BAD HONNEF PHYSICS SCHOOL

ULTRACOLD QUANTUM MATTER

Physikzentrum, Bad Honnef, Germany

August 10 – 16, 2025

Organizers

Carlos Sá de Melo (Atlanta, USA) & Axel Pelster (Kaiserslautern, Gemany)

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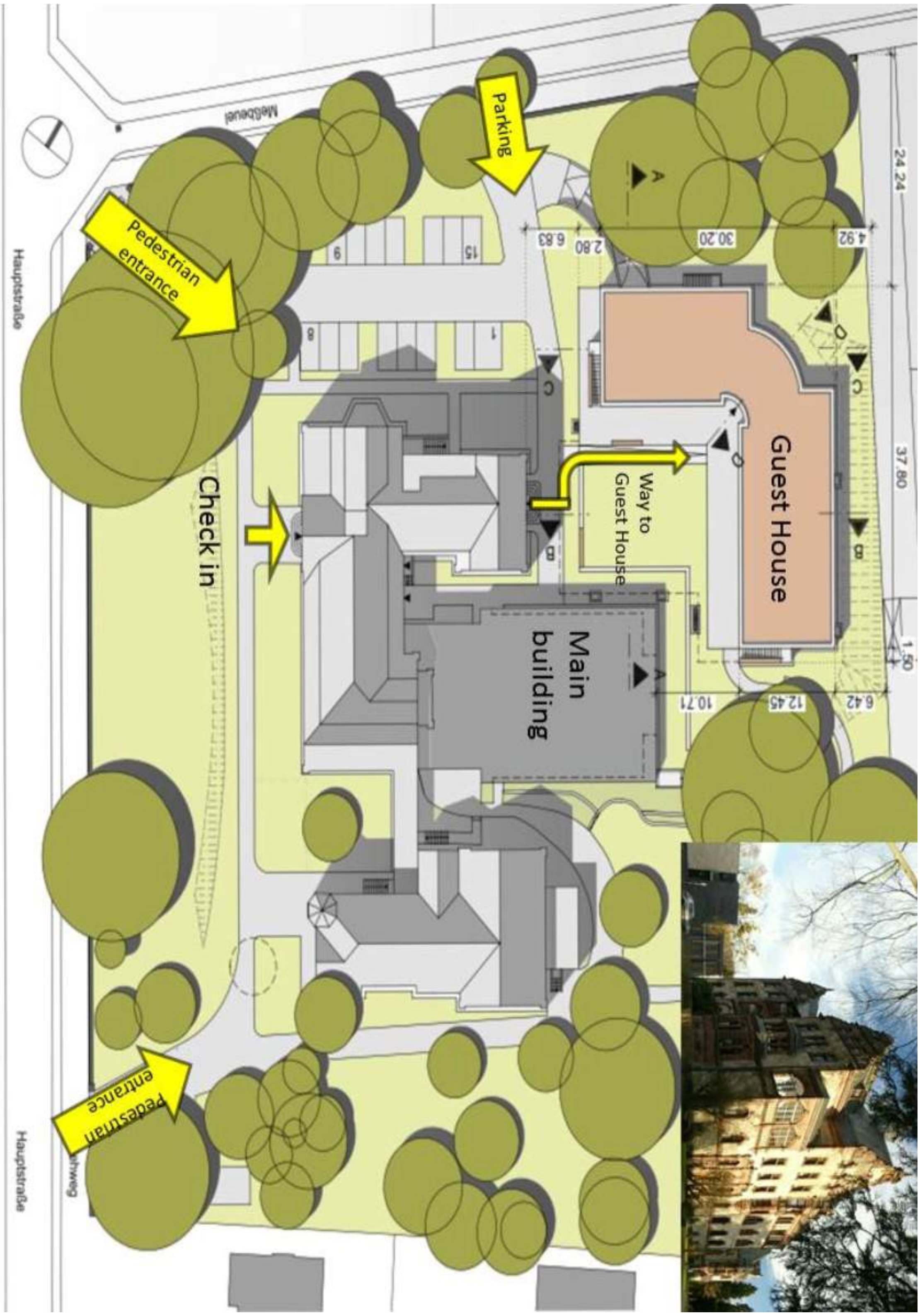

Venue

Physikzentrum Bad Honnef:

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Preface

Since the first Bose-Einstein condensate of ultracold atomic gases was realized experimentally in 1995, the research field of ultracold quantum gases has been extremely active and has expanded in many different directions. New areas of research are emerging at the borderlines of atomic and molecular physics, quantum optics, and condensed matter physics. However, this rapid evolution in the field of ultracold quantum gases is not adequately reflected in standard curricula. The daily work of a PhD student in both theory and experiment is now so specialized that a broad knowledge about the research field is lacking. To provide a common platform of understanding both theory and experiment in the field of ultracold quantum gases, we organize an international school for physics students. Although the school is mainly intended for PhD students, also interested master students and young postdocs will certainly profit from it.

The main goal of the school is to provide a solid introduction to the field of ultracold quantum gases, which will be delivered by internationally recognized experts of the field. Student solutions for the problems, which were mentioned at the lectures, as well as student questions are answered in four plenary sessions. Furthermore, the posters of the participants are presented in four evening sessions.

Together with invited speakers and organizers we expect to have more than 80 participants in presence at the Physics Center in Bad Honnef. And, finally, all presentations are recorded and are made available shortly afterwards at the platform **Panopto** hosted by RPTU Kaiserslautern-Landau, Germany, with the link

http://bit.ly/477SNaa

We wish all participants an interesting school week with many enjoyable discussions.

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Program

Bad Honnef Physics School
Ultracold Quantum Matter
Physikzentrum, Bad Honnef
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Sunday, August 10

14:00-18:30	Arrival and registration
18:30-20:00	Dinner
20:00-22:00	*Meet and Greet*

Monday, August 11

07:30-08:45	Breakfast
08:45-09:00	Carlos Sá de Melo (Atlanta, USA):
	Opening and welcome
09:00-10:00	David Snoke (Pittsburgh, USA):
	Design and characterization of polariton microcavities
10:00-10:30	Coffee break
10:30-11:30	Michiel Wouters (Antwerp, Belgium):
	Classical field models for condensates of light
12:00-13:30	Lunch
13:30-14:00	*Questions and Answers/Plenary Discussion 1*
14:00-15:00	*Plenary for Poster Sessions 1 & 2 (Poster Numbers 1-26)*
15:00-15:30	Coffee break
15:30-16:30	Uros Delic (Vienna, Austria):
	Cavity optomechanics with polarizable particles:
	From atoms to dielectric objects
16:30-17:00	Coffee break
17:00-18:00	Clara Wanjura (Erlangen-Nürnberg, Germany):
	Theory of cavity optomechanics
18:30-20:00	Dinner
20:00-21:00	*Poster Session 1 (Poster Numbers 1-13)*

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Tuesday, August 12

07:30-09:00	Breakfast
09:00-10:00	David Snoke (Pittsburgh, USA):
	Crossovers: Polariton BEC to lasing, and equilibrium to nonequilibrium BEC
10:00-10:30	Coffee break
10:30-11:30	Michiel Wouters (Antwerp, Belgium):
	Spatio-temporal coherence in nonequilibrium condensates of light
12:00-13:30	Lunch
13:30-14:00	*Questions and Answers/Plenary Discussion 2*
14:00-15:00	*Working Groups 1*
15:00-15:30	Coffee break
15:30-16:30	Uros Delic (Vienna, Austria):
	Collective optomechanics
	with optically trapped atoms and silica nanoparticles
16:30-17:00	Coffee break
17:00-18:00	Clara Wanjura (Erlangen-Nürnberg, Germany):
	Engineering sound and light -
	From non-reciprocity to non-Hermitian topology
18:30-20:00	Dinner
20:00-21:00	*Poster Session 2 (Poster Numbers 14-26)*

Wednesday, August 13

07:30-09:00	Breakfast
09:00-10:00	Cesar Cabrera (Hamburg, Germany):
	Experimental techniques for exploring the BEC-BCS Crossover
10:00-10:30	Coffee break
10:30-11:30	Hadrien Kurkjian (Paris, France):
	The BEC-BCS crossover from the normal to the superfluid phase

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12:00-13:30	Lunch
13:30-18:30	Excursion
18:30-20:00	Dinner
20:00-	*Socializing*

Thursday, August 14

07:30-09:00	Breakfast
09:00-10:00	Cesar Cabrera (Hamburg, Germany): *Experimental techniques for exploring the BEC-BCS crossover*
10:00-10:30	Coffee break
10:30-11:30	Hadrien Kurkjian (Paris, France): *The BEC-BCS crossover from the normal to the superfluid phase*
12:00-13:30	Lunch
13:30-14:00	*Questions and Answers/Plenary Discussion 3*
14:00-15:00	*Plenary for Poster Sessions 3 & 4 (Poster Numbers 27-51)*
15:00-15:30	Coffee Break
15:30-16:30	Sylvain Nascimbene (Paris, France): *Engineering topological quantum matter in ultracold atomic gases*
16:30-17:00	Coffee Break
17:00-18:00	Patrik Öhberg (Edinburgh, UK): *The role of topology in nature –* *From the standard model to condensed matter physics*
18:30-20:00	Dinner
20:00-	*Poster Session 3 (Poster Numbers 27-38)*

Friday, August 15

07:30-09:00	Breakfast
09:00-10:00	Sylvain Nascimbene (Paris, France): *Engineering topological quantum matter in ultracold atomic gases*

10:00-10:30	Coffee break
10:30-11:30	Silke Ospelkaus (Hanover, Germany):
	Ultracold polar molecules
12:00-13:30	Lunch
13:30-14:00	*Questions and Answers/Plenary Discussion 4*
14:00-15:00	*Working Groups 2*
15:00-15:30	Coffee break
15:30-16:30	Silke Ospelkaus (Hanover, Germany):
	Ultracold polar molecules
16:30-17:00	Coffee break
17:00-18:00	Luis Santos (Hanover, Germany):
	Dipolar gases: from supersolids to lattice models
18:30-20:00	Dinner
20:00-21:00	*Poster Session 4 (Poster Numbers 39-51)*

Saturday, August 16

07:30-09:00	Breakfast
09:00-10:00	Patrik Öhberg (Edinburgh, UK):
	The role of topology in nature –
	From the standard model to condensed matter physics
10:00-10:30	Coffee break
10:30-11:30	Luis Santos (Hanover, Germany):
	Dipolar gases: from supersolids to lattice models
11:30-11:45	Axel Pelster (Kaiserslautern, Germany)
	Concluding remarks
12:00-13:30	Lunch
13:30-	Departure

Speaker Abstracts

Experimental techniques for exploring the BEC-BCS crossover

Cesar Cabrera

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The BEC-BCS crossover in ultracold Fermi gases offers a unique platform for exploring strongly correlated quantum systems in a highly controlled environment. This workshop will provide a comprehensive overview of the experimental techniques used to realize and probe this crossover.

