FINESS 2022

FINITE TEMPERATURE NON-EQUILIBRIUM SUPERFLUID SYSTEMS

St. Martin, Germany

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Venue

Located in the heart of Germany's Southern Wine Route, overlooking vineyards, the Rhine valley and the charming village of St. Martin at the edge of the Palatine forest, the **Arens Hotel** offers the prefect setting for a meeting, celebration or vacation. Modern rooms, creative interregional cuisine and selected wines round off your stay.

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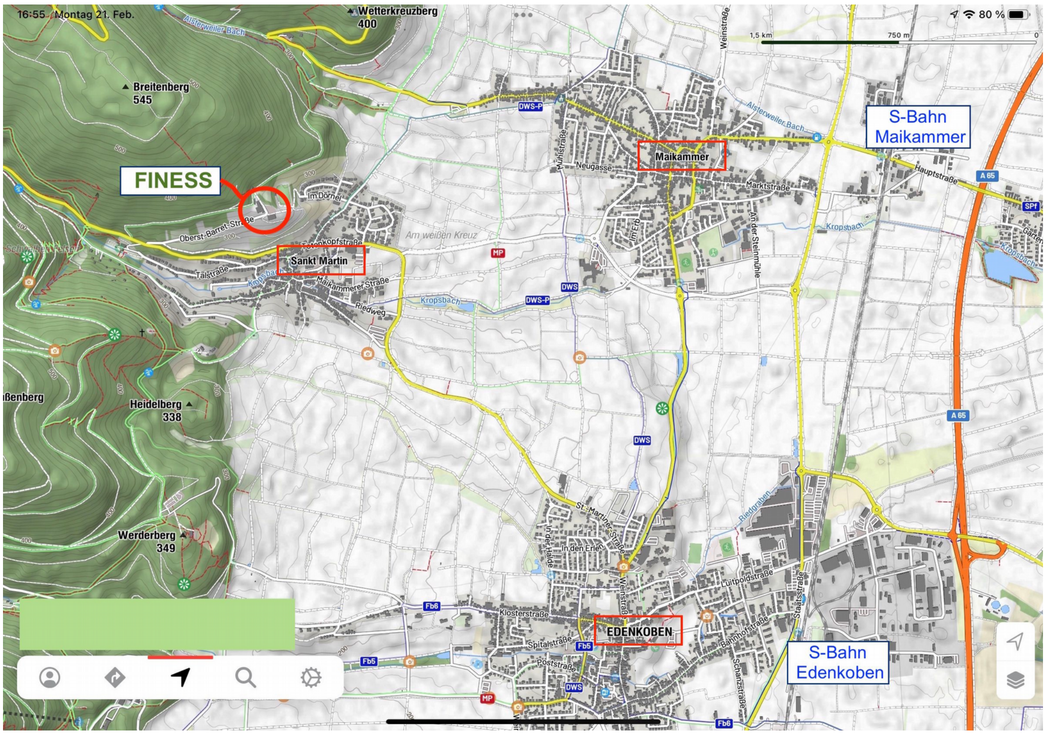

St. Martin is close to the historic **Hambach Castle**, one of the birthplaces of German democracy. Since May 1832, when the flag with the German national colors, black, red and gold, fluttered here, Hambach Castle has come to stand for the cradle of German democracy.

Preface

Over the last decade, finite temperature and out-of-equilibrium dynamics have become accessible in a controlled way in degenerate ultracold quantum gases of atoms or molecules, photonic superfluids as well as strongly correlated and open quantum systems. This offers new exciting insights into the dynamics of these intriguing quantum many-body systems, and promises new connections and applications to systems in related fields such as condensed matter physics. The conference **FINESS 2022** strives to bring together a critical mass of theoretical and experimental expertise at the forefront of research in these fields. The central aims of the conference **FINESS 2022** are

- to understand the physics behind the new phenomena seen in superfluids and quantum gases when one leaves equilibrium in the many-body regime,
- to seed development of theoretical approaches for finite-temperature non-equilibrium superfluid systems,
- to stimulate discussions between theoretical and experimental researchers on a range of active and emerging topics.

The conference **FINESS 2022** is part of a workshop series, which has taken place since 2007 every two or three years either in New Zealand or Europe. Whereas originally the overwhelming majority of contributions was concentrating more on the respective theoretical methods and techniques, the last editions have shifted the focus towards the corresponding experimental platforms and applications. Following this tradition, the 2022 edition includes now a significant number of participants from experimental research from a number of fields to facilitate direct interaction between experimental and theoretical research in out-of-equilibrium quantum many-body systems. Primarily the topics of the conference **FINESS 2022** focus upon but are not restricted to

- driven superfluid systems
- photonic superfluids
- quantum droplets
- polaron physics
- quantum turbelence
- nonequilibrium quantum phase transitions
- photon interactions
- atomtronics
- strong correlations
- quantum gases in microgravity

History

FINESS began as a workshop focused on theoretical methods for describing superfluid dynamics in finite-temperature ultracold gases. The founding meeting for **FINESS** was held in Sandbjerg, Denmark, in 2007, and involved 30 participants. The field of ultracold gases was maturing rapidly, and Fermi gases were attracting significant attention. The focus was primarily on theoretical techniques. In recent years **FINESS** has attracted more than 100 participants and involved an increasingly diverse range of topics at the intersection of experiment and theory, as the field of ultracold matter has continued to expand apace. Here is the complete list of previous conferences within this conference series in the opposite chronological order:

• FINESS 2018: Wanaka (New Zealand), February 19-23, 2018
http://physics.otago.ac.nz/finess2018

• FINESS 2015: Sopot, Gdansk (Poland), September 14-18, 2015
http://finess.ifpan.edu.pl

• FINESS 2013: Queenstown (New Zealand), February 16-20, 2013
http://www.physics.otago.ac.nz/finess/index.html

• FINESS 2011: Heidelberg (Germany), September 18-21, 2011
https://www.thphys.uni-heidelberg.de/~gasenzer/FINESS2011/index.html

• FINESS 2009: Durham (UK), September 14-17, 2009

• Non-Equilibrium Behavior in Superfluid Gases at Finite Temperature: Sandbjerg (Denmark), June 13-17, 2007

The first FINESS workshop held in Sandbjerg, Denmark 2007

Program

FINESS 2022
St. Martin, Germany
May 2-6, 2022

Monday, May 2

14.00-16:00	Arrival and registration
16:00-17:30	Jean Dalibard (Paris, France):
	Quantum gases in low dimension: from scale invariance to Quantum Hall physics
	Live streaming of Physics Colloquium in Kaiserslautern via Zoom
	Meeting ID: 699 4140 4654, Passcode: PhyKo#2022
18:30-20:00	Dinner
20:00-22:00	Meet and greet

Tuesday, May 3

08:30-08:40	Michael Fleischhauer (Kaiserslautern, Germany):
	Opening
Session 1:	**Driven superfluid systems**
08:40-09:20	Matthew Davis (Brisbane, Australia): online
	Transport in a one-dimensional chain of multimode Bose-Einstein condensates
09:20-10:00	Olivier Bleu (Melbourne, Australia):
	Bogoliubov excitations of a polariton condensate in dynamical equilibrium with an incoherent reservoir
10:00-10:20	David Snoke (Pittsburgh, USA):
	Dissipation in a polariton superfluid
10:20-11:00	Coffee break
Session 2:	**Hybrid systems**
11:00-11:40	Atac Imamoglu (Zurich, Switzerland):
	Strongly correlated electrons in atomically thin semiconductors
11:40-12:20	Michael Thorwart (Hamburg, Germany):
	Nonequilibrium quantum phases in driven cavity hybrid quantum systems

12:20-13:00	Sebastian Hofferberth (Bonn, Germany):
	Waveguide QED with Rydberg superatoms
13:00-14:00	Lunch
14:00-15:50	Free time
15:50-16:30	Coffee break
Session 3:	**Atomtronics**
16:30-17:10	Wolf von Klitzing (Heraklion, Greece):
	Manipulating matterwaves in atomtronic waveguides
17:10-17:50	Verònica Ahufinger (Barcelona, Spain):
	Dynamics of Bose-Einstein condensates carrying orbital angular momentum trapped in two stacked rings
17:50-18:10	Giulia Del Pace (Sesto Fiorentino, Italy):
	Controlling persistent currents in fermionic rings via phase imprinting
18:30-20:00	Dinner
Session 4:	**Poster session I**
20:00-22:00	Posters with odd numbers

Wednesday, May 4

Session 5:	**Photonic superfluids**
08:40-09:20	Julian Schmitt (Bonn, Germany):
	Compressibility and the equation of state of an optical quantum gas in a box
09:20-10:00	Natalia Berloff (Cambridge, United Kingdom):
	Unconventional computing with superfluid systems
10:00-10:40	Iacopo Carusotto (Trento, Italy):
	Quantum superfluids of atoms and of light as analog models of gravity: a fruitful synergy of gravity and quantum optics
10:40-11:20	Coffee break

11:20-11:40	Simon Jäger (Kaiserslautern, Germany):
	Dynamical superradiant phases of a thermal atomic beam interacting with an optical cavity
11:40-12:00	Michiel Wouters (Antwerpen, Belgium):
	Berezinskii-Kosterlitz-Thouless transition in photon condensates
Session 6:	**Interferences and fluctuations**
12:00-12:20	Simon Gardiner (Durham, United Kingdom):
	Dressed state approach to creating narrow barriers for soliton interferometry
12:20-12:40	Duncan O'Dell (Hamilton, Canada):
	Caustics in the dynamics of two coupled superfluids following a quench
12:40-13:00	Kazimierz Rzążewski (Warsaw, Poland):
	Fluctuations of Bose-Einstein condensate revisited
13:00-14:00	Lunch
Session 7:	**Plenary discussion**
14:00-14:40	Planning next FINESS conference
14:40-15:30	Free time
15:30-18:30	Wine tasting
18:30-20:00	Dinner
Session 8:	**Evening lecture**
20:00-21:00	Nathan Lundblad (Lewiston, USA):
	Ultracold bubbles in space: atomic physics aboard the International Space Station

Thursday, May 5

Session 9:	**Supersolidity**
08:40-09:20	Sandro Stringari (Trento, Italy): online
	Sound propagation and superfluid density of ultra-cold quantum gases

