Frontiers of Quantum and Mesoscopic Thermodynamics

26 July - 1 August 2026, Prague, Czech Republic

Under the auspicies of

Prof. Ing. Jiří Drahoš, DrSc.
1st Vice-President of the Senate of the Parliament of the Czech Republic

Prof. RNDr. Radomír Pánek, Ph.D.
President of the Czech Academy of Sciences

Ministry of Industry and Trade of the Czech Republic

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

Fields

- Non-equilibrium statistical physics, thermodynamics
- Foundations of quantum physics
- Cosmology, gravitation, astrophysics
- Many body physics, quantum field theory
- Quantum optics, optoelectronics, plasmonics, atomtronics
- Quantum simulations
- Metrology
- Tests of quantum gravity
- Physics of quantum information and computing
- Quantum machine learning
- Biophysics, physics of active matter, quantum biology
- Physics of neural networks, artificial intelligence

Phenomena

- Non-equilibrium quantum phenomena
- Transport phenomena far from equilibrium
- Quantum measurement, vacuum, entanglement, coherence
- Macroscopic quantum behavior, cold atoms and molecules
- Turbulence at various scales
- Dissipation, dephasing, noise, decoherence
- Emergent phenomena in strongly interacting open systems
- Topological states of quantum matter, quantum phase transitions
- Dynamics of cellular structures

Systems

- Quantum open systems at various space and time scales
- Quantum heat engines, molecular motors
- Mesoscopic, nano-electromechanical and nano-optical systems
- Biological systems, organoids

Scientific Committee

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Stefan Klumpp (University of Goettingen)
Norbert Kroo (Wigner Physics Research Center, Budapest)
Anthony J. Leggett (* 26 March 1938, † 8 March 2026)
Igor Lerner (University of Birmingham)
Maciej Andrzej Lewenstein (ICFO – The Institute of Photonic Sciences, Barcelona)
Heiner Linke (Lund University)
Peter Vaughan Elsmere McClintock (Lancaster University)
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Georgy Shlyapnikov (Université Paris Sud)
Ady Stern (Weizmann Institute, Rehovot)
Michael Thorwart (University of Hamburg)
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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

Organizing Committee

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Preface

FQMT'26 is a follow-up to the ten 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, FQMT'22, and FQMT'24). For the details of their programs and the history of the FQMT conferences see the www pages https://fqmt.fzu.cz/.

The FQMT'26 conference will be mainly focused on Non-equilibrium and Many-body phenomena; Physics of information; Foundations of quantum physics; and Open quantum, Mesoscopic, Biological, and Gravitational systems.

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, measurements, 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'26 program will thus be concentrated 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. Subjects from astrophysics, gravitation or cosmology related to the above scope will also be included. 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.

Special session on foundations of quantum physics to be held on Monday afternoon will be dedicated to the memory of Luis de la Peña, an exceptional Mexican theoretical physicist, who was regularly attending the FQMT conferences. Luis passed away 17 May 2026.

The second special session on Thursday evening will be dedicated to the memory of Anthony J. Leggett, an exceptional British-American theoretical physicist. Tony (as he was known by his friends) served repeatedly on the FQMT scientific committee, participated at the very first FQMT conference in 2004 and delivered on this occasion the very first of many FQMT conferences public lectures. Tony passed away 8 March 2026.

Following the tradition of the FQMT conferences, FQMT'26 will 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 FQMT'26 topics as defined above, 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'26 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 28) there will be two public lectures accompanied by a concert. The evening will start with a lecture by Philippe Grangier "Quantum Mechanics: from Fundamental Principles to Technological Revolutions". To expand a similar successful arrangement from FQMT'24, the second part of the evening will be devoted to jazz music: first, in the lecture by Bob Montgomery and Allen M. Hermann "How Jazz Musicians Use Improvisation in Communicating with Each Other and with the Audience" and then in the jazz concert of Allen M. Hermann and his Czech musician friends.

On Thursday (July 30) evening, there will be the next exceptional lecture "Macroscopic quantum phenomena and related matters: A brief history and the Nobel Prize in Physics 2025" by Amir O. Caldeira. The public lecture will be introduced by a talk "Remembering Tony Leggett" by Fernando Sols and followed by the concert of classical music.

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'26 program will altogether 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 St. Nicholas Church, the most famous Baroque church in Prague 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.

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'26 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'26 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:
St. Nicholas Church at the Lesser Town
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 public lectures, jazz concert and one of the classical concerts 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'26 participants, e.g., study room on the first floor.

Posters

Poster session will be held on Thursday July 30, from 4:50 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 27
- Public lecture: Pyramida Hotel Lecture Hall A, Tuesday July 28
  This early evening lecture will be given by Philippe Grangier.
- Public lecture: Pyramida Hotel Lecture Hall A, Tuesday July 28
  This evening lecture will be given by Bob Montgomery and Allen M. Hermann.
- Jazz concert: Pyramida Hotel Lecture Hall A, Tuesday July 28
- Classical concert: St. Nicholas Church at Lesser Town, Wednesday July 29

- Public lecture: Pyramida Hotel Lecture Hall A, Thursday July 30
  The evening lecture will be given by Amir O. Caldeira.
- Classical concert: Pyramida Hotel Lecture Hall A, Thursday July 30
- Conference dinner: Břevnov Monastery, Friday July 31
- Classical music concert: St. Margaret Church of the Břevnov Monastery, Friday July 31

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 27 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 **Břevnov Monastery**.
  Price: 75 EUR per person - tickets for this dinner will be available during the registration.

PROGRAM

Sunday, 26 July 2026

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

Monday, 27 July 2026

07:50 – 08:20	**Opening address**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Václav Špička)	
08:20 – 09:50	**1 session: Stochastic and quantum thermodynamics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Uri Peskin)	
08:20 – 08:50	Peter Hänggi:	*Quantum Brownian Motion: Facts, debatable issues and unsolved issues*
08:50 – 09:20	Udo Seifert:	*Entropy production and its model-free inference*
09:20 – 09:50	Ronnie Kosloff:	*Quantum thermodynamics, Quantum control, Quantum gates for open systems*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session: Quantum computing**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Eric Akkermans)	
10:10 – 10:40	Yuval Gefen:	*Quantum Cooling through Measurements*
10:40 – 11:10	Jens Eisert:	*Probing thermodynamics and entanglement with bosonic quantum simulators*
11:10 – 11:40	Franco Nori: online	*A few recent results on superconducting qubits: (1) one photon simultaneously exciting two qubits; (2) strong coupling between a single photon and a two-photon Fock state; and (3) Thouless pumping*
11:40 – 12:10	Mohammad Ansari:	*Information Transport in Classical-Quantum Hybrid System*
12:10 – 13:00	Lunch	
13:00 – 15:10	**3 session - A parallel: Many body systems out of equilibrium**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Riku Tuovinen)	
13:00 – 13:30	Branislav K. Nikolic:	*Driven-dissipative quantum spin systems: Fate of their entanglement and the origins of the classical Landau-Lifshitz equation*
13:30 – 14:00	Michael Galperin:	*Green's function methods for open molecular systems*
14:00 – 14:30	Jordan Horowitz:	*The geometry of nonequilibrium response*

14:30	–	14:50	Gabriele De Chiara:	*Nonclassical energy-change distribution as a witness of non-Markovian quantum dynamics*
14:50	–	15:10	David Edward Bruschi:	*Toward Algebraic Quantum Control*

13:00 – 15:10

3 session - B parallel: Quantum information

Location: Pyramida Hotel Lecture Hall B

(chairperson: Jens Eisert)

13:00	–	13:30	Saar Rahav:	*Information engines with self-propelling particles*
13:30	–	14:00	Alberto Imparato:	*Information engine fueled by first-passage times*
14:00	–	14:30	Henning Kirchberg:	*Optimizing Energy Conversion in Feedback-Controlled Nano Processes: Harnessing Time-Dependent Information*
14:30	–	14:50	Soroush Khademi:	*Post-processed estimation of quantum evolution*
14:50	–	15:10	Jose Este Jaloveckas:	*Conditional Dynamics of a Dual-Rail Qubit with Asymmetric Erasure Rates*

13:00 – 15:10

3 session - C parallel: Quantum optics

Location: Pyramida Hotel Lecture Hall C

(chairperson: Ernst Rasel)

13:00	–	13:30	Dana Z. Anderson:	*The Mechanics of Maxwell Matter Waves*
13:30	–	14:00	Volker Deckert:	*Scale Effects in Plasmon-Enhanced Raman Spectroscopy*
14:00	–	14:30	Walter Pfeiffer:	*Impact of surface scattering on photoelectron escape times*
14:30	–	14:50	Fabio Pistolesi:	*Quantum Rabi Model in the slow Oscillator Regime*
14:50	–	15:10	Thomas L. Schmidt:	*Fabry-Perot interferometry with stochastic anyonic sources*
15:10	–	15:30	Coffee break	

15:30 – 18:00

4 session: Foundations of quantum physics, dedicated to the memory of Luis de la Peña

Location: Pyramida Hotel Lecture Hall A

(chairperson: Theo Nieuwenhuizen)

15:30	–	16:00	Ana María Cetto:	*The vacuum electromagnetic field as the source of atomic stability*
16:00	–	16:30	Gregor Weihs:	*Quantum light sources for foundational tests and quantum communication*

16:30	–	17:00	Marco Genovese:	*Single pair measurement of CHSH, negative probabilities and testing relativistic independence through weak measurements.*
17:00	–	17:30	Philippe Grangier:	*Contextual unification of classical and quantum physics*
17:30	–	18:00	Hervé Zwirn:	*Are Events Absolute?*
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, 28 July 2026

07:50 – 09:50	**1 session: Quantum computing**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Mohammad Ansari)	
07:50 – 08:20	Jian-wei Pan: online	*Quantum Network: quantum communication, computation, and metrology*
08:20 – 08:50	Ralf Schuetzhold:	*Quantum Zeno effect versus adiabatic quantum computing and quantum annealing*
08:50 – 09:20	Alexia Auffèves:	*An energetic constraint for qubit-qubit entanglement*
09:20 – 09:50	Eric Akkermans:	*Topological sum rule for geometric phases of quantum gates*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session: Quantum thermodynamics, engines**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Ronnie Kosloff)	
10:10 – 10:40	Gershon Kurizki:	*From Nonlinear to Linear Control of Quantum Information and Thermodynamics*
10:40 – 11:10	Eric Lutz:	*Combining energy efficiency and quantum advantage in cyclic machines*
11:10 – 11:40	Mikko Möttönen:	*Autonomous Quantum Heat Engine*
11:40 – 12:10	Oren Tal:	*Molecular Archimedean Screw: A torque transfer molecular machine*
12:10 – 13:00	Lunch	
13:00 – 15:10	**3 session - A parallel: Quantum structures and dynamics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Oren Tal)	
13:00 – 13:30	Linda Reichl:	*Entanglement Propagation in quantum dots*
13:30 – 14:00	Leo Kouwenhoven:	*Experiments on Kitaev chains in nanowires*
14:00 – 14:30	Alexandre Zagoskin:	*Dissipative and nondissipative quantum circuit elements*
14:30 – 14:50	Alessandro Braggio:	*Quantum bipolar thermoelectricity*
14:50 – 15:10	Efrat Shimshoni:	*Striped Spin Density Wave in a Graphene/Black Phosphorous Heterostructure*

13:00 – 15:10	**3 session - B parallel: Quantum thermodynamics and transport**	
	Location: Pyramida Hotel Lecture Hall B	
	(chairperson: Saar Rahav)	
13:00 – 13:30	Mauro Antezza:	*Kapitza-like Modulation of Near-Field Radiative Heat Transfer*
13:30 – 14:00	Doron Cohen:	*Quantum measurement of work in mesoscopic systems*
14:00 – 14:20	Carsten Henkel:	*Mesoscopic models for electromagnetic fluctuations in and near conducting media*
14:20 – 14:40	Mateusz Wiśniewski:	*Fast directed transport via energy recuperation in non-Markovian media*

13:00 – 15:10	**3 session - C parallel: Quantum many body systems**	
	Location: Pyramida Hotel Lecture Hall C	
	(chairperson: Stefan Nimmrichter)	
13:00 – 13:30	Nir Navon:	*Emergence of Fermi's Golden Rule in a Quantum Many-body System*
13:30 – 14:00	Frédéric Chevy:	*AC transport in ultracold Fermi gases.*
14:00 – 14:30	Joseph Maciejko:	*Topological Landau theory*
14:30 – 14:50	Alexander Shnirman:	*Emergence of multiple zero modes bound to vortices in extended topological Josephson junctions*
14:50 – 15:10	Peter D. Keefe: online	*Phun with Phase Transions of the Quantum Mechanical Kind*
15:10 – 15:30	Coffee break	

15:30 – 17:00	**4 session: Information, classical and quantum dynamics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Doron Cohen)	
15:30 – 16:00	Igor M. Sokolov:	*Langevin equations with multiplicative noise: The mathematics, physics, and thermodynamics of interpretation.*
16:00 – 16:30	Thiago Rodrigues de Oliveira:	*Emergence of Classicality from Equilibration in Isolated Quantum Systems*
16:30 – 17:00	Tapio Ala-Nissilä:	*The Magic in Quantum Machine Learning*

18:15 – 22:00	**Evening session: Public lectures of Philippe Grangier and Allen Hermann followed by jazz concert**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Václav Špička)	
18:15 – 18:30	Opening address	

18:30	–	19:20	Public lecture:	
18:30	–	19:20	**Philippe Grangier:**	***Quantum Mechanics: from Fundamental Principles to Technological Revolutions***
19:20	–	19:30	Discussion after the lecture of Philippe Grangier	
19:30	–	19:45	Break	
19:45	–	20:35	Public lecture:	
19:45	–	20:35	**Allen Hermann:**	***How Jazz Musicians Use Improvisation in Communicating with Each Other and with the Audience***
20:35	–	20:45	Disscusion after the lecture of Allen Hermann	
20:45	–	21:00	Break	
21:00	–	22:00	Jazz concert	

Wednesday, 29 July 2026

07:50 – 09:50	**1 session: Quantum optics, superfluids out of equilibrium** *Location: Pyramida Hotel Lecture Hall A* *(chairperson: Nir Navon)*	
07:50 – 08:20	Ortwin Hess:	*Open Quantum Dynamics and Dissipative State Selection in Nanoplasmonic Cavities*
08:20 – 08:50	Ernst Maria Rasel:	*Interferometry with Bose-Einstein condensates in extended free fall*
08:50 – 09:20	Vanderlei S Bagnato:	*Stages of the relaxation for a far-from-equilibrium trapped superfluid*
09:20 – 09:50	Peter McClintock:	*Creation of quantised vortices at a moving surface in superfluid ^{4}He*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session: Quantum systems out of equilibrium** *Location: Pyramida Hotel Lecture Hall A* *(chairperson: Jürgen Stockburger)*	
10:10 – 10:40	Mark Dykman:	*The Many Faces of Quantum Fluctuations in Driven Vibrational Systems*
10:40 – 11:10	Joachim Ankerhold:	*Dynamics of Open Quantum Systems Revisited: From Non-Markovianity to Efficient Many-body Simulations*
11:10 – 11:40	Michael Thoss:	*Quantum dynamics and thermodynamics using the hierarchical equations of motion method*
11:40 – 12:10	Uri Peskin:	*Boltzmann subspaces and temperatures in systems driven far from equilibrium*
12:10 – 13:00	Lunch	
13:00 – 14:40	**3 session - A parallel: Quantum dynamics, spin systems** *Location: Pyramida Hotel Lecture Hall A* *(chairperson: Alexander Shnirman)*	
13:00 – 13:30	Christoph Bruder:	*Nonreciprocal synchronization of active quantum spins*
13:30 – 14:00	Thierry Martin:	*Anyon braiding, Fractional Charge, scaling dimension, and statistical angle in the fractional quantum Hall effect*
14:00 – 14:20	Ephraim Shahmoon:	*Quantum states and phases underlying collective dissipation phenomena*

14:20 – 14:40	David Gelbwaser-Klimovsky: online	*Physical requirements for anomalous thermalization (Mpemba effect)*

3 session - B parallel: Biophysics (13:00 – 14:40)

Location: Pyramida Hotel Lecture Hall B

(chairperson: Peter Schmitteckert)

13:00 – 13:30	Stefan Klumpp:	*Stochastic dynamics of molecular motors and filaments*
13:30 – 14:00	Thomas Vojta:	*Reflected fractional Brownian motion as model of serotonergic axons in the brain*
14:00 – 14:20	Václav Špička:	*Formation of action potential in neuron and the quantum diffusion of somatic ions*
14:20 – 14:40	Lev Mourokh:	*Vitacrystallography: X-ray diffraction of biological tissues for cancer detection*

3 session - C parallel: Quantum information (13:00 – 14:40)

Location: Pyramida Hotel Lecture Hall C

(chairperson: Henning Kirchberg)

13:00 – 13:30	Eliahu Cohen:	*Information Flow in Quantum Algorithms: Structure and Optimization*
13:30 – 14:00	Matthias Zimmermann:	*Advanced Quantum Networks - Future Applications and Technology Demonstrations*
14:00 – 14:20	Sergii Strelchuk: online	*The Power of Power-of-SWAP: Postselected Quantum Computation with the Exchange Interaction*
14:20 – 14:40	Sergey N. Shevchenko: online	*Quantum capacitances and resistances of electron boxes and transistors*
14:40 – 15:00	Coffee break	

4 session - A parallel: General physics - models and methods (15:00 – 17:10)

Location: Pyramida Hotel Lecture Hall A

(chairperson: Thomas Vojta)

15:00 – 15:30	Ofer Biham:	*First return processes on random networks*
15:30 – 16:00	Eytan Katzav:	*Structural Phase Transitions in Evolving Networks Under Different Node-Deletion Mechanisms*
16:00 – 16:30	Ivan Rungger:	*pyTTN: A tree tensor network based open-source toolbox for open and closed system quantum dynamics simulations and its application in quantum algorithms*

16:30 – 16:50	George E. A. Matsas: online	*A gravitational self-decoherence model and a gentle recovery of the classical world*

15:00 – 17:10	**4 session - B parallel: Foundations of quantum physics**	
	Location: Pyramida Hotel Lecture Hall B	
	(chairperson: Gregor Weihs)	
15:00 – 15:30	Gianluca Rastelli :	*Magnetically Levitated Systems Approaching the Quantum Regime*
15:30 – 16:00	Yutaka Shikano:	*Judea Pearl Meets Yakir Aharonov in Wheeler's Delayed-Choice Experiment*
16:00 – 16:30	Stefan Gerlich:	*A New Frontier in Matter-Wave Interferometry: From Large Metal Clusters to Biomolecules*
16:30 – 16:50	Masanao Ozawa:	*Value Reproducibility and Intersubjectivity of Quantum Measurements based on Quantum Perfect Correlations*
16:50 – 17:10	Lorenzo Maccone:	*Tight Entropic Uncertainty Relations*

15:00 – 17:10	**4 session - C parallel: General physics**	
	Location: Pyramida Hotel Lecture Hall C	
	(chairperson: Konstantin Beyer)	
15:00 – 15:30	Denys I Bondar:	*Alchemy as an optical problem: Theory and Experiments*
15:30 – 16:00	Julia Liebert:	*Operational impact of quantum resources in chemical dynamics*
16:00 – 16:30	Daniel M Dantchev:	*Contradictory predictions for the Casimir force under Dirichlet-Neumann boundary conditions: Gaussian versus mean-field model*
16:30 – 16:50	Jiří J. Mareš:	*Note on the so-called "big G puzzle"*
16:50 – 17:10	Dalibor Štys:	*Point information gain entropy density, and an ideal image from light microscopy*

17:10 – 19:00	Free time and transfer to the Church of Saint Nicholas
19:00 – 20:00	**Concert of classical music**
	Location: Church of Saint Nicholas

Thursday, 30 July 2026

07:50 – 09:50	**1 session: General physics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Ralf Schuetzhold)	
07:50 – 08:20	Ron Folman:	*Experiments at the interface of general relativity and quantum mechanics*
08:20 – 08:50	Joan Alfina Vaccaro:	*The quantum theory of time: Emergence of Lorentz invariance*
08:50 – 09:20	Bei-Lok Hu:	*Vacuum Viscosity*
09:20 – 09:50	Michael Prouza:	*Sources, Frequency Bands, and Instruments: An Overview of Existing and Planned Gravitational-Wave Detectors with a Focus on the Einstein Telescope*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session - A parallel: General physics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: John Bush)	
10:10 – 10:40	Georgi Gary Rozenman:	*Aharonov-Bohm, Kennard Phase, and Three-Slit Dynamics in Pilot-Wave Hydrodynamics*
10:40 – 11:10	Stefan Nimmrichter:	*Electron-enabled Nanoparticle Diffraction*
11:10 – 11:40	Nadav Katz:	*Measuring in the dark - classical and quantum results*
11:40 – 12:10	Themistoklis Mavrogordatos: online	*Quantum Jumps in Amplitude Bistability: Tracking a Coherent and Invertible State Localization*
10:10 – 12:10	**2 session - B parallel: Many body systems, dynamics, spins**	
	Location: Pyramida Hotel Lecture Hall B	
	(chairperson: Branislav Nikolic)	
10:10 – 10:40	Jaroslav Fabian:	*Correlations and spins in 2D materials*
10:40 – 11:10	David Santiago Quevedo:	*Out-of-equilibrium stochastic dynamics in power-law viscoelastic and non-Ohmic thermal environments*
11:10 – 11:40	Elisabetta Paladino:	*Circuit Quantum Electrodynamics with two-dimensional material-based Josephson Junctions*
11:40 – 12:10	Yasuhiro Utsumi:	*Network analysis for steady-state current fluctuations in the presence of finite affinity*

10:10 – 12:10 **2 session - C parallel: Quantum optics and dynamics**

Location: Pyramida Hotel Lecture Hall C

(chairperson: Fabio Pistolesi)

10:10 – 10:40	Peter Samuelsson:	*Lindblad master equation for deep strong coupling regime of the quantum Rabi model*
10:40 – 11:10	Paolo Piergentili: online	*Radio frequency to optical transducer based on a soft-clamped membrane*
11:10 – 11:40	Ievgen Arkhipov:	*Controlling Chiral State Dynamics in Multiqubit and Multimode Non-Hermitian Systems*
11:40 – 12:10	Oleh V. Ivakhneko: online	*Fast Nonadiabatic Gates for Quantum Signal Processing via Landau-Zener-Stückelberg-Majorana interferometry*

12:10 – 13:00 Lunch

13:00 – 14:30 **3 session: Quantum optics, cold atoms**

Location: Pyramida Hotel Lecture Hall A

(chairperson: Dana Anderson)

13:00 – 13:30	Aephraim Matthew Steinberg:	*The Private Lives of Photons: Asking particles where they spent the night*
13:30 – 14:00	Frank A. Narducci: online	*Sensitivity functions and phase scaling in light-pulse atom interferometers*
14:00 – 14:30	Jeremy R Armstrong:	*Finite Size Effects in LHY Droplets*

14:30 – 14:50 Coffee break

14:50 – 16:50 **4 session: General physics**

Location: Pyramida Hotel Lecture Hall A

(chairperson: Joachim Ankerhold)

14:50 – 15:20	Andrew N. Jordan:	*Thermodynamics of Quantum Measurement: Making tunneling particles and vacuum fluctuations work*
15:20 – 15:50	Shmuel Gurvitz:	*Time Delay in Tunneling Current and the Tunneling Time*
15:50 – 16:20	Eran Sela:	*Arrow of Time as an Order Parameter for Measurement-Induced Phase Transitions*
16:20 – 16:50	Fernando Sols:	*Hawking time crystals*

16:50 – 18:40 **Poster session and refreshment**

Location: Pyramida hotel - first floor

18:40	–	19:00	Free time
19:00	–	22:10	**Evening session: Public lecture of Amir Caldeira and concert, dedicated to the memory of Anthony J. Leggett**

Location: Pyramida Hotel Lecture Hall A

(chairperson: Václav Špička)

19:00	–	19:10	Opening address
19:10	–	19:40	**Fernando Sols: Remembering Tony Leggett**
19:40	–	20:30	Public lecture:
19:40	–	20:30	**Amir Ordacgi Caldeira:** ***Macroscopic quantum phenomena and related matters: A brief history and the Nobel Prize in Physics 2025***
20:30	–	20:40	Discussion after the lecture of Amir Caldeira
20:40	–	21:00	Break
21:00	–	22:10	Concert of classical music

Friday, 31 July 2026

07:50 – 09:50	**1 session: Biophysics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Lev Mourokh)	
07:50 – 08:20	Robert Hamilton Austin:	*Robert Dicke, Dicke Superfluoresence, Hopfield Polaritons and Amide-I Protein* alpha *Helix Coherent 4-Wave Mixing Gratings*
08:20 – 08:50	Miguel Rubi:	*Molecular entropic forces and scaling laws in chaperone-driven nanofilament unbundling*
08:50 – 09:20	Ralf Eichhorn:	*An artificial motor protein that walks along a DNA track*
09:20 – 09:50	Marc Tornow:	*What enables efficient long-range charge transport across protein layers?*
09:50 – 10:10	Coffee break	
10:10 – 12:10	**2 session - A parallel: Biophysics, dynamics**	
	Location: Pyramida Hotel Lecture Hall A	
	(chairperson: Ralf Eichhorn)	
10:10 – 10:40	Peter Schmitteckert:	*NMR: From Strong-Correlation to Life Sciences*
10:40 – 11:10	Philip Hemmer:	*Toward entangled spins in nanodiamonds for biosensing*
11:10 – 11:40	Mirko Rossini:	*Charge transfer through DNA - A new perspective from Human Genetics*
11:40 – 12:10	Sabine Tornow:	*When Does a Quantum System Return? Topology, Dark States, and Noise in Monitored Dynamics*
10:10 – 12:10	**2 session - B parallel: Many body systems, dynamics, spins**	
	Location: Pyramida Hotel Lecture Hall B	
	(chairperson: Linda Reichl)	
10:10 – 10:40	Eugene Sukhorukov:	*Suppression of quantized heat flow by the dielectric response of a compressible strip at the quantum Hall edge*
10:40 – 11:10	Cheolhee Han:	*Probing the structure of topological entanglement via selective partitioning*
11:10 – 11:40	Björn Sothmann:	*Single-spin flip dynamics in the Ising model*
11:40 – 12:10	Baptiste Lorent:	*Directionality emergence in 2D and 3D quantum random Lorentz gases*

10:10	–	12:10	**2 session - C parallel: Quantum computing**	
			Location: Pyramida Hotel Lecture Hall C	
			(chairperson: Soroush Khademi)	
10:10	–	10:40	Fabrizio Piacentini:	*Universal protection of quantum states from decoherence*
10:40	–	11:10	S. V. Polyakov:	*Phase stabilization for next-generation long-distance quantum networks*
11:10	–	11:40	Walter Hahn:	*Random layers for quantum optimal control with exponential expressivity*
11:40	–	12:10	Evgenii Narimanov:	*Hyperbolic Quantum Processor*
12:10	–	13:00	Lunch	
13:00	–	14:30	**3 session: General physics**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: Gianluca Rastelli)	
13:00	–	13:30	Lajos Diósi:	*Theorem on von Neumann entropy conjectured from physics of irreversibility*
13:30	–	14:00	Jonte R Hance:	*The Quantum Plumber's Problem (or Quantum Advantage in Interaction-Free Interferometric Which-Path Discrimination)*
14:00	–	14:30	Tjerk Oosterkamp:	*Time dilatations for collapse of massive superpositions: An experimentalists view*
14:30	–	14:50	Coffee break	
14:50	–	16:50	**4 session: Classical and quantum dynamics**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: Branislav Nikolic)	
14:50	–	15:20	Lea F Santos:	*Dissipation as a Resource: From Transient to Steady-State Chaos*
15:20	–	15:50	Jorge G Hirsch:	*Superradiance, Chaos, and Thermalization in Atom-Photon Systems*
15:50	–	16:20	Riku Tuovinen:	*Nonequilibrium Transport and Thermoelectricity in Open Quantum Systems*
16:20	–	16:50	Jürgen T. Stockburger:	*Entropy augmentation in irreversible dynamics: A journey from epistemology to numerical simulation.*
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	–	18:30	Guided tour through Břevnov monastery
18:30	–	18:50	Welcome
18:50	–	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, 1 August 2026

08:20	–	09:50	**1 session: General physics**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: Saar Rahav)	
08:20	–	08:50	John W. M. Bush:	*Pilot-wave hydrodynamics*
08:50	–	09:20	Kuan-Hsun Chiang:	*Superconducting circuits as a platform for experiments on open quantum systems*
09:20	–	09:50	Victor Flambaum: online	*Nuclear clocks and search for new physics*
09:50	–	10:10	Coffee break	
10:10	–	12:10	**2 session: Quantum systems out of equilibrium**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: Sabine Tornow)	
10:10	–	10:40	E.K.U. Gross: online	*Interplay of current-induced forces and electronic friction in nanoscale junctions far from equilibrium*
10:40	–	11:10	Konstantin Beyer:	*From Non-Markovianity to the Quantumness of Gravitational Dynamics*
11:10	–	11:40	Pawel Danielewicz:	*Deblurring of Nuclear Collisions*
11:40	–	12:10	Declan Mulhall:	*Simple Quantum-Chaotic toy system mimic a range of real nuclear phenomena.*
12:10	–	13:00	Lunch	
13:00	–	15:30	**3 session: Quantum physics and gravity**	
			Location: Pyramida Hotel Lecture Hall A	
			(chairperson: Andrew Jordan)	
13:00	–	13:30	Marlan Scully: online	*Quantum optics in curved spacetime: Surprises and insights*
13:30	–	14:00	James Freericks:	*Revisiting the classical-quantum correspondence*
14:00	–	14:30	Hartmut Abele:	*Gravity Resonance Spectroscopy*
14:30	–	15:00	Theo M. Nieuwenhuizen:	*Nonlocality in General Relativity: A missing link in Einstein's quest for a unified field theory*

15:00 – 15:30 **Closing remarks**

Location: Pyramida Hotel Lecture Hall A

(chairperson: Peter Keefe)

Public Lectures

Macroscopic quantum phenomena and related matters: A brief history and the Nobel Prize in Physics 2025

Amir Ordacgi Caldeira

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

It is my intention in this talk to present a chronological overview of the development of the basic ideas of what is nowadays called *macroscopic quantum phenomena*, show where to find and study them.

I shall approach the problem by introducing a few quantum mechanical phenomena through very simple examples accessible to a lay audience. Next I will extend them to mesoscopic superconducting devices - the SQUIDs and CBJJs - which act as “giant atoms”, where effects such as the quantization of energy, and quantum mechanical tunneling of a macroscopic variable take place. I shall further discuss the implications of these quantum phenomena, and the unavoidable influences to which they are subject such as, for example, the presence of dissipative effects. Actually, these systems have become the paradigm of the area of quantum dissipation.

Then, I shall present the experimental results which indisputably prove the existence of macroscopic quantum phenomena in superconducting devices, namely the pioneering measurements of J. Clarke, M. Devoret, and J. Martinis in the mid 1980s for which they were awarded the Nobel Prize in Physics in 2025.

Finally, I shall mention other possible examples of these phenomena in condensed matter physics, their potential applications, and even impact on the foundations of quantum mechanics.

Quantum Mechanics: from Fundamental Principles to Technological Revolutions

Philippe Grangier

Institut d'Optique / CNRS, Université Paris-Saclay, Palaiseau, France

In this talk I will present experimental properties of quantum light, as an illustration of the fundamental rules of quantum mechanics: superposition, interferences, and entanglement. Emphasis will be given to experimental tests of Bell's inequalities, that lead to the 2022 Nobel Prize in physics attributed to Aspect, Clauser and Zeilinger. This result opened the way to Quantum Technologies, and as an example I will present and discuss quantum simulators based on arrays of interacting trapped single atoms.

How Jazz Musicians Use Improvisation in Communicating with Each Other and with the Audience

Bob Montgomery and Allen Hermann

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

This presentation explores how jazz musicians use improvisation to communicate with each other and with the audience. Unlike orchestral music, which is written in advance, jazz improvisation involves creating music spontaneously. The presenters demonstrate this process through short solos supported by a rhythm section consisting of piano, bass, and drums. Soloists create melodies that fit the chords and rhythm being played, forming a musical "story" that listeners can follow and remember.

The presentation also explains how musicians choose notes that sound consistent with the musical background, introducing basic ideas of Western scales and chords. Audience members are invited to participate by singing melodies that fit the music heard from the rhythm section, allowing them to experience musical improvisation firsthand.

As the session progresses, the musicians perform longer and more complex improvisations to demonstrate musical conversation and interaction. The presenters also show how jazz musicians use hand signals and brief verbal cues to guide performances and strengthen communication during improvisation. Overall, the presentation highlights improvisation as a creative and interactive form of communication between musicians and audiences.

Invited Talks

Gravity Resonance Spectroscopy

Hartmut Abele

TU Wien, Atominstitut, Stadionallee, Wien, Austria
ILL, Grenoble
University of Vienna

We present a resonant spectroscopy technique that induces transitions between the quantum states of a reflected neutron in the Earth's gravitational field. This technique has applications ranging from studying gravitation and related cosmological problems, such as dark matter and dark energy, to developing quantum computers. The object of study is a quantum mechanical wave packet of an ultra-cold neutron. The new method extends Purcell, Rabi, and Ramsey techniques to neutron quantum states in the Earth's gravitational field. This technique is called Gravity Resonance Spectroscopy (GRS), similar to Magnetic Resonance Spectroscopy (MRS). In this technique, a neutron is placed on a reflecting mirror in the Earth's gravitational potential, and transitions between gravitational quantum states are induced by applying mechanical oscillations to the mirror at the proper transition frequency. In the MRS technique, an atom, molecule, or nucleus with a magnetic moment is placed in an outer magnetic field, and transitions between magnetic Zeeman splittings are induced by applying proper radiofrequency oscillations. We observe resonant transitions between several of the lowest quantum states for the first time. GRS's strength lies in its independence from electromagnetic interactions. Using neutrons as test particles bypasses the electromagnetic background induced by van der Waals forces and other polarizability effects, providing a sensitivity several orders of magnitude higher than that of atoms.

