YAO 2023

Barcelona, 12 - 16 June

28th

Young Atom Opticians Conference

Castelldefels (Barcelona), Spain

June 12 - 16 2023 at

ICFO

Conference Booklet

Castelldefels, June 2023

Welcome to YAO2023 in Castelldefels, Barcelona!

The YAO conference is a well-established annual international meeting. It has been organized by students since 1995 in many different scientific institutions around Europe. It is the largest student conference in the field of atomic and molecular optics. The main goal of the YAO conference is to strengthen scientific exchange among young students in the field in order to create a strong international community. It aims to offer an optimal platform for participants to obtain a broad overview of the state-of-the-art research, to expand their network and establish new contacts around the world and, for many, it is also the first opportunity to show their own results and discuss them among peers.
This year YAO takes place at the Institute of Photonic Sciences (ICFO) for its 28th edition, from the 11th to the 16th of June. As the organizer's of this YAO edition, it is our pleasure to welcome you and wish for you a fulfilling experience!
With kind regards,
YAO Organizing Committee

Contact Organising Committee

- E-mail: yao2023@icfo.eu
- Website: www.yao2023.icfo.eu/

Committee Members:

Natalia Alves, Javier Argüello Luengo, Sven Bodenstedt, Sandra Buob, Daniel Goncalvez Romeu, Lukas Heller, Jonatan Höschele, Tomáš Lamich, Jan Lowinski, Laura Zarraoa Sardón

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Conference Venue and Hotel

The conference will take place at ICFO:

ICFO, The Institute of Photonic Sciences
Mediterranean Technology Park,
Av. Carl Friedrich Gauss, 3, 08860
Castelldefels, Barcelona

Registration is open from 09:00h everyday at ICFO's front desk.

The accommodation has been arranged at the Hotel SB BCN Events.

Ronda de Can Rabadà, 22-24
08860 Castelldefels
Barcelona – SPAIN

Bed and breakfast are included from Sunday night until Friday morning. Check-in is Sunday after 15:00h and check-out is Friday before 12:00h.

Moving around (see map)

We recommend buying a T-casual transport card (1 zone). It includes 10 intermodal journeys, with 75 minutes between the first and last validation when changing lines or mode of transport. It is valid for one person only, it cannot be shared. It is only valid to reach the airport by bus or train, but not metro. It can be bought at ticket offices and vendor machines, bus drivers do not sell it.

Hotel-ICFO:

From the hotel there is a 10 minutes walk to ICFO or 1 stop by bus E95 or L95.

Airport-Hotel:

Train: From terminal T2 you can take the train to El Prat de Llobregat (one stop) and from there take the train R2 to Castelldefels (direction Vilanova I la Geltrú or Castelldefels).

Bus: There is a direct bus L99 to Castelldefels from terminal T1, tickets can be bought from the driver (only cash). You can also take the bus 46 (direction Barcelona) to Hospital de Bellvitge and from there take the E95 or L95 (direction Castelldefels).

Taxi: A taxi from the airport to ICFO is around 25€.

Castelldefels-Barcelona:

Train: the R2 train line connects Barcelona and Castelldefels with 4 to 6 trains an hour frequency. There's a 25 to 45-minute travel time to Barcelona's central stations: Sants, Passeig de Gracia and Estaciò de Francia.

Bus: the lines L95 and E95 (does not run on Sundays) are the most convenient to get to Barcelona. L95 takes around 60 minutes to Plaza Espanya, whereas the E95 (Express) takes around 40 minutes.

At night: The last train from Barcelona to Castelldefels leaves Estaciò de Francia at 23:49, and Sants at 00:04. There are two night buses from Plaza Espanya (Barcelona) to Castelldefels. The N16 is the fastest one (around 60-minute travel time) or the N14 (around 90-minute travel time).

Around Castelldefels:

Both the hotel and ICFO are in the town of Castelldefels, which is mainly known for its beaches. From the hotel to the beach, it takes around 25 minutes by foot or three stops by bus L95 (direction Barcelona).

The beach which is closest to ICFO (and the hotel) has only small seaside restaurants. For more varied offers, or supermarkets, we recommend going to the city center where you can also find the train station. For this you can take a 15-minute stroll or take the E95 or L95 bus (direction Castelldefels).

Following the beach into southern direction, you will eventually reach another zone with restaurants and bars. This area is around 4km away from the hotel, but it is close to the train station "Catelldefels Platja" and it can be reached also by bus combining L95/E95 with the L97 or by taking the CF2 bus.

Buses:
L99 (to/from Airport)
L95/E95 to Castelldefels
L95/E95 to Barcelona
HOTEL
Restaurant Area
Lunch
ICFO
Castelldefels Beach

Social Activities

We prepared for you a range of non-scientific activities whose sole purpose is to make you socialize beyond scientific context. Some people call it networking, but we think of it more as just having a fun time.

Beach Activities (Sunday and Monday): After you arrive in Castelldefels on Sunday afternoon, do not waste your time and hit the beach! We will bring some volleyballs and frisbees, and possibly some beers (we need to check the budget, though). We will chill there from 4 PM until the dinner time, which is 8-9 PM here. Don't forget your swimsuit and sunglasses! On Monday, after the poster session we will gather in front of ICFO in the picnic area to have some beers (totally illegal at the campus, so don't bother the guards too much). Later we will move to the beach to chill and maybe play some volleyball.

***Pub quiz (Monday)*:** On Monday, after lunch, to fight your food coma we will have a short kinda pub quiz. You will be at random assigned to small groups and answer some random questions (mostly about Spain and Catalunya, no physics, sorry). The winners will be awarded at the social dinner!

***Conference Dinner (Thursday)*:** We think we have got you quite a nice place for the social dinner. The restaurant is Oleum and is in MNAC (Museu Nacional d'Art de Catalunya), so reserve some time to get there, as you will have to climb some stairs. We will start gathering at 19:30 for an aperitivo and the food will be served at 8 PM. As the name suggests, the place is a museum, a pretty good one, especially if someone is interested in Catalan or Spanish art (there are great galleries on modernismo and gothic art). In principle we are not supposed to wander around the museum before getting to the restaurant, but you know. So, if you show up a bit earlier, you can hope to nourish your soul before your body (but no promises that it will work ;D, otherwise the entry ticket is 12 euro. If you stay longer after the conference, the museum is free on Saturdays from 3 PM).

***Afterparty (Thursday, TBC)*:** After the dinner, which should finish before 10 PM, we will take to some local place for a beer. Later, for those interested, we will aim for a proper party place. We will let you know the details later.

Time	Monday 12 June 2023	Tuesday 13 June 2023	Wednesday 14 June 2023	Thursday 15 June 2023	Friday 16 June 2023
09:00	Opening Remarks				
09:30	Francesca Ferlaino	Lukas Slodicka	Juliette Simonet	Daniel Barredo	Darrick Chang
10:00					
10:30	Fermi-Mixtures	Ions	Quantum Sim.	Quantum Sim. 2	Atom-Light Inter.
11:00	Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
11:30	BEC	Metrology	Atom Interferometry	Rydberg Atoms	Quantum Information
12:00					
12:30					
13:00	Lunch	Lunch	Lunch	Lunch	Closing Remarks
13:30					
14:00					
14:30	Pub Quiz	BEC 2	Non-Scientific Talk	Lab Tours	
15:00	Invited Talk Svenja Knappe		BEC 3		
15:30					
16:00	Hot Vapours	Pasqal	Thorlabs		
16:30	Poster Session + Coffee Break	Poster Session + Coffee Break	Poster Session + Coffee Break		
17:00					
17:30					
18:00					
18:30	Beers				
19:00	Beach Activites				
19:30				Gathering	
20:00				Conference Dinner	
20:30					
21:00					
21:30					

- Invited Talk
- Contributed Talk
- Industry Talk
- Poster Session
- Other

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Conference Schedule

Monday, 12 June

9:00 **Arrival**, Conference Venue: ICFO, Avinguda Carl Friedrich Gauss, 3

9:15 **Opening**, ICFO Auditorium

9:30 **Invited Speaker:**
Many-body physics in dipolar quantum gases
Francesca Ferlaino, IQOQI, Innsbruck

10:30 **Session - Fermi-Mixtures**

Strongly intacting Fermi-Fermi Mixture of 161Dy and 40K: Study of DyK Feshbach molecules
Alberto Canali, Universität Innsbruck, Institut für Experimentalphysik

Resonantly interacting 6Li-53Cr Fermi mixture and production of LiCr Feshbach molecules
Stefano Finelli, Università di Firenze

11:00 **Coffee Break**

11:30 **Session - BEC I**

Optimal control of a Bose-Einstein condensate in an optical lattice
Floriane Arrouas, LCAR

Superfluid fraction in an interacting spatially modulated Bose-Einstein condensate
Franco Rabec, LKB, Collège de France

Self-bound crystals of antiparallel dipolar mixtures
Maria Arazo, Universitat de Barcelona

Radio-frequency dressing Bose-Einstein condensates for investigating quantum phase
Natasha Bierrum, University of Sussex

Probing the Li-Haldane conjecture with a synthetic Quantum Hall Ribbon
Quentin Redon, Laboratoire Kastler Brossel

Collective behaviour in Rabi-coupled two component Bose-Einstein condensates

Roy Eid, Institut optique graduate school, Laboratoire Charles Fabry, groupe gaz quantique

13:00 **Lunch Break at UPC Cafeteria**

14:30 **Pub Quiz**

15:00 **Invited Speaker:**
Microfabricated hot-vapor magnetometers
Svenja Knappe, University of Colorado Boulder

16:00 **Session - Hot Vapors**

K-^{3}He Comagnetometer as an Advanced Sensor for the Global Network of Optical Magnetomters for Exotic Physics Searches (GNOME)

Grzegorz Łukasiewicz, Jagiellonian University, Kraków, Poland

Detection of quantum (Fano) interference in a hot vapor atomic gas

Ludovica Donati, European Laboratory for Non-linear Spectroscopy (LENS), Università degli Studi di Firenze

Quantum thermometry using topological fermionic chains

Anubhav Srivastava, Institute of Photonic Sciences - ICFO

16:45 **Poster Session I**

Tuesday, 13 June

9:30 **Invited Speaker:**
Coherence of light from ensembles of many independent atoms
Lukáš Slodička, Palacký University Olomouc

10:30 **Session - Ions**

Individual qubit addressing in chains of 137Ba+ ions using laser-written waveguides

Andrés Vazquez-Brennan, University of Oxford

Focussing of microwave-driven gate interactions for trapped ions

Molly Smith, University of Oxford

11:00 **Coffee break**

11:30 **Session - Metrology**

Isotope shifts of the 1P1 ← 1S0 and 3P1 ← 1S0 lines in atomic cadmium
Eduardo Padilla, Fritz-Haber-Institute der Max-Planck-Gesellschaft

The Design of the BECCAL Laser System for Cold Atom Experiments Onboard the ISS
Hamish Beck, HU Berlin

How much time does a resonant photon spend as an atomic excitation before being transmitted?
Kyle Thompson, University of Toronto

Accuracy of a commercial cold-atom microwave clock
Luc Archambault, Exail - SYRTE

Atom Interferometer Observatory and Network (AION) with ultra-cold strontium
Mariame Karzazi, University of Cambridge

Laser cooling of barium monofluoride molecules
Tatsam Garg, 5. Physikalisches Institut, IQST, University of Stuttgart

13:00 **Lunch Break at UPC Cafeteria**

14:30 **Session - BEC II**

Relative dynamics of quantum vortices and massive cores in binary BECs
Alice Bellettini, Department of Applied Science and Technology (DISAT) Politecnico di Torino Italy

Observation of vortices in dipolar quantum gasses of dysprosium
Clemens Ulm, Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences A-6020 Innsbruck, Austria

Universality of the superfluid Kelvin-Helmholtz instability by single-vortex tracking
Diego Hernandez Rajkov, LENS

A Digital Micromirror Device setup for enhanced control of a two-dimensional Bose-Einstein condensate
Marcel Kern, Heidelberg University

Dipolar Quantum Solids in an Erbium Quantum Gas Microscope
Michal Szurek, Harvard University

Mixtures of Superfluid Bose and Fermi Gases
Piotr Wysocki, Warsaw University of Technology

16:00 **Industry Partner: PASQAL** Company introduction & current research

16:30 **Poster Session II**

Wednesday, 14 June

9:30 **Invited Speaker:**

Quantum simulation with ultracold gases in optical lattices

Juliette Simonet, The Hamburg Centre for Ultrafast Imaging (CUI), University of Hamburg

10:30 **Session - Quantum Simulation I**

FermiQP - A Fermion Quantum Processor

Er Zu, Max-Planck-Institut of Quantum Optics Hans-Kopfermann Street 1, 85748 Garching, Germany

Spin squeezing via XXZ dipolar interactions in an optical lattice quantum gas microscope

Vassilios Kaxiras, Harvard University

11:00 **Coffee Break**

11:30 **Session - Atom Interferometry**

Stern-Gerlach Interferometry with the Atom Chip

Barak Trok, The Atom Chip Group at Ben-Gurion University, Be'er Sheva, 84105, Israel

Development of a compact cold atom gyroscope

Clément Salducci, ONERA

Frequency Comb atom interferometer

Clément Debavelaere, Laboratoire Kastler Brossel

High precision Atom Interferometer GAIN

Hrudya Thaivalappil Sunilkumar, Humboldt-Universität zu Berlin

Ultra high sensitivity quantum gravi-gradiometer

Joel Gomes Baptista, Observatoire de Paris

A hybrid cold atom accelerometer for space geodesy missions

Noémie Marquet, ONERA

13:00 **Lunch Break at UPC Cafeteria**

14:30 **Non-scientific Talk: TALK TITLE**

15:00 **Session - BEC III**

Experimental investigation of false vacuum decay in a ferromagnetic superfluid
Chiara Rogora, Pitaevskii BEC Center, CNR INO and Dipartimento di Fisica, Università di Trento

Einstein-Podolsky-Rosen experiment in split Spin-Squeezed Bose Einstein Condensates.
Lex Edgar Joosten, University of Basel

Preparation for the Integration of the BECCAL Laser System
Marc Kitzmann, HU Berlin

Towards a strontium quantum gas microscope
Jonathan Höschele, Institute of Photonic Sciences - ICFO

16:00 **Industry Partner: Thorlabs** Company introduction & current research

16:30 **Poster Session III**

Thursday, 15 June

9:30 **Invited Speaker:**
Exploring quantum spin models with Rydberg atom arrays
Daniel Barredo, Institut d'Optique-CNRS & CINN-CSIC

10:30 **Session - Quantum Simulation II**

Setup of an atom array with cavity-mediated interactions
Johannes Schabbauer, TU Wien

Towards quantum simulation in an optical kagome lattice with single-site resolved imaging
Tobias Marozsak, Cavendish Laboratory, University of Cambridge

Quantum Gas Magnifier for Ultracold Atoms in an Optical Quasicrystal
Zhuoxian Ou, University of Cambridge, Department of Physics

11:15 **Coffee Break**

11:45 **Session - Rydberg Atoms**

New method to probe a quantum phase transition in different spin Hamiltonians
Eduard Jürgen Braun, University of Heidelberg

Scalable Qubit Arrays for Quantum Computation And Simulation
Elliot Diamond-Hitchcock, University of Strathclyde

Trapping atoms in a cryogenic environment : enhancing scalability in quantum systems
Grégoire Pichard, PASQAL/LCF (Paris Saclay University)

Engineering gauge theories with a Rydberg atom processor
Julia Bergmann, ICFO / UAB

Characterizing Operator Growth in Disordered Quantum Spin Chains via Out-of-Time-Ordered Correlators
Maximilian Müllenbach, CESQ, Université de Strasbourg

Microwave-to-optical conversion based on room-temperature Rydberg atomic ensemble
Sebastian Borówka, University of Warsaw

13:15 **Lunch Break at UPC Cafeteria**

14:45 **Lab Tours**

20:00 **Conference Dinner** Reception from 19:30 onwards

Friday, 16 June

9:30 **Invited Speaker:**
The maximum refractive index of optical materials: from quantum optics to quantum chemistry
Darrick Chang, ICFO, Barcelona

10:30 **Session - Atom-Light interaction**

Observation of superradiant bursts in waveguide QED
Constanze Bach, Humboldt University of Berlin

Analysing nonlinearity of atomic arrays using a Green's function approach to time evolution
Simon Panyella Pedersen, Department of Physics and Astronomy, Aarhus University, Denmark

Effect of an optical dipole trap on resonant atom-light interactions
Teresa Karanikolaou, ICFO

11:15 **Coffee Break**

11:45 **Session - Quantum Information**

Kinetic energy distribution of the rescattering electrons from asymmetric $\omega/2\omega$ pulses
Athanasios Athanasopoulos, Institute for Electronic Structure and Lasers (IESL) Foundation for Research & Technology (FORTH) Heraklion, Greece

Using single atoms in optical cavities as efficient source for multiphoton graph states generation
Leonardo Ruscio, Max Plank Institut of Quantum Optics

A quantum frequency converter for the connection of rubidium atoms in a cavity over long distances
Maya Büki, Max-Planck-Institute for Quantumoptics

Entanglement Distribution - Towards a Suburban Quantum Network Link
Pooja Malik, Ludwig-Maximilians-University, Munich, Germany and Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Cavity-mediated interactions between pair of atoms and generation of entangled states of bosons in an optical cavity
SANKALP SHARMA, Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, ul. Grudziadzka 5, 87-100 Toruń, Poland

Optical spectrum to position converter for spectro-temporal processing based on quantum memory
Stanisław Kurzyna, Centre for Quantum Optical Technologies, Centre of New Technologies, University of Warsaw, Banacha 2c, 02-097 Warsaw, Poland

13:15 **Closing remarks**

Talks

The following chapter contains all the invited and contributed talks.

Links linking back either to the Table fo Content or to the long abstracts are provided in red.

Invited Speaker: Francesca Ferlaino

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Many-body physics in dipolar quantum gases

Francesca Ferlaino - University of Innsbruck and Institute for Quantum Optics and Quantum Information (IQOQI), Austria

Brought to quantum degeneracy, ultracold gases enable the study of many-body quantum phenomena, in which the interaction between atoms can be so carefully mastered as to determine the very state of matter. Typically, this interaction has a short-range and isotropic nature, the latter meaning that the atoms globally attract or repel each other. However, there is another possibility that naturally emerges for some specific atomic species, such as erbium and dysprosium, featuring an extraordinarily large magnetic dipole moment. Magnetic properties give rise to dipolar many-body interactions, qualitatively very different from others in that it is long-range and anisotropic, thus adding connectivity and directionality at the quantum level.

In the present talk I will retrace the fundamental steps in the study of dipolar gases, with emphasis on the Innsbruck results, from their creation to the new phenomena unveiled such as the emergence of rotonic excitations, so named by Landau, to the observation of a new and paradoxical state of matter with multiple spontaneous symmetry breaking, known as supersolid.

Francesca Ferlaino is Full Professor at the University of Innsbruck and Scientific Director at the Institute for Quantum Optics and Quantum Information (IQOQI) of the Austrian Academy of Science (ÖAW). She studied physics at the University of Federico II. Her PhD at the University of Florence and at the European Laboratory for Non-linear Spectroscopy (LENS) in Florence was under the supervision of Prof. M. Inguscio. There she was involved in the first realization of quantum gases mixture of different alkali atomic species. In 2009, thanks to a START-Prize (FWF) and an ERC Starting Grant, Francesca could establish her independent research group, the Dipolar Quantum Gas Group and started the so-called "ERBIUM" experiment, realizing the world-first Bose-Einstein condensate of Er in 2012. Now she has several labs in her group as well as a theory division. Her research is focused on ultracold strongly magnetic Lanthanides for realizing dipolar quantum matter.

Talks: Fermi-Mixtures

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Strongly intacting Fermi-Fermi Mixture of 161Dy and 40K: Study of DyK Feshbach molecules 10:30

Alberto Canali, *Universität Innsbruck, Institut für Experimentalphysik*

We reports on the preparation of an optically trapped ultracold sample of bosonic DyK Feshbach molecules, of fermionic isotopes of Dy and K. Using a magnetic sweep across a resonance located near 7.3 G, up to 5000 molecules were produced at a temperature of about 50 nK, corresponding to a phase-space density of 0.13. The study reveals a lifetime limitation caused by the infrared trap light; we were able suppress losses by replacing the 1064-nm laser originally used with a laser operating further in the infrared (near 1550 nm), reaching lifetimes of about about 100 ms

Degenerate Fermi gases, Cold atoms

Resonantly interacting 6Li-53Cr Fermi mixture and production of LiCr Feshbach molecules 10:45

Stefano Finelli, *Università di Firenze*

Mixtures of two different species of fermionic atoms open qualitatively new opportunities in the realm of ultracold Fermi gases, enabling access to a plethora of few- and many-body regimes unattainable with mass-symmetric systems. In our lab we produce the first chromium-lithium fermionic mixture worldwide. Tuning of the interspecies interaction by means of Feshbach resonances allows us to investigate elusive few-particle cluster states, as well as exotic superfluid and magnetic many-body regimes of highly-correlated fermionic matter.

Molecules, Degenerate Fermi gases, Exotic phases of matter

Talks: BEC

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Optimal control of a Bose-Einstein condensate in an optical lattice 11:30

Floriane Arrouas, *LCAR*

Cold atoms offer a high degree of control, but it can be improved using optimal control theory (OCT). In our Bose Einstein Condensates system, we use OCT to determine the required phase modulation of a 1D-optical lattice to prepare a target quantum state. The talk will present our results in reaching various states in the phase-space and characterizing their high fidelity and purity.

Lattices, Bose-Einstein condensates, Cold atoms

Superfluid fraction in an interacting spatially modulated Bose-Einstein condensate 11:45

Franco Rabec, *LKB, Collège de France*

At zero temperature, a Galilean-invariant Bose fluid is expected to be fully superfluid. We investigate the quenching of the superfluid density of a dilute Bose-Einstein condensate due to the breaking of translational (and thus Galilean) invariance by an external 1D periodic potential.

Quantum gases in low dimensions, Many-body physics, Bose-Einstein condensates

Self-bound crystals of antiparallel dipolar mixtures 12:00

Maria Arazo, *Universitat de Barcelona*

We show that a mixture of two antiparallel dipolar condensates allows for the creation of self-bound crystals which are maintained by the mutual dipolar attraction between the components, with no need of transversal confinement. This opens intriguing novel possibilities, including three-dimensionally self-bound droplet-ring structures, stripe/labyrinthic patterns, and self-bound crystals of droplets surrounded by an interstitial superfluid.

Cold atoms, Bose-Einstein condensates, Dipolar quantum gases

Radio-frequency dressing Bose-Einstein condensates for investigating quantum phase

12:15

Natasha Bierrum, *University of Sussex*

Adiabatic radio-frequency dressing creates a double well potential which is used for investigating relative phase of atomic ensembles. We will extend to multiple radio-frequency dressing for creating three or more wells at once for more extensive research into the quantum phase of Bose-Einstein condensates.

Atom-light interaction, Bose-Einstein condensates, Atom and matter-wave optics and interferometers

Probing the Li-Haldane conjecture with a synthetic Quantum Hall Ribbon

12:30

Quentin REDON, *Laboratoire Kastler Brossel*

Entanglement spectrum as a generalization of the entanglement entropy turns out to be a powerful tool to detect the underlying topology of a given state. This work implements a variational learning of the entanglement Hamiltonian of a synthetic quantum quantum Hall Ribbon starting from the Bisognano-Wichmann (BW) prescription. We then experimentally validate the BW ansatz and demonstrate the Li and Haldane correspondence.