09:20-10:00	Tim Langen (Stuttgart, Germany):
	Supersolidity in dipolar Bose-Einstein condensates
10:00-10:40	Lauriane Chomaz (Heidelberg, Germany):
	Novel many-body states in dipolar quantum gases
10:40-11:20	Coffee break
11:20-12:00	Thomas Pohl (Aarhus, Denmark):
	Supersolidity in long-range interacting quantum fluids
12:00-12:20	Giulia De Rosi (Barcelona, Spain):
	Thermal instability, evaporation, and thermodynamics of one-dimensional liquids in weakly interacting Bose-Bose mixtures
12:20-12:40	Xin-Yu Luo (Munich, Germany):
	A dipolar gas of molecules in the deeply degenerate regime
12:40-13:00	Marco Fedele Di Liberto (Innsbruck, Austria):
	Topological phonons in arrays of ultracold dipolar particles
13:00-14:00	Lunch
14:00-15:50	Free time
15:50-16:30	Coffee break
Session 10:	**Quantum turbulence**
16:30-17:10	Giacomo Roati (Sesto Fiorentino, Italy):
	A quantum vortex collider
17:10-17:50	Robert Smith (Oxford, United Kingdom):
	Characterising far from equilibrium states in a Bose gas
17:50-18:10	Maximilian Prüfer (Vienna, Austria):
	From a non-thermal fixed point to thermal equilibrium with one-dimensional Bose gases
18:30-20:00	Dinner

Session 11: **Poster session II**

20:00-22:00 Posters with even numbers

Friday, May 6

Session 12: **Strong correlations**

08:40-09:20	Giuliano Orso (Paris, France):
	Pairing in one dimension: from Bose-Fermi mixtures to flat bands
09:20-10:00	Christopher Vale (Melbourne, Australia): online
	Dynamics in Fermi gases quenched to unitarity
10:00-10:40	Andrew Daley (Glasgow, United Kingdom):
	Quantum state diffusion for strongly interacting non-Markovian systems
10:40-11:20	Coffee break

Session 13: **Polaron physics and disorder**

11:20-11:40	Sebastiano Peotta (Aalto, Finland):
	Universal suppression of the superfluid weight by disorder independent of quantum geometry and band dispersion
11:40-12:20	Artur Widera (Kaiserslautern, Germany):
	Nonequilibrium dynamics of interacting quantum gases after disorder quenches
12:20-13:00	Richard Schmidt (Aarhus, Denmark):
	Chemistry of an impurity in a Bose-Einstein condensate and finite temperature effects
13:00-14:00	Lunch
14:00	Departure

Poster Overview

1 **Adriano Angelone**
Out-of-equilibrium superglass and glass states in cluster-forming models

2 **Andrea Barresi**
Dipole collision and energy dissipation in 2D Fermi gases

3 **Erik Bernhardt**
Ultracold quantum gases in spatially and temporally engineered environments

4 **Giacomo Bighin**
An impurity in a heteronuclear two-component Bose mixture

5 **Russel Bisset**
2D supersolid formation in dipolar condensates

6 **Moritz Breyer**
Dynamics following an interaction quench in the BEC-BCS crossover and machine-learning the phase diagram

7 **Fabio Caleffi**
Collective excitations of a strongly-correlated photon fluid stabilized by incoherent drive and dissipation

8 **Charles Creffield**
Non-equilibrium superfluidity from Floquet engineering

9 **Piotr Deuar**
Full quantum dynamical description of a class of large driven dissipative Bose Hubbard models

10 **Moritz Drescher**
Non-equilibrium dynamics of the Bose polaron at zero and non-zero temperatures

11 **Romain Dubessy**
Fast rotating superfluid on a curved surface

12 **Tilman Enss**
Universal scaling at a pre-thermal dark state

13 **Giovanni Ferioli**
Subradiance and superradiance in dense atomic cloud

14 **Lennart Fernandes**
Gaussian trajectory description of fragmentation in an isolated spinor condensate

15 **Elmar Haller**
Floquet solitons and dynamics of periodically driven matter waves in optical lattices

16 **Philipp Heinen**
Simulating Bose gases with the complex Langevin method

17 **Tanausú Hernández Yanes**
One- and two-axis squeezing via laser coupling in an atomic Fermi-Hubbard model

18 **Tim Keller**
Self-pinning transition of a Tonks-Girardeau gas in a Bose-Einstein condensate

19 **Ayan Khan**
Effect of harmonic trapping on quantum droplets

20 **Maciej Kruk**
Stationary and thermal properties of flattened and elongated quantum droplets

21 **Stefan Lannig**
From vector solitons to universal dynamics in a spinor Bose-Einstein condensate

22 **Rodrigo Lima**
Out of equilibrium dynamical properties of Bose-Einstein condensates in ramped up weak disorder

23 **Manfred Mark**
Supersolidity in dipolar quantum gases

24 **Christopher Mink**
Continuous versus discrete truncated Wigner approximation for driven, dissipative spin systems

25 **Suman Mondal**
Topological charge pumping in the phonon coupled Rice-Mele model

26 **King Lun Ng**
Fate of the False Vacuum: A finite temperature stochastic model for the simulated early universe in BEC

27 **David Petrosyan**
On the quasi-adiabatic preparation of antiferromagnetic-like state of Rydberg excitations of atoms in a lattice

28 **Ulli Pohl**
Out-of-equilibrium dynamics of bosons on a 2D Hubbard lattice

29 **Ville Pyykkönen**
Non-equilibrium normal and superfluid transport through the flat band states of a finite-sized sawtooth lattice

30 **Niklas Rasch**
Wilsonian renormalization in the symmetry-broken polar phase of a spin-1 Bose gas

31 **Sayak Ray**
Non-local correlation and entanglement of ultracold bosons in the two-dimensional Bose-Hubbard lattice at finite temperature

32 **Ido Siovitz**
Instantons and self-similar scaling in a 1D spin-1 Bose gas far from equilibrium

33 **Renan da Silva Souza**
Green's function approach to the Bose-Hubbard model with disorder

34 **Enrico Stein**
Quantum mechanical description of thermo-optic interaction in photon BECs

35 **Mohsen Talebi**
Observation of fermionic superfluid current through a dissipative quantum point contact

36 **Marek Tylutki**
One-dimensional quantum droplets

37 **Kirankumar Karkihalli Umesh**
Photon gases in microstructured potentials: From 1D to 2D

38 **Etienne Wamba**
Using a space-time mapping for probing heating suppression in periodically driven many-body quantum systems: a mean-field example with Bose gases

39 **Martin Will**
Mobile dissipative impurities in one-dimensional Bose gases

40 **Kali Wilson**
Using vortices as probes of quantum many-body systems

41 **Gabriel Wlazłowski**
Quantum turbulence in ultracold Bose and Fermi gases: similarities and differences

42 **Alexander Wolf**
Shell-shaped dual-component BEC mixtures

43 **Louise Wolswijk**
Measurement of the order parameter and its spatial fluctuations across Bose-Einstein condensation

44 **Klejdja Xhani**
Decay of supercurrent in homogeneous atomic superfluids

45 **Tomasz Zawiślak**
Exotic structures in spin-imbalanced unitary Fermi gas

Abstracts of Invited Talks

Dynamics of Bose-Einstein condensates carrying orbital angular momentum trapped in two stacked rings

Eulàlia Nicolau[1], Jordi Mompart[1], Bruno Juliá-Díaz[2,3], and Verònica Ahufinger[1]

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[2]Departament de Física Quàntica i Astrofísica, Universitat de Barcelona, Spain
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The Josephson effect [1] is a fundamental phenomenon in Quantum Mechanics that has been widely explored in superconductors, and its study has been extended to weakly coupled BECs, which can act as basic building blocks for quantum technologies. In particular, the dynamics of Bose-Einstein condensates in tunnel-coupled ring potentials have been recently explored in a variety of geometries. In this work [2], we investigate the stability and dynamics of the orbital angular momentum (OAM) modes of a repulsive Bose-Einstein condensate trapped in two tunnel-coupled rings in a stack configuration. First, we consider an initial state with a single OAM mode equally populated in both rings, which gives rise to symmetric and antisymmetric stationary states. The stability conditions for these states against OAM perturbations were derived within the mean-field theory and using Bogoliubov analysis in [3]. Here, we revisit the problem and demonstrate that the system can be described by a two-state model with fixed point solutions. In particular, we derive a classical Hamiltonian that characterizes the dynamics of the system in terms of the orbits around the critical points. Second, by populating a single orbital angular momentum mode with an arbitrary population imbalance between the rings, we derive analytically the boundary between the regimes of Josephson oscillations and macroscopic quantum self-trapping and study numerically the stability of these solutions.

References

[1] B. Josephson, Physics Letters **1**, 251 (1962).
[2] E. Nicolau et al., Phys. Rev. A **102**, 023331 (2020).
[3] I. Lesanovsky and W. von Klitzing, Phys. Rev. Lett. **98**, 8 (2007); J. Brand, T. J.Haigh, and U. Zülicke, Phys. Rev. A **81**, 025602 (2010).

Unconventional computing with superfluid systems

Natalia Berloff

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The recent advances in developing physical platforms for solving combinatorial optimisation problems reveal the future of high-performance computing for quantum and classical devices. Unconventional computing architectures were proposed for numerous optical systems, memristors, lasers and nanolasers, optoelectronic systems, polariton and photon condensates. A promising approach to achieving computational supremacy over the classical von Neumann architecture explores classical and quantum hardware as Ising and XY machines. Superfluid systems naturally belong to the XY Universality class and, therefore, can be guided and controlled to act as an XY simulator. Gain-dissipative platforms such as the networks of optical parametric oscillators, coupled lasers and nonequilibrium Bose-Einstein condensates such as exciton-polariton or photon condensates use an approach to finding the global minimum of spin Hamiltonians which is different from quantum annealers or quantum computers. In my talk, I will discuss the principles of the operation of the devices based on such systems, the challenges they present, and the question of comparing different platforms' performance.

Bogoliubov excitations of a polariton condensate in dynamical equilibrium with an incoherent reservoir

Olivier Bleu

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Condensates of exciton-polaritons are nowadays routinely observed in experiments [1-3]. A generic consequence of their driven-dissipative nature is that they can coexist with an incoherent excitonic reservoir. In this talk, I shall present a joint theory-experiment work [4] in which we study Bogoliubov excitations of a polariton condensate in dynamical equilibrium with such a reservoir. We develop a generalized Bogoliubov theory for a polariton condensate in a microcavity embedding N quantum wells. In doing so, we highlight that the reservoir can consist of both excitonic high-momentum polaritons and optically dark superpositions of excitons across the different optically active layers. We show that the presence of the reservoir modifies both the energy and the amplitudes of the Bogoliubov quasiparticle excitations due to the non-Galilean-invariant nature of polaritons. Our theoretical findings are supported by our experiment, where we directly detect the Bogoliubov excitation branches of an optically trapped polariton condensate in the high-density regime. From the extraction of the densities we unveil a locking of the reservoir and condensate densities leading to a saturation of the condensate fraction. By analyzing the measured occupations of the excitation branches, we extract the Bogoliubov amplitudes across a range of momenta and find a good agreement with our generalized theory.

References

[1] H. Deng, H. Haug, and Y. Yamamoto, Rev. Mod. Phys. **82**, 1489 (2010).
[2] I. Carusotto and C. Ciuti, Rev. Mod. Phys. **85**, 299 (2013).
[3] A. V. Kavokin, J. Baumberg, G. Malpuech, and F. Laussy, *Microcavities*, 2nd ed. (Oxford University Press, Oxford, 2017).
[4] M. Pieczarka, O. Bleu, E. Estrecho, M. Wurdack, M. Steger, D. W. Snoke, K.West, L. N. Pfeiffer, A. G. Truscott, E. A. Ostrovskaya, J. Levinsen, M. M. Parish, arXiv:2112.03768 (2021).