The first session will focus on the experimental platform required to study fermionic pairing. Topics will include the cooling and trapping of fermionic atoms, the control of interatomic interactions using Feshbach resonances, and common detection techniques such as RF and Bragg spectroscopy for investigating pairing mechanisms.

The second session will explore the study of collective excitations across the crossover. We will discuss methods for exciting and measuring collective modes, and how their dynamical evolution reveals key properties of fermionic superfluids.

This workshop is intended for PhD students with a background in cold atom physics and will complement the theoretical lectures with a practical, experiment-focused perspective.

Cavity optomechanics with polarizable particles: From atoms to dielectric objects

Uros Delic

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Polarizable objects, such as atoms, molecules, or dielectric objects, experience optical gradient and scattering forces when illuminated by a laser beam. These forces can optically trap the object in an optical tweezer, move it around, and control its motion to the quantum ground state. This lecture will cover topics about optical forces on atoms and silica nanoparticles, and how to control their motion in free space and optical cavities.

Collective optomechanics with optically trapped atoms and silica nanoparticles

Uros Delic

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In recent years, arrays of optical tweezers have extended optical trapping to arbitrary patterns of atoms or silica nanoparticles. In these systems, optical forces induce an interaction mechanism, known as the light-induced dipole-dipole (LIDD) or “optical binding” forces. In this lecture, I will present the recent efforts in exploring collective motion in a few-body system of atoms or silica nanoparticles.

The BEC-BCS crossover from the normal to the superfluid phase

Hadrien Kurkjian*
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We will explore the properties of a two-component gas of atomic fermions, with an emphasis on the dynamical properties such as transport, dissipation and collective modes. Conceptually, the two-component Fermi gas is one of the simplest and purest quantum many-body system ever realized, with nowadays nearly homogeneous trapping geometries [1], a complete absence of disorder, and interatomic interactions characterized only by the scattering length a [2]. At the same time, the system displays a remarkably rich phase diagrams, which forces us to summon very different approaches of the quantum many-body problem. It also allows us to draw fruitful analogies with other fermionic or bosonic fluids, such as electrons gases, superfluid Helium or nuclear matter.

As a function of temperature, the gas evolves from a macroscopically-coherent superfluid phase at low temperature, to a normal quantum gas and eventually to a classical gas at high temperature. As a function of the interaction strength, it displays a well-known transition from a fermionic to a bosonic physics: the Bose-Einstein Condensate to Bardeen-Cooper-Schrieffer crossover, which (despite its name) applies to both the normal and superfluid phases [3].

During the first lecture, we will explore the low-temperature fermionic side of this crossover. Above the critical temperature T_c and much below the Fermi temperature $T_{\rm F}$, the gas behaves as a gas of Landau quasiparticles: a Fermi liquid [4]. From the properties of the Landau quasiparticles, I will explain how to derive the Naviers-Stokes equations obeyed by the hydrodynamic perturbations [5, 6]. I will also discuss the existence of collisionless collective modes. When approaching T_c from above, a soft pairing mode emerges in the quasiparticle gas, which we will interpret as a precursor of the superfluid phase transition.

During the second lecture, we will venture below T_c. The Landau quasiparticles then turn into BCS quasiparticles, with a gapped spectrum [7]. This drastically modifies the collective physics, with the emergence of an Anderson-Bogoliubov phase mode at low energy, and an amplitude Higgs mode at high energy, in place of the density modes of the Fermi liquid. Leaving the fermionic side of the phase diagram, we will study the dispersion of these two modes along the BCS-BEC crossover [8–11]. In the regime $T \ll T_c$, the phononic depart of the Anderson-Bogoliubov branch defines a universal regime where the dynamics of the gas is entirely determined by its phononic degrees of freedom [12, 13]. We will discuss the dissipative properties of this superfluid of phonons.

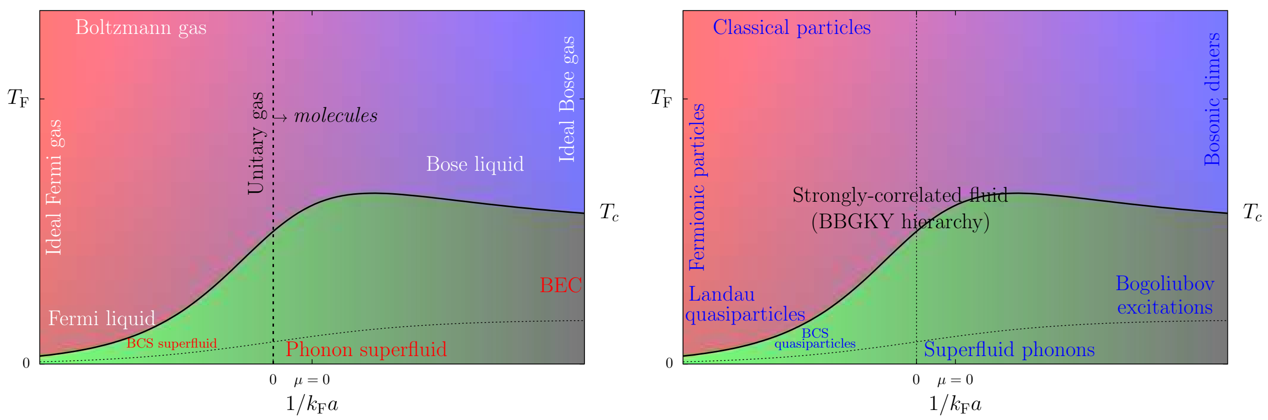

FIG. 1. (Left panel) Equilibrium phase diagram of the spin-1/2 Fermi gas with contact interactions. The various regimes of the normal and superfluid phase are shown in white and red respectively. (Right panel) Same diagram showing (in blue) the microscopic degrees of freedom that underly the dynamical properties.

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Engineering topological quantum matter in ultracold atomic gases

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Ultracold atomic gases can be used to engineer various types of topological bands and topological states of matter. In these lectures, I will present the different approaches developed so far to engineer artificial magnetic fields and spin-orbit coupling, and compare the assets and limitations of each method. I will explain how these effects give rise to topological states of matter, and how to probe topological properties.

The role of topology in nature –
From the standard model to condensed matter physics

Patrik Öhberg

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In these lectures we will discuss the role of topology in physics. The first lecture will focus on the mathematical aspects of topology where we will introduce key concepts and ideas, with a bit of history also thrown into the mix. In the second lecture we will look at a number of examples from physics where topology has provided a deeper understanding of the properties of quantum materials. We will in particular look at examples from condensed matter physics, photonics, and the standard model where field theories play a prominent role.

Ultracold polar molecules

Silke Ospelkaus

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Ultracold polar molecules offer unique opportunities to explore fundamental questions in quantum chemistry, quantum simulation, and many-body physics. In this talk, I will provide an overview of the state-of-the-art techniques for preparing ultracold molecular samples. These include both the indirect approach of associating ultracold atoms into molecules, effectively realizing a controlled chemical reaction, as well as direct cooling techniques applied to preexisting molecules.

Building on this foundation, I will highlight recent experimental advances involving ultracold molecular systems. Particular emphasis will be placed on studies of molecular collisions, the control of collisional properties via external fields, and the emergence of dipolar many-body phenomena in strongly interacting molecular gases.

Dipolar gases: from supersolids to lattice models

Luis Santos

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Due to dipole-dipole interaction dipolar quantum gases present qualitatively different physics compared with their non-dipolar counterparts. In theses lectures, I will discuss some general ideas of the theory of dipolar gases, focusing initially on dipolar Bose-Einstein condensates, including issues like condensate stability and dipolar rotons. I will then move to the physics of dipolar droplets and supersolids, and discuss briefly on dipolar mixtures. In the second part of the lectures, I will move to dipoles in optical lattices, first focusing on dipolar Hubbard models, both on their ground-state properties and peculiar non-equilibrium dynamics. I will then move to dipolar spin models, illustrating the discussion with some particular examples.

Design and characterization of polariton microcavities

David Snoke

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It is now routine to use molecular beam epitaxy (MBE) of GaAs/AlGaAs/AlAs to produce microcavity structures for polaritons with lifetimes of hundreds of picoseconds, which allows thermal equilibrium, as well as strongly interacting, coherent polaritons at room temperature. I will discuss some of the "tricks" that are used by two MBE groups to make these structures successfully, as well as how to characterize them. Many coherent polariton effects, and Bose condensation, become much easier with these structures with long polariton lifetime.

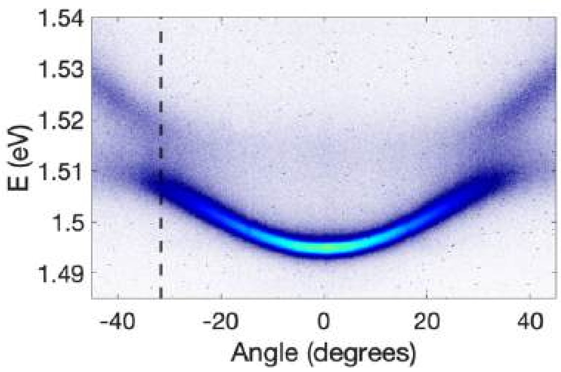

Figure 1. Experimentally measured dispersion of exciton-polaritons in a GaAs/AlGaAs structure at room temperature, showing anticrossing due to strong coupling. From Ref. [1].

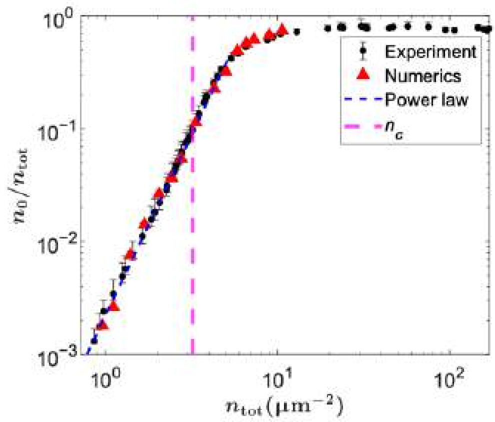

Figure 2. Coherent fraction (nominally, the “condensate” fraction) of polariton gas in a GaAs/AlGaAs structure at low temperature (~20 K), measured from interferometry, compared to numerical solution of Gross-Pitaevskii equation with infinite lifetime. From Ref. [2].

