Frontiers of Quantum and Mesoscopic Thermodynamics

(online conference)

18 - 24 July 2021, Prague, Czech Republic

Under the auspicies of

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

Supported by

- Committee on Education, Science, Culture, Human Rights and Petitions of the Senate of the Parliament of the Czech Republic
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- Department of Physics, Texas A&M University, USA
- Quantum Optics Lab at the BRIC, Baylor University, USA
- Institut de Physique Théorique, CEA/CNRS Saclay, France

Topics

- Non-equilibrium quantum phenomena
- Dissipation, dephasing and noise
- Quantum statistical physics and thermodynamics
- Foundations of quantum physics
- Quantum measurement, entanglement and coherence
- Many body physics, quantum field theory
- Light matter interactions, quantum optics
- Physics of quantum information and computing
- Topological states of quantum matter, quantum phase transitions
- Macroscopic quantum behavior
- Atomic physics, cold atoms and molecules
- Mesoscopic, nano-electromechanical and nano-optical systemss
- Molecular motors, quantum heat engines
- Biological systems
- Cosmology, gravitation and astrophysics

Scientific Committee

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

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Preface

FQMT'21 is a follow-up to the seven previous, successful Prague conferences "Frontiers of Quantum and Mesoscopic Thermodynamics" (FQMT'04, FQMT'08, FQMT'11, FQMT'13, FQMT'15, FQMT'17, and FQMT'19). For the details of their programs and the history of the FQMT conferences see the www pages https://fqmt.fzu.cz/. The contributions from the previous conferences have been published in Physica E (vol. 29, issues 1-2, 2005, and vol. 42, issue 3, 2010), Physica Scripta (vol. T151, 2012), Fortschritte der Physik (Progress of Physics, vol. 65, issue 6-8, 2017), and European Physical Journal-Special Topics (vols. 227, issue 15-16, 2019 and 230, issue 4, 2021).

Due to the well known circumstances, the FQMT'21 is the first fully virtual (online) FQMT conference, which, of course, can only partly replace the originally planned in person conference. Thus we hope the FQMT'22 conference will be possible to be held in Prague as an in-person conference in the summer 2022.

The present (FQMT'21) conference will be focused on a better understanding of the behavior of quantum systems out of equilibrium. To reach this aim we also need to improve our understanding of foundations of quantum physics, quantum many body physics, statistical physics, and thermodynamics relying on the theoretical and experimental methods of condensed matter physics and quantum optics. The systems considered will be mainly on the order of mesoscopic (nanoscale) size, and include those of both natural and artificial origin. Special attention will be given to non-equilibrium quantum systems, physics of quantum information and manifestation of quantum effects in biological systems. Subjects from astrophysics, gravitation or cosmology related to the above scope will also be included.

Following the tradition of the FQMT conferences, FQMT'21 will attempt to bring together, even under the extraordinary conditions of the pandemic, a unique combination of both young and experienced scientists across a disciplinary spectrum covering the above mentioned topics. The interdisciplinary character of the conference will be supported by the choice of key speakers who, apart from their specializations, are not only able to report specific results within their fields, but are also able to discuss the state of the art of their fields from the standpoint of a broader perspective of overlap with other fields. It is an objective to gather important scientists from overlapping branches of physics who can mutually benefit from the exchange of different views and ideas, experiences from studies of many different systems and various theoretical and experimental approaches to the study of current problems in physics. It is intended that this arrangement of the scientific program of the conference will again significantly contribute to the formulation of challenging questions and problems, as well as their related answers that are nowadays essential to improve the understanding of the foundations of quantum physics, many body physics, quantum statistical physics of systems far from equilibrium, the physics of nanoscale and biological systems, and further, will motivate new collaboration and intensive discussions between experts from differing fields of physics, chemistry, and biology.

Thus, as in the foregoing FQMT conferences, the aim of FQMT'21 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.

In keeping with the multidisciplinary character of the scientific program and the tradition of the previous FQMT conferences, the FQMT'21 program will feature two online concerts of classical music performed by world-class musicians. The first concert will be played in Václav Trojan's studio on piano of his father, a legendary Czech composer Václav Trojan, the second one will be held at an outstanding venue, St. Vitus Cathedral of the Prague Castle. We believe that both online and in-place (Czech and several foreign participants in the case of the concert from the cathedral) will enjoy these exceptional events.

Dear colleague, we welcome you to the FQMT'21 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

Contact address

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Emergency phone numbers (free calls):

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

Conference site

Online conference management and informal discussion meeting will take place at:
Pyramida Hotel
address: Bělohorská 24, Praha 6, phone: +420 233 102 111

Conference sessions

All conference sessions will be held online. See the conference program for details.

Social events

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'21 program will feature two concerts performed by world-class musicians. While the first concert will take place in a private studio the other one will be held at the outstanding venue of the city, the Gothic Cathedral of St. Vitus at Prague Castle (one of the symbols of the Czech Lands). Both concerts will be transmitted on the internet.

- Classical and jazz-inspired music concert will take place at Václav Trojan's studio, on Tuesday July 20, 20:00 of Prague time (UTC+2).
- Classical music concert will take place at the St. Vitus Cathedral, Prague Castle, on Thursday July 22, 19:30 of Prague time (UTC+2).

PROGRAM

Thursday, 15 July 2021

13:00	–	18:00	**Session for testing zoom connections**
13:00	–	14:00	Testing period for speakers from Australia and Far East
14:00	–	16:00	Testing period for speakers from Europe, Middle East and Africa
16:00	–	18:00	Testing period for speakers from America

Friday, 16 July 2021

13:00	– 18:00	**Session for testing zoom connections**
13:00	– 14:00	Testing period for speakers from Australia and Far East
14:00	– 16:00	Testing period for speakers from Europe, Middle East and Africa
16:00	– 18:00	Testing period for speakers from America

Sunday, 18 July 2021

13:00	– 16:00	**Final testing**

Monday, 19 July 2021

08:00 – 08:30	**Opening addresses**	
	Location: Virtual Zoom Session	
	(chairperson: Václav Špička)	
08:30 – 10:30	**1 session: Quantum optics**	
	Location: Virtual Zoom Session	
	(chairperson: Andrew Armour)	
08:30 – 09:00	Franco Nori:	*Quantum Nonlinear Optics without Photons, how to excite two or more atoms simultaneously with a single photon, and other unusual properties of ultra-strongly-coupled QED systems*
09:00 – 09:30	Howard M. Wiseman:	*The Heisenberg Limit to Laser Coherence*
09:30 – 10:00	Warwick P Bowen:	*Absolute quantum advantage in light microscopy*
10:00 – 10:30	Yuval Gefen:	*Measurement-Induced Quantum Steering*
10:30 – 10:50	Break	
10:50 – 13:10	**2 session: Many body physics, Graphene**	
	Location: Virtual Zoom Session	
	(chairperson: Amnon Aharony)	
10:50 – 11:10	Efrat Shimshoni:	*Superconducting Dirac point in proximetized graphene*
11:10 – 11:30	Llorenç Serra:	*Scattering of topological kink-antikink states in bilayer graphene*
11:30 – 11:50	A. De Martino:	*Volkov-Pankratov states in topological graphene nanoribbons*
11:50 – 12:10	Folkert Kornelis de Vries:	*Superconducting devices in magic-angle twisted bilayer graphene*
12:10 – 12:30	David Sanchez:	*Andreev drag effect in Coulomb coupled quantum dots*
12:30 – 12:50	Moshe Schechter:	*On the nature of tunneling two-level systems in amorphous solids, and the mitigation of their deleterious effects in superconducting circuits*

12:50	–	13:10	Wolfgang Belzig:	*Higher-dimensional topology in multi-terminal superconducting structures*
13:10	–	14:00	Break	

14:00 – 15:20 **3 session: Quantum thermodynamics**

Location: Virtual Zoom Session

(chairperson: Theo Nieuwenhuizen)

14:00	–	14:30	Jianshu Cao:	*Thermodynamics and Symmetry of Driven Open Quantum Systems*
14:30	–	15:00	Doron Cohen:	*Breakdown of quantum-to-classical correspondence for diffusion in high temperature thermal environment*
15:00	–	15:20	Peter D. Keefe:	*Thermodynamics of Mesoscopic Superconductors*
15:20	–	15:40	Break	

15:40 – 17:10 **4 session: Foundations of quantum physics**

Location: Virtual Zoom Session

(chairperson: Doron Cohen)

15:40	–	16:10	Denis V. Vasilyev:	*Quantum Variational Optimization of Ramsey Interferometry and Atomic Clocks*
16:10	–	16:30	Andrei Khrennikov:	*Getting rid of nonlocality from quantum physics through Bohr's complementarity*
16:30	–	16:50	Arkady Plotnitsky:	*"The Observations Obtained under the Specified Circumstances:" What quantum measurement is, and what it is not.*
16:50	–	17:10	Ehtibar Dzhafarov:	*Quantum contextuality: the most general definition?*
17:10	–	17:30	Break	

17:30 – 19:30 **5 session: Foundations of quantum physics**

Location: Virtual Zoom Session

(chairperson: Arkady Plotnitsky)

17:30	–	18:00	Gerard 't Hooft:	*Specific Models for Fast Hidden Variables, FreeWill, and all that*

18:00	–	18:30	Gregor Weihs:	*Multipath Interference Tests of Quantum Mechanics*
18:30	–	18:50	Denys I. Bondar:	*Decoherence-Free Entropic Gravity: Model and Experimental Tests*
18:50	–	19:10	Ana María Cetto:	*The physics behind quantum operators*
19:10	–	19:30	Luis de la Peña:	*How fast is a quantum jump?*

Tuesday, 20 July 2021

08:30 – 10:20	**1 session: Biophysics**		
	Location: Virtual Zoom Session		
	(chairperson: Aneta Stefanovska)		
08:30 – 09:00	Peter V. E. McClintock:	*Ionic Coulomb blockade and selectivity in biological ion channels*	
09:00 – 09:30	Stefan Klumpp:	*Coarse-graining discrete stochastic models of biochemical systems*	
09:30 – 10:00	Michael Thorwart:	*Vibronic quantum coherence at ultralow temperatures in photosynthetic protein complexes*	
10:00 – 10:20	Yutaka Shikano:	*Quantum Nanodiamond Thermometry for Biological System*	
10:20 – 10:40	Break		
10:40 – 13:00	**2 session: Hall effect, Thermodynamics**		
	Location: Virtual Zoom Session		
	(chairperson: Ora Entin-Wohlman)		
10:40 – 11:00	Jakub Spiechowicz:	*Quantum analogue of energy equipartition theorem*	
11:00 – 11:20	Konstantin Dorfman:	*Incoherent control of optical signals: Quantum-heat-engine approach*	
11:20 – 11:40	Jiří J. Mareš:	*Hall Effect and the problem of "hidden momentum"*	
11:40 – 12:00	Takafumi Kita:	*Charging and Thermal Hall Effect in Superconductors*	
12:00 – 12:20	Konrad Viebahn:	*Thouless pumping in a Floquet-driven lattice*	
12:20 – 12:40	Thibaut Jonckheere:	*Andreev reflection of fractional quantum Hall quasiparticles*	
12:40 – 13:00	Jerome Rech:	*Negative Delta-T Noise in the Fractional Quantum Hall Effect*	
13:00 – 14:00	Break		

14:00 – 15:20	**3 session: Physics of quantum information**		
	Location: Virtual Zoom Session		
	(chairperson: Elisabetta Paladino)		
14:00 – 14:30	Steven Mark Girvin:	*Using Boson Sampling for Efficient Simulation of Molecular Spectra on a Small Quantum Processor*	
14:30 – 15:00	James Freericks:	*Strategies for quantum chemistry on a quantum computer using a factorized form of the unitary coupled cluster method*	
15:00 – 15:20	Sebastian Deffner:	*Energetic cost of Hamiltonian quantum gates*	
15:20 – 15:40	Break		
15:40 – 17:20	**4 session: Nonequilibrium statistical physics**		
	Location: Virtual Zoom Session		
	(chairperson: Andreas Wacker)		
15:40 – 16:10	Michael Bonitz:	*Towards many-body quantum dynamics based on fluctuations*	
16:10 – 16:40	Pawel Danielewicz:	*Dynamics of Correlated Systems with Nonequilibrium Green's Functions*	
16:40 – 17:00	Michael Galperin:	*A Green's function perspective on the nonequilibrium thermodynamics of open quantum systems strongly coupled to baths*	
17:00 – 17:20	Michael Ridley:	*Time-dependent electromagnetics of molecular junctions*	
17:20 – 17:40	Break		
17:40 – 19:20	**5 session: Many body physics**		
	Location: Virtual Zoom Session		
	(chairperson: Steven Girvin)		
17:40 – 18:10	Harold U Baranger:	*Driven-Dissipative Phase Transition in a Kerr Oscillator*	
18:10 – 18:40	Dietrich Belitz:	*Soft modes in Fermi liquids*	

18:40	–	19:00	Thomas Vojta:	*Collective modes at the superfluid - Mott glass transition*
19:00	–	19:20	Lorenza Viola:	*Manifestation of topology in metastable driven-dissipative bosonic systems*
19:20	–	20:00	Free time	
20:00	–	20:45	**Concert of classical and jazz inspired music**	

Wednesday, 21 July 2021

08:30 – 10:30	**1 session: Quantum Thermodynamics**	
	Location: Virtual Zoom Session	
	(chairperson: Konstantin Dorfman)	
08:30 – 09:00	Stephen M. Barnett:	*Thermofields for Quantum Thermodynamics*
09:00 – 09:30	Maciej Andrzej Lewenstein:	*From Generalized Resource Theories of Quantum Thermodynamics to Novel Quantum Thermometry*
09:30 – 10:00	Jens Eisert:	*Quantum field thermal machines*
10:00 – 10:30	Gershon Kurizki:	*Unitary and Non-Unitary Few-Mode Heat Machines*
10:30 – 10:50	Break	
10:50 – 12:50	**2 session: Simulations**	
	Location: Virtual Zoom Session	
	(chairperson: Francesco Petruccione)	
10:50 – 11:10	Jürgen T. Stockburger:	*A novel quantum simulation method for complex system-reservoir dynamics*
11:10 – 11:30	Peter Schmitteckert:	*Cluster Embedding Schemes*
11:30 – 11:50	Christian Kokail:	*Characterizing Quantum Many-Body States via Entanglement Hamiltonian Learning*
11:50 – 12:10	Kareljan Schoutens:	*Kink dynamics and quantum simulation of supersymmetric lattice Hamiltonians*
12:10 – 12:30	Ilya Sinayskiy:	*Quantum Simulation of Markovian and non-Markovian channel addition on NISQ devices and in the Quantum Optics Lab*
12:30 – 12:50	Andreas Wacker:	*PERLind, a versatile approach to model bath coupling in quantum kinetics*
12:50 – 14:00	Break	

14:00 – 16:00	**3 session: Poster Session**	
	Location: Virtual Zoom Session	
	(chairperson:)	
16:00 – 17:30	**4 Session: Physics of superfluids**	
	(chairperson: Peter McClintock)	
16:00 – 16:30	Fernando Sols:	*Superfluidity from correlations.*
16:30 – 17:00	Stephanie M Reimann:	*Effects beyond mean-field in bosonic quantum systems*
17:00 – 17:30	Yoram Alhassid:	*The thermodynamics of the strongly interacting cold atomic Fermi gas in the crossover from BEC to BCS*
17:30 – 17:50	Break	
17:50 – 19:20	**5 session: Physics of superfluids**	
	Location: Virtual Zoom Session	
	(chairperson: Stephanie Reimann)	
17:50 – 18:20	Aneta Stefanovska:	*Non-Equilibrium Oscillatory Dynamics of Electrons on the Surface of Liquid Helium*
18:20 – 18:50	Vanderlei Salvador Bagnato:	*Quantum Turbulence in atomic superfluid: characteristics and presence of universality*
18:50 – 19:20	Ernst M. Rasel:	*Quantum gases in free-fall*

Thursday, 22 July 2021

08:30 – 10:20	**1 Session: Nonequlibrium statistical physics**	
	Location: Virtual Zoom Session	
	(chairperson: Giuseppe Falci)	
08:30 – 09:00	Thomas Gasenzer:	*Universal dynamics far from equilibrium*
09:00 – 09:30	Francesco Petruccione:	*Open quantum systems on quantum computers*
09:30 – 10:00	Mikko Möttönen:	*Experiments on open quantum systems made of superconducting qubits with tunable coupling to their environment*
10:00 – 10:20	Carles Altimiras:	*Experimental test of Kubo relation in a non-linear quantum conductor driven out of equilibrium*
10:20 – 10:40	Break	
10:40 – 12:40	**2 Session: Quantum liquids, Casimir force**	
	Location: Virtual Zoom Session	
	(chairperson: Fernando Sols)	
10:40 – 11:00	Bryan J Dalton:	*Discrete Time Crystals in Ultracold Quantum Gases*
11:00 – 11:20	Neill Lambert:	*Pseudo-modes for bosons and fermions*
11:20 – 11:40	Kensuke Kobayashi:	*Three-body correlations in nonlinear response of correlated quantum liquid*
11:40 – 12:00	Gergely Zaránd:	*Quantum work statistics in chaotic and disordered Fermi liquids*
12:00 – 12:20	Yigal Meir:	*Measuring entropies of exotic quasi-particles?*
12:20 – 12:40	Mauro Antezza:	*Casimir torque and force on gratings*
12:40 – 13:30	Break	

13:30 – 15:00 **3 Session: Biophysics**

Location: Virtual Zoom Session

(chairperson: Stefan Klumpp)

13:30 – 14:00 Felix Ritort: *Information-to-measurement conversion in DNA pulling experiments with feedback: from protocols to strategies*

14:00 – 14:20 Saar Rahav: *Uncertainty relation for enzymes, resetting systems, and other processes with irreversible transitions*

14:20 – 14:40 Alexandre Zagoskin: *Quantum entanglement of living organisms*

14:40 – 15:00 Philip Hemmer: *Biosensing applications of quantum emitters in diamond and phosphors*

15:00 – 15:20 Break

15:20 – 16:30 **4 Session: General physics**

Location: Virtual Zoom Session

(chairperson: Peter Keefe)

15:20 – 15:50 Georgi Gary Rozenman: *Gravitational and Quantum Mechanical Phenomena in Surface Gravity Water Waves*

15:50 – 16:20 Kimball A. Milton: *Negative Casimir Entropies and their Implications*

16:20 – 16:40 Roland E Allen: *Predictions of a fundamental statistical picture, including experimental signatures of a new dark matter WIMP*

16:40 – 17:00 Theo M. Nieuwenhuizen: *The interior of astrophysical black holes*

17:00 – 17:20 Break

17:20 – 18:50 **5 Session: Quantum Optics**

Location: Virtual Zoom Session

(chairperson: Frank Narducci)

17:20 – 17:50 Hui Cao: *Controlling nonlinear dynamics of complex lasers*

17:50 – 18:20 A. Douglas Stone: *Reflectionless Excitation of Arbitrary Photonic Structures: A General Theory*

18:20 – 18:50 Mark Dykman: *Resonant time-symmetry breaking in coupled oscillators*

18:50 – 19:30 Free time

19:30 – 21:00 **Concert of classical music**

Location: Prague Castle - St. Vitus Cathedral and live on internet

Friday, 23 July 2021

08:30	–	10:20	**1 Session: Many body physics, Spins**	

Location: Virtual Zoom Session

(chairperson: Yuval Gefen)

08:30	–	09:00	Amnon Aharony:	*Breaking Time-Reversal Symmetry and Spin Selection in chiral molecules*
09:00	–	09:30	Ora Entin-Wohlman:	*Magnetization generated by microwave-induced Rashba interaction*
09:30	–	10:00	E.K.U. Gross:	*Non-adiabatic Berry connection, the mediator of energy, momentum, and angular-momentum transfer between electrons and nuclei*
10:00	–	10:20	Yasuhiro Utsumi:	*Spin selectivity through time-reversal symmetric helical junctions*
10:20	–	10:40	Break	
10:40	–	13:00	**2 Session: Quantum thermodynamics**	

Location: Virtual Zoom Session

(chairperson: Jürgen Stockburger)

10:40	–	11:00	Alexia Auffèves:	*Two-qubit engine fueled by entanglement and local measurements*
11:00	–	11:20	Eric Lutz:	*Experimental verification of a reversed Clausius inequality in a closed system*
11:20	–	11:40	Marti Perarnau-Llobet:	*Optimal cycles for finite-time Carnot engines*
11:40	–	12:00	Rafael Sánchez:	*Interference-induced extrinsic thermoelectrics*
12:00	–	12:20	Artur Widera:	*Quantum probes and quantum engines realized via individual impurities immersed in an ultracold bath.*
12:20	–	12:40	Giuseppe Falci:	*Quantum operations in ultrastrongly coupled quantum networks*
12:40	–	13:00	Elisabetta Paladino:	*Thermal rectification through a nonlinear quantum resonator*
13:00	–	14:00	Break	

14:00 – 15:30	**3 Session: Quantum optics**	
	Location: Virtual Zoom Session	
	(chairperson: Douglas Stone)	
14:00 – 14:30	Olga Kocharovskaya:	*Quantum optics with ultra-narrow nuclear resonances*
14:30 – 14:50	Norbert Kroo:	*Plasmon assisted Cooper pair formation at room temperature*
14:50 – 15:10	Yuri Rostovtsev:	*Quantum control and coherence in 2D materials*
15:10 – 15:30	Anil Patnaik:	*Dispersion of a Single Atom Experienced by Single Photon*
15:30 – 15:50	Break	
15:50 – 17:20	**4 session: Quantum optics, Nonequilibrium statistical physics**	
	Location: Virtual Zoom Session	
	(chairperson: Anil Patnaik)	
15:50 – 16:20	Andrew Armour:	*Complex Resonances in Josephson Photonics*
16:20 – 16:40	Frank A Narducci:	*On the way to a demonstration of a T-cubed atom interferometer*
16:40 – 17:00	Radim Filip:	*Highly non-Gaussian quantum physics*
17:00 – 17:20	Lea F Santos:	*Speck of chaos*
17:20 – 17:40	Break	
17:40 – 19:00	**5 Session: Many body systems**	
	Location: Virtual Zoom Session	
	(chairperson: Andrew Armour)	
17:40 – 18:10	Joseph Maciejko:	*Hyperbolic band theory*
18:10 – 18:40	Tamar Seideman:	*Quantum Rotational Coherences in Complex Media*
18:40 – 19:00	Avik Ghosh:	*Exploiting topology and strong interactions in electronics*
19:00 – 19:30	**Closing Remarks**	
	Location: Virtual Zoom Session	
	(chairperson: Václav Špička)	

Invited Talks

Breaking Time-Reversal Symmetry and Spin Selection in chiral molecules

Amnon Aharony[1], Ora Entin-Wohlman[1], and Yasuhiro Utsumi[2]

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[2]*Mie University, 1577, Kurimamachiya-cho, Tsu, 514-8507, Japan*

Many recent experiments discovered chiral-induced spin selectivity (CISS): electrons scattered by helical organic molecules become spin-polarized. The theoretical explanation of this phenomenon is still under debate. Many theories start with spin-orbit interactions (SOIs) on the molecule, but the SOI preserves time-reversal symmetry, and therefore implies no spin selectivity in the linear conductance when the molecule connects two single channel terminals (Bardarson's theorem). Here we model the molecule by a tight-binding Hamiltonian, with a Rashba SOI along the helix and additional hopping in the direction of the helix axis, and present several ways to overcome the theorem and achieve CISS: allowing leakage from the molecular ions, adding a third terminal, adding magnetic fields, adding time-dependent potentials, adding more orbital states on the molecule, and various non-linear effects. [1] All of these yield CISS, so we are still far from having a unique explanation. Recent alternative theories will be criticized. [2]

[1] Many relevant references are included in Y. Utsumi, O. Entin-Wohlman, and A. Aharony, Spin selectivity through time-reversal symmetric helical junctions, Phys. Rev. B 102, 035445 (2020) - Editors' suggestion; (arXiv:2005.04041).

[2] O. Enrin-Wohlman, A. Aharony, and Y. Utsumi, Comment on: "Spin-orbit interaction and spin selectivity for tunneling electron transfer in DNA", Phys. Rev. B 103, 077401 (2021); (arXiv:2007.11238).

