Postgraduate School is building a very tall atom interferometer for precision measurements of inertial forces. Our first proposed experiment involves the measurement of the period of a nearby Foucault pendulum with the atom interferometer. In this talk, I will first motivate why we would want to do such a simple experiment in such a complicated way. The phase of the atom interferometer can be calculated using the Feynman path integral technique. I will outline these calculations, highlighting the differences that arise between our system and a more traditional Kasevich-Chu-style gravimeter [4]. Next, I will briefly show the status of the construction of the apparatus. Finally, I will speculate on other fundamental measurements that could be made with our apparatus.

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The Effective Permittivity of a Composite Material

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From the pioneering work of Ottaviano-Fabrizio Mossotti, Rudolf Clausius, Ludvig Lorenz and Hendrik Lorentz, to the seminal Maxwell Garnett's equation and Bruggeman's mixing formulae, to the recent cluster models and analytical bounds , for nearly two centuries finding the effective permittivity of an inhomogeneous composite medium remains one of the key problems in electromagnetic theory. While some of the existing methods offer accurate results in special limiting cases (such as e.g. Maxwell Garnett's approach that is valid ion non-percolating structures with small relative volume of inclusions), there is yet no theoretical approach that is applicable to a composite of arbitrary structure.

In the present work, we present the general analytical solution to this long-standing problem. We show that the permittivity of the composite is dominated by the universal contribution that only depends on the relative volume fractions of constituents, and present the analytical expressions for both the universal part of the permittivity and the non-universal correction due to the variations of the shape, size and spatial arrangements in the structure of the composite.

Many-body physics with Fermions in an Optical Box

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For the past two decades harmonically trapped ultracold atomic gases have been used with great success to study fundamental many-body physics in flexible experimental settings. However, the resulting gas density inhomogeneity in those traps has made it challenging to study paradigmatic uniform-system physics (such as critical behavior near phase transitions) or complex quantum dynamics. The realization of homogeneous quantum gases trapped in optical boxes has marked a milestone in quantum simulation with ultracold atoms [1]. These textbook systems have proved to be a powerful playground by simplifying the interpretation of experimental measurements, by making more direct connections to theories of the many-body problem that generally rely on the translational symmetry of the system, and by altogether enabling previously inaccessible experiments.

I will present a series of experiments with ultracold fermions trapped in a box of light [2-5]. First, I will present two studies of stability problems: the spin-1/2 Fermi gas with repulsive contact interactions [2] and the three-component Fermi gas with spin-population imbalance [3]. Next, I will show the first observation of the Joule-Thomson effect in Fermi systems [4]. Finally, I will show how properties of quasiparticles can be modified by a dressing field; in our case, Fermi polarons dressed with an rf field [5]. These studies have led to some surprising results, highlighting how spatial homogeneity not only simplifies the connection between experiments and theory, but can also unveil unexpected outcomes.

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How the vacuum explains the Lorentz electron, regular black hole interiors and the dark matter

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It is amazing how a new interpretation of the role of the vacuum makes the classical Maxwell-Einstein equations consistent. The postulate that vacuum energy can flow and condense when assisted by electric fields, explains 1) simple models for elementary particles; 2) provides exact solutions for black holes with a regular interior and no singularity; 3) explains the dark matter as a combination of electrostatic and vacuum energy; 4) provides a related structure for "hidden momentum" in classical electrodynamics.

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Schwinger-Keldysh nonperturbative quantum field theory for driven-dissipative spin systems

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The driven-dissipative many-body systems remain one of the most challenging unsolved problems in quantum mechanics. When "body" is spin, such many-spin systems underlie spintronics, magnonics and quantum computing. In this talk, I will first explain conditions [1] under which quantum spins interacting with a dissipative environment can transition toward classical dynamics governed by the celebrated Landau-Lifshitz-Gilbert (LLG) equation. The extended LLG equation for such classical spins, which includes non-Markovian and spatially nonlocal damping of quantum origin, can be rigorously derived from Schwinger-Keldysh (SK) quantum field theory (QFT) [2] by neglecting quantum fluctuations of spin fields. Its application [3] to spin waves explains recent experiments where quantum sensing has measured 100-fold increase of damping in yttrium iron garnet (one of the key materials in magnonics) due to metallic overlayer. In the case of fully quantum spin dynamics, by combining SK QFT with two-particle irreducible effective (2PI) action formalism and 1/N expansion, both of which have been developed originally in elementary particle physics, we derive [4] time evolution of spin in archetypical open quantum system, the spin-boson model of great importance for understanding superconducting qubit decoherence. Despite only a class of Feynman diagrams being effectively resummed to infinite order by 2PI, where those diagrams are generated by expansion in 1/N (where N in the number of Schwinger bosons to which spin is mapped) instead of expansion in coupling constant, our SK QFT can track numerically exact simulations (such as from hierarchical equations of motion or tensor networks) of the spin-boson model. This signifies that our SK QFT is nonperturbative and, furthermore, it can go reach regimes where numerically exact simulations become problematic due to long time evolution, specific temperature, more than one spin and ultimately emergence of "entanglement barrier."

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Machine Learning Techniques Applied to Quantum Physics

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This talk will provide a **brief pedagogical overview of Machine Learning** (ML) and, at the end, a few applications of ML to quantum Physics. Additional information is available in [1-10]. Special emphasis will be on [3,6,7,10]. Regarding [10]: Autonomous quantum error correction (AQEC) protects logical qubits by engineered dissipation and thus circumvents the necessity of frequent, error-prone measurement-feedback loops. Bosonic code spaces, where single-photon loss represents the dominant source of error, are promising candidates for AQEC due to their flexibility and controllability. Here, we propose a bosonic code for approximate AQEC by relaxing the Knill-Laflamme conditions. Using reinforcement learning (RL), we identify the optimal bosonic set of code words (denoted here by RL code), which, surprisingly, is composed of the Fock states $|2\rangle$ and $|4\rangle$. As we show, the RL code, despite its approximate nature, successfully suppresses single-photon loss, reducing it to an effective dephasing process that well surpasses the break-even threshold. It may thus provide a valuable building block toward full error protection.

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Eikonal formulation of large dynamical random matrix models

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The standard approach to dynamical random matrix models relies on the description of trajectories of eigenvalues. Using the analogy from optics, based on the duality between the Fermat principle (rays) and the Huygens principle (wavefronts), we formulate the Hamilton-Jacobi dynamics for large random matrix models. The resulting equations describe a broad class of random matrix models in a unified way, including normal (Hermitian or unitary) as well as strictly non-normal dynamics. This formalism applied to Brownian bridge dynamics allows one to calculate the asymptotics of the Harish-Chandra-Itzykson-Zuber integrals.

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Heat transport in the quantum Rabi model: Universality and ultrastrong coupling effects

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Heat transport in the quantum Rabi model at weak interaction with the heat baths displays various regimes upon acting on the qubit-oscillator coupling g, which essentially controls the conduction properties. In this work, we evaluate the linear conductance of the quantum Rabi model employing a diagrammatic approach based on a master equation formalism in Liouville space [1]. Universality of the linear conductance versus the temperature is found in the low-to-intermediate temperature regime, when quantities are scaled with a coupling-dependent Kondo-like temperature $T_K(g)$. At low temperatures, coherent heat transfer via virtual processes yields a $(T/T_K)^3$ behavior in the linear conductance modulated by a prefactor which is determined by the junction parameters and unravels its multi-level nature. Destructive interference arises in the presence of quasi-degeneracies in the spectrum. As the temperature increases, incoherent emission and absorption dominate. Upon increasing g, the conductance transitions from a resonant to a broadened, zero-bias peak regime in the presence of a bias on the qubit. Similarities with the heat transfer in a qubit highlight how the internal qubit-oscillator coupling plays the role of the qubit-bath coupling in the spin-boson model [2].

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From multi-photon entanglement to quantum computational advantage

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Photons, the fast flying qubits which can be controlled with high precision using linear optics and have weak interaction with environment, are the natural candidate for quantum communications. By developing a quantum science satellite *Micius* and exploiting the negligible decoherence and photon loss in the out space, practically secure quantum cryptography, entanglement distribution, and quantum teleportation have been achieved over thousand kilometer scale, laying the foundation for future global quantum internet. Surprisingly, despite the extremely weak optical nonlinearity at single-photon level, an effective interaction between independent indistinguishable photons can be effectively induced by a multi-photon interferometry, which allowed the first creation of multi-particle entanglement and test of Einstein's local realism in the most extreme way. By developing high-performance quantum light sources, the multi-photon interference has been scaled up to implement boson sampling with up to 76 photons out of a 100-mode interferometer, which yields a Hilbert state space dimension of $10^{30}$and a rate that is 10^{14} faster than using the state-of-the-art simulation strategy on supercomputers. Such a demonstration of quantum computational advantage is a much-anticipated milestone for quantum computing. The special-purpose photonic platform will be further used to investigate practical applications linked to the Gaussian boson sampling, such as graph optimization and quantum machine learning.

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Informational steady-states and conditional entropy production in continuously monitored systems

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I will put forward a unifying formalism for the description of the thermodynamics of continuously monitored systems, where measurmeents are only performed on the environment connected to a system. I will show, in particular, that the conditional and unconditional entropy production, which quantify the degree of irreversibility of the open system's dynamics, are related to each other by the Holevo quantity and discuss the existence of informational steady-states, i.e. stationary states of a conditional dynamics that are maintained owing to the unbroken acquisition of information. I will illustrate the applicability of such framework through several examples, including the modelling of a recent experiment in the field of cavity optomechanics.

Reconstructing the Quantum State of Photon Propagating Through Atmospheric Turbulence Simulator

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In striving for realization of a quantum-based internet and ground-to-space communication, propagation of photonic qubit through atmospheric turbulence is an inevitable requirement for global quantum network [1-4]. To enable development of robust quantum networks with higher fidelity, it is critical that we learn how the state of the qubit is transformed while propagating through the atmosphere [2]. In aiming at this goal, we are building up a laboratory based atmospheric turbulence simulator (ATS) at AFIT to characterize the effects of different scales of atmospheric turbulence on an entangled pair of photons as a function of statistical quantities of turbulence, such as the Fried parameter and scintillation index for long-distance communication.

The simulated turbulence is constructed using two afocal optical systems with a phase plate inserted in each to mimic both weak and strong atmospheric turbulence respectively. The qubit to propagate through the system was a polarization-entangled photon-pair source, produced using spontaneous parametric down-conversion. After propagation, the two beams are modified to be projected onto a specified component of polarization and quantum state tomography are performed on the photons to analyze the effects of the turbulence on the original state once reconstructed [5]. In characterization of the simulated turbulence, we were able to reach strengths up to a D/r_0 of 18.2, which approached the strong turbulence regime. We will discuss the results of the quantum state tomography and other quantum interoferic measurements.

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Time-Linear Quantum Transport Simulations: Electroluminescence rectification and high harmonic generation in molecular junctions

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Molecular systems are prospective elements of future electronic devices such as nano-junctions. State-of-the-art calculations are able to accurately predict ground and excited properties of technologically relevant molecules. However, *ab initio* description of photo-assisted tunneling, optical rectification, and electrically driven photon emission requires a new set of tools.

Therefore, I present a time-linear scaling method to simulate open and correlated quantum systems out of equilibrium [1]. The many-body diagrammatic theory provides a systematic approach to handle interactions between electrons, bosonic excitations, and embedding. To access the dynamical properties of the system, the Kadanoff-Baym equations for the two-time electron and boson Green's functions must be propagated. The time nonlocality of the scattering term poses a significant challenge for full two-time propagation, resulting in at least cubic scaling with the physical propagation time. The generalized Kadanoff-Baym ansatz (GKBA) alleviates the scaling problem by limiting the propagation to the time diagonal and working with density matrices rather than Green's functions. This approach leads to a coupled system of first-order ordinary differential equations (ODEs) with linear time scaling, as demonstrated in electronic [2], electron-bosonic [3], and open systems within the wide band limit approximation (WBLA) [1].

As a case study for the formalism, I report the quantum pump effect in a Benzenedithiol molecule connected to copper electrodes and coupled with cavity photons [4]. The nonequilibrium transport simulations by the recently developed Cheers code [5] reveal electric and photonic current responses to an ac bias voltage, pronounced electroluminescence and high harmonic generation (HHG) in this setup. The mechanism of HHG is more analogous to that from solids than from isolated molecules. Comparing the power carried by the photon flux with the total power, we found quantum efficiency around ten percent, similar to quantum-dot devices.

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Emergence of Boltzmann subspaces in open quantum systems far from equilibrium

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Single molecule junctions are important examples of complex out-of-equilibrium many-body quantum systems. We identify a non-trivial clustering of steady state populations into distinctive subspaces with Boltzmann-like statistics, which persist far from equilibrium. Such Boltzmann subspaces significantly reduce the information needed to describe the steady state, enabling modeling of high dimensional systems which are otherwise beyond reach of current computations. The emergence of Boltzmann subspaces is demonstrated analytically and numerically for fermionic transport systems of increasing complexity.

Quantumness in plasmon assisted multiphoton photoemission

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Plasmon polaritons are resonant modes arise through the interaction of electromagnetic fields with conductive materials. As resonators they form energy reservoirs. Although it is common knowledge that such reservoirs must in principle be represented as quantum oscillators in most cases these excitations can well be conceived as classical entities. The direct identification of the quantum nature of plasmons has been prevented by the delicate nature of the quantum states, the nanoscale field confinement of plasmons, and a lack of appropriate probes. A recent experiment using coherent multidimensional spectroscopy with nanoscale spatial resolution allowed to directly probe a plasmon polariton quantum wave packet [1]. To reproduce these results an improved quantum model of photoemission was required, in which the coherent coupling between plasmons and electrons is accounted for with the plasmon excitations extending beyond a two-level model. In this contribution the experiment and its theoretical modelling serves as a starting point for discussing further plasmon assisted nanoscale quantum phenomena such as emerging plasmon assisted few-photon down conversion [2] and a novel parametric down conversion process involving bulk plasmon.

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Entanglement-preserving single-pair measurement of the Bell parameter

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In 1965, J. S. Bell [1] turned a philosophical debate into a physical experiment capable of extracting the true nature of correlations in physical systems, opening several research fields spanning from quantum mechanics foundations to quantum technologies [2]. Over the past decades, the scientific community has thoroughly investigated Bell inequalities, eventually achieving loophole-free tests [3-5]. Nevertheless, some issues still persist: e.g., within the traditional (projective) quantum measurement framework, the wavefunction collapse and Heisenberg uncertainty principle forbid performing, on the same quantum system, all the measurements needed for evaluating the entire Bell parameter.

Conversely, here we present a method for estimating the entire Bell parameter from each entangled pair while preserving entanglement [6], ensuring its further availability. This method relies on weak measurements [7], where a tiny coupling between the observed system and the measurement device allows estimating the observables of interest while preventing the state from collapsing: one can therefore measure multiple observables on the same quantum state, extracting all the correlations needed to evaluate the full Bell parameter from each pair (although with a large uncertainty, typical of weak measurements).Our experiment provides new insights into understanding quantum mechanics foundations, like the concept of counterfactual definiteness [8]. Moreover, after the entanglement is certified, it results almost unaltered and therefore exploitable for other quantum information protocols or quantum foundations investigations, like testing novel bounds intertwining local and nonlocal correlations.

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Low Noise Opto-Electro-Mechanical Modulator for RF-to-Optical Transduction in Quantum Communications

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Quantum transduction plays a crucial role in quantum technologies [1,2]. One of the primary focus lies on achieving coherent conversion between optical and microwave/radiofrequency (Mw/RF) photons since optical spectrum is well-suited for long-distance communication, while the lower frequencies prove advantageous for precise local quantum operations. In this talk we present a complete theory to sympathetic cool a macroscopic radio-frequency LC electrical circuit to its ground state by means of an electro-optomechanical system, consisting of an optical cavity dispersively coupled to a nanomechanical oscillator, which is in turn capacitively coupled to the LC circuit of interest [3]. We show the realization of a novel electro-opto-mechanical device that can be used for the sympathetic cooling of the LC circuit, and as building block of an RF/Mw-optical transducer [4]. The key element of the device is a mechanical resonator based on a metal coated circular membrane capacitively coupled to an electrical circuit. We present the measurement of mechanical and electro-mechanical properties of the device. The quality factor of the mechanical oscillator has been characterized at room and cryogenic temperatures. The frequency shift of the fundamental mode of the oscillator due to the application of a potential difference is the evidence of the presence of the electro-mechanical coupling.

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Nanomechanically-induced nonequilibrium quantum phase transition in a Bose-Einstein condensate

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In this talk, we report a nonequilibrium quantum phase transition (NQPT) in a hybrid quantum many-body system consisting of a vibrational mode of a damped nanomembrane interacting optomechanically with a cavity, whose output light couples to two internal states of an ultracold Bose gas held in an external quasi-one-dimensional box potential [1]. For small effective membrane-atom couplings, we find that the system is in a homogeneous Bose-Einstein condensate (BEC) steady state with no membrane displacement. Depending on the transition frequency between the two internal atomic states, either one or both internal states are occupied. By increasing the atom-membrane couplings, the system transitions to a symmetry-broken self-organized BEC phase, which is characterized by a significantly displaced membrane steady state and density wave-like BEC profiles. We show that this NQPT can be both discontinuous and continuous for a certain interval of transition frequencies, and is purely discontinuous outside this interval. Finally, we discuss further research directions.