Acknowledgements. This work has been supported by the US National Science Foundation under grant DMR-2306977.

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Crossovers: Polariton BEC to lasing, and equilibrium to nonequilibrium BEC

David Snoke

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Bose-Einstein condensation (BEC) of polaritons is one of many types of coherent light-matter interaction; in general, the transition between this state and other states, such as photon condensation, lasing, and superradiance, can be either continuous or discontinuous, leading to a complicated phase diagram. I will discuss the underlying physics, including unifying principles, and the use of the quantum Boltzmann equation and Gross-Pitaevskii equation for modeling nonequilibrium dynamics.

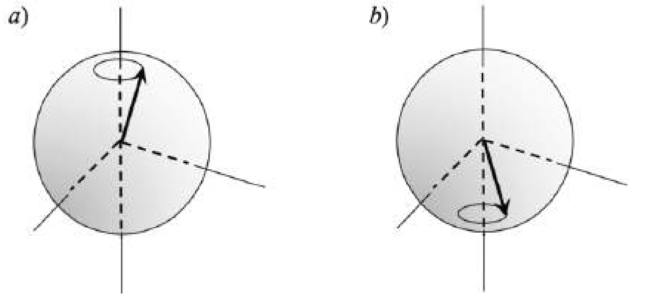

Figure 1. a) Bloch sphere representation of the state of electronic excitations in a laser, with inversion. b) Bloch sphere representation of the state of electronic excitations in an excitonic or polaritonic condensate. From Ref. [1].

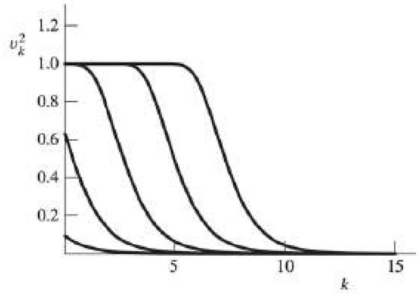

Figure 2. Electron occupation number as exciton density is increased from BEC to BCS limit. From Ref. [1].

Acknowledgements. This work has been supported by the US National Science Foundation under grant DMR-2306977.

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Theory of cavity optomechanics

Clara Wanjura

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The interaction between light and massive objects has been an object of research since the 17th century when Kepler noted that a comet's tail always points away from the sun. Nowadays, it is possible to engineer the interaction between light and mechanical motion in cavity optomechanical systems with remarkable experimental control which has given rise to a plethora of applications. In this lecture, I will discuss the optomechanical coupling, it's Hamiltonian formulation and the optomechanical equations of motion. Since optomechanical systems are typically driven-dissipative quantum systems, which are conveniently described in terms of quantum Langevin equations, I will furthermore give an introduction to input-output theory.

Engineering sound and light --
From non-reciprocity to non-Hermitian topology

Clara Wanjura

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In the second lecture, I will discuss how cavity-optomechanical interactions can be utilised to engineer certain desired interactions and I will give a few examples from current research where this has been successfully employed. Specifically, I will discuss how optomechanical interactions can be used to engineer non-reciprocal devices, i.e., devices which transmit signals in the forward direction but block or attenuate them in the reverse direction. Such devices are, for instance, relevant for the readout of fragile signal sources, such as superconducting qubits, which need to be protected from noise and back-scattered signals. Furthermore, I will show an example from our research in which we used an optomechanical system to engineer a non-Hermitian topological chain with interesting signal transmission properties.

Classical field models for condensates of light

Michiel Wouters

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In this lecture, I will discuss the modelling of nonequilibrium condensation in photonic systems, including polariton and photon condensation with a generalized noisy Gross-Pitaevskii equation. Various versions of the model will be discussed as well as the basic properties of their solutions, including quantized vortices.

Spatio-temporal coherence in nonequilibrium condensates of light

Michiel Wouters

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Bose-Einstein condensation is defined through the existence of off diagonal long range order (ODLRO) in systems described by a bosonic field. This definition is independent of the presence of thermal equilibrium in the system, but true ODLRO typically only exists in dimensions larger than two. Since photonic condensates are only one or two-dimensional, they are characterised by quasi-condensation at best. Interestingly, the nonequilibrium condition affects the spatiotemporal phase-phase correlations that belong to the Kardar-Parisi-Zhang universality class. In this lecture, I will discuss experiments probing and theory explaining the correlations in nonequilibrium polariton condensates.

Poster Overview

Poster 1–26

1 **Denylson Alvarez**
Quantum phase transitions in Bose-Hubbard Hamiltonians

2 **Tabitha Bates**
On the breathing mode of a photon Bose-Einstein condensate

3 **Corinne Beckers**
The effective three-body problem in a bosonic system

4 **Mark Bengyel**
An ultracold mixture of silver and rubidium

5 **Domantas Burba**
Two-dimensional subwavelength topological lattices for dark state ultracold atoms

6 **Miguel Clavero**
Topological dissipative phases with trapped ions

7 **Christopher Cumming**
Multi-state detection, spatial addressing and improved imaging fidelity in a quantum gas microscope

8 **Arjo Dasgupta**
Superfluid phases of dipolar bosons on a triangular ladder

9 **Ruben Erlenstedt**
The moving Fermi polaron

10 **Ratheejit Ghosh**
Dipolar droplets and supersolids

11 **Henry Harper-Gardner**
Modelling quantum engine cycles in a finite temperature atomic superfluid

12 **Pedro Iatauro**
Quantum conveyor belt for transport of NOON states

13 **Nicholas Jordinson**
Mechanism of spontaneous vortex cluster formation in 2D superfluids

14 **Nikolai Kaschewski**
Weighted Hartree-Fock-Bogoliubov method for interacting fermions

15 **Louisa Kienesberger, Alexander Guthmann**
Floquet-engineering of Feshbach resonances in ultracold lithium gases

16 **Lauritz Klaus**
A dipolar Er-K mixture in a homogenous trap

17 **Nele Koch**
Ultra cold ytterbium Rydberg states in electric fields

18 **Joshua Krauß**
Rate equation description of photon condensation

19 **Yoo Kyung Lee**
Coherent and incoherent light scattering by single atoms and atom pairs

20 **Yiming Liu**
Toward long-lived LiK molecules in magic-wavelength 3D optical lattice

21 **Francesco Lorenzi**
Variational approach to multimode nonlinear optical fibers

22 **Aasooda Malik**
Probing photon condensation and lasing in an optically excited semiconductor microcavity

23 **Forouzan Forouharmanesh**
Quantum turbulence and quantum metrology with ultracold atoms

24 **Hans Michel**
Vortices in a 2D fermionic superfluid

25 **Bastien Mirmand**
Toward a box trap potential on an atom chip

26 **María Morales**
Localized states in rotated bilayers with hexagonal symmetry

Poster 27–51

27 **Denis Mujo**
Collective dynamics of dipolar quantum droplets
28 **Jan Okoński**
Accurate ab initio calculations of interaction potentials of the alkali and alkaline-earth hydrides
29 **Daniel Ortuño-Gonzalez**
Pauli crystal superradiance
30 **Hyo Sun Park, Muhammad Mohid**
Towards a new high-performance ultracold dysprosium apparatus for quantum science experiments
31 **Sarah Philips**
Low-dimensional Bose gases with prospect on Rydberg-dressing
32 **Annie Pichery**
Efficient simulations for interacting Bose-Einstein condensate mixtures
33 **Maksym Prodius**
Interplay of localization and topology in disordered dimerized array of Rydberg atoms
34 **Charlotte Quirk**
Critical velocity and vortex nucleation for superfluid flow past a finite obstacle
35 **Sayak Ray**
Expansion dynamics of strongly correlated lattice bosons
36 **Jose Reyes-Calderon**
Dynamical domains and chaotic dynamics in spinor Bose-Einstein condensates
37 **Moroni Santiago-García**
Lattice polaron in a Bose-Einstein condensate of hard-core bosons
38 **Daniel Scheiermann**
Excitation spectrum of a double supersolid in a trapped dipolar Bose mixture
39 **Nico Schwersenz**
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Poster Abstracts

Quantum phase transitions in Bose-Hubbard Hamiltonians

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This work studies quantum phase transitions in a system consisting of a group of bosons trapped in a periodic potential with two and three wells, focusing on the characterization of the ground state. An order parameter, defined as the ratio between the terms of the Bose-Hubbard Hamiltonian, is introduced to explore and characterize the critical point associated with the phase transition.
To analyze this transition, semiclassical approximation techniques and numerical methods are employed. A correlation distribution is proposed, and a correlation function is calculated, allowing for a comparison between the semiclassical approach and the numerical treatment. This comparison aims to establish the relationship between both regimes and provide complementary information on the nature of the phase transition. The temporal evolution of correlations is analyzed as a function of the ratio, where represents the particle interaction and the tunneling coefficient between wells.
The model considers a symmetric one-dimensional Hamiltonian with wells of equal depth, ensuring an equitable structure in the distribution of bosons in the system. Changes in the spectral density of states and the presence of quantum entanglement are studied as indicators of the phase transition. Additionally, exact diagonalization methods and analytical approximations are implemented to obtain a detailed description of the system's evolution in different interaction regimes.
Finally, an extension of this model to the case of four potential wells is proposed, aiming to generalize the obtained results and explore potential new phenomena in the quantum dynamics of these systems. The feasibility of the collective modes approximation in this regime and its impact on the characterization of the phase transition are analyzed. The results contribute to a deeper understanding of the phase structure in confined bosonic systems and may serve as a basis for experimental studies in optical lattices.

On the breathing mode of a photon Bose-Einstein condensate

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Photon Bose-Einstein condensates (BECs), which were first observed experimentally in Ref. [1], differ from atomic BECs due to their open-dissipative properties. For instance, in the steady state particle supercurrents form within the condensate, which work as a stabilisation mechanism, as was demonstrated numerically in Ref. [2]. To achieve a better understanding of this intriguing mechanism, we strive for a corresponding analytical description. To this end, we consider the underlying equation of motion in the form of a complex Gross-Pitaevskii equation, which extends the Gross-Pitaevskii equation to open-dissipative systems [2]. We approximately solve this equation using the recently developed projection optimisation method [3] and determine the dynamic solution for the harmonically trapped condensate. This method generalizes the standard variational optimisation method and does not require knowledge of the action or a specific form of the ansatz. With this we determine how the steady state and the breathing mode of a photon BEC depend on pumping and dissipation, respectively. Our results agree with and generalise the literature for both the closed and open-dissipative systems in the respective limits [4-6].