The thermodynamics of the strongly interacting cold atomic Fermi gas in the crossover from BEC to BCS

Yoram Alhassid[1], Scott Jensen[2], Shasta Ramachandran[1], and Christopher N Gilbreth[3]

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Cold atomic Fermi gases provide a clean and well-defined paradigm of strongly interacting Fermi systems and have attracted much interest across diverse subfields of physics. They have also been the subject of intensive experimental studies in recent years.

We investigate the thermodynamics of the crossover between the Bose-Einstein condensate (BEC) and the Bardeen-Cooper-Schrieffer (BCS) limits in the two-species Fermi gas with attractive contact interaction in three (3D) and two (2D) spatial dimensions. In 3D we focus on the unitary limit of strongest interaction [1,2], while in 2D we consider the strongly interacting regime in the crossover [3]. The system undergoes a phase transition to a superfluid below a critical temperature but in 2D the transition is of the Berezinskii-Kosterlitz-Thouless type. We use auxiliary-field quantum Monte Carlo (AFMC) methods in the canonical ensemble on a discrete lattice and extrapolate to the continuum limit [2].

We study the superfluid phase transition and, in particular, the extent of a pseudogap regime, in which pairing correlations exist above the critical temperature for superfluidity. To this end, we calculate several observables including the condensate fraction and a model-independent pairing gap. We also calculate the contact which measures the pair correlation at short distances and is a fundamental property of quantum many-body systems with short-range correlations. We observe a rapid increase in the contact as the temperature decreases below the critical temperature for superfluidity in both 3D [2] and 2D [3]. The calculation of the contact has been a major challenge with many theories using uncontrolled approximations that lead to widely different results. Our results for the 3D unitary gas are in excellent agreement with recent precision experiments by two leading experimental groups [5].

Finally, we calculate the spin susceptibility and determine a spin gap temperature below which the spin susceptibility is suppressed due to pairing correlations.

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

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

[3] S. Ramachandran, S. Jensen, and Y. Alhassid, to be published (2021).

[4] C. Carcy et al, Phys. Rev. Lett. **122**, 203401 (2019); B. Mukherjee et al, Phys. Rev. Lett. **122**, 203402 (2019).

Predictions of a fundamental statistical picture, including experimental signatures of a new dark matter WIMP

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As explained in detail in an updated and enhanced version of a previous paper [1], the simplest imaginable statistical picture ultimately leads to standard physics (with the Standard Model supplemented by SO(10) grand unification, supersymmetry, and Einstein gravity) plus additional predictions. One prediction is a dark matter particle which is consistent with current experiment and observation, which can be detected in underground and collider experiments which are currently being planned, and which may already have been detected in space-based experiments [2].

[1] Roland E. Allen, "Predictions of a fundamental statistical picture", arXiv:1101.0586 [hep-th].

[2] Reagan Thornberry, Maxwell Throm, Gabriel Frohaug, John Killough, Dylan Blend, Michael Erickson, Brian Sun, Brett Bays, and Roland E. Allen, "Experimental signatures of a new dark matter WIMP", EPL [European Physics Letters], in press, arXiv:2104.11715 [hep-ph].

Experimental test of Kubo relation in a non-linear quantum conductor driven out of equilibrium

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We demonstrate a protocol giving acces to both non-symmetrized emission and absorption current noises of a non-linear quantum conductor from measuring the power it exchanges with its surrounding circuit. Combined with a linear response measurement, we test experimentally Kubo relation equating the difference between the absorption and emission current noises to the dissipative part of the conductor's admittance. Finally we argue that, within a quantum description of the current source detection scheme used in the experiment, Kubo relation should be understood as a quantum theorem for Joule effect.

Casimir torque and force on gratings

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We will discuss recent results: (i) on the Casimir torque between two metallic one-dimensional gratings rotated by an angle θ with respect to each other [1]; and (ii) on the Casimir force occurring between interpenetrating gratings [2]. These findings pave the way to the design of a contactless quantum vacuum torsional spring, and sensors with possible relevance to micro- and nanomechanical devices.

[1] Mauro Antezza, H. B. Chan, Brahim Guizal, V.N. Marachevsky, Riccardo Messina, Mingkang Wang, Phys. Rev. Lett. 124 (2020) 013903.

[2] Mingkang Wang, L. Tang, C.Y. Ng, Riccardo Messina, Brahim Guizal, J. A. Crosse, Mauro Antezza, C.T. Chan, H.B. Chan, Nature Communication 12 (2021) 600.

Complex Resonances in Josephson Photonics

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We explore theoretically the dissipative dynamics of nonlinearly driven oscillator systems tuned to resonances where multiple excitations are generated. Such systems are readily realised in circuit QED systems combining Josephson junctions with a microwave cavity and a drive achieved either through flux or voltage bias. For resonances involving 3 or more photons the system undergoes a sequence of two closely spaced dynamical transitions (the first one discontinuous and the second continuous) as the driving is increased leading to steady states that form complex periodic structures in phase space. In the vicinity of the transitions the system displays interesting bistable behaviour: we find that coherent effects can lead to surprising oscillations in the weight of the different dynamical states in the steady state of the system with increasing drive.

Two-qubit engine fueled by entanglement and local measurements

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We introduce a two-qubit engine that is powered by entanglement and local measurements. Energy is extracted from the detuned qubits coherently exchanging a single excitation. Generalizing to an N-qubit chain, we show that the low energy of the first qubit can be up-converted to an arbitrarily high energy at the last qubit by successive neighbor swap operations and local measurements. We finally model the local measurement as the entanglement of a qubit with a meter, and we identify the fuel as the energetic cost to erase the correlations between the qubits. Our findings extend measurement-powered engines to composite working substances and provide a microscopic interpretation of the fueling mechanism.

[1] L. Bresque et al, PHYSICAL REVIEW LETTERS 126, 120605 (2021)

Quantum Turbulence in atomic superfluid: characteristics and presence of universality

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Quantum turbulence, occurs in quantum fluids and has several natures. Its origin can be the formation and tangling of vortices as well as the formation of non-linear waves in the system, or even a combination of them. These excitations can evolve over time, promoting energy migration from the largest to the smallest scales in a process called cascade, which has mechanisms of occurrence. Starting with a Bose-Einstein condensate of Rb-87, trapped in a harmonic potential, we perform temporal excitations that consist of deformation and slight rotation of the potential, causing the system to evolve to a turbulent regime. Using time of flight techniques, we measure the moment distribution, n(k, t) and from it we obtain the energy spectrum E (k, t). This makes it possible to identify the inertial regions, where E (k, t) is clearly dependent on the power law (inertial region) characteristic of turbulent regime, and to measure the energy flow migrating between the scales and their preservation from the absence of dissipation. Finally, the temporal evolution of the moment distribution allows to verify the presence of a space-time scalability, which indicate the presence of a class of universality in the phenomenon. The problem is investigated on the basis of the theory of the existence of non-thermal fixed points in the system and a discussion around these aspects is offered. This work received support from FAPESP, CNPq and CAPES, all Brazilian development agencies. Thanks to students and PD: L. Madeira, A. Cedrin, A. G. Orosco, G. D. Telles.

Recent (2020) works related to the theme:

[1] L. Madeira, A. D. García-Orozco, F. E. A. dos Santos, V. S. Bagnato, *Entropy of a Turbulent Bose-Einstein Condensate*, Entropy **22**(9), 956 (2020).

[2] L. Madeira, A. Cidrim, M. Hemmerling, M. A. Caracanhas, F. E. A. dos Santos, and V. S. Bagnato, *Quantum turbulence in Bose-Einstein condensates: Present status and new challenges ahead*, AVS Quantum Sci. **2**, 035901 (2020).

[3] A. V. M. Marino, L. Madeira, A. Cidrim, F. E. A. dos Santos, V. S. Bagnato, *Momentum distribution of Vinen turbulence in trapped atomic Bose-Einstein condensates*, arXiv: 2005.11286.

[4] A. D. García-Orozco, L. Madeira, L. Galantucci, C. F. Barenghi, V. S. Bagnato, *Intrascales energy transfer during the evolution of turbulence in a trapped Bose-Einstein condensate*, Europhys. Lett. **130**, 46001 (2020).

Driven-Dissipative Phase Transition in a Kerr Oscillator

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We study open quantum many-body physics using a minimal model, namely a Kerr non-linear oscillator subject to two-photon driving and single-photon dissipation. Using mean-field theory, exact diagonalization, and the Keldysh formalism, we analyze the critical phenomena at the quantum phase transition in this system, showing which aspects can be captured by each approach and how the approaches complement each other [1].

Critical scaling and finite-size scaling are calculated analytically using the quantum Langevin equation. Spectral properties are given analytically using the Keldysh formalism (both the spectral function of the oscillator and the power-spectrum of the emitted photons).

The physics contained in this simple model is surprisingly rich: it includes a continuous phase transition, Z_2 symmetry breaking, PT-symmetry, state squeezing, and critical fluctuations. Due to its simplicity and solvability, this model can serve as a paradigm for exploration of open quantum many-body physics.

[1] X. H. H. Zhang and H. U. Baranger, Phys. Rev. A 103, 033711 (2021).

Thermofields for Quantum Thermodynamics

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Thermofields provide a neat and simple way to evaluate thermal averages and to introduce finite-temperature environments. The idea was developed, initially, for finite temperature field theory [1,2] but has subsequently found application in quantum optics [3,4] and in the study of quantum gasses [5]. The essential idea is to replace thermal density operators with pure states in a doubled Hilbert space; a technique later rediscovered by the Quantum Information community who named this process 'purification' [6]. In this talk I shall introduce the basic techniques for using thermofields and, if time allows, give some simple examples of the utility of the technique.

[1] Y. Takahashi and H. Umezawa, Collect. Phenom. 2, 55 (1975).

[2] H. Umezawa, H. Matsumoto and M. Tachiki, *Thermo Field Dynamics and Condensed States* (North-Holland, Amsetrdam, 1982).

[3] S. M. Barnett and P. L. Knight, J. Opt. Soc. Am. B 2, 467 (1985).

[4] S. M. Barnett and B. J. Dalton, J. Phys. A: Math. Phys. Gen. 20, 411 (1987).

[5] B. J. Dalton, J. Jeffers and S. M. Barnett, *Phase Space Methods for Degenerate Quantum Gasses* (Oxford University Press, Oxford, 2015).

[6] S. M. Barnett, *Quantum Information* (Oxford University Press, Oxford, 2009).

Soft modes in Fermi liquids

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[2]*University of Maryland, Institute for Physical Science and Technology, College Park, MD 20742, USA*

We use kinetic theory to discuss soft modes in Fermi liquids in both the collisionless and the hydrodynamic regimes. In the collisionless regime the basic soft modes are the are continuum of particle-hole excitations and all of their moments with respect to momentum. In addition to the continuum, there are well-known zero-sound modes that reflect angular fluctuations of the Fermi surface. In addition to the latter, radial fluctuations of the Fermi surface lead to a novel propagating entropy mode. At nonzero temperature all of these modes acquire a mass. With increasing temperature that mass increases, and the collisionless regime shrinks. At the same time, a hydrodynamic frequency regime opens up that displays the five hydrodynamic modes governed by conservation laws, namely: two first-sound waves, two shear-diffusion modes, and one heat-diffusion mode. We discuss the relation of these results to previous work that used field-theoretic methods, as well as the origins of the various soft modes.

Higher-dimensional topology in multi-terminal superconducting structures

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Topology ultimately unveils the roots of the perfect quantization observed in complex systems. The 2D quantum Hall effect is the celebrated archetype. Remarkably, topology can manifest itself even in higher-dimensional spaces in which control parameters play the role of extra, synthetic dimensions. However, so far, a very limited number of implementations of higher-dimensional topological systems have been proposed, a notable example being the so-called 4D quantum Hall effect. Here we show that mesoscopic superconducting systems can implement higher-dimensional topology and represent a formidable platform to study a quantum system with a purely nontrivial second Chern number [1]. We demonstrate that the integrated absorption intensity in designed microwave spectroscopy [2] is quantized and the integer is directly related to the second Chern number. Finally, we show that these systems also admit a non-Abelian Berry phase. Hence, they also realize an enlightening paradigm of topological non-Abelian systems in higher dimensions.

[1] H. Weisbrich, R.L. Klees, G. Rastelli and W. Belzig, Second Chern Number and Non-Abelian Berry Phase in Superconducting Systems, PRX Quantum 2, 010310 (2021)

[2] R. L. Klees, G. Rastelli, J. C. Cuevas, and W. Belzig, Microwave spectroscopy reveals the quantum geometric tensor of topological Josephson matter, Phys. Rev. Lett. 124, 197002 (2020)

Decoherence-Free Entropic Gravity: Model and Experimental Tests

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Erik Verlinde's theory of entropic gravity, postulating that gravity is not a fundamental force but rather emerges thermodynamically, has garnered much attention as a possible resolution to the quantum gravity problem. Some have ruled this theory out on grounds that entropic forces are by nature noisy and entropic gravity would therefore display far more decoherence than is observed in ultra-cold neutron experiments. We address this criticism by modeling linear gravity acting on small objects as an open quantum system. In the strong coupling limit, the entropic master equation recovers conservative gravity. We show that the proposed master equation is fully compatible with the qBounce experiment for ultra-cold neutrons. Furthermore, the entropic master equation predicts energy increase and decoherence on long time scales and for large masses, phenomena which tabletop experiments could test. In addition, comparing entropic gravity's energy increase to that of the Diosi-Penrose model for gravity induced decoherence indicates that the two theories are incompatible. These findings support the theory of entropic gravity, motivating future experimental and theoretical research.

Further information can be found at arXiv:2012.10626

T14 Tue, 20 July, 15:40 - 16:10, 4 session

Towards many-body quantum dynamics based on fluctuations

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Many-body quantum dynamics is a hot topic in a broad range of fields, including systems as diverse as cold atoms in optical lattices, correlated condensed matter systems and dense quantum plasmas and warm dense matter. The goal is the computation of the nonlinear response of the system to a time-dependent external excitation and the subsequent relaxation, fully including quantum, spin and correlation effects. The standard approaches include reduced density operators (RDO) and Nonequilibrium Green functions (NEGF) that give rise to a hierarchy of coupled equations of motion for the reduced quantities, such as the BBGKY-hierarchy of RDO or the Martin-Schwinger hierarchy of NEGF, e.g. [1]. Recently a dramatic speedup of the numerical solutions of the quantum dynamics that include dynamical screening and strong coupling could be achieved [2,3] which will be demonstrated in the first part of the talk. In the second part, we explore an independent approach to the quantum dynamics that is based on the time evolution of correlation functions of quantum fluctuations. This is motivated by successful concepts in classical plasmas [4], in correlated quantum plasmas in equilibrium [5] and various phenomenological stochastic concepts in quantum systems, e.g. [6]. Here we present a rigorous derivation of the hierarchy of equations of fluctuations of the NEGF and compare it to the aforementioned approaches [7].

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

[2] N. Schlünzen, J.-P. Joost, Phys. Rev. Lett. 124, 076601 (2020)

[3] J.-P. Joost, N. Schlünzen, and M. Bonitz, Phys. Rev. B 101, 245101 (2020)

[4] Yu.L. Klimontovich, „Kinetic Theory of Nonideal Gases and Nonideal Plasmas“, Pergamon Press 1982

[5] T. Dornheim, S. Groth, J. Vorberger, and M. Bonitz, Phys. Rev. Lett. 121, 255001 (2018)

[6] D. Lacroix, S. Hermanns, C. Hinz, and M. Bonitz, Phys. Rev. B 90, 125112 (2014)

[7] E. Schroedter, J.-P. Joost, and M. Bonitz, to be published

Absolute quantum advantage in light microscopy

Warwick P Bowen[1], Catxere A Casacio[1], Lars S Madsen[1], Alex Terrasson[1], Muhammad Waleed[1], Kai Barnscheidt[2], Boris Hage[2], and Michael A Taylor[1]

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[2]*Institut fur Physik, Universitat Rostock, Rostock, Germany*

State-of-the-art microscopes use intense lasers that can severely disturb biological processes, function and viability. This introduces hard limits on performance that only quantum photon correlations can overcome. In this talk I will report recent work from my laboratory which demonstrates this absolute quantum advantage [1]. We show, specifically, that quantum correlations enable signal-to-noise beyond the photodamage-free capacity of conventional microscopy. Broadly, this represents the first demonstration that quantum correlations can allow sensing beyond the limits introduced by optical intrusion upon the measurement process. We achieve this in a coherent Raman microscope, which we use to image molecular bonds within a cell with both quantum-enhanced contrast and sub-wavelength resolution. This allows the observation of nanoscale biological structures that would otherwise not be resolved. Coherent Raman microscopes allow highly selective biomolecular finger-printing in unlabelled specimens, but photodamage is a major roadblock for many applications. By showing that this roadblock can be overcome, our work provides a path towards order-of-magnitude improvements in both sensitivity and imaging speed.

[1] Catxere A. Casacio, Lars S. Madsen, Alex Terrasson, Muhammad Waleed, Kai Barnscheidt, Boris Hage, Michael A. Taylor, and Warwick P. Bowen, Quantum-enhanced nonlinear microscopy, in print Nature (2021). Available at: arXiv:2004.00178.

T16 Thu, 22 July, 17:20 - 17:50, 5 Session

Controlling nonlinear dynamics of complex lasers

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Nonlinear light-matter interactions induce irregular pulsations and filamentation in high-power multi-mode lasers. To control the nonlinear interactions between the lasing modes and the gain material, we manipulate the spatial structure of cavity resonances and vary their characteristic length scales. By tailoring the cavity geometry of a broad-area laser, we are able to disrupt the coherent nonlinear processes that form self-organized structures and cause temporal instabilities. With spatio-temporal instabilities suppressed, we utilize the spatio-temporal interference of numerous lasing modes to achieve massively-parallel ultrafast random bit generation with a chip-scale laser diode.

Thermodynamics and Symmetry of Driven Open Quantum Systems

Jianshu Cao

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The light-matter interaction has been pushed to the strong coupling regime in several experimental platforms, including superconducting qubits, NV centers, cold atoms in optical lattices, and molecules in cavities. This opens up new possibilities of quantum control, but also presents new theoretical challenges. To address this, we have systematically developed Floquet response theory for open quantum systems driven by a strong but periodic driving field and perturbed by a weak but arbitrary probe field. (i) Non-equilibrium stationary states of periodically-driven open quantum systems can strongly deviate from the Floquet-Gibbs distribution and exhibit exotic non-analytic behavior. [1] (ii) Dynamical symmetries of the stationary states lead to spectroscopic signatures including symmetry-protected dark states and Floquet-band selection rules. [2] (iii) Floquet response theory predicts the generation of squeezed and entangled light using a sequence of coupled strongly-driven quantum systems. [3]

[1] Phys. Rev. Lett. 123, 120602 (2019) G. Engelhardt, G. Platero, and J. Cao

[2] Phys. Rev. Lett. 126, 090601 (2021) G. Engelhardt and J. Cao

[3] G. Engelhardt and J. Cao (manuscripts in preparation)

T18 Mon, 19 July, 18:50 - 19:10, 5 session

The physics behind quantum operators

Ana María Cetto and Luis de la Peña

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A novel physical explanation is proposed for the emergence of the quantum operator formalism, from the perspective provided by stochastic electrodynamics (SED). We recall that according to SED, an otherwise classical, charged particle subject to a binding force reaches a stationary state of motion under the combined effect of the random electromagnetic zero-point radiation field (ZPF) and its own radiation reaction. In this work we focus on one such stationary state, and take into account that the zpf has taken control of the particle motion, acting as a driving force on it. The particle responds to a certain set of modes of the field, precisely to those that may take it to a different stationary state. A Hamiltonian analysis of this response, in which the Poisson bracket $\{x, p\}$ must now be taken with respect to the canonical field variables, allows us to derive the basic quantum commutator $[x, p] = i\hbar$. We discuss the implications of these results with regards to the physical meaning of the Heisenberg formulation of quantum mechanics.

Breakdown of quantum-to-classical correspondence for diffusion in high temperature thermal environment

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The spreading of a particle along a chain, and its relaxation, are central themes in statistical and quantum mechanics. One wonders what are the consequences of the interplay between coherent and stochastic transitions. This fundamental puzzle has not been addressed in the literature, though closely related themes were in the focus of the Physics literature throughout the last century, highlighting quantum versions of Brownian motion. Most recently this question has surfaced again in the context of photo-synthesis.

In [1] we re-consider the old problem of Brownian motion in homogeneous high-temperature thermal environment. The semiclassical theory implies that the diffusion coefficient does not depend on whether the thermal fluctuations are correlated in space or disordered. We show that the corresponding quantum analysis exhibits a remarkable breakdown of quantum-to-classical correspondence. Explicit results are found for a tight binding model, within the framework of an Ohmic master equation, where we distinguish between on-site and on-bond dissipators. The breakdown is second-order in the inverse temperature, and therefore, on the quantitative side, involves an inherent ambiguity that is related to the Ohmic approximation scheme.

For quantum coherent dynamics one expects to observe ballistic motion and Bloch oscillations, while for classical stochastic dynamics one expects to see diffusion and drift. In [2] we have considered the puzzling case where coherent and stochastic transitions co-exist "in parallel". With added disorder it becomes the quantum version of the Sinai-Derrida-Hatano-Nelson model, which features sliding and the delocalization transitions. They highlighted non-monotonic dependence of the current on the bias, and a counter-intuitive enhancement of the effective disorder due to coherent hopping.

[1] Breakdown of quantum-to-classical correspondence for diffusion in high temperature thermal environment, D. Shapira, D. Cohen, Phys. Rev. Research 3, 013141 (2021).

[2] Quantum stochastic transport along chains, D. Shapira, D. Cohen, Sci. Rep. 10, 10353 (2020).

T20 Thu, 22 July, 10:40 - 11:00, 2 Session

Discrete Time Crystals in Ultracold Quantum Gases

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A discrete time crystal (DTC) is an example of non-equilibrium quantum system which exhibits discrete time translation symmetry breaking, where measurable quantities such as the position probability density have periodicities that are an integer multiple of the period for that of the Hamiltonian [1].

We present a fully comprehensive multi-mode quantum treatment based on the truncated Wigner approximation (TWA) [2] to study many-body effects and effects of quantum fluctuations on the formation of a discrete time crystal in a Bose-Einstein condensate (BEC) bouncing resonantly on a periodically driven atom mirror [1]. Zero-range contact interactions between the bosonic atoms are assumed. Our theoretical approach avoids the restrictions both of mean-field theory, where all bosons are assumed to remain in a single mode, and of time-dependent Bogoliubov theory, which assumes boson depletion from the condensate mode is small. We show that the mean-field and time-dependent Bogoliubov approaches can be derived as approximations to the TWA treatment. Non-zero temperature BECs can also be treated.

For realistic initial conditions corresponding to a harmonic trap condensate mode function, our TWA calculations performed for period-doubling agree broadly with recent mean-field calculations [1, 3] for times out to at least 2000 mirror oscillations, except at interaction strengths very close to the threshold value for DTC formation, where the position probability density differs significantly from that in mean-field theory. For typical attractive interaction strengths above the threshold value for DTC formation and for the chosen trap and driving parameters, the TWA calculations indicate a quantum depletion due to quantum many-body fluctuations of less than about two atoms out of a total of 600 atoms at times corresponding to 2000 mirror oscillations, in agreement with time-dependent Bogoliubov theory calculations [3]. On the other hand, for interaction strengths very close to the threshold value for DTC formation, the TWA calculations predict a large quantum depletion - as high as about 260 atoms out of 600. We also show that the mean energy per particle of the DTC does not increase significantly for times out to at least 2000 mirror oscillations, typically oscillating around an average value close to its initial value; so TWA theory predicts an absence of thermalisation. Finally, we find that the dynamical behaviour of our system is largely independent of whether the boson-boson interaction is attractive or repulsive.

[1] K. Sacha, Phys. Rev. A 91, 033617 (2015); Time Crystals (Springer, Berlin, 2020).

[2] B. J. Dalton, J. Jeffers and S. M. Barnett, Phase Space Methods for Degenerate Quantum Gases (Oxford University Press, Oxford, 2015).

[3] A. Kuros et al., New J. Phys. 22, 095001 (2020).