Topological sum rule for geometric phases of quantum gates

Eric Akkermans[1], Nadav Orion[1], Nirron Miller[2], and Boris Rotstein[1]

[1]*Department of Physics, Technion-Israel Institute of Technology, Technion, Haifa, Israel*
[2]*Department of Physics, The University of Texas, Austin, Texas 78712*

We establish a topological sum rule, $\nu_U = \frac{1}{2\pi}\sum_n \gamma_n = 2m\nu_H$, connecting the geometric phases accumulated by a two-qubit system over a complete basis of initial states to the winding number ν_H classifying its Hamiltonian. Implementations of the same gate from different topological classes must distribute these phases differently, making their distinction measurable through the Wootters concurrence. As a corollary, nontrivial topology is a necessary condition for entanglement: only Hamiltonians with access to $\nu_H \neq 0$ can generate it.

This research was funded by the Israel Science Foundation Grant No. 772/21 and the Pazy Foundation.

The Magic in Quantum Machine Learning

Tapio Ala-Nissilä

Department of Applied Physics, Aalto University, P.O. Box 15600, FIN-00250 Espoo, Finland
Interdisciplinary Centre for Mathematical Modelling and Department of Mathematical Sciences, Loughborough University, Loughborough, Leicestershire LE11 3TU, United Kingdom

The boundary between classically simulable and computationally superior quantum systems is fundamental to identifying true quantum advantage. In this talk, we will first discuss our recent work based on interacting non-Hermitian spin system defined on random graphs [1]. We show that the onset of the first exceptional point - marking the real-to-complex spectral transition - also corresponds to an abrupt change in the system's learning capacity. We further demonstrate that this transition is controllable via local disorder and spin interactions strength, thereby defining a tunable learnability threshold. Within the learning phase, the system exhibits the key features required for memory-dependent reservoir computing. We further examine a class of tunable N-qubit random circuit models with a combination of Clifford and nonstabilizing gates [2]. We establish a direct correspondence between the reservoir's performance on temporal processing tasks and its entanglement spectrum statistics and long-range nonstabilizer resource content. Our offer a general strategy for designing powerful and trainable quantum machine learning systems and clarify the physical resources underpinning quantum computational advantage.

This work was supported by the European Union and the European Innovation Council through the Horizon Europe project QRC-4-ESP (Grant Agreement No. 101129663), and EU Horizon Europe Quest project (No. 10116088), and the Academy of Finland through its QTF Center of Excellence program (Project No. 312298).

[1] Moein N. Ivaki, Austin J. Szuminsky, Achilleas Lazarides, Alexandre Zagoskin, Gerard McCaul, Tapio Ala-Nissila, arXiv:2506.07676.

[2] Moein N. Ivaki, Matias Karjula, Tapio Ala-Nissila, arXiv:2510.18623.

The Mechanics of Maxwell Matter Waves

Dana Z. Anderson[1] and Katarzyna Krzyzanowska[2]

[1]*Infleqtion and the JILA Institute at the University of Colorado, Boulder, USA*
[2]*Materials Physics and Applications Division, Los Alamos National Laboratory, USA*

The understanding of circuits that involve ultracold atoms for sensing and other practical purposes is very much a topic of quantum thermodynamics since, by definition, ultracold atoms are governed by the laws of quantum mechanics, while useful circuit behavior is a consequence of a system that is in non-thermal equilibrium. The purpose of a circuit is generally to generate and manipulate *signals* – that is, for example, time-varying currents that are some way meaningful information bearers for the tasks at hand. Such signals explicitly involve, of course, AC currents. The physics of alternating matter currents and associated matter waves is far richer than one might expect from conceptually generalizing familiar single particle and many-body treatments of matter waves. In earlier work we have shown that a gauge field treatment of identical interacting through neutral particles (such as neutral atoms) leads to a set of matter-wave duals to Maxwell's equations. These, in turn lead to matter-wave duals to electromagnetic waves which we refer to as "Maxwell matter waves" or simply as "AC matter waves". The objective of this talk is two-fold: first to present the mechanics of Maxwell matter waves through a set of standard wave-propagation problems such as reflection from a potential step and transmission through potential barriers. The behavior of Maxwell matter waves proves to be dramatically different from the de Broglie (DC) waves described by Schrödinger's equations. For example, AC matter waves will propagate through a barrier with high transmission even when the corresponding particle energy is far less than the potential energy height of the barrier. Likewise, a low-particle-energy AC matter wave will have transmission through a step where a de Broglie wave is reflected with unit probability. The difference between AC and DC is due to the temporal coherence of the former, which itself of the reflection of the fact that a single-mode AC wave is characterized by two quantum numbers: the particle energy and the oscillation frequency, rather than just the particle energy as the case with a de Broglie wave. The other objective of this talk is to draw the connection between DC and AC, that is, between solutions of the time-independent Schrödinger equation and solutions to the matter wave duals to Maxwell's equations. We show that DC matter waves are comprised of a superposition of AC waves having a spectrum of oscillation frequencies. It is *not* the case that a DC wave corresponds to the limit in which the frequency of an AC wave goes to zero. Rather, an AC wave corresponds to the limit in which the spectral width of a DC wave becomes zero. Finally, I will give a brief peak at, and description of, how AC matter waves can be generated.

Dynamics of Open Quantum Systems Revisited: From Non-Markovianity to Efficient Many-body Simulations

Meng Xu, Jürgen T Stockburger, and Joachim Ankerhold

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

Recent advances in quantum technologies have triggered the need for highly accurate, versatile, and computationally efficient simulation techniques for the dynamics of open quantum systems. Long-lived system-reservoir correlation effects and the necessity for high precision beyond the Born-Markov approximation form particular challenges. Approaches to meet these challenges have been introduced, originating from different fields, such as hierarchical equations of motion, Lindblad-pseudomode formulas, chain-mapping approaches, quantum Brownian motion master equations, stochastic unravelings, and refined quantum master equations.

This diversity, while indicative of the field's relevance, has inadvertently led to a fragmentation that hinders cohesive advances and their effective cross-community application to current problems for complex systems. How are different approaches related to each other? What are their strengths and limitations? Here we give a systematic overview and concise discussion addressing these questions. We make use of a unified framework [1] 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 a fully reduced space of the system but in an extended state space which in a minimal fashion includes effective reservoir modes. This in turn offers on the one hand a comprehensive understanding of an entire class of existing methods and on the other hand a very efficient and versatile platform for many-body simulations with long-time stability [2-5].

[1] Meng Xu, V. Vadimov, J. T. Stockburger, and J. Ankerhold, Rev. Mod. Phys., Colloquium, in press, doi.org/10.1103/w3nw-hbjc

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

[3] Meng Xu, J. T. Stockburger, and J. Ankerhold, J. Chem. Phys. 161, 124105 (2024)

[4] K. Nakamura and J. Ankerhold, Phys. Rev. Res. 6, 033215 (2024)

[5] K. Nakamura and J. Ankerhold, Phys. Rev. Res., in press, arXiv:2510.05872v1

Information Transport in Classical-Quantum Hybrid System

Mohammad Ansari

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Key performance measures in quantum technology, such as fidelity, entanglement, and entropy, are intrinsically nonlinear and therefore cannot generally be represented by standard operator observables. Their time-dependent flow across a quantum device is consequently beyond the reach of conventional open-system descriptions. Multi-density-matrix extensions of the Keldysh formalism have recently enabled consistent calculations of Rényi and von Neumann entropy flows into a probe heat bath coupled to a quantum system mediating energy transport among reservoirs. These studies revealed a strong suppression of entropy flow relative to standard open-system predictions, but were restricted to the hierarchy in which the probe is the weakest-coupled reservoir. Here, we extend the formalism beyond this limit, treating regimes where all system-bath couplings remain perturbative but the probe is no longer singled out as the weakest element. This brings entropy-flow theory closer to realistic hybrid quantum-classical architectures. By deriving a generalized-density-matrix master equation, we show that quantum-classical hybridization suppresses entropy flow and creates a thermodynamic bottleneck. Our results provide a consistent thermodynamic framework for nonlinear information measures in quantum devices and offer practical guidance for resource-aware quantum-hardware design.

Kapitza-like Modulation of Near-Field Radiative Heat Transfer

Mauro Antezza

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We introduce [1] a Kapitza-like mechanism for the near-field radiative heat transfer and show that fast modulation of any parameter controlling the flux, such as the vacuum gap or a material response, produces a quadratic, time-averaged correction in the slow thermal dynamics. This correction splits into a frequency-independent static term and a low-pass dynamical term, yielding sizable modulation-induced temperature shifts and modified effective thermal conductances that can stabilize or destabilize the steady state. Applying the theory to gap modulation between SiC slabs, we derive analytical scaling laws and predict temperature shifts that are fully measurable with existing experimental platforms. Our results establish a thermal analogue of the Kapitza mechanism and provide a general route for controlling radiative heat flow in micro- and nanoscale platforms.

[1] Mauro Antezza, submitted (2025)

Controlling Chiral State Dynamics in Multiqubit and Multimode Non-Hermitian Systems

Ievgen Arkhipov

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Non-Hermitian systems host exceptional points and other spectral singularities that give rise to novel topological and dynamical effects, including both asymmetric and symmetric state-switching regimes. However, the complex spectra of these systems often lead to instabilities and breakdown of adiabaticity, limiting the ability to reliably access the desired state-transfer mode. In this talk, we present strategies for effectively controlling both chiral and symmetric switching dynamics in such setups. Specifically, we show that by appropriately designing trajectories along which the evolution operator remains real, or by combining exceptional points with diabolic points in the system spectrum, one can mitigate, or even completely eliminate, nonadiabatic transitions, thus enabling robust and controllable state transfer in multiqubit and/or multimode photonic systems. These findings open new avenues for topological quantum information processing and advanced wave-manipulation protocols in non-Hermitian platforms.

Finite Size Effects in LHY Droplets

Jeremy R Armstrong[1], Neelam Shukla[1], Oleks V Marchukov[2], Bastien Humbert[3], Jan Arlt[3], and Artem G Volosniev[3]

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[2]*Institute of Photonics, Leibniz University Hannover, Nienburger St 17, 30167 Hannover, Germany*
[3]*Department of Physics and Astronomy, Aarhus University, DK-8000 Aarhus C, Denmark*

Quantum droplets, stabilized by the Lee-Huang-Yang corrections, are governed by nonlinear interaction of dimension-dependent power that differs from the mean-field interaction of Bose-Einstein condensates. In this paper we investigate the superfluid properties of the quantum droplets by simulating the emergence of a scissor mode in a three-dimensional quantum droplet in a deformed harmonic oscillator after a rotational quench. We focus on the number of atoms dependence of the mode frequency and compare it with Bose-Einstein condensates and the analytical expression in the thermodynamic limit. We show that the finite size effects are defined by the interaction exponent and characterize this dependence. Finally, we demonstrate that the scissors mode frequency remains clearly identifiable even under strong quenches, which should facilitate the experimental observation of our findings.

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An energetic constraint for qubit-qubit entanglement

Kiarn Travis Laverick[1,2], Samyak Pratyush Prasad[1,2], Pascale Senellart[3], Maria Maffei[4], and Alexia Auffèves[1,2]

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We analyze qubit-qubit entanglement from an energetic perspective and reveal an energetic trade- off between quantum coherence and entanglement. We decompose each qubit internal energy into a coherent and an incoherent component. The qubits' coherent energies are maximal if the qubit-qubit state is pure and separable. They decrease as qubit-qubit entanglement builds up under locally- energy-preserving processes. This yields a "coherent energy deficit" that we show is proportional to a well-known measure of entanglement, the square concurrence. In general, a qubit-qubit state can always be represented as a mixture of pure states. Then, the coherent energy deficit splits into a quantum component, corresponding to the average square concurrence of the pure states, and a classical one reflecting the mixedness of the joint state. Minimizing the quantum deficit over the possible pure state decompositions yields the square concurrence of the mixture. Our findings bring out new figures of merit to optimize and secure entanglement generation and distribution under energetic constraints.

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Robert Dicke, Dicke Superfluoresence, Hopfield Polaritons and Amide-I Protein *alpha* Helix Coherent 4-Wave Mixing Gratings

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We will discuss quantum simple harmonic oscillators. Unlike collections of 2 level systems which when illuminated at the resonance frequency ω_o undergo Rabi flopping, that is periodic population inversion, a truly linear simple harmonic oscillator cannot be inverted. Does all of the remarkable physics of the Dicke super-fluorescence emission disappear for an ensemble of quantum linear oscillators? The answer is no, but things are different. The answer is that there remain fundamental mysteries in biology that seem be *perhaps* linked to coherent quantum mechanics. No, don't worry, we are not going down the Roger Penrose route of a possible connection between human consciousness and quantum gravity via the spatial organization of microtubules in tissue. Rather, we want to explore the possible dynamics of the α-helix motif so common in protein structures, especially in G-protein receptors which span membranes in cells, for a schematic of the G-protein receptor β-2 adrenergic receptor. What is notable in these proteins is the remarkable ordering of the α-helix bundles. The question we will address from a physics perspective is how binding of a ligand on the extracellular (top) side of the G-protein receptor is communicated to the G-protein which is bound on the cellular side of the complex, could there be some sort of a collective wave moving from one side to the other, via the chain of hydrogen bonds?

Stages of the relaxation for a far-from-equilibrium trapped superfluid

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Understanding the initial conditions that drive many-body quantum systems out of equilibrium is essential for getting into their thermalization dynamics. In this work [1,2,3], we identify two excitation regimes that lead a trapped Bose-Einstein condensate into turbulence regime evolving resulting in distinct final states. In the subcritical regime, the condensate partially reemerges after turbulence, whereas in the supercritical regime it dissolves completely into a thermal state. Despite these differences, both cases exhibit relaxation stages with common features: a direct energy cascade, the emergence of a nonthermal fixed point (characterized by identical scaling exponents), a prethermalization plateau, and eventual thermalization. Our results show that turbulence relaxation develops independently of the system's initial conditions or its ultimate state. At late times, both regimes display universal scaling dynamics consistent with predictions from wave turbulence theory. Finally, by analyzing the time evolution of the condensate's momentum distribution center of mass, we demonstrate how kinetic-energy dominance reflects the thermalized nature of the final states in each regime. The present results advance the field by showing that thermalization in far-from-equilibrium quantum systems follows universal relaxation dynamics, even when final states differ, thereby deepening our understanding on time evolution of many body quantum system thermalization. We shall present a new possible interpretation for the pre-thermatlization as well as an anlysis of the construction of the coherent length during the last stage of thermalization of the system.

GURI, CRI, CPRIT-grant RR220054, FAPESP - CEPID program, INCT - CNPq

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From Non-Markovianity to the Quantumness of Gravitational Dynamics

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Non-Markovian dynamics in open quantum systems arise from memory effects due to the coupling between a system and its environment. While such memory effects can often be accounted for by purely classical mechanisms, certain dynamical signatures necessarily require the environment to store and return genuinely quantum information. In these cases, the observed system dynamics alone certifies the quantumness of the environmental degrees of freedom, without any detailed knowledge of their structure. Building on this idea, we construct experimentally accessible witnesses for these signatures, based solely on measurements of the probe system. We then show that this framework enables a one-sided verification of the quantumness of gravitational dynamics, providing an alternative to the standard two-probe proposals based on gravity-induced entanglement.

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First return processes on random networks

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First return (FR) processes in which a stochastic walker returns to its starting point for the first time are fundamental for the understanding of diffusion and search dynamics. They are the building blocks of all return dynamics - via renewal theory they generate the full return statistics, and their distribution governs the mixing times of the system. On regular geometries, such as the one-dimensional lattice, combinatorial methods yield closed-form expressions for the return statistics, reflecting the underlying recurrence or transience. Extending these studies to disordered landscapes such as those encountered in random networks, the distribution of first return times reveals deep connections between structural features and dynamical behavior. Their relevance to search processes stems from the fact that first return events determine both the efficiency of exploration and the likelihood of redundant visits, thus providing key insights into how quickly and thoroughly a walker can cover a given structure.

In this talk I will present analytical results for the distribution of first return (FR) times of random walks (RWs) and on random networks. I will show that classical RWs exhibit two types of FR trajectories: retroceding trajectories in which the RW retrocedes its own steps backwards to the initial point and non-retroceding trajectories in which it returns via at least one cycle [1]. While tree networks (such as the Bethe lattice) accomodate only retroceding trajectories, general random networks such as the configuration model accomodate both. To reveal the distinction between the two types of trajectories, I will present analytical results for the distribution of FR times of non-backtracking walks (NBW's), which exhibit only non-retroceding trajectories [2]. These results provide useful insight on the advantages of NBWs which scan the network faster and more efficiently than classical RWs. As a result, they are exceptionally useful for network exploration, sampling procedures and search processes on networks.

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Alchemy as an optical problem: Theory and Experiments

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Using tracking quantum control, we theoretically unveiled an unexplored flexibility of nonlinear optics that a shaped laser pulse can drive a quantum system to emit light as if it were an arbitrary different system [1, 2]. This realizes an aspect of the alchemist's dream to make different elements *look alike*, albeit for the duration of a laser pulse. We will show how this unexplored flexibility of nonlinear optics opens new venues of investigation that include ultrafast artificial intelligence [3], chemical mixture characterization, and broadband epsilon-near zero (ENZ) materials with infinite phase velocity of light. Based on these theoretical insights, recent experimental results will be presented, showing how water can be transformed into alcohol and how ENZ materials can be dynamically created [5].

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Quantum bipolar thermoelectricity

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Thermoelectricity is generally understood as a classical effect arising from energy-dependent transport asymmetries [1]. Here [2], we uncover a purely *quantum* mechanism, where a superconducting S-I-S' tunnel junction in thermal equilibrium develops a nonlinear bipolar thermoelectric response owing to the dynamical Coulomb blockade[and the *emission-absorption imbalance* of a cold electromagnetic bath. In contrast to standard bipolar thermoelectricity [3], generated by a strong thermal gradient within the junction, the quantum effect has the cold bath given by the electromagnetic environment, and the junction is kept in equilibrium at a higher temperature. The bipolar thermoelectric effect is given by spontaneous particle-hole symmetry breaking induced by the interplay between interactions [4] and the temperature gradient, and is experimentally demonstrated [5]. Here, however, the dynamical Coulomb blockade [6] also plays a crucial role in mediating the environmental influence on the junction [2]. Two representative environments are analyzed, revealing Seebeck coefficients up to 100 μV/K for realistic junction parameters. Because the response directly reflects the spectral properties of the surrounding environment, our results suggest that bipolar quantum thermoelectricity could provide a new route for spectroscopic sensing of electromagnetic modes and for designing low-temperature thermoelectric devices with environmentally engineered performance.

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Nonreciprocal synchronization of active quantum spins

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Active agents are capable of exerting nonreciprocal forces upon one another. For instance, one agent, say A, may attract another agent B while B repels A. These antagonistic nonreciprocal interactions have been extensively studied in classical systems, revealing a wealth of exciting phenomena such as novel phase transitions and traveling-wave states. Whether these phenomena can originate in quantum many-body systems is an open issue, and proposals for their realization are lacking. In [1], we present a model of two species of quantum spins that interact in an antagonistic nonreciprocal way of the attraction-repulsion type. We propose an implementation based on two atomic ensembles coupled via chiral waveguides featuring both braided and non-braided geometries. The spins are active due to the presence of local gain, which allows them to synchronize. In the thermodynamic limit, we show that nonreciprocal interactions result in a nonreciprocal phase transition to time-crystalline traveling-wave states, associated with spontaneous breaking of parity-time symmetry. Remarkably, continuous monitoring of the output field of the waveguides induces a quantum traveling-wave state: a time-crystalline state of a finite-size quantum system, in which parity-time symmetry is spontaneously broken. Our work lays the foundation to explore nonreciprocal interactions in active quantum matter.

In [2], we apply some of these ideas to superradiant lasers, which consist of incoherently driven atoms coupled to a lossy cavity, are a promising source of coherent light due to their stable frequency and superior narrow linewidth. We show that when a fraction of the atoms is not driven, a shift in the lasing frequency and a broadening of the linewidth occur, limiting the performance of a superradiant laser. We explain this behavior by identifying nonreciprocal interactions between driven and undriven atoms, i.e., competing alignment and antialignment of their dipoles. Our results have implications for the realization of superradiant lasers, establishing the relevance of nonreciprocal phenomena for quantum technologies.

Work done in collaboration with Tobias Nadolny, University of Basel, Switzerland, and Matteo Brunelli, JEIP, UAR 3573 CNRS, Collège de France, PSL Research University, 11 Place Marcelin Berthelot, 75321 Paris Cedex 05, France.

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Toward Algebraic Quantum Control

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The ability to exactly obtain the dynamics of a physical system is a core goal of most areas of modern physics. Full knowledge of the state of a system at all times would be of greatest advantage for a myriad of tasks of current interest, such as quantum simulation, computing, and control. Quantum dynamics are characterized by the non-commutativity of operators in the Hamiltonian, which in turn implies that analytical solution are, in general, impossible to obtain. A standard way to approach this problem is to use of ad-hoc solutions or numerical techniques. While this allows for a better understanding of the physical processes of interest, such understanding remains only partial, and the question of how to obtain full control over the dynamics remains open.

We introduce a novel approach to determine the dimensionality of a Hamiltonian Lie algebra of interacting bosonic systems by appropriately classifying the space of its generating terms, thereby dividing the space of arbitrary linear Hermitian operators into classes with a meaningful physical interpretation. A first main result on the constraints that must be fulfilled by Hamiltonians without drift in order for the Hamiltonian Lie algebra to be finite-dimensional is obtained. Extension of this work to the classification of such algebras for one self-interacting bosonic mode is also provided. A generalization of the main result for arbitrary modes is obtained, thus tackling a wide range of physically-relevant scenarios. Our work has important implications for theoretical (quantum) physics as well as the theory Lie algebras.

Pilot-wave hydrodynamics

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In 2005, Yves Couder discovered that millimetric droplets may self-propel along the surface of a vibrating liquid bath, guided by their Faraday pilot-wave field. Subsequent studies have shown that these walking droplets exhibit features previously thought to be exclusive to the quantum realm, including single-particle diffraction and interference, quantized orbital states, probabilistic tunneling, statistical projection effects in corrals, Anderson localization, interaction-free measurement and violations in static Bell tests [1]. The key feature of the walking-droplet system is that it is non-Markovian: the bath serves as the memory of the droplet, and all of its emergent quantum features arise in the long-memory limit where its wave field is most persistent.

The walking-droplet system represents a macroscopic realization of the pilot-wave dynamics proposed for microscopic quantum particles by Louis de Broglie in his theory of the double-solution. Both systems are characterized by two distinct wave forms, a monochromatic pilot-wave field generated by the particle vibration, and an emergent wave form describing the particle statistics. In each of the hydrodynamic analogs, the droplet's bouncing frequency plays the role of the particle's Compton frequency in de Broglie's mechanics, and the Faraday wavelength plays the role of the de Broglie wavelength in its quantum counterpart [2]. Experimental and theoretical explorations allow us to assess the potential and limitations of the walking-droplet system as a quantum analog. Particular attention is given to illustrating how the non-Markovian droplet dynamics may give rise to features that are typically taken as evidence of quantum nonlocality in their microscopic counterparts.

Theoretical descriptions of pilot-wave hydrodynamics provide a point of comparison for existing quantum pilot-wave theories. We demonstrate that the walking droplets are more closely aligned with de Broglie's original conception, his double-solution pilot wave theory, than the subsequent de Broglie-Bohm theory. Our theoretical description has also allowed us to explore a broader class of classical pilot-wave systems. For example, extending our classical model to three dimensions has revealed the spontaneous emergence of classical spin states, in which the particle translates along a helical path that is quantized in both radius and angular momentum [3]. Finally, we compare the wave form accompanying the walking droplets to the wavefunction of an exciton-polariton. Since both systems are driven and dissipative, we are able to draw a direct mathematical map between the two systems, thereby rationalizing their strikingly similar wave forms.

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The vacuum electromagnetic field as the source of atomic stability

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Dedicated to the memory of Luis de la Peña.

Atomic stability has defied physical explanation since Bohr's original proposal of 1913. Here, we address the issue of the stability of the hydrogen atom from first principles within the context of stochastic electrodynamics (SED). To this end, we study the behavior of the adiabatic invariants when the Hamiltonian system is perturbed by the zero-point radiation field (ZPF). Initially, this approach leads to the ground state of the H atom. The excited states are obtained by considering that the field is composed of modes which may enter in phase with the system's orbits. When the system has an unperturbed orbital frequency and one or more associated adiabatic invariants, its long-time dynamics is not determined by the entire random field indiscriminately, but by the cumulative coherent contribution of those specific modes of the ZPF that resonate with the orbit. Steady balance is reached when the driving force of the resonant field modes on the orbiting electron exactly balances out the electron's dissipation due to radiation reaction. The resonant states are shown to correspond to integer values of the associated adiabatic invariant, thereby substantiating the Wilson-Sommerfeld quantization postulate. Furthermore, it is argued that when an orbit enters in phase with a specific mode that connects it with a different invariant state, it may absorb or lose energy coherently from that mode. In this case the adiabatic invariant undergoes a rapid, deterministic transition to a higher or lower value.

AC transport in ultracold Fermi gases.

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In this talk we will discuss the response of a gas of ultracold atoms to a periodic drive. We will discuss how exact results obtained at low and high frequencies can be used to find the response of the gas at arbitray frequencies and that this interpolation scheme is in good agreement with quantum gas microscope experiments. In particular, the resistivity of the cloud evolves linearly with temperature, a behaviour similar to bad metals in condensed matter physics.

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Superconducting circuits as a platform for experiments on open quantum systems

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Superconducting circuits, mesoscopic reservoir and tunnel junction thermometry provide a playground for open quantum system in the sub-kelvin regime. We experimentally demonstrate two distinct approaches for thermometry. First, we extract the thermal occupation of a qubit to diagnose its coupled environment [1]. Second, we utilize bolometric sensing of a mesoscopic resistive reservoir to probe the attached superconducting circuits [2] [3]. The methods enable the observation of open quantum systems through their dissipative interplay.

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Quantum measurement of work in mesoscopic systems

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Heat and work in thermodynamics refer to the measurement of changes in energy content of external bodies (baths and agents). We discuss the implications of quantum mechanics on the possibility to measure work in a mesoscopic context [1]. The agent is a quantum entity (say an oscillator) that is used to drive the system [2]. An obvious limitation is related to back-reaction [3], leading to a classical-like restriction. We furthermore find that in order to resolve fingerprints of interference an additional quantum uncertainty limitation should be taken into account in the design of the agent [1]. The quantum limitation is fundamental, not merely noise-like blurring.

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Information Flow in Quantum Algorithms: Structure and Optimization

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Quantum algorithms are often described in terms of computational speedups, query complexity, or circuit constructions. In this talk I will take a complementary, more physical point of view: a quantum algorithm is a controlled process in which information about an unknown object is encoded, transported through a quantum state, and finally extracted by measurement. From this perspective, the central question is not only whether the answer can be obtained, but how information flows through the quantum system, which correlations carry it, and how this flow can be optimized. I will first discuss oracle problems as communication tasks, where the hidden property of an oracle plays the role of a message encoded into a quantum system. This reformulation makes mutual information a natural figure of merit and reveals a connection between optimal measurements, quantum correlations, and coherence [1]. I will then show how the same idea can be used operationally in quantum Hamiltonian learning [2]: in Quantum Likelihood Estimation, one can choose the initial state, evolution time, and measurement basis so as to maximize the expected information gain about the unknown Hamiltonian. This leads to a physically motivated optimization principle for adaptive quantum experiments. Finally, I will briefly connect this viewpoint to hidden subgroup algorithms, emphasizing the role of the quantum Fourier transform as a mechanism for making latent group-theoretic information observable [3]. Overall, the talk will present information flow as a unifying physical language for understanding both the structure and optimization of quantum algorithms.

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Deblurring of Nuclear Collisions

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Central nuclear collisions compress nuclear matter, producing the highest pressures in the Universe, comparable to those reached in neutron-star mergers before black-hole formation. According to simulations, these pressures can give rise to intricate emission patterns tied to the reaction plane of the collisions. Unfortunately, that plane can at best be coarsely estimated in individual collision events, so only blurred emission patterns relative to the reaction plane can be recorded, limiting any inference of pressure. Working with ensembles of collision events, we infer the level of blurring due to poor reaction-plane resolution and apply optical deblurring techniques to recover fine details of particle emission in nuclear collisions.

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Contradictory predictions for the Casimir force under Dirichlet-Neumann boundary conditions: Gaussian versus mean-field model

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The mean-field model (MFM) is the workhorse of statistical mechanics: one normally accepts that it delivers results that, despite being numerically just close to the correct ones, are not ”very wrong,” i.e., they resemble the actual behavior of the system as can be eventually obtained by more advanced treatments. For example, this is true for the Casimir force under Dirichlet-Dirichlet (+,+) and (+,-) boundary conditions (BC), where the MFM is expected to deliver an attractive force for like BC or a repulsive force for unlike BC, with the maximum strength of the force positioned either below or above the critical point T_c. It turns out, however, that this is *not* the case with Dirichlet-Neumann (DN) BC. For them, the mean-field approach leads to an attractive Casimir force. This contradiction with the “boundary condition rule” is cured in the case of the Gaussian model under ND BC. Our results, which are mathematically exact, demonstrate that the Casimir force within the MFM is attractive as a function of temperature T and external magnetic field h, while for the Gaussian model it is repulsive. The treatment of the MFM is based on the exact solution of one non-homogeneous nonlinear differential equation of second order. The Gaussian model is analyzed both in its continuum and as a lattice realization. The obtained outcome teaches us that the mean-field results shall cautiously be accepted when concerning the fluctuation-induced forces and ought to be checked against better treatment of the fluctuations within the envisaged system.

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Nonclassical energy-change distribution as a witness of non-Markovian quantum dynamics

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We address the problem of identifying non-Markovian quantum time evolutions of an open quantum system by only performing measurements of the system's energy. We demonstrate that violations of CP-divisibility are always witnessed by non-positive values of the energy-change Kirkwood-Dirac quasiprobability distribution associated with the system's Hamiltonian, evaluated at consecutive times. The link between non CP-divisibility and non-positivity of the system's energy-change distribution is stronger when the system-environment interactions are energy-preserving. The witness works whenever anomalous energy fluxes, due to non-Markovianity, are realized. Anomalous fluxes are also detected by the non-Markovianity measure built over the quantum mutual information between the states of the open system and of a quantum correlated reference.

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Emergence of Classicality from Equilibration in Isolated Quantum Systems

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The emergence of macroscopic behavior is a central theme in both quantum mechanics and statistical physics. In the standard accounts, classicality and thermal equilibrium are typically explained by coupling the system to an external environment or bath: environmental interactions suppress interference (decoherence) and drive relaxation toward a thermal state. Over the last decades, however, a complementary perspective has emerged in which thermalization can occur even in fully isolated quantum systems evolving unitarily, in the operational sense that expectation values of relevant observables remain close to equilibrium values for most times. In this work we ask whether the same intrinsic equilibration mechanism can also account for the emergence of macroscopic classical behavior in quantum mechanics. Using bounds on equilibration in closed systems, we investigate conditions under which a time-evolved pure state is, for most times, indistinguishable (with respect some observables) from an appropriate classical mixture. This provides a route to an operational quantum-classical transition without invoking an explicit bath and suggests a direct link between two foundational questions: the origin of thermalization in closed quantum systems and the quantum-to-classical transition in macroscopic physics.

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Scale Effects in Plasmon-Enhanced Raman Spectroscopy

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Plasmon-enhanced Raman measurements are inherently scale-dependent, i.e. the apparent chemical information is determined by the spatial extent over which electromagnetic confinement, chemical coupling, and structural heterogeneity are sampled. In SERS, spectra are typically representative of an average over a multitude of molecules and multiple nonequivalent hotspots. Consequently, band positions and intensities reflect ensemble behaviour rather than a uniquely local configuration [1]. In TERS, the interaction volume is compressed to a single tip-sample junction, and in the highest-resolution regime, the signal becomes sensitive to the atomic structure of the apex itself [2, 3]. In such conditions, atomic-scale fluctuations in the apex geometry are not merely a secondary perturbation, but rather an integral component of the signal-forming mechanism. This is due to the fact that minor alterations in the apex geometry result in changes to the local field gradient, the effective Raman selection rules, and the degree of chemically specific tip-molecule coupling [2, 3]. This phenomenon elucidates the capability of TERS to approach base-to-base contrast in single-stranded DNA and to facilitate a sequencing-like readout along a quasi-one-dimensional molecular scaffold [4]. Concurrently, the same extreme confinement limits on transferability are evident: a spectrum acquired from a structurally heterogeneous object such as a single virus is expected to reflect localised nanoscale variation rather than a molecular fingerprint which is globally representative [5]. Consequently, scale effects in plasmon-enhanced Raman spectroscopy should be understood as a transition from ensemble averaging to atomically modulated local probing, where the experimental resolution defines both the information content and the interpretability of the spectrum [1-5].