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The effective three-body problem in a bosonic system

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Effective field theories (EFTs) are widely used to study many-body systems by incorporating two-body interactions via contact terms. However, when extended to three-body processes, these contact interactions lead to divergences due to the absence of an intrinsic length scale. In EFT, this is typically resolved by introducing a three-body contact term with coupling strength g3, which acts as a renormalization parameter dependent on a momentum cutoff Λ. We reconsider the need for such renormalization by replacing contact interactions with a separable potential. Separable potentials introduce a finite range, avoiding divergences and naturally suppressing high-momentum contributions. We focus on a single separable term, which simplifies the two-body interaction and allows us to study its implications for three-body physics without requiring regularization. The Storniakov-Ter-Martirosian (STM) equation is reformulated for this potential to describe the three-body scattering amplitude. Using the Faddeev decomposition, an integral equation is derived and solved both analytically and numerically. The results are compared with EFTs using contact interactions, revealing similarities and showing that a finite-range two-body potential can give rise to effective three-body forces without explicit renormalization. This highlights the potential of separable models to systematically address the three-body problem at low energies.

An ultracold mixture of silver and rubidium

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Ultracold polar molecules have many applications across the fields of quantum computing and simulation [1], quantum chemistry [2], and the precision measurement of fundamental constants [3]. A now common approach used to prepare ultracold polar molecules is to associate pairs of alkali atoms from a pre-cooled mixture [4]. In our experiments, we intend to extend this approach to a new species of ultracold molecule (AgRb) from an ultracold mixture of silver (Ag) and rubidium (Rb). This molecule is predicted to have a large dipole moment of 9 Debye [5] that can be aligned in the lab frame at relatively low electric fields. In addition, the laser cooling of silver [6] is relatively straightforward thanks to its alkali-like electronic structure, though with the added complication that the cooling transition is in the ultraviolet (328nm). Here we present our progress towards realising a dual-species magneto-optical trap of silver and rubidium.

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Two-dimensional subwavelength topological lattices for dark state ultracold atoms

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Ultracold atoms represent a flexible platform for simulating topological and many-body phenomena of condensed matter and high-energy physics. The use of atomic dark states (long-lived superpositions of atomic internal ground states immune to atom-light coupling) offers new possibilities for such simulations. Making the dark states position dependent, one can generate a synthetic magnetic field for ultracold atoms adiabatically following the dark states [1]. Recently, two-dimensional (2D) dark-state lattices were considered [2,3].
Here we present a general description of 2D topological dark state lattices elucidating an interplay with the sub-wavelength lattices [4]. In particular, we demonstrate that one can create a 2D Kronig-Penney lattice representing a periodic set of 2D subwavelength potential peaks affected by a non-staggered magnetic flux. Away from these patches of the strong magnetic field, there is a smooth magnetic flux of the opposite sign, compensating for the former peaks. While the total magnetic flux is zero, the system supports topological phases due to the flux variation over a unit cell, akin to Haldane-type lattice models with zero net flux over an elementary cell, but non-trivial topology due to non-zero fluxes over the plaquettes constituting the elementary cell. This work paves the way for experimental exploration of topological phases in dark-state optical lattices, offering new possibilities for simulating quantum Hall systems, fractional Chern insulators and related strongly correlated phases.

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Topological dissipative phases with trapped ions

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Trapped-ion systems offer exceptional platforms for investigating topological phase transitions and detecting ultra-weak forces, owing to the high degree of control over their vibrational degrees of freedom. We theoretically simulate topological driven-dissipative phases in a one-dimensional chain consisting of approximately 20–30 sites. The emergence of topological phases, characterized by a nontrivial winding number as a topological invariant, indicates the presence of edge states that amplify external fields and provide robustness against disorder. We explore a cutting-edge application in quantum sensing, demonstrating that topological phases enhance the scalability of the signal-to-noise ratio with the number of ions. Specifically, we achieve sensitivities on the order of 1 yN $Hz^{-1/2}$ by measuring the ion's displacement amplitude via photoluminescence in the micrometer regime.

Multi-state detection, spatial addressing and improved imaging fidelity in a quantum gas microscope

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Ultracold dipolar molecules are a promising platform for exploring quantum many-body phenomena by utilising the dipolar interactions between them [1]. Quantum gas microscopes (QGMs) allow investigation into the local properties of these phenomena using optical lattices and single-site resolution [2]. We have recently demonstrated the ability to simultaneously detect both the position and rotational states of individual ^{87}Rb^{133}Cs molecules in addition to local addressing of the sample [3]. However in order to study coherent dipolar interactions between molecules, differential light shifts between their rotational states due to the trapping light must be eliminated. This has been achieved for ^{87}Rb^{133}Cs using the rotationally magic wavelength of 1145.31 nm [4, 5]. The implementation of magic wavelength trapping is the next major upgrade of the QGM in Durham. Using the magic wavelength places a technical limit on the amount of laser power which can be used, and hence we need to collect fluorescence from atoms in significantly weaker lattices. To achieve this we have implemented a simple and effective fluorescence scheme using interleaved cooling which combines bright molasses and Lambda-enhanced grey molasses. We observe high fidelity imaging of ^{87}Rb atoms at lattice depths as low as $2300E_{rec}$, a factor of two lower than when using bright molasses alone.

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Superfluid phases of dipolar bosons on a triangular ladder

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Dipoles in optical potentials open up many possibilities for the simulation of interesting lattice models. In particular, dipolar particles in triangular ladder arrays are characterized by the interplay of long-range interactions and frustration, resulting in the possible appearance of chiral superfluids, which present non-vanishing chiral currents. We show how the control of the dipolar strength and dipole orientation may result in the transition between different superfluid phases, including a chiral superfluid and a double non-chiral superfluid. Interestingly, although this peculiar extended Hubbard model may be implemented using Floquet engineering, we show that dipolar spin models, as those recently studied in the context of polar molecules, may naturally implement the model without the need of any additional Floquet engineering. Finally, we discuss the non-trivial dynamics of chiral currents that results from quenches across the different phases.

The moving Fermi polaron

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Ultracold quantum gases offer a highly tunable platform for exploring strongly interacting many-body systems. In highly imbalanced mixtures, we can explore the quantum behavior of impurities. Our investigation focuses on bosonic K impurities interacting with a Fermi sea of Li atoms, forming a system that can be described in terms of quasiparticles known as Fermi polarons. While previous studies have probed the static and dynamic features of such polarons using radio-frequency spectroscopy, understanding kinetic properties such as effective mass and dispersion relation can be accomplished by means of Raman spectroscopy. Notably, Raman transitions do not only facilitate manipulation of the impurity's internal state but they also offer control over its momentum state. Utilizing a newly built Raman setup, we can transfer multiple photon momenta to the impurities in a controlled manner, enabling the investigation of polaron behavior with finite momentum within a Fermi sea. Here, we present our experimental results on the momentum-dependent polaron energy for different interaction strengths, highlighting the breakdown of the polaron picture at low momenta.

Dipolar droplets and supersolids

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Dipolar quantum gases are at the forefront of exploring complex many-body physics due to the anisotropic and long-range nature of dipole-dipole interactions. Ground-breaking discoveries of quantum droplets and supersolids have sparked interest in their existence, leading to numerous new studies. In this context, we investigated the physics of doubly dipolar Bose-Einstein condensates, characterized by competing dipolar interactions arising from both electric and magnetic dipole moments within each boson. Remarkably, our studies revealed the formation of pancake droplets, contrary to the usual cigar droplets, which subsequently led to the discovery of a pancake supersolid. Pancake droplets exhibit intriguing finite temperature properties, which we explored using quantum Monte Carlo techniques. Finally, we demonstrate the surprising emergence of supersolids in a dipolar condensate under rotation, stabilized by quantized vortex lines.

Modelling quantum engine cycles in a finite temperature atomic superfluid

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Recent experimental work in the field of atomic superfluids has begun to focus on developing systems which probe the quantum thermodynamics of highly coherent Bose-condensed atomic gases. Particular interest has centred on demonstrating ‘quantum enhancement’ to the performance of thermodynamic engine cycles operating on atomic superfluids, through a combination of potential- and interaction-energy exchange cycles. We take as the starting point of our investigation, the experiment of Ref. [1], in which they study a high purity trapped quantum gas of ^{7}Li atoms subjected to an Otto cycle. This cycle pumps energy between the magnetic and optical fields by alternately varying the scattering length and trapping frequency. We demonstrate that the quantum enhancement observed in this experiment is well recovered by Gross-Pitaevskii simulations, noting that in the zero-temperature limit the performance of the engine is determined by the spectrum of low-lying collective oscillations and driving frequency of the cycle. We then go beyond this regime with a model comprising a coupled system of a dissipative GPE and quantum Boltzmann equation to simulate atomic BECs at experimentally relevant temperatures. The presence of a significant thermal cloud introduces damping, particle exchange, and backreaction dynamics. We present preliminary numerical results on the impact of coupling to the thermal cloud on thermodynamic performance as the system transitions from a highly quantum degenerate condensate, to a mixed quantum-classical system, to a classical Boltzmann gas, as well as a characterisation of the nature of quantum enhancement in the highly degenerate case.

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Quantum conveyor belt for transport of NOON states

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The precise control of quantum systems will play a crucial role in the realization of atomtronic devices. In this study, we explore the integrable model of ultracold dipolar atoms confined in a four-well system [1, 2]. Specifically, we examine the tunneling control of the system in the integrable regime for NOON initial states. We propose a quantum conveyor belt designed to transport NOON states through different locations within an optical lattice [3]. Our method is based on external field operations, which we believe to be the key mechanism for transporting information carriers, fundamental in chips and logic gates.

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Mechanism of spontaneous vortex cluster formation in 2D superfluids

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Turbulence in two-dimensional (2D) fluids tends to give rise to long-lived, large-scale vortex structures. Recently, such vortex structures have been observed experimentally in turbulent 2D superfluids [1,2], where large-scale flows take the form of clusters of many singly-quantised vortices. Using mean-field Gross-Pitaevskii simulations, Simula et al. [3] predicted that such vortex clusters can emerge spontaneously from an initially random arrangement of vortices and antivortices, even in the absence of driving. To explain this behaviour, the authors proposed an “evaporative heating” mechanism, whereby vortex-antivortex annihilations remove only small amounts of energy from the vortex configuration, causing the average energy per remaining vortex to increase. More recently, Kanai et al. [4] proposed that single vortex annihilation at the boundaries are mainly responsible for the spontaneous ordering, while vortex pair annihilations in the bulk suppress clustering formation due to the creation of sound waves.