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Can auxiliary sites accelerate enzymatic reactions?

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Recent work suggests that inactive binding sites may play a role in the kinetics of molecular machines and motors. We study if the rate at which fuel molecules reach a catalytic site and react there can be enhanced by the presence of nearby auxiliary sites. A simple model of the flow of molecules from a reservoir to the site is defined, and its steady state is analyzed. Two possible mechanisms of rate acceleration have been identified. In the first the auxiliary site stores a fuel molecule and releases it when the nearby active site is empty. In the second mechanism, the escape of molecules from the active site is blocked. Our results demonstrate an interesting and largely unexplored out-of-equilibrium phenomenon.

Interferometry with Bose-Einstein condensates in microgravity

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Research on light-pulse atom interferometers is motivated by the interest in accurate and long-term stable inertial measurements. Important sensitivity levers for the latter are the extension of the interferometry time and the transfer of large numbers of photon momenta. Ultra-cold atomic ensembles are a promising resource for light-pulse interferometers considering all aforementioned aspects. We explore collimated Bose-Einstein condensates generated on atom chips as ultra-slowly expanding gas for light-pulse interferometry. I will report on the status of experiments in free-fall facilities and in space, i.e. during the last sounding rocket mission.

Entangled photon-pair emission in circuit QED from a Cooper pair splitter

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As a circuit QED architecture, we study the photon emission of a Cooper pair splitter formed by two double dots each of them coupled to a microwave transmission line. We demonstrate that it is possible to generate entangled photon pairs in frequency, in the left (L) and the right (R) line, namely two photon wavepackets with a superposition of states at different frequencies. The frequency entanglement of the two photons has origin in the particle-hole coherent superposition of the electronic entangled singlet that tunnels out from the superconducting nanocontact inserted between the two double dots. Using the parameters of the state of art of the circuit QED devices with quantum dots, we also estimate the efficiency of the entangled pair-photon generation assuming that non-radiative processes are also present in the two double-dots. So far no experiment has demonstrated that electrons leaking out in a Cooper pair splitter are entangled. Our proposal is a realistic and achievable within the reach of the state of art in quantum microwave engineering with quantum dots.

Particle-hole thermalization in a composite super and normal conducting nanowire

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The mechanisms by which isolated condensed matter systems thermalize is a topic of growing interest. Thermalization is known to be linked to the emergence of chaos in the dynamics of a system. We show that a solid state scattering system, containing superconducting elements, can thermalize scattered states without affecting the degree of entanglement of the scattered states. We consider a composite NSNSNSNSN nanowire, composed of BSCCO $Bi_2Sr_2CaCu_2O_{8+x}$ superconducting segments (S) and normal conducting segments (N). We consider parameter regimes where all current flow is due to tunneling currents that are facilitated by quasibound state resonances inside the SNSNSNS structure. At certain energies, scattered pure states approach ergodicity, even though they remain pure.

Finite width of anyons changes their braiding signatures

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Anyons are particles intermediate between fermions and bosons, characterized by a nontrivial exchange phase, yielding remarkable braiding statistics. Recent experiments have shown that anyonic braiding has observable consequences on edge transport in the fractional quantum Hall effect (FQHE). In this talk, we present transport signatures of anyonic braiding when the anyons have a finite temporal width. We show that the width of the anyons, even extremely small, can have a tremendous impact on transport properties and braiding signatures. In particular, we find that taking the finite width into account allows us to explain recent experimental results on FQHE at filling factor $2/5$ [Ruelle et al., Phys. Rev. X 13, 011031 (2023)]. Our work shows that the finite width of anyons crucially influences setups involving anyonic braiding, especially for composite fractions where the exchange phase is larger than $\pi/2$.

Correlated quantum photon states generated by vacuum fields

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This talk is to explore various techniques to manipulate populations in quantum systems by applying tailored optical pulses included even vacuum fields. The techniques are based on interactions between adiabaticaly changing quantum fields with the quantum systems. The obtained results will be beneficial to the fields of atomic and molecular physics, quantum electronics, and nonlinear physics. In particular, these new techniques will be important for developing quantum sensors, quantum information systems. The quantum fields created and emitted can be used for quantum communications.

Propagation of quantum field interacting with single two-level or three-level atoms has been studied. Using the Gaussian quantum mode functions, we calculate evolution of the quantum state that includes atomic and field variable. We demonstrated the phase acquired by the single photon propagation [1,2] that can be of great importance for long quantum communications. The results can be used for controlling quantum field propagation, and for design of optical elements such as a quantum prism and a quantum lens.

We consider a Lambda-type three-level atom in a QED cavity. One atomic transition is driven by a classical field and the other transition is driven by the “vacuum” field. The vacuum field can be strongly modified by the cavity, and in particular, the “vacuum” field can have a chirped frequency modulation that it can be a part of adiabatic rapid passage together with classical drive field. The action of the classical and “vacuum” or quantum field can result in the generation of the quantum fields with controllable parameters. Such QED cavity can be used to generate strongly correlated quantum fields that can be of interest for quantum sensing, spectroscopy at the single photon level, quantum teleportation, and other applications for quantum information.

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Quantum Mechanical and Optical Inspirations in Surface Gravity Water Waves: An Analogy Exploration

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Analogies between quantum and classical systems can be found in many areas of physics, from optics and acoustics to condensed matter and particle physics. Surface gravity water waves, for example, have been shown to exhibit analogies to both quantum mechanics and optics. By exploring such analogies, we can gain new insights into the fundamental behavior of both quantum and classical systems. While the two regimes of physics operate on vastly different scales, they are related through the notion of wave-particle duality. This duality allows quantum objects, such as photons and electrons, to display both wave-like and particle-like properties, like classical systems.

In that regard, the phase of a matter wave, governed by the Schrödinger equation, plays a crucial role in solving fundamental problems in quantum mechanics. However, it is quite difficult to measure the full wave packet (both amplitude and phase) of matter waves. In this research, we propose both theoretical and experimental study of quantum mechanical analogies with hydrodynamics, by measuring the propagation dynamics of surface gravity water waves, which, under certain circumstances, obey the Schrödinger equation. We began this research by exploring the propagation dynamics of Gaussian and Airy wave packets and successfully observed the Kennard cubic phase for the first time. We further investigated the propagation dynamics of solitons in linear potential, a problem in which the wave packets maintain their temporal shape but accelerate. Then, we explored various systems such as the Talbot effect (or Talbot carpets) and successfully showed experimentally that the Talbot effect occurs not only in the amplitude but also in the phase. In addition, we explored the Talbot effect in the nonlinear regime and observed for the first time the absence of fractional Talbot-effect, due to interference of the periodic wavepackets in a nonlinear medium. Currently, we study deeper analogies between quantum mechanics and surface waves and aim to measure scattering of wave packets from an inverted oscillator potential, quantum decoherence, ballistic wave packets as well as other different time-dependent potentials and an analogy of a black holes in phase space. Furthermore, we have recently discovered that our experimental setup allows measuring and studying Bohm trajectories and quantum potentials of different wave packet types, including two/three slits and Airy slits. In addition, this approach can also lead to an experimental observation of the Wigner distribution of the wave function or the adjunct entropy. Moreover, we have recently shown that our system can emulate antireflection temporal coatings, dark focusing and diffractive focusing and guiding of waves. These experiments aim to serve as a new type of a platform for different aspects of complex optical systems fundamentals as well as fundamental quantum phenomena.

Optimal transport of active particles induced by substrate concentration oscillations

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We show the existence of a stochastic resonant regime in the transport of active colloidal particles under confinement. The periodic addition of substrate to the system causes the spectral amplification to exhibit a maximum for an optimal noise level value. The consequence of this is that particles can travel longer distances with lower fuel consumption. The stochastic resonance phenomenon allows the identification of optimal scenarios for the transport of active particles, enabling them to reach regions that are otherwise difficult to access, and may therefore find applications in transport in cell membranes and tissues for medical treatments and soil remediation.

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Modelling non-Markovian noise in superconducting qubits

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Non-Markovian noise can be a significant source of errors in superconducting qubits. It is caused by ubiquitous effects such as quasiparticle induced charge parity fluctuations, as well as frequency fluctuations induced by two level systems or other defects. We develop a method based on mirrored pseudo-identity gates to characterise the non-Markovian noise in idle and driven qubits [1]. We compare three approaches to modelling the observed noise: (i) a Markovian noise model, (ii) a model including interactions with a two-level system (TLS), (iii) a model utilising the post Markovian master equation (PMME). We show that the Markovian noise model fails to capture the experimental behaviour, and that only by including the non-Markovian components one can describe the experiments. We further present fast time-resolved characterization techniques that allow us to indicate the physical origin of the non-Markovian noise. We find large changes of the dominating noise contributions, such as qubit frequency fluctuations, over both long time-scales of hours and days, and also over very short micro-seconds time-scales.

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Quantum measurement and control of a Maxwell demon in double quantum dots

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In scenarios coined Maxwell's demon, information on microscopic degrees of freedom is used to seemingly violate the second law of thermodynamics. This has been studied in the classical as well as the quantum domain. Here we study an implementation of Maxwell's demon that can operate in both domains [1,2]. In particular, we investigate information-to-work conversion over the quantum-to-classical transition. The system is analyzed within a recently developed Quantum Fokker-Planck master equation framework for continuous measurement and feedback control [2]. The demon measures the charge state of a double quantum dot, and uses this information to guide electrons against a voltage bias by tuning the on-site energies of the dots. Coherent tunneling between the dots allows for the buildup of quantum coherence in the system. Under strong measurements, the coherence is suppressed, and the system is well-described by a classical model. As the measurement strength is further increased, the Zeno effect prohibits interdot tunneling. A Zeno-like effect is also observed for weak measurements, where measurement errors lead to fluctuations in the on-site energies, dephasing the system.

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[2] B. Annby-Andersson, P. Samuelsson, V. F. Maisi, and P. P. Potts, Phys. Rev. B 101 (2020) 165404.

[3] B. Annby-Andersson, F. Bakhshinezhad, D. Bhattacharyya, G. De Sousa, C. Jarzynski, P. Samuelsson, P. P. Potts, Phys. Rev. Lett. 129 (2022) 050401.

Scattering theory of thermal and thermoelectric diodes

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Modern electronic devices are currently operated at the nanoscale regime, where overheating becomes a problem. Controlling the undesired heat flows in a useful manner is another less explored way of improving its performance. For this, efficient thermal diodes need to be designed [1]. Usual proposals rely in nonlinear scenarios [2]; here, we identify the minimal conditions for a nanoscale device to rectify the heat and thermoelectric currents, even in the linear regime. This is achieved for asymmetric coherent conductors that allow for some local thermalization of the heat carriers. We quantify the amount of rectification achieved by this mechanism in some proposed systems composed of resonant-tunneling quantum dots and compare (and combine) it with the non-linear scenarios. Finally, we propose feasible experimental realizations of this idea in an elastic conductor where the interplay between thermalization and nonlinearities can be controlled via quantum interference [3].

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[3] J. Balduque, R. Sánchez, in preparation.

Interacting laser-trapped circular Rydberg atoms

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Circular Rydberg atoms, namely Rydberg atoms with maximal orbital momentum, have long natural lifetimes, typically 100 times longer than their low-momentum counterparts. This makes them well suited to the quantum simulation of the dynamics of interacting quantum systems. Our experimental setup allows us to laser trap individual circular Rydberg atoms in an array of hollow optical tweezers, or bottle optical beams [1].

In this talk, I will report on our recent experimental activities that demonstrate the dipole-dipole interaction between two circular Rydberg atoms [2]. We characterize this interaction through microwave spectroscopy and observe the coupling between spin and motional degrees of freedom that it can induce. I will also show how we use the dipole-dipole interaction to locally detect and manipulate circular Rydberg atoms in the array.

[1] B. Ravon et al, Phys. Rev. Lett. 131, 093401 (2023)

[2] P. Méhaignerie et al, in preparation

Equivalence of Hamiltonians in Atom Optics

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The linearity of quantum mechanics and the resulting Hilbert structure of quantum space allows an amazing freedom in choosing an appropriate representation to describe a given quantum phenomena. Position, momentum or energy Eigenstates conserve and equivalent spaces to obtain a prediction for an observable. Although, the details of this analysis may be different in the individual representations, the final expressions for the probability for a measurement outcome are, of course, identical.

In the present talk, we [1] show that this freedom is not restricted to the choice of representations but also extends to the very heart of quantum dynamics, that is to setting up the appropriate Hamiltonian. In particular, we demonstrate this frame dependence of quantum phenomena using the example of the phrase difference between two atom waves in the Kasevich-Chu interferometer. We show that this quantity arises from different terms in the Hamiltonian. A crucial role in this analysis is played by the canonical momentum whereas in classical physics it cannot be observed, all of quantum mechanics rest on it. In this talk we emphasise this crucial difference.

[1] M. Zimmerman, M. A. Efremov, F. A. Narducci and W. P. Schleich, *Equivalence of Hamiltonians in Atom Optics*, Memorial Issue for Jonathan Patrick Dowling AVS Quantum, to be published.

Quantum geometry and semiclassical dynamics in inhomogeneous fields

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We revisit the problem of nonequilibrium semiclassical electron transport in the presence of inhomogeneous external perturbations. For this purpose, we study the quantum geometry of a Bloch band structure beyond the Berry connection contribution. We provide a systematic way of computing the geometric corrections to the semiclassical equations of motion in an N-band system, and extend the notions of Berry phase and quantum geometric tensor to higher orders in the inhomogeneity of the perturbation. We also demonstrate how to derive the dynamics from a generic coupling between Bloch momentum and an inhomogeneous external field, thus generalizing previous studies.

NMR: From Molecules to Spectra

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Nuclear Magnetic Resonance (NMR) is one of the most important tools for the structure analysis of molecules and a widely used technique in chemical and pharmaceutical industry. Here I present our approach to calculate NMR spectra starting from the SMILES description or just the name of the molecule. To this end we first determine the 3D structure of the molecule from which we obtain the NMR spin Hamiltonian. Finally we calculate the NMR Spectra from the spin-spin correlation functions.

One of the main challenges in NMR simulations consists in the large variation of energy scales involved. Typically high field proton NMR are performed at frequencies of the order of 700MHz, pulse duration are of the order of 10μs with a band width of a few kHz, while the measured spectra have sub Hz resolution. Since the energy scales of the effective spin Hamiltonian correspond to sub Kelvin temperature and measurements are done at room temperature simulations are in the infinite temperature regime, limiting the number of spins that can be treated in a full diagonalization on standard desktop machines to 20 spins. We discuss the application of symmetries and clustering to achieve these calculations and various approximation schemes to extend the simulations to large systems. Finally I discuss the calculation of NMR spectra on quantum computer and show results obtained on quantum hardware.

Entanglement in Unruh and Hawking radiation from a quantum optical perspective

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Free quantum field theory in flat space-time is often believed to be well established, holding no surprises. However, in recent work we show that a uniformly accelerated atom in Minkowski space-time emits entangled photon pairs into a squeezed state which mimics entanglement between Minkowski modes which are dominantly in opposite causal wedges of the space-time. Similar emission of photon pairs occurs if an atom is held above the black hole event horizon. Namely, a ground-state atom becomes excited by emitting a “negative”-energy photon under the horizon and then spontaneously decaying back to the ground state by emitting a positive-energy photon outside the horizon, which propagates away from the black hole.

[1] M. Scully, A. Svidzinsky, and W. Unruh, Phys. Rev. Res. 4 (2022) 033010.

Stochastic thermodynamics: From concepts to model-free inference

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Stochastic thermodynamics provides a universal framework for analyzing nano- and micro-sized non-equilibrium systems. Prominent examples are single molecules, molecular machines, colloidal particles in time-dependent laser traps and biochemical networks. Thermodynamic notions like work, heat and entropy can be identified on the level of individual fluctuating trajectories. They obey universal relations like the fluctuation theorem.

Thermodynamic inference as a general strategy uses consistency constraints derived from stochastic thermodynamics to infer otherwise hidden properties of non-equilibrium systems. As a paradigm for thermodynamic inference, the thermodynamic uncertainty relation discovered in 2015 provides a lower bound on the entropy production through measurements of the dispersion of any current in the system [1]. Likewise, it quantifies the cost of temporal precision for biomolecular processes and provides a model-free bound on the thermodynamic efficiency of molecular motors and microscopic heat engines. Generalizations allow us to apply it to time-dependently driven systems like the unfolding of proteins under mechanical force [2]. Waiting time distributions between observable events yield even better bounds on entropy production and the topology and driving affinity of the underlying network [3,4].

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[2] T. Koyuk and U. Seifert, PRL 125, 260604, 2020

[3] J. van der Meer, B. Ertel, and U. Seifert, PRX 12, 031025, 2022

[4] J. van der Meer, J. Degünther, and U. Seifert, PRL 130, 257101, 2023

Measuring stochastic thermodynamics in mesoscopic systems using a quantum work agent

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Non-equilibrium fluctuation theorems (NFTs) relate work performed on a system as its Hamiltonian varies with time, to equilibrium data of the initial and final states. In a classical context the system energy can be directly measured, while a quantum implementation requires the incorporation of a work-agent. We demonstrate that the uncertainty principle imposes inherent quantum limitation on the applicability of the NFT for probing non-trivial mesoscopic systems. We work out the NFT validity regime for the simplest quantum-dot toy model, and discuss future applications.