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Theorem on von Neumann entropy conjectured from physics of irreversibility

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Emergence of macroscopic irreversibility from the underlying microscopic dynamics is a fundamental puzzle in theoretical physics. In a Boltzmann gas under local reversible perturbation, the restoration of indistinguishability of the molecules (i.e., a non-equilibrium generalization of Gibbs famous factor 1/N!) turns out to generate microscopic entropy in exact coincidence with the thermodynamic entropy. A similar result holds in the abstract quantum gas, if we impose symmetrization of the perturbed composite state of the constituents — in quantum informatics, it is called twirling over the group of permutations of the constituents. Furthermore, in Gibbs quantum state of a homogeneous system, the thermodynamic entropy production of a local perturbation will be exactly underlined by the von Neumann entropy produced by twirling over the group of translations. Whether twirlings are the real and ultimate way for Nature to 'forget' some particular microscopic data remains an open question.

The coincidence of microscopic and thermodynamic entropies relies on an asymptotic relationship for von Neumann relative entropy, which was conjectured first by physicists (D. Feldmann, Kosloff) assuming the said coincidence of entropies, and was proved by mathematicians (Csiszár, Hiai, Petz). Imre Csiszár told me: I cannot see how you came to this conjecture. I answered: Oh, and I cannot follow how you proved it.

The Many Faces of Quantum Fluctuations in Driven Vibrational Systems

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Periodically driven quantum oscillators are one of the best controlled quantum systems far from thermal equilibrium. They provide a means to study generic features of quantum dynamics and quantum fluctuations away from equilibrium, including those with no analog in equilibrium systems. I will provide an overview of the theory of fluctuation phenomena in resonantly modulated nonlinear vibrational systems and describe the recent experiments. I will discuss the phenomenon of quantum activation where, even for zero temperature, switching between vibrational states occurs via a transition over the barrier in phase space rather than via quantum tunneling. The means of controlling the switching rate and revealing the features of the underlying real-time instantons in complex phase space will be outlined. I will also discuss many-body phenomena, where systems of coupled oscillators may experience quantum phase transitions, whereas disorder in such systems leads to nonreciprocal behavior, with the onset of a probability current and anomalous diffusion waves.

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An artificial motor protein that walks along a DNA track

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We demonstrate the realization of an artificial protein motor called Tumbleweed (TW) that walks directionally along a DNA track under external control. TW consists of three legs, each with a ligand-gated DNA-binding domain that enables selective interaction with specific sites along a DNA track. Using single-molecule fluorescence assays and a programmable microfluidic device, we show that TW steps directionally along a designed DNA track in response to a defined sequence of ligand inputs.

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Probing thermodynamics and entanglement with bosonic quantum simulators

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Quantum simulators based on bosonic systems–particularly cold atoms on atom chips, but also superconducting devices–allow us to probe thermodynamic features and protocols under precisely controlled conditions. This talk will elaborate on this theme along several lines of thought. We will explore how Landauer's principle can be experimentally tested, relating the erasure of information to the dissipation of heat in the quantum many-body regime [1]. We will also highlight the considerable challenge of detecting entanglement in such cold-atom quantum simulators [2], and examine how compactness can curb entanglement growth in bosonic systems [3]. Furthermore, we will argue that analog quantum simulators are presumably more robust to noise than their digital counterparts [4]. Finally, we will discuss in what ways quantum advantages may emerge in bosonic quantum simulators [5], and how notions of Hamiltonian learning are expected to support this endeavor [6].

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Conditional Dynamics of a Dual-Rail Qubit with Asymmetric Erasure Rates

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Dual-rail erasure qubits offer a promising route toward higher error correction thresholds by converting dominant energy relaxation errors into detectable erasure errors. Existing implementations typically assume that the erasure rates of the two logical modes are equal, or that any asymmetry is effectively suppressed by averaging or by dynamical decoupling. In this work we develop a detailed microscopic model for erasure errors in transmon-based dual-rail qubits and study the conditional dynamics of the qubit subspace upon post-selection against erasure events. We show that the erasure asymmetry $\delta\Gamma$ introduces an additional dephasing channel in the conditional dynamics. For single trajectories the coherence decays on a timescale set by $1/\delta\Gamma$, typically faster than in the symmetric limit. We further show that T_1 experiments have a reduced sensitivity to the $\delta\Gamma$ induced channel whereas T_2 experiments retain the single trajectory behaviour. We argue that this distinction explains an apparent contradiction in recent experimental data and poses a significant challenge in the calibration of DR qubit based systems. To mitigate the erasure asymmetry dephasing channel in T_2 experiments, the standard approach is to apply CPMG dynamical decoupling sequences. We show that even in the limit of purely static noise, the number of pulses required grows with the magnitude of the erasure asymmetry. Since long CPMG sequences are difficult to integrate into QEC circuits and themselves introduce additional dephasing, as an alternative, we propose a passive mitigation strategy based on modulating the energy splitting of the two-level system bath responsible for the asymmetry, which suppresses $\delta\Gamma$ and recovers the $T_2 = 2T_1$ limit without requiring active pulse sequences on the qubit.

Correlations and spins in 2D materials

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Electronic correlations in few-layer graphene systems, such as rhombohedral ABC graphene or Bernal AB graphene, enable novel Stoner- and intervalley-coherence-correlated states. The corresponding order parameters are typically meV in magnitude, similar to the strength of spin proximity effects–spin-orbit coupling and exchange interactions–induced by proximity to transition-metal dichalcogenides and van der Waals magnetic semiconductors. I will present several examples [1,2] of this interplay and outline our theoretical approach, which is based on realistic DFT-based effective single-particle Hamiltonians [3] and generalized RPA susceptibility. In particular, I will demonstrate that valley-Zeeman spin-orbit coupling in graphene gives rise to new spin-valley coherence phases in the presence of electron interactions.

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Nuclear clocks and search for new physics

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The isomeric transition in ^{229}Th - recently laser-excited by multiple groups - opens a path to a nuclear clock with accuracy competitive with, and potentially exceeding, the best optical atomic clocks. The nuclear clock can be realised using different charge states - Th^{+}, $Th^{2+,}$ $Th^{3+,}$ and Th^{4+} - each exhibiting distinct frequency shifts due to electron-nucleus interactions [1]. In effect, these represent different clocks, each with unique properties and precision limits.

The surrounding electrons strongly mediate excitation and decay via the electronic-bridge mechanism and can modify both transition probability and lifetime by orders of magnitude [2]. The clock performance is influenced by external perturbations, such as ion-trapping fields and blackbody radiation [3]. A "stretched-state" scheme suppresses leading-order electron-nucleus entanglement and mitigates key systematic effects [4].

The ^{229}Th transition is exceptionally sensitive to physics beyond the Standard Model: spatial/temporal variation of fundamental constants (α, quark masses, Λ_{QCD}) [5], ultralight dark-matter couplings to gluons and nucleons [6], and violations of Lorentz invariance and Einstein's equivalence principle [7]. For orders enhancement factors relative to electronic transitions, together with frequency-ratio networks linking nuclear and atomic references, enable stringent, model-aware constraints.

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Experiments at the interface of general relativity and quantum mechanics

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The two pillars of modern physics are the theories of General Relativity (GR) and Quantum Mechanics (QM). After decades of theoretical attempts to unify these two pillars under one theoretical framework (often referred to as quantum-gravity), these pillars remain independent. To some this situation is so unnatural, that they claim it actually hints that at least one of the theories is wrong in some fundamental way. As technology in quantum-optics labs improves, new experiments - working at the interface of these two theories - can be realized. Such experiments will hopefully provide new insights.

In this talk, I will present three experiments conducted at this interface, two already realized and one planned. The first involves clock interferometry, in which a single clock in a spatial superposition experiences two different proper times due to gravitationally induced red shift [1-3]. The second involves the observation of the consistency of the Einsteinian equivalence principle in the quantum domain [4]. While the first two were realized with atoms, the third involves massive objects, specifically, nano-diamonds [5]. Leaping by ten orders of magnitude in mass relative to the atomic experiments, the third experiment makes use of so-called active mass, where not only the gravitational field of Earth needs to be taken into account.

The experiments are based on Stern-Gerlach interferometry [6]. Time permitting, I will be happy to also address more technical questions. For example, interesting issues concerning decoherence arise [7,8].

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Revisiting the classical-quantum correspondence

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The most common quantum-classical correspondence follows from the Ehrenfest theorem, which relates the expectation values for the position and momentum to the expectation value of their corresponding Hamilton equation counterparts. In other words, the classical equations of motion hold after taking a quantum average of them. But, these equations can be misleading—for example, in a definite energy state of the harmonic oscillator, the averages are exactly zero, corresponding to the fact that these are stationary states. Instead, if we compare coherent states (a displaced ground state), their expectation value satisfies the same equation of motion as the classical system. The quantum system also has uncertainty, which the classical system does not. Key to this work is that the classical and quantum potentials are *identical*. But, then one finds the ground-state energy for the quantum system is different from the lowest energy state of the classical system.

We approach this differently [1.2]. If one takes the classical Hamilton equations of motion and decouples them by forming A=p+f(x), then the classical equation of motion can be solved exactly for all exactly sovlable quantum systems. This produces a new way to solve for Kepler orbits that is remarkably simple and apparfently unknown prior to this work. Furthermore, if we quantize position and momentum and form A^*A, we find it creates a Hamiltonian with an identical form of the equation of motion for the ladder operators. But, the quantum potential has a quantum correction relative to the classical potential. Now, however, the ground-state energy is identical to the lowest-energy state of the classical system. Furthermore, one can compare the orbits of position and momentum for the classical and quantum systems and in general there are now differences (for the simple harmonic oscillator, they do agree). We discuss how to compare classical to quantum motion in this new paradigm, which is quite similar, but different, from the conventional approach.

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Green's function methods for open molecular systems

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Developments of experimental techniques at the nanoscale require corresponding developments in theoretical methods. With the focus of experimental research shifting to open molecular systems, theory must provide methods capable of describing the responses of open nonequilibrium quantum systems while accounting for environmental effects. Nonequilibrium Green's functions provide a convenient theoretical tool that satisfies the requirements above. I will review our recent efforts on the theoretical formulation of optical spectroscopy and quantum control using various nonequilibrium Green's function techniques.

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Quantum Cooling through Measurements

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Quantum steering is a measurement-based state-engineering protocol. It represents a high-efficiency approach to generating resources for quantum computations, entanglement generation, quantum control and quantum cooling. I will provide a pedagogical overview of this important field. I will then discuss recent results concerning universal (state-independent) approach to cooling of many-body system. I will show that a quantum system can be cooled without knowledge of system details when system-meter interactions and meter splittings are chosen randomly. For sufficiently small interaction strengths and long interaction times, the protocol ensures that resonant energy-exchange processes, leading to cooling, dominate over heating.

Physical requirements for anomalous thermalization (Mpemba effect)

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The Mpemba effect is a thermodynamic anomaly in which a system farther away in temperature from equilibrium thermalizes before one that is initially closer. The effect has been experimentally observed across a wide range of systems, including water, colloids, and trapped ions. It has recently been the focus of numerous studies aimed at understanding its mechanisms and developing multiple applications. Despite extensive work in the field, it remains unclear which types of systems exhibit the Mpemba effect.

To address this, we derive simple necessary conditions on the transition rates for the Mpemba effect in a Markovian 3-level system. Furthermore, we analytically prove for baths at zero temperature and numerically show for the non-zero temperature case that the 3-level system conditions can be used to study the Mpemba effect in N-level systems. Multiple time scales govern thermalization in these systems. This allows the evolution to occur more quickly across larger temperature differences, explaining the Mpemba effect.

We apply our protocol to evaluate which types of systems exhibit the Mpemba effect and, in doing so, explain why the Mpemba effect in Markovian systems remains a thermodynamic anomaly. In particular, we found that the Mpemba effect requires transition rates that increase with the energy difference. Due to the maximum entropy principle, for bosonic baths the thermal component of the transition rates decays with the energy difference, limiting the bath spectra that can produce the Mpemba effect. This allows us to rule out the N-level system Mpemba effect for sub-Ohmic, Ohmic, and for some super-Ohmic spectra. These spectra describe a wide range of physical and chemical phenomena that will not exhibit the Mpemba effect. Moreover, our results provide a clear path to determine the minimal physical requirements for the Mpemba effect, and we use them to understand its underlying mechanisms better. Finally, our protocol could help identify relevant parameters for experiments, numerical simulations and diverse applications.

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Single pair measurement of CHSH, negative probabilities and testing relativistic independence through weak measurements.

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Bell inequalities are one of the cornerstones of quantum foundations and fundamental tools for quantum technologies [1], tied to specific aspects of quantum mechanics, such as quantum non-locality [2], sources of debate in the physicists' community.

Recently, the scientific community worldwide has put much effort towards them, culminating with loophole-free experiments [3]. Nonetheless, none of the experimental tests so far was able to extract information on the whole inequality from each entangled pair, since the wave function collapse forbids performing, on the same quantum state, all the measurements needed for estimating the entire Bell parameter.

We present here the first single-pair Bell inequality test [4] able to obtain a Bell parameter value for every entangled pair detected. This is made possible by exploiting sequential weak measurements, allowing to perform non-commuting measurements in sequence on the same state, on each entangled particle. Such a feature not only grants unprecedented measurement capability, but also removes the need to choose between different measurement bases [7]. We also demonstrate how this can be related to negative probabilities that can be directly extracted. Indeed, the attempt to introduce joint probabilities for incompatible observables leads to "unphysical" negative probabilities. This is particularly evident in the case of Bell inequalities. Here we present the first direct experimental determination of negative probabilities by exploiting sequential weak measurements in a Bell scenario, discussing its implications. We will discuss in detail the possible applications and the impact on Foundations of Quantum Mechanics.

Then, as a further use of sequential weak measurement, we present a test [5] of the relativistic independence proposed in [6].

Finally, next developments will be presented.

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A New Frontier in Matter-Wave Interferometry: From Large Metal Clusters to Biomolecules

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The superposition principle lies at the foundation of quantum mechanics, yet testing its validity at ever-increasing mass and complexity scales remains a major experimental challenge. Matter-wave interferometry provides a direct probe by coherently delocalizing massive particles over mesoscopic distances. Here, we present a high-mass matter-wave interference platform that extends this approach to a new material class: large metal clusters. **We report the first observation of quantum interference with sodium nanoparticles** comprising **more than 7,000 atoms**, corresponding to **masses above 170 kDa [1]**. The resulting spatial superposition states reach a **macroscopicity of $\mu = 15.5$**, improving existing bounds on generic macrorealistic modifications of quantum theory by over an order of magnitude.

I will further discuss recent advances in the generation, detection, and manipulation of **slow, neutral beams of clusters [2] and biomolecules [3]**, as well as the development of **deep-UV laser systems** that promise further scalability in particle mass and structural complexity.

These developments open new perspectives for **molecular metrology** [4,5] and high-resolution spectroscopy, enabling precise characterization of internal particle properties in free flight. Finally, I will outline ongoing efforts to extend quantum interferometry to increasingly **complex biomolecules, including proteins**, thereby broadening the range of composite quantum systems accessible to matter-wave experiments.

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Contextual unification of classical and quantum physics

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Following an article by John von Neumann on infinite tensor products, we develop the idea that the usual formalism of quantum mechanics, associated with unitary equivalence of representations, stops working when countable infinities of particles (or degrees of freedom) are encountered [1]. This is because the dimension of the corresponding Hilbert space becomes uncountably infinite, leading to the loss of unitary equivalence, and to sectorization. By interpreting physically this mathematical fact, we show that it provides a natural way to describe the "Heisenberg cut", as well as a unified mathematical model including both quantum and classical physics [2], appearing as required incommensurable facets in the description of nature [3].

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Interplay of current-induced forces and electronic friction in nanoscale junctions far from equilibrium

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Nano-scale junctions consisting of a single molecule or a quantum dot sandwiched between macroscopic metallic leads show a rich variety of non-equilibrium phenomena when exposed to a sufficiently large bias. For example, Coulomb blockade manifests itself in the time-domain as a periodic charging and discharging of the central quantum dot [1]. In this lecture, special attention will be paid to the current-induced forces on the nuclei. The real-time dynamics of the system is simulated by combining Ehrenfest dynamics with time-dependent density functional theory (TDDFT). Electronic viscosity is accounted for by the frequency-dependence of the TDDFT exchange-correlation kernel. To understand the subtle interplay between the current-induced forces on the nuclei and electronic friction, we study the translational, vibrational, and rotational motion of a diatomic molecule immersed in a current-carrying electron liquid [2]. Starting from the nuclear equilibrium distance and applying a current pulse, we first observe acceleration of the nuclei due to the initial dominance of the current-induced push. After this initial phase, stabilization sets in upon balancing of the two forces, and finally, deceleration is caused by the friction after the end of the pulse. Based on these observations, we then explore the design of an atomic “waterwheel” [3], periodically driven by an AC current flowing in the electron liquid. A steady rotation of the molecule can be achieved for certain combinations of the amplitude and frequency of the imposed AC current. For other combinations, the nuclear motion turns out to be chaotic. The somewhat unusual forces appearing here will be analyzed in terms of the exact factorization. [4,5,6].

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Time Delay in Tunneling Current and the Tunneling Time

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The question *"How long does quantum tunneling take?"* has remained a longstanding problem in quantum physics. In contrast to barrier transmission (or tunneling probability), no unique theoretical or experimental definition of tunneling duration as an intrinsic property of a system has been established. Instead, it is typically inferred through the application of an external perturbation or via a specific measurement protocol.

For example, Büttiker and Landauer proposed determining the tunneling (traversal) time by applying an external oscillating field to the barrier. In the present work, we implement this idea to evaluate the average time-dependent current (conductance) through an oscillating barrier that separates two reservoirs (leads) with finite bandwidth Λ, described by the Kronig-Penney model.

We find that, in the steady state, the average conductance follows the barrier oscillations with the same frequency ω, but with a time delay ($t \to t - t_0$) arising from the traversal (tunneling) time under the barrier. A particularly simple analytical expression for this delay is obtained in the limit $\omega \to 0$. Near the band center, it reduces to $t_0 = 1/\Lambda$. In the wide-band limit (Markovian reservoirs), $t_0 \to 0$, in agreement with the classic result of MacColl, obtained by entirely different means.

Remarkably, the tunneling delay persists even in the limit $\omega \to 0$, where the barrier effectively becomes time-independent. This suggests that t_0 reflects an intrinsic property of the system, despite being revealed through an external time-periodic perturbation. We therefore propose that our result for the tunneling time delay may be applicable to a broad class of systems.

As an illustration, we consider tunneling time measurements in an optical barrier system, which provides an optical realization of the one-dimensional Kronig-Penney model. Our simple expression for t_0 shows excellent agreement with experimental data, in contrast to the Büttiker-Landauer formula for complex tunneling time applied to the same system.

Importantly, our analysis explicitly incorporates the effects of the reservoirs on the time delay. This allows us to separate these contributions from t_0 and thereby isolate the tunneling (traversal) time through the barrier. We find that the tunneling time is zero for a single barrier. Consequently, we suggest that the nonzero tunneling times observed in experiments originate from non-Markovian effects associated with finite reservoir bandwidth, and we propose ways to test this experimentally.

Random layers for quantum optimal control with exponential expressivity

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A long-standing problem in quantum optimal control is finding an optimal pulse structure that leads to an efficient exploration of the unitary space with a minimal number of optimization parameters. We solve this problem by constructing parametrized pulse sequences from random-amplitude pulses grouped in layers with one optimization parameter per layer. We show that, when increasing the number of pulses, the resulting random unitaries converge exponentially fast to the uniform Haar-random ensemble, thus providing for an efficient exploration of the unitary space. Grouping the pulses into layers allows for lowering the total number of optimization parameters. We focus on two random-layer (RALLY) methods: In $\mathrm{RALLY_T}$, time durations of the layers are optimized while the pulse amplitudes are randomly chosen beforehand, possibly even from a few discrete values. $\mathrm{RALLY_A}$ optimizes a joint scaling factor of the random pulse amplitudes in each layer. We numerically validate the two methods by applying them to problems of unitary synthesis, ground-state preparation and state transfer in different quantum systems. For all problems considered, both methods approach an information-theoretic lower bound on the number of optimization parameters and outperform other commonly used algorithms. In gradient-free optimization, the RALLY methods are orders of magnitude more accurate with fewer figure-of-merit evaluations. The RALLY methods are promising for advancing quantum machine learning and variational quantum algorithms.

Probing the structure of topological entanglement via selective partitioning

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The topological entanglement entropy (TEE), defined as the subleading term of bipartite entanglement entropy, provides a universal signature of topological order. However, as a single number, it does not reveal its internal structure of more complex systems, such as multi component fractional quantum Hall (FQH) systems.

We propose a protocol to resolve this structure of complex FQH systems by selectively partitioning different components at the entanglement cut. By imposing constraints on chosen components in a stepwise manner, we track how the subleading contribution to the entanglement entropy evolves as individual components are partitioned. This procedure defines a sequence of partition-induced changes of the TEE that depends on the order in which the constraints are applied. We show that in Abelian systems these changes are governed by the scaling dimensions of the operators implementing the constraints, while in non-Abelian systems they deviate from this behavior.

Building on recent experimental advances, we show that this partitioning structure can be accessed via Maxwell relations in quantum point contact (QPC) and quantum dot (QD) setups.

The Quantum Plumber's Problem (or Quantum Advantage in Interaction-Free Interferometric Which-Path Discrimination)

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Recent work quantified the notion of quantum counterfactual gain—the advantage quantum interaction-free measurement gives over classical (un-interfering particle-type) strategies for identifying the presence or absence of an absorber in a given path. Using a recent analysis of the relation between states in the five measurement contexts for a three-level system, we here extend this work to identifying quantum advantage in a new scenario, which we term the "quantum plumber's problem". In this scenario, we imagine a "quantum plumber", who knows that one path of an interferometer is blocked, but wants to find the optimal strategy for identifying which path this is. We quantify the advantage that the use of quantum resources (beyond either interference-free particles or weak coherent states) gives the plumber, and present strategies for determining the optimal input state for the interferometer for performing such a task. We further link this to recent analysis showing to what extent such a three-path interferometer can and cannot be represented using either Quantum Simulation Logic (based on Spekkens' toy model) or the stabiliser subset of quantum mechanics, and use this to link advantage in this game to "magic" (or "non-stabiliser-ness") in the interferometer and initial state.

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Quantum Brownian Motion: Facts, debatable issues and unsolved issues

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The talk will provide an introduction to the theoretical schemes (methods and tools) to describe the features of *quantum Brownian motion* (which rule phenomena such as rate theory, stochastic resonance, etc.) which occur at extreme low temperatures, up to the transition towards higher temperatures where quantum correlations start to fade out and a classical behavior sets in. Special focus on is also paid to the regimes of validity of various those theoretical tools, together with various pitfalls and subtleties that arise in describing correctly of those arising quantum features.

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Toward entangled spins in nanodiamonds for biosensing

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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. To get the full benefits from the quantum nature of the NV, two or more entangled NVs are needed. While this has been done in bulk crystals, implementing it in nanodiamonds provides unique challenges, especially for the sub 10 nm sizes needed for the most interesting biosensing applications. In this talk I will review recent advances in nanodiamond growth and optimization, and the implantation of high-quality NVs.

Mesoscopic models for electromagnetic fluctuations in and near conducting media

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Dispersion interactions between polarisable objects arise from rectified electromagnetic fluctuations of both quantum and thermal origin. A commonly used framework is fluctuation electrodynamics, as developed by the Rytov school [1] and upgraded to macroscopic quantum electrodynamics by Welsch, Scheel, and Buhmann [2,3]. It explains the long-range tails of van der Waals and Casimir-Polder interactions, including their dependence on temperature and material properties. The talk discusses deviations between the theory and some experimental data that appear when both finite temperature and finite electric conductivity are relevant [4]. The idea is explored that electrons in metallic conductors may have a response to e.m. fields that resembles that of a superconductor, provided the length scales are below the mean free path. This is motivated by coherent electron interference in mesoscopic structures like rings where persistent currents have been observed [5, 6]. We thus extend the Rytov theory to conductors where fluctuating sources have correlation lengths in the 10 nm range.

I thank Jon Scouten and Alexander Schomburg for discussions. – This work is supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) within SFB 1636, ID 510943930, Projects No. A01 and A04.

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Open Quantum Dynamics and Dissipative State Selection in Nanoplasmonic Cavities

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Nanoplasmonic cavities realise an extreme regime of cavity quantum electrodynamics in which strong light-matter coupling emerges at the few-nanometre, few-femtosecond scale under intrinsically open, lossy, and dispersive conditions [1-4]. In contrast to conventional high-Q cavities, these systems operate far from the closed, Hermitian limit, raising fundamental questions on the role of dissipation, mode non-orthogonality, and the quantum description of radiative leakage. Here we develop a unified framework that connects experimentally accessible nanoplasmonic architectures [5,6] with a rigorous open-system quantization. In waveguide-coupled configurations, quantum nanoplasmonic coherent perfect absorption (qnCPA) [7] enables selective excitation and stabilization of dressed states through impedance matching, illustrating how dissipation and driving can be coherently balanced to control quantum states in non-Hermitian environments. On the theoretical side, a quantum quasinormal-mode (QNM) approach [8], rooted in macroscopic QED, provides a consistent quantization of open resonators via complex mode expansions and perfectly matched layers. This yields a modal Fock-space formulation and a microscopically derived Lindblad dynamics that captures both coherent and dissipative inter-mode coupling. These results establish nanoplasmonic cavities as a model platform for exploring quantum dynamics in open, non-Hermitian systems, where loss is not merely detrimental but can be harnessed as a resource for state preparation and control.

This work was supported by Research Ireland (formerly Science Foundation Ireland), Grants No. 18/RP/6236 and 22/QERA/3821.

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Superradiance, Chaos, and Thermalization in Atom-Photon Systems

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The Dicke model describes a system of N two-level atoms collectively coupled to a quantized field with a single bosonic mode. It provides a framework for understanding the phenomenon of superradiance in light-matter systems and is also a valuable tool for studying nonequilibrium dynamics.

The model has two classical degrees of freedom and exhibits both regular and chaotic dynamics, depending on the Hamiltonian parameters and the energy region under consideration. This framework makes it possible to explore the relationship between instability, classical chaos, and thermalization [1,2]. Chaos is dominant in the high energy region of the superradian phase [4]. The presence of classically unstable periodic orbits is associated with quantum scarring, which constrains the delocalization of eigenstates and gives rise to dynamical revivals [3].

A striking contrast arises when atoms interact with photon pairs. In this case, there exists a critical coupling at which the energy spectrum collapses, and the superradiant phase survives only as a finite-size effect [4]. Moreover, chaotic behavior becomes particularly relevant at high energies in the normal phase [5].

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The geometry of nonequilibrium response

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Near thermodynamic equilibrium, the fluctuation-dissipation theorem serves as an organizing principle and calculational tool for analyzing a system's sensitivity to external perturbations by linking response to fluctuations. However, driving a system out of equilibrium can enhance this sensitivity by breaking the traditional connection to fluctuations. In this talk, I will present bounds on the maximum response achievable by nonequilibrium systems that can be modeled as discrete-state Markov processes. The limits are determined by the network topology of the system's state space. As a result of this analysis a full description of the geometry of nonequilibrium response emerges, offering a decomposition of any nonequilibrium response in terms of a combination of optimal archetypal systems.

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Vacuum Viscosity

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Our recent investigation on **moving atom-quantum field interactions** [1] reveals a rather surprising fundamental phenomena: An atom with internal degrees of freedom moving at uniform relativistic or nonrelativistic speed in a free quantum field will experience a viscous force originating from the excitation of vacuum fluctuations (quantum noise) of the field, which we call **vacuum viscosity**. Vacuum viscosity is similar to the more familiar **quantum friction** but different in major ways: **a)** quantum friction, as has been explored in great details for several decades, shows up only when the neutral atom moves close to the surface of a dielectric medium or a conducting boundary. Here, **there are no boundaries; b)** this vacuum viscosity is **a quantum effect at zero temperature**, distinct from classical radiation reaction or Einstein-Hopf thermal drag; **c) this vacuum viscous force is reactive in nature,** like the reactance of an inductor, **not resistive** (no phase lag), as "friction" may conjure. As for its origin, we often hear "elegant" arguments based on Lorentz transformation, that there should not be any damping, but such reasoning forgets the fact that we are dealing with an *open quantum system* here, where backaction from the field plays an important role. In fact, the **dissipative dynamics of the system (charge or atom) is intrinsically nonMarkovian**. The conception and investigation of v*acuum viscosity* predated modern quantum friction discovery: It was first proposed in 1970 by Zel'dovich [2] to describe the backreaction effects of vacuum particle production on the dynamics of the early Universe. This idea was quantified and made precise by the rigorous work of many authors in the 70's using quantum field theory in curved spacetime methodologies and **semiclassical gravity theory** for treating **backreaction effects**, captured in terms of **vacuum viscosity** [3]. The one-to-one correspondence between cosmological particle creation and the dynamical Casimir effect enables one to understand the backaction effects of dynamically excited vacuum fluctuations in terms of a **quantum Lenz law**. In our work the uncovering of finer details and the revelation of subtleties are made possible by the adoption of a microphysics model, called the **mirror/atom-oscillator-field** (**MOF) model** in **quantum optomechanics** [4], where the internal (electronic) degrees of freedom of the atom interacts with the quantum field which takes on the values at the spacetime point of the atom's external (mechanical) degree of freedom, or its location, probing at a deeper level than the usual quantum radiation noise and backaction approach.

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Information engine fueled by first-passage times

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I will consider the thermodynamic properties of an information engine that uses feedback control to extract work from a manipulated stochastic system. I will discuss the fluctuation theorems that involve the information associated with the feedback-controlled stochastic trajectories. Such an information turns out to be based on the first-passage-time distribution. I will then discuss the experimental verification of the above results with a se tup consisting of a cantilever submitted to an electrostatic feedback force. I will finally show that the fluctuation theorems extend beyond the specific app lication to such an experiment.

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Fast Nonadiabatic Gates for Quantum Signal Processing via Landau-Zener-Stückelberg-Majorana interferometry

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Fast and accurate implementation of elementary quantum operations is a central requirement for scalable quantum computation. Most gate protocols rely on resonant driving, where rotations are produced by weak or moderately strong periodic fields. An alternative route is offered by nonadiabatic Landau-Zener-Stückelberg-Majorana (LZSM) transitions, where strong driving through an avoided crossing generates controllable population transfer through interference. Such dynamics can be used to construct fast quantum gates in small-gap two-level systems [1,2].

This work establishes a connection between LZSM-based gates and quantum signal processing (QSP). QSP implements polynomial transformations through sequences of elementary single-qubit operations, typically written as alternating fixed rotations and adjustable phase shifts [3,4]. A similar sequence structure naturally appears in the adiabatic-impulse model (AIM): adiabatic evolution produces phase accumulation, while nonadiabatic transitions act as population-changing operations. This correspondence allows AIM dynamics to reproduce the elementary structure required for QSP [5].

We show that suitable driving parameters can realize QSP sequences using double LZSM transitions. Within this formulation, the interferometric phase and transition probability determine the effective gate parameters, allowing QSP operations to be implemented through fast nonadiabatic passages rather than conventional resonant pulses. This connection provides a new interpretation of LZSM interferometry as a resource for quantum information processing and suggests possible high-speed implementations of QSP in strongly driven small-gap systems.

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Thermodynamics of Quantum Measurement: Making tunneling particles and vacuum fluctuations work

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Measuring an operator that does not commute with the system's Hamiltonian generally leads to exchange of energy between the system and the measuring device. I will describe how this disordered form of energy can be harvested to fuel engines and refrigerators. Recent advances will be described concerning the continuous measurement of the presence of a tunneling particle in its classically forbidden region [1]. I will show how the measurement leads to enhanced tunneling and how the energy the measurement process gives can be harnessed to make a thermoelectric engine and refrigerator [2]. This basic physics can be transferred to the many-body context, where a measurmement-based engine is fueled via many-body entanglement together with local measurements and feedback operations. This engine admits a universal thermodynamic characterization in terms of how the quantum vacuum bends under increasing interaction strength [3].

This work is supported by the John Templeton Foundation, grant number 63209.

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Measuring in the dark - classical and quantum results

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The use of destructive interference for measuring classical and quantum systems has a long and interesting history. I will present both microwave and optical experiments where we observe deep sub-wavelength spatial resolutions (with the necessary SNR trade-offs). Specifically, the focusing of Fisher information at the destructive interference nodes will be presented and via a steep phase gradient this leads to the observed resolution. These ideas will then be extended to work on Two-Mode-Squeezed-Vacuum sensing (joint work with the Gefen group). I will then show how we apply interference for spectroscopy of superconducting qubits via tailored adiabatic echo pulses. Finally I will briefly (time permitting) show a spin locking of a superconducting qubit for robust coherence protection against structured noise baths (joint work with the Retzker group).

This work was supported by EU project OpenSuperQPlus and the ISF.