Here, we use a point-vortex model with phenomenological annihilations included to simulate the dynamics of a turbulent 2D disk-shaped superfluid. We tune the relative frequency of annihilations in the bulk versus the boundary by altering the boundary annihilation radius. While we find that increasing the proportion of boundary annihilations does lead to more ordered vortex structures at late times, this behaviour appears to be due an increased overall annihilation rate. Importantly, we find that the amount of heating per annihilation is unaffected by the relative boundary annihilation frequency. We are currently performing Gross-Pitaevskii simulations to test this observation at the mean-field level, where density fluctuations are accounted for.

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Weighted Hartree-Fock-Bogoliubov method for interacting fermions

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For several decades it has been known that divergences arise in the ground-state energy and chemical potential of unitary superfluids, where the scattering length diverges, due to particle-hole scattering. Leading textbooks [1] and research articles [2,3] recognize that there are serious issues but ignore them due to the lack of an approach that can regularize these divergences. We find a solution to this difficulty by proposing a general method, called the weighted Hartree-Fock-Bogoliubov theory, to handle multiple decomposition channels originating from the same interaction [4]. We distribute the interaction in weighted channels determined by minimization of the action, and we apply this idea to unpolarized Fermi superfluids. Using our method, we solve a long-standing difficulty in the partitioning of the interaction into Hartree, Fock, and Bogoliubov channels for Fermi superfluids, and we obtain a phase diagram at the saddle-point level, which contains multichannel nonperturbative corrections. We find a previously overlooked superfluid phase for weak interactions, which is dominated by particle-hole processes, in addition to the usual superfluid phase only containing particle-particle physics.
We emphasize that our method is so general, that it can be applied to any fermionic system that can support competing interaction channels. This includes systems from particle and nuclear physics, condensed matter physics, ultracold atoms, and even astrophysical objects like the crusts of neutron stars.

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Floquet-engineering of Feshbach resonances in ultracold lithium gases

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Magnetic Feshbach resonances are a key tool for tuning interactions in ultracold atomic systems. In our recent work [1], we demonstrate that periodic modulation of the magnetic field enables the creation of Floquet-Feshbach resonances in a two-component gas of fermionic lithium-6, providing dynamic control over resonance positions.
We experimentally map out the structure of Floquet-dressed scattering states and confirm the theoretical predictions for their positions and widths. Our observations include clear signatures of higher-order resonances, revealing a rich spectrum of interaction control not accessible via static fields alone. Additionally, we show that inelastic atom losses can be strongly suppressed by introducing a second modulation frequency at exactly the second harmonic.
In conclusion, Floquet-engineering of Feshbach resonances opens new pathways for precise control of scattering in ultracold gases. As a prominent application, it enables the realization of Bound States in the Continuum (BICs) through interference at avoided crossings between Floquet-Feshbach resonances.

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A dipolar Er-K mixture in a homogenous trap

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Magnetic atoms such as erbium possess a large permanent magnetic dipole moment, giving rise to strong dipole-dipole interactions. These interactions can lead to the emergence of exotic quantum phases, including supersolids and the so-called "insulating droplet" regime, first observed in these systems in 2019. Since then, the field has seen rapid advancements, with a wide range of experimental and theoretical investigations exploring the rich physics of these systems, such as measuring Goldstone modes and nucleating quantized vortices.
Our research aims to expand this frontier by introducing two novel dimensions: (1) studying mixtures of dipolar and non-dipolar atoms, and (2) confining them in a quasi-two-dimensional, homogeneous trapping potential. This platform will enable the exploration of phenomena such as binary supersolids, polaron physics in a dipolar medium, and the influence of dipolar interactions on quantum turbulence.

Ultra cold ytterbium Rydberg states in electric fields

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In recent years Rydberg atoms with their special features, like dipole-dipole interaction or van-der-Waals blockade, have become more and more important for quantum optics. Particularly ultra cold Rydberg atoms are of great interest for the investigation of long-range interaction. A special feature of ytterbium is that due to its two valence electrons, atoms in Rydberg states can be easily manipulated and imaged using optical fields. A first step towards studies of ultra cold ytterbium is to gain precise knowledge on the Rydberg states.

Here we present the study of the Rydberg states of ultra cold ytterbium. Using a Micro-Channel-Plate to detect the Rydberg atoms it is possible to measure lifetimes and hyperfine structures of several states (n=35-90). In addition we are able to measure the energy and polarizability of s, p and d states in the region of high principal quantum numbers (n=70-90). Using a second stage trap we are able to cool the atoms down to several µK to reduce their distances and investigate interactions.

Rate equation description of photon condensation

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Photon condensation was experimentally realized in 2010 within a dye-filled microcavity at room temperature [1]. Since then the interest in the field has increased significantly, as a photon Bose-Einstein condensate (BEC) represents a prototypical driven-dissipative system. Here we investigate in detail how its inherent open nature influences the condensation process both quantitatively and qualitatively. To this end, we consider a mean-field model, which can be derived microscopically from a Lindblad master equation [2-4]. The underlying rate equations depend on various driven-dissipative parameters such as emission and absorption rates of the dye molecules as well as the cavity photon loss rate, for which we use recently measured experimental data [5]. In steady state we obtain an open-dissipative Bose-Einstein distribution across all modes, whose chemical potential depends on the occupation of the dye molecules in the ground and the excited state, respectively. We find that the resulting photon distribution is strongly influenced by the driven-dissipative parameters. With this we identify the main differences between an atomic BEC, a laser, and a photon BEC.

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Coherent and incoherent light scattering by single atoms and atom pairs

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We study the coherent and incoherent light scattered from single atoms and atom pairs in free space. For single atoms, we realize a Gedanken experiment which interferes single photons scattering off of atomic wave packets released from an optical lattice, and consequently demonstrate that the coherence properties of the scattered light are independent of the presence of the trap. We then extend our technique for single atoms to a pair of atoms on a single lattice site. Preliminary studies show a strong dependence on the duration of the light exposure and the interaction strength between atoms. These results suggest we observe light-induced dipole-dipole interactions between the atom pair. Our experiment demonstrates the potential of using atomic Mott insulators to create single atoms and atom pairs for fundamental studies.

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Toward long-lived LiK molecules in magic-wavelength 3D optical lattice

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We report our progress in achieving long coherence times for $^{6}Li^{40}K$ molecules confined in magic 3D optical lattices.
Our study begins with rotational spectroscopy of the J=1 hyperfine structure at 215.5 G. Through precise measurement and analysis of transition frequencies to excited rotational states, we extract the hyperfine interaction constants. A specific stretched transition is further investigated, achieving Hz-level resolution. In a 1070 nm optical dipole trap, the coherence time is measured to be approximately 10 microseconds.
In order to extend the coherence time, we perform frequency-dependent polarizability calculations for both the ground state and the first rotationally excited state of $^{6}Li^{40}K$. Spin-orbit coupling between A1S and b3Pi reveals a critical transition from ground state molecules to the $|$ b3Pi,v=0,J=1 $\rangle$ state at 314.2305 THz. Experimentally, we calibrate the polarizability spectra and identify a broad, far-detuned magic wavelength where the differential light shift across the trap is negligible. Magic points happen at detunings of −8.9 GHz (for 90° laser polarization) and +6.8 GHz (for 0° laser polarization) relative to the nearest transition. At the +6.8 GHz magic point, the differential polarizability changes by only 70 mHz/(W/cm^2) as laser intensity varies from 0 to 7 kW/cm^2. Based on these results, we have constructed a 3D magic optical lattice, with fine-tuning of coherence optimization is currently underway.

Variational approach to multimode nonlinear optical fibers

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We analyze the spatiotemporal solitary waves of a graded-index multimode optical fiber with a parabolic transverse index profile. Using the nonpolynomial Schrödinger equation approach, we derive an effective one-dimensional Lagrangian associated with the Laguerre–Gauss modes with a generic radial mode number p and azimuthal index m. We show that the form of the equations of motion for any Laguerre–Gauss mode is particularly simple, and we derive the critical power for the collapse for every mode. By solving the nonpolynomial Schrödinger equation, we provide a comparison of the statio-nary mode profiles in the radial and temporal coordinates.

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Probing photon condensation and lasing in an optically excited semiconductor microcavity

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Photon Bose-Einstein condensation (BEC) in semiconductor microcavities without external trapping offers a unique platform to explore macroscopic quantum phenomena in homogeneous, nonequilibrium systems. We investigate how spectral detuning between cavity modes and quantum well (QW) excitons affect the formation and properties of photon BECs and lasing states. Our experiments use a GaAs-based planar microcavity with InGaAs/GaAs quantum wells, grown via molecular beam epitaxy and cooled to 77 K with liquid nitrogen. The unprocessed λ-cavity structure, with AlAs/AlGaAs distributed Bragg reflectors, emits near 920 nm. Variations in QW composition and thickness across the sample allow us to explore a range of cavity-QW detunings by probing different positions.
We investigate the power dependence of BEC and lasing thresholds throughout various detunings using non-resonant, above-bandgap optical excitation. According to preliminary measurements, high-energy photons with substantial in-plane group velocities escape the excitation region prior to reabsorption, indicating that under a small spot excitation condition one observes imperfect thermalization of photon gas. We employed a defocused laser spot to increase the excitation area to improve the photon reabsorption probability.
This approach helps us create a BEC–lasing phase diagram in a monolithic planar semiconductor microcavity and to find optimal conditions for photon BEC to occur.

Quantum turbulence and quantum metrology with ultracold atoms

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We report progress toward achieving quantum degeneracy by first capturing atoms in a blue-detuned MOT. Its low photon-scattering rate suppresses light-assisted collisions and re-absorption heating, yielding high phase-space density and efficient loading into shallow optical traps. The degenerate cloud can then be transferred to a two-dimensional cylindrical potential, whose periodic boundary conditions stabilize persistent currents. A movable optical barrier can repeatedly perturb the circulating flow, allowing precise determination of the Landau critical velocity and controlled observation of the vortex-mediated breakdown of superfluidity.

In a parallel theoretical effort, we numerically simulate a Bose-Hubbard dimer in which atoms are transferred from optical tweezers into a tunable double-well potential. By periodically modulating the tunnel coupling we drive a crossover from regular to chaotic dynamics, reproducing the quantum kicked-top model and generating highly entangled spin states that promise quantum-enhanced sensing.

Vortices in a 2D fermionic superfluid

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Vortices are widely studied excitations in superfluid systems from superfluid helium to ultracold Bose Einstein Condensates. While many experiments observed vortices in 3D quantum gases, few realisations were made in 2D systems. Here I will report on the realisation of vortices in a 2D superfluid made up from Li6 dimers. We freeze out the vertical motion by strong confinement and generate vortices by dragging two tweezers through the gas, see also [1,2]. We detect the vortices using time of flight imaging. Our results provide insights into 2D superfluidity across the BEC-BCS crossover.