Dynamics of Correlated Systems with Nonequilibrium Green's Functions

Hao Lin[1,2], Hossein Mahzoon[1,2,3], Arnau Rios[4], and Pawel Danielewicz[1]

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Theory of non-equilibrium Green's function (NGF) provides a practical framework for studying quantum many-body systems out of equilibrium. Extending the previous mean field approach developed for nuclear systems in one dimension with NGF, we introduce isospin degrees of freedom to the Green's functions and incorporate short-range two-body interactions in the second-order self-consistent approximation to correlations, which represents the scattering of momentum orbitals in the Born approximation. We discuss the preparation of a finite nuclear system and examine the impact of correlations on the ground state. We also excite a finite symmetric nuclear system to oscillate in an isovector dipole mode and explore the dissipation effects in the oscillation. Finally, we demonstrate how to boost a slab to a constant and stable motion in a box, based on Galilean covariance of the theory. The studies in this paper lay the ground for the future exploration of collisions of correlated nuclear systems in one dimension.

T22 Tue, 20 July, 15:00 - 15:20, 3 session

Energetic cost of Hamiltonian quantum gates

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Landauer's principle laid the main foundation for the development of modern thermodynamics of information. However, in its original inception the principle relies on semiformal arguments and dissipative dynamics. Hence, if and how Landauer's principle applies to unitary quantum computing is less than obvious. Here, we prove an inequality bounding the change of Shannon information encoded in the logical quantum states by quantifying the energetic cost of Hamiltonian gate operations. The utility of this bound is demonstrated by outlining how it can be applied to identify energetically optimal quantum gates in theory and experiment. The analysis is concluded by discussing the energetic cost of quantum error correcting codes with non-interacting qubits, such as Shor's code.

[1] arXiv:2102.05118

How fast is a quantum jump?

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The physics of the transitions between quantum states is a matter that has received little attention in the past, despite the crucial importance of these transitions for atomic and molecular physics. Recently however the picture has started to change, thanks to calculational and experimental work using attosecond spectroscopy. In this work we focus on the basic underlying physics by carrying out a theoretical analysis informed by stochastic electrodynamics, which does not rely on specific experimental settings, with the ultimate purpose of estimating the duration of a transition. The proposal rests on the consideration that a resonance of the atomic electron with modes of the zero-point radiation field of Compton's frequency is at the core of the phenomenon. The theoretical result obtained for the jumping time lies within the range of the recently experimentally estimated values of the order of attoseconds (10^{-18}s).

T24 Mon, 19 July, 11:30 - 11:50, 2 session

Volkov-Pankratov states in topological graphene nanoribbons

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In topological systems, a modulation in the gap onset near interfaces can lead to the appearance of massive edge states, as were first described by Volkov and Pankratov. In this talk I will show that, in the presence of intrinsic spin-orbit coupling smoothly modulated near the system edges, graphene nanoribbons host Volkov-Pankratov states in addition to the topologically protected helical states. This result is obtained by means of two complementary methods, one based on the effective low-energy Dirac equation description and the other on a fully numerical tight-binding approach, with excellent agreement between the two. I will then briefly discuss how transport measurements might reveal the presence of Volkov-Pankratov states, and possible graphene-like structures in which such states might be observed.

Superconducting devices in magic-angle twisted bilayer graphene

Folkert Kornelis de Vries[1], Elias Portoles[1], Giulia Zheng[1], Takashi Taniguchi[2], Kenji Watanabe[2], Thomas Ihn[1], Klaus Ensslin[1], and Peter Rickhaus[1]

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Magic-angle twisted bilayer graphene (MATBG) has recently emerged as a versatile platform that combines metallic, superconducting, magnetic and insulating phases in a single crystal. These different correlated states arise at cryogenic temperatures and are tunable by controlling the electrostatic environment of the two-dimensional material. Because of this tunability, MATBG appears to be an ideal two-dimensional platform for gate-tunable superconductivity. However, progress towards practical implementations has been hindered by the need for well-defined gated regions. Here we use multilayer gate technology to create devices based on two distinct phases in adjustable regions of MATBG [1]. We electrostatically define the superconducting and insulating regions of a Josephson junction and observe tunable d.c. and a.c. Josephson effects. The ability to tune the superconducting state within a single material circumvents interface and fabrication challenges, which are common in multimaterial nanostructures. This work is an initial step towards devices where gate-defined correlated states are connected in single-crystal nanostructures. We envision applications in superconducting electronics and quantum information technology.

[1] de Vries, F.K., Portolés, E., Zheng, G. et al. Gate-defined Josephson junctions in magic-angle twisted bilayer graphene. Nat. Nanotechnol. (2021)

T26 Tue, 20 July, 11:00 - 11:20, 2 session

Incoherent control of optical signals: Quantum-heat-engine approach

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Optical pump-probe signals can be viewed as work done by the matter while transferring the energy between two coherent baths (from pump to probe). In thermodynamics, a heat engine, such as a laser, is a device which performs similar work but operating between two thermal baths. We propose an “incoherent” control procedure for the optical signals using the physics of a quantum heat engine. By combining a coherent laser excitation of an electronic excited state of a molecule with thermal relaxation we introduce an effective thermal bath treating stimulated emission of probe photons as work performed by the heat engine. We optimize power and efficiency for the pump-probe signal using control parameters of the pump laser utilizing a four-level molecular model in the strong and weak coupling regime illustrating its equivalence with the thermodynamic cycle of the heat engine.

[1] M. Qutubuddin and K.E. Dorfman, Phys. Rev. Res. 3, 023029 (2021)

Resonant time-symmetry breaking in coupled oscillators

Mark Dykman

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A periodically driven system has discrete time-translation symmetry with the period of the driving. Its quantum dynamics is described in terms of the Floquet states. A driven nonlinear oscillator allows one to see peculiar features of tunneling and dissipation in the Floquet world. Generally, if a system is in a Floquet state, its dynamical variables oscillate with the period of the driving. However, the discrete time-translation symmetry can be broken, the "time crystal" effect. Nonlinear oscillators, including nanomechanical systems and modes in electromagnetic cavities, can be used to study this effect. We will discuss the quantum phase transition to the broken-symmetry state in systems of coupled oscillators. The transitions occur due to a comparatively weak resonant driving. We will show that heating is exponentially suppressed, no many-body localization is required for this suppression. Time permitting, we will discuss frustration and a transition to a topologically nontrivial period-3 state.

Quantum contextuality: the most general definition?

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Quantum contextuality is traditionally defined in three ways: in terms of (non)existence of joint distributions of random variables recorded in different contexts; in terms of counterfactual pre-existence of values of the random variables; and in terms of the (non)existence of hidden variables with noncontextual mapping into observable variables. All these definitions apply to systems of random variables with no disturbance, those in which random variables measuring the same property in different contexts have identical distributions. However, disturbance and contextuality are different forms of context-dependence, they can coexist within a system, and need to be conceptually separated and separately measured. This requires a generalization of the traditional definitions, one satisfying several desiderata, such as: noncontextuality should be preserved for any subsystem of a noncontextual system, it should be preserved under course-graining of the random variables, and adding or removing deterministic variables should not affect contextuality status of a system. In addition, the generalized definition should properly reduce to traditional definitions when applied to system with no disturbance. The definition proposed within the framework of the Contextuality-by-Default theory is, arguably, the most general definition satisfying these desiderata. Contextuality is defied as difference between the following two differences: (1) the difference between random variables when taken in isolation, and (2) the difference between the same random variables when taken within their contexts. The mathematical language that makes this definition rigorous is that of probabilistic couplings.

[1] Dzhafarov, E.N. (2021). Contents, contexts, and basics of contextuality. In Shyam Wuppuluri and Ian Stewart (Eds). From Electrons to Elephants and Elections: Saga of Content and Context. To be published by Springer - The Frontiers Collection. (arXiv:2103.07954)

[2] Dzhafarov, E.N., Kujala, J.V., & Cervantes, V.H. (2020). Contextuality and noncontextuality measures and gener- alized Bell inequalities for cyclic systems. Physical Review A 101:042119. (arXiv:1907.03328)

[3] Kujala, J.V., & Dzhafarov, E.N. (2019). Measures of contextuality and noncontextuality. Philosophical Transactions of the Royal Society A 377:20190149. (arXiv:1903.07170)

[4] Dzhafarov, E.N. (2019). On joint distributions, counterfactual values, and hidden variables in understanding con- textuality. Philosophical Transactions of the Royal Society A 377:20190144. (arXiv:1809.04528)

Quantum field thermal machines

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Quantum systems undergoing out-of-equilibrium dynamics provide insights into how features of quantum statistical mechanics emerge. At the same time, they are thought to be relevant for notions in quantum thermodynamics, where quantum effects are expected to play a role in the understanding of the functioning of thermal machines operating in the nanoscopic realm. That said, for the latter, steps towards the realization of quantum thermal machines in which quantum many-body systems take center stage are quite painfully lacking. For the former, while the picture of quantum lattice systems has been becoming clearer, important questions are still widely open for quantum field systems. In this talk, we will have a look at a theoretical and experimental study of the dynamical emergence of Gaussian correlations in continuous quantum many-body systems [1], witnessed by new tomographic recovery techniques [3]. Building upon these efforts, we will discuss the blueprint for a quantum field thermal machine [2] for which first data are now being taken.

[1] Decay and recurrence of non-Gaussian correlations in a quantum many-body system, T. Schweigler, M. Gluza, M. Tajik, S. Sotiriadis, F. Cataldini, S.-C. Ji, F. S. Møller, J. Sabino, B. Rauer, J. Eisert, J. Schmiedmayer, Nature Physics 17, 559 (2021).

[2] Quantum field thermal machines, M. Gluza, J. Sabino, N. H. Y. Ng, G. Vitagliano, M. Pezzutto, Y. Omar, I. Mazets, M. Huber, J. Schmiedmayer, J. Eisert, PRX Quantum, in press (2021).

[3] Quantum read-out for cold atomic quantum simulators, M. Gluza, T. Schweigler, B. Rauer, C. Krumnow, J. Schmiedmayer, J. Eisert, Communications Physics 3, 12 (2020).

Magnetization generated by microwave-induced Rashba interaction

Ora Entin-Wohlman[1], Robert I Shekhter[2], Mats Jonson[2], and Amnon Aharony[1]

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We show that a controllable dc magnetization is accumulated in a junction comprising a quantum dot coupled to nonmagnetic reservoirs if the junction is subjected to a time-dependent spin-orbit interaction. The latter is induced by an ac electric field generated by microwave irradiation of the gated junction. The magnetization is caused by inelastic spin-flip scattering of electrons that tunnel through the junction, and depends on the polarization of the electric field: a circularly polarized field leads to the maximal effect, while there is no effect in a linearly polarized field. Furthermore, the magnetization increases as a step function (smoothened by temperature) as the microwave photon energy becomes larger than the absolute value of the difference between the single energy level on the quantum dot and the common chemical potential in the leads.

[1] O. Entin-Wohlman, R. I. Shekhter, M. Jonson, and A. Aharony, Magnetization generated by microwave-induced Rashba interaction, Phys. Rev. B 102, 075419 (2020); (arXiv:2007.04122).

Quantum operations in ultrastrongly coupled quantum networks

Giuseppe Falci[1,2,5], Luigi Giannelli[1,2], Giuliano Benenti[3], Alessandro Ridolfo[1,2], Simone Montangero[4], and Elisabetta Paladino[1,2,5]

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Ultrastrong coupling (USC) between light and matter has been recently achieved in architectures of solid-state artificial atoms coupled to cavities. New phenomena related to the highly entangled nature of the eigenstates are displayed. Such architectures may provide new building blocks for quantum state processing, where ultrafast quantum gates could be performed.

Concerning quantum state processing, it has been shown that in the USC regime the dynamical Casimir effect (DCE), may pose limits on the fidelity of standard quantum operations based on quantum Rabi oscillations [3], used for processing in strongly coupled (SC) circuit-QED systems. In the USC multiphoton generation deteriorates the fidelity of such quantum operations [3] even in absence of decoherence. We show that an adiabatic protocol similar to STIRAP [1,2] may overcome this problem [4]. Ideally, the cavity is never populated, operating as a virtual bus, thus it is expected to greatly reduce the impact of DCE. We show that high fidelity operations can be performed for moderate couplings in the USC regime [3] thus allowing to operate faster than in SC. Moreover, properly crafted control extends the high fidelity region to even larger couplings. The protocol is extremely robust against DCE, in the absence of decoherence yields almost 100% fidelity for remote state transfer and multiqubit entanglement generation. It is also resilient to decay due to leakage from the cavity, which is the main decoherence mechanism for present USC architectures [3]. In this more realistic scenario, it is seen that for larger coupling (entering the deep strong coupling regime) the fidelity decreases due to the interplay between decoherence and DCE. Our results suggest that adiabatic manipulations may be a promising tool for quantum state processing in the USC regime.

[1] N. V. Vitanov, A. A. Rangelov, B. W. Shore, and K. Bergmann, Rev. Mod. Phys. 89, 015006 (2017).

[2] G. Falci, A. Ridolfo, P.G. Di Stefano, and E. Paladino, Sci. Rep. 9, 9249 (2019); DOI: 10.1038/s41598-019-45187-y

[3] G. Benenti, A. DArrigo, S. Siccardi, and G. Strini, Phys. Rev. A 90, 052313 (2014).

[4] M. Stramacchia, A. Ridolfo, G. Benenti, E. Paladino, F. M. D. Pellegrino, G. D. Maccarrone, G. Falci, arXiv:1904.04141

T32 Fri, 23 July, 16:40 - 17:00, 4 session

Highly non-Gaussian quantum physics

Radim Filip

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The talk will report about recent theoretical and experimental achievements opening the door to highly non-Gaussian quantum physics with light and mechanical oscillators. This territory is challenging for investigation, both theoretically and experimentally. After a brief introduction to the quantum non-Gaussian effects, we will present recent theoretical and experimental activities including the faithful loss-tolerant hierarchy of quantum non-Gaussianity for multiphonon generation and its experimental verification, recent experimental result on the generation and accumulation of quantum non-Gaussianity of single-atom mechanical oscillators and preparation of highly non-Gaussian GKP states of single-atom mechanical systems and superconducting circuits. The talk will conclude with other related results and the next challenges in theory and experiments with light, mechanical oscillators and superconducting circuits to stimulate discussion and further development of this field.

Strategies for quantum chemistry on a quantum computer using a factorized form of the unitary coupled cluster method

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Quantum Chemistry has been viewed as one of the most likely fields of science to benefit from quantum computing. In this talk, I will discuss some of the different strategies that can be employed to calculate electronic structure of molecules with quantum computers. Most algorithms need to balance the number of qubits against the depth of the circuit in order to be able to be run on current hardware. We will describe the different ways in which the unitary coupled-cluster approximation can be implemented on a quantum computer including describing techniques to simulate only part of the molecule on the quantum computer and to use Green's functions in the analysis. We also will discuss how to make efficient circuits and the differences between electronic encoding versus hardware efficient ansatze. While most calculations of electronic structure on quantum computers have been simple demonstrations or proofs of principle, it is possible that we will be seeing real calculations initiated over the next few years using ideas discussed in this presentation.

A Green's function perspective on the nonequilibrium thermodynamics of open quantum systems strongly coupled to baths

Michael Galperin

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Rapid development of experimental techniques at the nanoscale in the last decade has led to miniaturization of devices for energy storage and conversion to sizes where quantum mechanics becomes relevant. For example, thermoelectric single atom and single molecule junctions are expected to operate more effectively compared to their bulk analogs due to possible utilization of quantum effects. Proper description of performance of nanoscale devices for energy conversion requires development of corresponding nonequilibrium quantum thermodynamics. Moreover, with molecules chemisorbed on at least one of the contacts, thermodynamic theory should account for strong system-bath couplings. In recent years there is a surge of research in this field both experimentally and theoretically. Another active area of research establishes a connection between thermodynamic and information theory.

One of the guiding principles for theoretical research is consistency of the thermodynamic description with underlying system dynamics. The latter is conveniently described within nonequilibrium Green's function (NEGF) techniques. Here, we give dynamical NEGF based perspective on thermodynamics formulations suggested in the literature for open quantum systems that are strongly coupled to baths [1]. For the thermodynamic formulation consistent with underline dynamics, we derive bath and energy resolved expressions for entropy, entropy production, and information flows [2]. Resulting expressions reduce to expected forms in limiting cases of weak coupling or steady state. Formulation of the flows in terms of only system degrees freedom is convenient for simulation of thermodynamic characteristics of open nonequilibrium quantum systems. We utilize standard NEGF for derivations in noninteracting systems, Hubbard NEGF is used for interacting systems.

[1] N. Bergmann and M. Galperin, Eur. Phys. J. Spec. Top. (2021) https://doi.org/10.1140/epjs/s11734-021-00067-3

[2] N. Seshadri and M. Galperin, Phys. Rev. B103 (2021) 085415.

Universal dynamics far from equilibrium

Philipp Heinen[1,3], Aleksandr N. Mikheev[1,3], Christian M. Schmied[1,3], Paul Wittmer[2,3], Carlo Ewerz[2,3], and Thomas Gasenzer[1,2,3]

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Quenched or continuously driven quantum systems can show universal dynamics near non-thermal fixed points, generically in the form of scaling behaviour in space and time [1-3]. Systems where such fixed points can be realized range from post-inflationary evolution of the early universe to low-energy dynamics in cold gases. Effective field theories hold promise to describe the non-perturbative infrared dynamics by allowing to identify the relevant degrees of freedom [1,4,5]. The status of different examples and their relevance to near-linear quasiparticle dynamics as well as to the strongly non-linear dynamics of solitary waves and topological defects will be discussed [4-6].

[1] C.-M. Schmied, A. N. Mikheev, T. Gasenzer, Non-thermal fixed points: Universal dynamics far from equilibrium, Proc. Julian Schwinger Centennial Conf. and Workshop, Singapore, 2018, arXiv:1810.08143 [cond-mat.quant-gas]

[2] M. Prüfer, P. Kunkel, H. Strobel, S. Lannig, D. Linnemann, C.-M. Schmied, J. Berges, T. Gasenzer, M.K. Oberthaler, Observation of universal dynamics in a spinor Bose gas far from equilibrium, Nature 563, 217 (2018).

[3] S. Erne, R. Bücker, T. Gasenzer, J. Berges and J. Schmiedmayer, Universal dynamics in an isolated one-dimensional Bose gas far from equilibrium, Nature 563, 225 (2018).

[4] A. N. Mikheev, C.-M. Schmied, T. Gasenzer, Low-energy effective theory of non-thermal fixed points in a multicomponent Bose gas, Phys. Rev. A 99, 063622 (2019); arXiv:1807.10228 [cond-mat.quant-gas]

[5] P. Heinen, C.-M. Schmied, A.N. Mikheev, T. Gasenzer, Universal scaling dynamics of the quenched sine-Gordon system, unpublished (2020).

[6] P. Wittmer, C.-M. Schmied, T. Gasenzer, C. Ewerz, Vortex motion quantifies strong dissipation in a holographic superfluid, arXiv: 2011.12968 [hep-th] (2020).

T36 Mon, 19 July, 10:00 - 10:30, 1 session

Measurement-Induced Quantum Steering

Yuval Gefen

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Steering a quantum state towards a predesignated target state can be achieved by a set of repeated quantum measurements. The latter could be represented by strong (projective) or generalized (e.g. weak) measurements. We will discuss and comparethe paradigm of blind steering and that of active decision making.

Exploiting topology and strong interactions in electronics

Avik Ghosh

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As Moore's Law grinds to a halt, we find ourselves entering a new world of software driven hardware, of Application Specific Integrated circuits (ASICs) and machine learning accelerators. This has opened up new opportunities for unique architectures that map onto specific computational paradigms, along with emerging materials underpinning them. Quantum computing, while being noteworthy for being disruptive in algorithmic scale-up, is limited severely by size scalability for embedded IoT applications. There are however many opportunities for classical computing with topological quantum states based on present day technology that can be quite disruptive even for embedded electronics. The focus of this talk is to show how one can capitalize on topological properties of materials to enable low-power electronic devices.

The specific example I will discuss exploits isolated, metastable skyrmions in thin magnetic films for temporal memory applications. These skyrmions can be generated as a topological defect by spatial symmetry breaking, such as by engineering interfacial Dzyaloshinskii-Moriya interactions (DMI) at the interface between a magnetic film and a heavy metal. I will discuss the physics of these skyrmions, such as how ferrimagnetic films near their compensation point reduce demagnetization field and shrink skyrmions, how we can increase their lifetime with film thickness and uniaxial anisotropy, and how the skyrmions can form elongated tubes stabilized by exchange stiffness even when the DMI decays sharply away from the interface. Furthermore, we discuss how the skyrmions tend to diffuse, how they can be localized with notches etched into racetracks, and how they can be driven with spin orbit torque at speeds comparable to domain walls, while simultaneously limited by topological damping (Magnus force), Gilbert damping, spatial distortion, and ultimately by transverse spin waves.

Where can this all lead us? Topological protection, while only partial for an isolated skyrmion, nonetheless allows to keep these skyrmions metastable at dimensions where perpendicular magnets get randomized by thermal fluctuations. This allows us to engineer skyrmions as tiny, mobile magnets with linear, current-tunable speeds. We can then use these magnets to do unary computing, encoding information in the analog spatial location of a single skyrmion along a racetrack, without the need for skyrmion creation or destruction. Skyrmions driven efficiently along racetracks, their quasi-linear operation and topologically stabilized lifetimes at ultra-small sizes can potentially function as temporal memory in race logic for rapid pattern matching and intermittent-sensor processing applications. I will discuss some of the practical challenges that need to be overcome, and the considerable payoffs that can come with overcoming those challenges.

Using Boson Sampling for Efficient Simulation of Molecular Spectra on a Small Quantum Processor

Steven Mark Girvin

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'Circuit QED' is non-linear quantum optics extended to superconducting electrical circuits and represents a leading architecture for the eventual creation of large-scale fault-tolerant quantum computers. Recent remarkable theoretical and experimental progress in our ability to measure and manipulate the quantum states of individual microwave photons is leading to novel applications in quantum information processing, bosonic quantum error correcting codes and quantum simulations of bosonic systems. In this talk I will discuss how the ability to make repeated quantum non-demolition (QND) measurements of photon numbers allow accurate quantum simulation of the vibrational spectra (Franck-Condon factors) of small molecules using efficient boson sampling.

[1] 'Efficient multi-photon sampling of molecular vibronic spectra on a superconducting bosonic processor,' Christopher S. Wang, Jacob C. Curtis, Brian J. Lester, Yaxing Zhang, Yvonne Y. Gao, Jessica Freeze, Victor S. Batista, Patrick H. Vaccaro, Isaac L. Chuang, Luigi Frunzio, Liang Jiang, S. M. Girvin, and Robert J. Schoelkopf, Phys. Rev. X 10, 021060 (2020).

Non-adiabatic Berry connection, the mediator of energy, momentum, and angular-momentum transfer between electrons and nuclei

E.K.U. Gross

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The quantum dynamics of molecules and solids often involves an electronic excitation followed by nuclear motion on a somewhat slower time scale. Some of the most fascinating phenomena in physics and chemistry, such as the process of vision or the Nobel-prize-winning femto-chemistry experiments of Ahmed Zewail are of this kind. Also processes in molecular junctions may be similar, when an applied voltage leads to an electron current through the junction which then triggers nuclear motion, e.g. a perpetual rotation of the molecule representing a nano "water wheel". What is common to these processes is that, after electronic excitation, energy, momentum or angular momentum is transferred from the electronic to the nuclear subsystem (and sometimes back). Usually these processes are non-adiabatic, i.e. they cannot be described by the motion of nuclei on a single Born-Oppenheimer surface. To tackle this situation we deduce an exact factorization [1] of the fully correlated electron-nuclear wave function into a purely nuclear part and a many-electron wave function which parametrically depends on the nuclear coordinates and which has the meaning of a conditional probability amplitude. The variational principle leads to formally exact equations of motion for these two wave functions. The electronic equation is involves non-Hermitian operators which yield a very efficient way to describe and control electronic decoherence [2] in laser-induced isomerization processes. The dynamics of the nuclear subsystem is described by a time-dependent Schroedinger equation which contains a single time-dependent scalar potential energy surface and a vector potential which has the structure of a Berry connection. It turns out that this "non-adiabatic Berry connection" plays a crucial role in the transfer of energy, momentum and angular momentum from the electronic subsystem to the nuclei. In the classical limit, and likewise in the nuclear Ehrenfest equations, the vector potential leads to an electric-like force and to a Lorentz force with a magnetic-like field given by the associated Berry curvature. Consequences of these unusual forces will be explored [3]. The exact vector potential leads to a molecular "non-adiabatic Berry phase" whose calculation does not invoke the Born-Oppenheimer approximation. The value of this exact Berry phase, depending on system, may differ significantly from the standard Born-Oppenheimer molecular Berry phase.[4]

[1] A. Abedi, N.T. Maitra, E.K.U. Gross, Phys. Rev. Lett. 105 (2010) 123002.