Quantum superfluids of atoms and of light as analog models of gravity: a fruitful synergy of gravity and quantum optics

Iacopo Carusotto

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In this talk, I will present the state of the art and the new perspectives in the theoretical and experimental study of analog models of quantum field theories in flat, curved, or time-dependent backgrounds using condensed matter and optical systems.

I will start by presenting recent results on superradiant effects in different geometries. In rotating configurations, the concept of ergoregion instability provides an intuitive understanding of the well-known instability of multiply charged vortices. Introduction of synthetic gauge fields in planar geometries extends the range of space-time metrics that can be generated and allows for analytical insight into superradiant phenomena using quantum optics concepts. In particular, the subtle relations between superradiant scattering, quantum superradiant emission and superradiant instabilities will be clarified.

I will then outline on-going work on the intriguing interplay between the Hawking emission and the quasi-normal modes of the black holes, which gives rise to a significant excitation of these latter. Speculative considerations on the possible consequences of these results in astrophysical context will be discussed.

Novel many-body states in dipolar quantum gases

Lauriane Chomaz

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Depending on their electronic configuration, some of the atoms may display a large magnetic dipole moment in their electronic ground state. For more than a decade, efforts have been dedicated to developing laser and evaporative cooling schemes for such atomic species, and quantum degeneracy was achieved. This has opened up new research directions in which long-range anisotropic dipole-dipole interactions play a crucial role in the physics of the quantum gases. In the case of Bose gases, these interactions are competing with the conventional short-range contact interactions, and thanks to so-called Feshbach resonances this competition can be tuned by altering the strength of the contact forces. In the case of the most magnetic atoms (erbium and dysprosium), a fine control of this interaction competition has yielded the discovery of novel many-body quantum states, which are stabilized from the mere effect of quantum fluctuations. These states include liquid-like droplets, droplet crystals, and supersolids, a paradoxical phase of matter which simultaneously exhibits solid and superfluid orders. In my talk, I will first review the investigations that we have carried out in my former group in Innsbruck on such exotic states in cigar-shaped three-dimensional quantum Bose gases of erbium and dysprosium. I will then discuss the future research directions that I am developing in my research group in Heidelberg, building a novel experimental setup working with dysprosium and focusing on quantum gases of magnetic atoms in lower dimensions.

Quantum state diffusion
for strongly interacting non-Markovian systems

Andrew Daley

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Recent developments with impurities in Bose-Einstein condensates and atoms in multimode cavity QED systems provide opportunities to study a strongly-interacting system that also couples strongly with its environment. Capturing the resulting effective dynamics is often challenging, especially because the number of degrees of freedom in both the effective non-Markovian environment can often be too large to represent exactly. By combining non-Markovian quantum state diffusion techniques with tensor network methods, we address this problem, and as a first example, we explore a Hubbard-Holstein model with dissipative phonon modes. This new approach allows us to quantitatively assess how correlations spread in the presence of non-Markovian dissipation in a 1D many-body system. We find regimes where correlation growth can be enhanced by these effects, offering new routes for dissipatively enhancing transport and correlation spreading. We also ask what information can be gained about the system from continuous measurement of the output field. For the multi-mode cavity case, we explore how different monitoring across output modes affects our information gain for an atomic state, and show how to use this to improve spin squeezing via measurement and feedback in a strong coupling regime.

Quantum gases in low dimension: from scale invariance to Quantum Hall physics

Jean Dalibard

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The physics of many-body systems depends strongly on their dimensionality, as illustrated by the unique properties of electron gases confined in quantum wells. More recently, advances in cold atom physics have led to new developments in the study of the "quantum flatland". By freezing certain dimensions of space, or by exploiting synthetic extra-dimensions, one can reveal spectacular features of low-dimensional physics at ultra-low temperature. In this talk, I will illustrate the richness of this 2D world by describing the emergence of scale invariance for flat atomic gases and discussing their connection with Quantum-Hall-type phenomena.

Transport in a one-dimensional chain of multimode Bose-Einstein condensates

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In previous work we have developed a c-field model of coupled multimode Bose-Einstein condensates to describe the driven-dissipative superfluid experiment by Labouvie et al. [1], where a single system site was subjected to controllable atom losses. We found that the c-field could successfully model the bistability of the steady states observed depending on whether the system site was initially full or empty [2].
More recently we have extended this model to explore an earlier experiment in the same geometry in which the refilling of the system site were explored [3]. The experimental observations found that the tunnel current increased with a decreasing chemical potential difference, analogous to the phenomenon of negative differential conductivity in semiconductors. This feature could potentially be utilised for superfluid circuit components such as amplifiers or diodes. We examine the microscopic origin of this behaviour, and evaluate its potential use for atomtronics.

References:

[1] R. Labouvie et al., Phys. Rev. Lett. **116**, 235302 (2016).
[2] M. T. Reeves and M. J. Davis, arXiv:2102.04712 (2021).
[3] R. Labouvie et al., Phys. Rev. Lett. **115**, 050601 (2015).

Waveguide QED with Rydberg superatoms

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Rydberg quantum optics (RQO) allows to create strong optical nonlinearites at the level of individual photons by mapping the strong interactions between collective Rydberg excitations onto optical photons.
The strong interactions lead to a blockade effect such that an optical medium smaller than the blockaded volume only supports a single excitation creating a so-called Rydberg superatom. Due to the collective nature of the excitation, the superatom effectively represents a single emitter coupling strongly to few-photon probe fields with directional emission into the inital probe mode.
Here we discuss how we use Ryderg superatoms to study the dynamics of single two level systems strongly coupled to quantized propagating light fields, enabling e.g. the investigation of three-photon correlations mediated by a single quantum emitter.
We also show our experimental progress towards implementing a cascaded quantum system by interfacing multiple superatoms in a one-dimensional chain with a single probe mode and show that this system can be used as a N-photon subtractor.

Strongly correlated electrons in atomically thin semiconductors

Atac Imamoglu

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In this talk, I will describe recent experiments in atomically-thin transition metal dichalcogenides (TMDs) where Coulomb interactions between electrons dominate over their kinetic energy. Our measurements provide a direct evidence that the electrons at densities < $3 \cdot 10^{11}$ cm^{-2} in a pristine $MoSe_2$ monolayer form a Wigner crystal even at B = 0 [1]. This is revealed by our low-temperature (T = 80 mK) magneto-optical spectroscopy experiments that utilize a newly developed technique allowing to unequivocally detect charge order in an electronic Mott-insulator state [2]. This method relies on the modification of excitonic band structure arising due to the periodic potential experienced by the excitons interacting with a crystalline electronic lattice. Under such conditions, optically-inactive exciton states with finite momentum matching the reciprocal Wigner lattice vector $k = k_W$ get Bragg scattered back to the light cone, where they hybridize with the zero-momentum bright exciton states. This leads to emergence of a new, umklapp peak in the optical spectrum heralding the presence of periodically-ordered electronic lattice.
Twisted bilayers of TMDs in turn offer a wealth of new phenomena, ranging from dipolar excitons to correlated insulator states. Another striking example of qualitatively new phenomena in this system is our recent observation of an electrically tunable two-dimensional Feshbach resonance in exciton-hole scattering [3], which allows us to control the strength of interactions between excitons and holes located in different layers. Our findings enable hitherto unexplored possibilities for optical investigation of many-body physics, as well as realization of degenerate Bose-Fermi mixtures with tunable interactions.

References

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Supersolidity in dipolar Bose-Einstein condensates

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I will report on a series of experimental and theoretical studies of supersolidity in dipolar Bose-Einstein condensates. In tube-like geometries, theory reveals a phase diagram with three distinct regimes - a regular Bose-Einstein condensate and incoherent and coherent crystals of quantum droplets. The coherent droplet crystals are connected by a background condensate, which leads - in addition to the periodic density modulation - to a robust phase coherence throughout the whole system. Experimentally we probe and confirm the signatures of the phase diagram by observing the in situ density modulation as well as the phase coherence using matter wave interference. We further prove the supersolid nature of the coherent droplet arrays by directly studying their low-energy Goldstone mode and density fluctuations across the superfluid-supersolid phase transition. Finally, we discuss the phase diagram in pancake-like geometries, where we theoretically observe rich pattern formation dynamics, and experimentally investigate the role of rotonic excitations in the corresponding phase transitions.

Ultracold bubbles in space: atomic physics aboard the International Space Station

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Exploring the effects of geometry, topology, dimensionality, and interactions on ultracold atomic ensembles has proven to be a continually fruitful line of inquiry. One heretofore unexplored configuration for such ensembles is that of a bubble or shell, where trapped atoms are confined in the vicinity of a spherical or ellipsoidal surface. Such a system could offer new collective modes, topologically-sensitive behavior of quantized vortices, self-interference and shell collapse, as well as the exploration of trapped ultracold systems with mm-scale spatial extent. While techniques for the generation of bubble-shaped traps have been known since 2001, terrestrial gravity has thus far prevented the observation of ultracold shells. With the construction of the NASA Cold Atom Lab (CAL) facility and its subsequent delivery to the International Space Station (ISS) and commissioning as an orbital BEC facility in 2018, experimental schemes requiring a sustained microgravity environment are now possible. I will present recent CAL observations of trapped shells of ultracold atoms, including a variety of shell configurations that are possible with this apparatus. I will also discuss the thermodynamics of ultracold shells and review open questions being explored in the current second science run of CAL aboard ISS.

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Pairing in one dimension: from Bose-Fermi mixtures to flat bands

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In this talk I will present some new and surprising results from recent DMRG simulations of 1D Hubbard-like models, describing fermions with attractive interactions. I first discuss how the superfluid pairing is affected when the system is repulsively coupled to a Bose gas. I show that, in the presence of a spin imbalance, bosons can be used to directly reveal the FFLO order, namely the condensation of Cooper pairs at finite momentum. In the second part of the talk I will discuss about pairing in the 1D sawtooth lattice, where the lowest Bloch band can be made dispersionless by fine-tuning the hopping rates. I show that the nature of the BCS-BEC crossover substantially differs from the linear chain model, which is integrable by Bethe ansatz. In particular I show that trimers do form in flat-band lattices and they are detrimental to superconductivity.

Supersolidity in long-range interacting quantum fluids

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In this talk, we will consider the effects of long-range interactions in atomic quantum fluids, as arising from static dipoles or induced by external optical driving. We will describe how such kind of interactions can cause the emergence of various distinct density waves and break the symmetry of the system in sometimes unexpected ways. The role of quantum and thermal fluctuations as well as experimental prospects will also be discussed.