Structural Phase Transitions in Evolving Networks Under Different Node-Deletion Mechanisms

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Many real-world networks evolve under concurrent processes of expansion and contraction. In growing systems, preferential attachment produces scale-free degree distributions with fat tails and hubs. However, empirical evidence from declining networks shows that network contraction does not necessarily destroy structural organization: some shrinking networks maintain a stable truncated degree distribution over long periods. This raises a fundamental question: **how does the mechanism of node deletion interact with preferential attachment to determine whether hubs persist, are suppressed, or disappear entirely?** In the family of models that we consider here, at each time step a node is added with probability P_{add} together with m edges (according to some growth mechanism, such as preferential attachment) or deleted with probability $P_{\text{del}} = 1 - P_{\text{add}}$. The balance between growth and contraction is expressed by $\eta = P_{\text{add}} - P_{\text{del}}$, $(-1 \leq \eta \leq 1)$, where $\eta > 0$ corresponds to net growth and $\eta < 0$ to net contraction. In particular, we extensively studied three growth-contraction scenarios, each leading to distinct qualitative and quantitative behaviors. These can be described using closed-form analytical expressions for the degree distributions $P(k)$, which characterize the different structural phases.

1. Random Attachment + Random Deletion (RARD): In this scenario, random deletion does not target hubs. For $-1 < \eta < 1$, the stationary degree distribution is Poisson-like [1]. At $\eta = 1$ (pure-growth), the distribution turns exponential, indicating a structural transition.

2. Preferential Attachment + Random Deletion (PARD): The stationary degree distribution exhibits a power-law tail for $\eta > 0$, while for $\eta < 0$ it becomes exponential. Thus a structural phase transition occurs at $\eta = 0$ [2].

3. Preferential Attachment + Preferential Deletion (PAPD): In this scenario, deletion is degree-biased and directly counteracts hub formation. The stationary distribution is power-law only in the pure-growth limit of $\eta = 1$ and becomes exponential for any $\eta < 1$ [3].

Discussion: These results demonstrate that the mechanism of deletion is structurally decisive. Random deletion preserves the preferential amplification of high-degree nodes, allowing scale-free structure to persist as long as growth dominates. In contrast, preferential deletion disrupts the accumulation of links by high-degree nodes, suppressing hubs even under net growth conditions. Thus, preferential deletion acts as an effective “anti-preferential attachment” force. This observation provides a theoretical explanation for the emergence of truncated or exponentially-tailed degree distributions in transient networks such as dating platforms, job-seeking platforms, and epidemic removal processes, as well as in strategically attacked networks.

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Phun with Phase Transions of the Quantum Mechanical Kind

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Mesoscopic-size Type I superconductors exhibit a first order phase transition in H-T space. For specimens undergoing an isothermal phase transition, the latent heat is supplied/absrbed by a bath. In contradistinction, for specimens undergoing and adiabatic phase transition, the latent heat is supplied/absorbed by the normal regime, resulting in a surprisingly fun non-isentropic result.

In conversations with the Author, John Bardeen wanted to eliminate all the fun by proposing the appearance of a mysterious magnetic hysteresis prior to phase nucleation.

Truth be told, his attempt to remove the fun only made for a more fun result. [1]

An experiment shows the fun in action. [2]

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Post-processed estimation of quantum evolution

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Weak quantum measurements enable real-time tracking and control of dynamical quantum systems, producing quantum trajectories – evolutions of the quantum state of the system conditioned on measurement outcomes. For classical systems, the accuracy of trajectories can be improved by incorporating future information, a procedure known as smoothing. Here we apply this concept to quantum systems, generalising a formalism of quantum state smoothing for an observer monitoring a quantum system exposed to environmental decoherence, a scenario important for many quantum information protocols. This allows future data to be incorporated when reconstructing the trajectories of quantum states. We experimentally demonstrate that smoothing improves accuracy using a continuously measured nanomechanical resonator, showing that the method compensates for both gaps in the measurement record and inaccessible environments. We further observe the signature of a key predicted departure from classical smoothing: quantum noise renders the trajectories nondifferentiable. These results establish that future information can enhance quantum trajectory reconstruction, with potential applications across quantum sensing, control, and error correction.

Optimizing Energy Conversion in Feedback-Controlled Nano Processes: Harnessing Time-Dependent Information

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Nanoscale devices that convert energy into useful work are becoming increasingly prevalent. A critical challenge in this area is managing energy transduction at the nanoscale. Quantum measurement and the associated acquisition of information can be harnessed to guide and enhance work output through feedback control. In this context, we explore a quantum information engine (QIE) as a prototype energy-transducing nanodevice controlled by measurement [1]. This engine leverages the information exchange between a working medium, represented by a two-level system, and a meter, modeled as a quantum harmonic oscillator. However, this information transfer is not instantaneous; it relies on the measurement time, which is the duration needed to establish a correlation between the quantum system and the meter. This measurement time sets a lower limit on the cycle time of the QIE, making time-dependent information acquisition a crucial resource for the process. We examine the relationship between the energetic cost of quantum measurement, the associated acquisition of information, and the potential extractable work during finite-time operations. To achieve this, we investigate performance quantifiers, including the conversion of information to extractable work, the efficiency of converting input energy to net extracted work, and power, defined as the rate of net work extraction during the cycle operation. Our findings indicate that all these factors are influenced by measurement time in various ways. For example, achieving high efficiency necessitates a long measurement time, but this, in turn, reduces power. To identify an optimal balance among these performance indicators, we employ Pareto optimization, a multi-objective optimization method, to determine ideal measurement times. We also discuss ways to extend our considerations using these concepts, such as in measurement-enhanced photochemical reactions [2].

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Stochastic dynamics of molecular motors and filaments

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The stochastic dynamics of molecular motors and filaments is a major driver of important processes in biological cells including transport of cargo, segregation of chromosomes during cell division, and maintenance of the mechanical structure of the cell. Understanding these processes from a physics perspective requires an understanding of the stochastic dynamics, which often occurs on multiple lenght and time scales. I will illustrate methods to approach these processes based on theoretical models as well as statistical analysis of experimental data. On the one hand, systematic coarse-graining can help to address the dynamics at multiple scales, such as from the chemomechanical cycle of a single molecular motor to active networks of motor-driven filaments. On the other hand, Bayesian inference from experimental data provides a method to reliably extract information from noisy experimental data and to quantify the obtained information or lack thereof.

Quantum thermodynamics, Quantum control, Quantum gates for open systems

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Any quantum system is inherently open, continuously interacting with its environment. Therefore, e ective manipulation of quantum devices must account for this reality. Control of open quantum systems is vital for advancing modern quantum science and technology. We demonstrate such control using a thermodynamically consistent framework, where the drive dynamically influences the systems interaction with the environment. This e ect is embedded in the dynamical equation, leading to control-dependent dissipationa fundamental component of open-system control.

We address two types of destructive noise: noise from the pulse generator and thermal noise from the environment. A Markovian model describes phase and amplitude noise from the external controller, and we investigate its impact on quantum gate execution, highlighting the degradation of gate fidelity. We show that optimal control techniques can mitigate fidelity loss. For this task we employ a highly accurate numerical solver and the Krotov algorithm to solve the optimal control equations in Liouville space.

To handle thermal noise, we construct the dissipative dynamical equations by evaluating a complete set of time-dependent invariants governed by the control field. The Lindblad jump operators emerge as eigen-operators of the commutator of a pair of invariants, satisfying thermodynamic consistency. We achieve the challenging task of controlling quantum gates for non-unitary reset maps with complete memory loss. Additionally, we identify a novel mechanism for controlling unitary gates by actively removing entropy from the system to the environment. This is a generalization of cooling to the quantum channel level.

This study is a joint effort of Aviv Aroch, Roie Dann, Shimshon Kallush.

Experiments on Kitaev chains in nanowires

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We have realized Kitaev chains in arrays of quantum dots intersected with hybrid semiconducting-superconducting sections. We exploit Andreev Bound States (ABS) in the hybrids to provide coupling between neighboring quantum dots through Elastic Co-Tunneling (ECT) and Crossed-Andreev Reflection (CAR). The combination of ECT and CAR can give rise to a ground state degeneracy for even and odd occupations. At these sweet spots partially-protected Majorana Bound States (MBS) arise in the outer quantum dots. We have studied chains ranging from minimal length with two quantum dots up to a six-site chain. We will discuss the improved protection when making the chains longer.

From Nonlinear to Linear Control of Quantum Information and Thermodynamics

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Quantum technologies ranging from computing and communication to sensing and thermodynamic devices rely on quantum information, entanglement being its key resource. Nonlinear unitary entanglement, based on giant long-range dipole-dipole interactions (DDI), has recently been demonstrated at Weizmann to result in single-polariton entanglement [1]. This nonlinear mechanism has been shown by us to open the road to novel quantum thermodynamic devices and quantum-enhanced sensing of thermodynamic variables [2,3]. Another recent major achievement of our group concerns DDI-coupled spin networks: we have shown how quantum information processing and thermodynamics in such quantum complex networks depend on topology, symmetry constraints [4] and disorder [5].

Yet nonlinear unitary entanglement at the few-quanta level remains experimentally challenging. A straightforward substitute is based on post-selection of multipartite states [6] which incurs infidelity. A promising alternative we here propose is based on linear stroboscopic phase control that can amplify two-mode photonic entanglement to a giant degree [7].

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Operational impact of quantum resources in chemical dynamics

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Quantum coherence and other non-classical features are widely discussed in chemical dynamics, yet it remains difficult to quantify when such resources are operationally relevant for a given process and observable. While quantum resource theories provide a principled way to compare "resource-free" and "resourceful" descriptions, most existing tools focus on state-based measures or constraints under restricted operations, rather than on the maximal influence a chosen resource can exert under fixed open-system dynamics. Here we introduce task-specific, process level quantifiers that provide computable upper bounds on the largest change a quantum resource can induce in a target figure of merit. The central idea is to compare the same dynamics acting on an initial state and on a paired, resource-free baseline that represents the closest "classical" counterpart for the task at hand. This yields a direct benchmark for the operational relevance of the resource for the chosen observable. We illustrate the framework on representative models including excitation energy transfer and derive theoretical bounds that identify conditions under which initial delocalization can, or cannot, improve trapping performance relative to incoherent preparations. Overall, the approach provides a general toolbox for diagnosing and benchmarking quantum-resource effects in chemical processes.

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Directionality emergence in 2D and 3D quantum random Lorentz gases

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The propagation of a spherical wave through a random Lorentz gas composed of small fixed scatterers is studied. Inspired by the Mott problem [1] (how an initially isotropic quantum wave can give rise to a single particle-like track), we investigate, on a schematic model, whether such a directional behavior can emerge purely from the multiscattering process, without any explicit measurement or decoherence mechanism. Using the Foldy-Lax formalism [2-4], we derive the far-field angular behavior of the wavefunction, and introduce a directionality vector to quantify its anisotropy and identify its preferred direction. In two dimensions [5], numerical simulations reveal the existence of a strongly directional regime within a specific wavenumber range. This behaviour emerges from multiscattering with more than 100 scatterers and can be related to Anderson localization [6]. Preliminary results in three dimensions are also presented.

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Combining energy efficiency and quantum advantage in cyclic machines

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Energy efficiency and quantum advantage are two important features of quantum devices. We here report an experimental realization that combines both features in a quantum engine coupled to a quantum battery that stores the produced work, using a single ion in a linear Paul trap. We begin by establishing the quantum nature of the device by observing nonclassical work oscillations with the number of cycles as verified by energy measurements of the battery. We moreover apply shortcut-to-adiabaticity techniques to sup- press quantum friction and improve work production. While the average energy cost of the shortcut protocol is only about 3%, the work output is enhanced by up to approximately 33%, making the machine significantly more energy efficient. We additionally show that the quantum engine consistently outperforms its classical counterpart in this regime. Our results pave the way for energy efficient machines with quantum-enhanced performance.

[1] Nature Communications 16, 5127 (2025)

Tight Entropic Uncertainty Relations

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Entropic uncertainty relations H(A) + H(B) $\geqslant \gamma$ give a nonzero lower bound γ to the sum of the Shannon entropies H of the outcome probabilities of incompatible observables A and B. They are better than the variance-based uncertainty relations because they only depend on the Born statistics of the outcomes and not on the outcomes themselves, and because bounds γ typically are state independent. Here we provide a state-independent lower bound γ_s that is better than the textbook Maassen-Uffink bound and, in the limit of the parameter s $\to$ 2, becomes asymptotically tight for all A, B. The bound can be extended to Renyi entropies.

Topological Landau theory

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I will discuss a notion of topology “hidden” in Landau’s theory of phase transitions. When the order parameter comprises several components in the same irreducible representation of symmetry, it can possess a nontrivial topology and acquire a Berry phase under the variation of thermodynamic parameters. To illustrate this idea, I will focus on the superconducting phase transition of an electronic system with tetragonal symmetry and a two-component order parameter. From the time-dependent Ginzburg-Landau equation in the adiabatic limit, we find that the order parameter acquires a Berry phase after a cyclic evolution of parameters. I will discuss two concrete models–one preserving time-reversal symmetry and one breaking it–and show that the nontrivial topology of the order parameter originates from thermodynamic analogs of gapless Dirac and Weyl points in the phase diagram. Finally, I will propose an experimental realization of a thermodynamic Dirac point in chiral superconductors under strain, and its detectable signature in the Josephson effect, the geometry of vortices, and the upper critical field.

Note on the so-called "big *G* puzzle"

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The problem, sometimes known as a "big G puzzle", is manifested by very low achieved accuracy of otherwise precise measurements of Newton's gravitation constant G and by very strange scatter of its values and error bars measured in different laboratories. It evokes an idea that such anomalous behaviour should be due to some undiscovered bias operating universally. A working hypothesis has been established, according to which a candidate for such a source of systematic errors is *the cosmological acceleration* related to the Hubble constant H_0 or to the cosmological constant Λ [1]. The hypothesis has been tested using various results of G measurements taken from the literature.

[1] J.J. Mareš, V. Špička, P. Hubík: On the nature of fundamental physical constants. Eur. Phys. J. Spec. Top. (2026). https://doi.org/10.1140/epjs/s11734-026-02191-4

Anyon braiding, Fractional Charge, scaling dimension, and statistical angle in the fractional quantum Hall effect

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Anyons are quasiparticles with fractional statistics, bridging between fermions and bosons. We propose an experimental setup to measure the statistical angle of topological anyons emitted from a quantum point contact (QPC) source. The setup involves an Ω-shaped junction along a fractional quantum Hall liquid edge, formed by defining a droplet with two negatively biased gates. In the weak tunneling regime, we calculate the charge current, showing its time evolution depends solely on the anyons' statistical properties, with temperature and scaling dimension affecting only the constant prefactor. We compute the cross-correlation between the anyon current transmitted from the source and the current after the Ω-junction, providing a direct method to detect anyon braiding statistics.

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A gravitational self-decoherence model and a gentle recovery of the classical world

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We begin by briefly discussing the reductionist program of reclaiming the classical world from quantum physics. Next, we argue that the combination of spacetime theory and quantum mechanics (QM) would preclude the measurement of distances at the Planck scale. This is used to argue that current QM would be unable to describe particles with Planck mass, M_P, requiring a Heisenberg cut to separate quantum particles ($m \ll M_P$) from classical particles ($m \gg M_P$). Finally, a minimal (Lorentz-invariant) gravitational self-decoherence model is presented to anticipate new physics at the Heisenberg cut $m \sim M_P$. In particular, free quantum particles would experience self-decoherence for masses $m \gg M_P$. Although our model prohibits the center of mass of crystals with $m \gg M_P$ from being in spatial superposition, it does not prevent them from hosting phonon superpositions, as seen in the Lab.

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Quantum Jumps in Amplitude Bistability: Tracking a Coherent and Invertible State Localization

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We investigate the nature of quantum jumps occurring between macroscopic metastable states of light in the open driven Jaynes-Cummings (JC) model [1]. We find that, in the limit of zero spontaneous emission considered in [2], the jumps from a high-photon state to the vacuum state entail two stages. The first part is coherent and modelled by the localization of a state superposition, in the example of a null-measurement record predicted by quantum trajectory theory. The underlying evolution is mediated by an unstable state, which often splits to a complex of states, identified by the conditioned density matrix and the corresponding *quasi*probability distribution of the cavity field. The unstable state subsequently decays to the vacuum to complete the jump.

Coherence in the localization allows for inverting the null-measurement photon average about its initial value, to account for the full switch which typically lasts a small fraction of the average cavity lifetime; an asymptotic law for the jump time is established in high-amplitude bistability. We find that the JC interaction is particular in stabilizing the attractors associated with amplitude bistability, as opposed to the 'weak-coupling limit' of the Kerr nonlinearity. Further, spontaneous emission degrades coherence in the localization, and prolongs the jumps.

The observed signatures of coherence can be employed to explore the absence of detailed balance in quantum amplitude bistability, already deduced at the level of stochastic Maxwell-Bloch equations [3]. At the quantum level, there is no coherent localization in upward jumps; photon emissions condition single-state cavity fields. Operationally, we find that while the path taken to attain a bright state can be tracked in detail by heterodyne current records produced by the free decay of the cavity mode initialized in a conditioned state of JC bistability. On the other hand, no interference fringes are expected to be seen in the homodyne current histograms, as is the case for the downwards jumps.

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Creation of quantised vortices at a moving surface in superfluid ^{4}He

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We describe an experiment to explore how quantum turbulence is created by relative motion between superfluid ^{4}He and a solid surface. Following a suggestion by the late W.F. (Joe) Vinen, we aim to eliminate the analogue of the classical instability where fluid flows over a convex surface: large-scale classical turbulence can then be emulated by bundles of quantised vortices acting coherently. Rather we use a pillbox-shaped experimental cell in which all internal surfaces are concave. The cell, filled with pure superfluid near 20 mK, is rigidly fixed to a high Q torsion oscillator [1]. Measurements of changes in the frequency and Q of the oscillator+cell are used to infer dissipation in the superfluid connected to the creation and dynamics of vortex lines. A second experiment, where the cell included small cones to provide convex moving surfaces, yielded distinctly different results, with a lower critical velocity for the onset of dissipation. It is concluded that dissipation in the first experiment involved the creation of individual quantised vortices which then reconnected and tangled, whereas the second experiment involved an emulation of classical flow by coherent bundles of vortices. The measurements were extended to higher temperatures, up to the λ-transition, where viscous normal fluid was present and shown to be in satisfactory agreement with theoretical expectations based on the known normal fluid viscosity. These early results and their implications for future investigations will be discussed.

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Autonomous Quantum Heat Engine

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Quantum heat engines provide appealing means in quantum thermodynamics for studying the flow of heat and work in open quantum systems. Experimental implementations of heat engines operating at the level of a few excitation quanta require external driving, which has made the observation of produced work challenging. Conversely, autonomous quantum heat engines only require a flow of heat to operate and generate usable work. However, autonomous quantum heat engines have not yet been experimentally demonstrated in any system despite numerous theoretical investigations. Here, we experimentally realize an autonomous quantum heat engine based on superconducting circuits. We construct the engine circuit implementing an approximate Otto cycle by coupling two superconducting resonators with a superconducting quantum interference device, and coupling this system to spectrally filtered hot and cold reservoirs. For varying the initial conditions, we observe coherent microwave power generation arising from the internal dynamics of the system driven only by the thermal reservoirs. Our results validate previous theoretical predictions for this quantum circuit [1], enable experimental studies of autonomous heat engines, and in general, provide means to enable the conversion of excess heat into coherent microwave radiation.

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Vitacrystallography: X-ray diffraction of biological tissues for cancer detection

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In the XX century, X-ray diffraction crystallography facilitated a breakthrough in materials science, allowing the determination of electron density and, hence, atomic positions from the angles and intensities of X-ray scattering. Later, in *biocrystallography*, this approach was extended to biological molecules. After crystallization, an electron density map can be constructed from X-ray diffraction data, and the molecular structure can be resolved.

We have further extended the X-ray diffraction to whole living tissues without crystallization. The extracellular matrix (ECM), which is not crystalline per se, contains many elements that exhibit structural periodicities that can contribute to X-ray diffraction patterns, such as collagen, keratin, adipose tissue, and water. These ECM components can be altered by cancerous cells, and the resulting cancer-induced modifications can serve as structural biomarkers.

In this presentation, three possible implementations will be addressed. First, this approach can be applied to small samples from the pathological lab for fast classification, serving as a triage procedure for histopathology. We achieved an excellent accuracy in distinguishing normal, benign, and malignant tissues. Second, it can be used for various animal models. I will report the revealing of cancer trajectories in mice with induced prostate or breast cancer. We have shown that cancer-induced alterations in the diffraction patterns can be observed not only in the affected organ but also in remote locations, such as the animal's skin. Another proxy organ for remote monitoring of the health status is the nails. We demonstrated that the nails of healthy and cancerous dogs can be distinguished with high accuracy. Recently, this approach has been extended to human samples. Finally, actual measurements of human patients to detect breast cancer are underway in our California lab.

Simple Quantum-Chaotic toy system mimic a range of real nuclear phenomena.

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Small quantum mechanical systems like the atomic nucleus exhibit a wide range of phenomena that are easily described by intuitive models. We see nuclei sometimes behave as deformed spinning charge distributions, or rigid objects vibrating. We can see them behave as clusters of alpha particles. These phenomena are inferred from the spectra of the nucleus. However, a toy model of N bosons on a one or two level system experiencing random 2-body interactions, exhibits the same spectral signatures [1]. In this talk we will start with a simple introduction to the relevant nuclear spectroscopic ideas, and then introduce the toy model and see the results. Hopefully the open questions can be discussed and maybe even answered!

[1] *Order, collectivity, structured yrast lines, and correlated energies in random bosonic systems*, Phys. Rev. C 112, 014319

Sensitivity functions and phase scaling in light-pulse atom interferometers

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We are currently constructing two novel atom interferometers. The first is designed to measure the perturbation caused by a nearby Foucault pendulum, and the second is to demonstrate improved scaling with interferometer time.

Atom interferometers are now firmly established as devices that can measure inertial forces with exquisite precision and stability. These devices are now making the transition from the pristine environment of a laboratory to the more difficult field environment. The field environment presents a long list of challenges that need to be overcome for these devices to be useful. One such challenge is attempting measurements on moving platforms, restricting the averaging time.

We are developing an atom interferometer to address exactly some of the design challenges associated with making precision measurements with limited time. We are constructing the interferometer next to a Foucault pendulum, whose period is about 10.5 seconds. The interferometer is oriented vertically and is designed such that we can conduct experiments over a range of baselines and at any desired position relative to the pendulum. In this way, we can explore the trade-off between making sensitive measurements and sensor size. A longer interferometer will average over an increased fraction of the pendulum swing. Also, the pendulum is not synchronized to the launching of the interferometer, so that averaging over many pendulum cycles will simply average the signal to zero.

To aid in the optimization of the interferometer, we have developed a novel sensitivity function, designed to highlight frequencies to which the interferometer is most sensitive.

We are also constructing a so-called T^3-light pulse interferometer, in which the phase sensitivity scales as T-cubed, where T is the time between laser pulses. Ordinary gravimeters based on atom interferometers have a phase scaling of T^2 but assume the acceleration the atoms experience in each arm is the same. This assumption is valid for most interferometers that use magnetically insensitive transitions; however, we apply a constant magnetic field gradient and use magnetically sensitive transitions, leading to different accelerations in each arm. We know from magnetism theory, a vertical field gradient leads to horizontal field gradients. Crucially, the interferometer must close not only along the vertical direction, but also horizontally. We have developed high-resolution, realistic magnetic models to simulate the field inside our vacuum chamber and utilized our cold atoms to provide verification. We use these models to characterize the open nature of our interferometer.

Hyperbolic Quantum Processor

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Achieving strong, coherent interactions between spatially separated qubits remains a central challenge in quantum science, fundamentally limited by the mismatch between emitter size and photon wavelength, which suppresses long-range coupling.

Here we show that this limitation can be overcome in hyperbolic materials, where optical polariton modes provide a qualitatively new interaction channel. In this regime, interactions are mediated by strongly confined electromagnetic modes supported by the anisotropic dispersion, enabling strong and highly directional coupling between distant qubits.

As a result, coherent interactions can be sustained over distances far exceeding the free-space wavelength, with dynamics governed by optical timescales. Such interactions enable high-fidelity quantum gate operations in platforms supporting low-loss hyperbolic polaritons, including van der Waals materials such as hexagonal boron nitride.

These results establish hyperbolic media as a platform for long-range quantum interactions, with applications to quantum information processing, nonlinear quantum optics, and many-body quantum systems.

Emergence of Fermi's Golden Rule in a Quantum Many-body System

Nir Navon

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Ultracold fermions in optical box traps are a fascinating platform for studying nonequilibrium many-body dynamics in highly controllable settings [1-5]. In this talk, I will present two such studies: (i) By tuning the power and pulse duration of an rf, we map the generic dynamical response of a strongly interacting Fermi gas coupled to a probing field, from the universal early-time quadratic regime to the onset and breakdown of Fermi's Golden Rule, and into coherent many-body Rabi dynamics [6]. (ii) We established a surprising link between the long-time properties of a thermalized driven state and the short-time weak-drive response of a spin coupled to a bath. This relation, which we coin 'the Kubo-Thermalization correspondence', formally connects macroscopic observables even though they can be very challenging to calculate independently, and is largely independent of the nature of the thermal bath [7].

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[3] Vivanco et al, Nat. Phys. 21, 564-569 (2025)
[4] Huang et al, Phys. Rev. X 15, 011074 (2025)
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[7] Huang et al, arXiv:2605.06666

Nonlocality in General Relativity: A missing link in Einstein's quest for a unified field theory

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Non-propagating vacuum modes in general relativity become physical when they couple to a galactic or an electrodynamic background [1]. The longitudinal vacuum mode, combined with a gauge mode, obeys a fourth order ordinary elliptic differential equation. The solution is nonlocal and reacts strongly to electrodynamic and other fluctuations in the full space-time. This causes a large, radiating gravitational cloud around an object.

In classical electrodynamics, this predicts a damping force on the motion of objects, sourced over all space-time and mediated by gravity, but independent of Newton's constant.

These findings revive Einstein's quest to derive the ontology underlying quantum mechanics with its nonlocality from a unified classical field theory. A candidate, (Linear) Stochastic Electrogravity, is considered.

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Driven-dissipative quantum spin systems: Fate of their entanglement and the origins of the classical Landau-Lifshitz equation

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The driven-dissipative many-body systems remain one of the most challenging *unsolved* problems of quantum physics. When "body" is spin, such as of electrons or of engineered ones like qubits, these many-body systems underlie spintronics, magnonics, and quantum computing technologies. 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 classical spin dynamics, which includes non-Markovian and spatially nonlocal damping of quantum origin, can be rigorously derived from Schwinger-Keldysh quantum field theory (SKFT) [2] by integrating out fermionic or bosonic baths and by neglecting quantum fluctuations of spin fields. It explains [2] how to properly bring light into the LLG equation and predict optically excited magnons. For antiferromagnetic two-dimensional semiconductors like CrSBr, it can explain [3] ultrafast optical excitation of magnons once the excitonic bath as mediator is included. In the case of fully quantum spin dynamics, by combining SKFT with two-particle irreducible effective (2PI) action formalism and 1/N expansion, both of which have been developed originally in elementary particle physics, we describe [4] time evolution of spin in archetypical open quantum system􏰀the spin-boson model (which is also of great importance for understanding decoherence of idle superconducting qubits). Despite only a class of Feynman diagrams being resummed to infinite order by 2PI, where those diagrams are generated by expansion in 1/N (N is the number of Schwinger bosons to which spin is mapped) instead of expansion in the system-bath coupling, our SKFT can track numerically exact non-Markovian simulations from tensor networks (TN) methods. It also provides access to longer times and higher spatial dimensions where TN fails due to the emergence of the "entanglement barrier." These newly developed methods make it possible to understand, for the first time, the fate of entanglement in open quantum spin liquids [5].

This work was supported by the U.S. National Science Foundation (NSF) under grant No. DMR-2500816 and Department of Energy (DOE) under grant No. DE-SC0026068.

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[5] F. Garcia-Gaitan and B. K. Nikolić, https://arxiv.org/abs/2510.02256 (2025).

Electron-enabled Nanoparticle Diffraction

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Modern matter-wave experiments cover a broad mass range from single electrons to molecules and nanoclusters consisting of hundreds or even thousands of atoms. Levitated optomechanics promises to become a platform for matter waves of nanoparticles weighing a billion atomic mass units. I present a scheme for diffracting a massive nanoparticle at its own crystal lattice with help of electrons: when a single electron undergoes Bragg diffraction at a free-falling nanoparticle, momentum conservation implies that the superposition of Bragg momenta is imprinted onto the relative coordinate between electron and nanoparticle, which entangles their wave functions. By imaging the electron interferogram, one maps the nanoparticle state onto a superposition of Bragg momenta, as if it was diffracted by its own lattice. This results in a coherent momentum splitting 1000 times greater than what is achievable with conventional standing-wave gratings, opening new possibilities for experimental tests of fundamental physics at the quantum-classical boundary.

A few recent results on superconducting qubits: (1) one photon simultaneously exciting two qubits; (2) strong coupling between a single photon and a two-photon Fock state; and (3) Thouless pumping

Franco Nori

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This talk will cover several experimental and theoretical results on superconducting qubits.

(1) We investigated a superconducting circuit composed of two flux qubits ultrastrongly coupled to a common *LC* resonator. Owing to the large anharmonicity of the flux qubits, the system can be described well by a generalized Dicke Hamiltonian containing spin-spin interaction terms. We observed an avoided level crossing providing evidence of the exotic interaction that allows the simultaneous excitation of two artificial atoms by absorbing one photon from the resonator. This multi-atom ultrastrongly coupled system opens the door to studying novel processes for quantum optics and quantum-information tasks on a chip.

A.F. Kockum et al., *Deterministic quantum nonlinear optics with single atoms and virtual photons,* Phys. Rev. A **95**, 063849 (2017). [PDF][Link][arXiv]; L. Garziano, V. Macri, R. Stassi, O. Di Stefano, F. Nori, S. Savasta, *One Photon Can Simultaneously Excite Two or More Atoms,* Phys. Rev. Lett. **117**, 043601 (2016). [PDF][Link][arXiv][Suppl. Info.]; A. Tomonaga, R. Stassi, H. Mukai, F. Nori, F. Yoshihara, J.S. Tsai, *Spectral properties of two superconducting artificial atoms coupled to a resonator in the ultrastrong coupling regime,* Nature Communications **16**, 5294 (2025). [PDF][Link][arXiv]

(**2)** We report an experimental observation of the strong coupling between a single-photon and a two-photon Fock state in an ultrastrongly-coupled circuit-QED system. The ultrastrong light-matter interaction breaks the excitation number conservation, and an external flux bias breaks the parity conservation. The combined effect of the two enables the strong one-two-photon coupling. Quantum Rabi-like avoided level-crossing is resolved when tuning the two-photon resonance frequency of the first mode across the single-photon resonance frequency of the second mode. Within this new photonic regime, we observe thresholdless 2nd-harmonic generation for a mean photon number in the resonator below one. These results represent a step towards a new regime of quantum nonlinear optics, where individual photons can deterministically and coherently interact with each other in the absence of any stimulating field.

S.P. Wang, A. Mercurio, A. Ridolfo, Y. Wang, M. Chen, W. Wang, Y. Liu, H. Sun, T. Li, F. Nori, S. Savasta, J.Q. You, *Strong coupling between a single-photon and a two-photon Fock state,* Nature Communications **16**, 8730 (2025). [PDF][Link][arXiv][Suppl. Info.]

(3) I will summarize experimental observations of the competition and interplay between Thouless pumping and disorder on a 41-qubit superconducting quantum processor. This highly controllable system provides a valuable quantum simulating platform for studying various aspects of topological physics in the presence of disorder.

Y. Liu, Y.R. Zhang, … , F. Nori, K. Xu, H. Fan, *Interplay between disorder and topology in Thouless pumping on a super-conducting quantum processor,* Nature Communications **16**, 108 (2025). [PDF][Link][arXiv][Suppl. Info.]

Time dilatations for collapse of massive superpositions: An experimentalists view

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In my group we perform experiments with ultra cold mechanical resonators, with a focus on experimental techniques that are necessary to make ever more massive superpositions [1]. In recent years we have also worked on heavier ($\sim$1mg), levitated systems to measure small gravitational forces in the attoNewton range [2]. This combination of measurements is inspired by the argument raised by Diosi and Penrose, that gravity might cause wavefunction collapse.

In my presentation I will present measurements as well as a theoretical model that uses time dilatation to explain an underlying mechanism of how general relativity could mix into quantum mechanics to cause wavefunction collapse [3].

This work was supported by the EIC and NWO.

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Value Reproducibility and Intersubjectivity of Quantum Measurements based on Quantum Perfect Correlations

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Suppose that two observers simultaneously measure the same observable. We ask whether they always obtain the same outcome, or their probability distributions are the same but the outcomes are uncorrelated. Contrary to the widespread view in favor of the second, we show that quantum mechanics predicts that only the first case occurs. This suggests the existence of the perfect correlation between the measurement outcome and the pre-existing value of the measured observable. In fact, we show that any measurement establishes a time-lik entanglement between the observable to be measured and the meter after the measurement, which causes the space-like entanglement between the meters of different observers, and hence every meter shows the same measurement outcome. We also argue that our conclusion cannot be extended to measurements of so-called “generalized” or “unsharp” observables, suggesting that conventional observables with projection-valued measures represent the system’s physical reality, but “generalized” or “unsharp” observables with non-projective POVMs represent only the statistical property of the measuring apparatuses.

This work was supported by JSPS KAKENHI Grant Numbers JP26H02539, JP25K07108, JP25H00595, JP24H01566, and JST CREST Grant Number JPMJCR23P4, Japan.