[2] S.K. Min, F. Agostini, E.K.U. Gross, Phys. Rev. Lett. 115 (2015) 073001.

[3] A. Scherrer, F. Agostini, D. Sebastiani, E.K.U. Gross, R. Vuilleumier, Phys. Rev. X 7 (2017) 031035.

[4] S.K. Min, A. Abedi, K.S. Kim, E.K.U. Gross, Phys. Rev. Lett. 113 (2014) 263004.

T40 Thu, 22 July, 14:40 - 15:00, 3 Session

Biosensing applications of quantum emitters in diamond and phosphors

Philip Hemmer

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Fluorescent nanoparticles can probe biological processes on the nanoscale. In some systems the potential exists for quantum-enhanced sensing. I will give a brief overview of the field with emphasis on what is still needed. Then I will discuss some particular examples of fluorescent diamond and upconversion phosphor particles that have showed recent promise in these areas.

Andreev reflection of fractional quantum Hall quasiparticles

Masayuki Hashisaka[2,3], Thibaut Jonckheere[1], Takafumi Akiho[2], Satoshi Sasaki[2], Jérôme Rech[1], Thierry Martin[1], and Koji Muraki[2]

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Electron correlation in a quantum many-body state appears as peculiar scattering behaviour at its boundary, symbolic of which is Andreev reflection at a metal-superconductor interface. Despite being fundamental in nature, dictated by the charge conservation law, however, the process has had no analogues outside the realm of superconductivity so far. Here, we report the observation of an Andreev-like process originating from a topological quantum many-body effect instead of superconductivity. A narrow junction between fractional and integer quantum Hall states shows a two-terminal conductance exceeding that of the constituent fractional state. This remarkable behaviour, while theoretically predicted more than two decades ago but not detected to date, can be interpreted as Andreev reflection of fractionally charged quasiparticles. The observed fractional quantum Hall Andreev reflection provides a fundamental picture that captures microscopic charge dynamics at the boundaries of topological quantum many-body states.[1]

[1] M. Hashisaka et al., Nature Communications 12, 2794 (2021)

Thermodynamics of Mesoscopic Superconductors

Peter D. Keefe

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The superconductive phase transition involves thermal and electrodynamic relaxation processes of the control variables, the electrodynamic relaxation being three orders of magnitude faster than the thermal relaxation. This potentially renders the time differences of the control variables observable in the mesoscopic size range. [1-3]

An experiment [4] that investigated magnetization change during the phase transition of a mesoscopically sized tin specimen will be used to extrapolate the thermodynamics.

[1] P.D. Keefe, Quantum mechanics and the second law of thermodynamics: an insight gleaned from magnetic hysteresis in the first order phase transition of an isolated mesoscopic size Type I superconductor, T151, 014029, IOP Publishing (2012).

[2] P.D. Keefe, Quantum limit to the second law by magneto-caloric effect, adiabatic phase transition of mesoscopic-size Type I superconductor particles, Physica E, Vol. 29, Oct. 2005, Pgs. 104-110.

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

[4] O.S. Lutes and E. Maxwell, Superconducting Transitions in Tin Whiskers, Phys. Rev., 97, 1718 (1955).

Getting rid of nonlocality from quantum physics through Bohr's complementarity

Andrei Khrennikov

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

This talk is aimed to dissociate nonlocality from quantum theory [1]. We demonstrate that the tests on violation of the Bell type inequalities are simply statistical tests of local incompatibility of observables. In fact, these are tests on violation of the Bohr complementarity principle. Thus, the attempts to couple experimental violations of the Bell type inequalities with "quantum nonlocality" is really misleading. These violations are explained in the quantum theory as exhibitions of incompatibility of observables for a single quantum system, e.g., the spin projections for a single electron or the polarization projections for a single photon. Of course, one can go beyond quantum theory with the hidden variables models (as was suggested by Bell) and then discuss their possible nonlocal features. However, conventional quantum theory is local.

[1] A. Khrennikov, Entropy 21 (2019) 806.

T44 Tue, 20 July, 11:40 - 12:00, 2 session

Charging and Thermal Hall Effect in Superconductors

Marie Ohuchi[1], Hikaru Ueki[2], Ezekiel Sambo Joshua[1], Wataru Kohno[1], Hiroki Morita[1], and Takafumi Kita[1]

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We present a talk about recent theoretical progress of our understanding on the charging and thermal Hall effect in superconductors, which has been brought about based on the augmented quasiclassical equations of superconductivity. The two phenomena are both outside the description of the standard Ginzburg-Landau and quasiclassical Eilenberger equations, for which we need to incorporate the next-to-the-leading order corrections. The resulting augmented quasiclassical equations have proved to be quite powerful in elucidating presence of new and/or unexpected phenomena in superconductors. They include inhomogeneous charging in the Abrikosov lattice that is superimposed on the magnetic-field distribution, intrinsic charging near the surface of d-wave superconductors, and a drastic enhancement of thermal Hall angle in d-wave superconductors at low temperatures. They will be discussed in detail together with the theoretical formalism for calculating them.

[1] H.Ueki, H. Morita, M. Ohuchi, and T. Kita, Phys. Rev. 101, 184518 (2020). “Drastic enhancement of the thermal Hall angle in a d-wave superconductor”

[2] E. S. Joshua, H. Ueki, W. Kohno, and T. Kita, J. Phys. Soc. Jpn. 89, 104702 (2020). “Zero-Field Surface Charge Due to the Gap Suppression in d-Wave Superconductors”

[3] M. Ohuchi, H.Ueki, and T. Kita, arXiv:2011.04856 “Charging in the Abrikosov lattice of type-II superconductors”

Coarse-graining discrete stochastic models of biochemical systems

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Many biological systems can be described by finite Markov models. Here we discuss methods for simplifying such models and present a method that is based on merging adjacent states. The approach preserves the steady-state probability distribution and all steady-state fluxes except the one between the merged states. A hierarchy of different levels of coarse graining of the underlying microscopic dynamics can be obtained by iteratively merging nodes. The tradeoff between the resulting simplification due to coarse-graining and the information loss relative to the original model provides a criterion for an optimal level of coarse-graining.

As a case study, the method is applied to the cycle kinetics of the molecular motor kinesin, where the optimally coarse-grained model is dependent on the load force, reflecting the different dominant chem-mechanical cycles under different load forces.

[1] D. Seiferth, P. Sollich, and S. Klumpp, Coarse graining of biochemical systems described by discrete stochastic dynamics, Phys. Rev. E 102, 062149 (2020).

Three-body correlations in nonlinear response of correlated quantum liquid

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Understanding the properties of correlated quantum liquids is a fundamental issue of condensed matter physics. Even in such a correlated case, fascinatingly, we can tell that the equilibrium fluctuations of the system govern its linear response to an external field, relying on the fluctuation dissipation relations based on the two-body correlations. To go beyond this well-established regime, the three-body correlations come into the game as we see in various physical systems.

Here, we investigate a quantum dot in the Kondo regime, which is a controllable realization of such a correlated quantum liquid [1]. We achieve the Kondo effect in the unitary limit and quantitatively measure the three-body correlations and their role in the non-equilibrium regime, which perfectly validates recent results of the Fermi liquid theory [2-5]. We demonstrate its importance when time-reversal symmetry is broken, solving a long-standing puzzle of the Kondo systems under the magnetic field [3].

The demonstrated method to relate three-body correlation and non-equilibrium transport opens a way for further investigation of the dynamics of quantum many-body systems.

This work was performed in collaboration with T. Hata, Y. Teratani, T. Arakawa, S.-H. Lee, M. Ferrier, R. Deblock, R. Sakano, and A. Oguri.

[1] T. Hata, Y. Teratani, T. Arakawa, S. Lee, M. Ferrier, R. Deblock, R. Sakano, A. Oguri, and K. Kobayashi, Nature Comm. 12, 3233 (2021).

[2] C. Mora, C. P. Moca, J. von Delft, and G. Zaránd, Phys. Rev. B 92, 075120 (2015).

[3] M. Filippone, C. P. Moca, J. von Delft, and C. Mora, Phys. Rev. B 95, 165404 (2017).

[4] A. Oguri and A. C. Hewson, Phys. Rev. Lett. 120, 126802 (2018).

[5] A. Oguri and A. C. Hewson, Phys. Rev. B 97, 035435 (2018).

Quantum optics with ultra-narrow nuclear resonances

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Narrow optical resonances corresponding to the quantum transitions in atoms, molecules, quantum dots, rare-earth doped crystals and color centers are in the basis of quantum optics with a broad range of its applications in frequency standards, quantum sensors, quantum communication and simulation, etc. Comparable or even much higher quality factors (such as 1012 in 57Fe or 1019 in 45Sc) are intrinsically inherent to the nuclear recoilless resonances at the hard x-ray frequencies. Moreover, such high-quality nuclear resonances occur at room temperature in solids. However, the direct realization of the quantum optical concepts such as Autler-Towns splitting, EIT and optical quantum memories in the nuclear ensembles is challenging due to the absence of the relatively bright spectrally narrow hard x-ray radiation sources as well as high quality cavities. Nevertheless, several alternative techniques, developed in the second part of the 20th century (see [1-3] and the references there in), can be used for efficient acoustic/magnetic control of the quantum interfaces between the x-ray photons and nuclear ensembles. In this talk we discuss our recent demonstration of the phenomenon of the acoustically induced transparency [4,5], as well as the recent proposals for realization of quantum memory and spectral intensity enhancement [6] in the hard X-ray range. F,G. V., Y.S., and O.K. appreciate the support by the NSF, grant number PHY-2012194. Y.V. R., I.R.K., and V.A.A. acknowledge support by the Ministry of Science and Higher Education of the Russian Federation under Contract No. 14.W03.31.0032 (numerical studies). Y.V.R. acknowledges financial support of his analytical studies from the Government of the Russian Federation (Mega-Grant No. 14.W03.31.0028). I.R.Kh. acknowledges support by the Foundation for the Advancement of Theoretical Physics and Mathematics “BASIS”.

[1] Yu. V. Shvyd'ko and G. V. Smirnov, J. Phys. Condens. Matter 4, 2663 (1992).
[2] Yu. V. Shvyd'ko, et al., Phys. Rev. Lett. 77, 3232 (1996).
[3] G.V. Smirnov et al., Phys. Rev. A 71, 023804 (2005).
[4] Y. V. Radeonychev et al., Phys. Rev. Lett. 124, 163602 (2020).
[5] I. R.Khairulin,et.al.,Sci Rep 11,7930 (2021).https://doi.org/10.1038/s41598-021-86555-x
[6] X. Zhang et al., Phys. Rev. Lett. 123, 250504 (2019).

Characterizing Quantum Many-Body States via Entanglement Hamiltonian Learning

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The experimental characterization and quantification of entanglement properties, and the entanglement spectrum in particular, play a major role in our understanding of modern quantum many body physics in the lab. For most quantum lattice systems of interest, the reduced density matrix ϱ of the lattice is described by a thermal state of a quasi-local Entanglement Hamiltonian $\varrho = \exp(-\beta H)$. As a I will show in this talk, the parametrization of the reduced density matrix in terms of the Entanglement Hamiltonian allows for the determination of entanglement properties like the Schmidt-decomposition with a drastically reduced number of measurements. Furthermore it enables efficient quantum protocols to determine the Entanglement Hamiltonian whose properties can be investigated on the quantum device without any additional classical post-processing steps. Finally, I will provide prospects that learning of local Hamiltonians has the potential of verifying quantum simulators in a regime inaccessible to classical simulations.

Plasmon assisted Cooper pair formation at room temperature

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Electron pair formation is the basis of low temperature superconductivity. Such pair formation phenomenon has been theoretically forecasted also for electron-electron scattering processes in strong electromagnetic fields. In the present work the strong electromagnetic fields were created by femtosecond Ti:Sa lasers, used to excite surface plasmons in gold films at room temperature in the Kretschmann geometry. Studies were conducted using a surface plasmon near field scanning tunneling microscope, measuring it's response to the excitation at plasmonic hot spots on the gold surface, and an electron time-of-flight spectrometer, measuring the spectra of multi-plasmon emitted electrons as the function of exciting laser intensity. Narrow periodic „resonances" have been found in the time-of-flight spectra of electrons, with anomalies in the laser intensity range, where electron pairing has been found, since in this laser intensity range, some of the also periodic in time, but less frequent narrow peaks have been detected. They are about twice as intense as the remaining ones, indicating the simultaneous detection of two electrons. These electrons could be emitted only from Cooper pairs, since in our and other's understanding this observation can not be interpreted in any other way [1,2]. In this laser intensity range the Meissner-effect has also been observed. Detailed analysis of both the STM and TOF findings are presented.

[1] P. Racz, N. Kroo: Physics of Wave Phenomena 27(3), pp. 1-5 (2019)

[2] K.A. Kouzakov, J. Berakdar: PRL 91, 257007 (2003)

Unitary and Non-Unitary Few-Mode Heat Machines

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The enormous number of hot and cold bath modes involved in standard heat machines (HM) justifies their thermodynamic description. Anomalous, non-thermal/coherent bath effects can strongly boost HM performance [1-3], but these HM, as their standard counterpart, are still treated as dissipative, open systems. Recently, we have changed the accepted paradigm by considering HM involving only few hot and cold "bath" modes at the same frequency. This allows their exact quantum analysis, without resorting to open-system approaches. Within the new paradigm, we have introduced [4] the concept of non-unitary work extraction from single-mode thermal noise by homodyne measurements followed by unitary manipulation of the post-measured state. For thermal noise with more than 1 quantum on average, optimized measurements can yield heat to work conversion with efficiency that approaches unity when the mean number of quanta is well above 1. This protocol is substantially superior to existing concepts of information and heat engines. Alternatively, we propose a fully coherent or unitary principle of operating HM by mixing few hot and cold modes in Kerr-nonlinear interferometers. Such devices enable heat to work conversion (or vice versa) in a selected mode at the expense of other modes. They are autonomous and require no information input. By breaking the dissipative HM paradigm, we can track the transition from coherent dynamics to thermodynamics as the number of "bath" modes grows. This may pave the way to new technologies of energy conversion.

[1] W. Niedenzu, V. Mukherjee, A.Ghosh, AG Kofman and G. Kurizki, Nature Commun. 9, 1 (2018)

[2] A.Ghosh, D. Gelbwaser, W. Niedenzu, A.I. Lvovsky, I. Mazets, MO.Scully and G.Kurizki, PNAS 115, 9941 (2018)

[3] A.Ghosh, CL Latune, L.Davidovich and G.Kurizki, PNAS 114, 12156 (2017)

[4] T.Opatrny, A.Misra and G.Kurizki, PRL in press);arxiv 2106.09653

Pseudo-modes for bosons and fermions

Neill Lambert[1], Mauro Cirio[2], Shahnawaz Ahmed[3], Po-chen Kuo[4], and Franco Nori[1,5]

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Pseudo-mode mappings of continuum environments to discrete modes have recently received new attention after earlier limitations to the method were overcome [1]. Here we summarize these improvements, focusing on the peculiar non-physical nature of some of the modes, and illustrate applications to zero and finite temperature open-quantum-system problems involving bosonic and fermionic environments. Comparisons to the hierarchical-equations-of-motion method [2] suggest pseudo-modes can be used to study a range of problems in many-body waveguide QED, quantum thermodynamics, light-harvesting in photosynthetic complexes, single-molecule electronics, and quantum control.

[1] N. Lambert, S. Ahmed, M. Cirio and F. Nori, Nature Communications 10, (2019), 3721.
[2] N. Lambert et al. arXiv preprint arXiv:2010.10806 (2020).

From Generalized Resource Theories of Quantum Thermodynamics to Novel Quantum Thermometry

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In my talk I will review recent efforts of ICFO Quantum Optics Group in the field pf quantum thermodynamics. First, I will start by discussing generalized laws of thermodynamics in the presence of system-bath correlations, as well as thermodynamics as a consequence of information conservation. Second, I will discuss resource theory of heat and work with non-commuting charges, providing yet another new foundation of thermodynamics. Resource theory with two baths will allow to demonstrate the possibility of attaining Carnot efficiency with quantum and nanoscale heat engines. Third, I will discuss quantum engines that deliver maximum power with Carnot efficiency in one-shot finite-size regime. I will relate these results to the general bounds on the capacity and power of quantum batteries. Finally, time permitting, I will review our proposals to use Bose polarons, or more generally impurities in an ultracold Bose gas to measure ultra-precisely ultralow temperatures.

Experimental verification of a reversed Clausius inequality in a closed system

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[2]*Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany*

Thermodynamic inequalities characterize the direction of nonequilibrium processes. A prominent example is the Clausius inequality that lower bounds a change in entropy by the ratio of supplied heat and temperature. However, this result presupposes that a system is in contact with a heat bath that drives it to a thermal state. For initially isolated systems that are moved from an equilibrium state by a dissipative heat exchange, the Clausius inequality has been predicted to be reversed. We here experimentally investigate the nonequilibrium thermodynamics of an initially isolated dilute gas of ultracold Cesium atoms that can be either thermalized or pushed out of equilibrium by means of laser cooling techniques. We determine in both cases the phase-space dynamics by tracing the evolution of the gas with position-resolved fluorescence imaging, from which we evaluate all relevant thermodynamic quantities. We confirm the validity of the usual Clausius inequality for the first process and of the reversed Clausius inequality for the second transformation. Our findings provide important insight into thermodynamic inequalities, and the associated direction of nonequilibrium processes, in nanoscopic systems that do not equilibrate on their own.

Hyperbolic band theory

Joseph Maciejko[1] and Steven Rayan[2]

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The notions of Bloch wave, crystal momentum, and energy bands are commonly regarded as unique features of crystalline materials with commutative translation symmetries. Motivated by the recent realization of hyperbolic lattices in circuit quantum electrodynamics, we exploit ideas from algebraic geometry to construct the first hyperbolic generalization of Bloch theory, despite the absence of commutative translation symmetries. For a quantum particle propagating in a large class of hyperbolic lattice potentials, we construct a continuous family of eigenstates that acquire Bloch-like phase factors under a discrete but noncommutative group of hyperbolic translations, the Fuchsian group of the lattice. A hyperbolic analog of crystal momentum arises as the set of Aharonov-Bohm phases threading the noncontractible cycles of a higher-genus Riemann surface that is naturally associated with this group. This crystal momentum lives in a higher-dimensional Brillouin zone torus, known in algebraic geometry as the Jacobian of the Riemann surface, and over which a discrete set of continuous energy bands can be computed. Familiar concepts such as particle-wave (Fourier) duality, point-group symmetries, and the tight-binding approximation are likewise generalized to hyperbolic lattices. We demonstrate our theory by explicitly computing hyperbolic Bloch wavefunctions and bandstructures numerically for hyperbolic lattice potentials associated with a particular Riemann surface of genus two, the Bolza surface.

Hall Effect and the problem of "hidden momentum"

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It is a generally accepted fact that electromagnetic field carries energy and momentum. If it interacts with a material system, momentum originally stored in the field may be partially converted into ordinary mechanical momentum of the ponderable system. While for quickly oscillating electromagnetic fields such a conversion of electromagnetic momentum into mechanical one was made clear by numerous theoretical studies and confirmed by convincing experimental evidence of the light pressure, for the case of purely static electromagnetic fields is the situation quite different. Since it is very difficult in this case to localize the converted momentum of non-electromagnetic nature within the material system, the term "hidden momentum" is traditionally used. Moreover, the effect is as a rule very subtle, of order of $\sim 1/c^2$, so that till now it has been studied only theoretically and has never been demonstrated experimentally. However, in this contribution we will show, that ordinary Hall Effect devices represent material systems where the momentum balance between static electromagnetic field and electronic subsystem is relatively easy to treat, both theoretically and experimentally. This circumstance may be helpful for resolution of controversies related to the momentum of static electromagnetic fields.

T56 Tue, 20 July, 8:30 - 9:00, 1 session

Ionic Coulomb blockade and selectivity in biological ion channels

William A. T. Gibby[1], Miroslav L. Barabash[1], Carlo Guardiani[1,5], Olena A. Fedorenko[3,4], Stephen K. Roberts[3], Dmitry G. Luchinsky[1,2], and Peter V. E. McClintock[1]

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Biological ion channels are essential to life in all its forms. By enabling the selective transfer of ions across lipid bilayers, they facilitate the establishment of intracellular media compatible with the biochemical reactions essential for replication and metabolism. Their selectivity is known to be associated with fixed negative charge Q_f in a narrow part of the channel called the selectivity filter. Remarkably, many properties of ion channels can now be understood [1] by analogy with the physics of quantum dots: e.g. Coulomb blockade oscillations in quantum dots correspond to the alternating conduction bands and stop bands seen for ions in channels as Q_f is varied (emergent phenomena, quite unexpected from known channel structure). The first systematic experimental and numerical tests of the ionic Coulomb blockade picture [2] will be discussed together with recent work developing a fundamental statistical theory [3] of the conduction process.

[1] I. Kh. Kaufman, P. V. E. McClintock, and R. S. Eisenberg, New J. Phys. 17 (2015) 083021.

[2] O. A. Fedorenko, I. Kh. Kaufman, W. A. T. Gibby, M. L. Barabash, D. G. Luchinsky, S. K. Roberts, and P. V. E. McClintock, Biochim. Biophys. Acta 1862 (2020) 183301.

[3] W. A. T. Gibby, M. L. Barabash, C. Guardiani, D. G. Luchinsky, and P.V.E. McClintock, Phys. Rev. Lett. 126 (2021) 218102.

Measuring entropies of exotic quasi-particles?

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In recent years many candidate setups have been proposed to support exotic quasi-particles, such as Majorana fermions (MFs), which may be relevant for quantum computing, but whether these particles have been observed experimentally is currently the topic of vivid debate. Entropy measurements can unambiguously separate these quasi-particles from other, simpler excitations. The entropy of a MFs is, for example, log2 /2 (in units of the Boltzman constant), a fractional value that cannot be attributed to a localized excitation. However, standard entropy measurements applicable to bulk systems cannot be utilized in measuring the additional entropy of a mesoscopic device, which may be due to less than a single electron in the device. In this talk I will describe recent theoretical and experimental progress in performing such measurements, either using thermopower and/or using the Maxwell relations. Particular examples will be single and double quantum dots in the Coulomb blockade regime. Lastly I will show how the formalism has been generalized to deduce the entropy from conductance measurements, and, applying it to a setup where two and three-channel Kondo physics have been previously observed, yields the fractional entropy of a single MF and a single Fibonacci anyon.

Negative Casimir Entropies and their Implications

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It has been recognized for some time that even for perfect conductors, the interaction Casimir entropy, due to quantum/thermal fluctuations, can be negative. This result was not considered problematic because it was thought that the self-entropies of the bodies would cancel this negative interaction entropy, yielding a total entropy that was positive. In fact, this cancellation seems not to occur. The positive self-entropy of a perfectly conducting sphere does indeed just cancel the negative interaction entropy of a system consisting of a perfectly conducting sphere and plate, but a model with weaker coupling in general possesses a regime where negative self-entropy appears. The physical meaning of this surprising result remains obscure. In this presentation we re-examine these issues, using improved physical and mathematical techniques, partly based on the Abel-Plana formula, and present numerical results for arbitrary temperatures and couplings, which exhibit the same remarkable features. The extension of these results to include dissipation, and the significance of such a negative self-entropy is being explored.