A quantum vortex collider

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Quantum vortices occur in a wide range of systems, from atomic Bose–Einstein condensates to superfluid helium liquids and superconductors. Their dynamics is associated with the onset of dissipation, which makes the superflow no longer persistent [1]. Paradigmatic examples are the motion of Abrikosov vortices which determines the resistance of the type-II superconductors or the vortex dynamics in helium superfluids, where the mutual friction between the normal and superfluid components plays a key role in superfluid turbulence. In this work, we study the fundamental mechanisms of vortex energy dissipation by realising a versatile two-dimensional vortex collider in homogeneous atomic Fermi superfluids across the BEC-BCS crossover [2].

We unveil vortex-sound interactions by observing the conversion of the energy of vortex swirling flow into sound energy during vortex collisions. We visualise vortices annihilating into sound waves, i.e., the ultimate outcome of small-scale vortex collisions, and we find indications of the essential role played by vortex-core-bound fermionic excitations in strongly-correlated fermion superfluids. Our programmable platform opens the route to exploring new pathways for quantum turbulence decay, vortex by vortex.

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Chemistry of an impurity in a Bose-Einstein condensate and finite temperature effects

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In ultracold atomic gases, a unique interplay arises between phenomena known from condensed matter, few-body physics and chemistry. Similar to an electron in a solid, a quantum impurity in an atomic Bose-Einstein condensate is dressed by excitations from the medium, forming a polaron quasiparticle with modified properties. At the same time, the atomic impurity can undergo the chemical reaction of three-body recombination with atoms from the BEC, which can be resonantly enhanced due to universal three-body Efimov bound states crossing the continuum. As an intriguing example of chemistry in a quantum medium, we show that such Efimov resonances are shifted to smaller interaction strengths due to participation of the polaron cloud in the bound state formation. Simultaneously, the shifted Efimov resonance marks the onset of a polaronic instability towards the decay into larger Efimov clusters and fast recombination. In the second part of the presentation we will show how finite temperature leads to decoherence of the polaron and discuss how the resulting broadening of spectral lines can be captured within a time-dependent coherent state framework [3].

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Compressibility and the equation of state of an optical quantum gas in a box

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The compressibility of a medium, quantifying its response to mechanical perturbations, is a fundamental property determined by the equation of state. For gases of material particles, studies of the mechanical response are well established, in fields from classical thermodynamics to cold atomic quantum gases. In my talk, I will discuss experimental work demonstrating a measurement of the compressibility of a two-dimensional quantum gas of light in a box potential, from which we obtain the equation of state for the optical medium. The experiment is carried out in a nano-structured dye-filled optical microcavity. We observe signatures of Bose-Einstein condensation at high phase-space densities in the finite-size system. Upon entering the quantum degenerate regime, the measured density response to an external force sharply increases, hinting at the peculiar prediction of an infinite compressibility of the deeply degenerate Bose gas.

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Characterising far from equilibrium statesin a Bose gas

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Characterising non-equilibrium many-body phenomena, analogously to the description of equilibrium states of matter with an equation of state or their classification into universality classes, is an outstanding problem in physics. I will describe two of our recent contributions to this challenge using a box-trapped Bose gas.
First, the observation of bidirectional self-similar (spatiotemporal) dynamic scaling in an isolated quench-cooled Bose gas. As the gas thermalizes and undergoes Bose–Einstein condensation, it shows self-similar net flows of particles towards the infrared and energy towards the ultraviolet. For both infrared and ultraviolet dynamics we find that the scaling exponents are independent of the strength of the interparticle interactions.
Second, the construction of a non-equilibrium equation of state for a turbulent quantum gas, which under continuous forcing and energy dissipation exhibits a steady-state cascade of energy from low to high momenta. We identify the amplitude of the gas's stationary momentum distribution and the energy flux as state variables whose relation does not depend on the details of the energy injection or dissipation, or the history of the system. We further explore how the equation of state depends on the gas density and on interparticle interactions.

Sound propagation and superfluid density of ultra-cold quantum gases

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I will review recent theoretical and experimental results on the propagation of sound at finite temperature in both Fermi and Bose gases, with special focus on the temperature dependence of the superfluid density fraction in both two and three dimensions. Results for the depletion of the superfluid density at zero temperature in systems violating translational and/or Galilean invariance will be also presented.

Nonequilibrium quantum phases in driven cavity hybrid quantum systems

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When an ultracold atom gas in an optical lattice potential interacts with a single harmonic mode, the quantum many-body dynamics of this strongly coupled system becomes highly non-trivial. The single mode can induce quantum phase transitions with interesting novel nonequilibrium collective phases. For instance, the harmonic mode can be realized in terms of a mechanical, vibrational mode of a nanomembrane, which interacts optomechanically with light in a cavity [1-3]. Then, a competition between the force localizing the motional degree of freedom of the atoms and the membrane displacement occurs, with a nonequilibrium quantum phase transition from a localized symmetric state of the atom cloud to a shifted symmetry-broken state [1]. The energy of the lowest collective excitation vanishes, and a strong atom-membrane entanglement arises [2].
In addition, internal atomic degrees of freedom can be addressed [3] and the hybrid atom-optomechanical system not only undergoes a nonequilibrium quantum phase transition between phases of different collective behavior, but also that the order of the phase transition can be tuned from second to first order.
These hybrid atom-optomechanical systems are unitarily equivalent to the well-known cavity Bose-Hubbard model of an ultracold gas placed directly in an optical cavity [4-6]. This system shows a nonequilibrium Dicke quantum phase transition [4,5]. In this set-up, the light outcoupled from the cavity can be used as a sensitive probe to detect quantum fluctuations of the atoms in the gas in a non-destructive manner.

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Dynamics in Fermi gases quenched to unitarity

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Ultracold atomic gases with tunable interactions provide a versatile setting to study quantum systems out of equilibrium. Here, we study Fermi gases following a rapid interaction quench to the unitarity limit. For quenches that cross the normal to superfluid phase transition, we observe both pair formation and pair condensation, along with the corresponding timescales to equilibrate. Smaller quenches in the superfluid phase excite the Higgs amplitude mode, which we observe using Bragg spectroscopy. The amplitude oscillations provide a direct measure of the pairing gap and decay according to a power law with a damping exponent approximately midway between the BCS and BEC limits.

Manipulating matterwaves in atomtronic waveguides

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Matterwaves are the atomic counterpart to photonic waves. Like light, they can be guided, focussed and expanded. Time-averaged Adiabatic Potentials (TAAPs) allow us to construct the first fully coherent waveguides for matterwave, where we propagate atoms over distances of tens of centimeters without any noticeable losses or heating from the waveguides. These compact devices now opened the possibility to perform extremely low energy/temperature experiments without the need for large drop-towers. Recently, we have used this to demonstrate gravito-magnetic lenses focusing or collimating matterwaves in a waveguide almost at will, e.g. reducing their expansion energies of condensates by a factor of 46 and thus measuring temperatures down to 800 pK. We will present the basic principles of TAAPs and its long-term prospects as a compact matterwave laboratory.

Nonequilibrium dynamics of interacting quantum gases after disorder quenches

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Ultracold gases have proven powerful model systems to study quantum dynamics in various scenarios. In particular, the ability to tune atomic interactions and interface these systems with precisely engineered potentials opens the door to experimentally probing nonequilibrium dynamics and relaxation.
I will discuss our experiments investigating an ultracold Fermi gas along the BEC-BCS crossover in quenched disorder. Specifically, we study the response of an interacting molecular Bose-Einstein condensate when quenched into and out of a disordered optical speckle potential. We unravel the contributions of the density response and the long-range phase coherence measured via hydrodynamic expansion and find markedly different time scales. Tracing the quantum relaxation following a quench out of a disordered system, we find that the quantum phase needs a surprisingly long time to relax, pointing at possibly long-lived phase excitations. We furthermore extend our study to a unitary Fermi gas and find clear differences in the relaxation time scales and the equilibrium reached compared to a Bose-Einstein condensate. Our work provides experimental insight into the combined effects of disorder and interactions in quantum many-body systems out of equilibrium.

Abstracts of Contributed Talks

Thermal instability, evaporation, and thermodynamics of one-dimensional liquids in weakly interacting Bose-Bose mixtures

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We study the low-temperature thermodynamics of weakly interacting uniform liquids in one-dimensional attractive Bose-Bose mixtures. The Bogoliubov approach is used to simultaneously describe quantum and thermal fluctuations. First, we investigate in detail two different thermal mechanisms driving the liquid-to-gas transition, the dynamical instability, and the evaporation, and we draw the phase diagram.

Then, we compute the main thermodynamic quantities of the liquid, such as the chemical potential, the Tan's contact, the adiabatic sound velocity, and the specific heat at constant volume. The strong dependence of the thermodynamic quantities on the temperature may be used as a precise temperature probe for experiments on quantum liquids. We studied uniform liquids, but all our findings at zero pressure apply directly also to saturated quantum droplets.

Controlling persistent currents in fermionic rings via phase imprinting

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Here I report on our recent results on exciting persistent currents in ring-shaped fermionic superfluids. By employing a phase imprinting technique, we populate finite and controllable circulation states throughout the BEC-BCS crossover. We make use of a second disk condensate as a local oscillator to extract the circulation state of the ring by means of an interferometric probe, which allows us to monitor the current in time. By increasing the number of phase imprinting pulses, we are able to access high circulation states as long lived as the atomic sample.
Finally, we trigger the current decay by inserting a defect inside the ring trap. In the BEC and BCS regime the high circulation currents are observed to dissipate via the emission of vortices, in well agreement with GPE simulation for the first case. On the other hand, in the unitary Fermi gas all the accessible circulation states are found to be robust against dissipation. Our work demonstrates phase imprinting as a powerful technique to control the circulation state of a superfluid, opening for further studies on superfluidity and dissipation of strongly-interacting fermions.

Topological phonons in arrays of ultracold dipolar particles

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We discuss how to design and study a large variety of topology-related phenomena for phonon-like collective modes in arrays of ultracold polarized dipolar particles. These modes are coherently propagating vibrational excitations, corresponding to oscillations of particles around their equilibrium positions, which exist in the regime where long-range interactions dominate over single-particle motion. We demonstrate that such systems offer a distinct and versatile tool to investigate topological effects that can be accessed by choosing the underlying crystal structure and by controlling the anisotropy of the interactions. Our results show that arrays of dipolar particles provide a promising unifying platform to investigate topological phenomena with phononic modes.

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Dressed state approach to creating narrow barriers for soliton interferometry

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Matter-wave bright solitons are strong candidates for high precision matter-wave interferometry, as their inherent stability against dispersion supports long interrogation times. A narrow potential barrier forms a beam splitter analog, but in a typical realisation using a blue-detuned optical dipole potential, the width is wavelength limited. To overcome this limit, we investigate an interferometry scheme using the geometric scalar potential experienced by atoms in a spatially dependent dark state. We propose a possible implementation and probe effects of deviations from ideality.
The implementation is based on two overlapping Hermite-Gaussian laser beams. Using approximate scalar GPE and full vector GPE models to characterize splitting and recombination, we demonstrate a very narrow effective barrier using moderately high laser intensity ratios, where near-unit interferometric contrast is in principle achievable. We have also shown a scalar GPE with correctly chosen nonlinear barrier provides an excellent description, provided the intensity of the weaker beam is sufficiently high [1].