On Observer-Dependent Description of Quantum State on Identical Particles

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The setup of the Einstein-Podolsky-Rosen (EPR) paradox leads to provide the observer-depedent description of the quantum state from quantum information perspectives. While this problem is based on the single-particle system, the problem can be extended to the many identical particle system. We provide the experimental proposal to clarify the quantum state description to the identical particle. This experimental proposal is used in the three-particles Aharonov Bohm effect.

New view on the quantum Hall phase diagram of bilayer graphene

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Bilayer graphene exhibits a rich phase diagram in the quantum Hall (QH) regime, arising from the interplay of the spin, valley, and orbital degrees of freedom. In particular, at very high magnetic fields, a perpendicular electric field (D) drives transitions between valley-unpolarized and valley-polarized states in several QH phases. In this study [1] we explore the behavior of these transitions as the magnetic field B is reduced, focusing on the phases in the filling-factor range 1< u<2. We find that as B is lowered, the variation of the critical electric field (D*) with filling factor exhibits a puzzling change of trend, from increasing to decreasing; near u=2, D* may even vanish if B is sufficiently small. We present a theoretical model for the lattice-scale interactions which correctly accounts for these surprising observations; contrary to earlier studies, it involves finite-ranged terms comprising both repulsive and attractive components. Furthermore, we (theoretically) analyze the nature of the u=2 state as a function of B and D, and find that a valley-coherent phase may emerge in the D D* regime. This suggests the existence of a Kekule bond-ordered phase at low magnetic fields, similarly to the phases recently observed in the u=0 phase through STM measurements.

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Quantum Simulation of Markovian Open Quantum Systems

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A simulation of quantum systems is one of the most exciting use cases for quantum computers. The simulation of closed quantum systems, or Hamiltonian simulation, has been explored in recent years. Novel methods have been developed, improving the widely used and well-known Suzuki Lie Trotter product formulas. However, in many practical situations, one must consider unavoidable interaction with the thermal environment. The success of quantum computers in simulating physical systems has led to the development of quantum algorithms to simulate open quantum systems in the fault-tolerant setting. However, these algorithms are limited to the Suzuki Lie Trotter product formulas of the first and second order. In this talk, I will give an overview of the quantum simulation of open quantum systems and focus on our recent work of reducing the gate complexity in the simulation of an open quantum system by using two methods that rely on randomisation.

Non-linear excitations and low-energy effective theories of spinor gases far from equilibrium

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A system driven far from equilibrium via a parameter quench can show universal dynamics, characterized by self-similar spatio-temporal scaling, associated with the approach to a non-thermal fixed point. Non-linear excitations such as solitons or vortices play a key role in the time evolution of such systems. Here we present a derived low-energy effective theory for an ultracold spin-1 gas, in addition to outlining the range of non-linear phenomena within this framework that impact the scaling behavior of the spinor gas. We also showcase experimental measurements of such excitations and discuss the real-time confinement dynamics of these excitations.

Simultaneous symmetry breaking in spontaneous Floquet states: Floquet-Nambu-Goldstone modes, Floquet thermodynamics, and the time operator

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We study simultaneous symmetry-breaking in a spontaneous Floquet state, focusing on the specific case of an atomic condensate. We first describe the quantization of the Nambu-Goldstone (NG) modes for a stationary state simultaneously breaking several symmetries of the Hamiltonian by invoking the generalized Gibbs ensemble, which enables a thermodynamical description of the problem. The quantization procedure involves a Berry-Gibbs connection, which depends on the macroscopic conserved charges associated to each broken symmetry and whose curvature is not invariant under generalized gauge transformations. We extend the formalism to Floquet states simultaneously breaking several symmetries, where Goldstone theorem translates into the emergence of Floquet-Nambu-Goldstone (FNG) modes with zero quasi-energy. In the case of a spontaneous Floquet state, there is a genuine temporal FNG mode arising from the continuous time-translation symmetry breaking, whose quantum amplitude provides a rare realization of a time operator in Quantum Mechanics. Furthermore, since they conserve energy, spontaneous Floquet states can be shown to possess a conserved Floquet charge. Both the temporal FNG mode and the Floquet charge are distinctive features of a spontaneous Floquet state, absent in conventional, driven systems. Nevertheless, these also admit a thermodynamic description in terms of the Floquet enthalpy, the Legendre transform of the energy with respect to the Floquet charge. We apply our formalism to a particular realization of spontaneous Floquet state, the CES state, which breaks U(1) and time-translation symmetries, representing a time supersolid. Using the Truncated Wigner method, we numerically compute its quantum fluctuations, which are theoretically predicted to be dominated by the temporal FNG mode at long times, observing a remarkable agreement between simulation and theory. Based on these results, we propose a feasible experimental scheme to observe the temporal FNG mode of the CES state.

Higgs-like pair amplitude dynamics in superconductor-quantum dot hybrids

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The order parameter of a bulk superconductor is a dynamic quantity that can exhibit collective excitations such as the Nambu-Goldstone mode and the Higgs mode. The former is an excitation of the superconducting phase which is shifted to the plasma frequency by the Anderson-Higgs mechanism. The latter is a massive excitation of the absolute value of the order parameter with an excitation energy equal to the superconducting gap. The experimental detection of the Higgs mode is challenging as it couples only quadratically to light and its energy is typically in the Terahertz regime.

Here, we consider an analogue of the Higgs dynamics in bulk superconductors. To this end, we study a single-level quantum dot tunnel-coupled to superconducting reservoirs. We analyze the dynamics of the pair amplitude induced on the quantum dot via the proximity effect. We focus on two different parameter regimes, namely the case of weak-tunnel coupling to superconductors with a finite gap [1] and the case of strong coupling in the infinite-gap limit [2]. We find that the pair amplitude exhibits a rich dynamics including coherent oscillations due to Cooper pair tunneling and exponential decay due to quasiparticle processes.

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[2] M. Heckschen and B. Sothmann, Phys. Rev. B **105**, 045420 (2022).

Physical processes controlling biological neural networks

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The intensive experimental and theoretical research into the nerve signalling, which lasts for more than two hundred and thirty years, has provided many valuable pieces of knowledge but no definite, really satisfying solution. Such an unfavorable state is due to the extraordinary complexity of this phenomenon and enormous technical difficulties encountered by experiments. At present, there are two main competing models of signal transfer in neuron networks: Hodgkin-Huxley electric theory and Heimburg's thermomechanical, soliton theory. Since the major premises of both these approaches are mostly different, their reconciliation is not probable. The talk will first briefly overview our efforts in improvement of our understanding of physical processes, which control information transfer and processing in biological neural networks. We then introduce a scenario of the signal transmission in nerves, intentionally based only on well turned-out physically transparent arguments. We hope it will be useful for the efforts aiming to the improvement of the present models.

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Effective mass approach to memory in non-Markovian systems

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Recent pioneering experiments on non-Markovian dynamics done e.g. for active matter have demonstrated that our theoretical understanding of this challenging yet hot topic is rather incomplete and there is a wealth of phenomena still awaiting discovery. It is related to the fact that typically for simplification the Markovian approximation is employed and as a consequence the memory is neglected. Therefore methods allowing to study memory effects are extremely valuable. We demonstrate that a non-Markovian system described by the Generalized Langevin Equation (GLE) for a Brownian particle of mass M can be approximated by the memoryless Langevin equation in which the memory effects are correctly reproduced solely via the effective mass M* of the Brownian particle which is determined only by the form of the memory kernel. Our work lays the foundation for an impactful approach which allows to readily study memory-related corrections to Markovian dynamics.

[1] M. Wiśniewski, J, Łuczka, J. Spiechowicz, Effective mass approach to memory in Non-Markovian systems, Phys. Rev. E 109, 044116 (2024)

Stability in multiscale oscillatory systems away from equilibrium

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Oscillatory dynamics pervades the universe, appearing in systems on all scales. It can be studied within the frameworks of either autonomous or non-autonomous dynamics. Autonomous dynamical systems serve as mathematical models for the time-evolution of the states of *isolated* physical systems, whereas non-autonomous dynamics describes *open systems* subjected to external driving with time-varying parameters (1). While autonomous dynamics can be studied within the long-time asymptotic framework, including asymptotic stability, we will argue that this framework can be inadequate or unsuitable when investigating open systems and studying the parameter-dependence of their stability. We will provide a new framework for non-autonomous oscillatory dynamics, within which we can define intermittent phenomena such as intermittent phase synchronisation, evaluated as the stability of phase interactions (2). We will demonstrate this framework with a coupled pair of non-autonomous phase oscillators as well as a higher-dimensional system comprised of two interacting phase-oscillator networks. Counterintuitively, non-autonomous external perturbation increases the stability of perturbed oscillatory systems.

The second part of the talk will address the question how to analyse effectively time series measured from open oscillatory systems operating on multiple timescales and away from equilibrium. We will review methods that enable explicit tracking of time-localised dynamical behaviour, as opposed to the traditional framework for dynamics analysis focused on time-independent dynamical systems and based on long-term statistics (3). We will show that time-dependent oscillatory systems with only a small number of contributions may appear noise-like when analysed according to the traditional framework using power spectral density estimation. However, methods characteristic of the time-dependent finite-time-dynamics framework, such as the wavelet transform, wavelet bispectrum, or wavelet phase coherence can identify the underlying determinism and provide crucial information about the analysed system (3,4). We will present several examples from physical and living systems, including the ageing brain.

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The return of the Anyons - news from the fractional quantum Hall effect

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The fractional quantum Hall effect, first observed some four decades ago, is believed to be a system where Anyons - particles of fractional charges and fractional quantum statistics - exist. In the last year, several important developments have brought the physics of Anyons back into the limelight. In particular, Anyons were shown to be quantum particles that can interfere as waves, and their traditional “alma mater”, the fractional quantum Hall effect, has been shown to exist without the application of any magnetic field.

I will review some of these developments and the theory behind them, making minimal assumptions of prior knowledge.

Entropy augmentation through subadditive excess: a sane introduction of irreversibility into micro-dynamics

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For irreversible thermodynamic processes there is a disparity between the increase of thermodynamic entropy and the conservation of Shannon-von Neumann entropy in the microscopic dynamics. The higher value of thermodynamic entropy reflects the fact that thermodynamic variables are insufficient probes for microscopic information. Instead of either defining macrostates as regions in phase space or imposing an increase of Shannon-von Neumann entropy by coarse-graining, a third approach is developed. Information theory, in particular the consideration of mutual information, is used to define an alternative approach leading to increasing entropy and equilibration. The salient point can already be found (*in nuce*) in the Boltzmann equation, when it is viewed through the lens of information theory rather than scattering theory. Applying information theoretic tools not only to states, but to processes, an entire class of Boltzmann-inspired effective dynamics is constructed from arbitrary (quantum or classical) Liouville equations under the principle of entropy augmentation through subadditive excess (EASE). The resulting equations display both entropy production and relaxation towards thermal stationary states like the Boltzmann equation. While still microscopic, the solution of these equations is within the reach of current numerical methods.

Charge-conserving equilibration of quantum Hall edge states

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We address the experimentally relevant situation, where a non-equilibrium state is created at the edge of a quantum Hall system by injecting charge current into a chiral edge state with the help of a quantum point contact, quantum dots, or mesoscopic Ohmic contact. We show that the commonly accepted picture of the full equilibration of a non-equilibrium state at finite distances longer than a characteristic length scale contradicts to the charge conservation requirement. We use a phenomenological transmission line model to account for the local equilibration process and the charge and energy conserving dynamics of the collective mode. By solving this model in the limit of long distances L from the injection point, we demonstrate that the correction of the electron distribution function to its eventual equilibrium form scales down slowly as $1/\sqrt{L}$.

Experimental demonstration of an atomic-scale heat pump

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At the limit of electronic conductor miniaturization, quantum phenomena can open the door for attractive heat-pumping schemes. I will discuss our recent demonstration of an all-metal atomic-scale heat pump. In this system, the combination of a many-body effect and quantum interference yields significant Peltier cooling. We find a Seeback coefficient that is higher by two orders of magnitude than detected in any other metallic system. The prepared atomic-scale heat pump can serve as an experimental platform for studying thermal management in a many-body system, with heat pumping that is significant enough for future applications.

Unraveling quantum coherences in photosynthetic protein complexes at ultralow temperatures

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The transfer of excitation energy in biomolecular complexes is inherently mediated by quantum delocalization. It is an interesting question to what extent does quantum coherence play a role in the transfer dynamics. I will discuss under what conditions such natural systems could show dynamic quantum coherent effects beyond the trivial quantum delocalization. In recent joint experimental and theoretical studies [1-3], we have investigated the quantum exciton dynamics in the Fenna-Matthews-Olson (FMO) complex and the Photosystem II Reaction Center (PSIIRC) by two-dimensional electronic spectroscopy in a large range of temperatures down to 20 K. Our experimental results reveal electronic coherence to occur on a time scale as long as 500 fs at 20 Kelvin for the case of FMO [2] and of about 200 fs for PSIIRC at 20 Kelvin [1]. They complete earlier results obtained under ambient conditions where we have found that at room temperature, electronic coherence fades out within 60 fs [3]. Yet, the new low-temperature data allow us to capture evidence of quantum coherence at ultralow temperature and to clearly disentangle electronic and vibrational dynamic coherence. The observed long-lived oscillations are due to Raman vibrational modes on the electronic ground state.

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Quantum transport and thermodynamics using the hierarchical equations of motion method

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The hierarchical equations of motion (HEOM) formalism is an accurate and efficient approach to simulate the dynamics of open quantum systems [1]. Formulated as a density matrix scheme, it generalizes perturbative quantum master equation methods by including higher-order contributions as well as non-Markovian memory and allows for the systematic convergence of the results. In this talk, applications of the HEOM method are discussed to quantum transport in nanostructures as well as to quantum thermodynamics. This includes the study of charge transport in driven quantum systems with electron-phonon interaction [2]. Furthermore, the principle of minimal dissipation is employed to investigate thermodynamic properties such as work, heat, and entropy production in open quantum systems [3]. In particular, the case of strong system-environment coupling is considered.

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Fundamental Physics with atomic Hydrogen

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Discrepancies between theory and experiments have been fueling the development of physics. Today, Quantum Electrodynamics (QED) is the most accurate theory and served as a blueprint for all subsequent field theories. Physics beyond the Standard Model must exist as we know from observations of the cosmos. It is likely to be found where no one has looked before, i.e., at very large energies, high sensitivity, or high precision. To progress with the so-called precision frontier, high resolution spectroscopy of atomic hydrogen and hydrogen-like systems continues to play a decisive role because their simplicity. Testing QED means to verify the consistency of parameters that enter this theory. Values for these parameters are extracted from as many different measurements as possible.

The sharpest metrologically relevant line in atomic hydrogen is due to the 1S-2S transition. Since there is no 1P state, the 2S state can neither decay nor be excited with a single photon dipole transition, at least not in a field-free environment. Therefore the lifetime of the 2S state is very long leading to natural line width of only 1.3Hz. The 1S-2S transition frequency has been measured with almost 15 digits accuracy using an optical frequency comb and a cesium atomic clock as a reference [1].

However, the largest leverage for the determination of the parameters, the Rydberg constant and the proton charge radius, is currently due to the 1S-3S transition frequency that we are investigating in our lab [2]. With another experimental setup we are conducting a series of measurements between the metastable 2S and *n*P states [3]. To go further we are developing a method to trap atomic hydrogen in an optical dipole trap that operates at the magic wavelength. The proposed scheme avoids a cooling laser and will not be more complex than existing optical lattice clocks. Besides of improving the measured transition frequencies, trapped atomic hydrogen could eventually be the motivation to redefine the SI second in terms of the Rydberg constant. This would remove the last remaining object in the definitions of the SI which is otherwise based defined values of physical constants (c, h and e).

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Spin states at the edges of a finite p-orbital helical atomic chain attached to a ferromagnetic substrate

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The chiral-induced spin selectivity (CISS) effect is the phenomenon in which a chiral molecule acts as a spin filter, selecting a specific spin orientation depending on its chirality. Over the last two decades, the CISS phenomenon has been observed in various chiral molecules and has attracted considerable attention due to its significant effect, even at room temperature, despite chiral molecules not containing magnetic atoms [1]. While numerous theoretical proposals have been made, a comprehensive understanding has not yet been established. We have analyzed the CISS phenomenon based on a p-orbital helical atomic chain with intra-atomic spin-orbit interaction (SOI), which serves as a toy model of helical molecules such as DNA [2-3]. Here, we apply this model to explain an enantioselective experiment [4], which demonstrated that molecules with specific chirality preferentially adsorb onto a magnetic substrate with a particular orientation of magnetization.

In the case of an infinite chain, our model supports a spin-filtering state where two up spins propagate in one direction while two down spins propagate in the opposite direction without breaking time-reversal symmetry (TRS). For a finite chain, the presence of evanescent states induces an enhancement of charge modulations concentrated at the edges, although spin density is absent due to the preservation of TRS [2]. A Zeeman field applied at the edge of the atomic chain, mimicking the effect of a magnetic substrate, breaks theTRS and induces a finite spin polarization. The direction of this polarization depends on the chirality of the molecule. The change in chirality leads to a reasonable amount of energy difference, offering insight into the enantioselective adsorption of chiral molecules on a ferromagnetic surface [2].