Experiments on open quantum systems made of superconducting qubits with tunable coupling to their environment

Mikko Möttönen[1,2], Roope Kokkoniemi[1,5], Jean-Philipper Girard[1], Arto Viitanen[1], Kassius Kohvakkka[1], Timm Mörstedt[1], Matti Silveri[1], Maté Jenei[1,5], Vasilii Sevriuk[1,5], Kuan Yen Tan[1,5], Dibyendu Hazra[1,2], Antti Laitinen[3,6], Joonas Govenius[1,2], Russell Evan Lake[1,7], Antti Karjasilta[1], Iiro Sallinen[1], Visa Vesterinen[1,2], Matti Partanen[1,5], Ji Yu Tan[4], Kok Wai Chan[5], Wei Liu[1,5], Pertti Hakonen[3], Suman Kundu[1], Jan Goetz[1,5], Leif Grönberg[2], Tapio Ala-Nissilä[1], Vasilii Vadimov[1], and Valtteri Lahtinen[1]

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We present a quantum-circuit refrigerator [1,2], i.e., a tunneling device that can be used to adjust on demand the dissipation of a superconducting quantum electric circuit. In our most recent experiments, we were able to operate this device in a full rf mode [3], where the energy needed for such refrigeration is provided by microwaves. In addition, we present ultrasensitive bolometers based on superconducting proximity effect [4]. Our bolometers have reached measured noise equivalent powers of a few tens of zeptojoules per square-root hertz at thermal time constants of a few hundred nanoseconds. In the calorimetric mode, these sensors show potential for energy resolutions of a single zeptojoule and well below. These bolometers could be used in the future as measurement and characterization devices of engineered environments such as those based on the quantum-circuit refrigerator.

[1] K. Y. Tan, M. Partanen, R. E. Lake, J. Govenius, S. Masuda, and M. Möttönen, Nature Commun. 8 (2017) 15189.

[2] M. Silveri, S. Masuda, V. Sevriuk, K. Y. Tan, Eric Hyyppä, M. Partanen, J. Goetz, R. E. Lake, L. Grönberg, and M. Möttönen, Nat. Phys. 15 (2019) 533.

[3] A. Viitanen, M. Silveri, M. Jenei, V. Sevriuk, K. Y. Tan, M. Partanen, J. Goetz, L. Grönberg, V. Lahtinen, M. Möttönen, Photon-number-dependent effective Lamb shift, arXiv:2008.08268 (2021).

[4] R. Kokkoniemi, J.-P. Girard, D. Hazra, A. Laitinen, J. Govenius, R. E. Lake, I. Sallinen, V. Vesterinen, P. Hakonen, and M. Möttönen, Nature 586 (2020) 47.

On the way to a demonstration of a T-cubed atom interferometer

Matthias Zimmermann[2], Maxim A Efremov[2], Wolfgang P Schleich[2], Jeffrey P Lee[1], and Frank A Narducci[1]

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In this talk, I will discuss a novel atom interferometer with phase that scales as T cubed, where T is the time between the light pulses that form the atom optics of the interferometer. Implementation of this interferometer requires that the atoms move in a linear potential, which we create using an appropriately tailored magnetic field. The magnetic field is imaged using Raman spectroscopy and details of the techniques to make the field will be discussed. I will next discuss our techniques to measure Raman and Ramsey spectra in a magnetic field with a gradient, which includes applying a chirp to the laser system providing the Raman fields. The spectra are produced and displayed as 2D images and the analysis requires some de-skewing of our data. Our preliminary measurements on a full atom interferometer showed oscillations that indeed scaled as T-cubed, but subsequent measurements showed that the oscillations may not be the effect we seek. The talk will end with a mystery.

The interior of astrophysical black holes

Theo M. Nieuwenhuizen

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A large class of stationary, non-rotating black hole metrics is proposed, in which the interior is regular with a core consisting of a condensate of Higgs and Z bosons generated from the nuclear binding energy of the initial H atoms. Gravitational collapse is prevented by the negative pressures of the Higgs particles and a negative radial pressure due to a small imbalance in the distribution of electric charges. Non-condensed, thermal particles are present as well.

The approach holds for masses exceeding 1.5 Neptune masses or 0.000075 solar masses, hence for all astrophysical black holes. The inner horizon sets an inner core of 11 cm, while the characteristic radius of the full core is 270 $(M/M_{\odot})^{1/3}$ cm. For increasing charge, the core expands; for extremal charge, it fills the interior.

While the existence of charged black hole is in doubt, the approach can likely be extended to rotating black holes. When the rotation is nearly extremal, the core may be exposed in black hole merging, so that such a black hole acts somewhat like a neutron star, be it with any mass.

[1] Theo M. Nieuwenhuizen, to appear

Quantum Nonlinear Optics without Photons, how to excite two or more atoms simultaneously with a single photon, and other unusual properties of ultra-strongly-coupled QED systems

Franco Nori

RIKEN, Saitama, Japan; and University of Michigan, Ann Arbor, USA

Spontaneous parametric down-conversion is a well-known process in quantum nonlinear optics in which a photon incident on a nonlinear crystal spontaneously splits into two photons. Here we propose an analogous physical process where one excited atom directly transfers its excitation to a pair of spatially separated atoms with probability approaching 1. The interaction is mediated by the exchange of virtual rather than real photons. This nonlinear atomic process is coherent and reversible, so the pair of excited atoms can transfer the excitation back to the first one: the atomic analog of sum-frequency generation of light. The parameters used to investigate this process correspond to experimentally demonstrated values in ultrastrong circuit quantum electrodynamics. This approach can be extended to realize other nonlinear interatomic processes, such as four-atom mixing, and is an attractive architecture for the realization of quantum devices on a chip. We show that four-qubit mixing can efficiently implement quantum repetition codes and, thus, can be used for error-correction codes.

A few recent references (mostly 2016-2021) on this topic (ultra-strong coupling cavity QED) are listed below and freely available online at: http://dml.riken.jp/pub/Ultra-strong/

[1] M. Cirio, et al., Ground State Electroluminescence, Phys. Rev. Lett. 116, 113601 (2016)

[2] L. Garziano, et al., 1 Photon Can Simultaneously Excite 2 Atoms, Phys.Rev.Lett (2016)

[3] A.F. Kockum, et al., Quantum nonlinear optics with ... virtual photons, PRA 95 (2017)

[4] M. Cirio, et al., Amplified ... Virtual Radiation Pressure, Phys. Rev. Lett. (2017)

[5] R. Stassi, et al., Quantum Nonlinear Optics without Photons, Phys. Rev. A (2017)

[6] V. Macrì, et al., Dynamical Casimir Effect in Optomechanics ..., Phys. Rev. X (2018)

[7] W. Qin, et al., Exponentially Enhanced Light-Matter Interaction, ..., PRL (2018)

[8] R. Stassi, F. Nori, Long-lasting quantum memories ... , Phys. Rev. A 97, 033823 (2018)

[9] A.F. Kockum, A. Miranowicz, S.D. Liberato, S. Savasta, F. Nori, Ultrastrong coupling between light and matter, Nature Reviews Physics 1, 19–40 (2019) - Pedagogical Review

[10] O. Di Stefano, et al., Interaction of Mechanical Oscillators Mediated by the Exchange of Virtual Photon Pairs, Phys. Rev. Lett. 122, 030402 (2019)

[11] O. Di Stefano, et al., Resolution of gauge ambiguities in ultrastrong-coupling cavity quantum electrodynamics, Nature Physics 15, pp. 803–808 (2019)

[12] V. Macrì, F. Nori, A.F. Kockum, Bell and GHZ states in USC circuit QED, PRA (2018)

Thermal rectification through a nonlinear quantum resonator

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We present a systematic study of thermal rectification in a prototypical low-dimensional quantum system - a nonlinear resonator: we identify necessary conditions to observe thermal rectification and we discuss strategies to maximize it. In the strongly anharmonic regime where the system reduces to a qubit, we derive general upper bounds on rectification in the weak system-bath coupling regime, and we show how the Lamb shift can be exploited to enhance rectification. We then go beyond the weak-coupling regime by employing different methods: (i) including cotunneling processes, (ii) using the nonequilibrium Green's function formalism, and (iii) using the Feynman-Vernon path integral approach. We find that the strong coupling regime allows us to violate the bounds derived in the weak-coupling regime, providing clear signatures of high-order coherent processes visible in the thermal rectification. In the general case, where many levels participate to the dynamics, heat rectification is calculated with the equation of motion method and with a mean-field approximation. We find that the former method predicts, for a small or intermediate anharmonicity, a larger rectification coefficient.

[1] Bibek Bhandari, Paolo Andrea Erdman, Rosario Fazio, Elisabetta Paladino, Fabio Taddei Physical Review B 103, 155434 (2021)

T64 Fri, 23 July, 15:10 - 15:30, 3 Session

Dispersion of a Single Atom Experienced by Single Photon

Yuri Rostovtsev[2], Billie DeLuca[1], Colin Roy[2], and Anil Patnaik[1]

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Refractive index of a system is typically considered as the bulk response of a medium to an incoming electromagnetic field. However, the incoming light would experience the same dispersion even with a single atom at the target. In this talk, we will consider propagation of single photon interacting with a single two-level atom to determine the dispersion behavior and also calculate the phase and group velocity of the single photon wave packet to further analyze the dispersion experienced by the single photon. The results are of significant importance for long-distance quantum communications.

Optimal cycles for finite-time Carnot engines

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[1]*ICFO – Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology,08860 Castelldefels (Barcelona), Spain*
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We consider the optimization of a finite-time Carnot engine characterized by small dissipations. We bound the power with a simple inequality and show that the optimal strategy is to perform small cycles around a given working point, which can be thus chosen optimally. This optimal point is independent of the figure of merit combining power and efficiency that is being maximized. Furthermore, for a general class of dissipative dynamics the maximal power output becomes proportional to the heat capacity of the working substance. Since the heat capacity can scale supra-extensively with the number of constituents of the engine, this enables us to design optimal many-body Carnot engines reaching maximum efficiency at finite power per constituent in the thermodynamic limit.

Open quantum systems on quantum computers

Francesco Petruccione

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The numerical solution of Markovian master equations can be approached through the unravelling into a corresponding stochastic Schroedinger equation. Here we describe how to implement the simulation of such a stochastic Schroedinger equation on a noisy Intermediate-scale quantum computer. As a proof of concept we show how to simulate the unravelling of various single-qubit and two-qubit master equations on IBMQ hardware.

"The Observations Obtained under the Specified Circumstances:" What quantum measurement is, and what it is not.

Arkady Plotnitsky

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This paper reconsider the concept of quantum measurement, following Bohr, leading him to his concept of "phenomena," as applicable in quantum physics, defined as "the observation obtained under the specified circumstances." This concept makes the terms "observation" and "measurement," as conventionally understood, inapplicable in considering quantum phenomena. These terms are remnants of classical physics or still earlier history, from which classical physics inherited it, beginning with the ancient Greek thinking and the rise of geometry there. As understood here, a quantum measurement does not measure any property of the ultimate constitution of the reality responsible for quantum phenomena, which this constitution would be assumed to possess before the act of observation. Hence, the concept of observation requires a different understanding as well. An act of observation in quantum physics establishes quantum phenomena by an interaction between the instrument and the quantum object, or in the present view the ultimate constitution of the reality responsible for quantum phenomena and, at the time of measurement, also quantum objects (with are RWR-type entities as well). I qualify because in the view, advanced in this paper, in contrast to that of Bohr, quantum objects are assumed to exist only at the time of measurement and not independently. Then what is so observed as the data or information can be measured classically, in classical bits, just as one measures what is observed in classical physics, where, however, what is so measured could be associated with the object itself considered for all practical purposes. As far as the observed data or information is concerns a quantum measurement is not a measurement of anything but a number or bit generator, something akin to a quantum computer created by our interaction with nature. The paper will also consider a quantum measurement as an entanglement between the quantum object considered and the measurement instruments, and implication of this aspect of quantum measurement for the question of quantum nonlocality.

Uncertainty relation for enzymes, resetting systems, and other processes with irreversible transitions

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[2]*School of Chemistry, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, 6997801, Tel Aviv, Israel.*

The thermodynamic uncertainty relation (TUR) shows that the fluctuations of currents are bounded from below by the inverse entropy production. When one or more transitions are completely irreversible the entropy production diverges, and the TUR becomes non-informative. We show that additional bounds, which mix entropic and dynamic contributions, hold for such processes. Crucially, these new bounds are tighter in the presence of irreversible transitions. A steady-state process with resetting, and a transient first-passage problem are used as examples. We also discuss the connections between the bounds and the Aldous-Shepp bound that is often used in statistical kinetics.

[1] A. Pal, S. Reuveni, and S. Rahav, Thermodynamic uncertainty relation for systems with unidirectional transitions, Phys. Rev. Research, 3, 013273 (2021).

[2] A. Pal, S. Reuveni, and S. Rahav, Thermodynamic uncertainty relation for first-passage times on Markov chains, arXiv:2103:16578 (2021).

Quantum gases in free-fall

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for the QUANTUS/MAIUS cooperation
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Free falling laboratories allow to generate, study and exploit quantum gases and their mixtures at lowest kinetic energy scales. By exploiting collective excitations in a Bose-Einstein condensate (BEC), we succeeded to reduce its total internal kinetic energy in three dimensions to few tens of Pikokelvins making it an interesting source for interferometry where wave packets are coherently split and travel for seconds in an interferometer. Vice versa, interferometry is a powerful method to analyse the expansion of a quantum gas over macroscopic time scales and to optimize the protocols for manipulating the BECs.

Regarding mixtures, the absence of buoyancy is one of the most intriguing consequences of weightlessness. On ground gravity breaks symmetry of space and introduces e.g. a preferential axis for the layering and alignment of different types of fluids. The sounding rocket mission MAIUS-1, being a stepping stone for space-borne coherent atom optics, served to investigate the generation of Rubidium Bose-Einstein condensates (BECs) in space and their spatial coherence after release in free fall. Building on this heritage, we prepare a second mission for investigating the generation of BECs made of potassium (K-41) and rubidium (Rb-87) and their mixing for comparisons to ground based experiments.

Beyond studies of the behavior of quantum fluids in the absence of buoyancy, both species will be in future simultaneously exploited for interferometry validating the methods as proposed for a satellite-based quantum test of the universality of Einstein's principle of equivalence (STE-QUEST mission). The experiments will complement the studies foreseen with NASA's Cold Atom Laboratory in the near future and prepare the NASA-DLR Bose-Einstein-Condensate and Cold-Atom-Laboratory (BECCAL), a future multi-user facility for exploring quantum mixtures in tailored potentials such as blue detuned boxes.

The QUANTUS experiments and MAIUS missions build on the cooperation between the groups of C. Lämmerzahl (Univ. Bremen), A. Peters (Humboldt Univ. Berlin/Ferdinand Braun Institut), T. Hänsch/J.Reichel (MPQ/ENS), K. Sengstock/P. Windpassinger (Univ. Hamburg/Univ. Mainz), R. Walser (TU Darmstadt), and W.P. Schleich (Univ. Ulm) and the Leibniz University Hannover.

This project is supported by the German Space Agency Deutsches Zentrum für Luft- und Raumfahrt (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWI) under grant number DLR 50WM1552-1557 and the Cluster of Excellence Quantum-Frontiers.

Negative Delta-T Noise in the Fractional Quantum Hall Effect

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Noise is a fundamentally inescapable ingredient of any electronic device. While at first it may be regarded as a nuisance, it has now been broadly accepted as a key tool to improve our understanding of nanoscale conductors. Electronic noise is typically broken down into two contributions associated with different underlying physical phenomena. Thermal (or Johnson-Nyquist) noise is an equilibrium property, arising at finite temperature from the thermal motion of electrons. Shot noise manifests itself in a non-equilibrium situation, when current flows through a conductor, as a consequence of electrons being transmitted or reflected predominantly on a given side of the device. While this non-equilibrium situation is typically achieved by imposing a bias voltage on the device, an intriguing alternative was recently uncovered. Indeed, one can in principle work at zero voltage bias and instead connect the sample to two reservoirs at different temperatures.

This was realized experimentally using atomic-scale metallic junctions [1], where the authors showed that, while no net current was flowing through the device, as expected, a finite non-equilibrium noise signal was measured, which they dubbed “delta-T noise”. This previously undocumented source of noise, distinct from thermoelectric effects, actually corresponds to some form of temperature-activated shot noise: it is purely thermal in origin, but only generated in a non-equilibrium situation.

Here, we propose to investigate the fate of delta-T noise in a prototypical strongly correlated state, namely the edge states of the fractional quantum Hall effect (FQHE). We study the current correlations of fractional quantum Hall edges at the output of a quantum point contact (QPC) subjected to a temperature gradient. Beyond the inherent interest in studying delta-T noise in such systems, it may help better understanding charge and heat transport in situations where strong electronic correlations are operating.

We show that the tunneling of Laughlin quasiparticles leads to a negative delta-T noise, in stark contrast with electron tunneling, a result which arises from the interplay of strong correlations and fractional statistics [2]. Moreover, varying the transmission of the QPC or applying a voltage bias across the Hall bar may flip the sign of this noise contribution, yielding signatures which can be accessed experimentally.

[1] O. Lumbroso, L. Simine, A. Nitzan, D. Segal, and O. Tal. Nature (London) 562, 240 (2018).

[2] J. Rech, T. Jonckheere, B. Grémaud, and T. Martin. Phys. Rev. Lett. 125, 086801, (2020).

Effects beyond mean-field in bosonic quantum systems

Stephanie M Reimann

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For long, we know that beyond-mean-field effects are essential when fermions form self-bound states as in nuclei or metallic clusters. More recently, an analogous yet somewhat different scenario was realized in experiments with dipolar or binary Bose gases: Self-bound quantum droplets may form out of a gaseous Bose-Einstein condensate stabilized by quantum fluctuations (see the Review by Böttcher et al. [1]). I will discuss the formation of vortices and persistent currents in such self-bound binary boson droplets [2] and comment on implications of these findings for toroidally confined dipolar [3] and binary bosonic [4,5] systems.

[1] *New states of matter with fine-tuned interactions: Quantum droplets and dipolar supersolids*, F. Böttcher *et al.*, Rep. Prog. Phys. **84**, 012403 (2020).

[2] *Persistent currents in toroidal dipolar supersolids*, M. Nilsson Tengstrand *et al.*, Phys. Rev. A **103**, 013313 (2021).

[3] *Rotating binary Bose-Einstein condensates and vortex clusters in quantum droplets*, M. Nilsson Tengstrand *et al.*, Phys. Rev. Lett. **123**, 160405 (2019).

[4] *Breathing mode in two-dimensional binary self-bound Bose-gas droplets*, P. Stürmer *et al.*, Physical Review A **103**, 053302 (2021).

[5] M. Nilsson Tengstrand and S.M. Reimann, *to be published*.

T72 Tue, 20 July, 17:00 - 17:20, 4 session

Time-dependent electromagnetics of molecular junctions

Michael Ridley

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In this talk, I will give an overview of recent developments in fast calculations of transient effects in quantum electronics using the time-dependent Landauer-Büttiker (TDLB) formalism [1]. First I discuss the generic model of a molecular junction described within the nonequilibrium Green's function (NEGF) framework. The switch-on of an arbitrary bias voltage is described in the case of both (i) the partitioned quench and (ii) the partition-free approach, which includes the effects of the pre-quench thermalization in the electronic response.

Within the TDLB, it is possible to derive analytic expressions for the first and second moments of the current for an arbitrary molecule described by a tight-binding Hamiltonian. I discuss how these are computed, and I propose a tight relationship between the current cross-correlations to the time taken for electrons to traverse the molecule [2,3].

Usually the sole concern of quantum transport calculations lies with currents, current noise and particle densities. However, it is possible to reverse this logic and instead use the molecular electronic currents as source terms for the local time-dependent electromagnetic fields. Recent work has shown how to do this, using a combination of the TDLB and Jefimenko's generalization of the Biot-Savart law [4]. As an application of this method, I present calculations done on benzene ring molecules in the ortho, para and meta configurations. The quantum interference between electron pathways can lead to a sign reversal of local currents and a strong switching effect in the local magnetic fields. I also present calculations of the emitted power in the field, showing that quantum effects should be detectable in the local radiation profile of the molecule.

[1] Ridley, M., MacKinnon, A., & Kantorovich, L. (2015). Current through a multilead nanojunction in response to an arbitrary time-dependent bias, Physical Review B, 91(12), 125433

[2] Ridley, M., MacKinnon, A., & Kantorovich, L. (2017). Partition-free theory of time-dependent current correlations in nanojunctions in response to an arbitrary time-dependent bias, Physical Review B, 95(16), 165440

[3] Ridley, M., Sentef, M. A., & Tuovinen, R. (2019). Electron traversal times in disordered graphene nanoribbons, Entropy, 21(8), 737

[4] Ridley, M., Kantorovich, L., van Leeuwen, R., & Tuovinen, R. (2021). Quantum interference and the time-dependent radiation of nanojunctions, Physical Review B, 103(11), 115439

Information-to-measurement conversion in DNA pulling experiments with feedback: from protocols to strategies

Felix Ritort

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Single-molecule experiments permit us to experimentally test fundamental results in the thermodynamics of information in the nanoscale [1]. Recently, we introduced a continuous Maxwell demon based on multiple measurements of a sDNA hairpin pulled with optical tweezers [2,3]. Here, I discuss the novel case of discrete and continuous feedback protocols for dissipation reduction and improved free energy determination (information-to-measurement conversion) in DNA pulling experiments [4]. It is found that a feedback strategy (defined as a correlated sequence of feedback protocols) remarkably reduces dissipation enhancing information-to-measurement efficiency. The study underlines the role of temporal correlations to develop feedback strategies for efficient information-to-energy conversion in small systems.

[1] F. Ritort, *The noisy and marvelous molecular world of biology*, Inventions, 4(2) (2019) 24

[2] M. Ribezzi-Crivellari and F. Ritort, *Large work extraction and the Landauer limit in the Continuous Maxwell Demon*, Nature Physics 15 (2019) 660–664

[3] J. P. Garrahan and F. Ritort, J. P. Garrahan and F. Ritort, *Generalized Continuous Maxwell Demons*, http://arxiv.org/abs/2104.12472, submitted

[4] M. Rico-Pasto, R. K. Schmitt, M. R. Crivellari, J. M. Parrondo, H. Linke, J. Johansson and F. Ritort, *Dissipation reduction and information-to-measurement conversion in DNA pulling experiments with feedback*, submitted

Quantum control and coherence in 2D materials

Yuri Rostovtsev, Brian Squires, Daniel Brown, and Arup Neogy

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In 1961, Franken et al. first demonstrated SHG in quartz, which opened the door for nonlinear optical effects. Although the NLO effects of materials are typically inherently weak, the second-order NLO susceptibility is used for various current optical devices based on bulk crystal materials (e.g. potassium dihydrogen phosphate, potassium titanyl phosphate, beta barium borate, lithium niobate), including ultrafast laser generation, ultrafast pulse measurement, optical parametric generation, and optical parametric amplification.

Today, technology is being developed towards miniaturization of photonic and optoelectronic devices for on-chip integration, e.g. on-chip nanophotonics and quantum nanophotonics, which, however, are limited by difficulties of miniaturization, compatibility and integration of traditional materials on chips. Therefore, for future photonics and optoelectronics applications, it is significantly important to discover new materials with large SHG responses that enable novel devices with high performance, small size and low cost.

Recently quantum coherence excited in the materials promises to be able to enhance nonlinear effects. In particular, the quantum engineering of light-matter interaction at the nanoscale has evolved from the existing research on exotic electromagnetic properties of materials and structures with novel shape and size. It has led not only to novel phenomenon and applications, but has opened up the exceptional potential to tailor, control and manipulate light-matter interactions for nanophotonics. Quantum coherence can drastically modify the optical properties of a media, in particular, absorption practically vanishes even at the single photon level. The changes in dispersion properties of the medium with excited quantum coherence has been initially studied theoretically and then experimentally demonstrated in atomic or molecular systems. Coherent interaction of plasmons to excitons in the strong coupling regime results in nonlinear effects.

In this talk, we report the results on experimental and theoretical studies of the second harmonic and parametric generation of two-dimensional layered materials. Strong dependence of intensity of SHG vs pump intensity has been observed. We develop a theoretical model to explain the observed features of the SHG. The model takes into account self-consistently the interaction of excitons, and it provides a qualitative agreement with the observed SHG spectra and intensity dependencies. The obtained results on the second harmonic and parametric generation of two-dimensional layered materials can be promising for many applications stretching from technology, sciences, and security because of the abilities of photon generation, manipulation, transmission, detection, and imaging for the applications to on-chip nanophotonic devices.