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Dynamical superradiant phases of a thermal atomic beam interacting with an optical cavity

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We theoretically study the superradiant phases of a thermal beam of inverted atomic dipoles interacting with an optical cavity. In this setup we find superradiant emission if the collective coupling strength exceeds all broadening mechanisms such as transit time and inhomogeneous broadening due to atomic motion. Here, we observe the build up and equilibration of a macroscopic coherent dipole that emits ultra-stable light.

We study the dynamics of this collective dipole by analyzing its amplitude and its phase mode. With the latter we can determine the linewidth of the collectively emitted light. In addition, we find a destabilization of these modes in presence of sufficiently large temperatures or the angle of the incoming atomic beam and the cavity axis. The emerging phases are still superradiant but dynamical with properties that depend on the underlying atomic motion. This opens the possibility to use such systems not only as ultra-narrow linewidth lasers but also as sensors.

A dipolar gas of molecules in the deeply degenerate regime

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I will show a general way to produce a degenerate Fermi gas of polar molecules with strong dipolar interactions in 3-dimensions. Starting from a density-matched degenerate atomic Bose-Fermi mixture, we produce a low-entropy sample of $^{23}Na^{40}K$ ground-state molecules by driving the mixture through a quantum phase transition from a polaronic to a molecule phase, followed by stimulated Raman adiabatic passage to their rovibronic ground state. The molecules are then stabilized against reaching short-range with a repulsive barrier engineered by coupling rotational states with a blue-detuned circularly polarized microwave. The microwave dressing induces strong tunable dipolar interactions between the molecules, leading to high elastic-to-inelastic collision ratio of about 500. This large elastic-to-inelastic collision ratio allows us to cool the molecular gas down to 21 nanokelvin, corresponding to 0.36 times the Fermi temperature. In the end, I will discuss possible measures for reaching even lower temperatures.

Caustics in the dynamics of two coupled superfluids following a quench

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Caustics are singularities arising from natural focusing in a wide range of systems, including optical, hydrodynamic and quantum waves. They take on universal shapes that are described by catastrophe theory and dominate wave patterns. Here we extend these ideas to quantum fields, such as the sine-Gordon and Bose-Hubbard models. Our physical motivation is to describe the dynamics of two one-dimensional Bose gases (quasi-condensates) that are suddenly coupled. The effects of thermal fluctuations are included by summing multiple classical field trajectories sampled from a Boltzmann distribution. We solve for the time evolution of these classical configurations numerically and find that the quench generates universal cusp shaped caustics in the number and phase difference degrees of freedom that also leave a characteristic imprint on the long-time probability distributions. These caustics represent a form of universal quantum many-body dynamics [1] associated with singularities in the underlying classical dynamics.

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Universal suppression of the superfluid weight by disorder independent of quantum geometry and band dispersion

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Motivated by the experimental progresses in controlling the properties of the energy bands in superconductors, significant theoretical efforts have been devoted to study the effect of the quantum geometry and the flatness of the dispersion on the superfluid weight (superfluid density). In conventional superconductors, where the energy bands are wide and the Fermi energy is large, the contribution due to the quantum geometry is negligible, but in the opposite limit of flat-band superconductors the superfluid weight originates purely from the quantum geometry of the Bloch wave functions.

In this work, we study how the energy band dispersion and the quantum geometry affect the disorder-induced suppression of the superfluid weight. Surprisingly, we find that the disorder-dependence of the superfluid weight is universal across a variety of theoretical models, and independent of the quantum geometry and the flatness of the dispersion. Our results suggest that a flat-band superconductor is as resilient to disorder as a conventional superconductor, even if the flat band is topologically nontrivial with nonzero Chern number.

From a non-thermal fixed point to thermal equilibrium with one-dimensional Bose gases

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On the macroscopic level novel, and even universal, phenomena can emerge. The underlying loss of information makes these phenomena insensitive to microscopic details and thus renders them interesting for quantum simulations. I will present experimental studies with ^{87}Rb spinor Bose-Einstein condensates obtained in the Oberthaler group in Heidelberg. Employing quantum quenches, we bring the system out of equilibrium and observe transient universal phenomena associated with the emergence of a non-thermal fixed point [1] and a suppression of the four-vertex at low momenta in the highly occupied regime [2]. We follow the system's dynamics beyond the non-thermal fixed point and observe its approach to thermal equilibrium. We characterize the underlying quasi-particle excitations by probing the dispersion relations. We find two Goldstone modes which are associated with the emergence of long-range coherence in the density and spin degree of freedom [3].

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Fluctuations of Bose-Einstein condensate revisited

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Thermal fluctuations of Bose-Einstein condensate are of interest ever since E. Schrödinger noticed their dependence on the choice of a statistical ensemble. Widely used the grand statistical ensemble, when applied to an isolated system yielding unphysical results. The problem of fluctuations was a hot topic after the first experiments on BEC. Asymptotic results were obtained and recurrence relations were derived for partition functions in microcanonical and canonical ensembles. The role of weak collisions remains controversial. Recently, the fluctuations were finally measured by the group of Jan Arlt from Aarhus [1,2]. We are providing theoretical background. In particular, in [2] we argue that the experiment unveiled for the first time microcanonical fluctuations of the condensate. We developed a novel method of computing the statistics of the non-zero temperature properties of the Bose gas, named the Fock States Sampling method, that gives access to both, canonical and microcanonical statistics for up to 100 000 particles.

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Dissipation in a polariton superfluid

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We have created quasi-one-dimensional wires in which polariton superfluids flow, and have studied long-distance propagation of condensates following quenches and in steady state. We directly measure three types of dissipation in these experiments due to interaction with a background reservoir: cooling of the condensate, friction due to interaction with a non-moving reservoir, and net force (drag) due to interaction with a moving reservoir. These effects can be described accurately using a model based on earlier theory of a cold atom condensate interacting with a thermal reservoir.

Berezinskii-Kosterlitz-Thouless transition in photon condensates

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I will present a classical field model for photon condensates, that describes the thermalization due to repeated emissions and absorptions by the dye molecules and the coherent propagation of the photons in the cavity, together with the fluctuations due to spontaneous emission.
With the help of this classical field model, we address the Berezinskii-Kosterlitz-Thouless (BKT) transition of photon condensates. In a homogeneous two-dimensional bose gas at thermal equilibrium, the phase transition to the superfluid state is of the BKT type provided that there are interactions. Photon condensates are however not at thermal equilibrium, due to cavity losses, that are compensated by laser drive. With our classical field model, we characterize the transition in photon condensates. We show that a BKT like transition is present, even though photon interactions are absent.

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Abstracts of Posters

Out-of-equilibrium superglass and glass states in cluster-forming models

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Glassy states, characterized by strong inhomogeneity in the absence of a crystalline structure, have been observed in several quantum models featuring quenched disorder sources of various kinds. In some cases, the coexistence of such behavior with superfluidity was also demonstrated, leading to superglasses, disordered counterparts of the well-known supersolid state. Whether or not such states can be realized in systems of experimental interest, and in the absence of externally induced frustration sources, however, remain open questions.

I demonstrate the existence of out-of-equilibrium (super)glasses and (super)solids in a class of disorder-free bosonic models featuring cluster-forming interactions of interest for experiments with Rydberg-dressed atoms. I simulate temperature quenching via unbiased path integral Monte Carlo simulations, in conjunction with energetic protocols which confirm the experimental relevance of the observed scenarios. I identify the effective polydispersity caused by the out-of-equilibrium formation of different types of clusters as a self-induced frustration source leading to (super)glassy physics.

Dipole collision and energy dissipation in 2D Fermi gases

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We study the propagation and collisions of vortex dipoles and quadrupoles in fermionic superfluids, both weakly and strongly interacting. The aim of the research is to explore the impact of the fermionic nature of the system on the dynamics of the vortices. The effects generated by Andreev states, localized within the cores, on dissipative processes will be discussed. Finally, results of simulations of quadrupole collisions at higher temperatures will be presented.

Ultracold quantum gases in spatially and temporally engineered environments

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We report on the experimental realization of a Kapitza pendulum for ultracold ^{87}Rb atoms. We show the dynamical stabilization of the atomic motion by a time periodic modulated potential. The time average of the modulated potential vanishes and the corresponding Floquet-Hamiltonian results in an effective time independent potential, which acts as a trap for the atoms. The Kapitza pendulum is generated by two time modulated Gaussian shaped laser beams, which create an attractive and repulsive potential. We analyse the stability of the trap depending on the driving frequency, as well as the role of experimental imperfections.

To continue the studies on Floquet driven systems and extend them to transport processes in time modulated environments, we are currently upgrading our ultracold quantum gas experiment to combine a scanning electron microscope and a high resolution optical objective. This will allow us to image and manipulate a cloud of ultracold ^{87}Rb atoms with high spatial resolution employing both techniques. Our system will be able to study resonance phenomena of a quasi 1D BEC tunneling through time modulated optical potentials in the presence of dissipation.

An impurity in a heteronuclear two-component Bose mixture

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We study the fate of an impurity in an ultracold heteronuclear Bose mixture, focusing on the experimentally relevant case of a ^{41}K-^{87}Rb mixture, with the impurity in a ^{41}K hyperfine state. Our work provides a comprehensive description of an impurity in a BEC mixture with contact interactions across its phase diagram. We present results for the miscible and immiscible regimes, as well as for the impurity in a self-bound quantum droplet. Here, varying the interactions, we find novel, exotic states where the impurity localizes either at the center or at the surface of the droplet.

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2D supersolid formation in dipolar condensates

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Dipolar condensates have recently been coaxed to form the supersolid phase. While 1D supersolids may be prepared via a roton instability, we find that such a procedure in 2D leads to a loss of both global phase coherence and crystalline order. We develop a finite-temperature stochastic GPE to explore the formation process in 2D, and find that evaporative cooling directly into the supersolid phase - hence bypassing the first-order roton instability - may produce a robust supersolid in a pancake-shaped trap. Importantly, the resulting supersolid is stable at the final nonzero temperature.

Dynamics following an interaction quench in the BEC-BCS crossover and machine-learning the phase diagram

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We quench the interaction strength of an ultracold cloud of ^{6}Li atoms instantaneously, i.e. faster than the Fermi time. In the short time dynamics following the quench we observe first indications of an oscillation in the condensate fraction reminiscent of the Higgs-mode. The observation was facilitated by a deep neural network trained to determine the amount of superfluidity in the cloud from simple time-of-flight images. This quantity is hidden for conventional fitting techniques, especially under real experimental conditions. We record a high-resolution phase diagram of the BEC-BCS crossover with the neural network and show that such networks are also able to detect the existance of a phase transition without any external training input.