Cold atoms, Synthetic gauge fields, Quantum simulation

Collective behaviour in Rabi-coupled two component Bose-Einstein condensates

12:45

Roy Eid, *Institut optique graduate school, Laboratoire Charles Fabry, groupe gaz quantique*

Mixtures of two components coupled Bose-Einstein condensate will be specifically addressed. First, large attractive effective three-body interactions can be engineered with striking consequences . Second, the beyond-mean field energy is precisely measured and is shown to be modified as compared to the uncoupled case .

Cold atoms, Many-body physics, Bose-Einstein condensates

Invited Speaker: Svenja Knappe

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Microfabricated hot-vapor magnetometers

Svenja Knappe - University of Colorado, Boulder

The field of Quantum Engineering has grow rapidly in the last decade in an effort to translate Quantum Sensors from the lab to real-world applications. Hot-vapor based sensors are at the forefront of this effort and have been translated successfully from academia into industry. They are now used in a variety of systems. The technologies developed for hot-vapor sensors and devices can serve as a stepping stone for many other quantum sensors to come. I will discuss our efforts in micro-fabricated hot-vapor magnetometers for a variety of applications ranging from brain imaging to space applications.

Svenja Knappe received her Ph.D. in physics from the University of Bonn, Germany. For 16 years, she worked at the National Institute of Standards and Technology (NIST) in Boulder CO, developing chip-scale atomic sensors. She is now an Associate Research Professor at the University of Colorado Boulder, and her research interests include microfabricated atomic magnetometers. In 2018, she founded FieldLine to commercialize a non-invasive functional brain imaging system based on quantum magnetometers. As the CTO of FieldLine Medical, she is aiming to expand the boundaries of this powerful imaging technology through quantum sensing.

Talks: Hot Vapors

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K-^{3}He Comagnetometer as an Advanced Sensor for the Global Network of Optical Magnetomters for Exotic Physics Searches (GNOME) 16:00

Grzegorz Łukasiewicz, *Jagiellonian University, Kraków, Poland*

We present the capabilities of a K-3He comagnetometer as a new sensor for the dark matter searches in the GNOME experiment. Principles of sensor operation and possible data analysis methods will be discussed.

Fundamental constants, Hot vapors

Detection of quantum (Fano) interference in a hot vapor atomic gas 16:15

Ludovica Donati, *European Laboratory for Non-linear Spectroscopy (LENS), Università degli Studi di Firenze*

Noisy-induced coherence via quantum interference can in principle enhance the performances of quantum heat engines, photovoltaic devices and photodetectors. We set an experiment for the detection of Fano coherences in a V-type three level system, realized in the hyperfine structure of hot Rb atoms, driven by a non-coherent source. This is expected to provide the first observation and new insight about quantum coherence terms originated by non-coherent excitation in a three-level atomic system.

Atom-light interaction, Quantum optics, Hot vapors

Quantum thermometry using topological fermionic chains 16:30

Anubhav Srivastava, *Institute of Photonic Sciences - ICFO*

With the advent of quantum technologies, there is a dire need to accurately measure the temperature of systems at regimes where quantum effects are dominant. This is challenging since there is no observable to measure the temperature of a given quantum system directly. Thus, we need quantum estimation theory to provide us with the lower bound for the temperature accuracy of a quantum system via the Cramer-Rao bound, which is inversely proportional to the square root of Quantum Fisher Information (QFI) for a general thermal state.

keywords

Invited Speaker: Lukáš Slodička

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Coherence of light from ensembles of many independent atoms

Lukáš Slodička - Department of Optics, Palacký University
17. listopadu 12, 771 46 Olomouc, Czech Republic

Cold ensembles of atomic ions in Paul traps provide a unique testbed for a rich variety of quantum optics phenomena. The feasibility of precise and deterministic control of their external-motional and internal-electronic quantum states directly manifests in many successful applications requiring nonlinear interactions and scalability to a large number of particles. We will show how the free-space optical emission from ion crystals containing a large number of independent single-photon emitters provides different paradigmatic regimes of quantum statistics of light including extremely pure single photon emission or the largest discreet photonic nonclassical states [1]. We will present the experimental evidence of a single-mode coherent light scattering from many ions [2,3], which provide all necessary ingredients for photonic generation of atomic entanglement or directional control of nonclassical light emission from ions [4]. We will discuss prospects of the unique experimental feasibility of engineering direct coupling between the emitted nonclassical light and the mechanical motion of ions in the quantum domain.

1. P. Obšil et al., *Phys. Rev. Lett.* **120**, 253602 (2018).
2. P. Obšil et al., *New J. Phys.* **21** 093039 (2019).
3. A. Kovalenko et al, *Optica* **120**, 193603 (2023).
4. G. Araneda et al., *Phys. Rev. Lett.* **120**, 193603 (2018).

Lukáš studied at Palacký University Olomouc for his Master's degree after which he moved on to Prof. Rainer Blatt's group in Innsbruck where he worked on interaction between an ion and a light field. There he wrote and successfully defended a thesis titled Single ion-single photon interactions in free space. During his later years, he worked on various post-docs in the trapped ions field before becoming a staff scientist at Palacký University Olomouc where he works now. His current research topics include quantum light generation from trapped ions and warm vapours.

Tuesday

Talks: Ions

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Individual qubit addressing in chains of 137Ba+ ions using laser-written waveguides 10:30

Andrés Vazquez-Brennan, *University of Oxford*

We present a system for individual qubit addressing in registers of trapped barium ions. We use a laser-cut waveguide array to output beams at 532 nm whose separation matches that of the ions. Due to the atomic properties of barium, light at this wavelength can drive Raman transitions between hyperfine states in either the ground or metastable levels, enabling advanced qubit manipulation schemes.

Quantum computing, Quantum information processing, Ions

Focussing of microwave-driven gate interactions for trapped ions 10:45

Molly Smith, *University of Oxford*

Quantum logic gates using trapped-ions are often performed using lasers but can also be driven by microwave fields, for which the technology is cheaper and more reliable. However, due to the centimetre wavelength of microwaves, they cannot be focussed to a small spot size making it difficult to address an individual ion in a chain. We present a novel method to drive a spin-dependent force only in a sub-ion-spacing region whilst suppressing this force everywhere else.

Quantum computing, Ions

Talks: Metrology

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Isotope shifts of the 1P1 ← 1S0 and 3P1 ← 1S0 lines in atomic cadmium 11:30

Eduardo Padilla, *Fritz-Haber-Institute der Max-Planck-Gesellschaft*

We present isotope shift and hyperfine structure measurements of low-lying singlet and triplet transitions in cadmium, by laser-induced fluorescence in a buffer gas cooled atomic beam. To reach MHz accuracy, we investigated thoroughly systematic uncertainties in the laser frequency measurement, and for the singlet transition we use isotopically enriched samples and emission-angle selective detection. Using a King-plot analysis, we extracted field and mass shift parameters for the transition pair.

Cold atoms

Tuesday

The Design of the BECCAL Laser System for Cold Atom Experiments Onboard the ISS 11:45

Hamish Beck, *HU Berlin*

The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is a cold atom experiment designed for operation onboard the ISS. An overview of the design and capabilities of the BECCAL laser system will be presented.

Atom-light interaction, Cold atoms, Bose-Einstein condensates

How much time does a resonant photon spend as an atomic excitation before being transmitted? 12:00

Kyle Thompson, *University of Toronto*

When a photon traverses a cloud of 2-level atoms, the average time it spends as an atomic excitation—as measured by weakly probing the atoms—is equal to the spontaneous lifetime of the atoms times the probability of the photon being scattered. A tempting inference from this is that an average scattered photon spends one spontaneous lifetime as an atomic excitation, while transmitted photons spend no time. However, using the weak-value formalism, we show that the time a transmitted photon spends as an atomic excitation is equal to the group delay, even when the group delay is negative.

Quantum optics, Cold atoms, Atom-light interaction

Accuracy of a commercial cold-atom microwave clock 12:15

Luc Archambault, *Exail - SYRTE*

We present MuClock, a commercial compact microwave clock using isotropic light cooling of rubidium atoms. MuClock is comparable to typical hydrogen masers in terms of volume and short-term frequency stability, which is 3.2E-13 at 1 s. The long-term stability outperforms typical masers with a fractional frequency stability of 1E-15 over more than one month, and we are now aiming at establishing an overall accuracy below 5E-15.

Cold atoms, Atomic clocks, Quantum metrology and sensing

Atom Interferometer Observatory and Network (AION) with ultra-cold strontium 12:30

Mariame Karzazi, *University of Cambridge*

I will be presenting our current advances in cooling and optical transport of strontium atoms and its context in AION. AION is an atom interferometry project in the UK looking to detect dark matter, gravitational waves and explore other fundamental physics.

Atom and matter-wave optics and interferometers, Cold atoms, Quantum metrology and sensing

Laser cooling of barium monofluoride molecules 12:45

Tatsam Garg, *5. Physikalisches Institut, IQST, University of Stuttgart*

I will report on our progress towards laser cooling of barium monofluoride molecules. Due to its high mass, resolved hyperfine structure in the excited state and branching losses through intermediate states, this molecular species is notoriously difficult to cool, but it shows high promise for various types of precision measurement applications. I will discuss laser cooling strategies for both the bosonic isotopologues, which are interesting for electron EDM searches, and the more complex fermionic isotopologues, which are used for parity violation experiments.

Molecules, Fundamental constants

Talks: BEC 2

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Relative dynamics of quantum vortices and massive cores in binary BECs 14:30

Alice Bellettini, *Department of Applied Science and Technology (DISAT) Politecnico di Torino Italy*

We study vortices with massive cores in binary mixtures of Bose- Einstein condensates. We extend a point-vortex model, introducing the coupling between quantum vortices and core masses. This improves the description of the vortex dynamics.

Bose-Einstein condensates, Quantum fluids, Cold atoms

Tuesday

Observation of vortices in dipolar quantum gasses of dysprosium 14:45

Clemens Ulm, *Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences A-6020 Innsbruck, Austria*

Due to anisotropic interactions, ultra-cold dipolar gasses exhibit exotic states such as supersolids, which are theorized to maintain phase coherence using a superfluid background. Quantized vortices, a defining feature of superfluidity, are an unambiguous probe of irrotational flow which can be used to prove the existence of the superfluid background in the supersolid phase. Here we study, both experimentally and theoretically, the creation of vortices in the unmodulated BEC phase and our progress towards creating vortices in the Dy-164 supersolids.

Dipolar quantum gases, Bose-Einstein condensates, Cold atoms

Universality of the superfluid Kelvin-Helmholtz instability by single-vortex tracking 15:00

Diego Hernandez Rajkov, *LENS*

We report on the observed universal behavior of the Kelvin-Helmholtz in strongly interacting Fermi gases across the BEC-BCS crossover. Extracting the instability growth rates by tracking the position of individual vortices we found that they follow universal scaling relations predicted by classical hydrodynamics.

Out-of-equilibrium trapped gases, Quantum fluids, Degenerate Fermi gases

A Digital Micromirror Device setup for enhanced control of a two-dimensional Bose-Einstein condensate 15:15

Marcel Kern, *Heidelberg University*

I present my master's thesis project about a Digital Micromirror Device setup for enhanced control of a two-dimensional Bose-Einstein condensate with tunable interactions. For the configurable in-plane potential, a far-detuned Digital Micromirror Device is already in use. The second, near-resonant device will enable us to optimize the existing potential or manipulate the Bose-Einstein condensate locally, for example to inject vortices.

Atom-light interaction, Quantum gases in low dimensions, Bose-Einstein condensates

Dipolar Quantum Solids in an Erbium Quantum Gas Microscope 15:30

Michal Szurek, *Harvard University*

We present dipolar phases of the extended Bose-Hubbard model in a quantum gas microscope of magnetic Erbium atoms. By adiabatically loading a BEC into a small-spacing lattice, the long-range dipole-dipole interaction dominates and we observe checkerboard, stripe, and diagonal dipolar phases.

Dipolar quantum gases, Exotic phases of matter, Many-body physics

Mixtures of Superfluid Bose and Fermi Gases 15:45

Piotr Wysocki, *Warsaw University of Technology*

In my work, I study superfluid quantum gases, as well as their mixtures. Presently, I study Andreev-Bashkin effect in Bose-Fermi mixtures, mainly through the investigation of topological defects such as quantized vortices.

Quantum gases in low dimensions, Bose-Einstein condensates, Cold atoms

Invited Speaker: Juliette Simonet

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Wednesday

Quantum simulation with ultracold gases in optical lattices

Juliette Simonet - The Hamburg Centre for Ultrafast Imaging (CUI), University of Hamburg

Quantum gases in optical lattices have proven to be a powerful tool for the investigation of various phenomena related to the field of many-body physics [1]. Increasingly sophisticated preparation and probing schemes have further boosted quantum simulation in optical lattices. A paradigm example of this advancement is the development of quantum gas microscopes that allow probing Hubbard models with unprecedented accuracy [2].
In the past years, great effort has been spent to develop methods for tailoring new properties so far lacking for quantum simulation of solid-state systems. In this context, time-periodic driving, subsumed under *Floquet engineering*, constitutes a powerful technique [3]. We will discuss recent achievements in realizing new classes of Hamiltonians including artificial gauge fields or topological band structures. A strong motivation for developing these methods is the prospect to study the interplay between topology and interactions in a system where both ingredients are fully tunable.

[1] Bloch, et al. Many-body physics with ultracold gases, Rev. Mod. Phys. **80**, 885 (2008)
[2] Gross and Bakr, Quantum gas microscopy for single atom, Nat.Phys. **17**, 1316 (2021)
[3] Weitenberg and Simonet, Tailoring quantum gases by Floquet engineering, Nat. Phys. **17**, 1342 (2021)

Juliette Simonet is senior scientist in the group of Prof. Dr. Klaus Sengstock at the University of Hamburg.
She studied physics at the Ecole Normale Supérieure in Paris. Her doctoral research studies, conducted in the group of Michèle Leduc and Claude Cohen-Tannoudji, have been centred on the experimental study of degenerated gases of metastable Helium in optical traps.
She is principal investigator in the SFB925 which addresses the topic of light induced dynamics and control of correlated quantum systems. Furthermore, she is a young investigator in the cluster of excellence CUI: Advanced Imaging of Matter (AIM).

Talks: Quantum Simulation 1

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FermiQP - A Fermion Quantum Processor 10:30

Er Zu, *Max-Planck-Institut of Quantum Optics Hans-Kopfermann Street 1, 85748 Garching, Germany*

FermiQP is a quantum processor based on ultracold fermionic lithium in optical lattices.It can act as a quantum gas microscope featuring single site resolution and spin-resolved detection.I will present my setup for a high-stability, large-volume bow-tie lattice used for imaging and cooling.

Quantum simulation, Cold atoms, Lattices

Spin squeezing via XXZ dipolar interactions in an optical lattice quantum gas microscope 10:45

Vassilios Kaxiras, *Harvard University*

We present a new method for preparing a metrologically useful spin squeezed state in an optical lattice. We utilize a dipolar XXZ power-law interaction between Erbium-167 atoms in one layer of a 3D optical lattice quantum gas microscope.

Dipolar quantum gases, Many-body physics, Quantum metrology and sensing

Wednesday

Talks: Atom Interferometry

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Stern-Gerlach Interferometry with the Atom Chip 11:30

Barak Trok, *The Atom Chip Group at Ben-Gurion University, Be'er Sheva, 84105, Israel*

We provide a review of our Stern-Gerlach (SG) experiments over the last decade. We describe several novel configurations such as that giving rise to the first SG spatial interference fringes, and the first full-loop SG interferometer realization. Fundamental applications include the probing of the foundations of quantum theory, gravity, and the interface of quantum mechanics and gravity.

Bose-Einstein condensates, Atom and matter-wave optics and interferometers

Wednesday

Development of a compact cold atom gyroscope 11:45

Clément Salducci, *ONERA*

We present our first results of our work concerning a compact cold atom gyroscope.

Quantum metrology and sensing, Cold atoms, Atom and matter-wave optics and interferometers

Frequency Comb atom interferometer 12:00

Clément Debavelaere, *Laboratoire Kastler Brossel*

We demonstrate the uses of frequency comb to drive atom interferometry. This technique, which we demonstrated in the visible spectrum on Rb atoms, paves the way for extending light-pulse interferometry to other spectral regions (deep-UV to X-UV) and therefore to new species.

Atom and matter-wave optics and interferometers, Cold atoms

High precision Atom Interferometer GAIN 12:15

Hrudya Thaivalappil Sunilkumar, *Humboldt-Universität zu Berlin*

The Gravimetric Atom Interferometer GAIN, is based on interfering ensembles of laser cooled 87Rb atoms in a fountain setup using stimulated Raman transitions. The rugged transportable design of the instrument enables precise and accurate on-site gravity measurements. We will report the improvements implemented into the apparatus.

Quantum metrology and sensing, Cold atoms, Atom and matter-wave optics and interferometers

Ultra high sensitivity quantum gravi-gradiometer 12:30

Joel Gomes Baptista, *Observatoire de Paris*

A cold atom gradiometer is a quantum sensor that measures the vertical component of the gravitational acceleration and its gradient using atom interferometry. Currently, we are working on the implementation of optimal control transfer techniques to maximize the efficiency of the Bragg transitions that allow us to realize the interferometer. This should allow us to increase the sensitivity of our sensor in order to reach the state of the art.

Atom and matter-wave optics and interferometers, Cold atoms, Quantum metrology and sensing

A hybrid cold atom accelerometer for space geodesy missions 12:45

Noémie Marquet, *ONERA*

Our ongoing work concerns the development of an hybridised electrostatic/atomic accelerometer dedicated to space applications. Cold atom accelerometers could improve current acceleration measurements because of their very good stability. In particular, we studied the problematic of satellite's rotation and its effect on the cold atom accelerometers.

Atom and matter-wave optics and interferometers, Quantum metrology and sensing, Cold atoms

Non-scientific talk: Simón Perera

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10 measures to improve LGBTIQA+ reality in STEM centres

Simón Perera - PRISMA

LGBTIQA+ individuals in STEM often face harassment, exclusion, and intimidation based on their sexuality, gender identity, with trans, non-binary people, and women being more affected than men. This occurs throughout their scientific careers, from students to faculty and research positions, leading to compromised mental health and even causing some to abandon their studies or careers. Studies have shown that diverse environments yield better results. However, science and scientific outreach can also misapply gender identity and biological sex to LGBTIQA+ individuals, promoting binary thinking. PRISMA, a Spanish association, advocates for LGBTIQA+ people in STEM, aiming to highlight diversity through building supportive communities, raising awareness of their experiences, providing data and evidence against discrimination, and promoting diversity practices in academia and industry. PRISMA envisions research centers as beacons of justice, equity, and diversity, where everyone can work without fear of exclusion or discrimination, regardless of their sexuality or identity. They believe in the importance of diversity of perspectives in science to address contemporary challenges. To improve the LGBTIQA+ reality in research centers and STEM spaces, PRISMA proposes 10 basic measures supported by statistical data and provides an implementation guide, offering ongoing collaboration with research centers for their implementation.

Simón Perera holds a Degree in Biotechnology and an MSc in Biological Anthropology. He is the Business Development Director at ProtoQSAR, a company specializing in computational chemistry, medicine design, structural bioinformatics, and computational toxicology. With a Ph.D. from UPF, his research focused on the Individuality Genomic laboratory at the Institute of Evolutionary Biology. Previously, he worked as a Project Manager and Business Developer at Anaxomics, an Associate Professor at UAB, and held roles as the European Projects and Bioinformatics Coordinator in Barcelona. Currently, Simón is the General Secretary of PRISMA "LGBTI+ Science," co-directs the scientific outreach event "BCNspiracy" and the exposition "Una Mirada LGTBI+" (An LGTBI+ Look). He also serves on the boards of the Spanish Association for Scientific Communication (AEC2) and the Biotechnology Communicators Association (ComunicaBiotec), while being a member of various scientific outreach associations. Find him on Twitter: @simonperera and Instagram: @simonper.

Talks: BEC 3

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Experimental investigation of false vacuum decay in a ferromagnetic superfluid 15:00

Chiara Rogora, *Pitaevskii BEC Center, CNR INO and Dipartimento di Fisica, Università di Trento*

We use a ferromagnetic superfluid mixture of two different hyperfine states of Sodium-23, coherently coupled to investigate the false vacuum decay process. We observed bubble nucleation characterizing the event probability.

Bose-Einstein condensates, Quantum simulation

Einstein-Podolsky-Rosen experiment in split Spin-Squeezed Bose Einstein Condensates. 15:15

Lex Edgar Joosten, *University of Basel*

In 1935 Einstein, Podolsky, and Rosen (EPR) conceived a Gedankenexperiment, which challenged quantum mechanics by showing its incompatibility with the classical principle of local realism. Although the EPR paradox has been shown with individual particles, how far quantum behaviour extends into the macroscopic world has so far remained untested. In our work we demonstrate the EPR paradox between two mesoscopic systems, namely two separated Bose-Einstein condensates each containing about 700 rubidium atoms.

Quantum metrology and sensing, Quantum optics, Bose-Einstein condensates

Preparation for the Integration of the BECCAL Laser System 15:30

Marc Kitzmann, *HU Berlin*

In contrast to lab-based cold atom experiments, BECCAL (Bose-Einstein Condensate and Cold Atom Laboratory) must be operable without interference for three years on the ISS. To reach that goal and match the complexity of this space-based system to the stringent size, weight, and power limitations, we have to fulfill strict product assurance requirements for the laser system including higher cleanliness facilities and ESD protection. In this context, the planning and implementation of the specific lab setup and the first essential integration tests, using mock-ups, will be presented.

Cold atoms, Bose-Einstein condensates

Towards a strontium quantum gas microscope

15:45

Jonatan Höschele, *Institute of Photonic Sciences - ICFO*

We are building a quantum gas microscope for ultracold strontium atoms. In my talk, I will explain the concept of a quantum gas microscope and present the current state of our machine, including the cooling processes to reach the quantum degenerate regime and a characterization of our optical lattice. Furthermore, I will discuss the imaging scheme to achieve single-site detection of the strontium atoms in the optical lattice.

keywords

Invited Speaker: Daniel Barredo

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Exploring quantum spin models with Rydberg atom arrays

Daniel Barredo - Institut d'Optique-CNRS & CINN-CSIC

Rydberg atoms in arrays of optical tweezers offer new perspectives for quantum simulation, computation and metrology. In this talk, I will give an overview about this platform, and describe our efforts to control Rydberg interactions to explore different types of spin Hamiltonians. We will review recent results on the implementation of the 2D Ising Hamiltonian [1] and the dipolar XY model with more than 100 spins to study quantum magnetism [2]. We will illustrate how entanglement in the out-of-equilibrium dynamics of these systems can be harnessed to generate scalable spin squeezing [3]. Finally, I will show our first steps to scale up the atom numbers in our platform by using a cryogenic environment [4].

[1] Scholl et al., Nature **595**, 233 (2021).
[2] Chen et al., Nature **616**, 691 (2023).
[3] Bornet et al., arXiv:2303.08053.
[3] Schymik et al., Phys. Rev. Applied **16**, 034013 (2021).

Daniel Barredo completed his PhD in the Surface Science laboratory at Universidad Autónoma de Madrid in 2009. He then was awarded a Marie Curie Fellowship to work with Rydberg atoms in thermal vapor cells in the group of T. Pfau in Stuttgart. He continued his research in the group of A. Browaeys at Institut d'Optique (Palaiseau), where he contributed to the development of a new platform for quantum simulation based on programmable arrays of individual atoms trapped in optical tweezers and excited to Rydberg states. This Rydberg quantum simulator can now operate with full individual control over 200 qubits and be reliably used to tackle real world open problems in condensed-matter physics. Daniel moved to CINN (CSIC, Spain) in 2021 with a Ramón y Cajal contract to continue his research in quantum information science.