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Toward a box trap potential on an atom chip

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We present an experimental molecular spectroscopy study of the last bound states of the sodium dimer (Na_2) using a sodium Bose-Einstein condensate confined on an atomic chip. These states play a key role in understanding microwave-induced Feshbach resonances.
A theoretical model in agreement with the experimental results has been created. In particular, it predicts the formation of mixed states between bound and free continuum states, inducing predissociation phenomena. Precise knowledge of the positions and decay rates of the various states paves the way for the realization of microwave-induced Feshbach resonances.
In parallel, we are developing the use of a micromirror device (DMD) to trap condensate longitudinally in a box. For the moment, the condensate is trapped harmonically. This tool will also enable us to explore non-equilibrium dynamics in elongated Bose-Einstein condensates.

Localized states in rotated bilayers with hexagonal symmetry

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Emergence of localized and extended states is analyzed in both an ideal and a weakly interacting Bose gas confined in a double lattice array having hexagonal structure. In particular, we study the ground stationary states and characterize the opposite extended and localized phases as a function of the interparticle interaction, the distance separating the layers d, and the rotation angle between them $\theta \in [0, \pi/6]$. By tracking the behavior of the index participation ratio (IPR) we identify special angles for which the resulting moiré structures form crystalline patterns and consequently give rise to extended states. We also found a delocalized to localized transition as a function of d, the particle-particle interaction, and the lattice potential depth. We reached these conclusions by performing extensive numerical calculations for both the Schrödinger and the Gross-Pitaevskii equations.

Collective dynamics of dipolar quantum droplets

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Since the first experimental realization of droplets [1], it was proven that quantum droplets in a dipolar Bose system are stabilized due to quantum fluctuations, correcting the ground-state energy [2,3,4,5,6]. We examine the behavior of collective oscillation modes and dynamics of dipolar quantum droplets. Our focus will be on the cylindrical symmetry, which gives us two oscillatory modes: the breathing mode and the quadrupole mode. To induce the droplet dynamics we perturb and modify relevant parameters such as contact interaction strength and harmonic trap potential. We also variationally derive equations of motion and the oscillatory modes from a given Lagrangian.

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Accurate ab initio calculations of interaction potentials of the alkali and alkaline-earth hydrides

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Simple diatomic molecules play an important role in quantum chemistry and physics by providing the playground for benchmarking molecular theory and implementing quantum control. Precise calculations of molecular properties are crucial for guiding ongoing experiments and for planning new ones. Ultracold molecules provide a good framework for observations of quantum effects and testing various theories. Alkaline-earth-metal mono-hydrides are also promising candidates for a source of ultracold hydrogen [1] and laser cooling to ultralow temperatures [2].

Calculations of potential energy curves are a groundwork for determining other molecule properties such as rovibrational states. Neutral alkali and alkaline-earth monohydrides have already been extensively studied by others [3], unlike their ions. Experimental spectroscopic studies on the BaH^{2+} molecule are currently underway in Prof. F. Merkt's group at ETH Zurich, where recently BaH^{+} and BaD^{+} were studied [4]. Here, we aim to provide the interaction energies for all neutral and ionic alkali and alkaline-earth hydrides as accurately as possible using various methods and basis sets.

We applied coupled cluster theory (CCSD, CCSD(T), CCSDT and MRCCSD) for post-Hartree-Fock calculations. A range of different electronic structure techniques was employed to achieve a high level of accuracy and provide insightful comparisons. Basis sets with cardinal numbers up to 5Z were utilized and the energies were extrapolated to the complete basis set limit. We applied corrections such as the diagonal Born-Oppenheimer correction (DBOC) and the correction for the full triple excitations in the coupled cluster calculations. Potential energy curves were calculated for distances ranging from 2 a0 up to 50 a0. Adopted corrections helped us improve the accuracy of our results. Additionally, the DBOC correction was also calculated for other alkaline earth metal monohydride ions. We reached a theoretical accuracy of around 0.5% - 1.5% at the minimum.

The results of our calculations are highly accurate and serve as a strong foundation for deriving other molecular parameters. The ionized alkaline-earth hydrides have not been extensively studied by others in terms of ab initio calculations and our results are among the most accurate available. Additionally, they provide a valuable reference for comparison with experimental data.

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Pauli crystal superradiance

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Pauli crystals are unique geometric structures of non-interacting fermions, resembling crystals, that emerge solely from Fermi statistics and confinement. Unlike genuine quantum crystals that arise from interparticle interactions, Pauli crystals do not break translation symmetry but nonetheless exhibit nontrivial many-body correlations. In this Letter, we explore Pauli crystal formation in a cavity-fermion setup. We analytically show that when coupled to a cavity, degeneracy in Pauli crystals can trigger zero-threshold transitions to superradiance. This superradiance is accompanied by the emergence of a genuine quantum crystalline state, wherein the atomic density is periodically modulated. We substantiate our findings using state-of-the-art numerical simulations. The combined interplay between statistics, confinement geometry and interactions mediated by light thus facilitates a novel pathway to quantum crystallization.

Towards a new high-performance ultracold dysprosium apparatus for quantum science experiments

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Dysprosium has emerged as a powerful platform for studying strongly correlated quantum systems. It possesses one of the largest magnetic dipole moments (~10 μB in the ground state) of any atomic species, allowing for studies of dipolar physics in optical lattice and simulations of the extended Hubbard model with dipole-dipole interactions. Our group has previously developed a novel bilayer system of ultracold dysprosium on a 50-nm scale that enhances dipole-dipole interactions by three orders of magnitude. However, the previous apparatus is limited by a low MOT loading rate and a lack of site-resolved imaging. Here we report on our progress toward building a next-generation dysprosium machine with a number of critical upgrades, including but not limited to: improvement in the production, trapping, and imaging of ultracold dysprosium atoms; a shorter cycle time of ~3 seconds; and the implementation of superresolution microspectroscopy capable of simultaneous imaging of the bilayer. Equipped with these novel improvements, we aim to study new bilayer physics, including interlayer pairing induced by attractive interactions, coupled superfluid-to-Mott-insulator phase transition, and strongly interacting Bose-Fermi mixtures using a two-isotope mixture of dysprosium.

Low-dimensional Bose gases with prospect on Rydberg-dressing

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In our experiment, we study low-dimensional ultracold dilute Bose gases of Rubidium atoms. We have developed a new apparatus with the aim of implementing a Rydberg dressing protocol to achieve the strong interaction regime. We report on the current state of the experimental setup, in which we create individual 2D gases. I will present recent developments on the study of dark solitons in the cross-over between one and two dimension.

Efficient simulations for interacting Bose-Einstein condensate mixtures

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Ultra-cold atomic ensembles are a prime choice for sources in quantum sensing experiments. The development of dual species sources would offer the possibility to implement simultaneous interferometry for applications such as tests of the Universality of Free Fall. The Cold Atom Laboratory (CAL) is a multi-user Bose-Einstein Condensate (BEC) machine aboard the International Space Station, operated by NASA's Jet Propultion Lab. After its upgrade in 2020, it enabled the production and manipulation of dual-species BEC mixtures of K and Rb. We report here about the first quantum mixture experiments realized in space [1].
The presence of gravity impacts greatly the trapping conditions of interacting dual species mixtures, thus influencing the geometry of the ground state of the system. On the other hand, space provides an environment where atom clouds can float for extended times with different miscibility conditions. In both cases, the atom clouds can be displaced and expand over large extents during their free expansion, providing computational challenges to simulate the dynamics of the interacting quantum gases. In this contribution, we present scaling techniques to overcome these limits [2], and show applications to the interpretation of mixture results obtained by the MAIUS collaboration in Hannover.

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Interplay of localization and topology in disordered dimerized array of Rydberg atoms

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Rydberg tweezer arrays provide a platform for realizing spin-1/2 Hamiltonians with long-range tunnelings decaying according to power-law with the distance. We numerically investigate the effects of positional disorder and dimerization on the properties of excited states in such a one-dimensional system. Our model allows for the continuous tuning of dimerization patterns and disorder strength. We identify different distinct ergodicity-breaking regimes within the parameter space constrained by our geometry. Notably, one of these regimes exhibits a unique feature in which non-trivial symmetry-protected topological (SPT) properties of the ground state extend to a noticeable fraction of states across the entire spectrum. This interplay between localization and SPT makes the system particularly interesting, as localization should help with stabilization of topological excitations, while SPT states contribute to an additional delocalization. Other regions of parameters correspond to more standard nonergodic dynamics resembling many-body localization.

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Critical velocity and vortex nucleation for superfluid flow past a finite obstacle

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When a superfluid flows about a cylindrical obstacle, vortex pairs are shed by the obstacle when the critical velocity is exceeded. This phenomenon was characterised in a theoretical study using the Gross-Pitaevskii equation by Frisch et al. in 1992 [1]. They investigated this behaviour for an infinite obstacle (zero density inside) and found that above the critical velocity, vortex pairs would arise at the obstacle's lateral edges. More recently, a study by Stockdale et al. in 2021 [2] looked at vortex pinning in a superfluid flow about a finite cylindrical obstacle (non-zero density inside). At some velocity, a vortex pair nucleated inside the obstacle. The vortices moved outwards with increasing velocity and were shed by the obstacle at the critical velocity.

This study aims to characterise vortex nucleation and subsequent shedding for a finite cylindrical potential obstacle within a superfluid flow in 2D. Using an analogy to Maxwell's equations of electromagnetism, we have developed an analytical model for stationary states of the system using hydrodynamics and the point vortex model. The model predicts the vortex nucleation velocity, as well as the critical velocity.

The analytic results for single vortex pair solutions have been compared to numerical stationary solutions of the Gross-Pitaevskii equation. We have found good agreement for larger and weaker obstacles. This is likely due to the reduced validity of the hydrodynamic approximation and point vortex model for smaller and stronger obstacles. Numerically, for large obstacles we have found additional solutions with two and three vortex pairs. We will present a map of the full excitation spectrum of an obstacle with multiple vortex pair solutions.

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Expansion dynamics of strongly correlated lattice bosons

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We study the spatio-temporal dynamics of bosons on a two-dimensional Hubbard lattice in the strongly interacting regime, taking into account the dynamics of condensate amplitude as well as the direct transport of non-condensed fluctuations by means of a density matrix approach, which, thus, goes beyond the standard Gutzwiller mean-field theory. Starting from the Liouville-von-Neumann equation we derive a quantum master equation for the time evolution of the system's local density matrix at each lattice site, with a dynamical bath that represents the rest of the system. We apply this method to case-study the expansion dynamics of trapped bosons initially in equilibrium following the removal of the trapping potential. An expected ballistic expansion of the condensate is observed, followed by a rather slow, diffusive transport of the normal bosons. We discuss, in particular, the robustness of the Mott insulator phase as well as its melting due to the incoherent transport.