Collective excitations of a strongly-correlated photon fluid stabilized by incoherent drive and dissipation

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Utilizing a simple and original approach to Gaussian quantum fluctuations around the Lindblad dynamics, we explore theoretically the spectral properties of the non-equilibrium photonic phases hosted by a lattice of coupled cavities in the presence of non-Markovian driving and dissipation, as well as strong photon interactions. In particular, we analyze how the elementary excitations of the system evolve across the Mott-superfluid-like dynamical transition exhibited by the model and point out the emergence of a diffusive Goldstone mode in the symmetry-broken phase whose structure indicates a close intertwining between dissipation and coherence as a consequence of strong correlations. Moreover, we investigate the one-body coherence of the insulating phase, showing how the dynamical properties of quasiparticles make this regime significantly different from its equilibrium counterpart. Our study goes in the direction of investigating the potential of driven-dissipative photonic fluids to quantum simulate a wider range of many-body scenarios.

Non-equilibrium superfluidity from Floquet engineering

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We study the one-dimensional Bose-Hubbard model in a lattice where the intersite tunnelling is periodically varied with time. Floquet analysis reveals that in the high-frequency limit this system is described by a static effective model where first-order hopping processes are suppressed, and the dynamics is driven by multi-particle correlations. Tuning the amplitude of the tunnelling allows the system to pass 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. We discuss how this non-equilibrium superfluid phase differs qualitatively from conventional superfluids, and demonstrate that its formation is robust against variations in experimental details. We thus show that driving the tunnelling ("kinetic driving") provides a novel form of Floquet engineering, which enables atypical Hamiltonians and exotic states of matter to be produced and controlled.

Full quantum dynamical description of a class of large driven dissipative Bose Hubbard models

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We have demonstrated that a scalable and complete quantum description of dissipative Bose-Hubbard models with sufficient dissipation can be obtained using the positive-P representation, and tractably simulated even with 100 000 or more sites [1]. The regime in question includes high and low density cases with significant interaction, strong antibunching or two-particle interference such as a photon blockade, provided dissipation is sufficiently strong. The presence of dissipation alleviates instabilities in the positive-P method that were known to occur for closed systems, allowing the simulation of dynamics up to and including the steady state. We also find that the regions of applicability of the positive-P, and truncated Wigner approaches are mutually complementary. Together these two approaches cover the majority of parameter space. The positive-P approach also provides a simple and physically intuitive way to calculate many unequal time correlations, possibly allowing their investigation in a non-perturbative and scalable way [2].

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Non-equilibrium dynamics of the Bose polaron at zero and non-zero temperatures

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We consider an impurity in a Bose gas in a far-from equilibrium situation where the impurity is quenched from a non-interacting to a strongly interacting state. For the case of a stationary impurity in an ideal gas, we explicitly derive the reduced density matrices at arbitrary temperatures. The dynamics can be understood analytically and are found to depend crucially on the presence of Bose-Einstein condensation. The results are compared to a recent experiment, for which we provide a new interpretation.

Finally, we turn to the case of a real Bose gas. A new non-local extension to Gross-Pitaevskii theory allows us to describe BECs with strong local deformation, providing acces to the regime of a strongly coupled impurity. Near a scattering resonance, we find a dynamical transition where initial signatures of repulsive scattering get replaced by such of attractive coupling.

Fast rotating superfluid on a curved surface

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I will report on recent experiments [1] performed in the BEC group of Paris North University with a Bose quantum gas confined in a rotationally invariant shell trap. In this trap the atoms can move freely on the surface and are strongly confined in the transverse direction. The atoms initially at rest at the bottom of the shell **-** because of gravity **-** are set into fast rotation until the centrifugal force pushes them away from the bottom such that they form an annular cloud rotating at supersonic speeds. This fast rotating superfluid exhibits collective modes that we probe spectroscopically: the observed shift of the lowest quadrupole mode frequency for increasing rotation rate is not fully understood.

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Universal scaling at a pre-thermal dark state

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Many open quantum systems are well described by an effective non-hermitian Hamiltonian generating a time evolution that allows eigenstates to decay and dissipate to the environment. In this framework, quantum coherent scaling is traditionally tied to the appearance of dark states, where the effect of dissipation becomes negligible. Here we discuss the universal dynamical scaling after a sudden quench of the non-hermitian O(N) model Hamiltonian.
While universality is generally spoiled by non-hermiticity, we find that for a given set of internal parameters short-time scaling behaviour is restored with an initial slip exponent different from that of closed quantum systems. This result is tied to the compensation of dissipation by interaction effects at short times leading to a pre-thermal dark state, where coherent many-body dynamics can be observed.

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Subradiance and superradiance in dense atomic cloud

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Usually, the interaction of atomic ensembles with light is treated as the sum of the independent contributions of each atom. However, when close enough, they can influence each other via their radiation, leading to a collective interaction with the light field. Dramatic manifestations are super- and subradiance. We have experimentally investigated these collective modes in a dense cloud of cold Rb atoms enclosed in a volume comparable to the wavelength of the optical transition (Dicke's regime) and excited by a strong and resonant laser drive.

In particular, we probe the nature of subradiant excitations when many photons are stored and, we have developed a novel protocol to release the stored light [1]. More recently, we studied the interplay between driving and superradiance that gives rise to modified Rabi oscillations [2]. Finally, we have investigated the interplay between super and subradiant modes and the mechanisms that lead to their population [3].

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Gaussian trajectory description of fragmentation in an isolated spinor condensate

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Spin-1 Bose gases quenched to spin degeneracy exhibit fragmentation: the appearance of a condensate in more than one single-particle state. Due to its highly entangled nature, this collective state is beyond the scope of a Gaussian variational approximation of the many-body wave function.

Here, we improve the performance of the Gaussian variational ansatz by considering dissipation into a fictitious environment, effectively suppressing entanglement within individual quantum trajectories at the expense of introducing a classical mixture of states. We find that this quantum trajectory approach captures the dynamical formation of a fragmented condensate, and analyze how much dissipation should be added to the experiment in order to keep a single realization in a non-fragmented state.

Floquet solitons and dynamics of periodically driven matter waves in optical lattices

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Periodic driving forces provide a great tool to design complex band structures for ultracold atoms in optical lattices. However, understanding heating mechanisms and the atoms' dynamics in driven lattices is still challenging. We experimentally study the time evolution of weakly interacting Bose-Einstein condensates of caesium atoms in a 1D optical lattice after a sudden start of the driving [1].
We observe the formation of stable wave packets with a negative effective mass, and we interpret these as Floquet solitons in periodically driven systems. The wave packets become unstable when we add a trapping potential along the lattice direction, leading to a redistribution of atoms within the Brillion zone. The concept of a negative effective mass and the resulting changes to the effective trapping potential and interaction strength are used to explain the stability and the time evolution of the wave packets.

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Simulating Bose gases with the complex Langevin method

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Complex Langevin (CL) is an approach to the solution of the sign problem, i. e. the fact that the numerical computation of path integrals is impossible with standard Monte Carlo techniques if the action is complex. The idea behind the method is to rewrite the path integral as a stochastic Langevin equation. In contrast to other Monte Carlo methods, the latter can be straightforwardly generalized to the case of a complex action, leading to a stochastic evolution in a complexified field manifold. Whereas the application of CL has a long standing tradition in high-energy physics, it is less established so far in the field of ultracold atomic gases. We here present results of our simulations of multi-component Bose Einstein condensates with CL.

One- and two-axis squeezing via laser coupling in an atomic Fermi-Hubbard model

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We study the production of spin-squeezed states with ultra-cold atomic fermions in a one-dimensional optical lattice in the Mott insulating phase. We show activation of two twisting mechanisms by a position-dependent laser coupling between internal degrees of freedom of atoms. A single laser coupling simulates the one-axis twisting model with the axis and direction of squeezing determined by the value of phase defining the atom-laser coupling. As such, adding a second laser beam with an adequately chosen phase paves the way to simulate the two-axis counter-twisting model, allowing reaching the Heisenberg-limited level of squeezing. Our scheme can be readily applied in state-of-the-art optical lattice clocks.

Self-pinning transition of a Tonks-Girardeau gas in a Bose-Einstein condensate

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We show that a Tonks-Girardeau (TG) gas that is immersed in a Bose-Einstein condensate can undergo a transition to a crystal-like Mott state with regular spacing between the atoms without any externally imposed lattice potential. We characterize this phase transition as a function of the interspecies interaction and temperature of the TG gas, and show how it can be measured via accessible observables in cold atom experiments. We also develop an effective model that accurately describes the system in the pinned insulator state and which allows us to derive the critical temperature of the transition.

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Effect of harmonic trapping on quantum droplets

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Recent observations of quantum droplets in ultra-cold bosonic systems have opened up exciting prospects to study quantum many-body theory. It is understood that the beyond mean-field effects plays a crucial role in stabilizing the droplet. Off late, we have reported the first analytical solution for these droplets in quasi one dimensional homogeneous binary Bose-Einstein condensate (BEC). Here, we plan to illustrate the significance of external trapping potential on these newly emerged liquid-like states. To be more precise, we observe a transition from a droplet like state to a localized soliton like state by modulating the harmonic trap frequency. We systematically study the energy, chemical potential and rms size of the droplets to comment on the nature of the transition.

Stationary and thermal properties of flattened and elongated quantum droplets

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We present our findings with regards to the theoretical description of quantum droplets that differ from the usual bulk form by being flattened, elongated, or at nonzero temperature. We show problems which arise while trying to describe thermal effects in quantum droplets (and Bose gases in general) and our proposition on how to deal with them. We compare the droplet stability at zero and finite temperatures. Moreover, we demonstrate an effective low dimensional theory for description of the quantum droplets in the flattened and elongated regimes.

From vector solitons to universal dynamics in a spinor Bose-Einstein condensate

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Ultracold gases provide a high level of control allowing for the investigation of soliton dynamics and collisions, especially in less explored multi-component settings. Well defined phase relations between the components lead to the existence of vector solitons with striking interaction features in the internal degree of freedom. We deterministically prepare such vector solitons in a quasi one-dimensional F=1 condensate of ^{87}Rb and observe non-trivial dynamics in the spin degree of freedom upon their collision [1]. This can be explained with an analytical Manakov model. We generate many such nonlinear excitations in the system which leads to strong spin fluctuations in the ensuing dynamics. These are characterized by persistent correlations between dips in the spin length and the spatial gradient of the Larmor phase. In this far from equilibrium setting we detect the emergence of self-similar dynamics.

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Out of equilibrium dynamical properties of Bose-Einstein condensates in ramped up weak disorder

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Based on Ref. [1] we investigate theoretically how the superfluid and the condensate deformation of a weakly interacting ultracold Bose gas evolve during the ramping up of an external weak disorder potential. Both resulting deformations turn out to consist of two distinct contributions, namely a reversible equilibrium one [2] as well as a non-equilibrium dynamical one, whose magnitude depends on the details of the ramping protocol. For the specific case of the exponential ramping up protocol, we are able to derive analytic time-dependent expressions for the aforementioned quantities. After sufficiently long time, a steady state emerges that is generically out of equilibrium. We make the first step in examining its properties by studying the relaxation dynamics into it. Also, we investigate the two-time correlation function and elucidate its relation to the equilibrium and the dynamical part of the condensate deformation.