Gravitational and Quantum Mechanical Phenomena in Surface Gravity Water Waves

Georgi Gary Rozenman, Freyja Ullinger, Lev Shemer, Matthias Zimmermann, Maxim A. Efremov, Wolfgang P. Schleich, Denys I. Bondar, and Ady Arie

Raymond and Beverly Sackler School of Physics & Astronomy, Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel

The time evolution of a wave function in quantum mechanics is analogous to that of surface gravity water wave pulses. In our studies, we have recently utilised this analogy and have measured the cubic phase [1,2] of accelerating wave packets in a linear potential for cases of linear and nonlinear propagation, including a case of initial non-zero momenta [3,4,5].

Inspired by these successful experiments, we extend this analogy to a study of electromagnetic fields around black holes and different types of amplitude and phase singularities, including a logarithmic phase singularity. The analogous system in hydrodynamics is obtained by generating Gaussian wave packets that propagate in a time dependent potential which has a shape of an inverted harmonic oscillator. Depending on the wave packet energy with respect to the peak energy of the potential, we observe three different cases: i) wave reflection, in the case of low energy waves. ii) wave stopping when the wave energy matches the potential peak energy or iii) wave transmission, for higher energy waves. We also studied this problem using Weber wave packets, which are the eigenstates of the inverted harmonic oscillator system. An interesting observation is that even without a potential, an initial state which is an energy eigenstate of the inverted harmonic oscillator would evolve in free space until it reaches an amplitude singularity, accompanied by a logarithmic phase singularity.

Furthermore, we propose methods to study the propagation of wave packets in an open system, coupled to the vacuum state. In the latter, we have managed to observe phenomena which is analogous to that of quantum decoherence.

[1] E. H. Kennard, Zur Quantenmechanik einfacher Bewegungstypen, Zeitschrift fur Physik, 44, 326 (1927).

[2] M. Zimmermann et al. T3 -Interferometer for atoms, Appl. Phys. B, 123:102 (2017).

[3] G. G. Rozenman et al. Amplitude and Phase of Wavepackets in Linear Potential, 122, 124302, Phys. Rev. Lett. (2019).

[4] G. G. Rozenman et al. Quantum Mechanical and Optical Analogies in Surface Gravity Water Waves, Fluids, 4(2), 96 (2019).

[5] G. G. Rozenman et al. Observation of Accelerating Solitary Wavepackets, Phys. Rev. E. 101, 050201(R) (2020).

Andreev drag effect in Coulomb coupled quantum dots

David Sanchez

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Coulomb drag is an effect of fundamental interest in nanoscale physics arising from the combined interplay of fluctuations and interactions. It appears as a spectacular consequence of broken symmetries and correlations as a measurable current in an equilibrium conductor under the influence of a nearby voltage-biased conductor. With very few exceptions, research activity has thus far focused on conductors coupled to metallic (normal) reservoirs. In our work [1], we consider the case of a hybrid conductor coupled to both a normal and a superconducting reservoir. Our results are to our knowledge the first obtained with normal-superconducting quantum dots in the drag regime. This setup is of utmost interest in studies on Andreev reflection, where an electron is transformed, upon tunneling from a normal lead, into a Cooper pair in the superconductor. This allows for many-body quantum superposition states in the dot, which have a strong impact in the drag physics, as our calculations demonstrate. Whereas drag currents in normal coupled dot systems are determined by rather uncontrolled energy-dependent tunnel asymmetries, we find that the Andreev-Coulomb drag gives rise to more robust signals, which can be significantly manipulated with external parameters (gate voltages, temperature or pairing coupling). Thus, we believe that our proposal can be easily realized with present experimental techniques.

The Coulomb drag effect is nowadays also explored for its application to energy harvesting and heat management in quantum conductors. Since quantum dots can serve as qubit platforms and coupled nanoconductors can work as ultrasensitive charge sensors, our proposal is also of interest for the investigation of quantum backaction effects. Finally, the system we consider has analogies with the ratchet effect, which would raise questions on the role of pair tunneling in quantum thermodynamics theories.

[1] Andreev-Coulomb Drag in Coupled Quantum Dots. S. Mojtaba Tabatabaei, David Sanchez, Alfredo Levy Yeyati, and Rafael Sanchez. Phys. Rev. Lett. 125, 247701 (2020)

Interference-induced extrinsic thermoelectrics

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Mesoscopic conductors become efficient thermoelectric converters by using the spectral properties of a nanostructure (e.g., a quantum dot or a quantum point contact) to separate the electron-hole excitations generated by a heat source to which it is coupled. This is the case in all proposals and experiments so far, be them based on two- or three-terminal configurations. We call them intrinsic because (i) the heat source might be switched off, but not be uncoupled from the conductor, and (ii) because the mechanism for broken electron-hole symmetry is a property of the conductor. In contrast to these, we present an extrinsic thermoelectric effect in conductors to which we do not impose any asymmetry, allowing for a dual operation of the system once the heat source is not coupled. We present this with the example of a ballistic one-dimensional conductor which is approached by a scanning tip [1]. The tip serves as a quantum coherent local heat injector that generates interference patterns. These enable two remarkable effects: a nonlocal thermoelectric response of an electron-hole symmetric system which is modulated by the position of the hot probe tip, and a nonreciprocal longitudinal response leading to a thermoelectric diode effect. We introduce a model of pure dephasing which confirms the quantum interference origin of the effect [2].

[1] G. Fleury, C. Gorini and R. Sánchez, "Scanning probe-induced thermoelectrics in a quantum point contact". arxiv.:2106.03908.

[2] R. Sánchez, C. Gorini and G. Fleury, "Extrinsic thermoelectric response of coherent conductors", in preparation.

Speck of chaos

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It has been shown that, despite being local, a perturbation applied to a single site of the one-dimensional XXZ model is enough to bring this interacting integrable spin-1/2 system to the chaotic regime. Here, we show that this is not unique to this model, but happens also to the Ising model in a transverse field and to the spin-1 Lai-Sutherland chain. The larger the system is, the smaller the amplitude of the local perturbation for the onset of chaos. We focus on two indicators of chaos, the correlation hole, which is a dynamical tool, and the distribution of off-diagonal elements of local observables, which is used in the eigenstate thermalization hypothesis. Both methods avoid spectrum unfolding and can detect chaos even when the eigenvalues are not separated by symmetry sectors.

[1] Physical Review Research 2, 043034 (2020)

Quantum Rotational Coherences in Complex Media

Benjamin Ashwell, Sai Ramakrishna, and Tamar Seideman

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Rotational wavepackets are superpositions of angular momentum eigenstates generated in general via sequential, Rabi-type cycles in moderately-intense laser fields. The fascinating spatial and temporal properties of such wavepackets follow directly from the phase relations among their rotational components. These include sharp alignment, whose quality could not be obtained via other alignment techniques, and, in the short pulse case, a rotational revival structure that mirrors the underlying rotational eigenvalue spectrum. The highly nonlinear nature of rotational spectra, along with the coherence properties of the excitation laser pulse, make for a unique revival structure, fundamentally different from vibrational and electronic revival patterns.

In the limit of small isolated molecules, rotational coherences, with the ensuing nonadiabatic alignment, have evolved during the past 2 decades into an active field of theoretical and experimental research with a rich variety of applications. In the present talk we extend these concepts to complex systems. First we consider the case of asymmetric top molecules, where alignment overcomes the mechanisms that render the rotations chaotic in the classical limit. Next we focus on dissipative media, and illustrate the application of rotational coherence as a probe of the decohering properties of the environment. We extend alignment to control the torsional motions of polyatomic molecules, and apply torsional control to manipulate charge transfer events. Turning to interfaces, we introduce a route to guided molecular assembly, wherein laser alignment is extended to induce long-range orientational order in molecular layers. Combining rotational coherence with recent research on nanoplasmonics and on conductance via molecular junctions, we develop an approach to coherent control of transport in the nanoscale. Finally, we explore the case of dense molecular ensembles, where alignment generalizes into a collective phenomenon that gives rise to formation of molecular assembly with long range translational and orientational order.

Scattering of topological kink-antikink states in bilayer graphene

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Gapped bilayer graphene can support the presence of intragap states due to kink gate potentials applied to the graphene layers. Electrons in these states display valley-momentum locking, which makes them attractive for topological valleytronics. Here, we show that kink-antikink local potentials enable modulated scattering of topological currents. We find that the kink-antikink coupling leads to anomalous steps in the junction conductance. Further, when the constriction detaches from the propagating modes, forming a loop, the conductance reveals the system energy spectrum. Remarkably, these kink-antikink devices can also work as valley filters with tiny magnetic fields.

[1] N. Benchtaber, D. Sanchez, L. Serra, Scattering of topological kink-antikink states in bilayer graphene, arXiv:2103.13323

Quantum Nanodiamond Thermometry for Biological System

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Diamond quantum thermometry exploits the optical and electrical spin properties of colour defect centres in diamonds and, acts as a quantum sensing method exhibiting ultrahigh precision and robustness. Compared to the existing luminescent nanothermometry techniques, a diamond quantum thermometer can be operated over a wide temperature range and a sensor spatial scale ranging from nanometres to micrometres. Further, diamond quantum thermometry is employed in several application, including electronics and biology, to explore these fields with nanoscale temperature measurements. This talk will cover the operational principles of diamond quantum thermometry for spin-based and all-optical methods, material development of diamonds with a focus on thermometry, and examples of applications in biological systems with demand-based technological requirements.

[1] M. Fujiwara, S. Sun, A. Dohms, Y. Nishimura, K. Suto, Y. Takezawa, K. Oshimi, L. Zhao, N. Sadzak, Y. Umehara, Y. Teki, N. Komatsu, O. Benson, Y. Shikano, and E. Kage-Nakadai, Sci. Adv. 6, eaba9636 (2020)

[2] M. Fujiwara, A. Dohms, K. Suto, Y. Nishimura, K. Oshimi, Y. Teki, K. Cai, O. Benson, and Y. Shikano, Phys. Rev. Research 2, 043415 (2020)

[3] Y. Nishimura, K. Oshimi, Y. Umehara, Y. Kumon, K. Miyaji, H. Yukawa, Y. Shikano, T. Matsubara, M. Fujiwara, Y. Baba, and Y. Teki, Sci. Rep. 11, 4248 (2021)

[4] M. Fujiwara and Y. Shikano, arXiv:2103.17137

Superconducting Dirac point in proximetized graphene

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Two-dimensional (2D) materials have attracted vast research interest since the breakthrough discovery of graphene. One major benefit of such systems is the simple ability to tune the Fermi level through the charge neutrality point between electron and hole doping. For 2D Superconductors, this means that one may potentially achieve the regime described by Bose Einstein Condensation (BEC) physics of small bosonic tightly bound electron pairs. In this work [1] we show that single layer graphene, in which superconducting pairing is induced by proximity to a low density superconductor, can be tuned from hole to electron superconductivity through an ultra-law carrier density regime where the BEC limit is effectively realized. We study, both experimentally and theoretically, the vicinity of this "Superconducting Dirac point" where reflections at interfaces between normal and superconducting regions within the graphene, suppress the conductance. In addition, the Fermi level can be adjusted so that the momentum in the normal and superconducting regions perfectly match, giving rise to ideal Andreev reflection processes.

[1] G. N. Daptary, E. Walach, E. Shimshoni and A. Frydman, arXiv:2009.14603

On the nature of tunneling two-level systems in amorphous solids, and the mitigation of their deleterious effects in superconducting circuits

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The generic existence of structural tunneling two-level systems (TLSs) in amorphous solids was postulated by the "Standard Tunneling Model" to explain the remarkable low temperature universality known by now to exist across the different classes of disordered solids. Being ubiquitous at low energies, TLSs dominate low energy noise, and as such restrict performance of quantum nanodevices including superconducting qubits, nanomechanical oscillators and photon detectors. Recently, the coupling of TLSs to superconducting qubits and microresonators has facilitated novel experimental studies of TLSs, including detailed studies of individual TLSs and studies of the TLS glass out of equilibrium. In this talk I will discuss some of these recent experiments, what insights they give with regard to the nature and characteristics of TLSs, and with regard to possibilities to mitigate the deleterious effects of TLSs in microresonators and qubits.

Cluster Embedding Schemes

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Despite the recent developments in simulating correlated quantum systems a rigorous solution of interacting quantum systems is only rarely possible. A common approximation scheme consists in treating a small part of the system, called the cluster, in a rigorous manner, while performing approximations to the rest, namely the bath. In this presentation I provide an overview over various cluster embedding schemes and provide a detailed description of the self consistent cluster embedding (SCCE) developed at HQS.

To this end I start with an introduction to the cluster perturbation theory (CPT), the dynamical mean field theory(DMFT) including its cluster extension (CDMFT). I then provide a short introduction to inverse mean field theories (iMF) and finally combine the idea of iMF and cluster embedding to our SCCE method.

Kink dynamics and quantum simulation of supersymmetric lattice Hamiltonians

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We propose a quantum simulation of a supersymmetric lattice model using atoms trapped in a 1D configuration and interacting through a Rydberg dressed potential. The elementary excitations in the model are kinks or (in a sector with one extra particle) their superpartners - the skinks. The two are connected by supersymmetry and display identical quantum dynamics. We provide an analytical description of the kink/skink quench dynamics and propose a protocol to prepare and detect these excitations in the quantum simulator. We make a detailed analysis, based on numerical simulation, of the Rydberg atom simulator and show that it accurately tracks the dynamics of the supersymmetric model.

[1] Kink dynamics and quantum simulation of supersymmetric lattice Hamiltonians, Jiri Minar, Bart van Voorden and Kareljan Schoutens, arXiv:2005.00607

T86 Wed, 21 July, 12:10 - 12:30, 2 session

Quantum Simulation of Markovian and non-Markovian channel addition on NISQ devices and in the Quantum Optics Lab

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The study of memory effects in quantum channels helps in developing characterization methods for open quantum systems and strategies for quantum error correction. Two main sets of channels exist, corresponding to system dynamics with no memory (Markovian) and with memory (non-Markovian). Interestingly, these sets have a nonconvex geometry, allowing one to form a channel with memory from the addition of memoryless channels and vice versa. Here, we use the NISQ device and photonic setup to investigate this nonconvexity by subjecting a single qubit to a convex combination of Markovian and non-Markovian channels. Our results highlight some practical considerations that may need to be taken into account when using memory criteria to study system dynamics given by the addition of Markovian and non-Markovian channels in experiments.

Superfluidity from correlations.

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We study a one-dimensional Bose-Hubbard gas in a lattice whose hopping energy is made to oscillate with zero time average. Such a driving suppresses first-order particle hopping while allowing even higher-order processes [1]. At a critical value of the driving amplitude, the system passes from a Mott insulator to an exotic superfluid phase whose cat-like ground state consists of two branches characterized by the preferential occupation of opposite momentum eigenstates [2]. In the absence of autonomous single-particle hopping, the resulting superfluidity is exclusively driven by correlations. We discuss how such a phase differs qualitatively from conventional superfluidity. The effect is robust against variations in experimental details [3]. We show that this system can be probed with time-of-flight experiments.

[1] G. Pieplow, F. Sols, C. E. Creffield, New J. Phys. 20, 073045 (2018).

[2] G. Pieplow, C. E. Creffield, F. Sols, Phys. Rev. Research 1, 033013 (2019).

[3] J. Mateos, G. Pieplow, C. E. Creffield, F. Sols, Eur. Phys. J. Spec. Top., https://doi.org/10.1140/epjs/s117
021-00077-1.

Quantum analogue of energy equipartition theorem

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One of the fundamental laws of classical statistical physics is the energy equipartition theorem which states that for each degree of freedom the mean kinetic energy equals $E_k = k_B T/2$, where k_B is the Boltzmann constant and T is temperature of the system. Despite the fact that quantum mechanics has already been developed for more than 100 years still there is no quantum counterpart of this result. In my talk I will formulate the quantum analogue of energy equipartition theorem [1] that holds true for all quantum systems which are composed of an arbitrary number of non-interacting or interacting particles subjected to any confining potentials and coupled to thermostat with an arbitrary coupling strength. I will discuss its implication for two paradigmatic, exactly solvable models, namely, a free quantum Brownian particle and a dissipative harmonic oscillator [2-4].

[1] J. Luczka, J. Stat. Phys. 179, 839 (2020)

[2] J. Spiechowicz, P. Bialas, J. Luczka, Phys. Rev. A 98, 052107 (2018)

[3] P. Bialas, J. Spiechowicz, J. Luczka, Sci. Rep. 8, 16080 (2018)

[4] J. Spiechowicz and J. Luczka, Sci. Rep. 11, 4088 (2021)

Non-Equilibrium Oscillatory Dynamics of Electrons on the Surface of Liquid Helium

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The two-dimensional electron system (2DES) formed by electrons above the surface of liquid helium facilitates the exploration of 2D non-equilibrium phenomena in an almost perfectly clean environment. Research highlights have included, Wigner crystallization, the ripplonic Lamb shift, coupling of Rydberg states to Landau levels, quantum information processing, zero-resistance states, and a plethora of important results on many-electron phenomena and non-equilibrium physics.

Under certain conditions, the surface electrons exhibit *spontaneous* oscillations. We have measured the resultant signals induced in 5 Corbino electrodes at $\sim$0.3 K, with a perpendicular magnetic field and microwave radiation applied to attain the zero-resistance state. Analysis of these signals using multi-scale, time-resolved, methods yields results consistent with magnetoplasmons modulated by slow surface gravity waves, with the latter requiring consideration of the 3rd dimension. Calculation of phase differences and phase coherences between signals from differently-positioned pairs of electrodes enables reconstruction of the electron dynamics on the helium surface.

We will show that treating the time-resolved dynamics with logarithmic frequency resolution, opens up new possibilities for understanding these paradigmatic far-from-equilibrium phenomena, bringing together the quantum and classical processes involved.

A novel quantum simulation method for complex system-reservoir dynamics

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Accurate modeling of decoherence and dissipation in complex quantum devices – or in the exploration of dissipative quantum phase transitions – must be based on techniques beyond the standard quantum optical master equations. This need is most pronounced in the case of non-monochromatic driving, where the rotating-wave fails even in weak-coupling scenarios. Currently the hierarchical representation of reservoir-induced self-interactions (Hierarchical equations of motion, HEOM) and exact non-hermitian stochastic modeling (Stochastic Liouville-von Neumann equation, SLN) are available to address this need, among others. However, both become prohibitively expensive when the regimes of low temperature or strong coupling are investigated. This problem is overcome by a judicious combination of both methods, allowing previously intractable problems to be studied.

Reflectionless Excitation of Arbitrary Photonic Structures: A General Theory

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Coupling an input wave into or through a scattering structure without any reflection is a ubiquitous challenge in all of wave physics, both classical and quantum. While reflectionless perfect transmission through parity symmetric 1D structures is familiar to all physicists, the conditions for reflectionless excitation of general, non-symmetric structures in multi-channel, 2D and 3D geometries have not previously been elucidated in terms of a general theoretical and computational framework. Here I will describe such a theory, which is based on general analytic properties of the scattering matrix, and applies to the linear wave equations of optics and photonics, acoustics and quantum mechanics [1,2]. It is shown that for finite resonant structures there exist a countably infinite number of complex frequencies at which such reflectionless harmonic solutions occur, which correspond to adapted input wavefronts, related to eigenvectors of a generalized reflection matrix with eigenvalue equal to zero. We refer to such discrete solutions as reflectionless scattering modes (RSMs). A special case of this is Coherent Perfect Absorption or time-reversed lasing, for which the energy is completely absorbed when the time-reverse of the analogous lasing mode is imposed on the system [3]. However in the more general theory these solutions can be fully transmitted into any specified set of output channels of a lossless structure. In order for RSMs to correspond to steady-state harmonic solutions (real frequency) either the structure must have a symmetry such as Parity-Time (PT), or one must be able to tune one parameter of the structure to achieve a real frequency RSM. Degeneracy of two RSM modes corresponds to a new kind of exceptional point (EP) and leads to an increase in the bandwidth of the perfect absorption or transmission resonance. Applications of the theory to demonstrate perfect impedance matching to non-trivial 2D photonic structures, such as chaotic waveguide junctions, will be presented, indicating its suitability and tractability for photonic design.

[1] Theory of Reflectionless Scattering Modes, William R. Sweeney, Chia Wei Hsu, and A. Douglas Stone, Phys. Rev. A, 2020, https://link.aps.org/doi/10.1103/PhysRevA.102.063511

[2] Reflectionless excitation of arbitrary photonic structures: A general theory, A.D. Stone, W.R. Sweeney, C.W. Hsu, K. Wisal, and Z. Wang, Nanophotonics, 10.1515/nanoph-2020-0403

[3] Coherent Perfect Absorbers: Time-reversed Lasers, Y.D. Chong, L. Ge, H. Cao, and A.D. Stone, Physical Review Letters, 105, 053901 (2010)

Specific Models for Fast Hidden Variables, FreeWill, and all that

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The machinery of quantum mechanics is fully capable of describing a single real world. Here we discuss the converse: in spite of appearances, and indeed numerous claims to the contrary, any quantum mechanical model can be mimicked, up to any required accuracy, by a completely classical system of equations. An implication of this observation is that Bell's theorem cannot hold in many cases. This is explained by scrutinising Bell's assumptions concerning causality, retrocausality, free will, statistical (in-)dependence, and his fear of 'conspiracy' (there is no conspiracy in our constructions, as soon as one uses the language of the deterministic models). The most crucial mechanism for the counter-intuitive Bell/CHSH violation is the fact that after every change in the settings chosen by Alice and Bob, the ontological status of the particles in the initial state must be adjusted. The potential importance of our construction in model building is discussed.

Vibronic quantum coherence at ultralow temperatures in photosynthetic protein complexes

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Synthesizing quantum coherence in artificial nanosystems might be inspired by the study of the exciton dynamics in natural photoactive molecular complexes. In this talk, I will address the fundamental question under what conditions such natural systems could show dynamic quantum coherent effects. We have revisited this in a joint experimental and theoretical effort studying the quantum exciton dynamics in the Fenna-Matthews-Olson (FMO) complex by two-dimensional electronic spectroscopy at different temperatures. Our recent experimental results in a broad range down to very low temperatures reveal electronic coherence to occur on a time scale of 500 fs at 20 K. They complete earlier results obtained under ambient conditions where we have found that at room temperature, electronic coherence fades out within 60 fs. Yet, the new low-temperature data allow us to capture solid evidence of quantum coherence at ultralow temperature and to clearly disentangle electronic and vibrational dynamic coherence. The observed long-lived oscillations are due to Raman vibrational modes on the electronic ground state. The experimental data are used to establish a carefully parametrized model.

Spin selectivity through time-reversal symmetric helical junctions

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Time-reversal symmetric charge and spin transport through a molecule comprising two-orbital channels and connected to two leads is analyzed. It is demonstrated that spin-resolved currents are generated when spin-flip processes are accompanied by a flip of the orbital channels. This surprising finding does not contradict Bardarson's theorem [J. H. Bardarson, J. Phys. A: Math. Theor. 41, 405203 (2008)] for two-terminal junctions: the transmission does possess two pairs of doubly-degenerate eigenvalues as required by the theorem. The spin-filtering effect is explicitly demonstrated for a two-terminal chiral molecular junction, modeled by a two-orbital tight-binding chain with intra-atomic spin-orbit interactions (SOI). In the context of transport through organic molecules like DNA, this effect is termed "chirality-induced spin selectivity" (CISS). The model exhibits spin-splitting without breaking time-reversal symmetry: the intra-atomic SOI induces concomitant spin and orbital flips. Examining these transitions from the point of view of the Bloch states in an infinite molecule, it is shown that they cause shifts in the Bloch wave numbers, of the size of the reciprocal single turn, whose directions depend on the left-and right-handedness of the helix. As a result, spin-up and spin-down states propagate in the opposite directions, leading to the CISS effect. To further substantiate our picture, we present an analytically-tractable expression for the 8×8 scattering matrix of such a (single) molecule.