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Spontaneous unitarity violation as a model for quantum state reduction

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The impossibility of describing measurement in quantum mechanics while using a quantum mechanical model for the measurement machine, remains one of its central problems. Objective collapse theories propose a solution to this problem by predicting deviations from Schrödinger's equation that can be tested experimentally. A class of objective theories based on spontaneous unitarity violation was recently introduced, which complements existing proposals based on stochastic modifications of Schrödinger's equation, but also differs from them in several aspects. Here, we contrast the stochastic dynamics encountered in both types of models, and highlight the unique features of spontaneous unitarity violation as well as their implications.

In particular, we will show that the physical requirements of the stochastic field being independent of the state to be measured and having non-vanishing correlations time, imply a unique form for the measurement dynamics of an isolated two-level system. Building on this minimal example, we show that the dynamics has a natural extension to systems with an arbitrary number of basis states, that it reduces to a purely dephasing Lindblad equation (and hence is explicitly norm-preserving and non-signalling) in the limit of vanishing correlation time, and that Born's rule emerges in the limit of macroscopic measurement machines, without the stochastic field depending in any way on the state being measured. For each of these results we will contrast their implementation and implications with other types of modified Schrödinger dynamics. We will conclude with a discussion of accessible signatures distinctive for spontaneous unitarity violation in experimental tests of quantum state reduction.

Emergence of Constructor-Based Irreversibility in Quantum Systems

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How irreversibility arises in a universe with time-reversal symmetric laws is a central problem in physics. In this talk, we discuss a radically different take on the emergence of irreversibility, adopting the recently proposed constructor theory framework. Irreversibility is expressed as the requirement that a task is possible, while its inverse is not. We prove the compatibility of such irreversibility with quantum theory's time-reversal symmetric laws, using a dynamical model based on the universal quantum homogenizer.

Critical Behavior and Collective Modes at the Superfluid Transition in Amorphous Systems

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We investigate the critical behavior and the dynamics of the amplitude (Higgs) mode close to the superfluid-insulator quantum phase transition in an amorphous system (i.e., a system subject to topological randomness). In particular, we map the two-dimensional Bose-Hubbard Hamiltonian defined on a random Voronoi-Delaunay lattice onto a (2+1)-dimensional layered classical XY model with correlated topological disorder. We study the resulting model by laying recourse to classical Monte Carlo simulations. We specifically focus on the scalar susceptibility of the order parameter to study the dynamics of the amplitude mode. To do so, we harness the maximum entropy method to perform the analytic continuation of the scalar susceptibility to real frequencies. Our analysis shows that the amplitude mode remains delocalized in the presence of such topological disorder, quite at odds with its behavior in generic disordered systems, where the randomness localizes the Higgs mode [1]. Furthermore, we show that the critical behavior of the topologically disordered system is identical to that of its translationally invariant counterpart, consistent with a modified Harris criterion [2]. This suggests that the localization of the collective excitations in the presence of disorder is tied to the critical behavior of the quantum phase transition rather than a simple Anderson-localization-type interference mechanism [3].

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A scalable quantum key distribution network based on time-bin entanglement - reloaded

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With the upcoming rise of quantum computers, most commonly used cryptography schemes in day-to-day communications will in time turn insecure. One way to preserve security is the development of quantum key distribution (QKD) and deployment of QKD-systems in large networks. For that, robust and scalable systems are needed.

We contribute to that goal with the construction and extension of a star-shaped QKD network utilizing the entanglement based BBM92 protocol. Adapting to the needs of a metropolitan network, we followed a fiber-based approach and chose time and phase as the bases of entanglement as opposed to polarization, which would be subject to varying birefringence in the fibers, e.g. due to vibrations or thermal instabilities [1].

Here, we report on the progress in various aspects of our QKD network. Specifically, in this contribution we address the scalability and cost of the system by simplifying the source setup, reducing the number of necessary detectors per party by implementing detector time multiplexing (DTM) [2] and physically separating two parties completing a key exchange including error correction.

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Beyond the first law: Peculiarly quantum conservation laws in thermodynamics

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Starting in undergraduate statistical physics, we study small systems that thermalize by exchanging quantities with large environments. Such thermalization helps define time's arrow, and the exchanged quantities–heat, particles, electric charge, etc.–are conserved globally. If quantum, the quantities are represented by Hermitian operators. We often assume implicitly that the operators commute with each other–for instance, in derivations of the thermal state's form. Yet operators' ability to not commute underlies quantum phenomena such as uncertainty principles. What happens if thermodynamic conserved quantities fail to commute with each other? This question, mostly overlooked for decades, came to light recently at the intersection of quantum thermodynamics and information theory [1]. Noncommutation of conserved thermodynamic quantities has been found to enhance entanglement [2], decrease entropy-production rates, alter the eigenstate thermalization hypothesis [3], and more. This growing subfield illustrates how 21st-century quantum information science is extending 19th-century thermodynamics.

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Generalized Pechukas-Yukawa formalism for quantum systems with discrete energy spectra

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The success of a perturbation theory expansion is determined by the appropriate choice of the zero-order approximation. The Pechukas-Yukawa formalism provides a promising alternative approach to the description of perturbed quantum systems with discrete energy spectra. It implicitly uses the matrix elements of the Hamiltonian in the basis of exact instantaneous eigenstates rather than the eigenstates of the unperturbed Hamiltonian. In this formalism, the evolution of the energy spectrum due to the perturbation is reduced to the Hamiltonian dynamics of a 1D classical gas of particles with cubic repulsion (a modified Calogero-Sutherland model). We develop the kinetic theory of this gas (BBGKY chain of equations for the probability distribution functions), which serves as the basis for the equations for the density matrix of the underlying quantum system. The approach provides a good basis for a perturbative treatment of the evolution of the density matrix of a quantum system in the presence of a time-dependent perturbation, and gives an insight into the evolution of large quantum systems.

Quantum convolutional neural networks for the recognition of many-body topological phases of matter

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Existing noisy intermediate-scale quantum computers can perform computations that are challenging for classical computers. However, quantum computing hardware and quantum algorithms need to be further developed to enable the exploitation of quantum computers in areas such as the simulation of many-body systems and machine learning. One of the major challenges in developing scalable quantum computers is characterizing the noisy quantum data produced by near-term quantum hardware. With increasing system size, standard characterization techniques using direct measurements and classical post-processing become prohibitively demanding due to large measurement counts and computational efforts.

Directly processing quantum data on quantum processors can substantially reduce measurement costs. Quantum neural networks based on parametrized quantum circuits, measurements and feed-forward can process large amounts of quantum data, to detect non-local quantum correlations with reduced measurement and computational efforts [1]. Characterizing non-local correlations is crucial in condensed matter physics for classifying quantum phases of matter and understanding new strongly correlated materials such as high-temperature superconductors.

A key requirement for employing quantum neural networks to characterize noisy quantum data produced by near-term quantum hardware is tolerance to errors due to decoherence and gate infidelities. In Ref. [2], we construct quantum convolutional neural networks (QCNNs) capable of recognizing symmetry-protected topological phases of many-body Hamiltonians in the presence of incoherent errors. These networks are designed to mimic renormalization-group flow and quantum error correction. We realize the error-tolerant QCNNs on a 7-qubit superconducting quantum processor [3]. The QCNNs reduce sample complexity exponentially with system size compared to direct Pauli measurements.

In a follow-up project, we generalize the QCNNs to detect intrinsic topological order in two-dimensional systems. Furthermore, we demonstrate that QCNNs can autonomously identify characteristics of topological phases via unsupervised learning.

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Loss-induced quantum information jet in an infinite temperature Hubbard chain

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Information propagation in the one-dimensional infinite temperature Hubbard model with a dissipative particle sink at the end of a semi-infinite chain is studied. In the strongly interacting limit, the two-site mutual information and the operator entanglement entropy exhibit a rich structure with two propagating information fronts and superimposed interference fringes. A classical reversible cellular automaton model quantitatively captures the transport and the slow, classical part of the correlations, but fails to describe the rapidly propagating information jet. The fast quantum jet resembles coherent free particle propagation, with the accompanying long-ranged interference fringes that are exponentially damped by short-ranged spin correlations in the many-body background. We identify the carrier of the fast front as a coherently moving spinless fermion, propagating on an infinite temperature spin texture [1].

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Quantum computing with continuous quantum systems

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Continuous-variable quantum computers [1,2] encode information and perform calculations with the help of continuous degrees of freedom, such as e.g. position or momentum. Despite the enormous resources available in a continous quantum system, typical encodings for quantum computation only exist for single qubits as, for instance, the Gottesman-Kitaev-Preskill (GKP)-states [3].

In this talk, we present an encoding scheme for two-qubit operations in a single continous quantum system. We introduce elementary logical gates which are characterized by continuous transformations, such as displacement, rotation and shearing. The action of these operations on the respective states is illustrated in phase space. With a representation-free theory we then analyze the implementation of the resulting gates by taking into account current experimental limitations. Finally, we discuss several challenges for the identification of states and operations when encoding more than two qubits within a single continous quantum system.

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Invited Posters

Simulation and Experiments with the cloud-accessible ultracold-matter hardware Oqtant

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This presentation introduces a cloud-accessible 87Rb-based ultracold atom platform, Oqtant, made available by Infleqtion. The platform provides a programmable means of producing and then manipulating ultracold matter using painted optical potentials. Experiments typically begin with the production of a Bose-Einstein condensate, then proceed by manipulating atomic potential through the distribution of laser light. The programming is done through Python programming. Oqtant is accompanied by simulation software that allows one to simulate dynamics on a classical computer, and then with the flip of a (software) switch, run the corresponding experiment. In addition to its educational value, Oqtant allows non-specialists to carry out meaningful ultracold matter experiments. We discuss present and possible future capabilities.

Nonlinear hydrodynamics on a chip: wave breaking and multisoliton fission in a superfluid waveflume

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In this poster I will present research interfacing cavity optomechanics and superfluid physics for the study of nonlinear wave phenomena.

Building upon our previous work in superfluid optomechanics [1], I will present a novel sensor architecture formed by covering nanofabricated silicon photonic crystal beams with a thin superfluid helium-4 film. This creates an optically addressable quasi-one-dimensional wave tank containing a few femtoliters of superfluid helium, upon which waves can be generated, propagate and be readout.

Superfluid helium's characteristics present a unique opportunity for the study of nonlinear wave propagation. Indeed, thanks to superfluid helium's vanishing viscosity, the depth of the film h can readily be made as small as a few nanometers without wave attenuation–something impossible to do with classical fluids. Our platform thus enables us to generate waves whose aspect ratio (defined as the wavelength over depth λ/h) exceeds 10,000:1, two orders of magnitude larger than that achievable in the world's largest wave tanks and exceeding that of the most extreme terrestrial phenomena such as tsunamis. This, combined with our recently developed ability to engineer strong fountain pressure forces [2], now allows us to combine within a single device high spatial and temporal resolution along with strong actuation capabilities.

Leveraging these unique characteristics, I will show how our superfluid wave tank enables us to generate and measure (within a sub-millimetre-sized device in a laboratory setting) a rich variety of superfluid nonlinear wave phenomena for the first time, including wavebreaking, multisoliton fission and optomechanical dissipative solitons [3] - opening up the way for the study of extreme regimes of nonlinear hydrodynamics on a chip.

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Thermoelectricity in superconducting nanotechnologies

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Thermoelectricity is a basic example of a thermodynamic engine which transforms thermal gradients into electrical power. However, many quantum machines and quantum thermodynamic electronic circuits[1] are realized with hybrid superconducting platforms which are expected with limited thermoelectrical properties, due to the particle-hole symmetry. However, thermoelectricity may be also generated in these systems [2,3], flux vortex systems[4] or, non-locally, due to helical properties of the topological edge states[5] or even to the emergence of Bogoliubov-Fermi points[6]. However, we have shown that photon-assisted tunnelling could even impact in some measure on the thermoelectricity[7]. In this contribution, we will explore how previous examples could be influenced by Coulomb blockade[8], time-dependent drivings or other interactions with the circuit's electrical environment.

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Asymptotic Charge Induced Decoherence in QED and Quantum Gravity

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In QED and (linearized) quantum gravity, we show that any localized charge will eventually decohere in the momentum basis in an asymptotically flat spacetime. This places an upper bound on the size of any coherent quantum superposition in space, and also generates an enhanced rate of wavepacket spreading. We estimate the size of these effects, which arise because any massive (or charged) particle necessarily radiates soft, entangling gravitons/photons to null infinity as it evolves. In the limit of infinite time–such as in QED scattering theory–this soft radiation gives rise to superselection in the electron momentum basis, with the result that almost all scattering states exhibit total delocalization of the charges. It is an experimental fact that this does not obstruct accurate predictions for collider experiments, where the central-momentum dependence of scattering cross sections can still be calculated. Nevertheless, in regimes where quantum coherence of charged particles becomes important, this total loss of coherence in traditional scattering theory is a fundamental obstacle to realistic predictions. In QED scattering, realistic physics only survives within a small class of carefully dressed states. In (nonlinear) quantum gravity, the conclusion is different, and suggests that valid physical states in quantum-gravitational scattering theory can only be described in terms of relational observables, e.g. by the introduction of extended objects.

Superconducting proximity coupling in thin films of magnetic topological insulators.

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Inducing superconducting correlations in magnetic topological insulators (MTIs) has attracted a lot of research interest in recent years [1]-[2], being a promising way to realize topological superconductors with non-abelian anyons [3]. In principle, an effective pairing can be achieved straightforwardly by placing a topologically-nontrivial MTI in proximity to an ordinary s-wave superconductor. However, several challenges need to be overcome to observe the simultaneous coexistence of magnetism, topology and superconductivity.
Here, we investigate the proximity effect produced by an s-wave superconductor grown on top of a thin film of MTI material. Using the Green's function formalism, we derive and solve the quantum mechanically Gor'kov equations for the MTI-SC heterostructure in presence of translational invariance on the MTI plane. We analyze how the induced SC correlations depend on out-of-plane coordinate and magnetization, showing that p-wave superconductivity can be achieved.

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Open-loop quantum control of small-size networks for high-order cumulants and cross-correlations sensing

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Quantum control techniques represent one of the most efficient tools to attain high-fidelity quantum operations and a convenient approach for quantum sensing and quantum noise spectroscopy. In this work, we investigate dynamical decoupling while processing an entangling two-qubit gate based on an Ising-xx interaction, each qubit being affected by pure dephasing classical correlated $1/f$-noises. To evaluate the gate error, we used the Magnus expansion introducing generalized filter functions that describe decoupling while processing and allow us to derive an approximate analytic expression as a hierarchy of nested integrals of noise cumulants. The error is separated in contributions of Gaussian and non-Gaussian noise, the corresponding generalized filter functions being calculated up to the fourth order. By exploiting the properties of selected pulse sequences, we show that it is possible to extract the second-order statistics (spectrum and cross-spectrum) and to highlight non-Gaussian features contained in the fourth-order cumulant. We discuss the applicability of these results to state-of-the-art small networks based on solid-state platforms.

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Fractional Charges and Triply Degenerate States of Fermion Zero Modes on the Domain Wall of the Quantum Dot

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Recent relationdship between condensed matter physics such as topological insulators and elementary particle physics is remarkable. The effective topological field in field-theoretical formula captures ther topological effects, including the quantization of the Hall conductance, the fractional charge, and statistics of quasiparticles. Kanazawa has indicated the importance of the hole-induced domain-wall in magnetoresistance in diluted magnetic semiconduictors [1,2]. In addition, Kanazawa and coworkers [3,4] have proposed that there might be emergent quasiparticles with fractional electronic charge such as dyon on the domain wall between topological insulators and spin ice compounds through the Witten effect [5] and interaction between the Dirac fermions and excited magnetic monopoles. Recently Kanazawa and Maeda [6] have discussed quark-like fermions of triply degenerate states of fermion zero mode on the quantum dot. In this study, we have discussed the anomalous excitations such as fractional charges on the quantum dot, extending the theoretical formula [7,8].

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Negative Wigner function by decaying interaction from equilibrium

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Bosonic systems with negative Wigner function superposition states are fundamentally witnessing nonlinear quantum dynamics beyond linearized systems and, recently, have become essential resources of quantum technology with many applications. Typically, they appear due to sophisticated combination of external drives, nonlinear control, measurements or strong nonlinear dissipation of subsystems to an environment. Here, we propose a conceptually different and more autonomous way to obtain such states, avoiding these ingredients, using purely sudden interaction decay in the paradigmatic interacting qubit-oscillator system weakly coupled to bath at thermal equilibrium in a low-temperature limit. We demonstrate simultaneously detectable unconditional negative Wigner function and quantum coherence and their qualitative enhancement employing more qubits, similarly as in [1].

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Bosonic phonon pairing causes a bulk-boundary duality

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Since the publishing of our seminary theory, "*Scale-free ferroelectricity induced by flat phonon bands in HfO_2*" [1], we have delved into the origins of unconventional ferroelectricity in HfO_2 beyond the flat phonon bands. Finally, we discovered that a bound phonon pair is responsible for the undiminished strength of the ferroelectricity even at the sub-nm scales.

While fermionic particles such as electrons are known to pair and induce observable effects such as superconductivity, bosonic entities such as phonons rarely exhibit pairing. However, in this phenomenon, all phonons in HfO_2 are paired, with each phonon is bound with its band-partner. Unlike the single phonons in conventional ferroelectricity that easily scatter at physical boundaries such as domain walls, the paired phonons bond with each other and successfully reach the domain wall's centre without losing their integrity. As a result, the condensed phonons and the structure of the bulk are fully retained at the domain wall, rendering the wall virtually indistinguishable from the bulk.