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Circuit Quantum Electrodynamics with two-dimensional material-based Josephson Junctions

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In the context of hybrid superconductor-semiconductor systems, Josephson junctions based on two-dimensional materials, such as graphene, offer promising opportunities because of their scalability and gate-tunable electronic properties. In this work, we investigate the inductive coupling between a quantum LC resonator and a superconducting loop embedding a short, ballistic, planar Josephson junction, with the graphene-based case as a representative example.

Within a mean-field formalism, we analyze how the properties of the global system depend on the light-matter interaction coupling, the Fermi level of the two-dimensional material, and temperature. Our findings reveal that the current-phase relation can show features indicative of spontaneous time-reversal symmetry breaking [1].

Moreover, we investigate the same system as a possible solid-state implementation of a Dicke-like quantum battery where Andreev bound states naturally act as non-interacting, energetically non-degenerate two-level systems, and the setup allows for both single-photon and two-photon resonant processes. The coupling between the LC-circuit flux and the supercurrent through the junction gives rise to peculiar longitudinal interaction terms that have no counterpart in the conventional Dicke model. These additional couplings can enhance energy storage for a proper range of parameters [2].

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Quantum Network: quantum communication, computation, and metrology

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With the continued development of quantum information science, it is anticipated that large-scale quantum networks will be established. Such networks are expected to enable ultra-precise information sensing through quantum metrology, secure and efficient information exchange via quantum key distribution (QKD) and quantum teleportation, and rapid information processing through quantum computing.

However, turning quantum networks from theoretical concepts into practical reality still faces numerous technical challenges. Achieving secure long-distance quantum communication requires addressing security issues under realistic conditions and overcoming the inherent loss in optical fibers, while building quantum computers demands solving the challenge of scalable and precise manipulation of qubits.

In this talk, I review our two-decade efforts toward quantum networks, including: developing decoy-state QKD and measurement-device-independent (MDI) QKD to close device imperfections loopholes; progressing quantum repeaters and satellites to extend communication range; using photon coherent manipulation techniques developed from quantum communication to demonstrate quantum computational advantage; employing ultracold atoms in optical lattices for quantum simulations of complex systems, advancing near-term quantum computing applications; surpassing the surface code quantum error correction threshold; and developing high-precision optical lattice clocks using ultracold atom technology.

Future prospects include building a global quantum communication network using efficient constellations and geostationary orbit (GEO) satellites. This will also support advanced quantum metrology, potentially redefining the SI second. In quantum computation, our five-year plan targets practical quantum simulators to study high-temperature superconductivity, quantum Hall effect, etc. Over the next 10-15 years, scaling to millions of qubits with quantum error correction may lay the foundation for universal quantum computers.

Boltzmann subspaces and temperatures in systems driven far from equilibrium

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Out-of-equilibrium many-body quantum systems are generally not associated with a thermal state. Yet, inspecting single molecule junctions in different scenarios, we found non-trivial clustering of steady state populations into distinctive subspaces with Boltzmann-like statistics, which persist far from equilibrium. The existence of Boltzmann subspaces simplifies our understanding of transport in open quantum systems and holds promise for reducing the numerical effort in simulations of driven molecular junctions which are otherwise beyond reach of current computations. In this lecture we focus on molecules under a thermal bias imposed by coupling to two electrodes at different temperatures. We demonstrate that within the realm of weak electrode-molecule coupling (Pauli master equations), even far from equilibrium, Boltzmann subspaces do emerge and the system can be assigned (at least approximately) an effective temperature. We demonstrate the emergence of Boltzmann subspaces under thermal bias and identify the corresponding effective temperature in a variety of molecular junction models, including account for electron-electron interaction, molecular disorder, asymmetric coupling to the electrodes, and the orbital energy density. The relation of the Boltzmann subspaces temperature to other definitions of a temperature in non equilibrium conditions, e.g., in terms of external probes, is discussed. Our results draw guidelines for controlling the effective temperature of single-molecule electronic devices operating far from equilibrium.

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Impact of surface scattering on photoelectron escape times

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What determines the precise moment when a photoelectron escapes from a solid? We demonstrate that the photoelectron escape time is not primarily determined by its inelastic lifetime but is fundamentally governed by scattering at the material - vacuum interface. This interface scattering couples *propagating* and *evanescent* partial waves–two emission channels with vastly different escape times–leading to pronounced energy-dependent variations in photoemission delays as function of final state energy. In quantum-mechanical terms, the electron simultaneously tunnels through the wall and exits through the door - and the interplay between both ways out determines the actual escape time.

To elucidate this mechanism, we first discuss the photoemission dynamics within a one-dimensional Kronig-Penney model, which clearly distinguishes the temporal behavior of propagating versus evanescent contributions. Building on this theoretical foundation, we present attosecond interferometric photoemission measurements on the topological insulators Bi_2Te_3 and Bi_2Se_3. Differential attosecond delays, i.e., relative photoemission delays between spin-orbit-split core levels (Bi 5d, Te 4d, Se 3d) - despite nearly identical final-state continua - reveal unexpectedly large relative delays of 30-100 as, far exceeding expectations from ballistic or atomic models.

Quantitative modeling within the one-step photoemission theory, combined with the Eisenbud-Wigner-Smith delay formalism, reproduces the experimental findings and attributes them to multiple scattering at the surface. This process mixes evanescent and propagating final states, establishing the interface as a timing element of photoemission.

Our results bridge two long-standing concepts - tunneling dwell times and solid-state photoemission delays - and identify *differential attosecond delays* as a robust and interpretable observable for ultrafast quantum dynamics in solids. The discovery that surface scattering alone can advance or retard electron emission by tens of attoseconds provides new theoretical and experimental access to correlation and transport phenomena at condensed-matter interfaces.

Universal protection of quantum states from decoherence

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Decoherence, i.e. the inevitable coupling of quantum states to their environment, remains a primary obstacle for the widespread diffusion of several quantum technologies. While the Quantum Zeno Effect (QZE) [1,2] is a well-established quantum control method for suppressing decoherence-induced noise, its application typically necessitates prior knowledge of the quantum state to be protected [3-6]. In order to overcome this limitation, here we introduce a new protocol named Quantum State Universal Protection (QSUP), providing state-independent protection for arbitrary quantum states [7]. We experimentally demonstrate QSUP using polarization-encoded single photon qubits in a quantum channel hosting a Mach-Zehnder-like interferometer (MZI), in which controlled decoherence is implemented via birefringence. By spatially separating the qubit polarization components within the MZI arms, we apply frequent QZE-projections on each polarization component to stabilize the state against birefringence-induced decoherence. Our experimental results [7] show near-unity Fidelity and Purity for the QSUP-assisted qubit transmission in several different scenarios, dramatically increasing the robustness and reliability of the transmitted quantum information. Our strategy is universally applicable, since it is independent of the form of decoherence occurring within the quantum channel as well as of the specific quantum state undergoing QSUP, in contrast to state-dependent protection schemes or tailored quantum error-correction codes. As such, it provides a broadly applicable solution for quantum communication, distributed quantum sensing, and quantum computation.

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Radio frequency to optical transducer based on a soft-clamped membrane

Francesco Marzioni[1,2], Giacomo Novelli[1], Riccardo Natali[1,2], Michele Bonaldi[3,4], Antonio Borrielli[3,4], Enrico Serra[4,5], Nicola Malossi[1,2], David Vitali[1,2,6], Giovanni Di Giuseppe[1,2], and Paolo Piergentili[1,2]

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The transduction of quantum signals at different energy scales plays a crucial role in Quantum Technologies [1]. Since optical spectrum is well-suited for long-distance communication, while lower frequencies of the electromagnetic field prove advantageous for precise local quantum operations, achieving coherent conversion between optical and microwave/radio frequency (mw/rf) photons is one of the primary tasks of a transducer. In this talk we present a complete characterization of a nanomechanical oscillator, which might be used for the realization of a novel electro-optomechanical device that can be implemented for the sympathetic cooling of the LC circuit [2], and as building block of an rf/mw-optical transducer [3]. The key element of the device is a mechanical resonator based on a TiN-coated circular Si_3N_4 membrane, optically coupled via radiation pressure and capacitively coupled to an electrical circuit through two electrodes. Since a primary thermodynamical cooling of the device is employed for achieving a quantum regime, the quality factor of the mechanical oscillator has been characterized at room and cryogenic temperatures by means of homodyne detection and ring-down technique. For mechanical frequencies in the MHz range, a quality factor of 10^6 and over $6x10^7$ at room temperature and below 100 mK, respectively, is measured by means of stroboscopic technique [4]. Moreover, the shift of the fundamental mode of the oscillator and the electro-mechanical induced transparency as a function of the potential difference between the device electrodes are reported as evidence of the presence of the electro-mechanical coupling.

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Quantum Rabi Model in the slow Oscillator Regime

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The quantum Rabi model is a fundamental building block in quantum optics and, more broadly, in qubit manipulation and detection. In the resonant case, where the oscillator frequency ω_m is close to the two-level system (TLS) splitting Δ, the model reduces to the celebrated Jaynes-Cummings model. A less explored regime occurs when $\omega_m \ll \Delta$, and the coupling constant is sufficiently large to induce a sizable anharmonic behavior in the oscillator, since this implies a coupling constant of the order of the oscillator frequency.

We investigated this regime by studying a TLS formed by a double-quantum dot embedded in a carbon nanotube, coupled to the second flexural mode of the nanotube [1]. In this talk, I will discuss the dynamics of this system in the presence of environmental coupling to both the oscillator and the TLS, and I will outline the different regimes that emerge depending on the physical parameters [2]. This study is primarily motivated by ongoing experiments in the ICFO group [3] where this regime of strong coupling has been achieved.

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Phase stabilization for next-generation long-distance quantum networks

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Tracking and stabilizing the optical phase over long-distance fiber infrastructure is crucial for next-generation phase-sensitive networking protocols. An additional challenge for quantum and faint-light networking is keeping the payload channel dark at the same time. Indeed, phase stabilization enables the so-called single rail entanglement distribution, that not only can drastically improve the rate of entanglement distribution but also enable key quantum repeater protocols. Those protocols were out of reach for practical networks because quantum compatible phase control was considered impossible. Indeed, a strong classical optical phase reference was required until now. That in turn introduces classical-to-quantum crosstalk: bright and broadband noise in quantum channels. Such a noise is not compatible with quantum signals.

Here, we demonstrate two distinct approaches to phase-stabilize a long distance quantum link: time-division multiplexed (TDM) phase stabilization that takes advantage of the quantum phase estimation and thereby needs just 650,000 photons per second at the receiving detector [1] and wave-division multiplexed (WDM) phase stabilization with picowatt-level signals, which keep the quantum payload channel dark and stabilized [2].

We use faint coherent light from an ultra-narrowband laser at 1550 nm to stabilize the 120 km optical fiber loop deployed between NIST (Gaithersburg) and UMD (College Park). An attenuated ultra-stable reference laser is time multiplexed (TDM) or used to generate a frequency comb (WDM). One arm of the interferometer carries the signal through a long optical fiber spool or a deployed fiber loop, while the other arm is used as a local oscillator.

TDM takes advantage of a displacement quantum phase estimation, i.e. when the reference signal is set to distructively interfere with the single-photon level reference signal. The success of such displacement is verified with a single photon detector such that even one photon detection suggests the need to adjust the phase. This technique outperforms an idealized classical phase measurement by 1.4dB in deployed fiber. WDM takes advantage of two teeth of a frequency comb and keeps the quantum channel dark with a minimal background of just 500 photons s^{-1}. In both schemes, we obtain phase stabilization with RMS timing jitter of ≈0.1 fs. In other words, a 120 km link is stabilized to within approximately 4 nm, or to a fraction of approximately 3×10^{-13}!

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Sources, Frequency Bands, and Instruments: An Overview of Existing and Planned Gravitational-Wave Detectors with a Focus on the Einstein Telescope

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This talk provides an overview of existing and planned gravitational-wave detectors.

It begins with a review of the expected sources of gravitational waves and their characteristic frequency bands, including hypothetical sources such as primordial black hole populations.

Then the principles and capabilities of different types of existing and future detectors operating across these frequency bands are discussed.

Particular attention is devoted to the Einstein Telescope, the planned next-generation underground gravitational-wave observatory in Europe. The presentation introduces the three candidate sites for the facility and compares the advantages and disadvantages of the two proposed detector geometries: the triangular configuration and the classical L-shaped configuration.

The final part of the talk focuses on the astrophysical and cosmological sources that are expected to be detectable with the Einstein Telescope.

Out-of-equilibrium stochastic dynamics in power-law viscoelastic and non-Ohmic thermal environments

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When particles diffuse in viscoelastic and non-Ohmic thermal environments, the resulting effective Langevin description becomes non-Markovian, exhibiting memory kernels and colored noise. In many cases, such environments lack a single relaxation scale and instead exhibit a broad continuum of timescales. This naturally leads to the use of fractional operators and fractional Gaussian noises in effective descriptions because of their scale-free and fractal-like properties. In this talk, I will present recent results on the fractional Langevin equation for out-of-equilibrium systems. Two types of forces driving out-of-equilibrium dynamics are discussed: linear white noise and rotational self-propulsion. In the first case, the long-range memory effects drive the emergence of prethermal periodic time-ordered phases, such as time crystals and time glasses, which are robust against white noise. In the second, counterintuitive persistent properties arise from the viscoelastic rotational dynamics. Finally, a general path-integral formalism for non-Markovian fractional settings is discussed, and an analytical route to simplify the propagator for heterogeneous processes driven by fractional Gaussian noise is provided.

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Information engines with self-propelling particles

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Information engines, setups that use measurements to extract additional work from a system, serve as examples for the deep connections between thermodynamics and information theory. In most studies the particles inside the engine are assumed to perform Brownian motion. In recent years much interest was devoted to the study of active matter, consisting of internally driven particles. How does the conversion of information to work changes when the particles inside the engine are active? We find qualitative differences between information engines with thermal and active particles. These turn out to originate from the tendency of active particles to bunch at boundaries. We further discuss the possible role of inelastic collisions in such systems, finding how they affect the pressure due to repeated collisions with the walls.

Interferometry with Bose-Einstein condensates in extended free fall

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on behalf of the QUANTUS and MAIUS-BEE Teams
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In the talk, I will report on experiments exploiting quantum degenerate gases for atom optics and interferometry in extended free fall.

New perspectives emerge for our research by exploiting the Bremen gravitower and the Hannover Einstein Elevator, they do offer two to four seconds of free fall in microgravity, respectively, but more importantly, they both offer much larger repetition rates and, hence, allow for more detailed systematic studies and better statistics.

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Magnetically Levitated Systems Approaching the Quantum Regime

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Studying the boundary between quantum and classical physics in macroscopic systems is a central challenge in modern physics. In this context, levitated systems are becoming increasingly important because they provide excellent isolation and avoid clamping losses, enabling improved quantum control of mechanical motion compared to traditional micro- and nano-mechanical resonators. Beyond optical tweezers, magneto-levitated systems based on static superconducting traps that exploit the Meissner effect are particularly promising, as they operate at cryogenic temperatures and exhibit exceptional immunity to dissipative effects.

Achieving quantum superpositions of massive objects in magnetically levitated systems requires overcoming two major challenges: (i) explaining the ultimate mechanisms of friction in such systems, and (ii) cooling them to the quantum ground state.

To address the first issue, we have examined the dissipation arising from surface resistance due to the unavoidable presence of quasiparticles. At the extremely low (sub-gap) frequencies of interest, this dissipation does not stem from Cooper-pair breaking, but rather from the oscillatory, damped motion of quasiparticles at finite temperatures. Our goal is to establish an upper bound on the intrinsic dissipation of this class of levitated systems.

To address the second issue, we carried out a first proof-of-concept experiment in which we cooled the angular motion of a levitated micromagnet in a superconducting Meissner trap using magnetic feedback. We analyzed the experimental data with a theoretical model tailored to our feedback scheme. Starting from an operating temperature of a few kelvin, we cooled the system down to a few millikelvin. We also discuss how lower temperatures could be reached through improvements in the performance of the experimental apparatus.

Finally, I will discuss preliminary results from a theoretical study exploring the use of a machine-learning-based strategy (reinforcement learning) to enhance the feedback cooling process. This approach introduces an adaptive agent that controls the feedback in real time, with the ultimate goal of reaching the quantum regime of a massive levitated system.

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Entanglement Propagation in quantum dots

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The Heisenberg exchange interaction plays an important role in the scatterng of entangled electrons in spin qubits. We analyse an exactly solvable scattering problem for entangled electrons in a GaAs/AlGaAs waveguide containing multiple quantum dots. We show that scattering resonances determine the dynamics of the scattering process for the entangled electrons.

Charge transfer through DNA - A new perspective from Human Genetics

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The hypothesis that quantum effects could influence the functioning of DNA in living cells at the molecular level has existed for a long time [1,2]. However, the question of whether this hypothesis is founded remains unanswered, as it is still unclear if quantum phenomena could occur at the necessary scale to affect biological processes, and if so, if they could influence the epigenetic regulation of cells.

We propose a clear formulation of this hypothesis in the form of a well-defined research question [3]. To this end, we put forward a potential mechanism that could enable quantum influences on DNA self-regulation, based on the idea that charge transfer could serve as an underlying mechanism to trigger the regulation of gene expression in cells. We then develop a complex, coarse-grained model that can capture the essential features of DNA and be scaled up to tens of bases, in order to address the typical scales of epigenetic mechanisms in living cells [4-6]. Finally, we will outline the next steps of our research and present a sketch of the experimental setup that is currently being developed, with the aim of further refining and validating the theoretical modelling that has been carried out so far.

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Aharonov-Bohm, Kennard Phase, and Three-Slit Dynamics in Pilot-Wave Hydrodynamics

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A millimetric droplet bouncing on a vertically vibrating fluid bath may self-propel through a resonant interaction with its own wave field. The resulting "walker", a particle dynamically coupled to a guiding wave, provides a macroscopic realization of de Broglie's pilot-wave conception of quantum dynamics, and has revealed hydrodynamic analogs of phenomena once thought exclusive to the microscopic quantum realm. We present several recent advances. First, we report an experimental analog of the Aharonov-Bohm effect: a walker orbiting in an annular cavity that encircles a shielded vortex, lying beyond the reach of its flow, nonetheless acquires a force-free, flux-dependent shift in its orbital speed, yielding Wigner-like phase-space distributions with a rigid, gauge-like translation. Second, we characterize a hydrodynamic analog of the cubic-in-time Kennard phase, and identify a Kennard critical point marking a sharp transition in the walker's drift dynamics. Third, we present exotic looped trajectories, novel orbital states reminiscent of the looping paths summed over in Feynman's path-integral construction of the propagator. Finally, we show how the pilot-wave framework may be tuned to emulate rotating black holes, capturing ergoregion-like structure and superradiant energy exchange. Collectively, these results extend the reach of hydrodynamic quantum analogs from gauge physics to analog gravity, deepening their connection to the foundations of quantum mechanics.

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Molecular entropic forces and scaling laws in chaperone-driven nanofilament unbundling

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Entropic forces are central to nanoscale phenomena ranging from colloidal self-assembly to biomolecular disaggregation. Here, we combine an exact analytical theory with a coarse-grained computational approach to derive general scaling laws for tether-mediated entropic forces in nanofilament bundles. We find that a single dimensionless parameter, the ratio of excluded-volume radius to tether length, determines whether filaments are pushed apart or, paradoxically, pulled together, challenging the assumption that entropic forces invariably promote disaggregation. Applied to amyloid α-synuclein disaggregation by Hsp70, we identify two classes of entropic effects (intra- and inter-protofilament) and show that only highly efficient chaperone systems, requiring co-chaperone networks and ATP hydrolysis, can overcome the free energy barrier of lateral protofilament association. These results, confirmed by Brownian dynamics simulations and supported by high-speed atomic force microscopy data, offer predictive insights for biophysics, soft matter, nanotechnology, and the design of therapies targeting protein-aggregation diseases.

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pyTTN: A tree tensor network based open-source toolbox for open and closed system quantum dynamics simulations and its application in quantum algorithms

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We present the Python Tree Tensor Network package (pyTTN) for the evaluation of dynamical properties of closed and open quantum systems that makes use of Tree Tensor Network (TTN) based representations of wavefunctions [1], and also demonstrate its integration in quantum algorithms. This package includes several features allowing for easy setup of zero- and finite-temperature calculations for general Hamiltonians using single and multi-set TTN ansätze with an adaptive bond dimension through the use of subspace expansion techniques. pyTTN provides several tools for setting up efficient simulation of open quantum system dynamics, including the use of the TTN ansatz to represent the auxiliary density operator space for the simulation of the Hierarchical Equation of Motion (HEOM) method and generalised pseudo-mode methods. We present a set of applications of the package, including photo-excitation and exciton dynamics in molecules, as well as open quantum systems, including the spin-boson model, a set of extended dissipative spin models, and an Anderson impurity model. We also present an Anderson impurity solver integrating tensor network methods with quantum computing [2], thereby exploiting the efficiency of tensor networks for preparing ground states on classical computers and taking advantage of quantum processors for the evaluation of the time evolution, which can become intractable on classical computers.

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Lindblad master equation for deep strong coupling regime of the quantum Rabi model

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The quantum Rabi model, describing a two-level system - a qubit - dipole coupled to a single electric field mode, constitutes a fundamental quantum model of light-matter interaction. Recent experiments have put the focus on the deep strong coupling regime of the model, when the light-matter coupling strength exceeds the mode frequency. For the field mode further coupled to a thermal bath - an open quantum system - the existing quantum master equations describing the deep strong coupling regime are typically formulated in terms of the exact eigenvalues and eigenfunctions of the quantum Rabi model, and hence amenable to numerical analysis only. Here we derive a simple Lindblad master equation, formally valid in the perturbative deep strong coupling regime where the light-matter coupling strength is much larger than the mode frequency. The Lindblad equation is benchmarked against the corresponding Bloch-Redfield equation and very good agreement is found for both equilibrium as well as non-equilibrium - transport as well as time-dependent - situations. Both numerical and analytical results are discussed.

Dissipation as a Resource: From Transient to Steady-State Chaos

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Ginibre statistics is often taken as an indicator of dissipative chaotic dynamics. However, we have shown that the Grobe-Haake-Sommers conjecture, which associates Ginibre statistics with chaos and 2D Poisson statistics to integrability, can break down. Our results indicate that Ginibre correlations primarily capture short-time dynamical instability, and therefore signal transient, rather than steady-state, chaos. We demonstrate that the quantum-classical correspondence can be restored by adopting a dynamical perspective based on information scrambling. In particular, diagnostics such as the von Neumann entropy and out-of-time-ordered correlators distinguish transient from long-time chaotic behavior. Building on these findings, we further show that dissipation can serve as a tool to regulate the duration of chaotic dynamics and information scrambling, enabling the recovery of coherence at long times.

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Fabry-Perot interferometry with stochastic anyonic sources

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We investigate the interference of Laughlin quasiparticles (QPs) in the fractional quantum Hall regime that are stochastically injected into a Fabry-Perot interferometer [1]. We find that the effective Aharonov-Bohm (AB) phase accumulated along the interferometer loop acquires an additional contribution of $\sin(2\pi\lambda)/2$ per QP present on it, where $\pi\lambda$ is the QP exchange phase. This contribution originates from time-domain braiding processes associated with injected QPs passing the interferometer quantum point contacts. In the limit of symmetric QP injection, the tunneling current noise exhibits AB oscillations as a function of the total injected current, providing access to the exchange phase $\pi\lambda$. In the regime of large total injection, we identify a universal Fano factor that displays power-law scaling and a characteristic phase shift reflecting real-space QP braiding along the interferometer edges. These results are relevant for accessing anyonic exchange statistics in mesoscopic interferometers.

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NMR: From Strong-Correlation to Life Sciences

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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. I briefly introduce 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 after averaging over conformers and rotamers. The resulting NMR Hamiltonian is a Heisenberg Hamiltonian with site dependent magnetic fields (chemical shifts). Although this Hamiltonian is strongly correlated, the corresponding NMR spectral functions can be calculated using a clustering approach due to the large gyromagnetic rations of the relevant nuclei.

Recently we enhanced our NMR simulation techniques to perform an automatic adaption of the obtained NMR parameter to experimental data. Using this technique we can determine accurate reference parameter for NMR spectra.

In a next step we are using these reference parameter to extract the concentration of compounds from the NMR spectrum of mixtures for example for applications in metabolomics like the analysis of urine and blood.

This work was supported by the German Federal Ministry of Education and Research, through projects QSolid (13N16155) as well as the European Innovation Council (EIC), through the Horizon Europe EIC Transition project HQS-NextNMR (grant agreement 101214526).

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Quantum Zeno effect versus adiabatic quantum computing and quantum annealing

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For the adiabatic version of Grover's quantum search algorithm as proposed by Roland and Cerf, we study the impact of decoherence caused by a rather general coupling to some environment. For quite generic conditions, we find that the quantum Zeno effect poses strong limitations on the performance (quantum speed-up) since the environment effectively measures the state of the system permanently and thereby inhibits or slows down quantum transitions. Generalizing our results, we find that analogous restrictions should apply universally to adiabatic quantum algorithms and quantum annealing schemes which are based on isolated Landau-Zener type transitions at avoided level crossings (similar to first-order phase transitions). As a possible resort, more gradual changes of the quantum state (as in second-order phase transitions) or suitable error-correcting schemes such as the spin-echo method may alleviate this problem.

Quantum optics in curved spacetime: Surprises and insights

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An atom uniformly accelerated in Minkowski vacuum can become excited by emitting a photon. This is known as Unruh acceleration radiation. The energy required to emit the photon by the accelerated atom is gained from the atom's kinetic energy. Using a combination of quantum optics and general relativity, we showed that atoms freely falling into a black hole emit radiation. We call the emitted radiation Horizon Brightened Acceleration Radiation (HBAR) and note that it is very similar to Hawking radiation, as we discuss in [1,2].

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Entropy production and its model-free inference

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Entropy production is a central and broadly applicable measure of nonequilibrium behavior in systems coupled to a heat bath, including driven soft and active matter and bio-molecular systems. Despite its fundamental role, both the theoretical identification and experimental inference of entropy production remain challenging, largely because many contributing degrees of freedom are experimentally inaccessible. This raises the key question of how entropy production can be consistently identified and inferred from coarse-grained models and observations [1].

I will show how model-free lower bounds on entropy production can be obtained from the observation of currents via the thermodynamic uncertainty relation, demonstrated with experimental data on the molecular motor kinesin [2]. Tighter bounds and a thermodynamically consistent identification of entropy production along individual coarse-grained trajectories are achieved using waiting-time distributions together with the concepts of Markovian events and Markovian snippets [3,4]. As an application, I present results from experimental data on the unfolding of a small peptide [5].

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Arrow of Time as an Order Parameter for Measurement-Induced Phase Transitions

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Measurement-induced phase transitions (MIPTs) in monitored quantum systems are typically diagnosed using entanglement-based measures. Here, we develop a complementary thermodynamic perspective based on the arrow of time (AoT), which arises from the intrinsic irreversibility of the quantum measurements driving these transitions. We study the AoT–defined as the logarithmic ratio of forward and backward trajectory probabilities–across a family of models exhibiting MIPTs. We find that, like entanglement entropy, the AoT is a nonlinear functional of the averaged density matrix; however, in contrast to entanglement, it is associated with a local operator. To determine whether the AoT exhibits critical behavior, we formulate and exactly solve a model of a random quantum circuit with non-projective measurements. This allows us to analytically demonstrate that the AoT displays nonanalytic behavior and identify its critical exponent. Our results establish the AoT as a novel diagnostic for phase transitions in monitored quantum systems.

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Quantum states and phases underlying collective dissipation phenomena

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We introduce a new family of collective spin states which, although being *quantum* entangled states, are responsible for the emergence of *classical* macroscopic response to light. We call these states coherently radiating spin states (CRSS), study their entanglement properties, the way they are produced, and how they underlie collective dissipation phenomena. In particular, we show that CRSS are naturally realized in superradiance and underlie the dissipative Dicke phase transition, hence predicting the optimal scaling of spin squeezing in superradiance, and its classical-like radiation. In a realistic system, where individual decay competes with collective dissipation, we show how the system develops a quantum bistability, exhibiting many-body quantum jumps between CRSS and a non-entangled state. More generally, CRSS emerge as ground states of an Ising Hamiltonian and underlie its quantum phase transition. CRSS thus provide a promising concept for studying many-body spin systems in various platforms, with applications ranging from quantum metrology and lasing to phase transitions.

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Quantum capacitances and resistances of electron boxes and transistors

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The issue of coupling quantum systems to classical ones appeared from the very first days of quantum physics. One notable example is the Bohr-Einstein photon box thought experiment. While such thought experiments could not be realized a century ago, when quantum mechanics was still being formulated, experimentalists now routinely work with coupled classical and quantum systems. In contrast to natural quantum systems (like photons), artificial ones are often operated dynamically and are coupled to driving and readout electronics [1].

In our work [2], we are interested in dissipative semiclassical systems, where a classical electromagnetic field is used to probe a quantum electronic system. The effective reactance may include capacitive and inductive terms that incorporate geometric, quantum, and tunneling components; while the effective resistance may be composed of Sisyphus and Hermes terms linked to relaxation and decoherence, respectively.

Our approach demonstrates how to introduce quantum and tunneling capacitances as well as Hermes and Sisyphus resistances, and how these values are modified when the dynamics of the subsystems become mutually dependent. We present the cases of a Cooper-pair box, a single-Cooper-pair transistor, a double quantum dot, and a single-electron box. Our approach is quite general, and such quantum reflectometry provides a convenient part of the quantum toolbox.

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Judea Pearl Meets Yakir Aharonov in Wheeler's Delayed-Choice Experiment

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We organize a framework that makes Judea Pearl's causal-inference vocabulary operational for Wheeler's delayed-choice experiments, and that uses weak values to quantify counterfactual attribution to intermediate measurements that are not actually performed. We model Wheeler-type delayed choice as an intervention $do(S = s)$ on a late setting variable S, and show that the interventional quantity $P(Y|do(S = s))$ is a forward-causal estimand that is identifiable from observed data via the back-door criterion under standard randomization assumptions. Apparent retrocausal narratives are reinterpreted as selection (collider or d-speration) bias induced by post-selection. We further interpret weak values for intermediate alternatives as conditional quasi-probabilities.

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Striped Spin Density Wave in a Graphene/Black Phosphorous Heterostructure

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A bilayer formed by stacking two distinct materials creates a moiré lattice, which can serve as a platform for novel electronic phases. In this work we study a unique example of such a system: the Graphene/Black Phosphorus heterostructure (G/BP), which has been suggested to have an intricate band structure. Most notably, the valence band hosts a quasi-one-dimensional region in the Brillouin zone featuring a high density of states, suggesting that various many-body electronic phases are likely to emerge. We derive an effective tight-binding model that reproduces this band structure, and explore the emergent broken-symmetry phases when interactions are introduced. Employing a Mean-Field analysis, we find that the favored ground-state exhibits a striped Spin Density Wave (s-SDW) order, characterized by either one of two-fold degenerate wave-vectors that are tunable by gating. Further exploring the phase-diagram controlled by gate voltage and the interaction strength, we find that the SDW-ordered state undergoes a metal to insulator transition via an intermediate metallic phase which supports striped SDW correlations. Possible experimental signatures are discussed, in particular a unique dispersion of the collective excitations.

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Emergence of multiple zero modes bound to vortices in extended topological Josephson junctions

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We study planar Josephson junctions formed on the surface of a three-dimensional topological insulator (Fu-Kane proposal). We examine the experimentally relevant parameter regimes in which the frequently used effective description in terms of two counter-propagating one-dimensional Ma- jorana modes with hybridization dependent on the Josepshon phase difference reaches its validity limit. This happens when the effective velocity of the emergent one-dimensional Majorana modes approaches zero. As parameters like the chemical potential or the width of the junction are tuned, instances of vanishing effective velocity mark the emergence of additional 'Dirac cones' at zero en- ergy and finite momentum. If the junction is subjected to an external magnetic field, Josephson vortices may then bind a number of zero modes in addition to the topological Majorana mode. The additional zero modes are 'symmetry-protected' and can be lifted by a broken mirror symmetry (which is to be expected in realistic scenarios) as well as by an in-plane magnetization (or Zeeman field). We note that the ensuing presence of additional low-energy Andreev states can significantly contribute to measured quantities like the Josephson current or microwave absorption spectra.

Langevin equations with multiplicative noise: The mathematics, physics, and thermodynamics of interpretation.

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Stochastic differential equations are quite different from customary differential equations encountered in the description of physical dynamical systems. The right-hand side of an overdamped Langevin equation with a multiplicative white Gaussian noise does not satisfy the assumptions of the existence / uniqueness (Picard-Lindelöf) theorem. The solutions to such equations can only be uniquely defined provided additional restrictions on the kind of solution (the correct interpretation of the stochastic integral) are given. Thus, similarly looking Langevin equations give rise to different Fokker-Planck ones, and, respectively, to different probability density functions of displacements at given times. This freedom of interpretation has a deep rooting in physics, since similar Langevin equations may appear as coarse-grained, and sometimes locally homogenized, descriptions of quite diverse physical situations [1]. The freedom given by the interpretation corresponds to the possibility to incorporate the information lost when passing from the micro- to the mesoscopic level of description (implying a specific kind of a limiting transition) into the ensuing mesoscopic-level picture. The corresponding physical information may come from thermodynamics, from local symmetries of the system, or from experiments, but the overall situation is much more faceted than typically assumed. In the present talk we discuss several aspects of the problem. We start from the history of the topic, and discuss the nature of limiting transitions and limit theorems leading to Langevin equations. We discuss the freedom left for the solution of the Langevin equation after the corresponding limiting transitions are done, and consider models leading to different interpretations of the Langevin equations after the corresponding limits are taken. We consider the thermodynamics of these models, and discuss the connections between their micro-, macro- and mesoscopic levels of description. We moreover consider the intimate connection between the interpretation and the geometric symmetries of transition rates in the corresponding system: if these symmetries are known, they define the interpretation uniquely. The situation can however be more complicated since the local symmetries may be broken. We moreover discuss how the correct interpretation can be obtained from the single-particle tracking experiments [2,3].