[1] Yasuhiro Utsumi, Ora Entin-Wohlman, and Amnon Aharony, "Spin selectivity through time-reversal symmetric helical junctions", Phys. Rev. B 102, 035445 (2020)

Quantum Variational Optimization of Ramsey Interferometry and Atomic Clocks

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We report a theory [1] - experiment [2] collaborative effort to devise and implement optimal N-atom Ramsey interferometry with variational quantum circuits on a programmable quantum sensor realized with trapped-ions. Optimization is defined relative to a cost function, which in the present study is the Bayesian mean square error of the estimated phase for a given prior distribution, i.e. we optimize for a finite dynamic range of the interferometer, as relevant for atomic clock operation. The quantum circuits are built from global rotations and one-axis twisting operations, as are natively available with trapped ions. On the theory side, low-depth quantum circuits yield results closely approaching the fundamental quantum limits for optimal Ramsey interferometry. Our experimental findings include quantum enhancement in metrology beyond squeezing and GHZ state interferometry, and we verify the performance of circuits by both directly using theory predictions of optimal parameters, and performing online quantum-classical feedback optimization to 'self-calibrate' the variational parameters for up to $N = 26$ ions. Successfully demonstrating operation beyond standard squeezing using on-device optimization opens the quantum variational approach to application across a wide array of sensor platforms and tasks.

[1] R. Kaubruegger, D. V. Vasilyev, M. Schulte, K. Hammerer, and P. Zoller, arXiv:2102.05593

[2] C. D. Marciniak, T. Feldker, I. Pogorelov, R. Kaubruegger, D.V. Vasilyev, R. van Bijnen, P. Schindler, P. Zoller, R. Blatt, and T. Monz, unpublished

Thouless pumping in a Floquet-driven lattice

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Thouless pumps allow robust quantised transport of particles in one-dimensional periodic potentials, in which the Hamiltonian is varied in a slow, cyclic manner. The time-trace of the adiabatic change plays the role of a second dimension, in which the topological pump can be understood as a quantum Hall effect. Previously, Thouless pumps in atomic and optical systems have relied on 'sliding' the underlying potential landscape in order to induce transport. However, such strong deformations of the lattice potential are not feasible in solid crystals, limiting the application of topological pumping to real-world materials. Here, we employ a Floquet drive to experimentally realise a topological pump in a generic sinusoidal lattice without any sliding potentials. Two-frequency lattice shaking is used to adiabatically prepare a topological Floquet-Bloch band, starting from a trivial insulating state of ultracold fermions. Near-quantised charge transport is achieved by modulating the drive waveform slow enough to ensure adiabaticity. Our results pave the way for studying topological pumping in Floquet-driven real materials.

Manifestation of topology in metastable driven-dissipative bosonic systems

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The role of topology in quasi-free bosonic systems remains an exciting open problem at the intersection of condensed-matter as well as atomic, molecular, and optical physics, and open quantum systems. While it is known that Hamiltonian systems of free bosons cannot be topological, I will show how non-trivial manifestations of topology may arise for free bosons undergoing Markovian dissipation, in metastable dynamical regimes. In particular, I will discuss how "Majorana bosons" may be identified in topologically non-trivial phases, that serve as tight analogues to the condensed-matter Majorana fermions. Each Majorana boson pair consists, in general, of a distinct zero mode and a symmetry generator, reflecting the breakdown of Noether's theorem in open quantum dynamics. This approximate symmetry implies the existence of a family of quasi-steady states possessing a number of unique properties uncharacteristic of steady-states in driven-dissipative systems, including non-vanishing first moments and persistent non-Gaussianity. Finally, I will discuss observable signatures of Majorana bosons in steady-state power spectra.

Collective modes at the superfluid - Mott glass transition

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We study the collective excitations, i.e., the Goldstone (phase) mode and the Higgs (amplitude) mode, near the superfluid–Mott glass quantum phase transition in a two-dimensional system of disordered bosons. Using Monte Carlo simulations as well as an inhomogeneous quantum mean-field theory with Gaussian fluctuations, we show that the Higgs mode is strongly localized for all energies. This leads to a noncritical scalar response characterized by a scalar spectral function that features a broad peak whose peak frequency does not soften but remains nonzero across the quantum phase transition.

In contrast, the lowest-energy Goldstone mode undergoes a striking delocalization transition as the system enters the superfluid phase, leading to a zero-frequency spectral peak. We also relate our findings to general results on the localization of bosonic excitations, and we discuss the limits and generality of our approach.

[1] M. Puschmann, J. Crewse, J.A. Hoyos and T. Vojta, Phys. Rev. Lett. 125 (2020), 027002

[2] M. Puschmann, J.C. Getelina, J.A. Hoyos and T. Vojta, arXiv:2101.11065

[3] J. Crewse and T. Vojta, arXiv:2104.04593

PERLind, a versatile approach to model bath coupling in quantum kinetics

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The position and energy-resolved Lindblad approach (PERLind) [1] is general theoretical approach to study the quantum kinetics in a system coupled to a bath. It is based on a Lindblad master equation containing both the terms of the common secular approximation and further terms, which allow to track coherences between energy eigenstates due to localization at the position of contacts. We show that PERLind is able to interpolate between local and global approaches. Examples are given for a variety of systems including the quantitative simulation of quantum cascade lasers.

[1] G. Kirsanskas, M. Frankie ad A. Wacker, Phys. Rev. B97 (2018) 035432

Multipath Interference Tests of Quantum Mechanics

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Quantum mechanics can be considered a special case of the class generalized probabilistic physical theories, which can be classified by how they deviate from classical probabilistic theories. Quantum mechanics, for example, deviates because it derives probabilities from wavefunctions and thus exhibits interference. By virtue of Born's rule, all interference terms stem from pairs of paths. Other probabilistic theories could go beyond that [1] and allow higher-order interference terms, thus violating Born's rule.

Using multipath interferometers [2,3] we were able to tighten the bound on the deviation from ordinary quantum interference to a level of 10^{-5} of the expected, ordinary interference, with a good part of the uncertainty originating from our limited accuracy in determining detector nonlinearity. More recently we have begun to apply our multipath interferometers towards tests for the generalization of quantum mechanics in terms of the underlying numbers, i.e. whether hypercomplex quantum mechanics is allowed or not [4]. For these tests, the achievable interferometer contrast is crucial [5]. Our latest interferometer, an integrated photonic circuit with electrically controllable interferometric shutters, allows us to improve the bound on higher-order interferences and hypercomplex quantum mechanics at the same time.

[1] R. D. Sorkin, *Quantum Mechanics as Quantum Measure Theory,* Modern Physics Letters A **9,** 3119 (1994), https://doi.org/10.1142/S021773239400294X

[2] U. Sinha, C. Couteau, T. Jennewein, R. Laflamme, and G. Weihs, *Ruling out multi-order interference in quantum mechanics,* Science **329,** 418 (2010), https://doi.org/10.1126/science.1190545

[3] T. Kauten, R. Keil, T. Kaufmann, et al., *Obtaining tight bounds on higher-order interferences with a 5-path interferometer,* New J. Phys. **19,** 033017 (2017), https://doi.org/10.1088/1367-2630/aa5d98

[4] A. Peres, *Proposed Test for Complex versus Quaternion Quantum Theory,* Phys. Rev. Lett. **42,** 683 (1979), https://doi.org/10.1103/PhysRevLett.42.683

[5] S. Gstir, E. Chan, T. Eichelkraut, et al., *Towards probing for hypercomplex quantum mechanics in a waveguide interferometer,* submitted to New J. Phys. (2021), https://arxiv.org/abs/2104.11577

T102 Fri, 23 July, 12:00 - 12:20, 2 Session

Quantum probes and quantum engines realized via individual impurities immersed in an ultracold bath.

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Technological advances in laser and vacuum technology have allowed realizing a dream of the early days of quantum mechanics: controlling single, laser-cooled atoms at a quantum level. Interfacing individual atoms with ultracold gases offer new experimental approaches to study fascinating phenomena of nonequilibrium quantum physics. Moreover, such systems allow experimentally addressing the question if and how quantum properties can boost the performance of atomic-scale devices.

In this talk, I will discuss how single atoms can be controlled and probed in an ultracold gas to establish new paradigms of sensing temperature or operating nanoscale engines. Understanding the impurity-gas interaction at the atomic level allows employing inelastic spin-exchange collisions, which are usually considered harmful, for quantum applications. First, I will show how the inelastic spin-exchange can map information about the gas temperature or the surrounding magnetic field to the quantum-spin distribution of single impurity atoms. Interestingly, the nonequilibrium spin dynamics before reaching the steady-state increases the sensitivity of the probe while reducing the perturbation of the gas compared to the steady-state. Second, I will discuss how the quantized energy transfer during inelastic collisions allows operating a single-atom quantum engine. We overcome the limitations imposed by using thermal states and run a quantum-enhanced Otto cycle operating at orders of magnitude larger powers compared to a thermal case, alternating between positive and negative temperature regimes at maximum efficiency. I will discuss the properties of the engine as well as limitations originating from the quantum aspects resulting in fluctuations of power. Finally, I will show that single atoms can act as coherent probes for an ultracold gas, where both the interaction-driven coherent evolution of a quantum superposition and the collisional decay of coherence allow inferring information about gas properties. Our work opens the door to experimentally interface quantum physics and thermodynamics and to study emerging novel phenomena.

The Heisenberg Limit to Laser Coherence

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To quantify quantum optical coherence requires both the particle- and wave-natures of light. For an ideal laser, it can be thought of as the number of photons emitted into the beam with the same phase. For some 60 years, it had been believed that for a laser with an ideal output beam (described by a phase-diffusing coherent state), this number, C, was limited by the Schawlow-Townes limit to the linewidth [1]. Specifically, the S-T limit implies that the coherence C is at most of order the square of the mean photon number μ in the laser itself: C = O(μ^2). Here, assuming nothing about the laser operation except that its inputs are incoherent, and that its output is close to the ideal beam, we find the ultimate (Heisenberg) limit: C = O(μ^4) [2]. For μ large this is enormously greater. Moreover, we find a laser model that can achieve this scaling, and show that, in principle, it could be realised with familiar physical couplings [2].

[1] A. L. Schawlow and C. H. Townes, "Infrared and Optical Masers", Phys. Rev. 112, 1940-9 (1958).

[2] Travis J. Baker, Seyed N. Saadatmand, Dominic W. Berry, and Howard M. Wiseman, “The Heisenberg limit for laser coherence”, Nature Physics 17, 179–183 (2021).

Quantum entanglement of living organisms

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Predictions of quantum mechanics are unsurpassedly precise and extremely counterintuitive. Quantum entanglement ("spooky action at a distance") is one such effect. Since 2000 AD, the breakthroughs in “Quantum Technologies 2.0” demonstrated the essentially quantum behaviour in increasingly large systems and put the problem of the quantum-classical transition on the forefront of research. In particular, there is an intense effort directed at the understanding of the role of quantum effects in life, mainly at the level of certain biochemical processes inside the cells.The question whether and how entanglement and other quantum correlations influence the behaviour of living organisms

Here I speculate on the possible effect of quantum entanglement on the behaviour of photosensitive single-cell organisms (e.g., Chlamydomonas). The pattern of correlations between the velocities of spatially separated groups of these organisms would depend on whether they are illuminated with quantum correlated light (e.g., entangled photon pairs) or not. I discuss the conditions under which such differences could be observed.

Quantum work statistics in chaotic and disordered Fermi liquids

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We present a theory of work statistics in generic chaotic, disordered Fermi liquid systems within a driven random matrix formalism. We extend Phil Anderson's orthogonality determinant formula [1] to compute the full distribution of quantum work [2]. The evolution of quantum work distribution is found to be universal, and characterized by just two parameters: the temperature in units of mean level spacing (giving the energy scale), and a dimensionless velocity, characterizing the frequency of avoided level crossings [3].

At zero temperature, the energy absorbed increases linearly with time, while its variance exhibits a superdiffusive behavior [2], reflecting Pauli's exclusion principle, and a non-Gaussian statistics is observed [3]. In slowly driven systems, quantum work can be well described in terms of a purely classical Markovian symmetric exclusion process in energy space, as generated by Landau-Zener transitions, and accurate analytical expressions can be derived for it.

Our random matrix predictions are compared to and validated by numerical simulations performed on realistic 2D quantum dot models. We propose to verify them experimentally by calorimetric measurements on nanoscale circuits [3].

[1] P. W. Anderson, Phys. Rev. Lett. 18, 1049 (1967).

[2] I. Lovas, A. Grabarits, M. Kormos, and G. Zaránd, Phys. Rev. Research 2, 023224 (2020).

[3] A. Grabarits, I. Lovas, M. Kormos, and G. Zaránd (to be submitted to Phys. Rev. Lett.).

Posters

Josephson quantum spin thermodynamics

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A 1D Josephson junction loop, doped with a spin-flipper and attached to two thermal reservoirs is shown to operate as a heat engine, or a refrigerator, or a Joule pump or even as a cold pump. When operating as a quantum heat engine, the efficiency of this device exceeds that of some recent Josephson heat engine proposals. Further, as a quantum refrigerator, the coefficient of performance of this device is much higher than previously proposed Josephson junction based refrigerators. In addition, this device can be tuned from engine mode to refrigerator mode or to any other mode, i.e., Joule pump or cold pump by either tuning the temperature of reservoirs, or via the flux enclosed in the Josephson junction loop. This makes the proposed device much more versatile towards possible applications.

P2

Two-body quantum energetics: the case of waveguide quantum electrodynamics

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We analyze the nature of energy exchanges between two coupled, but otherwise isolated, quantum systems. We define work as the component stemming from effective unitary interactions performed by each system on one another. The remainder of the energy is stored in the correlations and generally prevents full energy extraction by local operations. Focusing on the general scenario of a qubit coupled to the light field within a waveguide, we establish a bound relating work exchange and local energy extraction when the light statistics is coherent, that gets violated in the presence of a quantum light pulse. Our results provide operational, energy-based witnesses to probe non-classical resources.

Ultrafast charging in a two-photon Dicke quantum battery

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We consider a collection of two level systems embedded into a microwave cavity as a promising candidate for the realization of high power quantum batteries. In this perspective, the possibility to design devices where the conventional single-photon coupling is suppressed and the dominant interaction is mediated by two-photon processes is investigated, opening the way to an even further enhancement of the charging performance [1]. By solving a Dicke model with both single and two-photon coupling we determine the range of parameters where the latter unconventional interaction dominates the dynamics of the system leading to better performances both in the charging times and average charging power of the QB compared to the single-photon case. In addition, it is found that the scaling of the charging power with the finite number of qubits N shows a quadratic growth leading to a relevant improvement of the charging performance of quantum batteries based on this scheme with respect to the purely single-photon coupling case [1].

[1] A. Crescente, M. Carrega, M. Sassetti, D. Ferraro, Ultrafast charging in a two-photon Dicke quantum battery, Phys. Rev. B 102, 245407 (2020).

P4

An Analytical Framework for the Storage and Retrieval of Arbitrary Light Pulses

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As quantum information progresses towards quantum networking, the need for temporary storage and efficient retrieval of qubits at the networking nodes becomes critical. Viable quantum memory will require the storage and predictable retrieval of quantum states as light pulses. Previous works have experimentally determined retrieved pulse shapes for different control fields, but an analytical expression for a retrieved pulse has only been derived for a Gaussian pulse. This work develops a formula to store and retrieve and arbitrary pulse shape with explicit factors for controlling the output pulses' amplitude and width. The numerical implementation of this formula should be much faster than direct numerical solutions of the differential equations governing the evolution of the system.

[1] A. Patnaik, F.L. Kien, and K. Hakuta, Phys. Rev. A 69, 035803 (2004)

[2] I. Novikova, N. Phillips, and A. Gorshkov, Phys. Rev. A 78, 021802 (2008)

[3] P. Tsai, Y. Hsiao, and Y. Chen, Phys. Rev. Research 2, 33155 (2020)

Extreme depolarization for any spin

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We present a detailed study of the depolarization dynamics of an individual spin with an arbitrary spin quantum number j, or, equivalently, of a system of $N = 2j$ constituent spin-1/2 initially in a symmetric state undergoing collective depolarization. In particular, we identify the most superdecoherent states. In the case of isotropic depolarization, we show that a class of maximally entangled pure states distinct from GHZ and W states, a.k.a. spin anticoherent states [1,2], display the highest decoherence rate for any number of spins. Moreover, we find that these states become absolutely separable after a time which does not depend on the number of spins. We also prove that entanglement is a necessary and sufficient condition, both for pure and mixed states, for superdecoherence to take place [3]. Finally, for anisotropic depolarization, we identify not only the states with the highest initial decoherence rate, but also the states that lose their purity most rapidly over any finite time for a few spins.

[1] J. Zimba, Electron. J. Theor. Phys. 3, 143 (2006).

[2] D. Baguette, T. Bastin, and J. Martin, Phys. Rev. A 90, 032314 (2014)

[3] G. M. Palma, K.-A. Suominen, and A. K. Ekert, Proc. R. Soc. London, Ser. A 452, 567 (1996).

P6

Non-Gaussian work statistics in fermionic nanostructures

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We investigate the statistical properties of work performed on generic disordered fermionic nanograins during non-equilibrium quantum quenches. While much attention has been devoted to zero temperature properties[1,2], here we discuss the effects of finite temperature [3]. We generalize our zero temperature determinant formula for extracting the full statistics of work, and apply for finite temperature quenches in a fermionic random matrix ensembles. Similarly to the zero temperature case, the distribution of quantum work is found to be universal: it depends only on the temperature and the average work, and can be captured in terms of a classical Markovian diffusion process, considering particle transfers as random events mediated by Landau-Zener transitions. In contrast to the zero temperature case, the work can also take negative values, and for large temperatures it converges to a Gaussian distribution. We also find that average work grows linearly in time independently of the temperature. While work fluctuations preserve their superdiffusive character at low temperatures, in the opposite limit they grow diffusively. We also verified that for symmetrical cyclic driving our results satisfy the Crooks fluctuation relation at finite temperatures.

[1] I. Lovas, A. Grabarits, M. Kormos, and G. Zaránd, Phys. Rev. Research 2, 023224 (2020).

[2] A. Grabarits, I. Lovas, M. Kormos, and G. Zaránd (to be submitted to Phys. Rev. Lett.).

[3] A. Grabarits, M. Kormos, I. Lovas, and G. Zaránd (to be submitted to Phys. Rev. B).

Machine-learning framework for customized optimal quantum state tomography

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Finding the set of measurements which allows for quantum state tomography (QST) in the fastest way while reaching the desired precision is of high practical relevance. For a few scenarios, analytical solutions to this problem are known, e.g. for non-degenerate projective measurements, the eigenbases of the optimal set of measurement operators form a complete set of mutually unbiased bases (MUBs), which is known to exist for Hilbert spaces of prime-power dimension [1]; for measuring one qubit in a set of N qubits, the optimal choice for a QST measurement scheme is a set of mutually unbiased subspaces (MUSs), which can be constructed from a complete set of MUBs [2]. Here, we present a flexible scheme which allows to obtain numerically an optimized QST measurement set given the specifications of the system and of the measurements. It is applicable to many situations where no analytical expression of the optimal QST scheme is known. Its physical relevance is demonstrated by considering the qubit-qutrit system of dimension six where no complete set of MUBs is known. Such a system is realized for example in a nitrogen-vacancy center in diamond by the N-14 nuclear spin-1 (qutrit) and two electronic states (qubit). We formulate the search for the fastest QST measurement scheme as a high-dimensional optimization problem and numerically obtain a solution whose deviations from a set of MUSs are so small that they are without practical relevance [3]. Furthermore, we investigate the performance of machine learning approaches applied to the optimization problem we obtain for the case of individual rank-1 projection operators being the measurements in an eight-dimensional system [4]. We demonstrate the usefulness of machine learning techniques to discover measurement schemes, which are significantly better than the ones discovered by standard numerical methods. The high-performing quorums of projection operators we have discovered have complex structure and symmetries. This work was partially supported by the Zukunftskolleg (University of Konstanz) and the Bulgarian National Science Fund under the contract No KP-06-PM 32/8.

[1] W. K. Wootters and B. D. Fields, Ann. Phys. 191, 363 (1989).

[2] B. G. Bodmann and J. I. Haas, Proc. Amer. Math. Soc. 146, 2601 (2018).

[3] V. N. Ivanova-Rohling, G. Burkard, and N. Rohling, arXiv:2012.14494.

[4] V. N. Ivanova-Rohling and N. Rohling, Cyb. and Inf. Technol., 20 (6), 61 (2020).

P8

Pairwise Measurement Induced Synthesis of Quantum Coherence

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Quantum coherent superpositions of states with different energies, i.e., states with coherence with respect to energy basis, are important resource for modern quantum technologies. States with small coherence can be obtained either autonomously, due to the effect of a weak coherent drive or, potentially, due to the presence of an environment. Here, we propose a measurement-based protocol for quantum coherence synthesis from individual systems (with low initial coherence) into a global (and higher) coherence of the joint system. As an input, it uses N non-interacting copies of two-level systems (TLS), with low initial energy and coherence. These can be supplied by, e.g., a weak external drive or can result from an interaction with a bath. This protocol conditionally synthesizes an output state with higher energy and coherence than the initial state had, representing an universal process whose rules have not been well studied, yet. In addition to energy and coherence, we study the quantity called mutual coherence, showing increase after the protocol application, as well. This approach is based on application of sequential pairwise projective measurements on TLS pairs (conditionally removing their ground states), that are diagonal in the TLS energy basis. The functionality of the coherence synthesis is robust with respect to dephasing effects of the TLS environment on the system. Our approach may show its benefits in quantum sensing, quantum batteries charging, or other applications where synthesis of a larger coherent system from smaller (weaker) resources is useful.

[1] T. Baumgratz, M. Cramer, and M.B. Plenio, PRL 113, 140401 (2014).

[2] M. Gumberidze, M. Kolář, and R. Filip, Scientific Reports 9, 19628 (2019).

Work extraction from quantum coherence

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Classical thermodynamics is considered one of the pillars of macroscopic physics dealing with notions such as heat and work and their transfer. These notions of work and heat, however, should be revisited when entering the quantum regime. Many theoretical papers have addressed the issue of reaching a general theory of quantum thermodynamics with unambiguous definitions for heat and work, and thermodynamic laws. Within these theoretical explorations, special emphasis is given to the role of quantum coherence when extracting work from quantum systems which allows for strikingly different thermodynamic features [1]. Despite a growing number of papers investigating the theory of thermodynamics in the quantum realm, there have been few experimental studies thus far.

Here we demonstrate the ability to experimentally extract work from coherence in a quantum engine and add the work to a (classical) battery. Our quantum engine, a two level system (InGaAs quantum dot in a GaAs/AlGaAs micropillar cavity), is fueled by a classical laser drive. We show that by driving the engine with pulses up to full population inversion, we can extract work depending on the amount of quantum coherence induced in the two level system. We further show that the amount of extractable work depends on the purity in frequency domain and in photon number basis. Finally, we load this work to a battery (laser field) using homodyne-type measurements and determine the amount of work extracted from the quantum engine.

The present study highlights the key role of quantum coherence in the laws of quantum thermodynamics, and demonstrates unambiguously the ability to add work from a quantum engine to a battery.

[1] Monsel, J. et al., "The energetic cost of work extraction", PRL, 124, 130601 (2020)

P10

Thermalization of accelerated Brownian particles

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We consider a particle detector interacting with a massless scalar quantum field through the Unruh-DeWitt interaction Hamiltonian. We model the detector as a quantum oscillator of finite size. The detector-field system is shown to be mathematically equivalent to a quantum Brownian motion (QBM) model for an harmonic oscillator in an Ohmic environment, the role of which is played by the field. We evaluate the covariance matrix for an accelerated detector, identifying the regimes where non-Markovian effects become significant and discussing the effect of the size to the detector's response. We show that the late-time asymptotic state of the detector is a thermal state at the Unruh temperature.

Coupled Fermi seas: remotely inducing a moiré potential on a 2D semiconductor

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Artificially inducing lattices in electronic and photonic systems is a powerful tool to engineer material properties with applications ranging from crystal cavities to superconductivity. Here, we present a new way of inducing a lattice in the electronic states of a 2D semiconductor. Transition metal dichalcogenides (TMDs) are a class of 2D semiconductors that can be exfoliated down to the monolayer limit, yielding strong interactions between electrons whose motion is restricted to 2D. Because of the layered nature of exfoliatable 2D materials, TMDs can be combined with insulators (hBN) and conductors (graphene) to form complex nanostructures, exploring the ultimate limit of electronics by precise control over atomic thickness.