Talks: Quantum Simulation 2

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Setup of an atom array with cavity-mediated interactions 10:30

Johannes Schabbauer, *TU Wien*

We report on constructing a new platform for quantum simulation with neutral atoms trapped in an array of optical tweezers with photon-mediated interactions. Strong coupling of the single atoms to the photon field is achieved with a fiber cavity. With this approach we aim to study many-body physics and entanglement with programmable connectivity.

Tweezers, Cold atoms, Cavities

Towards quantum simulation in an optical kagome lattice with single-site resolved imaging 10:45

Tobias Marozsak, *Cavendish Laboratory, University of Cambridge*

I will present our progress towards quantum simulation in an optical kagome lattice and our recent work investigating the phase diagram of the bosonic triangular lattice at both positive (unfrustrated) and negative absolute temperatures (frustrated).

Cold atoms, Lattices, Quantum simulation

Quantum Gas Magnifier for Ultracold Atoms in an Optical Quasicrystal 11:00

Zhuoxian Ou, *University of Cambridge, Department of Physics*

Many-body localization (MBL) presents an unconventional regime where quantum systems with strong disorder are unable to thermalize. In our experiment, MBL can be characterized by measuring the transport of a ^{39}K quantum gas in an optical quasi lattice with an external trapping potential. On the basis of the current experimental apparatus, we aim to incorporate a quantum gas magnifier (QGM) to achieve single-site resolved imaging.

Lattices, Quantum simulation, Many-body physics

Thursday

Talks: Rydberg Atoms

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New method to probe a quantum phase transition in different spin Hamiltonians 11:45

Eduard Jürgen Braun, *University of Heidelberg*

Closed quantum system governed by unitary dynamics can show a continuous as a function of a nonthermal control parameter, like for example a magnetic field. For many body spin Hamiltonians which show a phase transition from a paramagnet to a different phase, we present a new method that relies only on preparation and measurement of the magnetization in the paramagnetic regime in order to characterize such a phase transition.

Many-body physics, Quantum simulation, Rydberg atoms

Scalable Qubit Arrays for Quantum Computation And Simulation 12:00

Elliot Diamond-Hitchcock, *University of Strathclyde*

We present progress towards developing a large scale quantum processor through the SQuAre (Scalable Qubit ARray) project. We demonstrate highfidelity single-qubit gate operations which achieves the threshold for fault-tolerant scaling. Further results pave the way to two qubit and multi-qubit gate operations using two-photon adiabatic rapid passage.

Quantum information processing, Rydberg atoms, Quantum computing

Trapping atoms in a cryogenic environment : enhancing scalability in quantum systems 12:15

Grégoire Pichard, *PASQAL/LCF (Paris Saclay University)*

Optical tweezer arrays show promise for quantum simulation, but scalability remains a challenge. Our innovative 4K cryogenic approach greatly extends the vacuum-limited lifetime, enabling the construction of arrays of more than 300 atoms. This breakthrough paves the way for more advanced Rydberg quantum simulators capable of handling thousands of particles.

Cold atoms, Tweezers, Rydberg atoms

Engineering gauge theories with a Rydberg atom processor 12:30

Julia Bergmann, *ICFO / UAB*

I explain how to engineer tunable anisotropic attractive as well as repulsive interactions with so-called superatoms by organizing two or more individual atoms in small clusters sharing one Rydberg excitation. I will use the Rokhsar-Kivelson Hamiltonian as an example to show how these Rydberg arrays can be used to investigate Ising models with $S = 1/2$ and higher in one, two and three dimensions.

Cold atoms, Rydberg atoms, Quantum simulation

Characterizing Operator Growth in Disordered Quantum Spin Chains via Out-of-Time-Ordered Correlators 12:45

Maximilian Müllenbach, *CESQ, Université de Strasbourg*

We study operator growth in disordered Heisenberg spin chains via out-of-time-ordered correlators (OTOCs). While for ordered spin chains operator growth is practically identical for both nearest-neighbour and power-law ($\alpha \geq 3$) interactions, we find that this is not the case for strong disorder. Additionally, we propose a scheme to measure OTOCs with Rydberg-excited atoms using Floquet Hamiltonian Engineering.

Many-body physics, Quantum thermodynamics, Rydberg atoms

Microwave-to-optical conversion based on room-temperature Rydberg atomic ensemble 13:00

Sebastian Borówka, *University of Warsaw*

Coherent microwave-to-optical conversion enables new methods of detection for microwave astronomy, coherent imaging and next-generation sensors. We present a simple yet robust device based on Rydberg atomic vapours, converting microwaves to near infrared light. The converter enable us to observe free-space microwave thermal radiation at room temperature, confirmed by its photon statistics.

Rydberg atoms, Hot vapors, Atom-light interaction

Invited Speaker: Darrick Chang

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The maximum refractive index of optical materials: from quantum optics to quantum chemistry

Darrick Chang - ICFO - The institute of photonic sciences

It is interesting to observe that all known optical materials have a refractive index that is of order unity at visible/telecom wavelengths. Furthermore, it is not easy to reconcile this with the fact that the individual atoms making up the material are well-known to have a huge optical response near resonance, when isolated, as characterized by a scattering cross section that is much larger than the physical size of the atom. Here, we discuss the role that non-perturbative collective effects and multiple scattering of light have on determining the index of a collection of atoms, starting from the "quantum optics" regime of well-isolated atoms, to the "quantum chemistry" regime relevant for real-life solids. We elucidate various mechanisms by which the index can be limited, either by pure electrodynamic effects or by many-body effects associated with quantum chemistry. We develop a minimal model suggesting that an ultrahigh index material (n 30) with low losses is in principle allowed by the laws of nature. If realizable, such a material would have profound implications for optical technologies, due to the extreme reduction of optical wavelength.

Darrick Chang obtained his bachelor's degree in physics from Stanford University in 2001, and his PhD in physics from Harvard University in 2008. Subsequently, he held a prize postdoctoral fellowship at the California Institute of Technology. In 2011, Darrick joined ICFO as the leader of the Theoretical Quantum Nanophotonics group. He was awarded an ERC Starting Grant in 2015, and an ERC Consolidator Grant in 2021.

The research of Prof. Chang and his group is based upon a vision that quantum effects are at the forefront of future technologies and discoveries, and that nanophotonic systems will be a prominent platform for this frontier. Specifically, they aim to harness the unique configurability, large optical forces, and strong light-matter interaction strengths achievable in nanophotonic systems to produce new applications and phenomena involving matter and light, which have no analogue in macroscopic setups. His work is highly inter-disciplinary, and the group explores the potential impact across atomic physics, quantum optics, nonlinear optics, nano-mechanics, low-dimensional materials, and quantum information science.

Talks: Atom-Light interaction

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Observation of superradiant bursts in waveguide QED 10:30

Constanze Bach, *Humboldt University of Berlin*

We experimentally observe superradiant burst dynamics with a one-dimensional ensemble of atoms that is coupled to a nanofibre waveguide and extends over thousands of optical wavelengths.

Cold atoms, Waveguides

Analysing nonlinearity of atomic arrays using a Green's function approach to time evolution 10:45

Simon Panyella Pedersen, *Department of Physics and Astronomy, Aarhus University, Denmark*

We find that two atomic lattices, which are themselves largely optically linear, can result in an emergent highly nonlinear cavity. As a complement to a previous numerical analysis, we use a Green's function approach to calculate the dynamics of atomic arrays. This allows for writing down analytical expressions for correlation functions.

Many-body physics, Quantum optics, Lattices

Effect of an optical dipole trap on resonant atom-light interactions 11:00

Teresa Karanikolaou, *ICFO*

The optical properties of fixed atoms and tightly trapped ions are well-known and investigated. However, in emerging quantum optics setups involving neutral atoms in dipole traps, the trapping of the ground and excited state may differ, leading to reduced elastic scattering cross sections and increased motional heating rates. We theoretically investigate the effect of a free or anti-trapped excited state on the scattering rate and heating.

Quantum optics, Atom-light interaction, Tweezers

Talks: Quantum Information

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Using single atoms in optical cavities as efficient source for multiphoton graph states generation 11:45

Leonardo Ruscio, *Max Plank Institut of Quantum Optics*

The generation of multiphoton entangled states is an essential ingredient for measurement based quantum computation. We experimentally demonstrate the feasibility of single atoms in optical cavities as an efficient source of multiphoton graph states.

Quantum information processing, Cavities, Atom-light interaction

A quantum frequency converter for the connection of rubidium atoms in a cavity over long distances 12:00

Maya Büki, *Max-Planck-Institute for Quantumoptics*

Rubidium atoms can be efficiently entangled with optical photons, making them a promising platform for long-distance quantum networks. However, the wavelength of these entangled photons is not suitable for long-distance communication due to intrinsic fiber losses, necessitating wavelength conversion to the telecom regime. A polarisation conserving quantum frequency converter (QFC) has been demonstrated in a Sagnac configuration, which can also be used to connect diverse platforms operating at different wavelengths.

Quantum networks and quantum memories, Quantum information processing, Quantum communication

Entanglement Distribution - Towards a Suburban Quantum Network Link 12:15

Pooja Malik, *Ludwig-Maximilians-University, Munich, Germany and Munich Center for Quantum Science and Technology (MCQST), Munich, Germany*

A crucial task for a quantum network is to distribute entanglement between quantum nodes over large distances. Here we present neutral atom-based quantum node with 7 ms coherence time which enables the distribution of entanglement over 101 km fiber by employing telecom wavelength photons. I also present preliminary fidelity and entanglement generation rates of a future project where we generate heralded entanglement between a single-atom at the MPQ in Garching and a single-atom at LMU in downtown Munich - approximately 14 km line-of-sight apart.

Quantum networks and quantum memories, Quantum communication

Cavity-mediated interactions between pair of atoms and generation of entangled states of bosons in an optical cavity 12:30

SANKALP SHARMA, *Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, ul. Grudziadzka 5, 87-100 Toruń, Poland*

In our study we explore cavity-mediated interactions between pairs of atoms in an optical cavity. We find that the effective induced interactions between atoms are sensitive to the state of photons and therefore, it can be exploited for generating the nonclassical states of light and in a controlled preparation of entangled states of atoms. Our results offer new insights into the formation of correlated states of matter with potential applications in quantum technologies.

Bose-Einstein condensates, Out-of-equilibrium trapped gases, Atom-light interaction

Friday

Optical spectrum to position converter for spectro-temporal processing based on quantum memory 12:45

Stanisław Kurzyna, *Centre for Quantum Optical Technologies, Centre of New Technologies, University of Warsaw, Banacha 2c, 02-097 Warsaw, Poland*

We implemented spectrum-to-position converter protocol in gradient echo quantum memory based ultracold rubidium-87 atomic ensamble. To perform measuremnts we utilized custom sCMOS camera with image intensifier sensitive to single photons, making this protocol suitable for single-photon-level pulses. We have achieved a spectral resolution of 150 kHz that is unachievable for diffraction grating spectrometers.

Quantum information processing, Cold atoms, Quantum optics

Posters

Posters: Session Monday (1)

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Automated characterisation of alkali vapour-cells for magnetometry

Leigh Page, *University of Sussex*

With the rise of optically pumped magnetometers (OPMs) in high sensitivity magnetometry, a method to analyse the quality of its main component, the vapour-cells, in bulk was required. To this end, I developed a system consisting a heated mirror for the vapour-cells to be placed upon, within an open source multipurpose 3-axis robot, mounted with a transmission spectroscopy setup, enabling the scanning of multiple cells in sequence via computer commands. The pressure determined from the spectroscopy absorption linewidths provide insight into the internal conditions of the cells.

Atom-light interaction

Neutral Atoms in Tweezer Arrays for Rydberg Hybrid Quantum Computing

Marijn Venderbosch, *Eindhoven University of Technology*

We are constructing a new experiment that will feature strontium-88 atoms trapped in optical tweezer arrays. Entanglement between the qubits will be generated by coupling one of the qubit states to a Rydberg state. On the poster, we show the design of the apparatus as well as experimental results on 'blue' and 'red' magneto-optical traps.

Tweezers, Rydberg atoms, Quantum computing

Building a commercial quantum computer

Neta Ilan, *Quantum Art*

Quantum Art is a full-stack quantum computing systems company, based on trapped ion qubits. In my poster I will showcase the fundamental building blocks of a trapped ions quantum computing system, as well as some of the challenges in realizing such systems.

Quantum computing, Ions, Quantum optics

A new ytterbium experiment for single-atom resolved many-body physics

Alessandro Muzi Falconi, *Physics department, University of Trieste*

I will report on the ongoing development of a new ultracold atom experimental apparatus, where we will employ optical tweezers to control and detect individual ytterbium atoms. Exploiting this high degree of control and the peculiar features of ytterbium atoms we will investigate many-body phenomena, ranging from collective atom-light interactions to orbital quantum impurities, with single-atom resolution.

Many-body physics, Quantum simulation, Tweezers

Atomic Mach-Zehnder Interferometer with Trapped Bose-Einstein Condensates

Andrea Santoni, *University of Florence*

I report on the realization of an array of Mach-Zehnder interferometers using Bose-Einstein condensates with tunable interactions trapped in double-well potentials. The cancellation of common mode noise allows the first realization of a trapped atom gradiometer

Atom and matter-wave optics and interferometers, Quantum metrology and sensing, Bose-Einstein condensates

Investigation of the generalized Euler characteristic of microwave networks split at edges

Omer Farooq, *Institute of Physics, Polish Academy of Science*

We investigate the condition when the original graph is split at edges into two disconnected subgraphs. We show that there is a relationship between the generalized Euler characteristic $\epsilon_o(|\text{VDo}|)$ of the original graph and the generalized Euler characteristics $\epsilon_i(|\text{VDi}|)$, i = 1,2, of two disconnected subgraphs, where |VDo| and |VDi| , i = 1,2, are the numbers of vertices with the Dirichlet boundary conditions in the graphs.

Quantum networks and quantum memories, Quantum thermodynamics, Waveguides

Quantum Computing Demonstrator based on neutral Strontium-88

Kevin Mours, *Max-Planck-Institute of Quantum Optics*

Quantum computers based on neutral atoms in optical tweezer face two main challenges. Up to now, the prepared array sizes and the two-qubit-gate-fidelity limited the ability to outperform classical computers. We present our approach to overcome these limits by an array size of up to 400 qubits and gate fidelities exceeding 99%.

Quantum computing, Rydberg atoms, Tweezers

Trapped ions in optical tweezers

Nella Diepeveen, *University of Amsterdam*

We plan to implement a novel platform for quantum simulation using 2-dimensional 171Yb+ ion crystals in a Paul trap with optical tweezers. I will describe the experimental setup and the creation and optimisation of the tweezer pattern with a spatial light modulator.

Ions, Quantum simulation, Tweezers

Design of an optically pumped magnetometer based on hot atomic vapor targeted at medical diagnostics

Philipp Neufeld, *Robert Bosch GmbH, Corporate Sector Advance Engineering, Germany*

We demonstrate and compare several techniques for the development of an optically pumped magnetometer (OPM) based on hot atomic vapor enclosed in MEMS vapor cells which should ultimately be applicable for the aforementioned medical diagnostics purposes.

Hot vapors, Quantum optics, Quantum metrology and sensing

Laser cooling alkali earth-like atoms and molecules in the deep ultraviolet

Lajos Palanki, *Imperial College London*

This project aims to create a high density MOT, and subsequently BEC of AlF molecules. Here we present experimental and computational results related to the trapping and slowing of AlF, as well as Cd.

Bose-Einstein condensates, Molecules, Atom-light interaction

Table-top Ultra-stable Optical Cavity as a kHz Gravitational Wave Bar Detector

Mateusz Narożnik, *Nicolaus Copernicus University in Toruń*

We propose to use a cryogenic table-top ultra-stable cavity made from present-day components as a resonant-bar detector with sensitivity superior to the other resonant-mass detectors in the kHz frequency regime. I will present calculated and simulated gravitational waves signals and strain sensitivities for different combinations of the cryogenic single-crystal silicon cavities and observationally promising sources such as neutron stars merger, subsolar-mass binary black holes merger, and ultralight bosons (as axions and axion-like particles) formed through a black hole superradiance.

Fundamental constants, Cavities, Exotic phases of matter

Two-colour ultra-stable optical cavity

Adam Linek, *Institute of Physics, Faculty of Physics, Astronomy and Informatics Nicolaus Copernicus University in Toruń, Poland*

We develop an ultra-stable optical cavity that operates at two wavelengths, namely 1064 nm and 908 nm. The purpose of the dual-wavelength ultra-stable optical cavity is to facilitate accurate spectroscopic measurements of the narrow clock lines of Hg atoms.

Atomic clocks, Cavities, Cold atoms

Differential Displacements in Multi-spatial Mode Squeezed Light

Joseph Kelly, *University of Birmingham*

A differential displacement between small squeezed regions of a two mode multispatial squeezed light source is investigated. It is hoped that the findings from this will pave the way to the creation of quantum enhanced images.

Quantum optics

Quantum Degenerate Mixtures of Cs and Yb: Beyond Mean Field Physics

Joe Bloomer, *Durham university*

We present our experiments on quantum degenerate mixtures of Caesium and Ytterbium. We explore the mixture's dynamics and stability. In addition, we identify two tune-out wavelengths of Cs, which will allow us to explore beyond mean field effects such as quantum droplets in mixed dimensions.

Bose-Einstein condensates, Cold atoms, Quantum fluids

Stationary, dynamic and thermal properties of quantum droplets

Maciej Bartłomiej Kruk, *Institute of Physics of the Polish Academy of Sciences*

We showcase our results with regards to Bose-Bose quantum droplets: stability at zero and finite temperatures in flattened and elongated 3D regimes.

Bose-Einstein condensates, Cold atoms, Quantum gases in low dimensions

Rymax-One: A neutral atom quantum processor to solve optimization problems

Silvia Ferrante, *University of Hamburg*

Here, we present our project Rymax-One - which aims at building a neutral atom quantum processor, where we trap single 171Yb atoms in arrays of optical tweezers. This enables us to have hardware efficient encoding of optimization tasks, Rydberg-mediated interactions and high-fidelity gate operations.

Rydberg atoms, Quantum computing, Tweezers

Electromagnetically-induced transparency cooling for ion-based qutrits

Katya Fouka, *University of Amsterdam*

In this work , we theoretically investigate an electromagnetically-induced transparency cooling scheme for the $^{176}\mathrm{Lu}^{+}$ ion where hyperfine states in the $^3D_1$ level form a qutrit.

Ions, Quantum computing, Quantum simulation

Quantum protactor

Arash Dezhang Fard, *Jagiellonian University*

we present our experimental studies on the reconstruction of a quantum protractor state of a spin-1 system, which is an optimal metrological resource for detecting rotations, known as protractor state. Thus, We demonstrate a preparation and full control of an important quantum metrological resource state.

Quantum metrology and sensing, Hot vapors, Quantum optics

Optical tweezer arrays of alkaline earth-like ytterbium atoms

Jonas Rauchfuss, *University of Hamburg*

We present our progress towards a fully programmable, intermediate-scale ytterbium quantum computer. Here, we will focus on the generation of an arbitrary, homogeneous optical tweezer array using a spatial light modulator as well as the generation of movable dipole traps using an acousto-optic deflector.

Rydberg atoms, Quantum computing, Tweezers

A single cold atom as a single-photon detector

Laura Zarraoa, *Institute of Photonic Sciences - ICFO*

Here we study theoretically and experimentally the use of laser-cooled single- or few-atom systems in optical microtraps as narrowband, ultralow-dark-count photodetectors with absolute frequency stability. As we describe, this approach promises orders-of-magnitude improvement in dark counts and out-of-band rejection relative to state-of-the-art single photon detectors, while preserving useful detection efficiency.

Atom-light interaction, Cold atoms

Posters: Session Tuesday (2)

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3D Anderson transition with ultracold atoms

Xudong YU, *IOGS, université Paris-Saclay*

To investigate the Anderson transition that occurs in three-dimensional systems between localized and diffusive states, we apply a state-dependent spectroscopic scheme using ultracold atoms and achieve some preliminary while promising results.

Cold atoms, Atom-light interaction, Bose-Einstein condensates

Coherent transmission of light through a dense cloud of cold atoms

Marcia Frometa Fernandez, *Institute of Physics of São Carlos - University of São Paulo*

In this work is proposed an experimental set up to obtain a dense cloud of Strontium (88) and then study collective effects using that ensemble of atoms. The first experiments consist in measuring the coherent transmission of a low intensity beam by the cloud. The results will be compared with simulations based on the Coupled-Dipole Model.

Cold atoms, Many-body physics, Atom-light interaction

A Permanent Manget Based Zeeman Slower Cold Atom Source for Dysprosium

Niclas Höllrigl, *Universität Innsbruck*

We present a new simple yet versatile approach for a permanent magnet Zeeman slower to be used in ultracold dysprosium quantum gas experiments.

Bose-Einstein condensates, Cold atoms, Atom-light interaction

Atom interferometry with ultra-cold atoms onboard a Zero G plane for space applications

Clément Métayer, *LP2N*

The ICE experiment uses atomic clouds of potassium and rubidium in a matter-wave interferometer to test the Weak Equivalence Principle. A microgravity simulator allows the experiment to be in microgravity for 500ms in order to get a long interrogation time. We also report the production of ultra cold atoms of Rubidium (Bose-Einstein condensate) in an all optical dipole trap.

Atom and matter-wave optics and interferometers, Cold atoms, Bose-Einstein condensates

Poster (2)

One-dimensional Bose gas with an atom chip

Manon Ballu, *Université Sorbonne Paris Nord*

One-dimensional interacting Bose gases offer a richness of physical regimes with striking specificities compared to three dimensions. For instance, in the strongly interacting regime, appearing at low temperature and large interactions, the hamiltonian of the system can be mapped into the one of non-interacting spinless fermions. In order to be able to reach this regime, a control over the atomic interactions is required : to this end we plan to rely on a microwave-induced Feshbach resonance.

Bose-Einstein condensates, Quantum gases in low dimensions, Cold atoms

Developing a Bose-Einstein condensate microscope

Poppy Joshi, *University of Sussex*

BECs are highly sensitive to magnetic fields in their environment. This property makes them an ideal probe for a microscope that maps the magnetic field distribution or current density in 2D samples such as novel nanomaterials. The sensitivity and spatial resolution of BEC-M is not accessible with any magnetometer.

Atom-light interaction, Bose-Einstein condensates, Cold atoms

Cold atom preparation for squeezed state atom interferometry

Edward Gheorghita, *Institute of Science and Technology Austria*

I would like to present the work that I have completed during the first semester of my PhD. This includes the TOF temperature measurement of both a far-detuned MOT (28 micro-Kelvin) and molasses cooled MOT (5.5 micro-Kelvin). If possible I can also include some MW-spectroscopy results as well.

Cold atoms, Atom-light interaction, Quantum metrology and sensing

Sensing interactions in atomic quantum systems

Claudia Galantini, *Tu/e*

Hybrid ion-atom systems are a unique testbed for quantum simulation of many-body physics and quantum chemistry. To fully benefit from the combination, it is essential to understand, characterize, and control the interactions between the atoms and ions.This poster reports on the development in the design of a new experiment at TU/e involving Yb+ and Dy.

Cold atoms, Ions

Rayleigh-Taylor instability in a phase-separated three-component Bose-Einstein condensate

Arpana Saboo, *Indian Institute of Technology Kharagpur*

In this work, we have investigated the Rayleigh-Taylor instability at the two interfaces in a phase-separated three-component Bose-Einstein condensate. We suggest different ways to instigate the instability in the system, i.e., by varying the scattering lengths of either the innermost component or the outermost component of the radially separated system, during the dynamical evolution of the system. We observe non-linear mushroom-shaped patterns at the interfaces which grows exponentially.