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Supersolidity in dipolar quantum gases

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In the short time since the first observation of supersolid states of ultracold dipolar atoms in 2019, substantial theoretical and experimental progress has been made to improve our understanding of these systems. Here, we present our recent theoretical and experimental work on dipolar supersolids. First, we will look more closely onto the out-of-equilibrium dynamics of the phase coherence within the supersolid state after an interaction quench. Our observed dynamics can be well reproduced using an extended GPE simulation and a simple Josephson junction array model. Next, we investigate the birth, life and death of a dipolar supersolid produced directly via evaporative cooling and decaying due to atom loss. Our measurements suggest the initial formation of a quasicondensate crystal with density modulation and only local coherence, while global phase coherence appears to be established only at a later stage of the evaporation process. Finally, we show and characterize the transition from one- to two-dimensional systems with intermediate zig-zag states and investigate angular oscillations and their relationship to superfluidity in such systems.

Continuous versus discrete truncated Wigner approximation for driven, dissipative spin systems

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We present an alternative derivation for the recently proposed discrete truncated Wigner approximation (DTWA) for the description of the many-body dynamics of interacting spin-1/2 systems. The DTWA is a semi-classical approach based on Monte-Carlo sampling in a discrete phase space which improves the classical treatment by accounting for lowest-order quantum fluctuations. We provide a rigorous derivation of the DTWA based on an embedding in a continuous phase space. We derive exact stochastic differential equations for dephasing, decay and incoherent pump processes, which in the standard DTWA suffer from problems such as non-positive diffusion. We illustrate the CTWA by studying the dynamics of dissipative 1D Rydberg arrays and compare it to exact results for small systems.

Topological charge pumping in the phonon coupled Rice-Mele model

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Adiabatic and periodic variation of the system parameters can make it possible to transport charge through the system even in the absence of net external electric or magnetic fields. This nontrivial phenomenon of charge pumping was first proposed by David Thouless. The amount of charge pumped in a cycle is quantized and entirely determined by the system topology, which makes it robust in perturbations such as disorder and interactions. We study this phenomenon when the system is coupled to the optical phonons in this work. We employ the Ehrenfest method to treat the phonons classically and analyze the effect of coupling strength and period of pumping on the topological quantization of transport.

Fate of the False Vacuum: A finite temperature stochastic model for the simulated early universe in BEC

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We present a theoretical model to numerically evaluate the dynamics of a two-species Bose field at finite temperature. The relative phase of the spin components decays from a metastable false vacuum state to a stable true vacuum state. This model is used to study a proposed table-top experiment using a two-species Bose-Einstein condensate (BEC) to simulate the inflationary universe. We apply the Bogoliubov method and the truncated Wigner method to include both the thermal fluctuations and the quantum fluctuations. Our simulation results provide a feasibility study and possible observations of the experiment at finite temperature condition.

On the quasi-adiabatic preparation of antiferromagnetic-like state of Rydberg excitations of atoms in a lattice

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We examine the adiabatic preparation of spatially-ordered Rydberg excitations of atoms in finite one-dimensional lattices by frequency-chirped laser pulses, as realized in a number of recent experiments simulating quantum Ising model. Our aims are to unravel the microscopic mechanism of the phase transition from the unexcited state of atoms to the antiferromagnetic-like state of Rydberg excitations by traversing an extended gapless phase, and to estimate the preparation fidelity of the target state in a moderately sized system.
We find that the system climbs the ladder of Rydberg excitations predominantly along the strongest-amplitude paths towards the final ordered state. Despite its complexity, the interacting many-body system can be described as an effective two-level system involving a pair of lowest-energy instantaneous collective eigenstates of the time-dependent Hamiltonian. The final preparation fidelity of the target state can then be well approximated by the Landau-Zener formula involving the minimal energy gap extrapolation of which permits to estimate the preparation fidelity for much larger systems.

Out-of-equilibrium dynamics of bosons on a 2D Hubbard lattice

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We study the collective excitations of bosons in two-dimensional optical Hubbard lattices, described by the Bose-Hubbard model, using the cluster mean field theory at zero temperature. The method has been shown to be very powerful to determine the phase boundaries both at zero and finite temperatures [1]. From the low-lying excitations, we identify the presence of the Higgs and the Goldstone modes of the superfluid, as well as the particle- and hole-like excitations in the Mott insulator phase and calculate their dispersion relations.
The effective mass of the quasiparticles and -holes vanish at the tip of the Mott lobe where the Higgs energy gap also vanishes. Finally, we present the real time dynamics of the collective excitations, particularly, the Higgs mode. Our findings, particularly the dynamics of excitations support the previous mean-field-like calculations and can be relevant for cold-atom experiments.

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Non-equilibrium normal and superfluid transport through the flat band states of a finite-sized sawtooth lattice

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Flat bands have gained attention recently, especially due to their role in the twisted bilayer graphene (TBG) superconductivity. Despite a wealth of theoretical studies, flat band superconductivity have not been studied experimentally besides the twisted multilayer graphene systems. In our recent work [1], we proposed a ultracold gas based two-terminal setup for this purpose. By DC Josephson effect simulations we show that flat band features are captured. Beyond the published results, we have considered the proposed setup out-of-equilibrium utilizing the Schwinger-Keldysh method. Here, we present results of the article and new, unpublished results on non-equilibrium transport.

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Wilsonian renormalization in the symmetry-broken polar phase of a spin-1 Bose gas

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Wilsonian renormalization group theory (WRG) is applied to the spin-1 Bose gas both in the thermal and in the symmetry-broken polar phase. WRG is employed in a 1-loop perturbative expansion. In the thermal phase all relevant flow equations are derived and analyzed for their fixed-point behavior and critical exponents. To describe the thermal phase transition, the symmetry is broken explicitly and flow equations in the polar phase are computed including the renormalization of the condensate density.

A scheme is established for investigating the flow equations in a cut-off independent manner at fixed particle density. We find cut-off independent critical temperatures, the decrease in condensate density towards criticality and predictions for the condensate depletion. However, anomalous scaling is observed in most couplings impeding convergence and physical predictions. This is overcome by inserting anomalous couplings for the temporal and spatial derivatives and deriving their flow equations. Including them yields the disappearance of cut-off dependencies and predictions for all couplings.

Non-local correlation and entanglement of ultracold bosons in the two-dimensional Bose-Hubbard lattice at finite temperature

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We investigate the temperature-dependent behavior emerging in the vicinity of the superfluid (SF) to Mott insulator (MI) transition of interacting bosons in a two-dimensional optical lattice, described by the Bose-Hubbard model. The equilibrium phase diagram at finite temperature is computed by means of the cluster mean-field theory (CMF) including finite cluster size scaling. The SF, MI, and normal fluid (NF) phases are characterized as well as the transition or crossover temperatures between them are estimated by computing the SF fraction, compressibility and sound velocity using CMF method.
The nonlocal correlations in a cluster, when extrapolated to infinite size, leads to quantitative agreement of the phase boundaries with quantum Monte Carlo (QMC) results and with experiments. Moreover, we show that the von Neumann entanglement entropy in a cluster corresponds to entropy density and that it enhances near the SF-MI quantum critical point (QCP) and at the SF-NF boundary. The behavior of the transition lines near this QCP, at and away from the particle-hole (p-h) symmetric tip of a Mott lobe, is also discussed.

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Instantons and self-similar scaling in a 1D spin-1 Bose gas far from equilibrium

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A system driven far from equilibrium via a parameter quench can show universal dynamics, characterized by self-similar spatio-temporal scaling, associated with the approach to a non-thermal fixed point [1]–[4]. The study of such universality classes may assist in a thorough investigation of many systems ranging from the post-inflationary evolution of the universe to low-energy dynamics in cold gases. Topological excitations in the system are considered to be one of the driving mechanisms of coarsening dynamics in the system and are, as such, a point of interest in the study of far from equilibrium physics. We will discuss the infra-red scaling phenomena of a one-dimensional spin-1 Bose gas quenched from the polar phase to the easy-plane phase and provide evidence of the existence of instantons and their contribution to the coarsening dynamics of the system [5]. Furthermore the dependency of the scaling exponents and the evidence of two different scaling behaviors driven by two distinct types of excitations will be presented.

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Green's function approach
to the Bose-Hubbard model with disorder

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We present the findings of the paper [1], where we have studied the three different ground states of spinless bosons with short-range interactions submitted to a random potential using the disordered Bose-Hubbard model. Applying the field theoretical method of Refs. [2,3] to construct a perturbative expansion to the single-particle Green’s function with respect to the hopping, we were able to analyze the criteria for identifying the superfluid, the Mott-insulator, and the Bose-glass phases at finite temperatures and for small values of the tunneling energy.
By performing a summation of tree-level contributions of the perturbative approximation we obtained the condition to the long-range correlations, which leads to the phase boundary between superfluid and insulating phases. Considering the first relevant contribution to the expansion of the local correlations we obtained a renormalized expression to the density of states, which unambiguously distinguishes the Mott-insulator and Bose-glass phases. As a result, we constructed the phase diagram considering bounded on-site disorder.

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Quantum mechanical description of thermo-optic interaction in photon BECs

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Photon Bose-Einstein condensates are created in a dye-filled microcavity. This confinement freezes the longitudinal motion out and maps the photons to a two-dimensional gas of massive bosons. The dye solution continually absorbs and re-emits these photons, causing the photon gas to thermalise and to form a Bose-Einstein condensate. Because of a non-ideal quantum efficiency, these cycles heat the dye solution, creating a medium that provides an effective photon-photon interaction. However, so far only a mean-field description of this process exists.
Therefore, this poster presents a quantum mechanical description of the effective photon-photon interaction, including the thermal cloud [1]. An Exact Diagonalisation approach exposes how the effective photon-photon interaction modifies both the spectrum and the width of the photon gas [2]. In particular, the Exact Diagonalisation turns out to be crucial for understanding the dimensional crossover from 2D to 1D, as here larger photon-photon interactions may occur. A comparison with a variational approach based on the Gross-Pitaevskii equation quantifies the contribution of the thermal cloud in the respective applications.

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Observation of fermionic superfluid current through a dissipative quantum point contact

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We investigate the effect of spin-selective particle dissipation on the transport of a fermionic superfluid. We prepare a unitary Fermi gas of lithium-6 atoms in a two-reservoir geometry connected via a quantum point contact (QPC). The relaxation of particle imbalance between the reservoirs manifests itself in a supercurrent with non-linear current-bias relation, which can be understood with multiple Andreev reflections (MAR) [1]. In this work, we apply a spin-selective resonant beam localized at the QPC and observe its influence on the supercurrent.