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Exploring phononlike interactions in one-dimensional Bose-Fermi mixtures

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We investigate a cold atomic Bose-Fermi (BF) mixture confined in an optical lattice potential solely affecting the bosons with the objective of simulating the physical behavior of electrons in a dynamic background. We do so by assigning tractable degrees of freedom to the lattice, which renders its description dynamic and enables the simulation of some analog of phonon-like interactions. In mixtures of bosons and spin-polarized fermions, it is well known that an attractive BF interaction leads to a so-called pairing phase in the strongly correlated regime [1]. This phase collapses if the interaction becomes too strong, resulting in clumping of the atoms and breaking of translational invariance. At the same time, deep optical lattices on BF mixtures render their description amenable to the BF Hubbard model, since an insulating phase of composite fermions is formed [2].

In our work, the bosons reside in the deep superfluid regime and inherit the periodicity of the optical lattice, subsequently serving as a dynamic potential for the polarized fermions. Owing to the atom-phonon interaction between the fermions and the condensate, the coupled system exhibits a Berezinskii-Kosterlitz-Thouless transition from a Luttinger liquid to a Peierls phase. However, under sufficiently strong BF interaction, the Peierls phase loses stability, leading to either a collapsed or a separated phase. We find that the primary function of the optical lattice is to stabilize the Peierls phase. Furthermore, the presence of a confining harmonic trap induces a diverse physical behavior, surpassing what is observed for either bosons or fermions individually trapped. Notably, under attractive BF interaction, the insulating phase may adopt a fermionic wedding-cake-like configuration, reflecting the dynamic nature of the underlying lattice potential. Conversely, for repulsive interaction, the trap destabilizes the Peierls phase, causing the two species to separate [3].

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Quantum Coherent Transfer Function for Generic Pulse Storage and Retrival

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Challenges in storage of quantum information is one of the bottlenecks for realizing the quantum network [1]. In last few decades, electromagnetically induced transparency (EIT) based light storage and retrieval has been demonstrated as the potential technique for quantum information storage, except for the stringent limitations of the delay-bandwidth product [2]. Most of the optical storage studies have been limited to storing Sech, Gaussian or other well-known regular pulse shapes [3]. We demonstrated that an analytical framework based on a Fourier-domain coherent transfer function for arbitrary pulse shapes and derived a generalized expression for the retrieved light pulse from EIT storage in a three-level Λ system. We implemented Fourier algebra to separate the effect of storage from the arbitrary shape of the pulse being stored, deriving a generalized formula for arbitrary pulse shape [4].

In this poster, we will demonstrate that the Fourier transfer function could be considered as the quantum coherent transfer function that resonantly imparts its effect on the incoming "signal" (light) pulse and, thus, we can deconvolve the output pulse from the transfer function to gain information on the signal pulse. This result will be significantly enhancing the ability to retrieve the critical information content of the signal, particularly in the quantum domain.

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Nanomechanically-induced nonequilibrium quantum phase transition in a Bose-Einstein condensate

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We report a nonequilibrium quantum phase transition (NQPT) in a hybrid quantum many-body system consisting of a vibrational mode of a damped nanomembrane interacting optomechanically with a cavity, whose output light couples to two internal states of an ultracold Bose gas held in an external quasi-one-dimensional box potential [1]. For small effective membrane-atom couplings, the system is in a homogeneous Bose-Einstein condensate (BEC) steady state with no membrane displacement. Depending on the transition frequency between the two internal atomic states, either one or both internal states are occupied. By increasing the atom-membrane couplings, the system transitions to a symmetry-broken self-organized BEC phase, which is characterized by a significantly displaced membrane steady state and density wave-like BEC profiles. This NQPT can be both discontinuous and continuous for a certain interval of transition frequencies, and is purely discontinuous outside this interval.

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The refractive index of a single three-level atom experienced by a quantum field

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The refractive index of a system is often considered as the collective response of a medium to an electromagnetic field. However, even when light targets a single atom, it undergoes dispersion. By studying the propagation of a single photon interacting with a two-level atom, we can examine the dispersion behavior of the photon wave packet and further analyze the dispersion experienced by the single photon [1,2]. These findings are critical for advancing long-distance quantum communications.

Moreover, the question of the refractive index of a single atom arises when the atom interacts with a quantum field consisting of multi-photon states of radiation. Surprisingly, there is no difference when the quantum field interacts with a single two-level atom. However, when the atom has more levels (e.g., three levels in Lambda or Ladder configurations), the dispersion for the quantum field differs compared to a two-level atom. In our poster, we will present the applications arising from the new findings on the dispersion of three-level atoms, which are important for advancing quantum information manipulation and improving quantum communications.

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Toward a coherent ultracold chemistry: controlling ultracold collisions of NaLi molecules

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Ultracold NaLi molecules represent a fascinating frontier in the study of quantum chemistry and physics. These molecules, cooled to temperatures near absolute zero, exhibit behavior that transcends classical understanding, allowing us to explore the quantum mechanical nature of matter. With their distinctive blend of sodium (Na) and lithium (Li) atoms, ultracold NaLi molecules serve as an ideal platform for probing the interactions and dynamics at ultralow temperatures. Among the myriad ultracold molecules, NaLi stands out due to its unique characteristics. It exhibits a notably small van der Waals radius, leading to diminished cross sections for inelastic collisions despite its high reactivity. Achieving control over chemical reactions at the quantum level through external fields remains a key ambition in modern chemistry. This ambition fuels the ongoing search for Feshbach resonances within molecular frameworks. Nonetheless, the existence of such resonances in many systems may be hampered by the brief lifetimes of collisional complexes or a crowded state density, making it difficult to identify distinct resonances. To date, the observation of molecule-molecule resonances has been limited, with a singular detection in collisions involving triplet NaLi molecules. When it comes to atom-molecule interactions, resonances have been identified solely in NaLi + Na and NaK + K collisions. In this presentation, I will delve into our investigation of Feshbach resonances encountered with NaLi. We uncovered a complex array of 25 resonances during NaLi + Na collisions, decipherable through cutting-edge quantum-chemical calculations. These findings are associated with collisional complexes measuring 30 to 40 Bohr radii, emerging from the interplay of spin-rotation and spin-spin couplings, alongside anisotropic atom-molecule interactions. Our studies on the inelastic collisions involving NaLi molecules present a puzzle, suggesting that even highly reactive molecules lacking a reaction barrier may form stable, long-lived collisional complexes.

Autonomous demon with coupled qutrits

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Few-level systems coupled to thermal baths provide useful models for quantum thermodynamics and the role of heat currents in quantum information settings. Useful operations such as cooling or thermal masers have been proposed in autonomous three-level systems. In this work, we propose the coherent coupling of two qutrits as a simultaneous refrigerator and heat pump of two reservoirs forming a system. This occurs thanks to the coupling to two other reservoirs which are out of equilibrium but do not inject heat in the system. We explore the thermodynamic performance of such operation and discuss whether it can be distinguished from the action of a Maxwell demon via measurements of current fluctuations limited to the working substance [1].

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Automatic generation of spin and spin-bath Hamiltonians

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Magnetism and spin physics is a true quantum mechanical effect and its description usually requires multi reference methods and can be hidden in the standard description of moelcules in quantum chemistry. Here we present a twofold approach to the description of spin physics in molecules and solid state physics for details see [1, 2]. First, we present a method that identifies the single-particle basis in which a given subset of the orbitals are equivalent with spin degrees of freedom for models and materials which feature significant spin physics. We introduce a metric for the spin-like character of a linear combinations of orbitals of which the optimization yields the optimal spin-like configurations. Second we demonstrate a generalized Schrieffer-Wolff transformation method to extract the effective Hamiltonian projected on the subspace of the Hilbert space in which the charge degree of freedom of electrons occupying the previously identified orbitals is negligible. The method then yields an effective spin or spin-bath Hamiltonian description for the system. This generalized Schrieffer-Wolff transformations is applicable to a wide range of Hamiltonians and has already been successfully employed with a selection of quantum chemistry Hamiltonians of molecules.

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Thermodynamic Property of a CMOS Device beyond Landauer Limit

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Understanding the thermodynamic properties of computation is not only physically interesting but also holds significant practical implications. In 1961, Rolf Landauer from IBM introduced the Landauer principle, establishing a lower bound for the dissipation of energy required to reliably erasing one bit of information. The bound is expressed as $k_BT \ln 2$, where k_B is the Boltzmann constant, and T is the temperature of a thermal reservoir. This value is approximately 3.0×10^{-21} J at room temperature. Although extremely small, achieving this limit is feasible through the quasi-static erasure process of memory. However, practical implementation may result in increased energy dissipation. Beyond serving as mere memory systems, computers execute complex mathematical operations through logic circuits composed of numerous logic gates. Hence, discussing the thermodynamic properties of this system is interesting. Recent advancements in nonequilibrium statistical mechanics have unveiled instances of dissipation surpassing the Landauer bound in practical applications. In addition to memory systems, the thermodynamic analysis of more complex computers, such as logic circuits, Brownian computers, and models proposed in computer science, has become possible. However, existing studies are limited to ideal models and settings. For physically implemented computers, only a few studies have analyzed the relationship between computational processes and their thermodynamic properties. This study focuses on a specific logic gate and analyzes the thermodynamic properties in terms of the extended Landauer bound [1]. NAND gates, comprising CMOS transistors operating in sub-threshold regions, exhibit additional dissipation due to dynamic changes in the logical states encoded in the output voltage. These findings have been quantitatively revealed. The Landauer bound stems from logical irreversibility and the inability to accurately infer the input from the output state after computation. This reduces the number of logical states (M) to be realized before and after the computation, thus increasing the corresponding entropy (H), up to ln 2 in the case of a 1-bit complete information erasure. In this study, alongside the dissipation associated with this logical irreversibility, an additional dissipation, contingent on the initial system distribution, was identified through an investigation of the Kullback-Leibler divergence evaluated with Gillespie algorithm. While no difference was observed in the former dissipation under varying input voltage conditions, the latter exhibited greater dissipation under certain conditions. We interpret this factor as a consequence of logic state flipping.

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Network analysis for the steady-state thermodynamic uncertainty relation

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We perform network analysis of a system described by the master equation to estimate the lower bound of the steady-state current noise, starting from the level 2.5 large deviation function and using the graph theory approach. When the transition rates are uniform, and the system is driven to a non-equilibrium steady state by unidirectional transitions, we derive a noise lower bound, which accounts for fluctuations of sojourn times at all states and is expressed using mesh currents. This bound is applied to the uncertainty in the signal-to-noise ratio of the fluctuating computation time of a schematic Brownian computation plus reset process [1,2] described by a graph containing one cycle. Unlike the mixed and pseudo-entropy bounds that increase logarithmically with the length of the intended computation path, this bound depends on the number of extraneous predecessors and thus captures the logical irreversibility [3].

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A Universal Framework for Quantum Dissipation: Minimally Extended State Space and Exact Time-Local Dynamics

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With the impressive advances towards quantum technological realizations, the need for highly accurate, versatile, and computationally efficient approaches to simulate the dynamics of open quantum systems has triggered compelling activities. A particular challenge is to consistently account for subtle quantum correlations between system and surrounding such as retarded reservoir feedback (non-Markovianity) as well as system-reservoir hybridization. Hence, for schemes that go beyond the conventional Markov approximation a variety of methods across different sub-disciplines has been developed such as hierarchical equations of motion, Lindblad-pseudomode formulas, Chain-mapping approaches, phase space Fokker-Planck equations, stochastic unravelings, and quantum master equations. This diversity, while indicative of the field's relevance, has inadvertently led to a 'fragmentation' that hinders a cohesive advancement and application to current problems for complex systems.

How are different approaches related to each other? What are their strengths and limitations? A systematic overview and concise discussion is highly wanted. Here, we make use of a unified framework which very conveniently allows to link different schemes and, this way, may also catalyze further progress. In line with the state of the art, this framework is formulated not in fully reduced space of the system but in extended state space which in a minimal fashion includes effective reservoir modes. This in turn offers a comprehensive understanding of existing methods, elucidating their physical interpretations, interconnections, and applicability.

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Full counting statistics and Kardar-Parisi-Zhang scaling in infinite temperature quantum spin chains

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We investigate the spin-transfer statistics in one-dimensional anisotropic Heisenberg (XXZ) spin models. We introduce a novel tensor-network approach, with which we extract high-order cumulants directly from the generating function at unprecedented long times. We can validate our approach against quantum trajectory simulations - which give access to the full distribution but are limited to shorter times - allowing us to compare cumulant up to the sixth order for S=1/2 and S=1 spin chains [1]. S=1/2 spin chains are integrable, and at the isotropic point (Δ=1) the variance of the spin transfer is characterized by an algebraic growth in time with a superdiffusive z=3/2 exponent as for a Kardar-Parisi-Zhang (KPZ) universal scaling. Fluctuations are weakly non-Gaussian but incompatible with a Baik-Rains distribution, in agreement with recent Google experiments [2] and with theoretical predictions for classical magnets [3]. In the easy-plane regime (Δ<1) transport is ballistic with asymptotically Gaussian distribution. In the XX limit (i.e., Δ=0), our simulations are verified by fermionizing the spin chain. Remarkably, in the diffusive easy-axis regime (Δ>1), we find distinctively non-Gaussian fluctuations, and cumulants consistent with those obtained from Mainardi-Wright family distributions [3]. For non-integrable S=1 spin chains, we find a distinctively different scenario. Spin transfer is the easy-plane regime displays a ballistic-to-diffusive crossover for S=1, while at the isotropic point, a resilient KPZ scaling is observed, suggesting near-integrability. The dynamical exponent drifts possibly towards a diffusive regime with z=2 - although we cannot rule out a z=5/3 Fibonacci-ratio exponent [4].

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Quantum Computing and Mobility (QCMobility)

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Mobility is currently undergoing major changes: new technologies and intelligent transport systems are creating challenges in short time that are not entirely foreseeable. In addition, climate change requires energy efficiency, for instance, in the control of routes and traffic flows, in demand-orientated transport or in the logistics sector.

In this poster we provide an overview of the project QCMobility, which explores how these topics might be attacked with the help of quantum computers in the future. The problems selected in QCMobility are issues that are already highly relevant today and will become even more important in the future due to more flexible or highly automated transport systems. Here, quantum computing could provide novel concepts for solving multidimensional optimisation problems. The use of these methods must be trialled in the near future in order to support a transformation in the field of mobility.

Posters

Exciton-Phonon Effects in the Coherently Driven Two Quantum Dots-Photonic Microcavity System Showing Cooperative Two-photon Lasing

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We show cooperative two-photon lasing in the coherently driven quantum dots coupled to single mode photonic crystal cavity system. We study the effect of exciton-phonon interaction present in the system in non-perturbative approach by making a polaron transformation[1] and shown results for T=5K and 20K. Here, we consider two separate quantum dots (QDs) coupled to a single mode photonic-crystal (PhC) cavity. The Hamiltonian for the system in rotating frame of cavity frequency is given by,

$$H = \hbar\Delta_1\sigma_1^+\sigma_1^- + \hbar\Delta_2\sigma_2^+\sigma_2^- + \hbar(g_1\sigma_1^+ a + g_2\sigma_2^+ a + H.C) + H_{ph}.$$

where, the detuning $\Delta_i = \omega_i - \omega_c$, ω_i, ω_c are the transition frequency between ground state $|g_i\rangle$ and excitonic state $|e_i\rangle$ for i^{th} QD, cavity mode frequency respectively. The lowering and raising operators for QDs are given by $\sigma_i^+ = |e_i\rangle\langle g_i|$, $\sigma_i^- = |g_i\rangle\langle e_i|$ and g_i is the exciton-cavity mode coupling constant, a is cavity field operator. The last term in Hamiltonian, H, represents the exciton and longitudinal acoustic phonon interaction , $H_{ph} = \hbar\Sigma_k\omega_k b_k^\dagger b_k + \hbar\Sigma_i\lambda_k^i|e_i\rangle\langle e_i|(b_k + b_k^\dagger)$. Here, $b_k(b_k^\dagger)$ is the annihilation(creation) operator of k^{th} phonon-bath mode of frequency ω_k. Here, λ_k^i is the coupling strength of exciton $|e_i\rangle$ to k^{th} mode of the phonon bath. We perform polaron transformation for the Hamiltonian, H using $H' = e^S H e^{-S}$, where $S = \Sigma_i\sigma_i^+\sigma_i - \Sigma_k\frac{\lambda_k^{e_i}}{\omega_k}(b_k^\dagger - b_k)$. Similar methods used to treat exciton-phonon interaction effect in other works [2]. We derive the time-convolutionless master equation for the system treating the phonon bath interaction terms after polaron transformation perturbatively using Born-Markov approximation. We have also included the incoherent processes present in the system such as spontaneous emission of excitons (γ_i), pure dephasing, (γ_i') and cavity decay (κ) phenomena.

$$\dot{\rho}_s = -\frac{i}{\hbar}[H_s, \rho_s] - L_{ph}\rho_s - \frac{\kappa}{2}L[a]\rho_s - \Sigma_{i=1,2}(\frac{\gamma_i}{2}L[\sigma_i^-] + \frac{\gamma_i'}{2}L[\sigma_i^+\sigma_i^-])\rho_s.$$

Here $L[\hat{O}]$ represents Lindblad super operator. L_{ph} corresponds to phonon induced processes. We further make approximations, $\Delta_i >> g_i, \eta_i$ to obtain a simplified master equation (SME). We use this SME to write the density matrix elements rate equations and by using Scully-Lamb theory [3], performing trace over collective QD states, the rate equation for probability of having ‘n’ photons in the cavity mode is obtained. Thereby, single and multi-photon emission and absorption rates are caluculated numerically.