Bose-Einstein condensates, Quantum gases in low dimensions, Quantum fluids

Optical Tweezer-Driven Gates on Trapped Ions

zeger ackerman, *University of Amsterdam*

We plan to combine trapped 171Yb+ ions with tightly focussed optical tweezers to test a novel two-qubit gate. The gate is based on the optical Magnus effect, which describes a spin-dependent, off-axis displacement of an ion by optical tweezers. The proposed tweezer setup enables high control of the beam shape while allowing fast switching between any ion pairs to implement the gates on.

Tweezers, Ions, Quantum computing

Extending Spin-Noise Spectroscopy with single photons to the Poincaré sphere

Adrià Medeiros Garay, *C2N*

We explore how photons are reflected by our device as a function of the spin of a single electron in a QD embedded in a micropillar cavity. We aim at performing a projective measurement of the spin state and to monitor its dynamics in the Poincaré sphere.

Quantum optics, Quantum networks and quantum memories, Cavities

A study of spin diffusive modes in high pressure vapour cells.

Joseph Nicholson, *University of Birmingham*

We study the diffusive nature of alkali metal and noble gas mixtures via the technique of co-magnetometry. This diffusive regime creates stable spatial modes within the vapour cell which could be a powerful tool in quantum information, imaging and enhancing the performance of sensing devices.

Quantum metrology and sensing, Many-body physics, Hot vapors

Construction of a versatile Rydberg atom platform

Sven Schmidt, *Department of Physics and research center OPTIMAS, RPTU Kaiserslautern-Landau*

We construct a new experiment for quantum simulation with an arbitrarily arranged two-dimensional array of optical tweezers containing one of a few atoms. Despite the large distance of a few microns between the lattice sites, the excitation of atoms to Rydberg states leads to long-range van der Waals type interactions, which allows different sites to interact with each other. Due to the precise control in the single- and few-particle regime, the systems will allow us to study topological phenomena as well as many-body effects arising from the interaction of the atoms within, and between sites.

Rydberg atoms, Quantum simulation, Tweezers

Quantum simulation with Rydberg states of erbium atoms

Johanna Hennebichler, *University of Innsbruck*

I want to present our on-going efforts in implementing a quantum simulator using Rydberg states of erbium in an optical tweezer array. Recently, we started loading erbium atoms into a one-dimensional optical tweezer array and we are now aiming towards expanding this array to a two-dimensional one of arbitrary geometry using a spatial light modulator.

Cold atoms, Tweezers, Rydberg atoms

Atomic Frequency Comb Memory in Warm Rubidium Vapour

Zakary Schofield, *University of Southampton*

Warm Rubidium quantum memory based on the Atomic Frequency Comb protocol.

Hot vapors, Quantum networks and quantum memories

Towards a variable-geometry multiplexed strontium optical atomic clock

Ivana Puljić, *Institute of Physics*

We are developing a new experiment with strontium atoms in optical lattices in which we plan to combine the unique flexibility offered by techniques used in optical tweezers with the high accuracy of 1D optical lattice clocks. Here, we report on the current state of our experiment and offer an outlook for our clock.

Quantum metrology and sensing, Cold atoms, Atomic clocks

Towards Doppler Compensated Cavity Based Atom Interferometry

Matthew Forward, *University of Birmingham*

A scheme for improving sensitivity of atom interferometers using an optical cavity to help alleviate the issues with with large momentum transfer is presented. Active Doppler compensation using an intra-cavity Pockels cell allows for longer free evolution times without losing the benefits of using the cavity. This significantly reduces the size, weight, and laser power requirements of the system.

Atom and matter-wave optics and interferometers, Cavities, Quantum metrology and sensing

Towards a strontium Rydberg quantum simulator

Ana Pérez, *ICFO*

I would like to present the first steps on the design of a new quantum simulator of Strontium Rydberg atoms. This includes the vacuum system, the electromagnetic field control and the laser system for cooling and trapping.

Cold atoms, Quantum simulation, Rydberg atoms

Ultracold & Ultrafast: Towards probing ultrafast electron and ion dynamics of ionized ultracold quantum gases

Amir Khan, *University of Hamburg*

Ultrashort laser pulses provide new pathways for manipulating quantum gases on femtosecond timescales. We present a novel coincidence unit consisting of an ion microscope and a velocity map-imaging spectrometer capable of probing the electron and ion dynamics of ionized quantum gases with a high spatial and temporal resolution.

Quantum gases, Ultrashort laser pulses, Cold atoms and ions

Optimizing Faraday Rotation Measurements on BECs: Enhancing Precision through Frequency Control and Noise Reduction

Diana Méndez Avalos, *Institute of Photonic Sciences - ICFO*

By combining Faraday rotation measurements, optical cavities, and advanced control techniques, we aim to advance our understanding of magnetic phenomena, enable precise measurements, and explore the potential applications of BEC in diverse fields of research.

Bose-Einstein condensates, Cold atoms, Atom-light interaction

Variational Quantum states for Eigenstate Thermalization Hypothesis violation in NISQ-era

David Pascual Solis, *Institute of Photonic Sciences - ICFO*

This project investigates Quantum Many-Body Scars (QMBS) in a PXP Model, capturing the Rydberg blockade phenomenon in a Rydberg chain. QMBS has been shown to exhibit weak ergodicity breaking, indicating a weak violation of the Eigenstate Thermalization Hypothesis (ETH). The project utilizes hybrid quantum-classical machine learning techniques, specifically applying automatic differentiation methods and gradients of objective functions. This allows for the discovery of the parametrized quantum circuit expression of these states.

keywords

Posters: Session Wednesday (3)

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Quantum Rayleigh-Taylor instability in two dimensional Bose gases

Pedro Henrique Cook Cunha, *Institute of Physics Of São Carlos*

A usual tridimensional gas can be taken into a quasi-bidimensional regime by strongly trapping it in one of its directions of space in such a way that its dynamics becomes practically reduced to the plane. Several aspects of these 2D systems are of great interest, especially those related to the transition to the superfluid state which occurs via the Berenzinskii-Kosterlitz-Thouless transition. We aim to develop a new experimental system for the purpose of studying degenerate 2D gases, focusing on the hydrodynamic analysis of the quantum Rayleigh-Taylor instability.

Bose-Einstein condensates, Quantum fluids, Quantum gases in low dimensions

Dark Energy search using atom interferometry in microgravity

Sukhjovan Singh Gill, *Leibniz Universität Hannover*

The project DESIRE studies the chameleon field model for dark energy using Bose-Einstein Condensate of Rb atoms as a source in a microgravity environment. Einstein-Elevator provides 4 seconds of microgravity time for multi-loop atom interferometry to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity. This work will further constrain thin-shell models for dark energy by several orders of magnitude.

Atom and matter-wave optics and interferometers, Bose-Einstein condensates, Quantum optics

Waveguide QED with Rydberg superatoms

Daniil Svirskiy, *University of Bonn*

On this poster we demonstrate how a single Rydberg superatom strongly couples to an incident low-photon light field and how the chain of such superatoms can behave like a few-photon absorber in the fast dephasing regime. We want to implement a magic-wavelength optical lattice that will enable us to reduce the motional dephasing of the collective excitation.

Quantum optics, Rydberg atoms, Cold atoms

Strapdown multi-axis inertial quantum sensor

Cyrille Des Cognets, *Laboratoire Photonique Numérique and Nanosciences (LP2N)*

In the joint laboratory IXAtom, we build a compact and transportable 3-axis Raman interferometry sensor. Our goal is to validate a "strapdown" strategy by tackling the issues of vibrations and rotations using hybridization. I work on the hybridization of the inertial sensor with gyroscopes to compensate rotation effects.

Atom and matter-wave optics and interferometers, Quantum metrology and sensing, Atom-light interaction

Quantum Thermodynamics in Ultracold Mixtures - Towards Single Atom Quantum Heat Engines

Thomas Hewitt, *University of Birmingham*

Our experiment explores quantum thermodynamics and it aims to realize a single atom quantum heat engine. We take advantage of low-field interspecies Feshbach resonances to control the interactions between an ultracold atomic bath of 87Rb and a trapped single 41K atom in a species-selective optical tweezer. Engine cycles become realizable by implementing quantum thermodynamic transformations using these interactions.

Tweezers, Bose-Einstein condensates, Quantum thermodynamics

A dipolar quantum gas microscope

Fiona Hellstern, *University Stuttgart*

We present the progress towards constructing a dipolar quantum gas microscope using dysprosium atoms. This opens up the possibility to explore strongly correlated systems, long-range dipolar interactions as well as the extended Hubbard model.

Cold atoms, Dipolar quantum gases

Towards a Sr Optical Lattice Clock

Antonio Estarellas, *ROA*

As the Designated Institute for Time and Frequency Metrology in Spain, ROA has recently started building up an optical lattice clock based on 87Sr atoms. The first steps of the construction have already been implemented and the next steps are being carried out.

Atomic clocks, Cold atoms, Lattices

Theoretical and experimental developments for a continuous superradiant laser

Jana El badawi, *Institut Femto-st/ Institut Utinam*

Frequency standards based on atomic transitions in the optical domain can reach remarkable fractional frequency stabilities of 10 - 17 at one second of integration. We present developments towards the realization of an ultra-stable laser based on the phenomenon of superradiance. Such a laser consists of cold atoms confined within a mode of a high-finesse optical cavity.

Atom-light interaction, Atomic clocks, Cold atoms

Spin- and momentum-correlated atom pairs mediated by photon exchange

Jacob Fricke, *ETH Zurich, Quantum Optics Group*

We observe the rapid production of atom pairs simultaneously correlated in well-defined internal and external modes. The pairs are generated in a Bose-Einstein condensate via exchange of virtual photons in a high-finesse optical cavity. Coherent pair creation within tens of microseconds offers promising prospects for quantum-enhanced magnetometry and gravitometry with massive particles.

Spinor gases, Cavities, Atom and matter-wave optics and interferometers

Characterization of a new dual-species atomic source for lithium and potassium

Adrian König, *IQOQI Innsbruck*

We present the characterization of a new home-built dual-species atomic source for our ultracold atom experiment working with lithium and potassium. We measure the total flux as well as the spatial intensity distribution of the emitted atomic beam and observe good agreement with theoretical predictions.

Cold atoms, Many-body physics, Atom-light interaction

Rydberg spectroscopy in the strong driving limit for atoms and molecules

Florian Binoth, *RPTU Kaiserslautern-Landau*

We create new long-range bound states in the 5S-6P molecular potential of Rb87 via strong coupling to a Rydberg molecule potential. Additionally, we investigate the Autler-Townes splitting in a multilevel system. We investigate these spectra by resonantly coupling the 6P3/2, F=3 state of Rb87 to a Rydberg state.

Molecules, Atom-light interaction, Rydberg atoms

Construction of a versatile Rydberg atom platform

Aaron Thielmann, *Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau*

We plan to realize arbitrarily arranged two-dimensional arrays with up to 100 lattice sites, each of them containing one or a few atoms. Due to the long-range character of the introduced Rydberg interactions, an interaction of the atoms in and between lattice sites is given. This setup is a prime candidate to investigate both topological systems of single atoms as well as effects arising from many-body properties in a controlled manner.

Rydberg atoms, Quantum simulation, Tweezers

Trade off-free microfabricated cells for atomic devices

Linda Péroux, *Centrale Lille / IEMN*

We present a method to produce alkali vapor cells for atomic devices such as atomic clocks or atomic magnetometers. We replicate the glass-blowing technique used in the fabrication of macro-cells on wafer-integrated microstructures. The cells are filled with the desired chemical species and sealed with a CO2 laser in a vacuum chamber.

Atomic clocks, Hot vapors, Quantum metrology and sensing

Delta-Kick Collimation of quantum mixtures for dual species atom interferometry in space

Lakshmi Priyanka Guggilam, *PhD student*

Dual species atom interferometry under microgravity is a promising tool to precisely test the Einstein's Equivalence Principle (EEP). MAIUS-2 (Matter wave interferometry under microgravity) focuses on understanding the dynamics of K-41 and Rb-87 quantum mixtures in microgravity and preparing the system to perform a test of EEP during MAIUS-3.Here, we concentrate on studying and optimizing the time steps, number of kicks of DKC required to collimate both species simultaneously based on harmonicity and isotropic natures of the trap.

Cold atoms, Quantum optics, Bose-Einstein condensates

A ytterbium source for quantum-clock interferometry

Mario Montero, *Institut für Quantenoptik, Leibniz Universität Hannover*

Quantum-clock interferometry is a novel proposal to test gravitational time dilation effects in quantum systems. We present the characterisation of a laser-cooled ytterbium source to be implemented at the VLBAI facility to perform QCI experiments.

Cold atoms, Atom and matter-wave optics and interferometers, Atomic clocks

Local periodic driving in optical lattices

Georgia Nixon, *University of Cambridge*

Local periodic driving of optical lattices allows for local control of parameters in a tight-binding model. We employ Floquet theory to capture the behaviour of locally driven lattices under a variety of conditions. This technique allows for the simulation of a wide range of quantum phenomena.

Lattices, Cold atoms, Quantum simulation

Momentum-space correlations of lattice Bose gases close to the Mott transition

Maxime Allemand, *Laboratoire Charles Fabry - Institut d'Optique*

We study interacting Helium-4 Bose gases in an optical lattice, realising the 3D Bose-Hubbard hamiltonian. Our unique experimental probe which consists in detecting metastable Helium-4 atoms one by one after a long time-of-flight enables us to measure atom correlations in momentum space. We report our on-going efforts to characterise many-body correlations across the superfluid to Mott insulator transition.

Many-body physics, Bose-Einstein condensates, Lattices

Cryogenic Strontium Quantum Processor

Roberto Franco, *University of Tübingen*

Neutral Rydberg atoms in optical tweezers are a promising platform for quantum computing. In our project we aim at the unification of the optical tweezer technology with cryogenic technology at 4K, using fermionic strontium. This will result in record-long coherence and lifetimes of the atoms in the optical tweezer array and it will form the basis for scalability to large atom numbers.

Quantum simulation, Tweezers, Rydberg atoms

Anderson Localization of Light by Cold Atoms

Apoorva Singh, *Institut de Physique de Nice, Université Cote d'Azur*

I will present our new experimental setup aiming to study Anderson localization of light using large clouds of 174Y b cold atoms in three dimensions.

Atom-light interaction, Atom and matter-wave optics and interferometers, Cold atoms

Generation and control of quantum coherence in single atom mechanics

Kratveer Singh, *Palacký University Olomouc*

Through examination of the associated observable coherence on a single trapped 40Ca+ ion-motional oscillator, we experimentally show climbing up a hierarchy of criteria that exclude the convex closure of Gaussian states of the linear oscillations. According to the interaction with thermal amplitude and phase reservoirs, we assess their resistance to the most prevalent decoherence processes in mechanical systems.

Quantum optics, Ions, Atom-light interaction

Coupling of non-classical light to Rydberg ensemble based non-linearities

Felix Hoffet, *Institute of Photonic Sciences - ICFO*

Rydberg blockaded atomic ensembles display highly non-linear interactions to light. We report on a experiment in which we stored non-classical light - generated in a first atomic ensemble using DLCZ - in a second Rydberg-blockaded atomic ensemble using electromagnetically induced transparency. We demonstrate strong non-linearities and multi photon filtering of the non-classical field.

Quantum memory, atomic ensembles, EIT, Rydberg blockade, single photons

About YAO

The Young Atom Opticians conference (YAO) is an annual meeting aimed at young PhD and master students in the field of atomic and molecular physics. Its goal is to provide participants with a platform to learn from and extend their network with peers from around the world.

YAO 2023 conference is arranged by PhD students from ICFO and will take place in Barcelona from June 12th to 16th 2023.

Since 1995 it has been hosted by different institutions all over Europe.

1995:	Innsbruck, Austria	2010:	Amsterdam, Netherlands
1996:	Oxford, UK	2011:	Hannover, Germany
1997:	Parco dell'Orecchiella, Italy	2012:	Krakow, Poland
1998:	Gif-Sur-Yvette, France	2013:	Birmingham, UK
1999:	Potsdam, Germany	2014:	Barcelona, Spain
2000:	Brighton, UK	2015:	Zurich, Switzerland
2001:	Stuttgart, Germany	2016:	Munich, Germany
2002:	Volterra, Italy	2017:	Paris, France
2003:	Amsterdam, Netherlands	2018:	Glasgow, Scottland
2004:	Insbruck, Austria	2019:	Hamburg, Germany
2005:	Hannover, Germany	2020:	Cancelled due to COVID-19
2006:	Palaiseau, France	2021:	Aarhus, Denmark (online)
2007:	Durham, UK	2022:	Stuttgart, Germany
2008:	Florence, Italy	2023:	**Barcelona, Spain**
2009:	Vienna, Austria	2024:	Strassbourg, France

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Strongly intacting Fermi-Fermi Mixture of ^{161}Dy and ^{40}K: Study of DyK Feshbach molecules

Alberto Canali,[1,*] Zhu-Xiong Ye,[1] Elisa Soave,[1]
Marian Kreyer,[1] Emil Kirilov,[1,2] and Rudolf Grimm[1,2]

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Ultracold heteronuclear Fermi-Fermi mixtures provide a unique platform to explore exotic regimes of superfluidity in mass-imbalanced fermionic systems [1]. We report on the preparation of a pure ultracold sample of bosonic DyK Feshbach molecules, which are composed of the fermionic isotopes ^{161}Dy and ^{40}K, employing a magnetic sweep across an isolated resonance located near 7.3 G [2]. We produce up to 5000 molecules at a temperature of about 50 nK, corresponding to a phase-space density of the trapped molecules of 0.13. These molecules have a large magnetic moment ($>$ 8.3 Bohr magneton), which allows us to selectively prepare them in a weak optical dipole trap (ODT) using a Stern-Gerlach technique. We also demonstrate a peculiar anisotropic expansion effect observed when the molecules are released from the trap and expand freely in the magnetic levitation field. Our study reveals a lifetime limitation caused by the infrared trap light itself and not by inelastic collisions. We find that the light-induced decay rate is proportional to the trap light intensity and the closed-channel fraction of the Feshbach molecule [3]. We could suppress losses by replacing the 1064-nm laser originally used for the trap by a laser operating further in the infrared (near 1550 nm). By tuning the magnetic field close to the center of the Feshbach resonance we can reach lifetimes of about $\sim$ 100 ms. Here elastic collisions dominate over inelastic collisions and the conditions are promising for further evaporative cooling to create a Bose-Einstein condensate of heteronuclear molecules.

[1] K.B. Gubbels *et al. Phys. Rep.* **525**, 255 (2013).
[2] Z.-X. Ye, A. Canali *et al. Phys. Rev. A* **106**, 043314 (2022).
[3] E.Soave, A. Canali *et al.*, manuscript in preparation.

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Resonantly interacting ^{6}Li-^{53}Cr Fermi mixture and production of LiCr Feshbach molecules

Stefano Finelli[1,*]

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Heteronuclear mixtures of ultracold fermionic atoms, resonantly interacting close to a Feshbach resonance [1], are regarded as clean and versatile frameworks optimally-suited for the disclosure of exotic few-particle states [2–6], and the exploration of novel quantum phases – primarily in the context of unconventional superfluid pairing [7–10] and quantum magnetism [11–15]. In particular, mixtures made of fermionic ^{6}Li (alkali) and ^{53}Cr (transition metal) atoms, with mass ratio $M/m = 8.8$, are especially appealing from a few-particle physics perspective: They are predicted to support (already in three dimensions) non-Efimovian three-body cluster states [3, 6], completely unexplored thus far, that exhibit universal character and p-wave orbital symmetry. These elusive states are extremely relevant also from a many-body viewpoint, in light of their predicted collisional stability. Besides this, in the regime of strong repulsive interactions, three-body recombination processes are expected to be drastically suppressed for the specific Cr-Li mass ratio [16], thus making this system a pristine platform to explore quantum magnetism. Finally, recent ab initio calculations [17] foresee, for the ground state of the Li-Cr dimer, a sizable electric dipole moment of about 3.3 Debye that, combined with a S = 5/2 electronic spin, makes Li-Cr mixtures also extremely appealing candidates to realize ultracold paramagnetic polar molecules.

In our lab in Florence, we produce the first Li-Cr degenerate Fermi mixtures worldwide. Our experimental strategy is formally similar to the all-optical one developed for the Li-K system in the Innsbruck experiment [18], and it consists in the following main steps: (1) realization of a cold Li-Cr mixture in a dual-species magneto-optical trap (MOT); (2) direct loading of the bi-atomic sample into an optical dipole trap (ODT); (3) evaporative cooling of the lithium sample, populating the two lowest Zeeman atomic states (hereafter referred to as Li$|1\rangle$ and Li$|2\rangle$, respectively) and, simultaneously, sympathetic cooling of chromium atoms prepared in their lowest internal state (Cr$|1\rangle$). However, in spite of its conceptual simplicity, successful application of this approach to Li-Cr requires to tackle various challenges – mostly connected with fermionic chromium, its rich level structure, and its rather limited experimental investigation (see Refs. [19–21] for details).

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Optimal control of a Bose-Einstein condensate in an optical lattice

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Cold atoms are a highly controllable and tunable platform for various applications, such as quantum simulation or quantum metrology. However, further control can be achieved using optimal control theory (OCT), for example to prepare various specific quantum states that could be challenging to reach using conventional methods.

In our system, a Bose-Einstein condensate in a 1D-optical lattice, we use OCT to determine the optimal modulation of the lattice phase to prepare specific target states of the collective wavefunction. In this talk, I will demonstrate our ability to prepare diverse reachable states, such as arbitrary momentum states with chosen relative phases [1] as well as Gaussian states with chosen angle, position, or squeezing in the phase-space of a lattice cell.

I will also describe the reconstruction method we use, based on a maximum-likelihood algorithm, to certify that the prepared states have a high purity and a high fidelity to the non-trivial target states [2].

Once obtained, we have demonstrated how these states can be stabilized periodically, or used to initiate a quantum simulation experiment with a precised control on the tailored initial state.

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Superfluid fraction in an interacting spatially modulated Bose-Einstein condensate

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At zero temperature, a Galilean-invariant Bose fluid is expected to be fully superfluid. Here we investigate the quenching of the superfluid density of a dilute Bose-Einstein condensate (BEC) due to the breaking of translational (and thus Galilean) invariance by an external 1D periodic potential [1]. Leggett found an upper bound for the superfluid fraction [2], that only depends on the density profile of the fluid. We prove that for a weakly interacting Bose gas, with a separable density profile, this upper bound turns into an equality. The superfluid fraction of the gas can thus be extracted with an in-situ density measurement. We perform the experiment for a planar BEC of ^{87}Rb atoms confined in an optical dipole trap, we break translational invariance by projecting a large-period 1D optical lattice of variable depth on our sample. We also do an independent measurement of the superfluid fraction based on a speed of sound measurement. We compare both methods to a numerical simulation of the Gross-Pitaevskii equation and find a very good agreement.

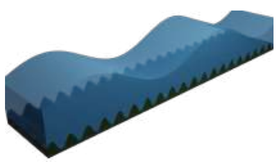

FIG. 1. Artistic view of the experiment: a BEC is subject to a lattice potential. A long-wavelength sound mode is excited

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Self-bound crystals of antiparallel dipolar mixtures

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Quantum fluctuations can stabilize bosonic mixtures and Bose-Einstein condensates with dipolar interactions against the collapse predicted by the mean-field theory. This stabilization mechanism allows for two new states of matter to arise: self-bound quantum droplets and dipolar supersolids. When dipolar interactions between the atoms are present, the droplets can self-assemble into arrays and form a supersolid, which presents both a crystalline structure and superfluid properties. The dipolar interaction between such droplets is repulsive, so these crystals unravel in the absence of external confinement.