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Hawking time crystals

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After a brief introduction to black-hole lasers and continuous-time crystals, we propose a time crystal based on a quantum black-hole laser, where the genuinely spontaneous character of the symmetry breaking stems from the self-amplification of spontaneous Hawking radiation [1]. The resulting Hawking time crystal (HTC) is characterized by the periodic dependence of the out-of-time density-density correlation function, while equal-time observables are time-independent because they embody averages over different realizations with a random oscillation phase. The HTC can be regarded as a nonlinear periodic analogue of the Andreev-Hawking effect, exhibiting anticorrelation bands resulting from the spontaneous, quantum emission of pairs of dispersive waves and solitons into the upstream and downstream regions. Remarkably, the time-crystal formation is understood in terms of two time operators: one associated to the initial black-hole laser and another associated to the final spontaneous Floquet state [2,3].

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Single-spin flip dynamics in the Ising model

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The Si(001) surface is formed by dimers of surface atoms arranged in parallel rows which are alternatingly buckled both along and between the rows. The dimerized Si(001) surface can be mapped onto an anisotropic 2D Ising model on a rectangular lattice such that the two states of the Ising spin correspond to the two buckling orientations of the Si dimers.

In order to study the real-time dimer-flip dynamics, we perform kinetic Monte Carlo simulations of spin-flip dynamics in the Ising model. We analyze the waiting-time distribution between subsequent flips of a single spin. For a ferromagnetic 1D Ising model, we find that that large temperatures the waiting-time distribution shows an exponential decay due to thermal excitation and relaxation of spins. At low temperatures, it is dominated by an algebraic decay which is caused by the random walk of domain walls. The latter can be suppressed by an external magnetic field which mimics the coupling to neighbouring dimer rows. The presence of defects is modelled by quenched boundary conditions which lead to an increased (decreased) life time of spins which are parallel (antiparallel) to boundary spin. Finally, we compare our results of the 1D case to a simulation of the 2D Ising model.

Formation of action potential in neuron and the quantum diffusion of somatic ions

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The talk will review our efforts to improve the understanding of physical processes which control information transfer and processing in biological neural networks. The essential component of any model of action potential is traditionally based on the existence of gated ionic channels in neurons membranes. Nevertheless, as we have recently shown, the kinetics of K^+ and Na^+ ions are governed by the quasi-selective quantum diffusion for which the gated channels are, at least for initial phase of action potential, not necessary. For this purpose, temporary fissures, spontaneously created in neuron membrane by flexoelectric effect, are quite sufficient. On the other hand, for the recovery phase of action potential, which brings the neuron back to the homeostasis, gated channels and natrium/potassium ion pumps are necessary.

In the second part of the talk, the two competing models of signal transmission (action potential) through the neuron, Hodgkin-Huxley electrochemical theory and Heimburg thermomechanical soliton theory, will be introduced and their shortages discussed. Based on this discussion a novel minimal model of transmission of the all phases of the action potential via neuron will be presented. This minimal model is based on the scenario which considers fundamental experimental facts and undeniable elements of both leading theories [1-4].

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The Private Lives of Photons: Asking particles where they spent the night

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The interaction of a resonant electromagnetic field with a cloud of two-level atoms is so well studied that one would hardly expect it to hold any more mystery, and yet it turns out to still have surprises in store when one considers the effect of post-selection. While photons famously don't follow definite trajectories, there are interesting questions one can ask - experimentally as well as theoretically - about where they have spent their time before being observed. This raises thorny issues about how to talk about the past of a quantum system.

I will describe an experiment we initially built to observe optical nonlinearity at the single-photon level, aiming towards applications such as QND and quantum computing. I will pay particular attention to some of the strange effects we observed when post-selecting on the final state of a photon. In one, we could in a sense "amplify" the phase shift an individual photon wrote on a probe beam. Most recently, we began using this apparatus to probe how much time atoms are caused to spend in the excited state by a resonant photon. Specifically, we investigated whether the answer depends on whether the photon in question is transmitted or reflected Not only was the answer yes, but the result for transmitted photons turned out to be quite unexpected. I will present both theory and experiment supporting a simple, yet disturbing, connection between the delay time experienced by a pulse and the time atoms spend in the excited state. Finally, I will address the question of how to think about a photon which is prepared in a narrow frequency mode, but later observed at a particular time.

Entropy augmentation in irreversible dynamics: A journey from epistemology to numerical simulation.

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Reconciling the axiomatic status of irreversibility in phenomenological thermodynamics with time-reversal symmetry in microscopic models is a challenge which has been recognized ever since kinetic theory acquired predictive power. Known approaches picturing irreversibility as *emerging* from microscopic dynamics either feature deliberate modifications of the microscopic dynamics (Stoßzahlansatz, coarse-graining) or postulate a map which assigns to each phase-space point $X(t)$ (microstate) a region $\Gamma(t)$ (macrostate), whose volume determines the (Boltzmann) entropy.

Both approaches reflect the important fact that is important but is sometimes overlooked: A thermodynamic system is a system under *incomplete* observation. Modifications of microdynamics are performed under the proviso that they remain undetectable within the scope of incomplete observation. Direct mappings from microstates X to macrostates Γ implicitly require that the macroscopic state cannot be further differentiated by any practical observation.

The EASE (entropy augmentation through subadditive excess) approach [1] constructs modifications of microdynamics from an information theoretic perspective which embraces the Boltzmann equation as a paradigmatic model, yet radically generalizes the idea of lost correlation information. Its key features are the following:

i) A physical system is partitioned into subsystems, whose size can be microscopic or macroscopic or anywhere in between.

ii) A memory time represents a delay period after which the detection of past correlations between subsystems is deemed infeasible.

While EASE propagation can be based on either classical or quantum Liouville equations, the quantum case has special features: Entanglement arising in an initially pure quantum state can be the seed of entropy augmentation. This allows EASE-based quantum jump methods describing self-equilibration.

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The Power of Power-of-SWAP: Postselected Quantum Computation with the Exchange Interaction

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We introduce Exchange Quantum Polynomial Time (XQP) circuits, which comprise quantum computation using only computational basis SPAM and the isotropic Heisenberg exchange interaction. Structurally, this sub-universal model captures decoherence-free subspace computation without access to singlet states. We show that XQP occupies an intermediate position between BPP and BQP, as its efficient multiplicative-error simulation would collapse the polynomial hierarchy to its third level. We further provide evidence that additive-error simulation of XQP would enable efficient additive-error simulation of arbitrary BQP computations. Remarkably, the restricted family of XQPcircuits consisting solely of $\sqrt{\text{SWAP}}$ gates remains hard to simulate to multiplicative error. We additionally prove that circuits generated by $\sqrt{\text{SWAP}}$ gates are semi-universal, generate t-designs for the uniform distribution over SU (2)-invariant unitaries, and maximise the entangling power within XQP. Finally, we derive structural results linking computational basis states in XQP to the Gelfand-Tsetlin basis of the symmetric group, and expressing XQP output probabilities as partition functions of the six-vertex and Potts models. Our findings indicate that XQP circuits are naturally suited to near-term hardware and provide a promising platform for experimental demonstrations of quantum computational advantage.

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Point information gain entropy density, and an ideal image from light microscopy

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The derivation of PIED was inspired by the need to extract the maximum amount of information from a microscopic image. Instead of the traditional approach to entropy, which seeks to characterize a macroscopic system as a whole, we derived a quantity that quantifies each element's contribution to the information in a discrete data set. Here, it is necessary to distinguish between (1) the system itself, such as a structured mesoscopic system like a living cell, a metal alloy, or a self-organized chemical system in the Belousov-Zhabotinsky reaction, and (2) our information about this system, such as an image from a light microscope or a camera. From an experiment, we always obtain a partial reflection of the system's structure, but never complete information about the system itself.

In this presentation, we focus on the implications of extracting information about a metal alloy from a light microscope. In light microscopy, an image refers to an interference object we observe in a plane called the focal plane. The relationship between the observed structure and the image is defined, on the one hand, by the formation of the image itself–i.e., by interference phenomena that often make observation impossible–and, on the other hand, by the non-idealities of the optics, which typically project the image at different wavelengths into different planes and in different ways, and both of these occur differently in different parts of the image. It follows that the very definition of a single focal plane for all wavelengths is practically impossible. Digitizing a color image is a problem in itself, introducing additional distortion.

In our lecture, we will demonstrate how to define the focal plane using PIED and how this definition differs from that based on standard Shannon entropy. We will also show how PIED varies within a single focal plane at different wavelengths. Finally, we will propose a method for obtaining an idealized light image from any imaging device. This method is general and always provides improved information about the observed system at the physical-chemical level. It has been implemented in the Spectral Spaces wide-field microscope allowing simplest possible sample manipulation and thus providing space for any scientific and industrial use.

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Suppression of quantized heat flow by the dielectric response of a compressible strip at the quantum Hall edge

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We develop a unified perturbative framework for energy transport along a chiral quantum Hall edge coupled to a disordered, compressible strip. Treating the strip as a generic linear response environment characterized by its retarded susceptibility, we obtain leading corrections to both the heat flux carried by the edge plasmon and to its spectrum. Two generic regimes emerge: (i) a gapped, local dielectric response with finite-range coupling, producing a negative correction to the quantized heat flux that scales as T^4 at low temperatures together with a convex cubic shift of the plasmon dispersion; and (ii) a hydrodynamic (diffusive) response with relaxation, yielding a crossover from T^4 to $T^{3/2}$ scaling and a change of sign in the correction. We further introduce a microscopic dipolar model in which the edge couples electrostatically to localized dipole moments inside a wide compressible strip. This long-range interaction amplifies the nonlocal dielectric back-action and generates new suppression laws, T^3 or even T^2 for smooth disorder profiles, together with a universal ratio connecting spectral curvature to thermal response. Across all regimes, the total heat flux remains quantized: the apparent deficit of the plasmon contribution reflects reversible heat drag into the compressible strip rather than a breakdown of quantization. The framework thus provides a coherent and quantitatively plausible explanation of the "missing heat flux" anomaly and unifies the thermal and spectral signatures of quantum Hall edge dynamics.

Molecular Archimedean Screw: A torque transfer molecular machine

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Machines based on torque transfer have played a central role in the development of our technology, from ancient Archimedean water pumps and windmills to modern jet engines. Miniaturizing such machines to the molecular scale could enable new nanoscale functionalities and reveal unexplored physical effects. Here we report the realization of a molecular Archimedean screw, consisting of a single helical molecule suspended between atomically sharp electrodes. This molecular machine operates both as a turbine driven by electric current and as a mechanical current booster. An applied voltage induces cyclic molecular motion with 100% directional preference, reversible upon inversion of the voltage polarity. Above a threshold voltage, the device exhibits a pronounced enhancement of electrical current. This current amplification is mechanically tunable: stretching or compressing the molecular helix shifts the onset of the effect. Calculations show that current-induced molecular rotation explains both the cyclic motion and the enhanced conductance, associated with a transition from stochastic cyclic jumps to continuous molecular rotation that enables access to highly conducting configurations. This work establishes a prototype for a new class of torque-transfer molecular machines with perfect turbine unidirectionality and mechanically controlled current boosting.

Quantum dynamics 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, recent developments of the HEOM method are discussed, including the combination with tensor network approaches [2] and extensions that allow the efficient treatment of structured spectral densities [3]. Applications of the HEOM method are discussed to nonadiabatic quantum dynamics of molecules at metal surfaces [4]. Furthermore, the principle of minimal dissipation is employed to investigate thermodynamic properties such as work, heat, and entropy production in open quantum systems [5]. As a specific example, a quantum Otto cycle in the Anderson impurity model is studied.

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What enables efficient long-range charge transport across protein layers?

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For molecular layers only $\approx$ 1-2 nm thick, coherent tunneling is a widely accepted mechanism of charge transport. We have studied such systems systematically, including molecules with reversibly switchable asymmetric tunnel barriers [1] and chiral molecules exhibiting structure-dependent spin selectivity [2].

Protein multilayers extend this problem into a qualitatively different length regime, with layer thicknesses reaching several tens of nanometers. For multilayers of the protein bacteriorhodopsin (bR), we find a mono-exponential attenuation of conductance with bR layer thickness up to 16 nm, with a small attenuation coefficient of $\beta \approx 0.8$ nm^{-1} [3]. This weak, exponential length dependence is surprisingly reminiscent of non-resonant tunneling. Indeed, together with the observed temperature behavior, it is consistent with tunneling through the thin protein-protein and protein-electrode interfaces. However, the microscopic (quantum) mechanism underlying the apparently efficient long-range electron transport through the *protein interior* remains elusive and calls for new theoretical approaches.

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When Does a Quantum System Return? Topology, Dark States, and Noise in Monitored Dynamics

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The recurrence time, the duration for a monitored system to return to its initial state, is a fundamental probe of quantum dynamics under repeated measurement. For strong stroboscopic monitoring, the mean return time is topologically quantized through the winding number of the monitored state, with subspace measurements yielding fractional quantization. Remarkably, this quantization survives on real, noisy hardware using restarts: on IBM quantum processors, we track a quantum walker on a triangle ring with complex edge weights and directly observe quantized return times and dark states the detector never sees. In interacting many-body spin systems, the recurrence time is fractionally quantized. We show that the quantized values count the dark states, an experimentally accessible probe of Hilbert-space fragmentation and ergodicity breaking. Even weak monitoring through an ancilla follows a simple scaling law in the measurement strength.

After many measurement rounds without restart, noise reshapes this structure: without restarting, after we observe a quantum Kac law connecting the return to the unmeasured steady state, connecting quantum quantization to a Kac law, with dark states controlling slow crossovers in between. A simple question: when does the system return? thus becomes a probe of topology, dark states, and the quantum-to-classical transition, and a practical benchmark for mid-circuit measurements on today's quantum computers.

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Nonequilibrium Transport and Thermoelectricity in Open Quantum Systems

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Understanding energy and charge transport in nanoscale systems requires theoretical tools capable of describing quantum coherence, interactions, and nonequilibrium environments on equal footing. A common simplification in open quantum systems is the wide-band limit, where reservoirs are assumed to have energy-independent spectral properties. While this approximation enables compact descriptions of transport, it obscures spectral information and limits the predictive power of thermodynamic modeling.

We present a framework for nonequilibrium quantum transport that overcomes this limitation while remaining computationally efficient. Within nonequilibrium Green's function theory, we develop a formulation of open-system dynamics that scales linearly in simulation time and treats structured environments with finite bandwidth [1]. The approach enables accurate time-resolved simulations of interacting quantum junctions beyond the wide-band approximation while retaining direct access to physical observables such as charge, energy, and heat currents.

The formalism further reveals new ways to probe spectral properties through transport measurements. In multi-terminal setups, the interplay between different leads allows nonequilibrium current responses to encode information about the underlying many-body spectrum, providing a route to reconstruct spectral features directly from transport observables [2].

Finally, we demonstrate how these developments enable the study and optimization of thermoelectric energy conversion in molecular junctions driven far from equilibrium. Combining accurate open-system dynamics with energy-resolved transport analysis identifies regimes where nonequilibrium effects, spectral structure, and interactions cooperate to enhance thermoelectric performance [3].

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Network analysis for steady-state current fluctuations in the presence of finite affinity

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We present a graph-theoretic analysis of steady-state current fluctuations in stochastic systems described by master equations [1]. We adopt full counting statistics for both currents and dwell times to rederive the level-2.5 large-deviation function. For uniform transition rates, we perform a duality transformation and derive a signal-to-noise expression formulated as a quadratic optimization problem over mesh currents [1]. We apply this expression to the fluctuating computation time in a schematic Brownian computation process with resetting, represented by a tree-like graph with a single reset cycle. Unlike the previously derived thermodynamic uncertainty bounds, which increase logarithmically with the length of the intended computation path, this bound depends on the number of extraneous predecessors and therefore captures logical irreversibility [2].

Next, we extend the framework to arbitrary transition rates [3] by introducing a twisted incidence matrix and the corresponding modified circuit matrices, which preserve the orthogonality between the cycle space and the cut space. This allows us to perform the duality transformation in the presence of finite cycle affinity. Applying this formalism to the Brownian computation process under forward bias, we show that, in the limit of an infinitely long computation path, the Fano factor of the reset current exhibits a transition from Poissonian to nearly noiseless behavior at a forward/backward rate ratio whose threshold depends on the degree of logical irreversibility. This noise transition corresponds to the easy-hard transition in Brownian computational time complexity [4]. The transition point precisely characterizes the thermodynamic cost of logically irreversible computation: in the absence of affinity, the reset cost scales logarithmically with the length of the intended computation path, whereas reaching the transition point requires a thermodynamic force equal to the logarithm of the number of immediate predecessors per step to counteract backward branching.

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The quantum theory of time: Emergence of Lorentz invariance

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The violation of the discrete symmetries of charge conjugation (C), parity inversion (P), and time reversal (T) observed in high energy physics are fundamental aspects of nature. A new quantum theory [1,2] has been introduced to explore the possibility of their large-scale physical consequences. The new theory does not assume any conservation laws or equations of motion at the outset. In particular, if T violation is turned off, matter is represented in terms of virtual particles that exist momentarily only. However, with T violation turned on, what was the mathematical structure of a virtual particle now traces out an unbounded world line that satisfies conservation laws and an equation of motion. The important point here is that time evolution and conservation laws are shown to emerge phenomenologically from T violation.

A key point of the theory is that the effective strength $\lambda = \mathrm{i}\langle[\hat{H}_F, \hat{H}_B]\rangle$ of the T violation, where $[\hat{H}_F, \hat{H}_B]$ is the commutator of the Hamiltonians for forward $\hat{H}_F$ and backward $\hat{H}_B$ directions of time, determines a relative scale for clock time. (Here $\hat{H}_B = \hat{T}^{-1}\hat{H}_F\hat{T}$ and $\hat{T}$ is Wigner's time reversal operator.) Consequently, the time shown by an accurate clock depends on the value of λ in its local region. In fact, the theory predicts that two identical clocks will loose synchronicity if they are in spatial regions with differing values of λ [3]. Importantly, this effect is manifested as differences in the quantum states of the clocks (rather than differences in coordinate times). The T violation exhibited by neutrinos emitted by nuclear reactors offers an opportunity for testing this prediction experimentally [4].

It follows that a velocity-dependent λ would induce a corresponding velocity-dependent variation in clock time. Indeed, under a Galilean transformation, interacting scalar fields with vacuum expectation values exhibit an effective T violation that changes in a velocity-dependent way to give precisely the time dilation of the Lorentz transformation, but associated with the relative quantum states of the clocks rather than their coordinates. In other words, quantum clocks are found to undergo time dilation. The speed of propagation of the scalar fields is found to be a limiting speed for all dynamics deduced from quantum states, and an operationally-derived length contraction is found to operate in the relative description of the quantum states. Hence, without being directly introduced, Lorentz invariance is found to *emerge phenomenologically* in the relative quantum description as a consequence of what is essentially a Doppler shift of the effective T violation. This remarkable result suggests that Lorentz symmetry is not an elemental one, as usually assumed, and it illustrates how the new theory offers fresh insight into the quantum nature of time.

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Reflected fractional Brownian motion as model of serotonergic axons in the brain

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Fractional Brownian motion (FBM), a non-Markovian self-similar Gaussian stochastic process with long-time correlations, is a widely applied model of anomalous diffusion. In confined geometries, the interplay between the long-time correlations of FBM and the reflecting boundaries leads to striking deviations of the stationary probability density from the uniform density found for normal diffusion. Particles accumulate at the boundaries for superdiffusive FBM while their density is depleted at the boundaries for subdiffusion [1,2].

Reflected FBM has recently emerged as a promising model for the self-organization of serotonergic axons in vertebrate brains. These fibers form a dense matrix that releases serotonin, a neurotransmitter that modulates a wide range of neural processes. We employ large-scale computer simulations to model serotenergic fibers as FBM-paths in realistic brain-shaped geometries. We demonstrate that the resultant steady state distributions approximate the fiber distributions in physical brain sections of several vertebrate species. This suggests that this framework supports predictive descriptions of the serotonergic matrix that can be further extended by incorporating details of the fibers and their environment [3,4.5].

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Quantum light sources for foundational tests and quantum communication

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Single photons and entangled states of light have been instrumental to the investigations into the foundations of quantum physics, which in turn led to the creation of the field of quantum information science and the resulting quantum technologies. Major advances in quantum photonics, such as the various generations of Bell inequality tests, could often be attributed to a new and improved quantum light source. Likewise, for optical quantum technologies, especially in quantum communication, source performance is as important as detector technology.

In our research we have been developing semiconductor waveguide sources of photon pairs and semiconductor quantum dots as sources of single photons and entangled photon states. Depending on the intended application in a quantum information processing protocol or foundational test there are a number of specifications that such a source must fulfil, such as the emission rate, -efficiency, and -statistics, state purity, indistinguishability, spectral and time properties, etc.

Achieving the desired characteristics not only requires designing and fabricating innovative devices, but also engineering the excitation of the quantum emitter or nonlinear element that is at the heart of the source. While much work has gone into adapting quantum optical coherent control techniques invented for atoms and molecules towards solid-state environments, also completely new methods have emerged that help avoid or mitigate unwanted decoherence mechanisms. For example, we have implemented the so-called Swing-up of Quantum Emitter Population (SUPER) scheme and Adiabatic Rapid Passage (ARP) in single quantum dots. Furthermore, we have been able to coherently excite and control dark states, which will be useful in entanglement generation and as quantum memories.

Fast directed transport via energy recuperation in non-Markovian media

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Recent experimental studies show that driven overdamped Brownian particles can recover energy stored in non-Markovian environments [1]. Using the Generalized Langevin Equation formalism, we demonstrate that energy recuperation is, in fact, an inherent feature of systems exhibiting memory and occurs even in the simplest models, such as a free Brownian particle driven by thermal noise. Moreover, we show that inertial particles can recover energy from their environments even when thermal noise vanishes and without any external forcing. Next, we investigate the influence of energy recuperation on the directed transport of Brownian particles in the presence of energetic barriers. In particular, we demonstrate that the delayed response of the non-Markovian medium to the particle's motion results in the emergence of running solutions, which are absent in analogous Markovian media. The running solutions are qualitatively different from those encountered in viscous fluids in that the particle repetitively reverses the direction of its motion to recover energy from the non-Markovian medium, which enables it to overcome potential barriers. Notably, in our system, the transport in a non-Markovian medium can almost reach the free-particle limit, in contrast to the locked behaviour of particles in a Markovian case. Our findings shed new light on the role of energy exchange between Brownian particles and their environments in transport at the micro-scale, with direct applications to the dynamics of colloids in viscoelastic fluids and intracellular transport.

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Dissipative and nondissipative quantum circuit elements

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Quantum analogues of nondissipative circuit elements, that is, structures which can exist in a superposition of states with different values of inductance or capacitance, are readily realized using, e.g., superconducting qubits. Here I consider the possibility of the existence of quantum analogues of dissipative circuit elements, which demonstrate superpositions of states with different resistances or memristances. Using the Landauer view of transport through a scattering barrier, I show that this leads to no contradiction with the dissipative character of these elements.

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Advanced Quantum Networks - Future Applications and Technology Demonstrations

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Classical communication is the basis for many of our current and future technologies, such as mobile phones, video conferences, autonomous vehicles and particularly the internet. It is not unlikely, that quantum communication and quantum networks might open up novel opportunities on a similar scale. Governed by the basic laws of quantum mechanics, quantum networks might offer enormous benefits for security applications, more precise measurements, faster computations, and many other fields of application by interconnecting different quantum devices, such as quantum sensors, quantum computers, or quantum memories [1,2].

In this talk, we provide an overview of ongoing research activities in our group regarding quantum information networks and their future opportunities. In particular, we address topics such as blind quantum computing, quantum authentication, a development roadmap for quantum networks and technology demonstrations. Moreover, we present steps towards establishing an entanglement-based quantum information network in Ulm and beyond.

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Are Events Absolute?

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Solving the measurement problem has led to various attempts relying on very different hypotheses. One path is to exit from the standard formalism of Quantum Mechanics (QM) either by extending it (as in de Broglie - Bohm theory, dBB) or by modifying it (as in the spontaneous collapse theories, GRW or Diosi-Penrose). Alternatively, the Everett interpretation embraces multiple outcomes per observer. Changing the standard formalism has the advantage that it is in principle possible to empirically test the candidate theory (unlike dBB theory, whose predictions mirror those of QM under quantum equilibrium). If we want to stay inside the standard formalism, it is necessary to explain why and when the unitarity of the Schrodinger equation describing the evolution of the state of a system is broken to give rise to a collapse (projection principle). Many recent interpretations assume that QM is universal. That means first that it applies to every system independently of its size and even if the system is itself an observer, and second that all physical processes, including measurements, are described by a unitary interaction. However, this does not solve the measurement problem, as it remains unclear how a definite measurement result emerges from a unitary process. This issue sparks philosophical debates, notably around Wigner's friend experiment and its extensions, which explore the non-absoluteness of events and its implications for our understanding of reality. In this paper, we are going to dive into these discussions that shed light on the question of knowing what that means for events to not be absolute (one apparent conclusion of these discussions) and what is the new conception of reality that this implies. This will allow to give a detailed comparison of many so-called perspectival interpretations.

Invited Posters

Overturning the Measurement Postulate: Continuous Thermodynamic Localization vs. Wavefunction Collapse and Statistical Ensembles

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The quantum measurement postulate remains a fundamental physical contradiction, enforcing a non-unitary, observer-dependent projection that interrupts continuous dynamical evolution. In this work, we demonstrate that the orthodox instantaneous collapse postulate is both a thermodynamic impossibility and a logical redundancy. The observer-dependent actualization of macroscopic particle ensembles would require an instantaneous deposition of latent heat ($dt \to 0$), triggering an unphysical, infinite power divergence. Furthermore, because an unobserved apparatus must undergo continuous open-system thermodynamic relaxation prior to conscious inspection, any subsequent mathematical projection is theoretically obsolete.

Crucially, this work systematically invalidates leading alternative paradigms, specifically decoherence theory [1] and mean-field thermodynamic ensemble models, such as the Allahverdyan, Balian, and Nieuwenhuizen (ABN) formalism [2]. We demonstrate that these models commit a fundamental category error by conflating the mathematical description of a statistical ensemble (truncated density matrices) with the physical reality of a single experimental run. As a direct mathematical consequence of this conceptual flaw, their reliance on mean-field thermodynamic averages inadvertently forces single-run outcomes to be deterministic, fundamentally failing to explain the probabilistic actualization dictated by the Born rule.

To replace these paradigms, we introduce the Open-System Measurement Framework (OSMF). The OSMF models measurement as a concrete, continuous physical process where the quantum-apparatus interaction generates a transient, thermodynamically unstable macroscopic superposition. Driven by coupling to a reservoir, this state undergoes continuous thermodynamic relaxation into a stable local minimum, irreversibly actualizing a definite outcome without invoking a ”Heisenberg cut.”

Finally, we propose a direct, empirically falsifiable experimental protocol to test the OSMF against orthodox projection. By modifying a Stern-Gerlach apparatus with an asymmetric detection screen–engineered with a gradient in atomic adhesion energy–we demonstrate how measurement probabilities can be dynamically steered by the environment, proving that the standard Born rule is an emergent approximation for symmetric detectors.

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Dual-qubit heat valve: an experimental study on collective photonic heat transport

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A photonic quantum heat valve [1] is investigated here experimentally, in the configuration of two superconducting qubits placed in parallel between two temperature-biased local reservoirs. The setup is such that the two qubits collectively mediate the photonic heat current across the reservoirs [2][3], which is experimentally determined by normal metal - insulator - superconductor (NIS) thermometry. The suppression of steady-state heat current is observed when both qubits are in action. Our study implies that steady-state collective coherence can be sustained autonomously in a dissipative system, without the need for external coherent drives.

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Role of scrambling, noise, and symmetry in temporal learning with quantum systems

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Scrambling quantum systems have been demonstrated as effective substrates for temporal information processing. While their potential and limitations for learning static data has been studied in our previous work [1], a theoretical understanding of their performance in temporal tasks, where quantum systems work as both computational substrate and memory, is still lacking. Going beyond our previous setting of a single step iteration and static data, here we consider a general quantum reservoir processing framework that captures a broad range of temporal learning models using quantum systems. We examine the scalability and memory retention of the model with scrambling reservoirs modelled by high-order unitary designs in both noiseless and noisy settings. In the former regime, we show that measurement readouts become exponentially concentrated with increasing reservoir size, yet strikingly do not worsen with the reservoir iterations. Thus, while repeatedly reusing a small scrambling reservoir with quantum data might be viable, scaling up the problem size deteriorates generalization unless one can afford an exponential shot overhead. In contrast, the memory of early inputs and initial states decays exponentially in both reservoir size and reservoir iterations. In the noisy regime, we also prove exponential memory decays with iterations for local noisy channels. We further prove that the scalability limitations also hold for model variants that incorporate mid-circuit measurements and feed-forward, which have been demonstrated as a source that improves performance of learning models. To sidestep these scalability barriers, we show that by employing less scrambling or symmetrized reservoirs, the exponential concentration of outputs can be avoided. Proving these results required us to introduce new proof techniques for bounding concentration in temporal quantum learning models. Our results lay the ground work for understanding the potential of a quantum advantage for temporal learning tasks using quantum reservoir processing.

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Robust Working Memory Computation and Entropy Production in Random Neuronal Networks

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Training recurrent neuronal networks consisting of excitatory (E) and inhibitory (I) units with additive noise for working memory computation slows and diversifies inhibitory timescales, leading to improved task performance that is attributed to emergent marginally stable equilibria [1]. Yet the link between trained network characteristics and their roles in shaping desirable dynamical landscapes remains unexplored. We first discuss the phenomenology from [1], where trained cortical networks with heterogeneous inhibitory dynamics are more robust to noise in working memory models that compute using discrete attractors (fixed-point equilibria) hopping mechanism. Then, we study the Jacobian matrices describing the dynamics near these equilibria and show that they are sparse, *non-Hermitian rectangular-block* matrices modified by *heterogeneous synaptic decay timescales* and activation-function gains. We specify a random matrix ensemble that faithfully captures the spectra of trained Jacobian matrices, arising from the *inhibitory core-excitatory periphery network motif* (pruned E weights, broadly distributed I weights) observed post-training. An analytic theory of this ensemble is developed using statistical field theory methods: a Hermitized resolvent representation of the spectral density followed by a supersymmetry-based treatment in the style of Fyodorov and Mirlin. In this manner, an analytic description of the spectral edge is obtained, relating statistical parameters of the Jacobians (sparsity, weight variances, E/I ratio, and the distributions of timescales and gains) to near-critical features of the equilibria [2]. These results reveal that the slow, inhibitory core naturally pushes the equilibria of these cortical networks toward marginal stability without requiring parameter fine-tuning. Furthermore, we will show that this stable computation arises when the network dynamics is sustained in a non-equilibrium steady state (NESS). In this context, we will also discuss a newly discovered, *universal entropy production rate* formula for stochastic dynamics in an NESS driven by a variety of directed networks [3].

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Superoscillations at Dark Ports: Interference-Engineered Sensing and Spectrally Constrained Light-Matter Control

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Superoscillations allow a band-limited optical field to display local behavior that appears to lie outside its global spectral content. I will discuss how such effects arise near engineered destructive-interference minima, where local wave vectors, weak values [1], and Fisher information densities [2] can become strongly concentrated. As a spatial example, I will begin with "optical ventriloquism" [3]: near a diffraction minimum, light can appear to originate from a displaced, nonexistent source, due to sharp transverse shifts of the local wave vector. I will connect this physics to sensing with dark-port interferometric encoders, where an ideal interference null can concentrate shot-noise Fisher information into a photon-poor region, while coherent leakage and stochastic phase noise reshape and ultimately limit the advantage. Next, I will turn to quantum light-matter interaction under spectral constraints. In protected quantum platforms, decoherence mitigation often imposes photonic bandgaps or filtered control lines. I will discuss how a superoscillatory pulse whose global spectrum avoids a two-level-system resonance can nevertheless produce a resonant-like response through a spectrally filtered multimode cavity. Finally, I will connect these ideas to interference-generated regularization from postselected superpositions of time evolutions [4]. The central message is that superoscillations redistribute response and information in unique ways that can be useful for quantum sensing and quantum control.

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Is Entanglement Necessary for the Typicality Argument in Statistical Mechanics?