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Experimentally probing Landauer's principle in the quantum many-body regime

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Landauer's principle establishes a bridge between information theory and thermodynamics by fundamentally relating the erasure of a single bit of information to a minimum amount of heat dissipation. While extensively explored in the context of few-body quantum systems, the question arises whether this insight can be extended and potentially leveraged in complex quantum many-body systems, where thermodynamics emerges as an effective coarse-grained description. This talk aims to present the first experimental measurement of Landauer's principle in a quantum field simulator consisting of two coupled one-dimensional ultra-cold Bose gases. We characterized (generalized) entropy production along a global mass quench from a Klein-Gordon to a Luttinger liquid model. Additionally, we may briefly discuss theoretical work on the quantum thermodynamics of local quantum quenches in the many-body domain.

Coherent ergotropy in thermalized intra-system couplings

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In this study, we delve into the interplay between ergotropy, the extractable energy by unitary operations and thermodynamic work input. Focusing initially on a single two-level system (TLS), we establish a direct correspondence between work input, required for changing the TLS transition frequency, and its ergotropy, assuming the state of system is pure. However, presence of mixedness breaks the correspondence between the extractable energy and the injected one (work), the latter being consistently larger than the former. Expanding our investigation to a two-TLS thermal state governed by a model with proper interaction which allows for local coherence (and coherent ergotropy, in turn) generation, as explored by some of us [1], we uncover a non-trivial relation between the work input needed to manipulate the frequency of one of the subsystems and its ergotropy. This reveals a mechanism whereby the work done on the system is partially converted into extractable energy, particularly in a scenario where the ergotropy originates only from coherence and not population inversion. We compare these results to a similar two-TLS thermal state under a model with xx interaction (transverse Ising model) which lacks the local coherence generation feature. Here, we identify a loss-loss scenario, wherein the injected work remains inaccessible as it can not be transformed to a useful form of energy, i.e. ergotropy. Our research illuminates the relation between important energy-transformation concepts in quantum systems. By elucidating these relationships, we contribute to a deeper understanding of the energy-transformation properties of quantum systems, offering insights into energy storage or transfer processes and their implications for quantum technologies

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Tunable anomalous diffusion of ultracold Fermi gases in time-dependent disorder: From localization to Fermi-accelerated superdiffusion

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Transport through disorder has been actively studied for the last decades. The majority of these studies, e.g. of Anderson localization, assume a static disorder potential. However, time dependence can strongly accelerate dynamics, and the interplay between localization effects and acceleration could have strong impact on diffusion properties of quantum matter. I will present the results of our experimental investigation of the dynamics of ultracold, spin-polarized fermionic lithium atoms when exposed to an optical speckle potential that can be frozen or continuously varying in both space and time. Depending on the disorder's strength and rate of change, we observe several distinct regimes of tunable anomalous diffusion, ranging from weak localization and subdiffusion to superdiffusion. Especially for strong disorder, where the expansion shows effects of localization, an intermediate regime is present in which quantum interference appears to counteract acceleration. Our system connects the phenomena of Anderson localization with second-order Fermi acceleration and paves the way to experimentally investigate Fermi acceleration when entering the regime of quantum transport.

Resolution of Discrete Quantum Clock-Time Observable

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Time is perhaps the most enigmatic concept in physics [1]. Indeed, we still lack an acceptable explanation for the observed preferred direction of time, and a universally-accepted quantum treatment of time as an observable [2 - 4].

The recently introduced Quantum Theory of Time (QTT) [5] describes the evolution of a quantum state over time as a variable, undergoing virtual displacement, with translations generated by the Hamiltonian. The theory attributes the differences between the spatial and temporal dimensions to the violation of the time reversal symmetry, known as T-violation. If there is no T-violation present, the spatially-averaged time is fixed at one value and so there is no time evolution. However, with T-violation in the system, time is represented as fluctuating at every point in space about a spatially-averaged time that corresponds to the usual time evolution. Although QTT describes the change in the state of clock, it has not yet been applied directly to an operator that represents observable time, i.e. *clock-time*. The aim of this work is to investigate how the expectation value of a clock-time observable changes in time and determine the expected statistics of a clock, within QTT.

For consistency with QTT, any time observable needs to have a canonically conjugate relationship with the Hamiltonian, due to the fact that the Hamiltonian is the generator of translations in time. We examine the complement of the Hamiltonian, Pegg's Age operator [4], as a basis for defining the time observable. In QTT, a clock is represented as a composite system entangled with a T-violating background field. Pegg defined the Age to represent time associated with changes in an arbitrary system. Age can be utilised in QTT to define the time associated with a clock-time observable. Here we apply the Age operator to explore the time-energy uncertainty relation for clock-time and the potential correlation of clock-time with temporal fluctuations in the T-violating background field. We further examine the relationship of the observable to conventional studies of time in quantum mechanics such as the time associated with flight measurement [6].

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Quantum Phase Transitions in periodically quenched systems

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Quantum phase transitions encompass a variety of phenomena that occur in quantum systems exhibiting several possible symmetries. Traditionally, these transitions are explored by continuously varying a control parameter that connects two different symmetry configurations. Here we propose an alternative approach where the control parameter undergoes abrupt and time-periodic jumps between only two values [1]. This approach yields results surprisingly similar to those obtained by the traditional one and may prove experimentally useful in situations where accessing the control parameter is challenging.

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Quantum ratchet with Lindblad rate equations

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A quantum random walk model is established on a one-dimensional periodic lattice that fluctuates between two possible states [1]. This model is defined by Lindblad rate equations that incorporate the transition rates between the two lattice states. Leveraging the system's symmetries, the particle velocity can be described using a finite set of equations, even though the state space is of infinite dimension. These equations yield an analytical expression for the velocity in the long-time limit, which is employed to analyze the characteristics of directed motion. Notably, the velocity can exhibit multiple inversions, and to achieve directed motion, distinct, nonzero transition rates between lattice states are required.

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Electronic Transport in Quantum-Chaotic Nanostructures

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In the exploration of **mesoscopic** two-dimensional (2D) nanostructures, we employ Landauer-Büttiker approach to gain insights into and control over the electrical properties of chaotic quantum transport systems [1,2]. On the classical side, it is widely acknowledged that dynamics is difficult to predict due to chaos, for instance stemming from impurities in a nanostructure. However, in mesoscopic systems, we can push the limit further by employing quantum coherence for our benefit. A striking visual manifestation of quantum mechanical suppression of classical chaos is a **Quantum Scar** [3], where the probability density of an eigenstate condensates in the vicinity of an unstable classical periodic orbit. Our transport setup consists of a 2D quantum dot of an arbitrary shape [4], strongly coupled to finite-width leads [2]. The system is also exposed to an external uniform magnetic field. The computational framework enables calculations of transmission, conductivity, and currents in multi-terminal 2D transport devices. Additional tools facilitate the computation of the local density of states, showcasing possibilities to exploit quantum scars, for example, the so-called bouncing-ball states [5], in the **control of quantum transport**. This approach enables a multitude of applications in quantum electronics.

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Strong light-matter interaction in ferroelectric materials

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In the pursuit of ultra-efficient nanoelectronic devices for the next generation of non-volatile memories, ferroelectric materials have emerged as a focal point of extensive research and interest. This heightened attention stems from their distinct properties, including rapid response speed, non-volatility, and low power consumption [1, 2].

Traditionally, polarization switching in ferroelectric devices has relied on static electric fields. However, achieving a stable switching through single light pulses remains a challenge. Yet, such an accomplishment holds the promise of offering unique advantages, including ultrafast operation, non-contact switching, and retention-loss suppression. In conventional ferroelectric perovskites, such as $LiNbO_3$, $BaTiO_3$ and $PbTiO_3$, only a transient switching under single THz pulses has been theoretically demonstrated [3, 4, 5]. This can be attributed to the dominance of appearing depolarization fields in the switched domains [6] and inter-domain phonon interactions, resulting in the destabilization of the reversed state.

In our research, we are exploring ferroelectric systems and mechanisms capable of achieving permanent switching in response to single THz pulse perturbations. We propose that light pulse-driven ferroelectric switching can substantially improve the switching properties and pave the path for commercialization of the ferroelectric memories.

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Universal Approach to Dynamics of Finite and Extended Atomistic Systems in the Phase Space

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In our work, we propose and construct the theoretical framework for nonadiabatic dynamics under general non-equilibrium conditions based on the stochastic hierarchy of equations of motion (EoM) for various dynamical moments, combinations of positions and momenta. In principle, it unifies the thermalization and real-time evolution for finite atomic systems along the Konstantinov-Perel's contour, i.e. both electrons and nuclei are tackled under the same quantum-mechanical footing.

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Concurrent fermionic simulation gates for superconducting qubits

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Most quantum computation architectures rely on a single specific type of two-qubit gate to form a universal gate set. However, having flexible native entanglement gates can help to reduce circuit complexity, which is highly relevant for the performance of NISQ devices. Here, we propose a scheme to implement a continuous fermionic simulation gate (fSim gate) for superconducting qubits. We simultaneously apply two parametric drives with different frequencies targeting two different transitions. iSWAP-type and CPhase-type of operations can be realized at the same time in one single gate round with tunable angles controlled by drive amplitudes and frequencies. We give analytical formulas of effective coupling strengths covering from dispersive regime to strong drive regime. Our study opens up new possibilities for more versatile gate schemes.

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Entropy flow in CR-gate

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Cross-resonance gate is a two-qubit gate performed by driving one of the qubits (control) at the frequency of the other (target). We study such a sytem in the presence of external reservoirs [1]. In our model each qubit is coupled to a reservoir, where each reservoir is at a different temperature. The qubits also interact with each other and hence evolve to become entangled. We calculate the entropy flow through the reservoirs and see how it is affected by the entanglement between the qubits [2]. We use Keldysh formalism to calculate this entropy flow [3]. Obtaining such a relation makes it feasible to control the entropy flow within a system by controlling the entanglement between qubits.

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The role of virtual photons in the quantum locality of the Aharonov-Bohm effect

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In the Aharonov-Bohm (AB) effect, quantum interference is observed for a charged particle even when there is no local overlap with the external magnetic field. Here we argue that the quantum electrodynamic approach provides a microscopic picture that can solve this "locality problem". In particular, the interaction between a charge and a distant magnetic flux is mediated by virtual photons. We show the gauge invariance of the local phase shift induced by an external magnetic flux [1], which is in sharp contrast to the standard semiclassical result.

In addition, the effect of virtual photons in the interference is manifested by a change in their spectrum. When a vacuum is confined between two ideal conducting plates, the photons acquire effective mass and satisfy the 2D Proca equation. This results in a short-range interaction between the charge and the magnetic flux, and the AB effect is exponentially reduced at a large distance between the two bodies [2]. On the other hand, a semiclassical description of this short-range AB effect is also possible. This raises an interesting question about the reality of virtual photons.

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Monitoring human respiration and diagnosing sleep disorders using an infrared gas imaging camera with quantum detector

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The standard method for diagnosing obstructive sleep apnea (OSA), full-night polysomnography (PSG), requires multiple sensors attached to the body, potentially disturbing sleep. Carbon dioxide, at 4% of exhaled airflow, has a distinct infrared absorption wavelength (4.26 μm), enabling clearer analysis of breathing and sleep via infrared optical gas imaging [1]. This study aimed to monitor respiration and diagnose sleep disorders using an infrared gas imaging camera with a quantum detector, assessing its suitability for OSA diagnosis. Data from PSG and infrared imaging were collected from 50 volunteers concurrently. Respiratory signals were extracted from infrared images using automated algorithms, and compared with PSG results. Respiratory events detected by infrared imaging strongly correlated with PSG findings. Receiver operating characteristic analysis supported the appropriateness of infrared imaging for OSA diagnosis. It accurately detected sleep-related respiratory events, suggesting its potential as an OSA screening tool.

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Emerging Weyl Point in a ferroelectric

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After a discover of topology in condensed matter physics, tremendous research has been worked to find topological material in electronic system which Dirac point or Weyl point is inherited. The interest has not been restricted in Fermionic system but extended to Bosonic system spontaneously for its exotic potential in application.

While Dirac states are required to have time reversal symmetry (TRS) and inversion symmetry (I) simultaneously, Weyl points are required not to respect one of them. As phonon is a bosonic particle, TRS is always be protected whereas inversion symmetry would be replaced by other crystalline symmetries. Based on a data driven discovery work in topological phononic material with crystalline symmetry analysis, it could be noted that materials with topological phonon would be easily found. Interestingly, however, ferroelectric material deserves to have further attention due to its external controllability and we find nonsymmorphic ferreoelctric materials could be provocative for its usage in memory industry.

Utilizing nonsymmorphic symmetry in ferroelectric materials, it is expected to facilitate topological states possessing Weyl points in ferroelectric, which is attractive candidate in memory device industry [1]. We also present strain engineering to maximally activate topological states.

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Confinement effects on the weak-field magnetic susceptibility of a two-dimensional electron gas

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Modern techniques can restrict the motion of an electron gas to a two-dimensional plane, say in GaAs-AlGaAs heterojunctions, without posing any conceptual challenges. However, confining such a low-dimensional system whose linear dimension is comparable to or less than the cyclotron radius to a finite volume introduces new energy scales in the problem and leads to modifications in the Landau susceptibility. Explicit spin-orbit coupling (SOC), albeit small compared to other involved characteristic energies, via Rashba [1] or Dresselhaus [2] interactions produces a splitting of the otherwise degenerate energy bands around the Fermi level. This may significantly affect the thermodynamic [3] and the transport properties [4] of low-dimensional systems. We study the weak-field magnetic susceptibility of two-dimensional electron gas under isotropic parabolic, anisotropic, and Gaussian confinements. The asymmetric (anisotropic) confinement, in semiconductor quantum dot structures, restricts the motion of the charge carriers. They are quite popular in the field of elliptical quantum dots. In semiconductors, impurity is considered very important in maneuvering the system's properties. Gaussian confinement potential is a pure mathematical representation of such impurity potentials. We found that susceptibility strongly depends on the boundary confinement and removal of the boundary results in a singularity. We show that a field-dependent susceptibility emerges when the confinement is Gaussian, in contrast to the canonical case of a field-independent susceptibility. We also show that the weak-field susceptibility is independent of the anisotropy parameter as well as the spin-orbit coupling for the anisotropic confinement model. For all the other models, the susceptibility vanishes for large spin-orbit coupling [5]. We also found the de-Haas van Alphen oscillations of the magnetic susceptibility, at very low temperatures and very strong magnetic fields, depend significantly on the depth and the range of the confining potential for Gaussian confinement [6].

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Spin ordering in an intercalated magnetic bilayer

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Two-dimensional magnetic materials are considered as promising candidates for developing next-generation spintronic devices by providing the possibility of scaling down to nanometers. However, a low Curie temperature is a crucial problem for practical applications, being intimately related to weak interlayer exchange coupling. We recently reported a chemical way of intercalation to raise the Curie temperature dramatically [1].

The Heisenberg model of istropinc spins impedes long-range ordering in a 2D lattice above 0 K according to the Mermin-Wagner theorem. 2D magnet at finite temperature has been enabled by presence of spin gap like magnetic anisotropy. It is also possible to introduce the spin gap through interlayer exchanging coupling via magnetic atoms intercalated as in our study. Here we study thermodynamic behavior of spins across the Curie temperature with and without intercalation.

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Quantum correlations from work statistics of many-body systems

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We study manifestations of quantum coherence and quantum criticallity in the work distribution function (WDF) of many-body systems. We consider general processes whose drive couples to a conserved charge in a sybsystem. In the sudden limit we find exact relations between moments of the WDF and charge coherence in the initial state. While the first two moments are captured by the charge susceptibility, charge coherence affects the third moment $\langle W^3 \rangle$. We then study the crossover to the adiabatic limit in solvable models and near quantum critical points. We demonstrate our results in quantum dots (QDs), where the WDF allows to directly measure the Kondo binding energy.

Charge dissipation in Josephson Circuits and its Impact on Phase Dynamics

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We theoretically investigate the escape rate occurring via quantum tunneling in a system affected by tailored dissipation. Specifically, we study the environmental assisted quantum tunneling of the superconducting phase in a current-biased Josephson junction. We consider Ohmic resistors inducing dissipation both in the phase and in the charge of the quantum circuit. We find that the charge dissipation leads to an enhancement of the quantum escape rate. This effect appears already in the low Ohmic regime and also occurs in the presence of phase dissipation that favors localization [1]. We further discuss the influence of temperature on the observed effect and possible technological applications.