On a binary mixture of antiparallel dipolar condensates, however, the attractive dipolar interaction between components allows for the formation of self-bound crystals with no transversal confinement [1]. We explore the ground-state physics of the system, which includes three-dimensionally self-bound droplet-ring structures and, in the presence of only axial confinement, stripe/labyrinthic patterns and self-bound crystals of droplets surrounded by an interstitial superfluid.

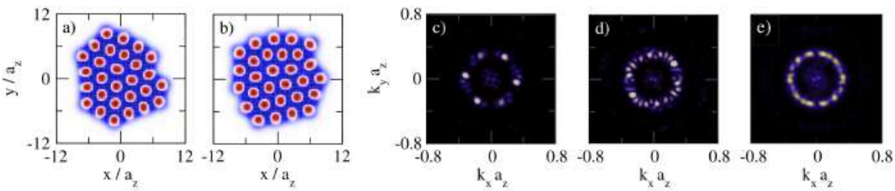

FIG. 1. (a,b) Single-shot realizations of the column magnetization for a binary mixture with antiparallel dipoles where red (blue) regions are populated by component 1 (2). (c,d) Corresponding momentum distribution for the second component in the cases of (a) and (b). (e) Momentum distribution averaged over 10 realizations.

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Radio-frequency dressing Bose-Einstein condensates for investigating quantum phase

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Adiabatic radio-frequency dressing of ultra-cold atoms has been used in a number of experiments to create double well potentials for investigating relative phase and tunnelling between two coherent atomic ensembles. The phase difference between the two Bose-Einstein condensates (BECs) depends on experimental parameters, such as the lowest energy of each well, trap frequency, atom number and barrier between the two wells. The interaction of two BECs with different relative phase produces matter-wave interference in time of flight. This makes it an excellent tool for investigating the behaviour of quantum phase. Using multiple radio-frequencies, we can create a triple well potential and extend exploration to more versatile systems.

In this work we perform adiabatic radio-frequency dressing of rubidium-87 Bose-Einstein condensates in a magnetic trap produced by an atom chip. Precise control over the dressing radio-frequency, amplitude, and timing allows for coherent splitting of the atomic ensemble. The results of radio-frequency dressing with one frequency are compared to simulations, using the rotating-wave approximation theory. Multiple radio-frequency potential has not been achieved on an atom chip before, and we discuss how the single radio-frequency results will inform creating three or more BECs at once. Simulations of multiple radio-frequencies have been performed as well as simulations of the results of the interference pattern [1]. However, there are challenges that need to be overcome in order to achieve the goal experimentally.

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Long Abstracts

Probing the Li-Haldane conjecture with a synthetic Quantum Hall Ribbon

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Topological phases of matter exhibits a valuable robustness to external perturbations, such as quantized Hall conductivity in a 2D electron gas. Such phases are not described by a local order parameter, thus looking at the entanglement between two sub-partitions (A and B) of a system would give us new insights regarding its underlying topology [1, 2]
One way to quantify entanglement entropy is through the Von Neuman entropy defined as $S = -\rho_A \log \rho_A$. While this single number compresses all the information carried out by the reduced density matrix, we could take a closer look at the so called entanglement spectrum (ES), eigenvalues of the entanglement Hamiltonian $\bar{H}_A$ (EH) being defined as $\bar{H}_A = -\log \rho_A$ [3]. Following this idea, Li and Haldane conjectured that topological order signatures could be revealed thanks to a direct relation between the ES and the edge excitations of the system [4]
Experimentally access to the ES is not straightforward, especially for large system size, as it would mean to acquire complete knowledge of the reduced density matrix. An alternative route would be to genuinely realize this fictitious EH based on Bisognano-Wichmann (BW) theorem giving its local structure [5]. We experimentally validate the BW prescription for a synthetic quantum Hall Ribbon in a atomic Dy gas. The BW Hamiltonian is used as a starting point of a variational implementation [6] of the EH and finally give a experimental demonstration the Li and Haldane correspondence.

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Collective behaviour in Rabi-coupled two component Bose-Einstein condensates

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Mixtures of Bose-Einstein condensate offer situations where the usually dominant mean-field energy in weakly interacting systems can be reduced such that higher-order (for example beyond-mean-field) terms may play a dominant role in the equation of state. In this context, the case of two-component coupled Bose-Einstein condensate will be specifically addressed. First, large attractive effective three-body interactions can be engineered with striking consequences [1]. Second, the beyond-mean field energy is precisely measured and is shown to be modified as compared to the uncoupled case [2].

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K-^{3}He Comagnetometer as an Advanced Sensor for the Global Network of Optical Magnetomters for Exotic Physics Searches (GNOME)

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The Global Network of Optical Magnetometers for Exotic physics searches (GNOME) [1] uses precision atomic sensors (magnetometers and comagnetometers) to search for the ultralight dark matter (e.g., axions and axion-like particles). A recently constructed Advanced GNOME sensor is a K-^{3}He comagnetomter operating in the so-called self-compensating regime [2]. With regards to the sensors already used in GNOME, the new sensor not only has a better sensitivity to nonmangnetic perturbations, but also suppresses magnetic noises at low frequencies (< 1 Hz), which are the limiting factor for the sensitivity of regular magnetometers. We have demostrated that with the sensor an overall gain in sensitivity of 3 to 4 orders of magnitude to non-magnetic neutron spin couplings is possible. To explain this capabilities, principles of the sensor operation and possible data analysis methods will be presented.

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Detection of quantum (Fano) interference in a hot vapor atomic gas

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Quantum interference is a quantum process whose effects are several: changing optical properties of media, like absorption and transparency, enhancing energy transport in light-harvesting complexes or information transfer in quantum networks, among many others. Of particular interest is the fact that this process can arise through the application of coherent fields or, more surprisingly, even through incoherent processes, like spontaneous emission, or interaction with noisy electromagnetic fields, such as black body radiations. [1].

Photovoltaic devices, photodetectors or quantum heat engines could see improvements in their performances exploiting quantum interference between internal states [2]. Using a V-type three-level system to model a quantum dot photocell, Svidzinsky *et al.* demonstrate theoretically in [3] that the cell, if excited by natural incoherent light, *i.e.* sunlight, can experience quantum interference involving the transitions from a common ground state to the excited states. The phenomenon leads to a mitigation of radiative recombination and thus to a significant increase in photocurrent and electric power that can be extracted from the cell.

Starting from this model, we perform an experiment realizing a V-type three-level system on atomic platform, *i.e.* in the hyperfine structure of hot ^{87}Rb atoms as depicted in figure 1. As theoretically predicted by Dodin *et al.* in [4], the aim is the observation of spatial anisotropy in the spontaneous

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Quantum thermometry using topological fermionic chains

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With the advent of quantum technologies, there is a dire need to accurately measure the temperature of systems at regimes where quantum effects are dominant. This is challenging since there is no observable to measure the temperature of a given quantum system directly. Thus, we need quantum estimation theory to provide us with the lower bound for the temperature accuracy of a quantum system via the Cramér-Rao bound, which is inversely proportional to the square root of Quantum Fisher Information (QFI) for a general thermal state. In short, if we can maximize the QFI for a given system, we will have ideal bounds for the variance in temperature of the given quantum system. It was further showed in 2015 that an optimal quantum thermometer has a particular energy spectrum with a single ground state but a highly degenerate first excited state. This energy gap is proportional to the estimated temperature of the system [1].

We propose a quantum thermometer with a topological SSH model realized with ultracold fermions in a one-dimensional optical lattice. The proposed thermometer has a very similar energy level structure to the OQT. Assuming that the thermometer is already thermalized to the thermal state of the given system, we study QFI for temperature estimation accuracy. We also analyze the thermalization dynamics when our thermometer in the pure state is coupled to a given many-body quantum system. We can characterize it using the Bures' distance between the reduced density matrices of the thermometer and the system.

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Individual qubit addressing in chains of $^{137}Ba^+$ ions using laser-written waveguides

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Trapped-ion quantum computers encode qubits in the electronic structure of ions confined to a chain. Often, quantum gates are driven by exciting two-photon Raman transitions, which has yielded some of the highest fidelity single- and two-qubit gates [1]. However, addressing individual ions in a long chain is challenging. The addressing beams must be tightly focused well below the ion separation ($\sim 5\ \mu$m) to minimise unwanted illumination of a target ion's neighbours. Additionally, precise control of the intensity, phase and frequency of each beam is required to implement a universal gate set.

We present an all-fibre system for individually addressing 532 nm beams onto a chain of $^{137}Ba^+$ ions for driving two-photon Raman transitions. A network of fibre splitters separates the light into multiple channels, which each addresses a single ion. The intensity, frequency and phase of each beam is controlled by a fibre-coupled acousto-optic modulator. A custom laser-written waveguide device alongside a simple telecentric lens configuration tightly focuses the beams to $\sim 1\ \mu$m diameter and matches their separation to that of the ions.

The atomic properties of Ba^+ allow 532 nm light to drive Raman transitions between hyperfine states in both the ground $S_{1/2}$ and the long-lived metastable $D_{5/2}$ level. Thus, qubits encoded in either manifold can be manipulated with the same individual addressing system. This enables advanced qubit manipulation schemes such as *omg* protocols [2] without added experimental overhead. In addition, turning on just one Raman tone induces an AC Stark shift on the quadrupole $S_{1/2} \Leftrightarrow D_{5/2}$ transition. We exploit this to achieve effective individual addressing of our global quadrupole laser, which allows us to individually address our fluorescence lasers through qubit hiding schemes.

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Long Abstracts

Focussing of microwave-driven gate interactions for trapped ions

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Trapped-ions are a promising platform for quantum computing as they can form fundamentally identical qubits with long coherence times. Quantum logic gates are often performed using lasers but can also be driven by microwave fields for which the technology is cheaper and more reliable, making it simpler to scale up. However, due to the centimetre wavelength of microwaves, they cannot be focussed to a small spot size making it difficult to address an individual ion within a cluster of ions confined by the same potential well.

We have demonstrated a novel method to drive a spin-dependent force only in a sub-ion-spacing ($< 5\mu$m) region whilst suppressing this force everywhere else. This is done by utilising the variation of the phase of the microwave-field across the surface trap.

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Isotope shifts of the $^1P_1 \leftarrow {}^1S_0$ and $^3P_1 \leftarrow {}^1S_0$ lines in atomic cadmium

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The isotope shifts of atomic transitions provide a means to study nuclear structure. Cadmium possesses eight stable isotopes, a strong $^1P_1 \leftarrow {}^1S_0$ laser cooling transition and a narrow spin-forbidden $^3P_1 \leftarrow {}^1S_0$ transition. It is therefore an interesting atom to study in a tabletop experiment.

We produce a cold, slow beam of atomic Cd in a cryogenic buffer gas source, and use it to perform isotope-resolved laser induced fluorescence spectroscopy of the $^1P_1 \leftarrow {}^1S_0$ and $^3P_1 \leftarrow {}^1S_0$ lines. For the $^1P_1 \leftarrow {}^1S_0$ transition, we use isotopically enriched samples and emission-angle selective detection to unambiguously determine the isotope shifts with MHz accuracy. In combination, these two techniques enable discriminating between the two fermionic and six bosonic isotopes, whose transitions are poorly spectroscopically resolved due to the large natural linewidth of the transition. We show that for the fermionic isotopes, quantum interference is observable between the excited states, complicating the interpretation of the spectrum. After carefully accounting for quantum interference in the spectral lineshape of the fermions, we measured the radiative lifetime of the $^1P_1$ state as 1.60(5) ns. For the $^3P_1 \leftarrow {}^1S_0$ transition, whose natural linewidth is three orders of magnitude smaller, it is straightforward to resolve the individual isotopes, and we benefit from the small Doppler shifts present in our slow atomic beam. We performed systematic checks to determine the accuracy of our transition frequency and isotope shift measurements, comparing to previously measured structure in cadmium, precisely known transitions in atomic copper, and an ultrastable optical cavity. This allows us to assign a systematic uncertainty to the isotope shifts of 3.3 MHz, sufficient for the application of our measurements in nuclear theory via a King-plot analysis [1, 2].

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The Design of the BECCAL Laser System for Cold Atom Experiments Onboard the ISS

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The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL)[1] is a cold atom experiment designed for operation onboard the ISS. It is a collaboration between DLR and NASA, built upon the heritage of previous sounding rocket and drop tower experiments, and NASA's CAL[2]. This multi-user facility enables the exploration of fundamental physics with Rb and K BECs and ultra-cold atoms in microgravity, facilitating prolonged timescales and ultra-low energy scales. The scientific envelope targets atom interferometry, atom optics, scalar and spinor BECs, quantum gas mixtures, strongly interacting gases and molecules, and quantum information.

An overview of the design and capabilities of the BECCAL laser system will be presented. The broad scientific aims of the laboratory require a flexible laser system architecture whilst meeting a stringent Size, Weight and Power (SWaP) budget. To achieve this, we combine micro-integrated diode lasers and fibre-connected Zerodur boards of miniaturized free-space optics.

This work is supported by the DLR with funds provided by the BMWK under grant numbers DLR 50WP1702, and 50WP2102.

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How much time does a resonant photon spend as an atomic excitation before being transmitted?

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When a single photon traverses a cloud of 2-level atoms on resonance, the average time it spends as an atomic excitation—as measured by weakly probing the atoms—is equal to the spontaneous lifetime of the atoms multiplied by the probability of the photon being scattered into a side mode. A tempting inference from this is that an average scattered photon spends one spontaneous lifetime as an atomic excitation, while photons that are transmitted through the cloud spend no time at all as atomic excitations. However, our recent experimental work shows that this is incorrect [1]. Here we examine this problem using the weak-value formalism and show that the time a transmitted photon spends as an atomic excitation is equal to the group delay, which can take on positive or negative values. We also determine the corresponding time for scattered photons, which turns out to be related to the *Wigner time* associated with elastic scattering [2]. This work provides new insight into the complex and surprising histories of photons travelling through absorptive media.

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Accuracy of a commercial cold-atom microwave clock

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We present MuClock, a commercial compact microwave clock using isotropic light cooling of rubidium atoms [1]. MuClock is comparable to typical hydrogen masers in terms of volume and short-term frequency stability, which is 3.2×10^{-13} at 1 s. The long-term stability outperforms typical masers with a fractional frequency stability of 1×10^{-15} over more than one month.

The MuClock set-up is based on a spherical copper cavity, where 10^7 atoms are cooled to 60 μK using isotropic light cooling [2]. Six bare fibres are glued into 1.0-mm diameter holes in the cavity. The light enters through those holes with a numerical aperture of 0.13 and optical reflections create an intensity pattern with speckles and interferences. In this pattern, sub-Doppler cooling can be achieved as in the well-known six beam molasses. The cavity is also resonant for the interrogation microwave and Ramsey spectroscopy with $T_R = 40$ ms probes the atoms in the same position. Having demonstrated a long-term competitive clock frequency stability, we have started investigating systematic frequency shifts, aiming at an overall accuracy $<5\times10^{-15}$. Among the systematic effects that have already been evaluated to better than 5×10^{-15} are the quadratic Zeeman effect and cavity pulling. Recently we have focused on microwave phase transients. They require fine investigation because the atoms are always inside the microwave cavity in our clock scheme, contrary to the fountain geometry for which phase transients have extensively been characterized [3]. Using a specifically designed test bench, we are able to measure the microwave phase with 1 μrad resolution. The long-term stability of this effect converted into fractional frequency is $<1\times10^{-15}$ over a few days. The frequency bias has been measured and reduced to 1×10^{-14}. Current efforts aim to lower this contribution to the overall clock accuracy.

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Atom Interferometer Observatory and Network (AION) with ultra-cold strontium

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AION is an Atom Interferometer Observatory and Network that will use its unique sensitivity scope to explore gaps where ultralight dark matter candidates may be detected, probe for gravitational waves in the mid frequency band that is less accessible to other detectors, and in network with multiple atom interferometers, explore other fundamental physics [1]. AION consisits of a consortium of UK universities, each of which are developing a key stage of the project, the University of Cambridge is looking at techniques to efficiently cool and transport atom clouds from the atom source chamber to the interferometry shaft.

Atom interferometry uses the wave-particle duality of atoms to operate similarly to an optical interferometer, where the wave packet can be split and recombined in momentum states using laser pulses . The interference fringes created provide information on the relative phase and thus on the physical phenomena that may affect it. By operating multiple atom interferometers with a common laser source in a vertical tower, differential measurements can be made for detection while removing common mode laser noise. The planned large scales of the interferometry shafts to be constructed (from 10m to 1km), as well as the high repetition rate required for the experiments, mean that consistently achieving the lowest possible temperature for the atom clouds and efficiently transporting them to the shaft is vital.

AION will use ultra-cold fermionic strontium atoms for its interferometry sequence, the alkaline earth atom is characterised by its ultra-narrow "clock" transition as well as useful cooling transitions that make it convenient for atom interferometry. I will be presenting our current advances in cooling and optical transport of strontium atoms and its context in AION.

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Long Abstracts

Laser cooling of barium monofluoride molecules

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I will report on our progress towards laser cooling of barium monofluoride molecules. Due to its high mass, resolved hyperfine structure in the excited state and branching losses through intermediate states, this molecular species is notoriously difficult to cool, but it shows high promise for various types of precision measurement applications. I will discuss laser cooling strategies for both the bosonic isotopologues, which are interesting for electron EDM searches, and the more complex fermionic isotopologues, which are used for parity violation experiments.

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Long Abstracts

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Relative dynamics of quantum vortices and massive cores in binary BECs

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We study vortices with massive cores [1, 2] in binary mixtures of Bose-Einstein condensates. We consider the case of a simple 2D disc geometry. Taking up the work of Richaud et al. [3, 4], we introduce a point-vortex model where quantum vortices in the majority species are coupled to the corresponding core masses, i. e. local peaks of the minority species. The point-like dynamics is obtained via a variational Lagrangian approach. In parallel, we validate our analytical results via the numerical resolution of two coupled Gross-Pitaevskii equations. Conversely to the previous works [3, 4], where a vortex centre was assumed coincident with the centre of its massive core, we instead introduce a more refined dynamical model: here, the two objects are described by independent sets of dynamical variables and coupled by an harmonic term. Consequently, we study the effect of the new degree of freedom on the vortex-mass relative motion and average dynamics.

As already observed, the first striking effect of the second species is a change of trajectory. Whereas a massless vortex in a 2D disc moves of uniform circular motion, in presence of a second species some radial oscillations may arise. Specifically, our new model brings to a more articulated normal mode analysis, and improves the previous model thanks to the depedency of the small oscillations on the inter-species coupling parameter g_{ab}. This dependency could not be appreciated in the previous model as it did not include the parameter g_{ab} at all. On the other hand, we confirm that, within the physical ranges of the coupling parameters, there is no significant relative motion of the vortex with respect to its core mass.

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Observation of vortices in dipolar quantum gasses of dysprosium

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Due to anisotropic interactions, ultra-cold dipolar gasses exhibit exotic states such as supersolids – density-modulated and phase coherent degenerate states. These supersolids are theorized to maintain phase coherence using a superfluid background. While density modulation can be directly observed using in situ imaging and phase coherence emerges from interferometric probes, the superfluid nature of the system in terms of irrotational flow and thermodynamic properties is much trickier to measure. Quantized vortices, a defining feature of superfluidity, are an unambiguous probe of irrotational flow which can be used to prove the existence of the superfluid background in the supersolid phase. Here we study, both experimentally and theoretically, the creation of vortices in the unmodulated BEC phase and our progress towards creating vortices in the Dy-164 supersolids. Finally, we will report on our recent advances towards a dual-species dipolar quantum gas microscope.

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Universality of the superfluid Kelvin-Helmholtz instability by single-vortex tracking

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At the interface between two fluid layers in relative motion, infinitesimal fluctuations can be exponentially amplified, inducing vorticity and the breakdown of the laminar flow. This process, known as the Kelvin-Helmholtz instability, is responsible for many familiar phenomena observed in the atmosphere and the oceans, as well as in astrophysics. It is one of the paradigmatic routes to turbulence in fluid mechanics. While in classical hydrodynamics, the instability is ruled by universal scaling laws, to what extent universality emerges in quantum fluids is yet to be fully understood. Here, we shed light on this matter by triggering the Kelvin-Helmholtz instability in atomic superfluids across widely different regimes, ranging from weakly-interacting bosonic to strongly-correlated fermionic pair condensates. Upon engineering two counter-rotating flows with tunable relative velocity, we observe how their contact interface develops into an ordered circular array of quantized vortices, which loses stability and rolls up into clusters in close analogy with classical Kelvin-Helmholtz dynamics. We extract the instability growth rates by tracking the position of individual vortices and find that they follow universal scaling relations, predicted by both classical hydrodynamics and a microscopic point-vortex model. The results of this work are reported in [1].

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A Digital Micromirror Device setup for enhanced control of a two-dimensional Bose-Einstein condensate

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Our experiment produces a two-dimensional Bose-Einstein condensate (BEC) of ^{39}K with tunable interactions and a configurable in-plane potential. The resulting full control of the mean field Hamiltonian enables us to study many-body quantum dynamics far from equilibrium. For the manipulation of the potential, a Digital Micromirror Device (DMD) is used to precisely shape the intensity profile of a blue detuned dipole trap within the two-dimensional plane.

In my master's thesis, I am implementing a second DMD that uses near-resonant light. The two DMD's operating with different wavelengths allow for manipulation on different energy scales. This will enable us to optimize the existing potential or manipulate the BEC locally for example, to inject vortices. In my talk, I will present the current status regarding the upgrade of the DMD control in our experiment.

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Dipolar Quantum Solids in an Erbium Quantum Gas Microscope

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Two-dimensional quantum lattice systems of dipolar atoms present the opportunity to study a rich set of many-body states that arise from long-range, anisotropic interactions. Here we demonstrate dipolar phases of the extended Bose-Hubbard model in a quantum gas microscope of magnetic erbium atoms. By adiabatically loading a BEC into a small spacing square lattice, we probe a regime in which the dipolar interaction dominates over other energy scales in the system. Under these conditions we observe a quantum phase transition in which superfluid order is broken and exotic dipolar phases are formed. Using site-resolved images and connected density-density correlations we identify and explore different half-filling dipolar phases in the hard-core boson limit. We rotate the direction of the dipole-dipole interaction by tuning the orientation of the atomic dipoles via an external magnetic field. Depending on this direction we can form checkerboard, stripe, and diagonal phases. This work opens the door to study of long-range interactions in lattice systems with single-site resolution. The clean and tunable nature of dipolar quantum gas microscope systems allows for the study of other exotic many-body states such as super-solids and Haldane insulators.

Mixtures of Superfluid Bose and Fermi Gases

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In quantum mechanics, particles are divided into two types: bosons and fermions, according to their spin. This property determines their collective behavior, which is fundamentally different for both types of particles.

At very low temperatures, bosons undergo Bose-Einstein condensation, as predicted by A. Einstein in 1925 and experimentally realized for the first time in 1995. The existence of Bose-Einstein condensate (BEC) is closely related to the superfluid state, which may be observed in ultracold quantum gases. Superfluidity in fermionic systems is also connected to BEC through condensation of Cooper pairs, which exhibit boson-like properties.

Some of the characteristic properties of superfluids are zero viscosity and the existence of quantized vortices, which may be observed experimentally.

In my work, I study both types of ultracold quantum gases, as well as their mixtures, mainly through the investigation of the properties and stability of topological defects. In particular, I am interested in systems where bosons and fermions coexist. Presently, I study superfluid entrainment - the phenomenon predicted by Andreev and Bashkin [1], whereby in a mixture of two superfluid components, a flow of one component drags along the other, despite the lack of dissipation [2].