We show experimentally that the nonlinear current-bias relation is smoothly connected to a linear, Ohmic transport as the dissipation increases. Moreover, we confirm this finding theoretically using the Keldysh formalism. Our results show that the superfluid current enabled by high-order MAR is rather robust to particle dissipation. We are now extending our exploration to spin transport between the reservoirs. Our work opens new ways that dissipation engineering provides in further understanding of non-equilibrium superfluid systems.

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One-dimensional quantum droplets

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We calculate the excitation spectrum of a one-dimensional self-bound quantum droplet in a two-component bosonic mixture described by the Gross-Pitaevskii equation (GPE) with cubic and quadratic nonlinearities. The cubic term originates from the mean-field energy of the mixture proportional to the effective coupling constant, whereas the quadratic nonlinearity corresponds to the attractive beyond-mean-field contribution. The properties of the droplet are governed by a single control parameter that depends on the particle number.

For large values of this parameter, the droplet features the flat-top shape with the discrete part of its spectrum consisting of plane-wave Bogoliubov phonons propagating through the flat-density bulk and reflected by edges of the droplet. With decreasing control parameter, these modes cross into the continuum, sequentially crossing the particle-emission threshold at specific critical values. A notable exception is the breathing mode, which we find to be always bound. As the control parameter tends to minus infinity, the droplet transforms into the soliton solution of the integrable cubic GPE.

Photon gases in microstructured potentials: From 1D to 2D

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Bose-Einstein condensate (BEC) of light has been realized at room temperature in a dye-filled microcavity. In such microcavities the longitudinal dimension is frozen out, limiting photons to two transversal directions, which makes them inherently a 2D system. In this system thermodynamic properties, formation dynamics as well as fluctuation properties have been studied in detail in the past. Recently, also the formation of photon condensates in microstructured potentials have been studied.
In our project, we intend to study the spatial dimensional crossover from a 2D photon gas to 1D photon gas, by the tailored asymmetric harmonic potential of varying trap frequencies. While in two dimensions a phase transition to a BEC exists, in one dimension no thermodynamic phase transition is expected in our model system. As in the photon BEC thermalization proceeds via the coupling to a heat bath, namely a dye solution, thermalization here also is observed for the one-dimensional case, in which integrability of the system usually suppresses or slows down thermalization. Here, in this poster, I present the latest experiment results for such a spatial dimensional crossover study.

Using a space-time mapping for probing heating suppression in periodically driven many-body quantum systems: a mean-field example with Bose gases

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We recently introduced a non-traditional use of exact space-time mappings which consists not necessarily in finding analytical solutions. It consists rather in exactly mapping time evolutions of different quantum many-body systems both with [1] and without [2] dissipation and applicable in quantum gas experiments. In this work [3], based on our previous resluts, we construct a mean-field model of many-body systems with rapid periodic driving. The single-particle potential and the inter-particle interaction strength are both time-dependent at once, in related ways. We map the evolutions of the model system onto evolutions with slowly varying parameters. Such a mapping between a Floquet evolution and a static or slow process allows us to investigate non-equilibrium many-body dynamics and examine how rapidly driven systems may avoid heating up, at least when mean-field theory is still valid. From that special but interesting case, we learn that rapid periodic driving may not yield to heating because the time evolution of the system has a kind of hidden adiabaticity, inasmuch as it can be mapped exactly onto that of an almost static system.

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Mobile dissipative impurities in one-dimensional Bose gases

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We study an impurity immersed into a one-dimensional Bose gas with a fluctuating impurity-Bose interaction (i.e. a dissipative „polaron“). We use a mean-field description which takes the deformation of the quasi condensate into account such that quantum fluctuations are small. The stochastic coupling creates a coherent flow of particles towards the impurity, similar to the effect of a local loss. In addition there is an outward flowing incoherent current of particles. Depending on the amplitude of the noise and the velocity of the impurity a normal or Zeno-like quasi stationary state emerges.

Above a critical value of the velocity there is a continuous emission of solitons such that no stationary state forms even for a subsonic impurity. In the case of two impurities, we find evidence for a dissipation-mediated long-range interaction between the impurities for weak noise, while strong noise results, similar as a moving impurity, in a constant creation of solitons.

Using vortices as probes of quantum many-body systems

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Quantum mixtures formed of ultracold atoms offer exquisite experimental control over the system geometry and interactions, which has enabled recent demonstrations of beyond-mean-field phenomena such as quantum droplets and Lee-Huang-Yang gases. Here the mean-field interactions are significantly reduced such that quantum fluctuations play a dominate role in governing the behaviour of the system.
I will discuss how vortices may be used to probe binary superfluids and quantum-fluctuation-enhanced regimes, and how this might be implemented experimentally. Within this context, I will also present an overview of the experimental capabilities that I will be developing at the University of Strathclyde to enable studies of vortex dynamics in binary superfluids.

Quantum turbulence in ultracold Bose and Fermi gases: similarities and differences

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Recent advances in ultracold-atom technology enable quantum turbulence to be studied in regimes with both experimental and theoretical control. While much work has been performed with bosonic systems, detailed studies of fermionic quantum turbulence are nascent, despite wide applicability to other contexts such as rotating neutron stars. In this work, I will present the results of a comparative study of the turbulence obtained by means of the Gross-Pitaevskii equation (bosonic case) and time-dependent density functional theory called the superfluid local density approximation (fermionic case).

These results demonstrate that dissipation mechanisms intrinsic to fermionic superfluids play a key role in differentiating fermionic from bosonic turbulence. In particular, the difference manifests by enhanced damping of Kelvin waves for Fermi superfluids, as compared to Bose systems.

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Shell-shaped dual-component BEC mixtures

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Since the launch of NASA's Cold Atom Lab there have been ongoing efforts to create shell-shaped Bose-Einstein condensates (BECs) in microgravity. The experimental realization is based on radio-frequency (rf) dressing which, however, is intrinsically sensitive to typical inhomogeneities of the involved magnetic fields. A fully closed shell of Bose-Einstein condensed atoms is therefore yet to be created.

Motivated by this experimental challenge, we propose an alternative approach based on dual-component BEC mixtures where one component forms a shell around the other due to a repulsive inter-component interaction. We find that the mixture shows similar signatures in its collective excitation spectrum at the transition between a filled sphere and a hollow sphere as the rf-dressed BEC but offers additional benefits such as the conservation of the shell structure during the free expansion dynamics. Additionally, we are performing self-consistent simulations of the Gross-Pitaevskii and Bogoliubov-de Gennes equations to study the quantum depletion and finite temperature effects.

Measurement of the order parameter and its spatial fluctuations across Bose-Einstein condensation

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We investigate the strong out-of-equilibrium dynamics occurring when a harmonically trapped ultracold bosonic gas is evaporatively cooled across the Bose-Einstein condensation transition. By imaging the cloud after free expansion, we study how the cooling rate affects the timescales for the growth of the condensate order parameter and the relaxation dynamics of its spatial fluctuations.
We find evidence of a delay in the condensate formation related to the collisional properties and a universal condensate growth following the cooling rate. Finally, we measure an exponential relaxation of the spatial fluctuations of the order parameter that also shows a universal scaling, following a different power law.

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Decay of supercurrent in homogeneous atomic superfluids

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The motion of quantized vortices is of fundamental importance in different phenomena in condensed matter physics such as the resistive behaviour of superconductors or other dissipative collective phenomena in superfluids. In particular, here we firstly investigate theoretically its role on the decay of persistent currents in ring-shaped atomic superfluids and in the presence of a small defect. Secondly, we study the origin of dissipation during vortex dipoles collision.
In our studies, we model recent experiments of ^{6}Li at LENS in the limit of Bose-Einstein condensate. The numerical simulation are performed at T=0 by solving the Gross-Pitaevskii equation. A finite circulation state is excited by imprinting a phase in the equilibrium condensate wavefunction. When a small defect is introduced, there is a critical velocity, i.e. a critical circulation, at which the vortices are emitted into the superfluid causing phase slips and thus a decay of the current, otherwise persistent. On the other hand, accelerating vortices may dissipate their energy due to sound emission as happens during the collision of two vortex dipoles and this would constitute the second part of our studies.

Exotic structures in spin-imbalanced unitary Fermi gas

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Recent studies on ultracold Fermi gas have shown the existence of a self-bound, spin-polarized impurity dubbed as ferron. The object can be generated dynamically by applying a time-dependent, spin-selective potential. Once the object is created, the external potential is turned off and the object shows no sign of decay during its time evolution. Moreover, ferrons can be characterized by a critical velocity. Beyond such velocity, the ferron loses its integrity while moving on a superfluid environment.
In this work, we present the existence of more exotic phases within the static 2D Bogoliubov de-Gennes framework. The pairing field has been subjected to a random noise in order to create the nodal lines for unpaired particles to occupy. For small polarizations, we can see several distinct ferrons are created by this method. As the total polarization increases, these structures become more complex and no longer consist of separate ferrons. At moderate spin polarization the gas exhibits locally ordered structure of superfluid domains separated by polarized matter in normal state.

time	Mo. 02.05.	time	Tue. 03.05.	time	We. 04.05.	time	Thu. 05.05.	time	Fr. 06.05.
		08:30-08:40	Opening						
		08:40-09:20	Davis *(online)*	08:40-09:20	Schmitt	08:40-09:20	Stringari *(online)*	08:40-09:20	Orso
		09:20-10:00	Bleu	09:20-10:00	Berloff	09:20-10:00	Langen	09:20-10:00	Vale *(online)*
		10:00-10:20	Snoke	10:00-10:40	Carusotto	10:00-10:40	Chomaz	10:00-10:40	Daley
		10:20-11:00	Coffee break	10:40-11:20	Coffee break	10:40-11:20	Coffee break	10:40-11:20	Coffee break
	Arrival	11:00-11:40	Imamoglu	11:20-11:40	Jäger	11:20-12:00	Pohl	11:20-11:40	Peotta
		11:40-12:20	Thorwart	11:40-12:20	Wouters Gardiner	12:00-12:20	De Rosi	11:40-12:20	Widera
		12:20-13:00	Hofferberth	12:20-13:00	O'Dell Rzążewski	12:20-13:00	Luo Di Liberto	12:20-13:00	Schmidt
		13:00-14:00	Lunch	13:00-14:00	Lunch	13:00-14:00	Lunch	13:00-14:00	Lunch
		14:00-15:50	Free time	14:00-14:40	Plenary discussion	14:00-15:50	Free time		Departure
					Free time				
16:00-17:30	Dalibard *Physics Colloquium TUKL (online)*	15:50-16:30	Coffee break	15:30-17:30	Wine tasting	15:50-16:30	Coffee break		
		16:30-17:10	Von Klitzing			16:30-17:10	Roati		
		17:10-17:50	Ahufinger			17:10-17:50	Smith		
		17:50-18:10	Del Pace		Free time	17:50-18:10	Prüfer		
18:30-20:00	Dinner	18:30-20:00	Dinner	18:30-20:00	Dinner	18:30-20:00	Dinner		
	Meet & Greet	20:00-22:00	Poster session I: odd numbers	20:00-21:00	Lundblad	20:00-22:00	Poster session II: even numbers		