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Quantum reservoir computing on random regular graphs

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Quantum reservoir computing combines the inherent dynamics of many-body quantum systems with classical learning techniques. Notably, this approach differs from variational quantum algorithms on noisy systems, which are susceptible to the well-known barren plateaus phenomenon. Here, we introduce a strongly interacting spin model on random regular graphs as the quantum component, and investigate the interplay of static disorder, graph connectivity, learnability, and memory capacity. We address linear and non-linear tasks such as delayed decision making, logical multitasking, and the reconstruction of entangled states, and discuss optimal learning and memory performance regimes in terms of various encoding schemes, interactions, localization, and the many-body structure of the static Hamiltonian.

Kadanoff-Baym Equations for open quantum systems

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We study the temporal evolution of quantum mechanical fermionic particles exhibiting one bound state within a one-dimensional attractive square-well potential in a heat bath of bosonic particles. For this open quantum system we formulate the non-equilibrium Kadanoff-Baym equations for the system particles by taking the interactions to be elastic 2-2 scatterings with the heat-bath particles. The corresponding spatially imhomogeneous integro-differential equations for the one-particle Greens's function are solved numerically. We demonstrate how the system particles equilibrate and thermalize with the heat bath and how the off-diagonal elements of the density matrix, expressed in the one-particle energy eigenbasis, decohere, so that only the diagonal entries, i.e. the occupation numbers, survive. In addition, the time evolution of the (retarded) Green's function also determines the spectral properties of the various one-particle quantum states.

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Quantum Reinforcement Learning in the presence of Thermal Dissipation.

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A study of the effect of thermal dissipation on quantum reinforcement learning is performed. For this purpose, a nondissipative quantum reinforcement learning protocol is adapted to the presence of thermal dissipation. Analytical calculations as well as numerical simulations are carried out, obtaining evidence that dissipation does not significantly degrade the performance of the quantum reinforcement learning protocol for sufficiently low temperatures, in some cases even being beneficial. Quantum reinforcement learning under realistic experimental conditions of thermal dissipation opens an avenue for the realization of quantum agents to be able to interact with a changing environment, as well as adapt to it, with many plausible applications inside quantum technologies and machine learning [1-2].

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Static and dynamics spin states in quantum mechanical solenoid structures

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We have used the real-time time-dependent Kohn-Sham equations, within adiabatic local density approximation, to reveal various Berry-curvature characteristics of solid states. We demonstrate that the quantum anomalous Hall conductivity and the quantum spin Hall conductivity of real-material bulk topological insulators can be directly obtained in the real-time profile. We now extend our study to nonlinear optical responses associated with spin-orbit dynamics. We particularly focus on the structures with the built-in geometrical chirality. When such a chiral structure is exposed to an axial magnetic field, the consequent charge dynamics exhibits sharply analogious responses as the axial anomaly of high-energy physics of massless fermions. We discuss the limitation and utility of local spin density approximation for the exchange-correlation magnetic field in the aforementioned spin-orbit dynamics.

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Ab initio molecular dynamics of Rydberg-type electronic excited state dynamics in small sodium water clusters

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Ab initio molecular dynamics calculations on a time scale of 20 picoseconds were performed for Rydberg-type excited states of Na (H2O)n (n = 1, .., 5) mixed clusters considering the TDDFT method, including the ωB2PLYP double-hybrid exchange-correlation functional and def2-TZVPD basis set. Fluctuations of the charge and the sodium-oxygen atomic distances predict that, the 3s1 electron of the sodium atom are transferred from the delocalised Rydberg orbitals to the Rydberg orbitals around the water molecules and the sodium atom becomes positively charged with around 0.6e after the first 10 ps. On the other hand, some of the water molecules can move away up to 5 Å from the sodium with a significant negative charge on them. It has been shown that non-radiative relaxation cannot be excluded, they can mostly occur for cases n >= 4. The results confirm that the adiabatic photo-ionisation can occur on the basis of cluster disintegration.

Telling different unravelings apart via non-linear quantum-trajectory averages

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The Gorini-Kossakowski-Sudarshan-Lindblad master equation (ME) [1] governs the density matrix of open quantum systems (OQSs). When an OQS is subjected to weak continuous measurement, its state evolves as a stochastic quantum trajectory, whose statistical average solves the ME [2]. The ensemble of such trajectories is termed an unraveling of the ME. We propose a method to operationally distinguish unravelings produced by the same ME in different measurement scenarios, using nonlinear averages of observables over trajectories. We apply the method to the paradigmatic quantum nonlinear system of resonance fluorescence in a two-level atom [3]. We compare the Poisson-type unraveling, induced by direct detection of photons scattered from the two-level emitter, and the Wiener-type unraveling, induced by phase-sensitive detection of the emitted field. We show that a quantum-trajectory-averaged variance is able to distinguish these measurement scenarios [4]. We evaluate the performance of the method, which can be readily extended to more complex OQSs, under a range of realistic experimental conditions.

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Open Quantum Systems with Kadanoff-Baym- and Lindblad equations

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Open Quantum Systems are widely used to describe the density matrix of one particle or a chain of interacting particles, which are surrounded by a thermal heat bath. Usually this heat bath is assumed to be coupled as proposed in the Caldeira-Leggett model, in a Markovian approximation with weak coupling and Ohmic environment. Nevertheless, the question of thermalization and a variety of assumptions that are made in this ansatz are not fully understood yet. However, Lindblad dynamics are frequently discussed in heavy ion physics (Quarkonia) and recently become of interest in quantum computer applications (Schwinger model).

We want to pave the way for another application of Lindblad dynamics, the description of non-relativistic bound states, as for example the deuteron, by using the already well understood techniques on a quantum mechanical level, and adapting them to a one dimensional non-relativistic bound state framework. Furthermore, we discuss limitations and subtleties of the application of Lindblad dynamics in heavy ion physics. Here we will argue, using Keldysh-Schwinger techniques, that collisions in the language of second quantization can only be modelled if further terms are added to the Lindbladian. However, this contradicts the ansatz of Caldeira and Leggett concerning the (weak) linear coupling and requires to rethink, what the actual frameworks are.

Detector tuned overlap Catastrophe in quantum dots

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Anderson overlap catastrophe (AOC) is a well-known many-body effect that arises when a local potential of a Fermi-sea is abruptly changed. The AOC physics is expected to play a key role in the prototypical experimental setup of a charge detector that is electrostatically coupled to a mesoscopic system, in the form of measurement back action (MBA). In quantum dot structures, that are highly tunable mesoscopic systems, AOC physics is yet not experimentally explored with the much desired tunability. Moreover, the MBA effects that are observed in experiments are often interpreted using approximate phenomenological theories, which fail to properly account for the non-perturbative aspects associated with AOC. We demonstrate that a standard quantum-dot detector can be employed as a highly tunable probe of the AOC. We show that, signatures of AOC are present in the MBA effects observed in existing experiments, and give explicit predictions allowing to tune and pinpoint their non-perturbative aspects. A key ingredient of our analysis is an exact numerical solution of the MBA, that we developed based on the techniques used to understand the famous X-ray edge problem. We also show that the popular phenomenological theory used to account for MBA, referred to as P(E) theory, is a perturbative limit of our exact theory. Our approach serves as an effective theoretical framework to study complex MBA effects in experiments.

Detecting single gravitons with quantum sensing

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The quantization of gravity is widely believed to result in gravitons - particles of discrete energy that form gravitational waves. But their detection has so far been considered impossible. Here we show that signatures of single gravitons can be observed in laboratory experiments. We show that stimulated and spontaneous singlegraviton processes can become relevant for massive quantum acoustic resonators and that stimulated absorption can be resolved through continuous sensing of quantum jumps. We analyze the feasibility of observing the exchange of single energy quanta between matter and gravitational waves. Our results show that single graviton signatures are within reach of experiments. In analogy to the discovery of the photoelectric effect for photons, such signatures can provide the first experimental evidence of the quantization of gravity.

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Optomechanical analogues of spacetime superpositions

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We develop of an experimental proposal to simulate the model for spacetime superpositions proposed by Foo, Arabaci, Zych, and Mann in Phys. Rev. Lett. 129, 181301 (2022) , using an optomechnical experiment. The idea is to create a superposition of boundary conditions, which is the core feature of the proposed quantum gravitational model, in a laboratory experiment. This project will in particular explore what scenarios can be implemented by preparing one mirror of an optical cavity in a spatial superposition reffered to as an optomechanical cat-state - that would in turn create a superposition of cavity sizes.

Dynamics of a quantum interacting system - Global approach extended beyond the Born-Markov and secular approximations-

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Open quantum interacting systems are prototypical in various fields such as quantum optics, quantum transport and quantum thermodynamics. The role of interaction between the subsystems in obtaining a master equation has been repeatedly discussed to describe a reasonable stationary state for the total relevant system [1-4]. A recent study on quantum thermodynamics[5] showing the necessity of the interaction to keep the thermodynamics 2nd law attracts renewed interest, called the global approach. However, the approach has been frequently discussed under the Born-Markov and secular approximations.

In this presentation, we show how the choices of the following points in deriving master equations affect the dynamics :

(1) interaction between the subsystems (global or local approach),

(2) the rapid oscillating terms in the dissipator (with or without the secular approximation),

(3) the finiteness of the correlation time of the environmental system (with or without Born-Markov approximation),

taking a model of energy transport under a local dissipation[6].

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Heat transport across a Josephson junction

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In heat transport through nanostructures, quantum effects play an important role. There, intriguing phenomena can emerge from the properties of a quantum system and heat baths. For instance, in 1983, Pendry predicted the quantization of thermal conductance [1] and then it has been observed in various systems involving phonons and photons. As triggered by this seminal work, quantum heat transport serves as a tool for understanding fundamental physics as well as applications for quantum thermal devices.

The superconducting quantum circuit is an ideal platform for the observation of controllable heat current at extremely low temperatures (sub-kelvin temperature range). The Josephson junction is the main building block of the superconducting circuits, and its non-linearity induces the nontrivial transport property. Although the properties of an isolated Josephson junction have been understood well, when it is coupled to a dissipative environment, its properties change drastically. Schmid predicted that the Josephson junction shunted by a resistor undergoes a quantum phase transition at zero temperature [2]. When the shunted resistance is smaller than the resistance quantum, $R_{\mathrm{Q}} = h/(2e)^2 \approx 6.45\ \mathrm{k}\Omega$, the Josephson junction behaves superconducting. In contrast, when the resistance exceeds the critical value, the Josephson junction becomes insulating. Recently, thanks to the technological development of superconducting circuits, the Schmid transition has been investigated from the viewpoint of heat transport and questioned for the existence of the insulating phase [3].

In this poster, we present our recent theoretical work on heat transport across the Josephson junction, which exhibits the Schmid transition [4]. We first derive the relation between the linear thermal conductance and the admittance of the superconducting circuit at finite frequency and temperature. After that, we evaluate the thermal conductance in the context of the Schmid transition. Our non-perturbative results provide a signature of the Schmid transition in the temperature dependence of the thermal conductance both in the superconducting and insulating sides.

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Quantum simulation of various non-Hermitian systems

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We investigate general NH systems, using the linear combination of unitaries (LCU) in the scheme of duality quantum computing[1] and the unitary expansion (UE) techniques. We utilize the linear combination of unitaries technique for nonunitary dynamics on a single qubit to give explicit decompositions of the necessary unitaries, and simulate arbitrary time-dependent single-qubit nonunitary operator F(t) using duality quantum algorithm. We find that the success probability is not only decided by F(t) and the initial state, but also is inversely proportional to the dimensions of the used ancillary Hilbert subspace. In a general case, the simulation can be achieved in both eight- and six-dimensional Hilbert spaces. In phase matching conditions, F(t) can be simulated by only two qubits. We illustrate our method by simulating typical non-Hermitian systems and single-qubit measurements. We investigate a novel NH quantum system of PT-arbitrary-phase, pseudo-Hermitian- ϕ-symmetric and τ-anti-pseudo-Hermitian. We optimize the quantum circuits and calculate the success probabilities.

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Non-Hermitian generalization of quantum Rényi entropy

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Entropy, which is indispensable in classical and quantum channels, is one of the most important cornerstones in information theory. Non-Hermitian (NH) quantum systems attract research interest increasingly in recent years, among which the PT-symmetric, P-pseudo-Hermitian and their anti-symmetric counterpart systems are focused much more. Many meaningful results and interesting phenomena will appear when we investigate the entropy in quantum systems with NH Hamiltonians. In our work, on the one hand, we extend the application of entropy to distinguish time-evolutions of different classes and phases of typical NH systems. In a general case, we show how to distinguish all the eight phases of the above NH systems step by step. On the other hand, we investigate how to describe the Rényi entropy for NH systems more appropriately. We obtain a concisely and generalized form of α-Rényi entropy, which we extend the unified order- α from finite positive real numbers to zero and infinity. Applied it to anyonic-PT symmetric systems, we reveal the continuous change of information dynamics patterns that originates from the continuity of anyonic-PT symmetry. By exploring the mathematics and physical meaning of the negative entropy in open quantum systems, we connect negative non-Hermitian quantum Rényi entropy and negative quantum conditional entropy, paving the way to rigorously investigate negative entropy in open quantum systems.

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Conference Site Buildings

Pyramida Hotel

Pyramida Hotel was built in 1980 in the neo-functionalist style with an interesting star-like ground plan and pyramid-like outer shape. Last renovation of the hotel took place in 2021-2022. The hotel offers a wide selection of conference services. The hotel offers a wide selection of conference services.

Pyramida Hotel is situated in the residential area of Prague called Břevnov near the Prague Castle and the historical centre of Prague - see map Prague Center. It is, in the same time, near the Prague international airport - about 20 minutes by car. From the Pyramida Hotel you can reach easily many historical and important places of Prague by trams which have their stops nearly in front of the Pyramida Hotel: Prague Castle within 5 minutes, Lesser Town is about 10 minutes by tram, Charles Bridge area, too, Old Town and New Town centers (in the vicinity of Old Town Square and Wenceslas Square) within 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’24 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’.

Church of Our Lady before Týn

The **Church of Our Lady before Týn** (Týn Church) is located in Prague’s Old Town near the Old Town Square. Its construction took place from the middle of the 14th century to the first decades of the 16th century. It is one of the most artistically important churches in Prague, both in terms of architecture and its preserved interior furnishings. Its western facade facing the square is one of the most famous landmarks of Prague.

The Church of Our Lady before Týn really features rare works of art: e.g. the Gothic Passion motifs on the north portal, the altar paintings by the Baroque painter Karel Škréta, the unique Renaissance tombstone of the astronomer Tycho de Brahe, and the rare organ. The Týn organ was built in 1673 by Johann Heinrich Mundt. It is the oldest working organ in Prague; thanks to sensitive reconstruction it has been preserved in its original Baroque form. Their authentic sound can be heard on numerous recordings and in the classical music concerts that are held in Týn Cathedral.

How to get there:
The Church of Our Lady before Týn is situated in the Prague Old Town and its entrance can

be reached from the Old Town Square (see also map ‘Prague Center’).

Special tram will depart from the Pyramida Hotel to a suitable tram stop to facilitate FQMT’24 participants transfer.
The church can also be reached from the Pyramida Hotel by **public transport** and a 15-20 minute walk. First take tram No. 22 or 23 to the Malostranská stop. From this stop, you can cross the Vltava River on the Mánes Bridge in 6-8 minutes on foot. At the end of the bridge you will reach the Jan Palach Square (Náměstí Jana Palacha). Alternatively, you can cross the river by tram No. 2 or No. 18 or by metro (line A) (from Malostranská to Staroměstská stations). On the right hand side of the Jan Palach Square, continue along Kaprova Street (roughly perpendicular to the river) to the Old Town Square (Staroměstské náměstí). When you reach the central part of the square (within about 8-10 minutes), you can easily identify the Church of Our Lady before Týn with two almost identical tall Gothic towers and behind a group of two houses. The entrance to the church is in one of these houses - you will be guided from the area in front of the houses.

Břevnov Monastery

The **Břevnov Monastery** (Břevnovský klášter) was founded as the first monastery in Bohemia by Prince Boleslav II and Saint Adalbert (Vojtěch) of the Slavnik dynasty, Bishop of Prague already in 993 AD. The monastery was built amidst forests, at the source of the Brusnice stream and on a road leading westwards from Prague. For centuries there was only a small settlement around the monastery which was later on surrounded by farms. This Benedictine monastery, however, played the decisive role for the spreading of culture and art in Czech Lands.

The oldest parts of the monastery date back to the 10th century. In 1964 the Pre-Romanesque crypt (open nowadays to the public) of the original 10th century church was discovered below the choir of the present St. Margaret Church. Neither the Romanesque nor the Gothic buildings of the monastery survived. From the 15th century on, the monastery was in a state of poverty for three centuries. During 18th century it was largely rebuilt in the Baroque style.

Most of the Monastery’s present day buildings are dated from 1708 to 1745 and were built in Baroque style by Christoph Dientzenhofer. The same architect also erected the Church of St. Margaret, which is considered to be one of the most remarkable works of Czech Baroque architecture. The presbytery of the church was built by Christoph’s son, Kilian Ignaz Dientzenhofer, architect of many important Baroque churches and palaces of Prague. The altarpieces are the work of Peter Brandl, one of the best Czech painters of high Baroque era.

The interiors of the Břevnov Monastery are decorated by valuable paintings; e.g. in the former ceremonial hall of the monastery, nowadays called Theresian Hall, there is a ceiling painting the Miracle of the Blessed Gunther painted by Kosmas Damian Asam of Bavaria in 1727. This is one of the best preserved ceiling paintings in Prague. The entrance to the monastery is through the ornamented main gateway built by Kilian Ignaz Dientzenhofer in 1740 and decorated with a statue of St. Benedictine. The main building of the monastery complex can be reached then by crossing a large courtyard.