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FermiQP - A Fermion Quantum Processor

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FermiQP is a quantum processor based on ultracold fermionic lithium in optical lattices. In its analogue mode, the machine acts as a quantum gas microscope featuring single site resolution and spin-resolved detection. In this mode, quantum simulation of the Fermi-Hubbard model can be performed in two-dimensional optical superlattices with dynamical control over the lattice configuration. In the digital model, single- and two-qubit gates acting on the spin degree of freedom will enable universal quantum information processing. The single qubit gates will be implemented as Raman rotations between hyperfine states and the two-qubit gates with controlled collisions between atoms using superlattice double well paired with tweezer-based resorting techniques. Together, these serve for full programmability of the quantum computer.

The experiment is being built with the goal to reduce cycle times. Loading the atoms into milliKelvin-deep pinning lattice directly after the 3D MOT and performing Raman-Sideband-Cooling starting from the higher lattice states will allow us to reduce evaporation times. I will present my setup for a high-stability, large-volume bow-tie lattice used for imaging and cooling.

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Spin squeezing via XXZ dipolar interactions in an optical lattice quantum gas microscope

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Spin squeezing has been demonstrated as a method for overcoming the standard quantum limit in high-precision metrology. Recent theoretical and experimental work has focused on the potential for power-law XXZ models to realize scalable spin squeezing. We present recent experimental progress towards observing such spin squeezing in a quantum gas microscope. Our experiment prepares fermionic Er^{167} atoms in one layer of a 3D short-spacing optical lattice. We exploit a zero first-order-Zeeman (ZEFOZ) microwave transition in the hyperfine structure of Er^{167} to achieve a T2 coherence time of 1 second, limited by a dipolar spin-exchange interaction. We use this interaction to observe squeezing via free evolution on the 100ms timescale. This establishes a new method for preparing a metrologically useful spin-squeezed state in a 3D optical lattice.

Long Abstracts

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Stern-Gerlach Interferometry with the Atom Chip

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We describe a decade of Stern-Gerlach (SG) interferometry on the atom chip. The SG effect has been a paradigm of quantum mechanics throughout the last century, but there has been surprisingly little evidence that the original scheme, with freely propagating atoms exposed to gradients from macroscopic magnets, is a fully coherent quantum process. Specifically, no full-loop SG interferometer (SGI) has been realized with the scheme as envisioned decades ago. Furthermore, several theoretical studies have explained why it is a formidable challenge. Here we provide a review of our SG experiments over the last decade. We describe several novel configurations such as that giving rise to the first SG spatial interference fringes, and the first full-loop SGI realization. These devices are based on highly accurate magnetic fields, originating from an atom chip, that ensure coherent operation within strict constraints described by previous theoretical analyses. Achieving this high level of control over magnetic gradients is expected to facilitate technological applications such as probing of surfaces and currents, as well as metrology. Fundamental applications include the probing of the foundations of quantum theory, gravity, and the interface of quantum mechanics and gravity. We end with an outlook describing possible future experiments.

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Development of a compact cold atom gyroscope

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Since 1990's, a new generation of inertial sensor based on matter-wave interferometry has appeared: accelerometers [1], gradiometers [2] and gyroscopes [3] have been developed and demonstrated high sensitivity and accuracy. Major applications for atom interferometers are today geophysics, inertial navigation and fundamental physics. However, for measurements in a dynamic environment, people use for now classical (non quantum) sensors which require calibration and a correction to their inherent drift. Most of the atom interferometry-based sensors are laboratories experiments and cannot perform onboard measurements, except for some notable exceptions such as ONERA's marine and airborne gravimeter [4, 5].

In this paper, we present our first results concerning a compact cold atom gyroscope, which is incorporated within the framework of the development of a cold atom inertial measurement unit. The sensor is sensitive to rotations if the atoms enter the interferometer with an initial velocity. We therefore propose a scheme compatible with a compact multi-axis sensor in which the atoms are horizontaly launched thanks to a magnetic gradient and interrogated with a single Raman laser. We have obtained 35% contrast interferometry fringes and measured the Earth rotation with 10% accuracy.

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Frequency Comb atom interferometer

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Atom interferometry is a leading precision measurement technology that harnesses the wave-like interference of atoms to perform highly accurate measurements of, e.g. velocities, accelerations, rotations, gravity or gravity gradients. In particular, light-based atom interferometry, where light pulses are used to coherently split, reflect and recombine atom wave-packets, has led to extremely sensitive and accurate sensors that can be used to perform very stringent tests of fundamental physics such as: testing the equivalence principle, detecting gravitational waves, probing short-range forces or measuring fundamental constants (e.g. the fine-structure constant)

We demonstrate the implementation of a light pulse atom interferometer based on the diffraction of free-falling atoms of Rubidium by a frequency-comb laser[1]. We study the impact of the pulses' length as well as of the interrogation time on the contrast of the fringes. A measurement of the Earth gravitational field with a relative uncertainty of 10^{-5} is performed using this method. This technique, which we demonstrated in the visible spectrum on Rb atoms, paves the way for extending light-pulse interferometry to other spectral regions (deep-UV to X-UV) and therefore to new species, since one can benefit from the high peak intensity of the ultrashort pulses which makes nonlinear frequency conversion in crystals and gas targets more efficient. Especially, the modest relative sensitivity on g ($\sim 10^{-5}$) that we demonstrated, if it were reproduced on the 121 nm transition in anti-hydrogen would lead to a stringent test of the interaction of anti-matter with gravity, where the classical tests currently underway at CERN aim relative accuracy of $\sim 10^{-3}$ at best.

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High precision Atom Interferometer GAIN

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The Gravimetric Atom Interferometer GAIN, is based on interfering ensembles of laser cooled ^{87}Rb atoms in a fountain setup using stimulated Raman transitions. The rugged transportable design of the instrument enables precise and accurate on-site gravity measurements. Its performance has been compared to other state-of-the-art gravimeters in the past measurement campaigns at geodesic observatories with an accuracy of 10^{-9} level in g and a long-term stability of 0.5 nm s^{-2} [1].

We will present the improvements implemented into the apparatus and the aspects of using GAIN as a testbed for the interferometric measurements of the BECCAL laser system [2].

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Ultra high sensitivity quantum gravi-gradiometer

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Inertial sensors based on cold atom interferometry are one of the most mature quantum technologies today and can achieve sensitivities that rival conventional sensors [1]. Here, we present a cold atom gravi-gradiometer, which measures the local value of the vertical component of $\vec{g}$ and its vertical gradient ∇g.

Our sensor simultaneously probes the gravitational acceleration with two atomic clouds separated by one meter and interrogated with common laser beams [2]. The main advantage of this architecture is the rejection of common-mode noises (i.e. vibration or laser phase noise) in the differential signal ∇g, which opens a perspective for dramatic sensitivity improvements. We currently focus on implementing multiphotonic Bragg beamsplitters to increase the sensor's scale factor; ant the optimal control methods on Bragg diffraction to improve the efficiency of the matter-wave optics. Furthermore, we will use atom chip traps to efficiently prepare Bose-condensed atomic samples and implement novel quantum metrology protocols for inertial sensing beyond the standard quantum limit [3].

The enhanced sensitivity of our novel generation sensor may significantly bypass the state-of-the art [4], which is of interest for various applications in geophysics and accurate onboard inertial sensing. The simultaneous measurment of g and ∇g would allow for resolving the ambiguity between detected weak mass and its localization.

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Long Abstracts

A hybrid cold atom accelerometer for space geodesy missions

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Space gravimetry missions such as GRACE or GOCE determine the Earth gravity field with great accuracy [1]. The data gathered are very useful in the sciences of climatology, hydrology or geophysics and to understand global climate change. These missions board state-of-the-art space electrostatic accelerometers displaying a very good sensitivity but also a long-term drift. By combining an electrostatic accelerometer with a very stable cold atom accelerometer, it is possible to correct this drift. To this day, no acceleration measurements with a cold atom accelerometer has been performed in space, mostly because of the harmful effect of the satellite's rotation on the interferometer output [2].

In this paper, we present our ongoing experimental work concerning the development of a hybridised electrostatic/atomic accelerometer. In particular, we addressed the problematic of satellite's rotation and its detrimental effect on the cold atom interferometer. The hybrid lab prototype is made of an electrostatic accelerometer and a cold atom interferometer. The test mass of the electrostatic accelerometer, very well controlled in angle and position, is employed as the retro-reflection mirror of the interferometer. By rotating the test mass, we studied the impact of inertial acceleration on the atomic interferometer contrast and phaseshift. Moreover, we are working on the rotation compensation technique: the test mass is rotated in order to limit the impact of the whole instrument's rotation [3].

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Experimental investigation of false vacuum decay in a ferromagnetic superfluid

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In the last decades Bose Einstein Condensates have become a valuable platform for quantum simulations thanks to the high control reached in their manipulation. In particular the BEC mixture of the two hyperfine states $|1,-1\rangle$ and $|2,-2\rangle$ of ^{23}Na, coherently coupled through a microwave radiation, is equivalent to the spin $\frac{1}{2}$ system at zero temperature, whose behavior is explained in terms of the quantum Ising model. Thus BECs can be used to study the quantum paramagnetic-ferromagnetic phase transition. The main advantages in using a BEC mixture for the phase transition investigation are the possibility of making coexist different magnetic phases, by properly choosing the external trapping potential, and the non dissipative nature of the condensate, compared to solid state environment, which allows for the study of system dynamics.

Long Abstracts

After characterizing the phase diagram [1] we are able to prepare the system in a metastable ferromagnetic state and study the relaxation process to the absolute energy minimum, hence opening the way to the experimental study of false vacuum decay process. The latter consists in the decay from a metastable to an absolute minimum resulting in the creation of bubbles. While false vacuum decay was introduced in the cosmological context the energies involved are not experimentally accessible. Using the atomic platform we manage to observe bubble nucleation and to characterize the event probability.

[1] R.Cominotti *et al.*, *Ferromagnetism in an extended coherently-coupled atomic superfluid*, arXiv:2209.13235v3 (2023)

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Einstein-Podolsky-Rosen experiment in split Spin-Squeezed Bose Einstein Condensates.

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In 1935, Einstein, Podolsky, and Rosen (EPR) conceived a Gedankenexperiment which became a cornerstone of quantum technology and still challenges our understanding of reality and locality today. While the experiment has been realized with small quantum systems, a demonstration of the EPR paradox with massive many-particle systems remains an important challenge, as such systems are particularly closely tied to the concept of local realism in our everyday experience and may serve as probes for new physics at the quantum-to-classical transition. Here we report an EPR experiment with two spatially separated Bose-Einstein condensates, each containing about 700 Rubidium atoms. Entanglement between the condensates results in strong correlations of their collective spins, allowing us to demonstrate the EPR paradox between them. Our results represent the first observation of the EPR paradox with spatially separated, massive many-particle systems. They show that the conflict between quantum mechanics and local realism does not disappear as the system size increases to more than a thousand massive particles. Furthermore, EPR entanglement in conjunction with individual manipulation of the two condensates on the quantum level, as demonstrated here, constitutes an important resource for quantum metrology and information processing with many-particle systems [1].

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Long Abstracts

Preparation for the Integration of the BECCAL Laser System

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Long Abstracts

BECCAL (Bose-Einstein Condensate and Cold Atom Laboratory) [1] is a cold atom experiment designed for operation on the ISS. It is a DLR and NASA collaboration, built on a heritage of sounding rocket and drop tower experiments, and NASA's CAL [2]. This multi-user facility enables the exploration of fundamental physics with Rb and K BECs and ultra-cold atoms in microgravity, facilitating prolonged timescales and ultra-low energy scales.

In contrast to lab-based cold atom experiments, BECCAL must be operable without interference for three years on the ISS. To reach that goal and match the complexity of this space-based system to the stringent size, weight, and power limitations, we have to fulfill strict product assurance requirements for the laser system including higher cleanliness facilities and ESD protection. In this context, the planning and implementation of the specific lab setup and the first essential integration tests, using mock-ups, will be presented.

This work is supported by the DLR with funds provided by the BMWK under grant numbers DLR 50WP1702, and 50WP2102.

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Towards a strontium quantum gas microscope

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Ultracold atoms in optical lattices represent an outstanding tool to create and study quantum many-body systems. Combining these lattice systems with the properties of alkaline-earth atoms such as strontium gives rise to exciting phenomena. On one hand, sub-wavelength arrays of bosonic strontium exhibit strong cooperative effects in atom-photon scattering. On the other hand, fermionic strontium allows to investigate the Fermi-Hubbard model, where SU(N) symmetric interactions between the $N = 10$ internal states give rise to exotic magnetic phases beyond the limits of natural materials.

To study these systems experimentally, we will realize a strontium quantum gas microscope. To prepare a quantum gas of strontium, we first employ laser cooling on a broad transition, followed by further cooling on a narrow transition. We reach temperatures of a few µK, which enable direct loading into an optical dipole trap for evaporative cooling. We routinely generate Bose-Einstein condensates of 300000 strontium atoms, which we plan to load into an optical lattice. An imaging setup involving a high-NA objective will allow us to image with single-atom and single-site resolution, enabling the detection of density as well as spin correlations in the prepared many-body states.

In my talk, I will present the current state of our machine, including the cooling processes required to reach the quantum degenerate regime and a characterization of our optical lattice. Furthermore, I will discuss the imaging scheme to achieve single-site detection of the strontium atoms in the optical lattice.

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Setup of an atom array with cavity-mediated interactions

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Achieving non-local interactions and multiparticle entanglement are essential goals for quantum simulation and quantum information processing. We report on the construction of a new platform with neutral atoms trapped in an array of optical tweezers (FIG. 1) with photon-mediated interactions. A strong coupling of the single atoms to the photon field is implemented by a fiber cavity with high finesse (FIG. 2). The atoms are individually addressable by using a high resolution microscope, which is also used for imaging. In addition, site-resolved non-destructive readout can be achieved via dispersive coupling to the cavity field. Our approach provides a scalable platform to study many-body physics and entanglement with programmable connectivity.

FIG. 1. Optical tweezer array created with an acousto-optical deflector (AOD) for trapping the atoms.

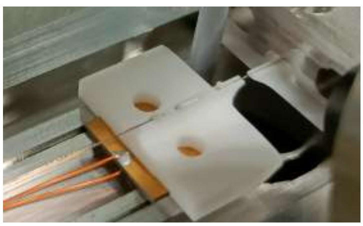

FIG. 2. Fiber cavity setup with mount (white) and piezoelement (yellow).

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Towards quantum simulation in an optical kagome lattice with single-site resolved imaging

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The kagome lattice exhibits strong geometric frustration and hosts a motional band that becomes analytically flat in the tight-binding limit. The macroscopic degeneracy of the associates states leads to novel physics, such as the predicted spin liquid phase at the fermionic ground state [1].

We create an optical kagome lattice [2] by overlapping a triangular and honeycomb lattice composed of 532nm and 1064nm light respectively. The experiment is designed to cool bosonic ^{87}Rb and ^{39}K as well as fermionic ^{40}K atoms and load them to the lattice. We plan to access the (flat) highest energy subband by creating a negative absolute temperature state [3], allowing for the study of equilibrium phases. We are also working towards implementing a quantum gas microscope for single-site-resolved imaging of the atoms.

By tuning interactions and lattice depth it is then possible to simulate a wide range of Hamiltonians with different lattice geometries. Our current work includes studying the bosonic superfluid to Mott insulator transition in a triangular lattice, both at positive (unfrustrated) and negative (frustrated) temperatures.

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Quantum Gas Magnifier for Ultracold Atoms in an Optical Quasicrystal

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Many-body localization (MBL) presents an unconventional regime where quantum systems with strong disorder are unable to thermalize, in contrast with the conventional closed systems that follow the classical eigenstate thermalisation hypothesis. Ultracold atoms in a quasicrystalline optical lattice provides a novel and highly controllable platform to investigate the enriched physics of disordered many-body interacting systems [1, 2]. In our experiment, MBL can be characterized by measuring the transport of a ^{39}K quantum gas in an optical quasi lattice with an external trapping potential [2].

On the basis of the current experimental apparatus, we aim to incorporate a quantum gas magnifier (QGM) to achieve single-site resolved imaging [3]. To implement a QGM to the density distribution of atoms in an optical lattice, a harmonic potential in the x-y plane with a trapping frequency of $\omega = 2\pi/T$ is ramped up and held for $T/4$, followed by a time of flight (TOF) of duration t_{TOF}. This scheme results in a magnification of ωt_{TOF} [3]. With a proper trapping frequency and TOF duration, a QGM should be able to achieve single-site resolution. In comparison with the previous approach using the magnetic trap [3], we aim to use an optical dipole trap as the harmonic trap after the lattice. The quantum gas magnifier demonstrated here paves the way for exploring localization with a single site resolution.

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New method to probe a quantum phase transition in different spin Hamiltonians

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Interesting emergent phenomena found in the thermodynamic limit are phase transitions. At zero temperature, these transitions are driven purely by quantum fluctuations and related to a closing gap in the many-body spectrum. One way to experimentally characterize them is by measuring the number of defects as predicted by the Kibble-Zurek mechanism.

Magnetic systems described by Heisenberg Spin Hamiltonians show a paramagnetic phase when a strong transverse field is applied. If such a model shows a continuous quantum phase transition where the transverse field serves as a control parameter, the magnetization in the paramagnetic phase can be related to the defect density in the Kibble-Zurek formula. However, in order to apply the Kibble-Zurek formula, one has to prepare the system close to the ground state of the phase where the transverse field is small, which is experimentally challenging especially in the presence of disorder.

In this talk, I will propose a new method that allows for the detection of such a phase transition by preparing the ground state in the paramagnetic phase, which is a fully spin polarized state, and measuring the magnetization in the same phase. Starting with an analytical prove that this method shows a similar behaviour as the Kibble-Zurek formula for a nearest-neighbour Ising model, I will investigate numerically whether this method also predicts phase transitions in the disordered 1D Ising model and use this method to probe the presence of a phase transition in a disordered dipolar Rydberg gas described by a Heisenberg XX model[1–3]

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Scalable Qubit Arrays for Quantum Computation And Simulation

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Quantum computation offers a revolutionary approach to how information is processed, offering new applications in material design, quantum chemistry and speed up of real-world optimisation problems. However, a large number of qubits are required to obtain quantum advantage over classical hardware. Neutral atoms are an excellent candidate for practical quantum computing, enabling large numbers of identical qubits to be cooled and trapped, overcoming major barriers to scaling experienced by competing architectures [1].

We present progress towards developing a large scale quantum processor through the SQuAre (Scalable Qubit ARray) project. We demonstrate high-fidelity single-qubit gate operations with $< F^2 >= 0.99992(2)$ over 225 qubits [2], which achieves the threshold for fault-tolerant scaling. We further implement low-loss non-destructive and state-selective readout on 49 atoms to suppress SPAM errors.

Further results pave the way to two qubit and multi-qubit gate operations using two-photon adiabatic rapid passage [3].

This work is supported by the EPSRC Prosperity Partnership with M Squared Lasers, Grant No. EP/T005386/1.

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Trapping atoms in a cryogenic environment : enhancing scalability in quantum systems

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Optical-tweezer arrays have proven to be an effective platform for realizing analog and digital quantum simulators. However, like all quantum hardware, scalability remains a significant challenge. In this talk, we will present a novel experimental setup that incorporates tweezer technology in a cryogenic environment. Our setup operates at 4K, where we have achieved a vacuum-limited lifetime exceeding 6000 seconds [1], an improvement of two orders of magnitude over room temperature setups. By implementing an optimized trap loading equalization procedure [2], we can construct arrays of over 300 atoms while maintaining a high level of accuracy and defect-free realizations. These findings mark the first step towards Rydberg quantum simulators capable of handling more than a thousand particles.

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Engineering gauge theories with a Rydberg atom processor

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In the last years, Rydberg atoms in reconfigurable optical tweezers proved to be an excellent platform to implement Spin-like Hamiltonians in ultracold atom experiments [1]. An important subject in this matter is the exploration of Ising models with S = 1/2 and higher in one, two and three dimensions, including the investigation of gauge theories emerging in condensed matter physics [2]. As an example, I consider the well-known Rokhsar-Kivelson Hamiltonian, a 2D U(1) lattice gauge theory describing quantum dimer and spin-ice dynamics, in different geometries and investigate the resulting phase diagrams [3]. I explain how to engineer tunable anisotropic attractive as well as repulsive interactions with so-called superatoms by organizing two or more individual atoms in small clusters sharing one Rydberg excitation. The control of the couplings translates in blockade and antiblockade conditions arising in the dual formulation of the Rokhsar-Kivelson Hamiltonian [4]. In collaboration with the experimental group of Leticia Tarruell, I develop protocols to investigate this and other gauge theories with Rydberg atoms in reconfigurable tweezer arrays.

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Characterizing Operator Growth in Disordered Quantum Spin Chains via Out-of-Time-Ordered Correlators

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We investigate operator growth and information propagation in disordered, isolated quantum spin systems using out-of-time-ordered correlators (OTOCs) as a diagnostic tool. Specifically, we characterize the evolution of OTOCs of two initially local Pauli operators in one-dimensional XXZ Heisenberg models using numerically exact techniques. We survey both the ordered case and the disordered cases, where disorder may take the form of either random on-site potentials or random couplings from which in the limit of strong disorder many-body localization (MBL) emerges. While in ordered spin chains, operator growth is almost indistinguishable for power-law ($\alpha \geq 3$) and nearest-neighbour interactions, we observe a much faster growth in power-law interacting systems with strong on-site disorder than in their nearest-neighbour interacting counterparts. The light cones observed in the case of power-law interactions and strong disorder are found to be power-law, rather than logarithmic. Additionally, we propose an experimental method for measuring OTOCs with Rydberg-excited atoms through an echo scheme and analyze advantages and disadvantages of different classes of initial states to optimize measurement.

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Microwave-to-optical conversion based on room-temperature Rydberg atomic ensemble

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The task of interconnecting microwave and optical domains of light is crucial to quantum communication, as it would enable hybrid quantum networks. Various realisations have been presented with that aim [1], with cold Rydberg atoms being an example of a medium capable of this feat [2], along other electro-optical devices in cryogenic temperatures.

However, less demanding implementations of microwave-to-optical conversion will find their use in microwave astronomy, coherent imaging and next-generation microwave sensors. Inspired by the recent progresses in microwave detection assisted by atomic vapours [3], here we present a simple realisation of room-temperature microwave-to-optical converter [4] of a 13.9 GHz field to an infrared 776 nm beam. The microwave transition between Rydberg atomic levels, accessed with laser fields, enables this process.

Despite operating with Doppler-broadened energy level spectra of atomic vapours, we exhibit the converter's reliability and versatility. With the use of optical single-photon counter we demonstrate the readout of converted photons spanning over 57 dB of intensity, with 16 MHz of conversion bandwidth. These properties, coupled with extremely low intrinsic noise, allow us to show the conversion of microwave thermal radiation at room temperature. To support this claim, we perform temporal autocorrelation measurements on the converted field, revealing Hanbury Brown and Twiss effect of thermal photons and thermal-coherent fields' interference.

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Observation of superradiant bursts in waveguide QED

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Dicke superradiance describes the collective decay dynamics of a fully inverted ensemble of two- level atoms. There, the atoms emit light in the form of a short, intense burst due to a spontaneous synchronization of the atomic dipoles. Typically, to observe this phenomenon, the atoms must be placed in close vicinity of each other. In contrast, here we experimentally observe superradiant burst dynamics with a one-dimensional ensemble of atoms that extends over thousands of optical wavelengths. This is enabled by coupling the atoms to a nanophotonic waveguide, which mediates long-range dipole-dipole interactions between the emitters. The burst occurs above a threshold atom number, and its peak power scales faster with the number of atoms than in the case of standard Dicke superradiance. Moreover, we study the coherence properties of the burst and observe a sharp transition between two regimes: in the first, the phase coherence between the atoms is seeded by the excitation laser. In the second, it is seeded by vacuum fluctuations. Our results shed light on the collective radiative dynamics of spatially extended ensembles of quantum emitters and may turn out useful for generating multi-photon Fock states as a resource for quantum technologies.