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Typicality arguments replace the postulated mixed-state ensembles of statistical mechanics with pure states sampled uniformly at random, explaining why most microstates of large systems exhibit thermal behavior. This paradigm has been revived in quantum contexts, where entanglement is deemed essential, but no clear quantitative link between entanglement structure and typicality has been established. Here, we study pure quantum states with controlled multipartite entanglement and show that when entanglement grows with system size N, fluctuations in macroscopic observables decay exponentially with N, whereas if entanglement remains finite, one recovers only the classical $1/\sqrt{N}$ suppression. Our work thus provides a quantitative connection between entanglement structure and the emergence of typicality, demonstrating that entanglement is crucial for thermalization in small quantum systems but unnecessary to justify equilibrium in macroscopic ensembles. This unifies classical and quantum foundations of statistical mechanics by pinpointing exactly when–and why–entanglement matters

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Energy conversion at the nanoscale: exploiting non-thermal resources

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Nanoscale engines - such as on-chip thermoelectric devices - are increasingly used to transduce energy and particles between reservoirs for *useful* tasks like cooling. Unlike macroscopic engines, these systems often operate under conditions where environmental reservoirs are constantly out-of-equilibrium and cannot be described by well-defined thermal distributions. Consequently, temperature and chemical potential lose their meaning, and fluctuations in energy and particle flows become significant. Rather than treating this non-thermal nature as a limitation, we exploit it as a *resource* to design devices that can even outperform traditional engines in performance. We investigate a prototype quantum thermoelectric device operating between a non-thermal and thermal reservoir, analyzing energy and particle flows in the coherent transport regime via scattering theory [1]. Our approach seeks to optimize the device's performance based on the efficiency, precision, or a trade-off between the two at a given output cooling current while the usual heat-work distinction breaks down. We introduce entropy currents as resources and exploit a Lagrange multiplier method to optimize the particle transmission characteristics to achieve the optimal performance. We find that the resulting optimal transmission filters are directly shaped by the non-thermal distribution. Our work provides a framework for characterizing and leveraging non-thermal resources, opening pathways for unconventional energy conversion strategies in quantum thermodynamics and nanoscale physics.

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Josephson diode effect in superconducting circuits

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We investigate the superconducting diode effect in circuits composed of two Josephson junctions in series, connected to three cuperconductors. This cricuit was implemented experimentally by S. Matsuo et al, with Josephson junctions where a semiconductor was embeded in order to change the transmission with a gate. Here we embed quantum dots - which are here considered as resonant energy levels - in the two junctions in order to optimize the Josephson current. The diode effet occurs because of the two fundamental Cooper pair processes occuring at the central superconductor: double crossed Andreev reflection and Cooper pair cotunneling through the latter. We use the Masubara formalism is employed and the partition function can be written as a simple sum over Mastubara frequency of a determinant which incorporates tunneling processes to all orders between the dots and the leads. The diode behavior is studied as a function of the parameters of the system such as the ratio of the tunneling rates of the dots to the gap energy and the position of the levels of the two dots.

Holiday in a black hole

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It is first stressed that at the BH horizon, massive objects move with light speed. This is already evident from relating their local Minkowski frames with the known infinite redshift.

Escape from a black hole is possible by using the rocket's engines. In an eternal charged black hole, an exit typically happens automatically.

A closed time-like curve has an equal-time crossing point of the ingoing path and the path after exiting the BH. The crossing is a peculiarity of the mathematical description by the stationary observer; it does not occur for freely falling Painlev'e-Gullstrand observers, hence it does not relate to a physical event for any observer

The "grandfather paradox" thus gets a simple answer: the equal-time crossing does not relate to a physical event: the grandson cannot kill his young grandfather and thereby erase his existence.

If one throws a bomb in a nearby BH and it explodes inside, one is not safe. This has been shows for a quantum-bomb: for a neutron decaying in a black hole, the created electron can escape. After the classical demonstration, it is shown that narrow quantum wave packets move classically.

The Penrose-Carter diagrams for a Schwarzschild BH has only two patches: exterior and interior. For charged and/or rotating black holes, there is a patch for the exterior, for the manlte and for the core – no infinite tower of patches.

The misconception in the field is the separation between the "black" hole, where stuff and light can only go inwards, from the "white" hole, where they can only go outwards. In general, like with the bomb, both can occur simultaneously for the respective components. This is obvious when considering the local Minkowski frames. Such cases are neither covered nor excluded by trapping theorems.

Discussion with Erik Verlinde is acknowledged.

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Implementing Single-Qubit General Quantum Dynamical Maps on Quantum Devices

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The dynamics of open quantum systems is typically described by completely positive trace-preserving maps, which guarantee physical consistency and direct experimental implementability. However, many transformations of both fundamental and practical interest fall outside this standard framework. Examples include inverse quantum channels, non-Markovian propagators, effective reduced dynamics, and other generalized dynamical maps that are not necessarily completely positive.

We present a general mathematical framework that enables the implementation of such maps for single qubits on quantum devices by decomposing them into experimentally accessible operations combined with classical post-processing. This provides a constructive route to realize transformations that would otherwise be considered nonphysical, while allowing one to characterize the associated experimental overhead.

The method opens several relevant applications. It enables the simulation of generalized open-system dynamics beyond standard Markovian evolution, including reversed dissipative processes for single-qubit systems. It also provides a natural framework for error mitigation through inversion of experimentally reconstructed noise channels, with potential applications in both quantum computing and quantum sensing. In particular, tailored mitigation strategies may significantly improve the performance of noisy single-qubit processors and sensing platforms.

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Optical Emulation of Bell Tests, Information Entropy, and QKD Protocols with Pulsed Lasers

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Emulation offers a useful framework for exploring quantum-information protocols in controllable classical and quantum platforms. In this talk, I present a hybrid approach combining pulsed-laser optical emulation, IBM superconducting quantum-computer experiments, and machine-learning reconstruction methods for studying Bell-type correlations and related quantum-information protocols.

The optical system uses polarization-encoded pulsed laser pulses, basis-selective measurements, and time-resolved detection to reproduce the algebraic structure of Bell-state analysis, including effective density-matrix reconstruction and CHSH-type correlation matrices. In parallel, IBM quantum hardware implements a two-qubit CHSH circuit in which entanglement is generated through a Hadamard-CNOT sequence, converted to the $|\psi^+\rangle|\psi^+\rangle$ Bell state, and measured after programmable RyRy rotations of Alice and Bob's measurement axes. These data provide a genuine quantum reference for comparison with the optical emulator.

A central direction of this work is the use of machine learning to reconstruct incomplete Bell-test data. In a standard CHSH experiment, the Bell parameter is obtained from 16 measurement-angle settings, but realistic free-space, satellite, photonic, and matter-wave systems may lose settings because of turbulence, obstruction, detector dead time, or finite acquisition time. We show that supervised models can infer a missing correlator and recover the Bell parameter from only 15 of the 16 settings.

This strategy is validated across IBM quantum hardware, the MIT optical Bell-test emulator, single-photon entangled-pair data, and metastable-helium atom-pair Bell-test data. The results suggest a practical route toward stabilizing Bell certification and QKD protocols against partial measurement loss, while providing a compact platform for studying how quantum-style correlations are encoded, reconstructed, and certified.

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Interaction-driven dynamics in Graphene flakes

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We study interaction-driven ultrafast dynamics in finite graphene flakes following an optical pump quench in an interacting tight-binding model. By comparing exact real-time evolution with simulations restricted to particle-hole excitation subspaces, we assess when relaxation can be captured by low-order many-body processes and when this is not sufficient.

This work is is motivated by the observation, that basically all observables in Graphene are described by a non-interacting tight binding Hamiltonian on a honeycomb lattice. One of the few exceptions is the decay of particle-hole excitations, created by a pump laser and probed by a probe laser. These excitations decay in the order of 30 fs, too fast for any relaxation mechanism like phonons except electronic interaction. However, in a description based on non-interacting fermions, including HF or DFT, these excitations can't decay. The typical simulation techniques therefore includes second order Born approximations for the self-energy. We therefore address the question: if an effect is only driven by electron-electron interaction, can we check whether methods based on restricting the particle-hole excitations are justified?

To this end we study the entropy A of the single-particle density matrix ϱ, S = Tr (- ϱ log(ϱ) - (1- ϱ) log(1- ϱ)). This quantity is time independent for unitary time evolutions governed by free fermion systems, and stays single-particle basis independent for interacting systems. To investigate the role of particle-hole excitations we analysed the influence of the number of particle hole excitations we allow.

Looked like a straight-forward plan. Yet, the results are confusing, on small Graphene flakes, second order excitations, i.e. a system including all one- and two- particle-hole excitations, is sufficient to describe the quench. Increasing the system size suddenly increases the importance of higher order particle-hole excitations. For periodic boundary conditions, less excitations are needed albeit leading to much faster relaxation rates. In contrast, for a square lattice, the difference between hard-wall boundary conditions, and periodic BC are significantly smaller.

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Atmospheric Newtonian noise in torsion-balance measurements of the gravitational constant G

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Measurements of Newton's gravitational constant remain limited by environmental and apparatus-dependent systematics whose treatment is often less explicit than that of instrumental noise. Among these, atmospheric density fluctuations generate unshieldable gravity gradients that couple directly to torsion-balance observables as atmospheric Newtonian noise. Here, we develop a GUM-consistent framework for propagating this contribution through the torque estimator into the uncertainty budget of torsion-balance measurements. We derive closed-form spatial transfer functions for two benchmark geometries: a two-mass dumbbell, which provides an upper-coupling reference, and a perfectly symmetric cross, which serves as an idealized rejection limit and exposes the trade-off between suppressing low-order environmental coupling and preserving signal response. We also separate stationary correlated inputs from non-stationary baseline drift, using the Ornstein–Uhlenbeck process only as a benchmark for the former. Atmospheric pressure benchmarks indicate that the resulting background contribution is below present reference uncertainty levels, but can become relevant as systematic floors approach the part-per-million regime. This framework provides a practical route for incorporating site-specific environmental gravity gradients into future torsion-balance uncertainty budgets [1].

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Posters

How to map between any two pure states with a single unitary

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It is well-known that any two pure quantum states (in the same Hilbert space) can be mapped to any other using unitary transformations. However, it was previously unknown how to determine the simplest transformation which achieves this for an arbitrary pair of pure states in arbitrary Hilbert space dimension. This contribution shows how to utilise novel algebraic methods to construct such a unitary transformation in general; and proves that the desired mapping is always possible using a single exponential of unitary Lie algebra generators. This provides a useful tool for studying the relationships between systems of pure states in quantum information theory, as well as more elementary analyses of quantum circuits.

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Coexistence of Anderson Localization and Quantum Scarring in Two Dimension

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We investigate finite two-dimensional disordered systems with periodic confinement. At low energies, eigenstates exhibit strong Anderson localization, while at higher energies a subset of states exhibits variational scarring with anisotropic intensity patterns that deviate from random-wave expectations. Scaling theory predicts that in two dimensions all eigenstates localize in the large-system-size limit, yet the energy-dependent localization length and finite-size effects allow these regimes to coexist. We demonstrate that this coexistence produces distinct, robust signatures in both spatial intensity patterns and spectral statistics that are directly observable in mesoscopic electronic, photonic, and cold-atom systems.

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Fate of entanglement in open quantum magnets

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Many-body entanglement properties of quantum magnets, including conventional ferro- and antiferromagnets as well as exotic quantum spin liquids, have been intensively explored over the past two decades, but mostly as closed quantum systems. However, in experiments and potential applications, candidate materials will always interact with a dissipative environment, such as the one generated by bosonic quasiparticles in solids at finite temperature. Here we investigate both the stability and spatial distribution of entanglement for Heisenberg ferro- and antiferromagnetic models, as well as for the Kitaev model of quantum spin liquid, which are made open by its sudden coupling to an infinite bosonic bath of Caldeira-Leggett type and then time-evolved using a wide variety of numerical and analytical tools in both the Markovian and non-Markovian regimes. For the Heisenberg family of Hamiltonians, we determine necessary conditions for a quantum-to-classical transition where the effective dynamics are well described by the conventional Landau-Lifshitz-Gilbert equation. The presence of strong coupling between the quantum magnet and dissipative reservoir is found to impede such a transition. For the quantum spin liquid model, we observe unusual persistence of typically fragile entanglement patterns in the presence of a non-Markovian bath. We also extend our discussion to driven-dissipative versions of these models, where we identify optimal opportunities to enhance entanglement properties. Overall, we observe that the conventionally detrimental role of dissipative baths for genuine quantum features can be turned into useful entanglement-stabilization protocols when a structured bath is considered.

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Quantum Thermal Logic Gates

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We propose a new concept for quantum thermal logic gates – analogous to classical electronic logic gates – where we exploit the heat current in a coupled quantum-dots, tunnel-coupled to electronic thermal reservoirs for logic operations in a quantum circuit. We obtained a remarkable one-to-one correspondence with the classical electronic logic gates. An experimental setup is presented that demonstrates a realizable nano-electronic quantum circuit architecture for implementing such quantum thermal logic operations.

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P5

Syntropy Time Crystal State: Gate Coherence Quantum Simulations

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This article presents a paradigm shift: the Time Crystal as a Syntrodynamic State. We propose the syntropic time crystal and syntrodynamic coherence teleportation theory (SCTT), a mathematical model in which information is encoded not in static spatial configurations, but in the temporal structure of matter itself. Central to this framework is a new 13-dimensional real algebra C_{11}, defined by a dual algebraic structure where conjugate imaginary units i and j satisfy the fundamental relation j = 1/i. This duality creates a split-complex sector allowing information to be represented simultaneously in entropic and syntropic forms. The algebra embeds naturally into twistor space via the Penrose transform, where quantum states become holomorphic sections and teleportation manifests as null-geodesic propagation along a Lorentzian information manifold with metric ds2=dS2-d Σ2.

We construct a mapping from this algebra into quantum circuits via a compiler pipeline–the Hopf Gold Simulation Framework–which translates higher-dimensional algebraic structures (including X(11) modular geometry) into executable unitary operators. These operators are embedded into Floquet-engineered quantum circuits and evaluated using GPU-accelerated statevector simulation. To overcome the exponential memory bottleneck inherent in classical quantum simulation, we implement a heterogeneous parallelization architecture combining CPU memory capacity with GPU computational throughput. The system leverages high-bandwidth tensor operations on NVIDIA H100 GPU while extending qubit capacity through distributed CPU memory allocation. This hybrid model enables simulation of larger Hilbert spaces while preserving performance-critical GPU execution paths. Simulations were executed using a GPU-accelerated quantum backend (Qiskit Aer with CUDA/cuQuantum integration), achieving numerical state fidelities exceeding 0.9999998 over 100 Floquet cycles, validating the stability of syntrodynamic states. The resulting dynamics exhibit a π-spectral gap characteristic of robust time-crystalline order, with decoherence suppressed exponentially via frequency-domain encoding.

Gate operations preserving this structure correspond to knot invariants–specifically Jones polynomials at q=e2 πi/11. We identify the prime number n = 11 as optimal for balancing minimal redundancy with maximal topological protection, leveraging the arithmetic geometry of the modular curve X(11). We detail the construction of the syntrodynamic state, its stabilization via Floquet engineering, and the emergence of a π-spectral gap that provides exponential suppression of decoherence. Furthermore, we explore the Quantum Theory of Frequencies Information, where information is encoded in stable frequency modes.

Teleportation Syntrodynamics; Algebra Quantum Computing

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Teleportation Syntrodynamics; Algebra Quantum Computing is a unified mathematical framework that synthesizes teleportation syntrodynamics, quantum algebraic computation, and Lorentzian information geometry in string syntrodynamic theory applications. We assume that quantum information propagation is not transmission through spacetime but null-geodesic evolution on an 11-dimensional manifold $M_{11} \cong R^{1,3} \times X^7$, where X^7 admits G_2 or Calabi-Yau structure compatible with M-theory compactification.

The fundamental assumption is the Syntropy Algebra $C_{11,}$ a 13-dimensional real associative algebra with dual imaginary units i,j satisfying $j = i^{-1}$ and cyclic frequency generators $\{\omega_k\}_{k=1}^{11}$ forming Z_{11}. This algebra embeds into twistor space PT≈CP^3 via the Penrose transform, where quantum states become holomorphic sections and teleportation manifests as boundary-state synchronization enforced by the Master Stability Predicate $L_{teleport} \equiv \langle C_4 \rangle = 0$.

We argue that the topological locking security stems not from computational difficulty, but from the arithmetic rigidity of the Riemannian Zeta Spectral Guard ($R_\zeta > 0.95$) combined with the E8 automorphism symmetry of the C_{11}system via the McKay correspondence. The framework yields Infinite Finality for distributed ledger systems – where consensus is replaced by unique constraint satisfaction – and enables distance-independent quantum communication via the Null Twistor Vacuum.

Computationally, we implement a GPU-accelerated Syntropy Σ/QIPR/SQIPR simulator with novel metrics: the Syntropic Quantum Inverse Participation Ratio (SQIPR) and Syntropic Stability Index (SSI). The Boundary Field Interface v14.0 operationalizes the theory through Hepta-Modal Synthesis, monitoring real-time equilibrium via the Syntropic Norma ($N_{syn} \approx 0.5$) and grounding all reasoning in Bonded Science.

P7

Ergotropy Extraction Under Observational Constraints

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Coherent energy transfer in quantum systems plays an increasingly important role in emerging platforms such as quantum batteries and engineered many-body quantum systems. In this setting, ergotropy, the maximum work extractable from a quantum state via unitary operations, quantifies the operationally accessible energy stored in a quantum system. Standard formulations of ergotropy assume complete knowledge of the quantum state, allowing one to construct a globally optimal work-extraction unitary.

We instead consider the experimentally relevant setting in which one has access to many identical copies of an unknown quantum state, but only to a restricted set of coarse-grained measurements that one can perform on these copies. Such an observational constraint fundamentally limits the information we can obtain about the state and therefore the amount of extractable work. This raises the following questions: can one design an ergotropy extraction protocol that operates under restricted measurement access, and can such a protocol be realized on an existing experimental platform? In this poster, we present an observational ergotropy extraction protocol introduced in [1] and analyze the feasibility of its implementation within a trapped-ion quantum simulator architecture.

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Non-abelian string-breaking dynamics on a qudit quantum computer

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The Standard Model of particle physics underpins our understanding of fundamental interactions by describing the interplay of matter and forces through gauge theories. Yet, despite their huge success in studying a wide range of phenomena, the intrinsic quantum nature of gauge theories renders certain problems notoriously difficult to study. Particularly, real-time dynamics remain largely inaccessible to high-energy experiments and classical simulations. While quantum computers and simulators have recently made great progress in the simulation of abelian dynamics, more complex non-abelian theories, such as quantum chromodynamics, have proven to be extremely challenging. Here we demonstrate the use of a trapped-ion qudit quantum processor to study non-abelian string-breaking dynamics in a truncated SU(2) model. We experimentally demonstrate the coherent evolution of strings prepared in unbreakable configurations—leading to string oscillations, as well as breakable configurations—leading to gluonic (glueball) excitations. This highlights the potential of hardware-efficient and problem-tailored qudit quantum simulations for the field of high-energy physics.

Entropy flow in Programmable quantum heat engine

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We evaluate the entropy flows between two reservoirs mediated by a quantum chip. This chip in principle can be made up of multiple qubits connected in a complex manner. The goal is to find how the entropy flow to the probe reservoir can be controlled in a programmable manner by a quantum system which acts as a junction [1]. We study this problem for X-gate [2] and Cross-Resonance(CR)-gate setups. We compare and contrast the results. Both setups are seen to have advantages in different parameter regimes. Multi-world diagrams are seen to play a significant role in altering these results and hence their contributions can not be ignored. Negative differential entropy conductance (NDEC) is also observed and is shown to have different characteristics for each setup.

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P10

Angular Momentum Quantization in Two-Dimensional Charge-Flux Composites: A Quantum Electrodynamic Approach

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The fractional angular momentum, commonly referred to as "fractional spin," of a two-dimensional charge-flux composite is a foundational concept in the study of anyons and fractional statistics [1]. When derived from a standard semiclassical Hamiltonian, the kinetic angular momentum of such a system takes the fractional value $L_k = n\hbar - q\Phi/2\pi$. However, if the charge and magnetic flux are treated together as an isolated quantum system in free two-dimensional space, the fundamental rotational and reflection symmetries of the $O(2)$ group demand that the total net angular momentum be quantized in integer or half-integer units of $\hbar$.

In this work, we address this apparent theoretical discrepancy by adopting a full quantum electrodynamic (QED) framework, building upon recent studies on treating the locality problem in the Aharonov-Bohm effect [2]. We demonstrate that when the charge and flux interact via the vacuum electromagnetic field, the composite system possesses an intrinsic interaction angular momentum derived directly from Noether's theorem. This interaction component naturally incorporates both the localized field momentum and the hidden relativistic mechanical momentum.

Our formalism shows that this gauge-invariant interaction angular momentum exactly compensates for the fractional portion of the kinetic angular momentum. Consequently, the integer quantization rule for the net angular momentum of the isolated system is fully restored. Our approach clarifies that the conventionally accepted fractional spin corresponds to the expectation value of the kinetic contribution within the perturbed QED ground state. Ultimately, we demonstrate that the exotic fractional spin of two-dimensional charge-flux composites can be rigorously understood without abandoning fundamental spatial symmetries when the vacuum electromagnetic field is properly accounted for.

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A Coupled-Field Ontology for Entanglement, Spin, and Fermionic Structure

Doron Kwiat

Independent, Erez 17/2, Mazkeret Batya, Israel

We propose a real, local, deterministic coupled-field (CF) framework that provides an ontological underpinning for key quantum phenomena traditionally treated as axiomatic. Within this approach, quantum entanglement is not a primitive nonlocal feature but emerges from a shared internal phase structure established at pair creation and accessed locally at measurement. We show that this mechanism reproduces the exact singlet-state correlation while remaining fully consistent with Bell's theorem, whose constraints apply to preassigned discrete values rather than continuous internal degrees of freedom with deterministic response functions.

Crucially, entanglement appears here as the first experimentally constrained manifestation of a deeper coupled-field ontology. The same internal field structure naturally gives rise to spin-1/2 behavior, conserved charge as a Noether current, and a characteristic action scale identified with Planck's constant. In this sense, standard quantum mechanics is recovered as an effective formalism describing ensembles of coupled-field configurations, rather than as a fundamental ontology.

Although quantum mechanics preceded such a field-based description historically, the logical dependence appears to be reversed: the coupled-field framework explains why the quantum formalism works and clarifies the physical origin of phenomena that quantum mechanics postulates. This work suggests that fermions may be understood as structured dynamical entities composed of interacting real fields, offering a unified ontological account of entanglement, spin, and charge.

Coupled Real Fields as a Foundation for Spin, Entanglement, and Gravitation

Doron Kwiat

Independent, Erez 17/2, Mazkeret Batya, Israel

We present the Coupled Fields (CF) framework, a real-field, Lagrangian-based **ontological** approach to quantum phenomena in which spin, charge, entanglement, and gravitation emerge from the dynamics of two coupled real fields. Although the pair may be represented mathematically as a complex field, the formulation is fundamentally real and local. The interaction between the fields introduces an internal continuous phase degree of freedom associated with a U(1) symmetry and a conserved current.

In the CF model, spin 1/2 is not postulated as an intrinsic spinor property. Instead, the internal phase acts as a hidden but physical variable whose projection onto a measurement direction produces an **effective** SU(2) double-cover behavior at the level of observed correlations, yielding the characteristic $\cos^2\alpha$ angular dependence found in quantum experiments. For multiparticle systems, correlated internal phases established at the source lead to exact recovery of quantum entanglement correlations. The model remains local but explicitly contextual, thereby violating Bell inequalities via contextual response functions without invoking nonlocality.

Electric charge arises as a conserved phase current, with quantization following from topological constraints on admissible field configurations. The framework has also been extended consistently to curved spacetime, where spacetime curvature is sourced by the energy density of coupled fields rather than idealized point particles. In the weak-field limit, Einstein gravity is recovered, while curvature singularities are naturally avoided.

The CF framework reproduces established quantum predictions while offering a deterministic, physically transparent interpretation, and defines an open research program connecting real field dynamics, quantum phenomena, and gravitation.

Realization of Thread Level Parallelism on Quantum Devices

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Scaling up quantum devices is a central challenge for realizing practical quantum computation. Modular quantum architectures promise scalability, yet experiments to date have relied on either $\lesssim 10^3$-qubit monolithic chips or fragile interconnects with high loss. Here, we introduce a classical linkage scheme that merges multiple independent quantum processing units (QPUs) into a single logical device, enabling thread-level parallelism (TLP). Theoretically, we show that quantum routines with product-state inputs and low-rank entangling layers can be re-expressed in an efficient parallelizable form. Experimentally, we validate this architecture on clusters comprising up to sixteen benchtop nuclear magnetic resonance (NMR) quantum nodes. A four-qubit Greenberger-Horne-Zeilinger (GHZ) state is partitioned into parallel two-qubit subcircuits, achieving a fidelity of $93.8\,\%$ with respect to the ideal state. A non-Hermitian evolution, implemented via a truncated Cauchy integral on Hermitian Hamiltonians, reproduces exact observables with high accuracy. Our results demonstrate that classical links suffice to scale up the logical size of quantum computations and realize general, non-unitary channels on today's hardware, opening an experimentally accessible route toward software-defined, clustered quantum accelerators.

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Strong nonlinear thermoelectricity generation and close-to-Carnot efficient heat engines in Superconductor-Insulator-2D electron gas junctions

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The use of thermoelectricity in a cryogenic environment opens pathways for ultrasensitive passive detection and for control and cooling of quantum technology applications. We introduce the Superconductor-Insulator-2DEG junction [1] as a novel nonlinear thermoelectric element. We assess its potential via a fully nonlinear model where we consider the temperatures of both sides, T_S and T_{Sm}, and the conduction band edge of the 2DEG, E_c. Its band structure allows the formation of nonlinear thermoelectricity even for relatively small temperature gradients, enhancing the thermoelectric figures of merit. For $T_S>T_{Sm}$, we obtain a maximum Seebeck potential larger than the superconductor gap Δ_0, $V_S\sim6.75\ \Delta_0$ in the $E_c=0.03\ \Delta_0$ regime, and a maximum efficiency of $\eta=0.92\ \eta_c$ when used as a heat engine, close to the Whitney limit for efficiency at maximum power in nonlinear quantum systems [2]. For the relevant case $\Delta_0=200\ \mu$eV and tunnel resistance $R_t=1$ k Ω, we obtain a maximum Seebeck coefficient of $\sim$1 mV/K, a maximum Peltier current of $I_0\sim20$ nA, and a maximum output power of 4 pW for $T_S-T_{Sm}\sim0.9T_c$, with $T_c=1.3$ K. We discuss the causes and the implications for these large figures of merit, in particular, the impact of energy filtering on efficiency. In different regimes, the system also shows a large dV_S/dT_S and a bistability pattern, which show potential for detection and control applications, respectively. It also shows bidirectional cooling, being the first system to cool a superconductor via a tunnel junction without another superconductor.

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Two-qubit encoding strategy for a continuous quantum system

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Bosonic codes employ particular states of an infinite-dimensional Hilbert space to encode a qubit within a continuous quantum system. Despite the enormous resources available in a continuous quantum system [1], typical encodings only exist for single qubits [2]. Here we go one step further and present an encoding scheme for two qubits (four states), which protects against errors in small shifts of the canonical variables position q and momentum p. Furthermore, we present a universal set of single and two-qubit operations, based on particular symmetry operations for continuous quantum states represented by a square lattice in phase space.

To provide support for numerical calculations we present a self-built simulation package that can simulate quantum operations for a huge variety of continuous quantum systems on powerful HPC hardware as well as on a local pc. Our software does support many well-known codes like GKP or cat codes. Moreover it offers several predefined gates for simulating operations acting on single and composed quantum systems and allows, in particular, the coupling of discrete to continuous systems.

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Modeling dissipation and decoherence in qubit systems via the spin-boson model

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The usual approach to studying the dynamics of an open quantum system is to use a quantum master equation (QME) with Markovian evolution and weak coupling, leading to the Redfield or Lindblad equations [1]. However, in the presence of strong coupling or a strong driving field, the Markovian time evolution may no longer be valid.

We model a qubit coupled to an environment using the spin-boson model and examine the effects of strong coupling and driving pulses on the system's dynamics. The pulses represent laser pulses used in the implementation of gate operations between qubits in quantum computers [2]. We investigate how strong system-bath coupling influences both the adiabatic preparation of the coupled equilibrium state and the subsequent nonequilibrium dynamics after the two-level system is driven out of equilibrium. We find that the adiabatic preparation time depends on the specific observable used to assess convergence: when the ground-state energy is the target, the required switching time increases monotonically with coupling strength, whereas for local observables such as Pauli matrix expectation values, the behavior can appear non-monotonic. Starting from this prepared coupled state, we then track the system's nonequilibrium evolution and relaxation under driving, highlighting how strong coupling controls the post-drive dynamics [3].

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Majorana Signatures in Quantum Dot-Topological Superconductor Junctions with Electron-Phonon Coupling

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We theoretically study quantum transport through a quantum dot coupled to Majorana bound states confined at the ends of a topological superconducting nanowire. The topological superconductor forms a loop and is threaded by a tunable magnetic flux, which allows one to control the electron transport in the system. In particular, we investigate phonon-assisted transport properties in the device when the central quantum dot interacts with a single long-wave optical phonon mode. We find that when the two Majorana bound states are unhybridized, the zero-temperature linear conductance has a $2\,\pi$ periodicity as a function of magnetic flux phase, independent of the electron-phonon interaction, the quantum dot energy, or the finite values of dot-Majorana couplings. For a finite overlap between the Majorana bound states, the linear conductance periodicity generally changes to $4\,\pi$ either due to a finite electron-phonon coupling strength, or a dot energy level that is tuned away from the Fermi level. Additionally, the differential conductance periodicity changes from $2\,\pi$ to $4\,\pi$ when the Majorana bound states hybridize and the electron-phonon coupling is finite. Our results provide insight into transport signatures expected in topological quantum computational platforms that integrate quantum dots as a means for Majorana qubit readout. The energy exchange with an environmental bath, here a single phonon mode, significantly alters the current signatures expected from Majorana modes [1].

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Tunneling-current signatures of phonon effects in quantum dot-Majorana nanowire junctions

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We propose a realistic nanodevice formed by embedding of a quantum dot between two conducting leads via symmetrical tunnel junctions in the presence of electron-phonon interaction. The quantum dot is coupled to one of the ends of a Majorana nanowire, which leads to probe Majorana bound states under conditions where the influence of an environmental bath, modeled here by a single long-wave optical phonon mode, on the tunneling current characteristics is considered. To analyze the transport characteristics of the nanojunction, a combination of the nonequilibrium Green's function technique with a canonical transformation has been employed. The corresponding retarded Green's functions have been determined by applying the equation of motion method. The behavior of the current vs. gate voltage, the current vs. bias voltage and the current vs. quantum dot-Majorana coupling characteristics is studied for an experimentally relevant parameter range. We demonstrate that the tunneling current is sensitive to, and depends non-trivially on the parameters of the dot-Majorana setup, in the regime of low voltages combined with low temperatures. The current-bias voltage curves present a step-like structure in the presence of electron-phonon coupling due to the phonon-assisted tunneling through the dot. We hope that our quantum dot-based setup can serve as a possible platform for future Majorana detection experiments [1].

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Amplification and generation bounds of gravity-induced entanglement

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The unification of gravity and quantum mechanics remains incomplete, and the possibility that gravity is fundamentally classical has not yet been ruled out. In recent years, gravity-induced entanglement in the low-energy Newtonian regime has attracted considerable attention as a possible sigature of the quantum nature of gravity. Since such entanglement cannot be generated by a purely classical gravitational interaction, its observation could provide evidence that gravity follows quantum mechanics.

In this work, we discuss both the amplification of gravity-induced entanglement and a universal bound governing its generation [1]. Several schemes have been proposed to enhanced gravity-induced entanglement, including approaches based on mediator systems and unstable potentials. Here, we propose an amplification method using a pulsed optomechanical system. In the pulsed regime, the quantum state of a mechanical oscillator can be swapped with that of an optical mode, allowing one to prepare the mechanical oscillator in a highly nonclassical state. we show that using such a state can amplify the amount of gravity-induced entanglement.

While this method increases the amount of entanglement, the condition for entanglement generation is determined by the competition between thermal noise and the gravitational interaction, and no example exceeding this bound has been found. We therefore demonstrate that this bound is universal for the initial two-mode Gaussian states and Fock states. We also clarify the same universal bound holds for non-Gaussian dynamics and even in the presence of a mediator [2].

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Fast and reliable quantum state tomography

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Quantum computing, communication, and sensing technologies rely on precise knowledge of quantum states, that cannot be directly measured. Quantum state tomography (QST) reconstructs these states from indirect measurements by minimizing the statistical discrepancy between experimentally observed data and predictions from quantum theory. This optimization problem is nonlinear and subject to physical constraints on the states. We present a Julia implementation that efficiently and robustly minimizes this statistical distance while enforcing the physical constraints. Our work provides a practical, extensible toolkit for QST and a comparative guide to choosing optimizer based on accuracy, speed, and robustness. Our approach minimizes a residual between predicted and measured statistics and supports both least-squares and log-likelihood formulations. Physical constraints are enforced through Cholesky parameterization or projection methods. We benchmark on simulated data several optimization strategies, like projected Gauss-Newton, L-BFGS, and trust-region solvers. The benchmarks evaluate reconstruction accuracy, scaling with the number of qubits, convergence speed, and stability, offering practical guidance for selecting optimizer in QST applications.

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Microwave response of fractional quantum Hall droplets with quasiparticle tunneling

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The study of anyonic excitations in the edge states of fractional quantum Hall (FQH) systems has been pursued for many years [1,2], and recent research has made significant progress in probing their statistical properties [3,4]. So far, the statistics of anyons have mainly been investigated through measurements of edge currents and current noise. A new measurement scheme has been proposed that utilizes the interaction between microwaves and an isolated FQH droplet without employing lead contacts [5]. In this setup, microwave radiation is absorbed when the incident frequency resonates with the edge modes, resulting in measurable changes in the amplitude and phase of the transmitted signal. Furthermore, it has been proposed that the statistical properties of anyons could be probed by introducing a quantum point contact (QPC) and performing microwave spectroscopy.