Dynamical domains and chaotic dynamics in spinor Bose-Einstein condensates

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Spinor Bose-Einstein condensates have been explored for years as an intriguing many-body system to study the rich interplay between internal and external degrees of freedom. Spinor dynamics is typically investigated within the single-mode approximation (SMA), in which all spin components share the same spatial distribution. We show that the interplay between spin-changing collisions, quadratic Zeeman energy, and an inhomogeneous spatial profile results in rich physics for spin-1 condensates beyond the SMA. Resembling recent experiments on coherently coupled mixtures, a spatially inhomogeneous density profile may lead to the formation of coexisting spatial domains of excited-state phases (ESPs). These domains exhibit markedly different spin dynamics, separated by domain walls that can be understood as spatial excited-state quantum phase transitions (ESQPTs). Remarkably, domains with regular, periodic spin dynamics may become unstable, giving rise to chaotic dynamics. We investigate elongated, quasi-one-dimensional condensates, revealing a highly nontrivial universal phase diagram with regular phases (both with coexisting domains and uniform dynamics) as well as chaotic phases. Our work reveals a surprisingly rich phenomenology that can be readily probed experimentally.

Lattice polaron in a Bose-Einstein condensate of hard-core bosons

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Lattice polarons, quasiparticles arising from the interaction between an impurity and its surrounding bosonic environment confined to a lattice system, have emerged as a platform for generating complex few-body states, probing many-body phenomena, and addressing long-standing problems in physics. In this study, we employ a variational ansatz to investigate the quasiparticle and spectral properties of an impurity coupled to a condensate gas of hard-core bosons in a two-dimensional optical lattice. Our findings demonstrate that the polaron features can be tuned by adjusting the filling factor of the bath, revealing intriguing polaron characteristics in the strongly interacting regime. These results offer valuable insights for lattice polaron experiments with ultracold gases and can serve as a guide for new experiments in emergent quantum devices, such as moiré materials, where optical excitations can be described in terms of hard-core bosons.

Excitation spectrum of a double supersolid in a trapped dipolar Bose mixture

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Dipolar Bose-Einstein condensates are excellent platforms for studying supersolidity, characterized by coexisting density modulation and superfluidity. The realization of dipolar mixtures opens intriguing new scenarios, most remarkably the possibility of realizing a double supersolid, composed of two interacting superfluids. We analyze the complex excitation spectrum of a miscible trapped dipolar Bose mixture, showing that it provides key insights about the double-supersolid regime. We show that this regime may be readily probed experimentally by monitoring the appearance of a doublet of superfluid compressional modes, linked to the different superfluid character of each component. Additionally, the dipolar supersolid mixture exhibits a nontrivial spin nature of the dipolar rotons, the Higgs excitation, and the low-lying Goldstone modes. Interestingly, the analysis of the lowest-lying modes allows for monitoring the transition of just one of the components into the incoherent-droplet regime, whereas the other remains coherent, highlighting their disparate superfluid properties.

Simulating matter-wave lensing of BECs

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The extended microgravity conditions granted by cold-atom experiments in space enable free-evolution times of many seconds, which can be exploited in high-precision measurements based on atom interferometry. However, in order to reach such long evolution times, it is necessary to employ ultracold atoms combined with matter-wave lensing techniques, and a detailed modeling is required.

We present numerical simulations of spherically- and axially-symmetric BECs freely expanding for tens of seconds. A particularly interesting case arises when the lensing potential is applied after the BEC has expanded substantially in at least one dimension since then the diffraction effects associated with the finite size of the BEC can dominate over the mean-field interaction. This enables the validation of our simulations in a regime where the time-dependent Thomas-Fermi approximation fails to provide an accurate description of the dynamics. Finally, we compare the harmonic lens to an imperfect lens, which contains anharmonicities typically found in the magnetic potentials generated by atom chips.

Integrable models of dipolar bosons: Quantum control, device applications and superintegrability

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The accurate control of quantum systems is crucial for advancing quantum technologies. Integrable systems offer a particularly promising platform for such technologies since they provide precise predictions and accurate information about a system's dynamics and physical properties.

In our study, we investigate a family of integrable models involving dipolar bosons confined to a bipartite structure of m + n wells. We demonstrate their potential for quantum device applications, including the 2 + 1 configuration functioning as a quantum switch, the 2+2 model for generating NOON states and the 3+1 system, which can work either as a directional quantum switcher or as an atomtronic diplexer.

Furthermore, we examine the emergence of superintegrability in static models where either m or n > 2. In such systems, such as the 3 + 1 model, the number of independent conserved operators exceeds the number of degrees of freedom. This property permits the inclusion of additional terms in the Hamiltonian that break superintegrability while maintaining integrability. Such control enables the design of protocols that exploit this feature for novel quantum device applications.

Origins of collectivity in few-body systems

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Recent experiments with ultracold fermionic gases have demonstrated that even in extremely small systems with only 10 atoms, fluid-like behaviour can emerge [1]. As this is far outside the traditional regime of applicability for hydrodynamics, this ongoing project seeks to understand how this can arise from a microscopic theory. We present two approaches, density functional methods and kinetic theory, that we will use to try and reproduce the experimental observations.
We further showcase kinetic theory computations in the context of heavy-ion collisions, where similar hydrodynamic features have been observed in the last two decades [2]. Previous works had investigated attractor features to demonstrate the loss of information even far before the onset of thermal equilibrium [3]. We show how spatial transverse gradients, which are particularly relevant for small systems, can modify such attractor behaviour and may prevent full thermalisation of the system by coupling different spherical harmonic modes in momentum space on a new timescale inversely related to the strength of the gradients.

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Towards light scattering experiments in dense dipolar gases

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In ultracold atomic ensembles where interatomic spacing is smaller than the wavelength of scattered light, direct matter-matter coupling through electric and magnetic interactions significantly influences system dynamics, challenging the approximation of atoms as independent emitters. We study the role of magnetic dipole-dipole interactions (DDI) in the cooperative behavior of dense atomic ensembles using dysprosium, which has the highest ground-state magnetic moment (10 Bohr magnetons). Our light-scattering experiments probe these effects in dense dipolar media. This poster details progress in generating ultradense cold dysprosium clouds, including the optical transport of atoms into a home-built science cell enabling precise cloud manipulation. The cell's compact design allows tight dipole trapping with a high numerical aperture objective made in-house. We also discuss the impact of optical dipole trap polarization on atomic lifetime and outline future experiments to uncover collective effects, advancing the study of cooperative quantum phenomena.

Formation of polariton condensates under ring-shaped excitation

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Understanding the exciton-polariton condensation threshold behaviour is crucial for the development of future polariton-based experiments and devices. In this work, we investigate the formation of polariton condensates under a ring-shaped excitation and analyze the dependence of the condensation threshold on the exciton-photon detuning and the radius of the ring-shaped pump. For small ring radii, we observe a deviation from the standard U-shaped dependence of the threshold on detuning. We present our theoretical progress toward explaining this behavior using the open-dissipative Gross-Pitaevskii equation. In particular, we examine the roles of polariton lifetime, critical density, stimulated scattering rate, and polariton diffusion – especially in regimes where the polaritons exhibit a stronger excitonic character – and discuss their impact on the threshold behavior and spatial dynamics of the condensate.

Transport coefficients of a low-temperature Fermi gas with contact interactions

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We compute the shear viscosity, thermal conductivity and spin diffusivity of a Fermi gas with short-range interactions in the Fermi liquid regime of the normal phase, that is at temperature T much lower than the Fermi temperature and much larger than the superfluid critical temperature T_c. In line with recent advances in the precision of cold atom experiments, we provide exact results up to second-order in the interaction strength.
Using a perturbative expansion of the quasiparticle Hamiltonian, we derive effective interaction functions and solve the linearized Boltzmann transport equation treating exactly the collision kernel, leading to significant corrections beyond relaxation-time or variational approximations. The transport coefficients, as functions of the s-wave scattering length a and Fermi wavenumber k_F, follow $(1+\gamma k_F a)/a^2$ up to corrections of order $O(a^0)$, with a positive coefficient γ for the viscosity and negative one for the thermal conductivity and spin diffusivity. The inclusion of the correction linear in $k_F a$ greatly improves the agreement with the recent measurement of the viscosity by the Yale group [1].

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Correlation functions of the anyon-Hubbard model from Bogoliubov theory

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Applying a modified Bogoliubov theory to the bosonic representation of the anyon-Hubbard model faithfully describes its characteristic low-energy properties. These are manifested by an asymmetric dispersion of the Bogoliubov particles, which arises due to the breaking of parity and time reversal symmetry. Furthermore, statistical interactions cause a depletion of both the condensate and the superfluid densities even in the absence of any Hubbard interaction. On the basis of this Bogoliubov theory we determine then characteristic correlation functions as, for instance, density-density correlations, which are experimentally accessible via quantum gas microscopes. In view of recent experimental progress, we re-investigate a quantity previously declared as unobservable, the anyonic quasi-momentum distribution.

Finite-temperature entanglement and coherence in asymmetric bosonic Josephson junctions

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We investigate the finite-temperature properties of a bosonic Josephson junction composed of N interacting atoms confined by a quasi-one-dimensional asymmetric double-well potential, modeled by the two-site Bose-Hubbard Hamiltonian. We numerically compute the spectral decomposition of the statistical ensemble of states, the thermodynamic and entanglement entropies, the population imbalance, the quantum Fisher information, and the coherence visibility. We analyze their dependence on the system parameters, showing, in particular, how finite temperature and on-site energy asymmetry affect the entanglement and coherence properties of the system. Moreover, starting from a quantum phase model which accurately describes the system over a wide range of interactions, we develop a reliable description of the strong tunneling regime, where thermal averages may be computed analytically using a modified Boltzmann weight involving an effective temperature. We discuss the possibility of applying this effective description to other models in suitable regimes.

[1] C. Vianello, M. Ferraretto and L. Salasnich, Phys. Rev. A **111**, 063310 (2025).