Behind the monastery is situated its large Baroque garden. At its gate is a nice Baroque pavilion called Vojtěška with a chapel above a well which marks the spot where Prince Boleslav and Bishop Vojtěch are supposed to have met and decided to build the Břevnov Monastery.

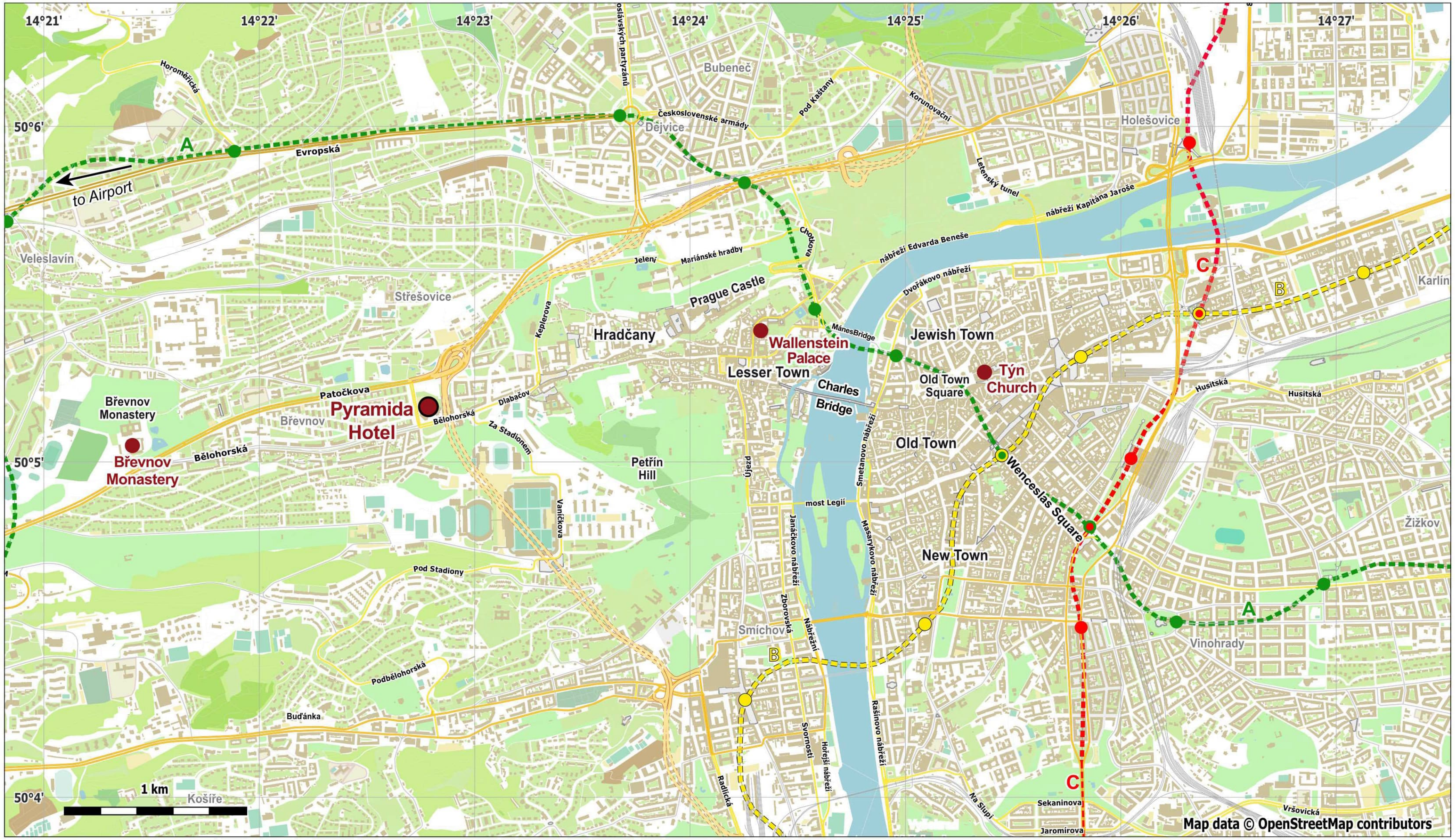
How to get there:

Special tram will depart from the Pyramida Hotel to the Břevnovský klášter stop on Friday afternoon to facilitate FQMT'24 participants transfer. Exact departure time will be announced during the Conference.

For those who will use an **individual transfer**, (see also map 'Pyramida Hotel neighborhood'): The best way from the Pyramida Hotel is to use tram No. 22 or No. 25 (starting up along the Bělohorská street) and reach the Břevnovský klášter stop (4th stop, about 5 minutes). From this stop walk right with respect to the direction in which the tram arrived, cross a wide road (Patočkova street). From here you will see the monastery entrance within about 100 m distance.

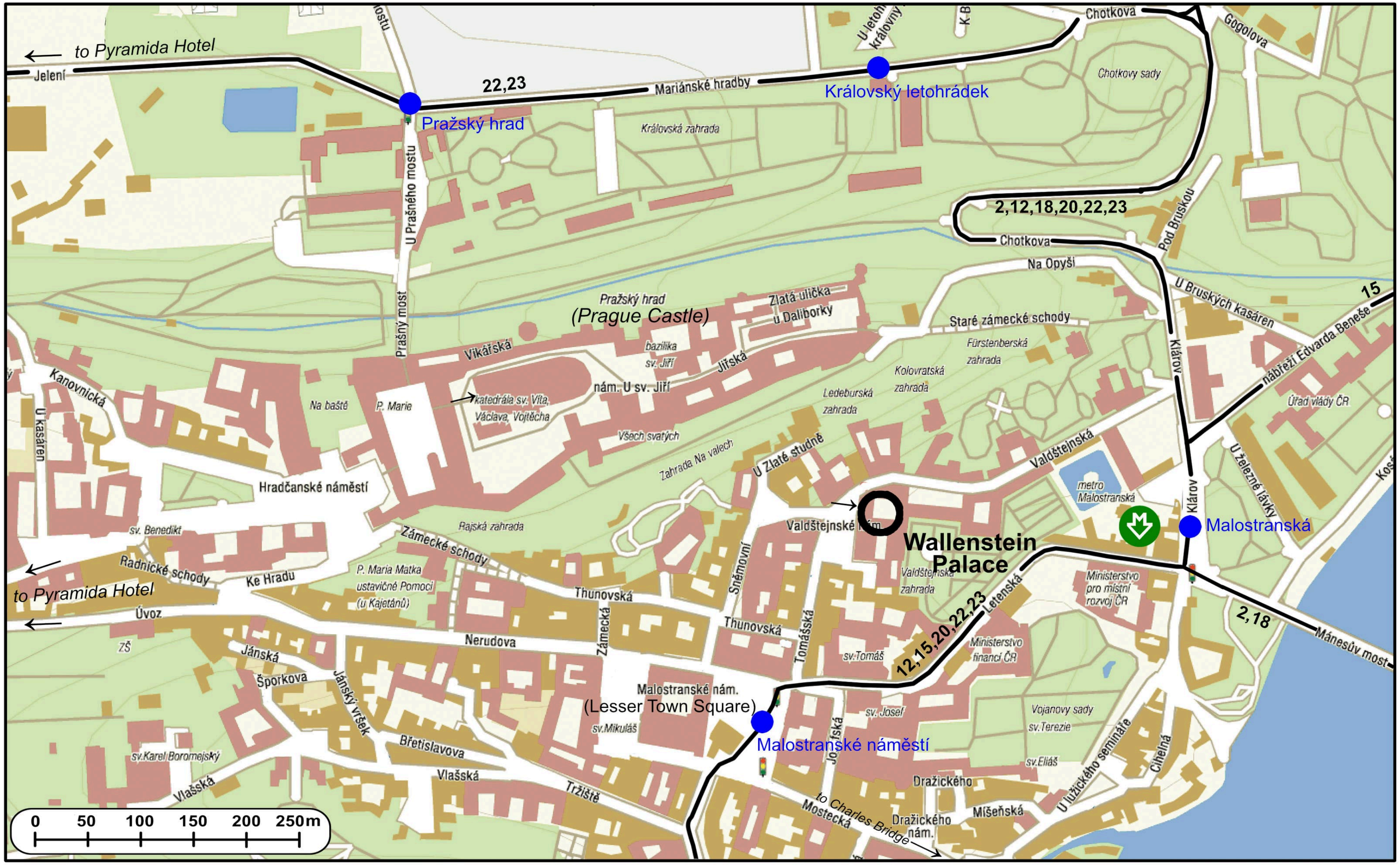
Maps

Prague center



Old Town	*Historical part of Prague*	Pyramida Hotel	*FQMT'24 conference site*	A	*Underground (metro) line with line label and station*
Břevnov Monastery	*Important historical or interesting place*	Týn Church	*FQMT'24 related place*	B	
Břevnov	*Other part of Prague*			C	

Prague Castle and Wallenstein Palace neighborhood



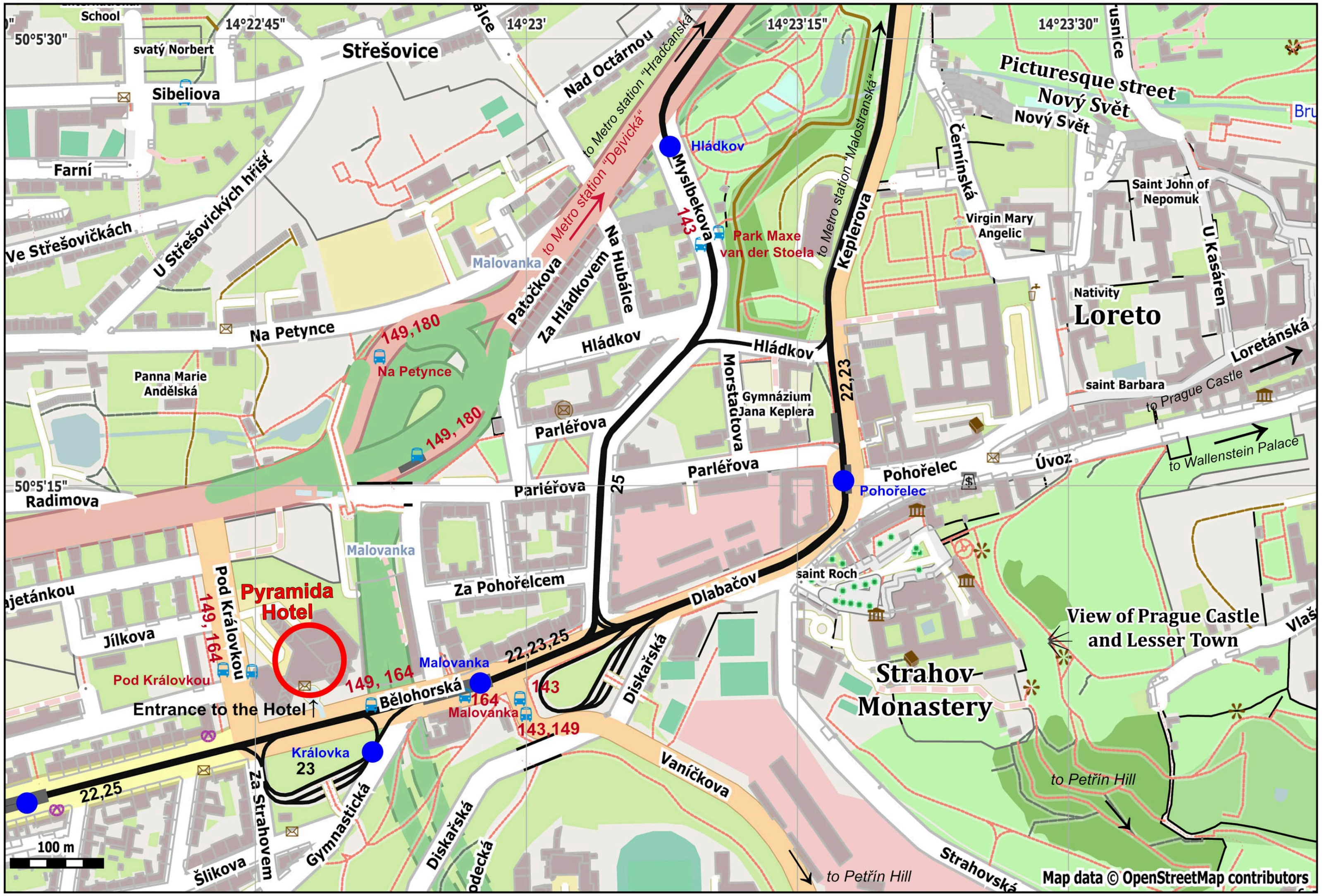
22,23 Tram line with line numbers

Tram stop

Line A underground (= subway, tube, Metro) station

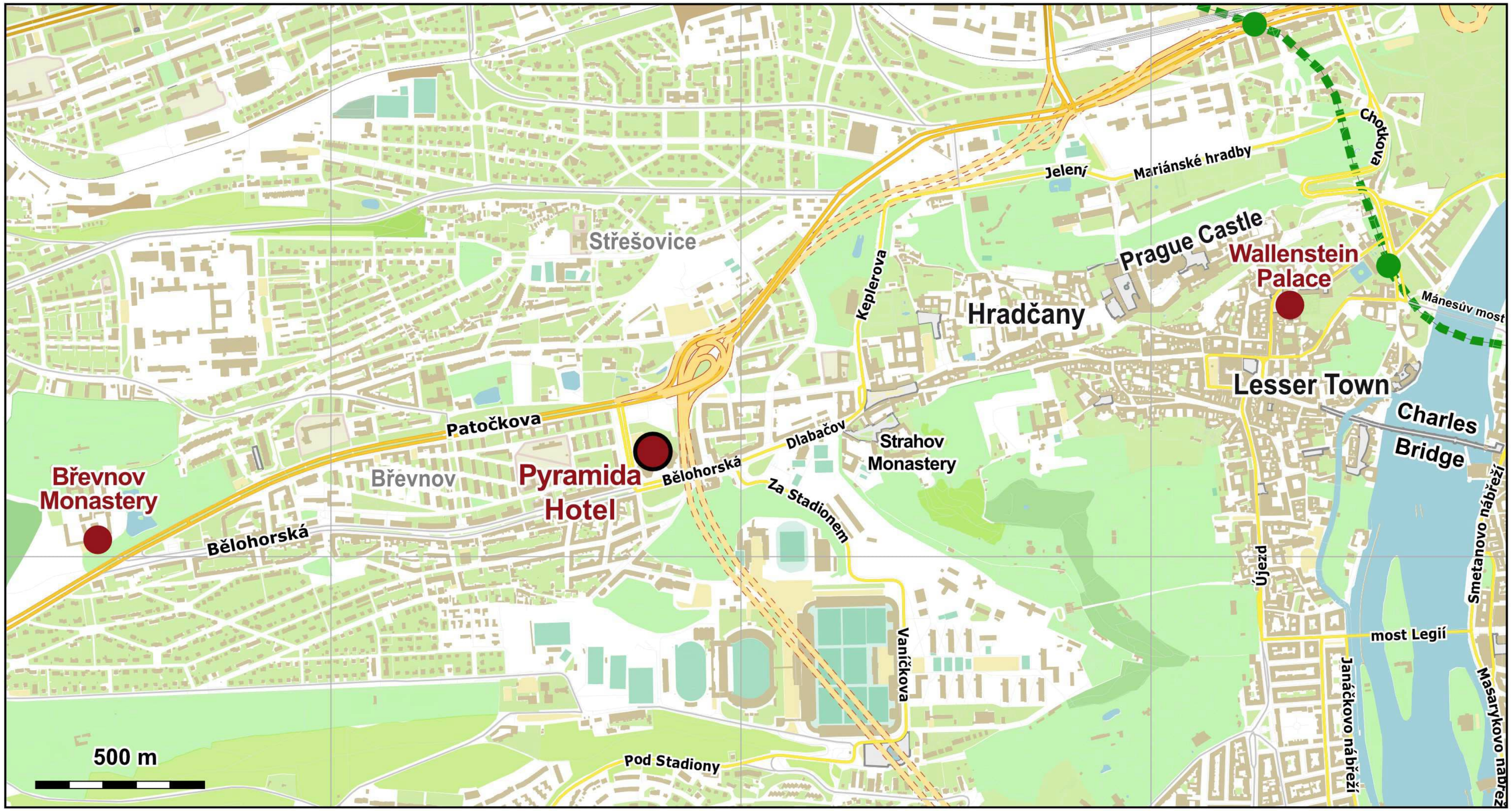
FQMT‘24 relevant places

Pyramida Hotel - access and nearest neighborhood



22,25	Tram lines with line numbers			**Loreto**	interesting place near the Pyramida Hotel
Malovanka	Tram stop with stop name	149, 180 Na Petynce	Bus stop with line numbers and stop name	○	FQMT'24 relevant place

Pyramida Hotel neighborhood



Map data © OpenStreetMap contributors

Lesser Town	*Historical part of Prague*
Strahov Monastery	*Important historical or interesting place*
Střešovice	*Other part of Prague*
Pyramida Hotel	*FQMT'24 conference site*
Wallenstein Palace	*FQMT'24 related place*
	Underground (metro) line A with a station