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Analysing nonlinearity of atomic arrays using a Green's function approach to time evolution

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Sub-wavelength atomic arrays, which have been found to have remarkable linear optical properties [1, 2], are in themselves only weakly nonlinear due to their collective interaction with photons, despite the underlying nonlinearity of the individual saturable atoms. We have found that by putting together two such arrays, we can recover the nonlinearity via an emergent cavity-like behaviour with a large delay time that allows photons to interact strongly before being emitted from the system [3]. As a complement to a previous numerical analysis, we will study this system analytically using a Green's function approach to calculate the dynamics of the system and the interaction of the photons using the T-matrix. This allows for writing the two-photon correlation functions of the system analytically and an effective Hamiltonian for the interacting photons. We will thus study the nature of the photon-photon interaction and the many-body physics of the system. As an initial step to this, the analysis has been performed for a single array, yielding the two-photon temporal correlation and the two-photon momentum density.

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Effect of an optical dipole trap on resonant atom-light interactions

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The optical properties of a fixed atom are exquisitely well-known and investigated. For example, one important phenomenon is that the atom can have an extraordinarily strong response to a resonant photon, as characterized by a resonant elastic scattering cross section given by the wavelength of the transition itself, $\sigma_{sc} \sim \lambda^2$. The case of a tightly trapped ion, where the ground and excited states are equally trapped, is also well-known [1]. Then, the elastic cross section is reduced by a fraction corresponding to the square of the "Lamb-Dicke parameter", while this same parameter also dictates the probability of inelastic scattering that gives rise to motional heating.

In contrast, there are many emerging quantum optics setups involving neutral atoms in tight optical dipole traps, such as coupled to nanophotonic waveguides and cavities or in atomic arrays [2, 3], where the goal is to utilize efficient atom-light interactions on resonance. Often, while the ground state is trapped, the excited state may in fact be untrapped or even anti-trapped. Here, we systematically analyze the consequences that this unequal trapping has on reducing the elastic scattering cross section, and increasing the motional heating rate. This analysis may be useful to optimize the performance of quantum optics platforms where equal trapping cannot be readily realized.

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Using single atoms in optical cavities as efficient source for multiphoton graph states generation

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Generating multiphoton entangled states is an essential step for the utilization of quantum information protocols such as measurement-based quantum computation (MBQC). So far, the most widely employed source of entangled photons has been spontaneous parametric down conversion, where scaling up to larger photon numbers is dramatically limited by the intrinsically probabilistic nature of the photon emission process. We now experimentally demonstrate [1] the feasibility of a single Rubidium atom in an optical cavity (Fig.1.a) as a highly efficient source of multiphoton graph states. We use the atom to mediate the entanglement generation between the photons and we efficiently grow GHZ states of up to 14 photons and linear cluster states of up to 12 photons. With an overall generation, propagation and detection efficiency of 43% per photon (Fig.1.b), our experiment opens a way towards scalable MBQC, where our scheme could be extended to multiple atoms in a cavity in order to generate higher-dimensional cluster states[2].

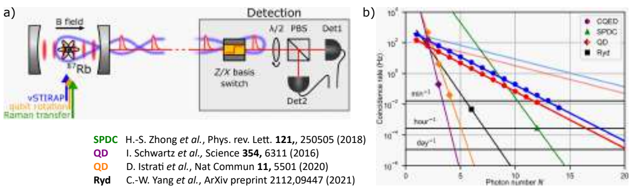

FIG. 1. a) An atom is trapped in an optical cavity and multiple laser beams drive Raman transitions, perform single qubit rotations and produce single photons. The photons are measured with a setup that can switch between two settings of the measurement basis. b) Scaling of the coincidence rate for a N-photon state. Our data are in blue (GHZ) and red (cluster).

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A quantum frequency converter for the connection of rubidium atoms in a cavity over long distances

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Rubidium (Rb) atoms in a cavity are a promising platform for realising long-distance quantum networks as the atomic ground states can be efficiently entangled with optical photons [1]. However, photons entangled with Rb atoms are typically at a wavelength (λ_{Rb} = 780 nm) which is unfavourable for long-distance communication due to intrinsic fiber losses in this regime. To efficiently transport the quantum information encoded in optical polarisation qubits over long distances, wavelength conversion to the telecom regime (λ = 1460 - 1565 nm) is necessary.

Here, we demonstrate such a polarisation conserving quantum frequency converter (QFC) in a Sagnac configuration [2] and investigate the possibilities of increasing the signal-to-noise ratio (SNR) by choosing a suitable final wavelength. Provided a good SNR and high fidelities can be achieved, the QFC represents one of the many necessary building blocks to establish a long distance quantum network. Furthermore, it can be used to connect diverse platforms operating at different wavelengths, with the goal to form a hybrid quantum network which takes advantage of the specific capabilities of each subsystem.

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Entanglement Distribution - Towards a Suburban Quantum Network Link

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A quantum network comprises of multiple quantum nodes which are capable of storing and processing quantum information and which are connected by links to share entanglement between them. A crucial task for such a quantum network is to distribute entanglement between any of these quantum nodes, also over large distances. For this, a quantum node requires an efficient light-matter interface, long coherence times, and connection to a low-loss quantum channel.

Here we present a neutral atom-based quantum node with 7 ms coherence time. We prolong the coherence time of the memory by employing a state-selective Raman transfer that changes the encoding of the atomic qubit [1]. Moreover, efficient polarization-preserving quantum frequency conversion provides a telecom interface for the quantum memory and hence minimizes photon loss in optical fibers [2]. This finally enabled us to show atom-photon entanglement distribution over 101 km telecom fiber with a fidelity $\geq 70.8\%$.

A future project is to generate heralded entanglement between a single-atom at the MPQ [3] in Garching and a single-atom at LMU in downtown Munich - approximately 14 km line-of-sight apart. We sketch the planned set-up and give first estimates of fidelity and possible entanglement generation rates.

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Long Abstracts

Cavity-mediated interactions between pair of atoms and generation of entangled states of bosons in an optical cavity

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The development of quantum technologies, such as quantum-enhanced metrology, relies on generation of nonclassical states of matter or light. A promising route for tuning the interactions between atoms is offered by photon exchange in optical cavities as it leads to effective long-range interactions that competes with short-range van der Waals potential.

Recently, formation of pair-polaritons formed by strong coupling between cavity photons and pairs of atoms in an ultracold atomic gas was experimentally demonstrated [1]. In our study we extend this concept to cavity-mediated interactions between pair of atoms and investigate their induced effective interactions. We show that coupling cavity photons to molecular states in the dispersive regime generates short-range interactions that are sensitive to the state of photons.

We investigate the application of our approach on atoms confined in a double well potential within an optical cavity. We show that the effective interaction can be a source of nonclassical states of light and enable control over generation of entangled states of atoms. Our findings provide novel insights into formation of correlated states of matter with potential applications in quantum technologies.

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Optical spectrum to position converter for spectro-temporal processing based on quantum memory

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Spectro-temporal processing of light plays a crucial role in quantum optics and quantum communication. Reconstruction of the spectral profile of impulse is the basic tool in spectroscopy. Here we propse a protocol that allows performing spectrum-to-position mapping. The experiment is based on gradient echo quantum memory (GEM) in ultracold rubidium-87 atoms. Atoms are trapped in magneto-optical trap (MOT) and slowed to the temperature of few micro kelvins. The memory utilizes two-photon Raman transition to map signal pulse onto atomic coherence. During the write-in process, atomic ensamble is placed in constant magnetic field gradient allowing for frequency-to-position mapping along the propagation axis, thus different frequencies are absorbed into different parts of the atomic cloud. By illuminating atoms with far detuned beam we implement ac-Stark shift which allows as to impose spectral phase onto stored optical pulse, making different frequencies be emitted at different angles. This way we separate them in the far field of the ensemble and allow spectrally resolved detection. To characterize the converter we utilized custom sCMOS camera with image intensifier sensitive to single photons, making this protocol suitable for single-photon-level pulses. We have achieved a spectral resolution of 150 kHz that is unachievable for diffraction grating spectrometers.

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Automated characterisation of alkali vapour-cells for magnetometry

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The sensitivity of optically pumped magnetometers (OPMs) have matched and even surpassed that of superconducting quantum interference devices (SQUIDs) [1], with a number of advantages including its lack of required cryogenic cooling, increased portability and reduced maintenance costs. This has brought about an increase of interest in the technology. Applications in magnetic imaging, such as medical magnetoencephalography (MEG) or current density imaging in electric vehicle batteries, require many sensor channels to create detailed maps of magnetic fields. One crucial component in the sensor head is the atomic vapour cell. Such cells can be manufactured at large scales using standard silicon microfabrication techniques. To analyse the quality of a large number of microfabricated cells, we developed a system consisting of an open source multipurpose 3-axis robot, mounted with a transmission spectroscopy setup, enabling the scanning of multiple cells in sequence via computer commands. The absorption lines in the scan can then be fit to linewidth broadening models, providing insight into the internal conditions of the cells. The automated quality analysis with our robotic system allows the calibration of manufacturing processes and selection of the vapour cells with desired parameters to be used in high-performance magnetometers.

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Neutral Atoms in Tweezer Arrays for Rydberg Hybrid Quantum Computing

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Neutral atoms trapped in optical tweezers show promise as an implementation of quantum computation. For example, the number of qubits can be scaled naturally by increasing the tweezer laser power.

In Eindhoven, we are constructing a tweezer machine that features strontium-88 atoms in an array of optical tweezers. The chosen qubit states are ${}^1S_0$ and ${}^3P_0$, which are connected by the doubly forbidden clock transition. Site-selective control of the clock laser onto the qubits will be done with the help of acousto-optic deflectors. Entanglement will be generated by coupling the ${}^3P_0$ state to a ${}^3S_1$ Rydberg state using 317 nm laser pulses.

The quantum processor will run hybrid variational type algorithms, for example pulse-based optimization algorithms, whereby the quantum processor runs in tandem with a classical processor. On the poster, we will show recent progress towards this goal: we elaborate on the design of the apparatus and show experimental results on trapping ultra-cold strontium atoms in "blue" and "red" magneto-optical traps (see fig. 1).

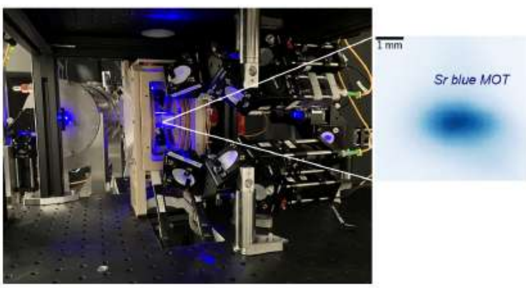

FIG. 1. Picture of the current state of our experiment, with a magneto optical trap (MOT) on the strontium-88 blue transition.

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Building a commercial quantum computer

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Trapped ions are among the leading candidate platforms for the implementation of quantum computation and simulation. This is primarily attributed to their high controllability, long coherence times due to strong isolation from the environment and natural all-to-all qubit connectivity.

Among the major challenges facing the field of trapped ion quantum computation are scallability, robust high fidelity entangling gates and real-time quantum coherent feedback.

Quantum Art, a spin-off start-up company from the Ozeri group at the Weizmann Institute of Science, Israel, is a full-stack quantum computing systems company, based on trapped ion qubits [1, 2].

In my poster I will showcase the fundamental building blocks of a trapped ions quantum computing system, as well as some of the challenges in realizing such systems.

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A new ytterbium experiment for single-atom resolved many-body physics

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Cold atomic systems provide a unique playground for exploring quantum many-body phenomena, owing to an exceptional control over Hamiltonians and to their long coherence times. Novel techniques for the manipulation and detection of individual atoms have recently allowed to further increase the degree of control to the single-atom level. In particular, optical tweezer arrays allow the realization of programmable quantum systems for exploring quantum simulation and quantum information schemes. Here I will report on the ongoing development of a new ultracold atom experimental apparatus, where we will employ optical tweezers to manipulate and detect individual ytterbium atoms. Such degree of control will allow us to engineer artificial quantum systems for investigating mesoscopic many-body systems with a bottom-up approach. The peculiar features of ytterbium make it ideal for tackling open questions both in quantum impurity problems and collective light-matter interactions. The long-lived clock state provides a natural choice for the implementation of orbital impurities, displaying either ferromagnetic or antiferromagnetic coupling to ground state atoms as well as optically tunable mobility. We will trigger and monitor the dynamics of many-particle systems with the precise tools of two-electron atoms interferometric spectroscopy. We will also exploit the rich internal structure of ytterbium to isolate two and three-level systems which show great potential to implement new laser cooling schemes and collective atoms-light interactions.

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Atomic Mach-Zehnder Interferometer with Trapped Bose-Einstein Condensates

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Trapped atom interferometers are important tools for the measurements of forces with high spatial resolution. My work is based on the realization of a Mach-Zehnder interferometer with Bose-Einstein condensates of ^{39}K trapped in double-well potentials (DWs). The DWs are obtained with an innovative optical potential [1] that uses the superposition of three standard optical lattices with commensurate wavelengths. That allows to implement three identical DWs working simultaneously. Having more than one correlated interferometers is useful, since it's possible cancel out the effect of common sources of noise acting on the three DWs via differential analysis and relize a trapped atom gradiometer.

In our system we can finely tune interactions via a broad Feshback resonance, changing the two-body scattering length from positive to negative values. This allows us to operate the interferometer without interactions and with long coherence times.

We are also working on the possibility of generate number squeezed states in our system introducing repulsive interactions. Exploiting non classic states at the interferometer's input will allow us to enhance the sensitivity of our sensor beyond the standard quantum limit.

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Investigation of the generalized Euler characteristic of microwave networks split at edges

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Quantum graphs are networks of bonds and vertices that provide an efficient model system for studying quantum dynamics in closed and open systems with chaotic classical behavior. In current study, We show that there is a relationship between the generalized Euler characteristic $\mathcal{E}_o(|V_{D_o}|)$ of the original graph that was split at edges into two disconnected sub-graphs $i = 1, 2$ and their generalized Euler characteristics $\mathcal{E}_i(|V_{D_i}|)$. Here, $|V_{D_o}|$ and $|V_{D_i}|$ denote the numbers of vertices with the Dirichlet boundary conditions in the graphs. Theoretical predictions are verified experimentally using microwave networks which simulate quantum graphs. We demonstrated that the evaluation of the generalized Euler characteristics $\mathcal{E}_o(|V_{D_o}|)$ and $\mathcal{E}_i(|V_{D_i}|)$, $i = 1, 2$ allow us to determine the number of edges where the two subgraphs were initially connected.

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Long Abstracts

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Quantum Computing Demonstrator based on neutral Strontium-88

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Alkaline earth atoms trapped in arrays of optical tweezers are a promising platform to realize quantum computers and quantum simulators. Based on a long history in realizing optical atomic clocks, qubits can be encoded between the ground and excited clock state of Strontium-88. Interactions between individual atoms as well as two-qubit gates can be induced by coupling to highly-excited Rydberg states. However, up to now, the sizes of arrays that were prepared as well as the limited two-qubit gate fidelity have prevented reaching the regime where classical computers are outperformed.
Within this project, we aim at overcoming both of these limitations by realizing an array of up to 400 qubits with single qubit control and two-qubit gate fidelities exceeding 99%. The technical developments to achieve these goals will be undertaken within the Munich Quantum Valley initiative together with several partners in industry and academia. Our work will bring neutral-atom quantum computers en par with other approaches and open the path to running quantum algorithms in a classically intractable regime.

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Trapped ions in optical tweezers

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Quantum simulation provides insight into the dynamics of complicated systems through more controllable ones. We plan to implement a novel platform for quantum simulation using 2-dimensional $^{171}Yb^{+}$ ion crystals in a Paul trap with optical tweezers [1]. The hyperfine splitting of the ground state of the ions is used as a qubit transition and the interaction between the qubits is mediated by the phonon modes in the crystal. The optical tweezers provide an additional trapping potential thereby changing the phonon mode spectrum. We can thus increase the range of Hamiltonians which are otherwise not accessible [2].

We are using a high power infrared laser far detuned from any transition which creates a deep trapping potential while keeping the photon scattering rate to a minimum. The tweezer pattern is generated by a Spatial Light Modulator. In this poster, I will describe the experimental setup and the creation and optimisation of the tweezer pattern.

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Design of an optically pumped magnetometer based on hot atomic vapor targeted at medical diagnostics

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Optically pumped magnetometers (OPMs) pose an alternative to the conventionally used superconducting quantum interference devices (SQUIDs) in the field of diagnostic medicine. Many applications in this field require the measurement of tiny magnetic fields, i.e., magnetoencephalography (MEG) or magnetocardiography (MCG)[1].

We demonstrate and compare several techniques for the development of an optically pumped magnetometer (OPM) based on hot atomic vapor enclosed in MEMS vapor cells which should ultimately be applicable for the aforementioned medical diagnostics purposes. In addition to providing a theoretical description of the OPM dynamics and the overall working principle, technical challenges that arise in the experimental realization of a laboratory prototype are discussed. Several performance criteria[2] of the OPM such as sensitivity and bandwidth are weighted against one another and the trade-offs between those metrics are discussed, leading to a selection of different OPM implementations.

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Laser cooling alkali earth-like atoms and molecules in the deep ultraviolet

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Ultracold molecules have been proposed as useful tools in many emerging quantum technologies, such as quantum simulators [1], high-precision clocks to search for variations in fundamental constants [2], as well as ultra-precise sensors to probe new physics beyond the Standard Model of particle physics [3].

In this work, we present our recent progress towards laser cooling Cd atoms and polar AlF molecules in the deep ultraviolet near 228 nm. AlF is a very promising candidate molecule to create an ultracold gas of polar molecules at a high phase-space density using direct laser cooling. We produce the molecules in a cryogenic helium buffer gas beam [4] and aim to capture and cool them in a magneto optical trap (MOT), followed by narrow-line cooling or sub-Doppler cooling. To test the deep UV laser systems, the slowing and efficient capture from a pulsed cryogenic beam we use Cd atoms. Cd has very similar properties to AlF, but is significantly easier to cool and trap. Here, we present recent simulations of a Cd beam and compare them to the experiment, investigating MOT capture velocities as well as efficiency of a Zeeman slower, under various beam conditions.

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[4] S. C. Wright *et al.*, *Molecular Physics*, e2146541, (2022)

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Table-top Ultra-stable Optical Cavity as a kHz Gravitational Wave Bar Detector

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We propose to use a cryogenic table-top ultra-stable cavity made from present-day components as a resonant-bar detector with sensitivity superior to other resonant-mass detectors in the kHz frequency regime. The cavity bar-like resonator can be treated as a damped harmonic oscillator driven by a gravitational wave (GW) force [1], where the gravitational radiation amplitude is translated into the cavity length variation with known transfer function. Using two perpendicularly positioned cavities we can measure the change in length of one of them by reading out the beat note between the lasers locked to the cavities modes. The ultimate detector's limit is set by thermodynamical fluctuations of the cavity elements (i.e. spacer, substrates and coatings) which can be expressed quantitatively using fluctuation-dissipation theorem [2].

We calculated GWs signals and strain sensitivities for different combinations of the cryogenic single-crystal silicon cavities with crystalline coatings [3]. We demonstrate that an ultra-stable cavity detectors with a spacer length below 2 meters covers 2-20 kHz frequency spectrum. This range of GWs signal is very promising for the observation of such sources as neutron stars merger (NS-NS) [4], subsolar-mass ($< 1\mathrm{M}_{\odot}$) binary black holes (BHs) merger [5], and ultralight bosons (as axions and axion-like particles) formed through a black hole superradiance [6]. The latter is one of the possible solution for the strong CP problem [7] and dark matter puzzle [8].

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Two-colour ultra-stable optical cavity

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We develop an ultra-stable optical cavity that operates at two wavelengths, namely 1064 nm and 908 nm. The purpose of the dual-wavelength ultra-stable optical cavity is to facilitate accurate spectroscopic measurements of the narrow clock lines of Hg atoms.

In the context of a typical atomic clock, the ultra-stable optical cavity plays an indispensable role. It facilitates tight stabilisation of the clock laser's frequency to the optical resonance of the cavity, which enables the transfer of stability between the cavity length and the laser frequency. The spectral narrowing of laser line offered by ultra-stable cavity can be also utilised for various other studies. For instance, it can enable precise atomic spectroscopy and accurate measurements of isotope shifts. This can serve as a foundation for accurate studies of King plot linearity, a promising experimental technique for exploring new fundamental interactions. We have already applied this method in isotope shift spectroscopy and the determination of nuclear parameters of mercury [1, 2].

Significant improvement can be achieved by utilising the exceedingly narrow transitions, namely $^1\mathrm{S}_0 \rightarrow {}^3\mathrm{P}_0$ and $^1\mathrm{S}_0 \rightarrow {}^3\mathrm{P}_2$, which have natural linewidths below 1 Hz [3]. To realise this, we have developed a dual-wavelength ultra-stable optical cavity that can operate simultaneously at 1064 nm and 908 nm.

These wavelengths correspond to the Hg clock transitions at 266 nm and 227 nm before frequency quadrupling. The utilisation of the cavity enables precise fundamental research based on King-plot analysis with isotopically-rich cold mercury atoms [4], which holds promise for experimental verification of the Standard Model [5].

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Differential Displacements in Multi-spatial Mode Squeezed Light

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A coherent beam can be viewed as a continuous stream of photons travelling through space. Assuming their generation is a random process and they do not interact with themselves we can then intuit that the photon's distribution is poissonian. This leads to random intensity fluctuations on the beam, often referred to as shot noise; this is a limiting factor in many systems. A technique known as squeezing can be used to drop this intensity noise, at the expense of increasing phase noise. In this way, Heisenberg's uncertainty principle is still adhered to.[2]
In recent years, ways of producing squeezed light have been studied extensively. One method, four wave mixing (4WM) in an atomic vapour, has been shown to produce two beams with a correlated intensity distribution. Therefore, the intensity difference between them is squeezed. Even localised regions of the beams are correlated in intensity, so squeezing occurs in multiple spatial modes within the beam. [1]
It is hopped that one day this MSM squeezing could be used to produce quantumly enhanced images. However, there have been significant challenges in realising this. This is believed to be due to a differential displacement caused by the 4WM process itself. This leads to the correlated regions not being in an expected place in each beam. As such, the focus of this work largely concerns the identifying and untangling this phenomena.

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Long Abstracts

Quantum Degenerate Mixtures of Cs and Yb: Beyond Mean Field Physics

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Dual-species ultracold atom mixtures are a useful platform for studying quantum fluids, the mean field of which are encapsulated in the Gross-Pitaevskii equation. Beyond mean-field effects, such as those described by the famous Lee-Huang-Yang (LHY) term [1], are usually obscured by the stronger mean-field interaction. However, through careful control of the interspecies and intraspecies interactions in a two-species quantum degenerate gas, the dominant mean-field interaction can be nulled, allowing studies of the quantum fluctuations described by the LHY term. This can lead to novel bound states such as the formation of self-bound quantum liquid droplets [2].

We present details of our experiments on quantum degenerate mixtures of Caesium and Ytterbium. The highly tuneable intraspecies scattering length of Cs as well as the many available Bosonic and Fermionic isotopes of Yb allow us to study Bose-Bose and Bose-Fermi mixtures of Yb and ^{133}Cs over a range of interspecies scattering lengths. We demonstrate the producion of a dual-degenerate gas of Cs and Yb atoms in a bichromatic optical dipole trap [3] and explore its stability [4]. Additionally, we study the polarizability of Cs in a tuneable 460nm optical lattice. We identify two tune out wavelengths[5] where the polarisability of Cs is zero and describe how such wavelengths will allow us to study quantum degenerate mixtures and droplet formation in mixed dimensions.