We fabricate a heterostructure consisting of a 2D semiconductor in close proximity to an angle-aligned combination of hBN and graphene. We show that the superlattice potential from hBN-graphene is imprinted onto the TMD via Coulomb interaction, leading to miniband formation and characteristic spectroscopic signatures of step-like charging upon electrostatic doping. This is a system of two different Fermi seas which are coupled via Coulomb interaction. This uncharted territory enables explorations in many directions.

P12

Dynamically assisted tunneling in the impulse regime

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We study the enhancement of tunneling through a potential barrier $V(x)$ by a time-dependent electric field with special emphasis on pulse-shaped vector potentials such as $A_x(t) = A_0/\cosh^2(\omega t)$. In addition to the known effects of pre-acceleration and potential deformation already present in the adiabatic regime, as well as energy mixing in analogy to the Franz-Keldysh effect in the non-adiabatic (impulse) regime, the pulse $A_x(t)$ can enhance tunneling by "pushing" part of the wave-function out of the rear end of the barrier. Besides the natural applications in condensed matter and atomic physics, these findings could be relevant for nuclear fusion, where pulses $A_x(t)$ with $\omega = 1\ \mathrm{keV}$ and peak field strengths of $10^{16}\ \mathrm{V/m}$ might enhance tunneling rates significantly.

Superconducting insulators

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Low-dimensional systems suffer from fluctuations which tend to destroy long-range order. In superconducting nanowires, this general statement manifests itself most prominently in the effect of so-called phase slips. In sufficiently thin wires phase slips completely disrupt long-range phase coherence and induce finite resistance which persists down to lowest temperatures T, thus, destroying superconductivity in the usual sense. Here, we address – both experimentally and theoretically – this state and show that in fact, it demonstrates a mixture of superconducting-like properties at shorter scales and non-superconducting behavior at long scales. Here, we introduce a physical concept of QPS-controlled localization of Cooper pairs that may occur even in uniform nanowires and identify a width-dependent critical length scale L_c which separates relatively long wires that remain resistive within the whole range of temperatures and relatively shorter ones with resistances sharply decreasing as the temperature is lowered. In contrast, the electron spectrum of all, even the most resistive, wires exhibits a well-defined superconducting gap while performing tunnel measurements on them yields superconducting-like $I - V$ curves. Furthermore, some of the samples demonstrate clear signs of Josephson current passing through the wire. Owing to the simultaneous presence of both superconducting-like and insulating-like properties, we name this state a superconducting insulator [1].

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[1] K. Arutyunov, J. Lehtinen, A. Radkevich, A. Semenov, and A. Zaikin, Comm. Phys. 4 (2021) 146

P14

Interaction effects in Quantum Hall edge channels at ν=2

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The evolution of the peak height of energy-resolved electronic wave-packets ballistically propagate along integer quantum Hall edge channels at filling factor equal to two is related to the elastic scattering amplitude for the fermionic excitations evaluated at different injection energies. We investigate this quantity assuming a short-range capacitive coupling between edge channels [1]. Moreover, we also phenomenologically take into account the possibility of energy dissipation towards additional degrees of freedom—both linear and quadratic—in the injection energy. Through a comparison with recent experimental data [2], we rule out the non-dissipative case as well as a quadratic dependence of the dissipation, indicating a linear energy loss rate as the best candidate for describing the behavior of the quasi-particle peak at short enough propagation lengths. Moreover, the unavoidable effects of interactions, in realistic experimental situations, can be taken into account in a quantum point contact geometry to investigate the squeezing of the emitted microwave radiation through the study of the current fluctuations at finite frequency [3].

[1] G. Rebora et al., Entropy 138 (2021)

[2] R. H. Rodriguez et al., Nat. Comm. 2426 (2020)

[3] G. Rebora et al., New J. Phys 23, 063018 (2021)

Optimal quantum state tomography measurement set under noise

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Quantum state tomography (QST) is the process of obtaining an estimate for the density matrix of a quantum system performing measurements on several copies of the state of the system. We focus here on systems of finite dimension n. QST is an essential yet time-consuming tool for the verification of a quantum device. Consequently, finding the set of measurements which allows for QST with the largest information gain is of high practical relevance. An information-gain-based quality measure for a QST measurement set was introduced by Wootters and Fields [1]. This quality measure is the volume spanned by the linear independent projection operators included in the set of measurement. In case of non-degenerate projective measurement this was used by Wootters and Fields to show that a set of $n+1$ mutually unbiased bases is the ideal choice for the eigenbases of the measurement operators. The same quality measure can be used to obtain numerically an optimal QST measurement set for degenerate measurements, e.g. for measurements projecting on one-dimensional [2] or $n/2$-dimensional subspaces [3]. Here, we introduce a quality measure for a QST measurement set under noise, which is given by Wootters and Fields' quality measure times a noise-dependent correction factor. When the noise-affected measurement j performs the noise-free measurement with a probability q_j and project on the maximally mixed state with a probability $1-q_j$, then the correction factor is the product of the q_j to a power depending on the dimension n and on the rank of the projectors describing the ideal measurements. We use this formalism to investigate (i) QST for a single qubit with noise being zero at the poles and maximal at the equator of the Bloch sphere, (ii) QST for two qubits with non-degenerate measurements, and (iii) QST for two qubits with rank-1 projectors, where the measurements in (ii) and (iii) are realized by measuring in standard basis preceded by a sequence of perfect single-qubit rotations and noisy two-qubit gates. This work was partially supported by the Zukunftskolleg (University of Konstanz) and the Bulgarian National Science Fund under the contract No KP-06-PM 32/8.

[1] W. K. Wootters and B. D. Fields, Ann. Phys. 191, 363 (1989).

[2] V. N. Ivanova-Rohling and N. Rohling, Phys. Rev. A 100, 032332 (2019).

[3] V. N. Ivanova-Rohling, G. Burkard, and N. Rohling, arXiv:2012.14494.

P16

Influence of coherent population trapping on propagation of chirped pulses

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Nonlinear optics related to a one-photon and a two-photon resonances with atomic or molecular levels when laser pulses excite the quantum coherence is a broad area of research. For example, Raman spectroscopy is one among many powerful techniques that has been widely used in engineering, chemical, and biological applications. In an effort to improve the raman spectroscopy, new techniques have evolved introducing modified optical pulses and models. Applying the femtosecond adaptive technique allows researchers to excite maximal vibrational coherence to improve the sensitivity of coherent Raman spectroscopy and to perform real time identification of bacterial spores and biomolecules. The femtosecond-laser-based coherent anti-Stokes Raman spectroscopy (CARS) has been used extensively in time-resolved nonlinear spectroscopy research in recent years. It is used in several fields of study, such as identifying molecules in chemistry, measuring temperature in solid-state physics, and non-invasive monitoring of muscle tissue, among other things.

It is the quantum coherent effects that have strong influence on the Raman scattering. Quantum coherence effects, such as coherent population trapping (CPT) and electromagnetically induced transparency (EIT), have been the focus of broad research activity for the last decades, as they drastically change optical properties of media. For example, for EIT in CW and pulsed regimes, absorption practically vanishes.

In this poster, we present our study of the excitation of the quantum coherence in a Λ-type molecular media. We have considered the two- and three-level molecules. The dressed state basis approach is employed, which provides deep physical insights showing interaction of "bright" and "dark" states with radiation. For the four-level model, we find two sets of the bright and dark states that show the important role of coherent population trapping between split ground states on Raman scattering in such molecular systems. The level structure of the model is common for the molecular media, where the split ground states can be viewed as rotational levels in addition to the vibrational levels with much higher frequency. We demonstrate the importance of formation of dark states between rotational levels on Raman and stimulated Raman scattering. We consider the propagation effects for the case when the vibrational-rotational coherence is induced. In particular, we consider a gas of three- and four-level atoms or molecules in the presence of two coherent optical pulses.

Phenomelogy of quantum states

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Theories of classical physics do not need the necessity for an interpretation of the meaning of their mathematical symbols. They are abbreviations of concepts derived from the observed phenomena of the macroscopic world and thus already endowed with it. As to fundamental equations, then the character of their actions is in harmony with the course of the observed reality they designed to describe. Therefore we have an intuitive understanding of classical physics.

The opposite situation is in quantum physics. It has an acute need for an interpretation. The reason for it is that the symbols of its mathematical formalism are no more abbreviations of concepts emerging from the observed phenomena. Its fundamental equations are not derivable from empirical data by the analogy of the classical case but appear in an ad hoc manner. This lack of a direct link between mathematical formalism and empirical reality and the abstract character of equations makes quantum theory incomprehensible.

Nevertheless, it works, giving a complete and consistent description of all quantum phenomena. It means that to elicit the meaning of quantum physics's conceptual content, one must go beyond the frameworks of its theory. In particular, since quantum states whose existence is not deducible from any observations correctly describe measurement results, one must recognize a kind of realness that belongs to them. More precisely, it follows from the eigenvalue- eigenstate link axiom: In the measurement of an observable, existence of its eigenstates macroscopically manifests as measurement outcomes - eigenvalues. It does not mean that a quantum object comes into an eigenstate (an observable acquires a numerical value) in the act of measurement. It must already be in an eigenstate of an observable in order for this state to realize in measurement.

However, the kind of reality of quantum states cardinally differs from the well-known passive and inert material reality dominated in classical physics. Their existence has a kind of activity by indicating its non-material or non-physical nature.

At the quantum level, it happens the schism of material reality, as it were. The reality of a quantum object is the same as the reality of a macroscopic object - it is material. Non-material become its space-time dynamical properties.

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Collecting information about a quantum system through indirect measurements

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In tasks of quantum thermodynamics and many body physics, one often needs to extract information about the system by making some types of measurements. Typically, these are energy measurements, particle number measurements, or work measurements. However, in certain cases these types of measurements are not directly accessible. For example, performing an energy measurement on a many-body system is experimentally unfeasible. In such cases it might be still possible to use a proxy - an auxilliary system, which we call a probe. This probe interacts with the system and some information is transferred to it. I will show that one can define a measure that shows how much information has been transferred and therefore can extracted, by measuring this probe. This measure is known as observational entropy (also known as coarse-grained entropy), now generalized to include arbitrary generalized measurements. We will demonstrate the general theory on the example of the well-known and experimentally realizable von Neumann measurement scheme, which translates measurement of any quantum observable on the system to a position measurement of a classical particle. This theory creates a conceptual framework of treating general information extraction from a quantum system, by any (most general) means necessary. While it has already found applications specifically in defining non-equilibrium thermodynamic entropy that characterizes evolution of quantum many-body systems, this generalized definitions could find applications in open systems, especially in entropic considerations for example in driven systems, in quantum and information engines, and generally in nanoscale thermodynamics, which are of growing both theoretic and experimental interest.

The induced order of quantum distinguishability and quantum speed limit

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We present a comprehensive analysis of the set of energy probability distributions, $\{r_i\}$, that give rise to pure qutrits that evolve towards a distinguishable state at a finite time, when evolving under an arbitrary and time-independent Hamiltonian (it generalizes in this case the results presented in Ref. [1]). The orthogonality condition is exactly solved, revealing a non-trivial interrelation between τ and the energy spectrum, and allowing the classification of $\{r_i\}$ into families organized in a 2-simplex, δ^2, contained in the probability 2-simplex of R^3. Furthermore, the states determined by $\{r_i\}$ are likewise analyzed according to their quantum-speed limit. Namely, we construct a map that distinguishes those distributions $\{r_i\}$ in δ^2 correspondent to states whose orthogonality time is limited by the Mandelstam-Tamm bound, from those restricted by the Margolus-Levitin one. Our results offer a complete characterization of the physical quantities that become relevant both in the preparation and in the study of the dynamics of 3-level states evolving towards orthogonality.

[1] Andrea Valdés-Hernández and Francisco J. Sevilla, A new route toward orthogobality, Journal of Physics A: Mathematical and Theoretical 54 (2) (2021), 025301 (2021). arXiv:2009.03478 [quant-ph].

[2] Francisco J. Sevilla, Andrea Valdés-Hernández and Alan J. Barrios, The underlying order induced by orthogonality and the quantum speed limit, arXiv:2104.01802 [quant-ph].

P20

Reconstruction of the electron oscillations on the surface of liquid helium.

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In recent years, system of electrons on the liquid helium surface is considered as hot topic because the electrons encounter very little physical resistance and liquid helium is actually a very clean medium. Indeed, such a system has been widely used as an experimental model for investigating two dimensional (2D) quantum and nonequilibrium phenomena. At 0.3 K, we have recorded currents induced in five Corbino electrodes by spontaneous oscillations of surface electrons on liquid helium, with a perpendicular magnetic field and microwave radiation. Approaches of time-resolved multi-scale analysis were used to distinguish stochastic from frequency-modulated deterministic dynamics and visualize the electrons' underlying oscillatory dynamics from these recorded data. We have revealed oscillations with a variable frequency which is dependent on changing the pressing voltage and electron densities. The main frequency of the oscillations was confirmed to be generated by the inter-edge magnetoplasmons and modulated by interactions with gravity waves of the surface of liquid helium. The corresponding patterns of electron motion will be shown for different electron densities and pressing voltages.

Dynamics of the defective Schrödinger cat state in dispersive media

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The dynamical properties of the defected Schrödinger cat states [1] in a dispersive medium are considered within the phase-space approach based on the Wigner distribution function. In this approach, the propagation of the Wigner distribution function corresponding to these states can be expressed by the equation of motion in the Moyal form that is numerically solved by applying the spectral split-operator method [2,3]. Utilizing this method, the quantumness of the considered states expressed by the volume of the negative part of the corresponding Wigner distribution function [4] is analyzed as a function of time. Similarly, the localization degree of the considered states in the phase space is considered by using the entropic measure [5]. The above-mentioned analysis is performed in two cases. The first case describes the free propagation of the defected Schrödinger cat in a one-dimensional homogeneous dispersive medium. The second case concerns a dispersive medium with a Gaussian barrier which breaks its homogeneity. Both of these cases are analyzed in the above-barrier reflection regime [6]. This regime does not have a counterpart in classical mechanics and it becomes the source of the backscattering diffraction process [7].

[1] D. Kołaczek , B. J. Spisak, and M. Wołoszyn, Sci. Rep. 11 (2021) 11619.

[2] R. Cabrera, D. I. Bondar, K. Jacobs, and H. A. Rabitz, Phys. Rev. A 92 (2015) 042122.

[3] D. Kołaczek, B. J. Spisak, and M. Wołoszyn, Int. J. Appl. Math. Comput. Sci 29 (2019) 439.

[4] A. Kenfack and K. Życzkowski, J. Opt. B: Quantum Semiclass. Opt. 6 (2004) 396.

[5] I. Bialynicki-Birula, and Ł. Rudnicki in *Statistical Complexity: Applications in Electronic Structure* , edited by K. D. Sen (Springer Netherlands, Dordrecht, 2011), Chap. 1.

[6] N. T. Maitra and E. J. Heller, Phys. Rev. A 54 (1996) 4763.

[7] E. J. Heller, *The Semiclassical Way to Dynamics and Spectroscopy* (Princeton University Press, 2018), Chap. 13.

P22

Oscillations in the agent - based model of the mucose virus spreading indicate and explain the general failure of lockdown measures in combatting the SARS-CoV2 in European countries

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We have examined some of the origins of oscillatory behaviour in agent-based models which include our current knowledge on SARS-CoV-2 infectiousness and immunisation. We discuss only the model that correctly predicts the 11-week oscillation period observed in the Czech Republic and the mechanisms behind the successful 2020 spring virus suppression. Lockdown in strict sense or its weaker version - oscillation dampening after first wave - was not achieved in any European country.

The model is based on following concept: (1) Agents move for a given length of the step in the random direction. (2) An infected agent infects all non-immune agents present at a given field. (3) The infected agent is infected for a given time, then becomes immune or dies. (4) For the mucosal virus, we added the attribute system infection, which makes the agent susceptible for infection but not dying by the infection. (5) Immunisation is modelled as change of given number of agents into system immune. (6) Agents have finite lifespan and may reproduce. *The starting parameters are:* (1) Population density. (2) Initial number of infected agents.

The length of the step is a simulation of lockdown. At the step 0, the strict lockdown, infected agents infect only agents initially present at a given field and the virus dies out. A step 1, which was used all agent-based models before, leads to heavily dampen first oscillation. Any larger step leads to dampened oscillations with period determined by combination of population density, duration of the disease, duration of immunity and probability of infection. We know the period of oscillations in the Czech Republic, 11 weeks, and we determined parameters satisfying this criterion. *This is the main conclusion of this work.* The decrease of population density has similar effect as lockdown, the heavy dampening. We suggest that the reason of success of the spring anti-covid measure in Czechia was dilution of the population by re-location of people into countryside cottages. The system immunity (prevention of deaths) is more complicated to predict since we do not know its average duration. Nevertheless, one of the conclusions from our model is that the existence of oscillations means that the whole population was infected and is now system immune. The effectively low impact of vaccination on the level of mucosal infection – as observed by PCR test - is then caused by the fact that (1) we vaccinate mostly the system immune and (2) the effect of system immunity on mucosal immunity is very small, if any. *The dampened oscillations are consequence of spatial inhomogeneities which fade-away in time. In the homogeneous/equilibrium state we observe stable infection of over 20% and mucose immunity of over 35% of the population.*

Quantum Energy Lines and the optimal output ergotropy problem

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We study the transferring of useful energy (work) along a transmission line that allows for partial preservation of quantum coherence. As a figure of merit we adopt the maximum values that ergotropy, total ergotropy, and non-equilibrium free-energy attain at the output of the line for an assigned input energy threshold. For Phase-Invariant Bosonic Gaussian Channels (BGCs) models, we show that coherent inputs are optimal. For (one-mode) not Phase-Invariant BGCs we solve the optimization problem under the extra restriction of Gaussian input signals.

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Quantum speed and mode-entanglement in multipartite bosonic systems

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We revisit the problem of determining conditions under which a pure state, evolving under an arbitrary unitary transformation, reaches an orthogonal state in a finite amount of the transformation parameter. Simple geometric considerations disclose the existence of a fundamental limit for the minimal amount required, providing, in particular, an intuitive hint of the Mandelstam-Tamm and the Margolus-Levitin bounds. The geometric considerations leads us to focus on a particular, yet relevant, family of states that evolve towards orthogonality. Several dynamical features are discussed, which include the (relative) entropy production during transformation, and special attention is paid to multipartite systems of N bosons that are allowed to tunnel between two sites. The effects of the tunneling in the amount of transformation required for the system to attain an orthogonal state are revealed, and the relation between the latter, the tunneling intensity and the mode-entanglement is explored.

[1] Andrea Valdés-Hernández and Francisco J. Sevilla, J. Phys. A: Math. Theor. 54 (2021) 025301.

Towards detecting traces of quantum friction in the corrections of the accumulated geometric phase

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Spatially separated bodies in a relative motion through vacuum experience a tiny friction force known as quantum friction (QF). This force has so far eluded experimental detection due to its small magnitude and short range. Quantitative details revealing traces of the QF in the degradation of the quantum coherence of a particle are presented. Environmentally induced decoherence for a particle sliding over a dielectric sheet can be decomposed into contributions of different signatures: one solely induced by the electromagnetic vacuum in the presence of the dielectric and another induced by motion. As the geometric phase (GP) has been proved to be a fruitful venue of investigation to infer features of the quantum systems, herein it is proposed to use the accumulated GP acquired by a particle as a QF sensor. Furthermore, an innovative experiment designed to track traces of QF by measuring the velocity dependence of corrections to the GP and coherence is proposed. The experimentally viable scheme presented can spark renewed optimism for the detection of non-contact friction, with the hope that this non-equilibrium phenomenon can be readily measured soon.

[1] npj Quantum Information (2020)6:25 ; https://doi.org/10.1038/s41534-020-0252-x

[2] Adv. Quantum Technol. 2021, 2000155; DOI: 10.1002/qute.202000155

P26

What Temperature is Schrödinger's Cat?

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In the context of quantum thermodynamics—where thermodynamical quantities are associated with quantum systems—a question arises whether the notion of temperature can be associated with quantum features, in analogy to whether the notion of time can exhibit quantum features when it is associated with a clock that is itself a quantum system.

In this work we explore two scenarios in which the notion of a 'superposition of temperatures' may arise. In the first scenario, the probe system interacts with different baths depending on the state of another quantum system. In the second, there is a thermalising interaction with a bath, however the bath together with its purification is correlated with another quantum system. The bath state is thermal at a temperature dependent on the state of this additional, control, degree of freedom (DoF). In both cases we derive the final state of all systems and discuss conditions for thermalisation of the probe and for temperature coherence—understood as coherence in the DoF on which the temperature depends. We show that the two cases are surprisingly different: For example, in the first scenario the probe does not thermalise and the temperature coherence is reduced even when the bath states are identical, at the same temperature. In the analogous case of equal temperatures in the second scenario, the probe does thermalise and the coherence is maximal. We also find that the final probe states depend on the physical context and even physical realisation of the thermalising channels—being sensitive to the particular Kraus representations of the channels—which may explain some of the results obtained in the context of quantum interference of relativistic particle detectors thermalising with Unruh/Hawking radiation. Our results extend to partial and pre-thermalisation, which we study by introducing a collisional model of thermalising interactions between the system and the bath(s).

Single Photon Atmospheric Turbulence Simulator Buildup

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The Air Force Institute of Technology (AFIT) is building a quantum optics and quantum information laboratory to study single photon phenomena and its applications. Examples of applications include the storage of light in electromagnetically induced transparency and the free space propagation of qubits through a turbulent atmospheric turbulence. This presentation details the current equipment available at AFIT, some initial experiments conducted with the equipment, and the plan for building an atmospheric turbulence simulator that statistically represents ground-to-space quantum communications. Currently, the lab contains QuTool's QuEd kit and IDQuantique's Quantum Key Distribution (QKD) system. Both an interference pattern and a HOM dip were measured using QuTool's Michelson Interferometer and Hang-Ou-Mandel modules. A visibility of 83% and a coherence length of 1.5mm were recorded. IDQuantique's QKD system successfully generated secret keys and measured the quantum bit error rate. A quantum bit error rate of 1.18% was measured and the secret key generation rate was on 32761 bits per second.

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Conference Site Buildings

Pyramida Hotel

Pyramida Hotel was built in 1980 in the neo-functionalist style with an interesting star-like ground plan and pyramid-like outer shape. During 2010-2013, the hotel was modernized and some rooms were upgraded to business class. The hotel offers a wide selection of conference services.

The Pyramida Hotel is situated in the residential area of Prague called Břevnov near the Prague Castle - see map ‘Prague center’. It is in the same time very near the historical center of Prague and Prague international airport - about 20 minutes by car. From the Pyramida Hotel you can reach easily many historical and important places of Prague taking trams No. 22 which have their stops nearly in front of the Pyramida Hotel: Prague Castle within about 5 minutes, Lesser Town is about 10 minutes, Charles Bridge area, too, Old Town and New Town centers (in the vicinity of Old Town Square and Wenceslas Square) within about 20 minutes ride.

Prague Castle, St. Vitus Cathedral

The **Prague Castle**, the ancient seat of Czech sovereigns, now the seat of the president of the Czech Republic, is the most important historical and cultural place of Prague. Its palaces, Saint Vitus Cathedral and churches situated at the hill above the Vltava River represent the symbol of the Czech Lands. These palaces, gardens and churches create the largest castle complex in Europe. You can read more about the Prague Castle in various books on the European and Czech history besides much special literature devoted just to the Prague Castle, its history and architecture.

St. Vitus Cathedral (St. Vitus, St. Wenceslas and St. Adalbert Cathedral in full name) has been always considered to be the most important church of the Czech Lands and intimately related to the history of the Czech state. The coronations of Czech kings took place in it, and many kings are buried there.

From the Pyramida Hotel you can reach the Prague Castle

1. either by about 20 minutes walk, starting down along the Bělohorská street (the main street where the Pyramida Hotel is situated)
2. or by tram No. 22 (1 stop, about 2 minutes) down along Bělohorská street from the stop Malovanka to the stop Pohořelec, from where you can reach the Prague Castle within 15 minutes walk
3. or going by tram No. 22 (3 stops, 5 minutes) to the Pražský Hrad stop from where you can reach the central part of the Prague Castle by a side entrance within 5 minutes walk.

The St. Vitus Cathedral is situated in the central part of the Prague Castle.