In this study, we numerically evaluate the microwave response of the edge states using quantum Monte Carlo simulations that incorporate nonperturbative effects of inter-edge scattering, and compare the results with analytical calculations based on second-order perturbation theory in the inter-edge coupling strength [6]. Our analysis focuses on the shift of the resonance peak position and the linewidth of the microwave absorption spectrum.

Using this approach, we capture experimentally relevant features not addressed in previous work [5], including coupling-strength-dependent peak shifts and temperature-induced changes in the linewidth. Moreover, we find that higher-order effects become more pronounced as the Landau-level filling factor decreases, leading to enhanced peak shifts and related spectral features [6].

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Classical-Quantum Gravity as an Open Quantum System: Dilations, Decoherence and Conservation Laws

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Whether gravity must be quantized remains one of the central open questions at the interface of quantum foundations, open-system dynamics, and tests of quantum gravity. Classical-quantum hybrid theories have recently attracted attention as a possible framework in which gravity remains classical while interacting consistently with quantum matter. Schemes based on completely positive dynamics satisfy most formal consistency requirements: they preserve positivity, incorporate irreversibility and stochasticity, avoid finite-time breakdown, and enable a systematic treatment of quantum backreaction. At the same time, they invite the question of whether the hybrid description is fundamental or instead an effective sector of a larger quantum theory.

Here, we show that classical-quantum gravity based on completely positive dynamics admits a fully quantum realization on an enlarged Hilbert space. In this construction, the classical variable is represented by a commutative pointer algebra, and the hybrid evolution arises as the diagonal, operationally classical sector of a completely positive trace-preserving quantum channel, equivalently admitting a Stinespring unitary dilation. This is not a canonical quantization of the classical phase space; rather, it identifies the hybrid theory as a reduced open-system description with an imposed restriction on accessible observables.

As a complementary illustration, we consider a qubit interacting with a classical particle and demonstrate that the corresponding hybrid system violates angular momentum conservation despite rotational symmetry of the underlying equations of motion. This provides an explicit example of a fully closed, rotationally invariant classical-quantum system with completely positive dynamics that violates a conservation law. The results show that completely positive classical-quantum gravity can be embedded naturally within the framework of open quantum systems, while also demonstrating that formal consistency and symmetry alone do not guarantee the conservation laws expected of a closed physical theory.

Coherent Andreev Reflection in Stress-Engineered Nb / Bi_2Se_3 Vertical Mesoscopic Junctions

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We probe Andreev reflection at an s-wave superconductor / three-dimensional Topological Insulator interface, a mesoscopic platform for proximity-induced unconventional pairing on spin-momentum-locked surface states [1,2]. Sputter-stress-engineered Nb survives multi-step lithography on MBE-grown Bi_2Se_3 while preserving bulk Nb superconductivity, yielding vertical four-probe Nb/Bi_2Se_3 junctions. The R-T shows the bulk Nb transition near 7.5 K and a lower-temperature crossover near 5.8 K below which the dI/dV spectra develop strongly enhanced Andreev-reflection features; we interpret this enhancement as the vertical transport path turning into a single effective coherent Andreev channel. A modified-BTK analysis of this regime yields an interface barrier $Z < 0.5$, indicating a clean, highly transparent Nb/Bi_2Se_3 interface enabled by stress-controlled, in-situ growth of the Nb layer.

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A Relativistic Extension of Stochastic Electrodynamics

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Based on the approach to quantization of Cetto's et al. [1-4], we develop a relativistic extension of stochastic electrodynamics. The proposed framework reproduces the relativistic quantum theory in appropriate limits and enables the systematic study of quantum phenomena of relativistic origin. Our formulation is based on the Lorentz-covariant, canonical description of the particle-field system provided by the multisymplectic Hamiltonian formalism [5-7] and relies on a generalized Poisson bracket that yields a unified description of the system [8]. We show that in the stationary regime the particle's canonical variables can be expressed as a Fourier expansion in terms of the field's normal modes, rendering the particle dynamics fully driven by the field. This assigns a new kinematic meaning to the associated Poisson bracket, forming the basis of our relativistic generalization of stochastic electrodynamics [9]. The results suggest a physical basis for the replacement of phase-space functions by operators in quantum theory and contribute toward a Lorentz-covariant formulation of canonical quantization.

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Bringing light to the Landau-Lifshitz-Gilbert equation: Optically induced magnetic inertia and magnons

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The Landau-Lisfhitz-Gilbert (LLG) equation has been the cornerstone of modeling the dynamics of localized spins, viewed as classical vectors of fixed length, within nonequilibrium magnets. When light is employed as the nonequilibrium drive, the LLG equation must be supplemented with additional terms that are usually conjectured using phenomenological arguments for direct opto-magnetic coupling between localized spins and (real or effective) magnetic field of light. However, direct coupling of magnetic field to spins is $1/c$ smaller than coupling of light and electrons; or both magnetic and electric fields are too fast for slow classical spins to be able to follow them. Here, we displace the need for phenomenological arguments by rigorously deriving an extended LLG equation via Schwinger-Keldysh field theory (SKFT). Within such a theory, light interacts with itinerant electrons, and then spin current carried by them exerts spin-transfer torque onto localized spins, so that when photoexcited electrons are integrated out we arrive at a spin-only equation. Unlike the standard phenomenological LLG equation with local-in-time Gilbert damping, our extended one contains a non-Markovian memory kernel whose plot within the plane of its two times arguments exhibits fractal properties. By applying the SKFT-derived extended LLG equation, as our central result, to a light-driven ferromagnet as an example, we predict an optically induced magnetic inertia term. Its magnitude is governed by a spatially nonlocal and time-dependent prefactor, leading to the excitation of coherent magnons at sharp frequencies in and outside of the band of incoherent (or thermal) magnons.

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Hanbury Brown-Twiss Interferomter in ν=2/5 Fractional Quantum Hall Effect

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The fractional quantum Hall effect (FQHE) provides one of the most celebrated arenas for emergent quasiparticles with fractional charge and anyonic exchange statistics, whose direct detection remains experimentally challenging [2-4]. In conventional Fabry-Pérot and Mach-Zehnder interferometers, single-particle Aharonov-Bohm phases are generally mixed with charge, statistical, and edge-structure effects, obscuring a direct extraction of the statistical angle.

An alternative approach is provided by two-particle interferometry, pioneered in mesoscopic conductors through Hanbury Brown-Twiss (HBT) experiments [5]. Campagnano *et al.* [6] have proposed an anyonic HBT interferometer for a single-mode edge, showing that the cross-correlation of currents can reveal the fractional nature of the tunneling excitations even when single-particle coherence is suppressed. However, the HBT concept has not yet been extended to hierarchical states with multiple co-propagating edge modes. A similar design principle was adopted in MZ setups for the $\nu = 2/5$ Jain state [7]. Extending the HBT geometry to such hierarchical edges thus opens a new route to probing the properties of fractional quasiparticles in multi-mode edge systems.

Motivated by these considerations, we propose a Hanbury Brown-Twiss interferometer built on a $\nu = 2/5$ fractional quantum Hall edge [8]. In contrast to previous FP/MZ schemes, the flux-dependent signal in our geometry arises purely from two-particle interference processes involving tunneling at all four QPCs. We derive an analytic expression for the flux-dependent cross-correlation of the drain currents.

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Finite-Size Bosonization of the Fractional Quantum Hall Edge: Optical Response of an Isolated Ring and DC Transport through an Antidot

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Fractional quantum Hall (FQH) edge states are a prototypical realization of chiral Luttinger liquids, and their low-energy dynamics are commonly described within bosonization theory [1-3]. While this framework has been highly successful for extended edges, many experimentally relevant systems involve mesoscopic geometries, such as ring-shaped edges and antidot structures, in which finite circumference, compactness, and zero modes become essential to observable quantities. In particular, isolated ring geometries provide a natural setting for studying the optical response of a finite FQH edge [4,5], while antidot devices offer a controlled platform in which charging effects, enclosed magnetic flux, discrete edge excitations, and anyon-related phase effects may influence measurable transport characteristics [6-9]. A theoretical framework that consistently incorporates such finite-size effects as well as finite-temperature effects is therefore important for connecting effective edge theory with measurable signatures in confined FQH systems.

In this work, we develop a finite-size bosonization framework for the fractional quantum Hall edge at finite temperatures. In contrast to the standard treatment for an infinitely extended edge, a finite geometry requires a careful treatment of compactification and zero modes, which play a central role in mesoscopic observables. By expressing finite-size and finite-temperature contributions exactly in terms of Jacobi theta functions, our formulation provides a unified low-energy description of edge excitations in closed geometries and allows both linear and nonlinear optical responses, as well as transport observables, to be evaluated in closed analytic form.

Using this approach, we study the optical response of an isolated ring, including both the linear electrical polarization susceptibility and the nonlinear optical response, and analyze how the discrete mode structure of the finite edge appears in these observables. For the isolated ring, we find that while the linear optical response exhibits peak shifts reflecting quasiparticle tunneling, the nonlinear optical response is nonzero only in the presence of tunneling, thereby isolating the tunneling-induced contribution. The combination of these two responses is expected to provide a route to extracting the anyonic statistics of fractional quantum Hall quasiparticles. For the antidot geometry, we demonstrate that the crossover from Coulomb-blockade-dominated sequential tunneling to coherent resonant tunneling and cotunneling can be systematically controlled by tuning the antidot size.

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Fully autonomous model of a mechanical Maxwell demon engine

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We present a fully autonomous model of a mechanical Maxwell demon engine that converts heat absorbed by a qubit into population inversion in an attached quantum battery. A damped mechanical oscillator acts as a pointer that incorporates the essential demon function of information acquisition about the qubit state and subsequent feedback into the system dynamics, replacing external measurements and control operations. This is achieved by means of a Holstein-type Hamiltonian, which makes the pointer's equilibrium position depend on the qubit state and thereby induces a state-dependent resonance shift. The mechanism enables a selective energy transfer to an attached spin system that acts as the quantum battery. We derive both local and global Lindblad master equations for the coupled system and identify the parameter regimes in which the engine operates efficiently. The figure of merit is the resulting steady-state population inversion of the battery, quantified in terms of ergotropy. Based on these results, we discuss the necessary conditions for practical implementations of the demon engine on realistic experimental platforms.

Recurrence in Quantum Stochastic Walks

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Interplay between quantum interference and classical randomness can enhance performance of various quantum information tasks. We analyze recurrence phenomena in the discrete-time quantum stochastic walk on a line, which is a quantum stochastic process that interpolates between quantum and classical walk dynamics [1]. Surprisingly, we find that introducing classical randomness can reduce the recurrence probability — despite the fact that the classical random walk returns with certainty — and we identify the conditions under which this intriguing phenomenon occurs [2]. Numerical evaluation of the first-return generating function [3] allows us to investigate the asymptotics of the return probability as the step number approaches infinity. This provides strong evidence that the suppression of recurrence probability is not a transient effect but a robust feature of the underlying quantum-classical interplay in the asymptotic limit. Our results show that for certain tasks discrete-time quantum stochastic walks outperform both classical random walks and unitary quantum walks.

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Maximum-Likelihood Quantum Tomography beyond Petz Recovery

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The Petz recovery map is a leading candidate for a quantum analogue of Bayes' theorem, providing a generalized reversal of noninvertible quantum channels. In the classical setting, Jacobs showed that the Bayes-Jeffrey update always improves the prior by decreasing its divergence from the observed distribution. We prove an analogous monotonicity result for quantum-to-classical channels, a setting closely related to POVM measurements. This result leads naturally to a fixed-point iterative algorithm for full quantum state tomography. For general quantum channels, we show that the Petz recovery map requires a correction, and we propose a modified update governed by the inverse Kubo-Mori operator.

Quantum Heat across Capacitively Coupled Quantum Dots

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Thermal transport in the quantum coherent regime has attracted significant attention, particularly in studies of various quantum heat engines [1,2] and measurement processes [3]. While most heat carriers are bosonic excitations, purely electronic heat currents in the absence of charge currents remain relatively unexplored. Theoretical studies have examined capacitively coupled quantum dots (QDs), each tunnel-coupled to a reservoir in local thermal equilibrium [4-7]. Most of these results can be understood without invoking quantum coherence.

In this work, we extend this model to investigate quantum effects on heat transport in a capacitively coupled QD system. Our system consists of three QDs: two arranged in parallel, each tunnel-coupled to a left reservoir, and a third QD tunnel-coupled to a right reservoir. The left and right QDs are capacitively coupled without direct tunneling. We evaluate the heat current using non-equilibrium Green's functions with the equation-of-motion method as a function of the temperature difference, for various values of the energy-level difference δ between the two left QDs. The capacitive coupling energy between the left QDs and the right QD is set to U.

If the two left QDs are closely spaced and their energy difference δ is smaller than the level broadening Γ, indirect quantum coherence via the left reservoir can be established [8]. We phenomenologically characterize the strength of this coherence using a parameter α. This coherence is suppressed by increasing δ or by introducing asymmetry in the capacitive coupling energies to the right QD, which can be interpreted as an effective measurement of the left QDs by the right QD.

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Ultrafast optical excitation of magnons in 2D antiferromagnetic semiconductors via spin torque mediated by unbound electron-hole pairs and excitons: Signatures in magnonic charge pumping

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Recent experiments observing how femtosecond laser pulse (fsLP) excites magnons in two-dimensional (2D) antiferromagnetic (AF) semiconductors—such as CrSBr, $NiPS_3$, and $MnPS_3$, or their van der Waals heterostructures—suggest an important role played by excitons. However, microscopic details of such an effect remain obscure, as resonant coupling of magnons, living in the sub-meV energy range, to excitons, living in the ~ 1 eV range, can hardly be operative. Here, we develop a quantum transport theory of this effect, in which the time-dependent nonequilibrium Green's function (TDNEGF) for electrons driven by fsLP is coupled self-consistently to the Landau-Lifshitz-Gilbert (LLG) equation describing classical dynamics of localized magnetic moments (LMMs) residing on magnetic atoms of 2D AF semiconductors. This theory explains how fsLP, of central frequency *above* the semiconductor gap, generates a photocurrent that becomes spin-polarized due to the background of LMMs, which, in turn, exerts spin-transfer torque (STT) onto LMMs as a genuinely nonequilibrium spintronic mechanism. By analyzing the collective motion of LMMs via the windowed Fast Fourier transform (FFT), we extract frequencies of excited magnons, as well as their lifetime governed by *nonlocal* damping with the LLG equation due to (explicitly included via TDNEGF) electronic bath. The TDNEGF part of the loop can also include excitons, which is achieved in the present study by utilizing the off-diagonal elements of the nonequilibrium density matrix as the mean-field treatment of Coulomb-binding of electron-hole pairs into excitons. Finally, our theory makes it possible to predict that excited magnons will *pump* time-dependent charge currents into the attached electrodes, or locally within the 2D AF semiconductor, thereby emitting electromagnetic radiation. The windowed FFT of these two signals contains imprints of excited magnons, as well as the possible presence of excitons, which could be exploited as a novel probe in future experiments.

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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 and in 2025. 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 ‘Wallenstein Palace and St.Nicholas Church’.
Special tram will depart from the Pyramida Hotel to the Malostranská station on Monday afternoon to facilitate FQMT’26 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 ‘Wallenstein Palace and St.Nicholas Church’.

St. Nicholas Church

The **St. Nicholas Church** (chrám svatého Mikuláše) is located in Prague’s Lesser Town at the Lesser Town Square. This church is the most famous Baroque church in Prague and belongs to the most valuable Baroque buildings north of the Alps. Its was designed by members of the famous family of Baroque architects, Dientzenhofer, mostly in the first half of 18th century. High-Baroque facade of the church exhibits strong dynamic effect dominated by alternating concave and convex forms. The interior of the church has impressive dimensions: the dome diameter is 20 meters while the interior height, measured to the top of the lantern, reaches nearly 57 meters; it is the tallest interior in Prague. At the same time, the interior ranks the second in Prague, just behind St. Vitus Cathedral, in terms of the most beautiful sacral architecture.

The St. Nicholas Church features two historical organs, the great organ in the main gallery and a smaller one in the side gallery. The great organ was built between 1745 and 1747 and was played, among others, by W.A. Mozart during his stays in Prague. The organ has been recently restored; the FQMT’26 participants will listen one of the first concerts on this instrument after its restoration.

How to get there:
The St. Nicholas Church is situated in the Prague Lesser Town (Malá Strana) and its entrance can be reached from the west part of the Lesser Town Square (Malostranské náměstí, see also map Wallenstein Palace and St. Nicholas Church). Warning! Do not confuse this church with the church of the same name located on the Old Town Square.

On Wednesday, a special tram will depart from the Pyramida Hotel to a suitable tram stop to facilitate FQMT’26 participants transfer. The church can also be reached from the Pyramida Hotel by regular public transport, namely, tram No 22 or 23 to the Malostranské náměstí stop (don’t be confused by the similar name of the Malostranská stop - Malostranské náměstí is the following stop). From the tram stop, head in the direction the tram was going and turn right twice; you will reach the entrance to St. Nicholas Church within 3 minutes.

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.

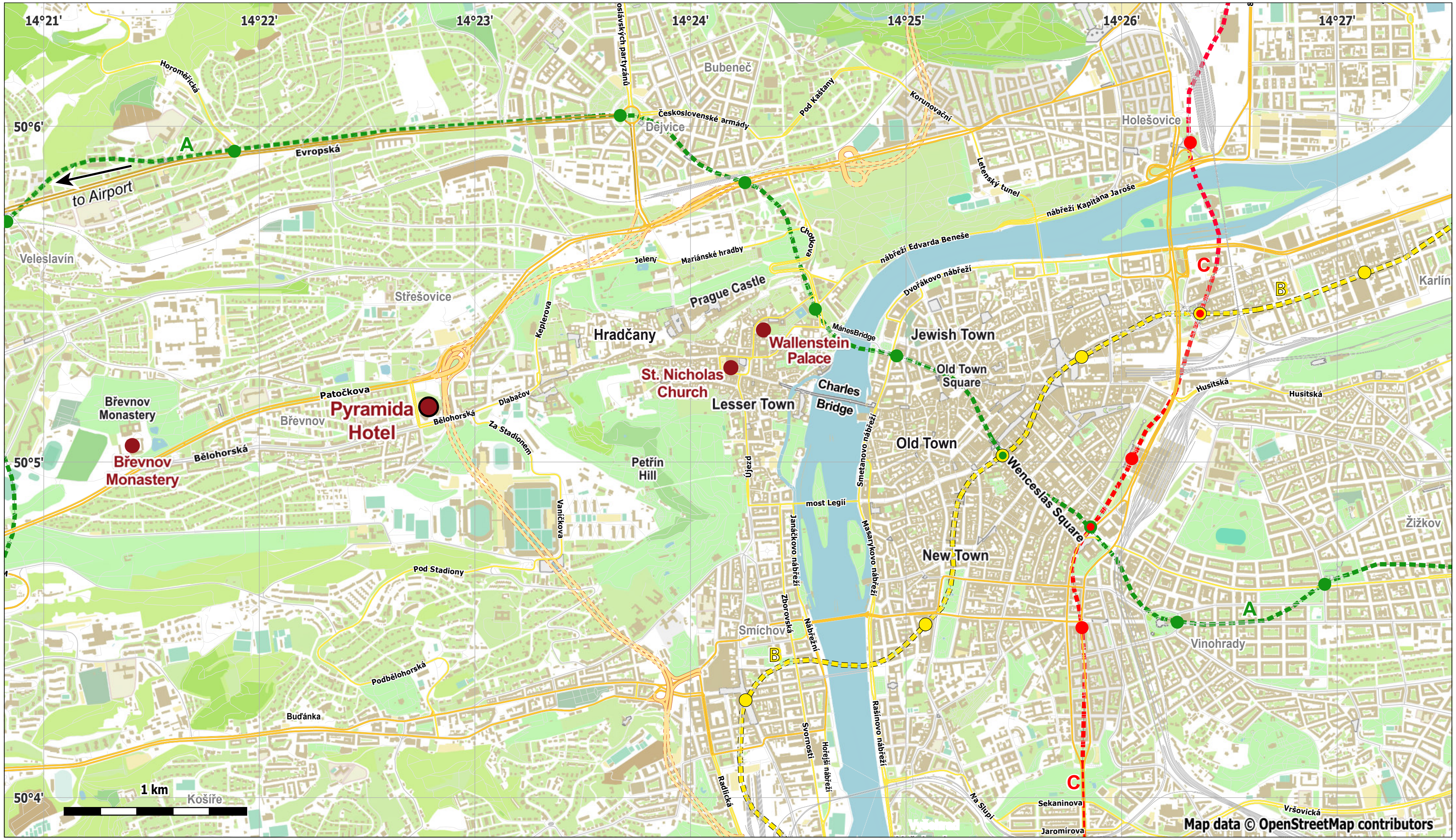
The interiors of the Břevnov Monastery are decorated by valuable paintings; e.g. in the former ceremonial hall of the monastery, nowadays called Theresian Hall, there is a ceiling painting the Miracle of the Blessed Gunther painted by Kosmas Damian Asam of Bavaria in 1727. This is one of the best preserved 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'26 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.

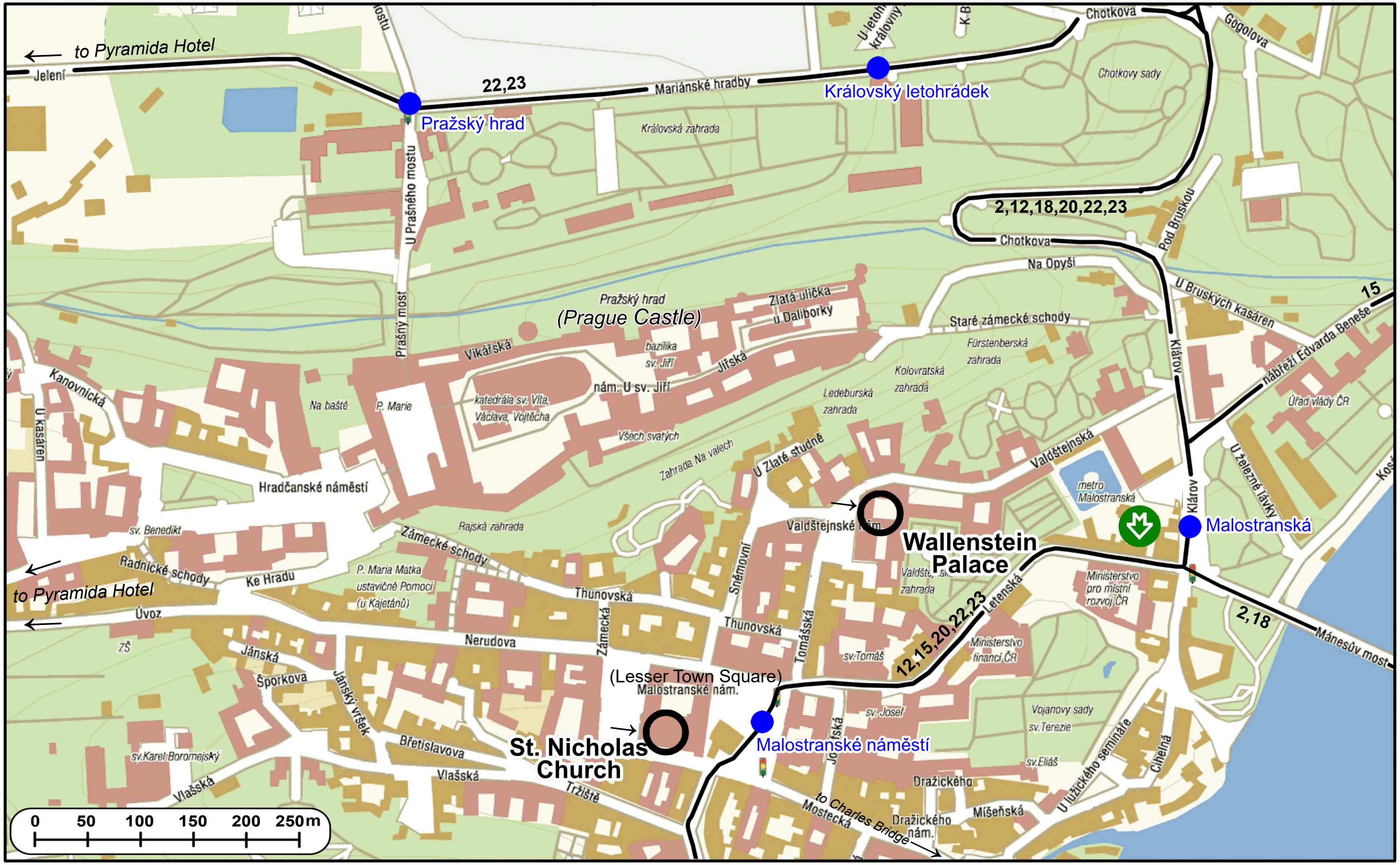
Maps

Prague center



Old Town	*Historical part of Prague*	Pyramida Hotel	*FQMT'26 conference site*	A	*Underground (metro) line with line label and station*
Petřín Hill	*Important historical or interesting place*	Wallenstein Palace	*FQMT'26 related place*	B	
Břevnov	*Other part of Prague*			C	

Wallenstein Palace and St. Nicholas Church neighborhood



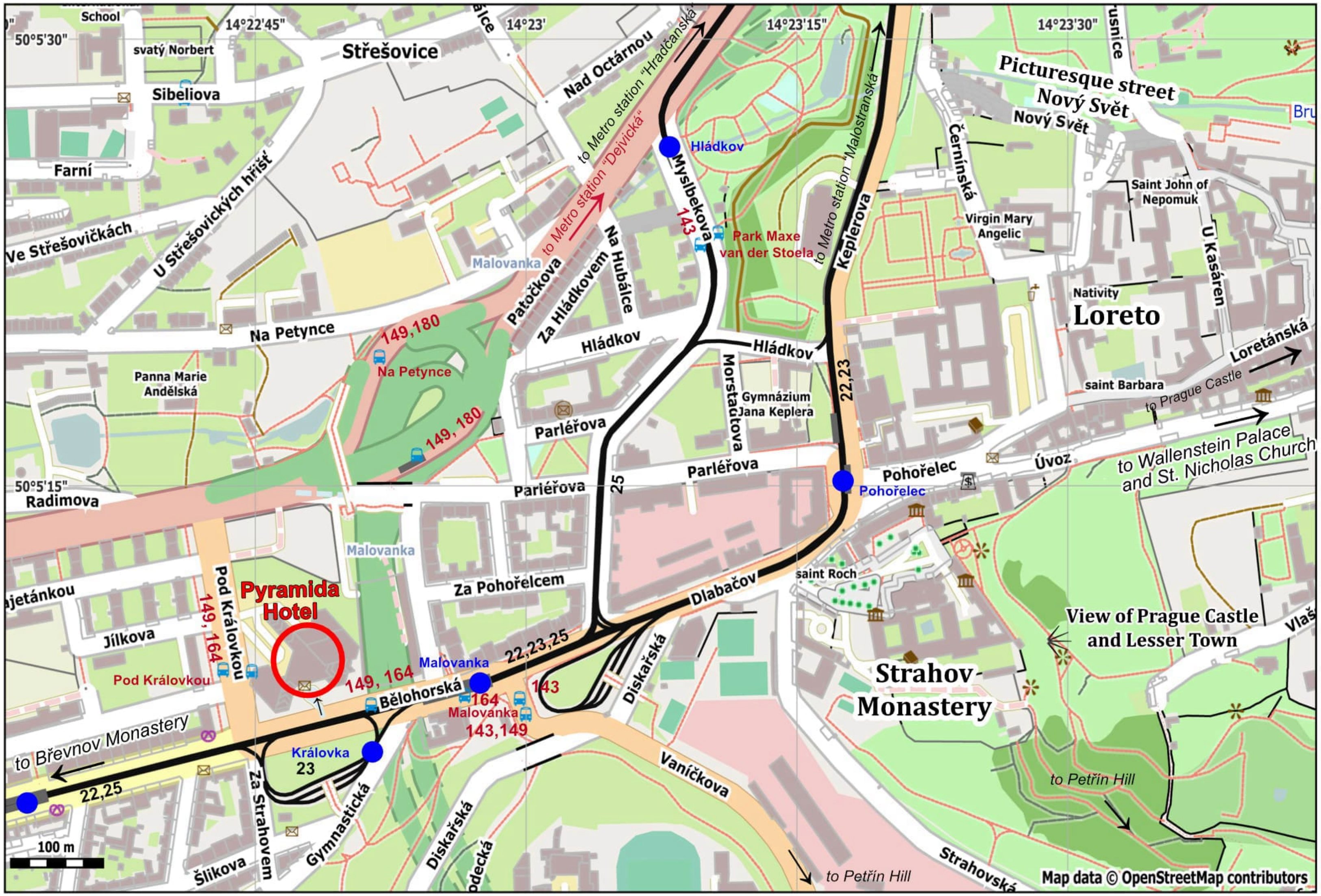
22,23 Tram line with line numbers

Tram stop

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

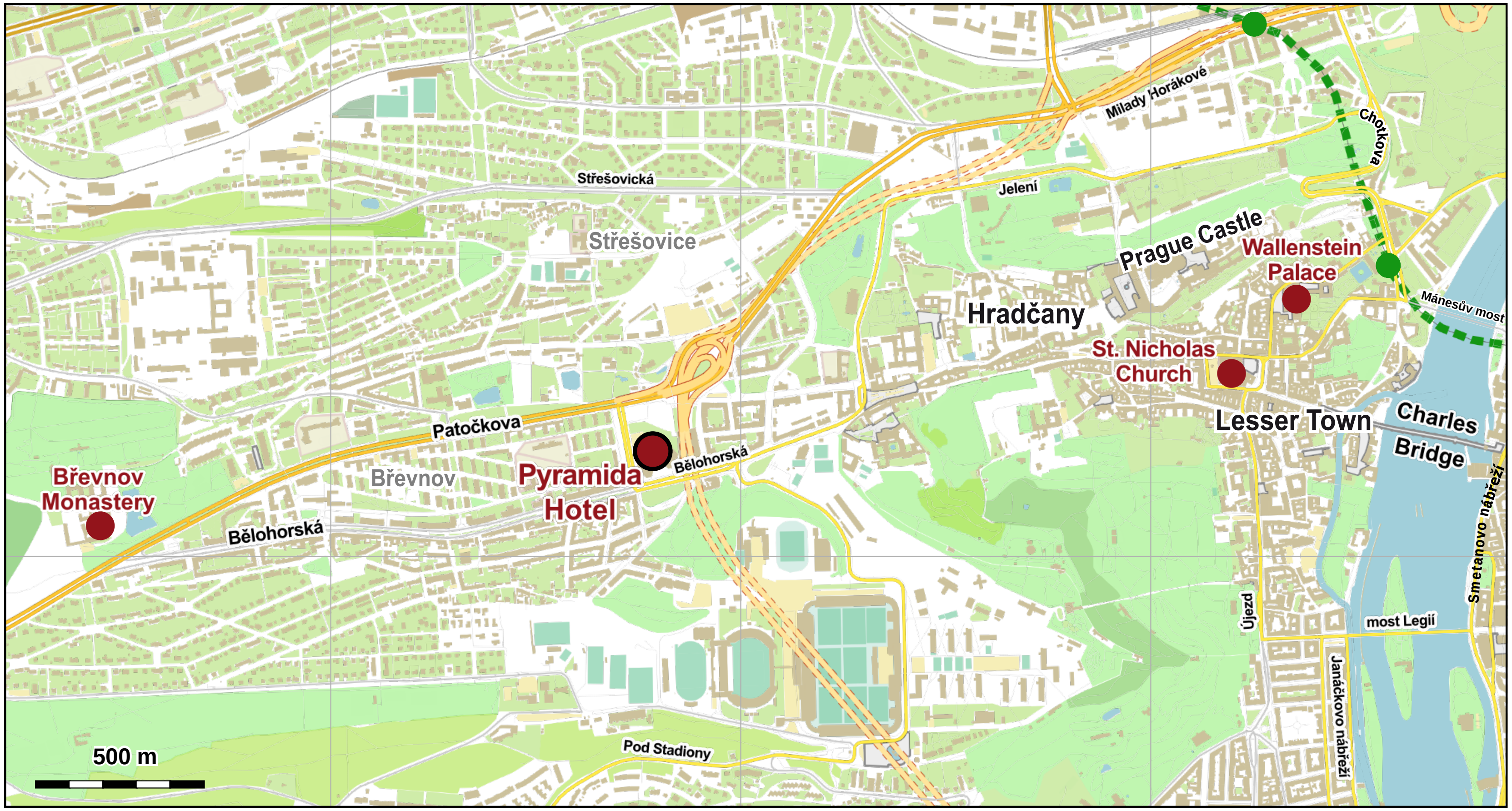
FQMT'26 relevant places

Pyramida Hotel - access and nearest neighborhood



22,25	Tram lines with line numbers
Malovanka	Tram stop with stop name
149, 180 Na Petynce	Bus stop with line numbers and stop name
Loreto	interesting place near the Pyramida Hotel
	FQMT'26 main conference site

Pyramida Hotel neighborhood



Map data © OpenStreetMap contributors

Lesser Town	*Historical part of Prague*	Pyramida Hotel	*FQMT'26 conference site*		*Underground (metro) line A with a station*
Charles Bridge	*Important historical or interesting place*	Wallenstein Palace	*FQMT'26 related place*		
Střešovice	*Other part of Prague*				