Correlation functions in interacting Fermi gases: A mean-field perspective

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We present calculations of the first- and second-order correlation functions for interacting Fermi gases based on the mean-field Hartree-Fock-Bogoliubov theory.
Interacting ultracold Fermi gases provide a highly tunable platform for studying many-body physics, where strong interactions coexist with dilute conditions. This unique feature enables a direct comparison between theory and experiment in a well-controlled environment, where theoretical models are to be boiled down to essential parameters like temperature and scattering parameter. Furthermore, experiments are able to explore the complete parameter space of the many-body physics model by exploiting Feshbach resonance techniques. The representative example is the BCS-BEC crossover, connecting the weakly interacting BCS superfluid phase with the molecular Bose-Einstein condensate (BEC) phase. Correlation functions serve as critical quantities linking theoretical predictions with experimental observables, offering insights into coherence, phase transitions, and collective behaviour in these systems.
Our results reveal that the correlation functions are strongly influenced by temperature, interaction strength, and the effective range of the interaction. These effects manifest through multimodal phase transitions in the phase diagram, which can be directly compared to experimental measurements. Within the validity range of mean-field theory, the study offers a pathway to extract otherwise challenging physical quantities, such as temperature and the finite effective interaction range, from experimental data on interacting fermions.

Bouncing an ultracold potassium-39 atomic ensemble for creating time crystals

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Time crystals have been of significant interest recently in theoretical proposals and experimental realisations in which a periodically driven many-body system spontaneously breaks time-translation symmetry [1]. These systems exhibit ultra-stable subharmonic motion that is synchronised with the driving frequency. Such time crystals are expected to be robust against external disturbances and to have potential applications in quantum technologies.

The goal of this project is to experimentally demonstrate the formation of a discrete time crystal using weakly interacting Bose-condensed potassium-39 atoms bouncing on a modulated light-sheet atom mirror [2]. When tuned to resonance, this bouncing atomic ensemble can evolve along stable trajectories with a period that is an integer multiple (s) of the driving period. This behaviour effectively generates a large number of atomic lattice sites in the time domain. We utilise the potassium-39 atomic system due to its several broad Feshbach resonances, which allow precise tuning of atomic interactions near the zero-crossing point.

The experimental sequence begins with a two-dimensional magneto-optical trap (MOT) to load a three-dimensional MOT containing about 10^9 potassium atoms, initially cooled to around 2.6 mK. Owing to the small hyperfine splitting in the excited state, standard laser cooling cannot reach the Doppler limit. To overcome this, we implement a hybrid D2/D1 MOT configuration followed by grey molasses cooling on the D1 line, reducing the atomic temperature to 6 μK. The cold atoms are then transferred into a crossed-beam optical dipole trap operating at 1064 nm. In this setup, we have observed four broad Feshbach resonances at magnetic field strengths of 32.6 G, 59 G, 163 G, and 403 G. For evaporative cooling, we focus on the 32.6 G resonance and will report progress toward achieving quantum degeneracy of potassium-39 in the crossed optical dipole trap.

In our experiment, we investigate the dynamics of a bouncing Bose-condensed atomic ensemble released from a height of approximately 150 μm onto an atomic mirror formed by a 532 nm laser beam, modulated at a frequency of about 3 kHz. When the modulation of the mirror is synchronised with the bouncing period of the atoms (e.g., for the case of s = 30), it can generate up to 30 stable wave-packets, effectively forming temporal lattice sites that retain their shape and probability as they reflect from the driven mirror. By tuning the atomic scattering length to a small negative value (around $-2a_0$), tunnelling between adjacent temporal sites is strongly suppressed, enabling the formation of a large-scale discrete time crystal. Realising time crystals that involve many temporal lattice sites opens exciting possibilities for studying novel condensed matter phenomena in the time domain, including the emerging concept of “time-tronics”[3], a temporal analogue of electronics and atomtronics.

[1] K. Sacha, Physical Review A **98**, 013613 (2015).
[2] K. Giergiel et al, New Journal of Physics **22**, 085004 (2020).
[3] K. Giergiel, P. Hannaford, and K. Sacha, arXiv:2406.06387 (2024).

Anomalous Doppler effect in superfluid and supersolid atomic gases

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By employing the formalism of hydrodynamics, we derive novel analytic predictions for the Doppler effect in superfluids with broken Galilean invariance and hosting persistent currents at zero temperature. We consider two scenarios: when Galilean invariance is broken explicitly (by external potentials) and spontaneously, as it happens in a supersolid. In the former case, the presence of a stationary current affects the propagation of sound via an anomalous Doppler term proportional to the density derivative of the superfluid fraction. In supersolids, where, according to Goldstone theorem, distinct sounds of hybrid superfluid and crystal nature can propagate, the Doppler effect can be very different for each sound. Quantitative estimates of the Doppler shifts are obtained for Bose-Einstein condensed atomic gases, described by Gross-Pitaevskii theory. The estimates are obtained both calculating the thermodynamic parameters entering the hydrodynamic results, and from full time-dependent simulations.

Understanding Hall effect in interacting systems with an atom-based quantum simulator

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Despite being of one of the most fundamental phenomena in solid-state physics, a comprehension of the Hall effect remains challenging whenever interactions are present among the carriers. I will report on the first quantum simulation of the Hall effect for strongly interacting fermions [1]. By performing direct measurements of current and charge polarization in an ultracold-atom simulator, we trace the buildup of the Hall response in a synthetic ladder pierced by a magnetic flux through controllable quench dynamics. We unveil a universal interaction-independent behavior above an interaction threshold, where the Hall response deviates significantly from that expected for a non-interacting electron gas, approaching a universal value [2]. Our system, able to reach hard-to-compute regimes also demonstrates the power of quantum simulation to describe strongly correlated topological states of matter.
The quantum simulation of the Hall effect with ultracold atoms subjected to artificial magnetic fields opened up a path to gain new insight into the physics of interacting Hall systems, but the Hall resistance associated with the transverse transport in strongly correlated systems and often interpreted as a measure of the inverse carrier density, has only been observed in electronic systems so far. I will report on a direct measurement of the Hall voltage and of the Hall resistance in a neutral system, where we demonstrate a novel technique for the measurement of the Hall voltage in a neutral-atom-based quantum simulator [3,4]. From that we provide the first direct measurement of the Hall resistance in a non-electronic system and study its dependence on the carrier density, along with theoretical analyses. Our work closes a major gap between analog quantum simulations and actual measurements performed in real solid-state systems.

[1] T.-W. Zhou et al., Science **381**, 427 (2023).
[2] S. Greschner et al., Phys. Rev. Lett. **122**, 083402 (2019).
[3] T.-W. Zhou et al., arXiv:2411.09744 (2024).
[4] M. Buser et al., Phys. Rev. Lett. **126**, 030501 (2021).

Leveraging Yb clock states to make CsYb molecules

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Ultracold polar molecules offer a wide range of exciting research directions spanning ultracold chemistry, precision measurement, quantum simulation and quantum computation. Molecules with a 2Σ ground state, such as alkali–closed-shell combinations like CsYb, offer new possibilities of quantum simulations due to their electronic magnetic dipole moment. Our vision is to create magnetic polar CsYb molecules in an optical lattice with a high fraction of singly occupied sites. We have undertaken a study of interspecies Feshbach resonances in the Cs–Yb 1S0 system, where the predicted resonances are extremely narrow, making magnetoassociation particularly challenging. Recent theoretical work predicts that preparing Yb atoms in the metastable 3P0 clock state will produce significantly broader Feshbach resonances, thereby enabling more efficient magnetoassociation into weakly bound molecular states. We have implemented substantial upgrades to our apparatus, including a high–numerical–aperture imaging system, custom-designed magnetic field coils capable of generating uniform bias fields up to 1700 G, nanostructured anti-reflection coatings for improved optical access, and an optical transport system for the precise delivery of ultracold atomic clouds into a high-resolution glass science cell. These developments establish a robust experimental framework for the creation of dense samples of ultracold CsYb molecules and their coherent transfer to the rovibronic ground state via STIRAP, thereby expanding the range of molecular species available for quantum simulation.

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Ultracold Quantum Matter
Physics Center Bad Honnef, 10.08.-16.08.2025
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Bad Honnef Physics School *Ultracold Quantum Matter*

time	Sunday	time	Monday	time	Tuesday	time	Wednesday	time	Thursday	time	Friday	time	Saturday
		07:30-08:45	Breakfast	07:30-09:00	Breakfast	07:30-09:00	Breakfast	07:30-09:00	Breakfast	07:30-09:00	Breakfast	07:30-09:00	Breakfast
		08:45-09:00	Sá de Melo: Opening										
		09:00-10:00	Snoke I	09:00-10:00	Snoke II	09:00-10:00	Cabrera I	09:00-10:00	Cabrera II	09:00-10:00	Nascimbene I	09:00-10:00	Öhberg II
		10:00-10:30	Coffee Break	10:00-10:30	Coffee Break	10:00-10:30	Coffee Break	10:00-10:30	Coffee Break	10:00-10:30	Coffee Break	10:00-10:30	Coffee Break
		10:30-11:30	Wouters I	10:30-11:30	Wouters II	10:30-11:30	Kurkjian I	10:30-11:30	Kurkjian II	10:30-11:30	Ospelkaus I	10:30-11:30	Santos II
		12:00-13:30	Lunch	12:00-13:30	Lunch	12:00-13:30	Lunch	12:00-13:30	Lunch	12:00-13:30	Lunch	11:30-11:45	Pelster: Conclusion
		13:30-14:00	Questions/ Answers I	13:30-14:00	Questions/ Answers II	13:30-14:00	Excursion	13:30-18:30	Questions/ Answers III	13:30-14:00	Questions/ Answers IV	12:00-13:30	Lunch
14:00-18:30	Arrival & Registration	14:00-15:00	Post. Plen. I No. 1-26	13:30-14:00	Working Group I	13:30-14:00			Post. Plen. II No. 27-51	13:30-14:00	Working Groups II	13:30-	Departure
		15:00-15:30	Coffee Break	15:00-15:30	Coffee Break	15:00-15:30			Coffee Break	15:00-15:30	Coffee Break		
		15:30-16:30	Delic I	15:30-16:30	Delic II	15:30-16:30			Nascimbene I	15:30-16:30	Ospelkaus II		
		16:30-17:00	Coffee Break	16:30-17:00	Coffee Break	16:30-17:00			Coffee Break	16:30-17:00	Coffe Break		
		17:00-18:00	Wanjura I	17:00-18:00	Wanjura II	17:00-18.00			Öhberg I	17:00-18:00	Santos I		
18:30-20:00	Dinner	18:30-20:00	Dinner	18:30-20:00	Dinner	18:30-20:00	Dinner	18:30-20:00	Dinner	18:30-20:00	Dinner		
20:00-22:00	Meet & Greet	20:00-21:00	Post. Sess. I No. 1-13	20:00-21:00	Post. Sess. II No. 14-26	20:00-	Socializing	20:00-21:00	Post. Sess. III No. 27-38	20:00-21:00	Post. Sess. IV No. 39-51		

Panopto: **http://bit.ly/477SNaa**