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Stationary, dynamic and thermal properties of quantum droplets

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We present our findings with regards to quantum droplets that differ from the usual extended form in 3D by being flattened, elongated, or at nonzero temperature, but not yet in a hard low dimensional regime that would modify the LHY term.

We compare the Bose-Bose droplet stability at zero and finite temperatures. We demonstrate an effective low dimensional theory for description of the quantum droplets in the flattened and elongated regimes. As a benchmark of the effective theory, we studied droplet dynamics in the case of collisions, showcasing similarities and differences compared to regular 3D droplet collisions.

For finite temperature cases we show existence of a critical temperature above which droplets exhibit finite lifespan.

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Rymax-One: A neutral atom quantum processor to solve optimization problems

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Quantum computers are set to advance various domains of science and technology due to their ability to efficiently solve computationally hard problems. A particular interest is directed toward combinatorial optimization problems, as their solution could provide the basis for optimal supply chains or efficient vehicle routing. However, achieving a quantum advantage is still challenging due to the quality and scale of the available quantum computing hardware.

Here, we present our project Rymax-One, which aims at building a neutral atom quantum processor. More specifically, we will trap single ^{171}Yb atoms in arbitrary and reconfigurable arrays of optical tweezers, which will enable us to have hardware efficient encoding of optimization tasks, qubit realizations with long coherence times, Rydberg-mediated interactions and high-fidelity gate operations to realise a scalable platform for quantum processing.

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Electromagnetically-induced transparency cooling for ion-based qutrits

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One of the avenues to overcome the obstacles of scalability of quantum computers is to use discrete d-level quantum systems known as qudits, which are intrinsically present in most current quantum computing platforms. While qudits offer significant additional computational resources and allow for the natural implementation of a number of industrially relevant problems, the underlying theory of designing qudit computational primitives and their experimental implementation remain largely unexplored. An essential step for any computation will require sub-dopper cooling of the qudits. Here, we design and simulate an electromagnetically-induced transparency cooling scheme for the $^{176}\mathrm{Lu}^{+}$ ion where hyperfine states in the $^{3}D_{1}$ level form a qutrit. Moreover, we propose a scheme based on mutually unbiased basis which can be used for full-state tomography [1, 2].

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Quantum protactor

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Quantum metrology aims at precise measurements of physical quantities using quantum-mechanical principles. The recent advancement of the field originates from the development of more accurate and precise measurements at a quantum level. For that, the creation and control of quantum states sensitive to external perturbation are of a paramount importance.

Here, we present our experimental studies on the reconstruction of a quantum protractor state of a spin-1 system [1], which is an optimal metrological resource for detecting rotations. A unique property of such a state is that, under rotations around three orthogonal axes by angles of 0, $2\pi/3$, and $4\pi/3$, it transforms into mutually orthogonal states. In our experiment, the protractor state is generated in an $F = 1$ ground state of a room-temperature ^{87}Rb vapor, which is first optically pumped into $m = 0$ Zeeman sublevel, and then the state is rotated by $-\pi/4$ around the x-axis and next by $\arccos(1/\sqrt{3})$ around the z-direction. In such a way the atoms are prepared in the protractor state.

The protractor state properties are investigated using quantum-state tomography that is based on polarization rotation of linearly polarized probe light traversing the vapor [2]. The tomography enables to verify the initial protractor state, as well as investigate state of the ensemble after each individual rotation. We present that the coherence, which we measure during experiment, encodes the entire information about axes and the angle of the applied rotations. We thus demonstrate a preparation and full control of an important quantum metrological resource state.

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Optical tweezer arrays of alkaline earth-like ytterbium atoms

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Neutral atoms have shown to be a promising candidate for building large scale quantum computing devices, with fast high-fidelity single and two-qubit gates as well as flexible initialisation and readout [1].

Recently, alkaline earth (-like) atoms such as Ytterbium (Yb) and Strontium (Sr) have shown to offer promising ways to overcome some of the main challenges on the road to large scale, fully programmable quantum computers with decent effective circuit depth. Triple optical trapping allows to extend the coherence and lifetime of the involved Rydberg states dramatically, while optical addressing of the second valence electron gives rise to additional manipulation and detection tools for these Rydberg states. Additionally, an optical coherent qubit mapping scheme enables mid-circuit measurements and advanced error correction techniques.

Here, we present our progress towards a fully programmable Yb quantum computer, with emphasis on the generation and optimization of an arbitrary, homogeneous optical tweezer array using a spatial light modulator (SLM), as well as generating a movable dipole trap using acousto-optic deflectors (AODs) for sorting of single atoms. We give an outlook on our envisioned cooling and qubit manipulation schemes.

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Individual cold atoms as single-photon detectors

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LIDAR and free-space optical communications applications require high detection efficiency within a known detection band, together with high rejection of out-of-band background light. An established solution is SPAD detection after a Faraday atomic rotation optical filter (FADOF [1]), which employs GHz-bandwidth optical resonances in atomic vapors. In systems with low transmitter power and/or high link losses, detector dark counts can also be a limiting factor. Here we study theoretically and experimentally the use of laser-cooled single- or few-atom systems in optical microtraps as narrowband, ultralow-dark-count photodetectors with absolute frequency stability. This approach promises orders-of-magnitude improvement in dark counts and out-of-band rejection relative to state-of-the-art FADOF-SPAD and also FADOF-SNSPD, while preserving useful detection efficiency [2, 3]. These qualities are, more generally, attractive for applications in which a low power signal must be detected against a stronger optical background.
The solution we describe is a quantum jump photodetection (QJPD) technique for measuring single photons using a single neutral 87Rb atom in a strongly-focused optical dipole trap [3, 4]. We report results for the main dark count contributions: spontaneous Raman transitions driven by readout light (which can be avoided by separating the detection and readout time windows) and spontaneous Raman transitions driven by trap light (which is unavoidable but gives dark count rates two orders of magnitude below that state of the art single-photon detectors). We quantify the frequency selectivity with the equivalent noise bandwidth, which we find is up to two orders of magnitude narrower than the best atomic filters.

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3D Anderson transition with ultracold atoms

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The study of disordered systems with ultracold atoms has attracted much attention over the past decade, particularly to investigate the Anderson transition that occurs in three-dimensional systems between localized and diffusive states. However, significant discrepancies have been reported between experiments and numerics about the precise location of the mobility edge (energy of the transition), rendering new investigations desirable.

In this poster session, we will present recent progress along that line, including measuring the spectral functions in laser speckle disordered potential, the configuration of double speckles, and the controlled spectroscopic transfer of atoms to create well-defined energy states. By scanning the energy across the mobility edge, this method enables precise measurement and direct observation of the 3D Anderson transition, which enhances our understanding of the critical regime. Preliminary measurement applying this method has shown promising results of mobility edge. [1, 2].

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Coherent transmission of light through a dense cloud of cold atoms

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The main objective of this research is to study a particular case of the light-matter interaction: light diffusion in dense samples. In dense clouds, short-range atomic interactions cannot be neglected and in these systems we can observe the emergence of collective effects such as sub or super radiance [1]. In this work, an experimental arrangement is proposed to obtain a dense cloud of ^{88}Sr and then study collective effects in that ensemble of atoms. The first experiments to be carried out consist in measuring the coherent transmission of a low intensity beam by the cloud [2]. For this, we will use an incident light close to the resonance with a $J = 0 \leftrightarrow J = 1$ ^{88}Sr transition. Once experimentally detected the coherent optical response of the dense cloud, we will make a comparison of the results with what it is expected by the theory based on the Coupled-Dipole Model. [3].

Keywords: Dense regime, Optical Dipole Trap, Coupled Dipole Model.

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A Permanent Manget Based Zeeman Slower Cold Atom Source for Dysprosium

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A large portion of atomic physics experiments relies on the loading of atom traps by cold atomic beams provided by either a Zeeman slower [1] or a two-dimensional MOT [2]. We are working on the development of a permanent-magnet-based Zeeman slower as a cold atom source for dysprosium (Dy) which has not yet been realized with heavy lanthanides except ytterbium [3]. A redesign of commonly used beam sources is beneficial regarding size, power consumption, and maintenance. Our approach relies on magnetic rods of custom shape and promises said improvements while severely reducing overall complexity. A following two-dimensional MOT stage is planned to redirect the atomic beam into any main experiment. Our work mainly consists of finding the ideal design, magnet shape, and engineering techniques to provide a proof of principle. We can already report promising results on the construction and measurements of the final design. The device can then easily be adapted to other atomic species and projects.

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Atom interferometry with ultra-cold atoms onboard a Zero G plane for space applications

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The ICE project (Interférométrie à source Cohérente pour l'Espace) aims to be a proof of concept for a space mission using quantum particles, i.e., atomic clouds of potassium and rubidium in a matter-wave interferometer to test the Weak Equivalence Principle in microgravity [2]. The whole experiment is adapted to the Novespace Zero G aircraft that provides 22 s of microgravity per parabolic trajectory. In parallel with the onboard experiments, a microgravity simulator installed in the laboratory allows the sensor head (200 kg) to be in weightlessness for 500 ms, with a high repetition rate. To increase the interrogation time and the sensitivity of the measurement, the production of ultra-cold sources in microgravity with all-optical methods is studied both on the simulator and onboard the Zero G plane. In microgravity with ultra-cold sources, a particular regime of atomic interferometry called double diffraction takes place [1], which we study theoretically and experimentally on the simulator. We report on the production of Bose-Einstein Condensates (BEC) in microgravity both on the simulator and onboard the aircraft, and on our first results of interferometry in the double diffraction regime .

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One-dimensional Bose gas with an atom chip

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One-dimensional (1D) interacting Bose gases offer a richness of physical regimes with striking specificities compared to three dimensions. For instance, in the strongly interacting regime, appearing at low temperature and large interactions, the hamiltonian of the system can be mapped into the one of non-interacting spinless fermions [1].

In order to access such physics, we have built a cold atoms experiment at Laboratoire de Physique des Lasers, relying on an atom chip, which allows for very anisotropic magnetic confinements. We are now able to reach a degenerate regime where the atoms occupy the transverse ground state of the trap and the physics is effectively 1D, in the weakly interacting regime.

In order to be able to reach the strongly interacting regime, a control over the atomic interactions is required. To this end, we plan to rely on a microwave-induced Feshbach resonance [2]. The atom chip encompasses a microwave waveguide allowing to reach large microwave amplitudes in the near field, needed to enlarge the width of the resonance. We are currently trying to locate the resonance and characterize it.

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Developing a Bose-Einstein condensate microscope

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Bose-Einstein condenstaes (BECs) are highly sensitive to magnetic fields in their environment. This property makes them an ideal probe for a microscope that maps the magnetic field distribution or current density in 2D samples such as novel nanomaterials. Our goal is to develop a BEC microscope which can detect magnetic fields on the order of hundred picotesla, and map the distribution of nanoampere currents with microscopic resolution. This combination of sensitivity and spatial resolution is not accessible with any existing imaging methods.

In order to characterise the novel materials, the BEC must be brought very close to the surface. In this region there is a large amount of scattering of the laser light which presents challenges when imaging the atoms. We present a novel imaging technique that eliminates imaging noise from the scattered light. Rubidium atoms are excited using 420 nm laser transition and their fluorescence is detected at 780 nm and 795 nm, allowing for efficient filtering of scattered laser light. The imaging system is optimised for a long working distance (13 cm) and 8x magnification, leading to a diffraction limited resolution of 3 um.

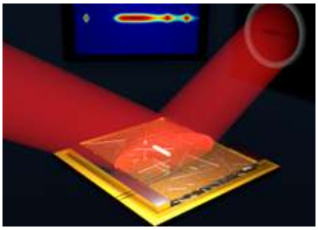

FIG. 1. The fragmented BEC imaged on top of the nanotube sample. The BEC fragmentation is caused by the magnetic fields generated by the current flowing through the sample below.

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Cold atom preparation for squeezed state atom interferometry

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Atom interferometers are precise measurement tools which have an extended range of metrological applications. The sensitivity of a classical atom interferometer, however, is fundamentally constrained by the shot-noise limit (SNL). It has been shown that with quantum-correlated atomic ensembles (spin squeezed states) one can surpass this limit [1]. In fact, many experiments have pursued this route, with the largest reduction of spin variance in an ensemble of 10^6 atoms being demonstrated in 2016 [2]. Even with this progress, there has yet to be producible "metrologically useful states" ie. entangled atomic ensembles which outperform their classical counterparts. In Onur Hosten's group, we plan to build an atom interferometer which utilizes both cavity-mediated and quantum non-demolition spin squeezing. Prior to loading the ring-cavity for the interferometry sequence it is necessary to precool the atoms with a magneto-optical trap - this was my primary objective for the first semester. I will present the optimization and cooling techniques we used which resulted in a temperature measurement of 5.6 micro-Kelvin for 8 million ^{87}Rb atoms.

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Sensing interactions in atomic quantum systems

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Experiments that cool, trap, and control atoms, ions, and molecules provide a unique testbed. Hybrid ion-atom systems combine the well-controllable platforms of trapped ions and ultracold quantum gases and link them together by the intermediate-range ion-atom interaction. These quantum systems offer opportunities for buffer gas cooling, quantum simulation of many-body systems as well as for state-to-state quantum chemistry [1]. To fully benefit from the combination, it is essential to understand, characterize, and control the interactions between the atoms and ions. Therefore, at TU/e a new experimental setup is being build which combines a trapped ion – Yb^+ - with dipolar atoms - Dy. This poster reports on the development of its design and how it can be used to sense interactions in these atomic quantum systems.

FIG. 1. CAD drawing of our designed ion trap. [2]

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Rayleigh-Taylor instability in a phase-separated three-component Bose-Einstein condensate

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We investigate the Rayleigh-Taylor instability at the two interfaces in a phase-separated three-component Bose-Einstein condensate in the mean-field framework[1]. The subsequent dynamics in the immiscible three-component condensate has been studied in detail for different cases of instigating the instability in the system. The rotational symmetry of the system breaks when the atom-atom interaction is tuned in such a way that the interface between the components becomes unstable giving rise to non-linear patterns of mushroom shapes which grow exponentially with time. We also identify these non-linear patterns as the solutions of the angular Mathieu equation, representing the normal modes.

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Optical Tweezer-Driven Gates on Trapped Ions

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Trapped ions are one of the most reliable systems for quantum computing, due to their long coherence times, high fidelity and long-range interactions. We plan to combine trapped $^{171}Yb^{+}$ ions with tightly focussed optical tweezers to test a novel two-qubit gate [1]. This tweezer-driven gate promises a high fidelity without needing ground-state cooling of the ions. The two-qubit gate is based on the optical Magnus effect [2]: an ion will, depending on its spin, be displaced off-axis by the strong polarization gradients of tightly focused optical tweezers. The optical tweezers thus couple the ion spin to the ion motion $\hat{x}_i$. Ions interact with each other through their collective motional modes. Describing $\hat{x}_i$ only in terms of the center-of-mass eigenmode results in an effective spin-spin Hamiltonian $\hat{H}_{eff} \propto \hat{\sigma}_z^{(i)}\hat{\sigma}_z^{(i)}$. This makes it possible to implement a two-qubit phase gate. To test it, we will generate an array of hollow tweezers on the ions using an Acousto Optical Deflector and a Spatial Light Modulator, with an accurate alignment down to tens of nanometers. These tweezers minimize photon scattering and AC Stark shifts. Moreover, the proposed setup enables high control of the beam shape while allowing fast switching between any ion pairs to implement the gates on. In this poster I will describe the tweezer-gate architecture and the experimental setup.

Long Abstracts

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Extending Spin-Noise Spectroscopy with single photons to the Poincaré sphere

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An efficient, deterministic light-matter interaction is required to scale future quantum networks. An important milestone is represented by the implementation of conditional operations on flying qubits with a single stationary qubit. As our matter qubit candidate we use a single electron confined in an InAs quantum dot (QD) embedded in an electrically contacted micropillar cavity. The flying qubit is encoded by the polarization state of the incoming photons that interacts with the spin degree of freedom of the confined electron.

In our work, we explore the interference between the reflected light from the cavity and the QD emission, phenomena at the core of large polarization rotations [1]. The system is under the influence of a transverse magnetic field and we study how the reflected polarisation states are affected by the spin. Detecting a first photon with a certain polarization modifies the spin state by performing a projective measurement (Fig. 1). While the spin evolves back to the stationary state, we monitor the polarization state of the reflected photons in the Poincaré sphere, which directly translates the spin dynamics in the Bloch sphere.

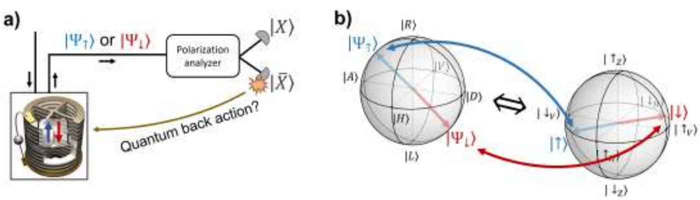

FIG. 1. a) Scheme showing the principle of a measurement back action. b) Detecting a photon in $|\Psi_\uparrow>$ (resp. $|\Psi_\downarrow>$) ideally projects the spin in $|\uparrow>$ (resp. $|\downarrow>$).

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A study of spin diffusive modes in high pressure vapour cells.

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Gaseous mixtures of alkali-metal and noble gas atoms are widely used in quantum optics and sensing due to the long-lived collective spin states of such ensembles [1]. We have constructed a co-magnetometer in a Bell-Bloom configuration using a glass cell containing Rubidium vapour mixed with a high pressure Neon buffer gas located inside a 4 layer mu-metal magnetic shield. In this setup, collisions between the alkali and the buffer gas have been observed to modify the thermal motion of the spins, establishing a diffusive regime where atoms arrange into distinct stable spatial modes within the cell [2, 3]. These spatial modes each contribute to the overall signal, and the collective spin dynamics are observed to be highly dependent on the overlap between the spatial modes and the pump/probe beams. We analyse these multi-mode dynamics, including the dependence on intensity and position of the pump/probe beams, and investigate the appearance of a potential coherent coupling between modes, resulting in non-trivial spin dynamics [4]. These results show that a multi-mode approach to the spin dynamics could be powerful tool in enhancing the performance of sensing devices, and also opens new avenues in quantum information and imaging with the realization of such optically accessible localised spin modes.

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Construction of a versatile Rydberg atom platform

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In recent years, atomic arrays emerged as a ground-breaking platform in quantum physics. These setups do not only feature single-atom control, additionally exciting addressable atoms to Rydberg states introduces further possibilities to study physical problems in different geometric configurations.

We plan to realize arbitrarily arranged two-dimensional arrays with up to 100 lattice sites, each of them containing one or a few atoms. The arrays are holographically generated by an SLM in combination with a 1064 nm YAG-laser. Via a two-photon Rydberg transition, we collectively excite the atoms to Rydberg states. Due to the long-range character of the resulting Rydberg interactions, an interaction of the atoms in and between lattice sites is also intrinsically given. This setup is a prime candidate to investigate both topological systems of single atoms as well as effects arising from many-body properties in a controlled manner.

Adding controlled microwave transitions between different Rydberg states and the incorporation of a second atomic species open up possibilities to study even more complex physical systems in future research.

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Quantum simulation with Rydberg states of erbium atoms

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Quantum simulation has become a promising avenue in research as it offers an efficient way of studying complex systems and solving problems in quantum physics. In this regard, lanthanide atoms provide an ideal platform for quantum simulation thanks to their large number of optical transitions, their anisotropic interaction properties, and their large spin space and magnetic moment [1]. Combining these powerful properties with the newly-established technique of optical tweezers provides exciting systems for quantum simulation.

We present our on-going efforts in implementing a quantum simulator utilising Rydberg states of erbium in an optical tweezer array. In a recent work, we have already identified hundreds of individual states in the erbium Rydberg series [2]. Recently, we started loading erbium atoms into our currently one-dimensional array of optical tweezers and we are now aiming towards expanding this array to a two-dimensional one of arbitrary geometry using a spatial light modulator (SLM). In the future, we want to superimpose the optical tweezer array obtained by the SLM with a moveable optical tweezer created by two AODs for rearrangement in order to create large-scale defect-free optical tweezer arrays.

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Atomic Frequency Comb Memory in Warm Rubidium Vapour

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Quantum memories are used as a means of scaling quantum networks. Protocols based on warm atomic ensembles allow for a large number of atoms with technical simplicity allowing for efficient operation at ambient temperatures. AFC is a photon echo quantum memory based on spectral shaping of an in homogeneously broadened transition into a frequency comb with spacing Δ [1].

A photon with a bandwidth equal to the width of the frequency comb can be collectively absorbed. Once the photon is absorbed, the ensemble collects phase, but due to the periodic structure of the combs the ensemble re-phases coherently after a time equal to $1/\Delta$ and the photon is re-emitted. Experimentally, this comb structure is achieved my modulating the narrow band laser in frequency space. We demonstrate this protocol in a warm Rubidium Vapour using a 2ns pulse of light with a storage time of 7.5ns.

[1] Mikael Afzelius, Christoph Simon, Hugues de Riedmatten, and Nicolas Gisin "Multimode quantum memory based on atomic frequency combs" Phys. Rev. A 79, 052329

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Towards a variable-geometry multiplexed strontium optical atomic clock

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In the last two decades, experimental platforms based on alkaline earth atoms in optical lattices have developed rapidly. Current state-of-the-art optical lattice clocks can reach levels of accuracy below 10^{-18}, making these clocks a unique platform for metrology and precision measurements. Meanwhile, in the last few years optical tweezers have pushed the possibilities of single optical qubit control and detection, opening new research possibilities for quantum simulation, quantum computing and metrology.

We are developing a new experiment with strontium atoms in optical lattices in which we plan to combine the unique flexibility offered by techniques used in optical tweezers with the high accuracy of 1D optical lattice clocks. Here, we report on the current state of our experiment and offer an outlook for our clock.

We also report on our measurements of the singlet $5s5p^1P_1 - 5s5d^1D_2$ transition. Our data improves the frequency accuracy by several orders of magnitude compared to previous measurements [1, 2].

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Towards Doppler Compensated Cavity Based Atom Interferometry

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A Mach-Zehnder type of atom-interferometer uses interference between different internal states of free-falling atoms to measure gravity, and has applications in civil engineering, navigation, and in fundamental physics such as searches for dark matter, tests of the equivalence principle, and as a mid-band gravitational wave detector [1]. A technique known as Large Momentum Transfer (LMT) aims to increase the sensitivity of atom interferometers by increasing the momentum separation between wavepackets by increasing the number of Raman pulses applied during the measurement sequence [1]. Errors due to wavefront inhomogeneity occur with every pulse, meaning efficient LMT requires homogeneous wavefronts [1]. Since the optimal pulse length is inversely proportional to laser power and the entire sequence has a limit on free-fall time, the pulse power must be increased to reach higher momentum separations. An optical cavity addresses these points by providing geometric filtering of higher order modes and resonant power enhancement, allowing for higher orders of LMT in a system with reduced size, weight, and power, and correspondingly increased sensitivity [2, 3]. However, Doppler shifts induced by gravity pull atoms away from the cavity resonance frequencies which must be compensated for to preserve power enhancement. We propose the use of an intra-cavity Pockels cell with a voltage-dependant birefringence to sweep the frequency of orthoganally polarised cavity modes in opposite directions to preserve the resonance condition for free-falling atoms [3].

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Long Abstracts

Towards a strontium Rydberg quantum simulator

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Ultracold neutral atoms have proven to be a suitable quantum simulation platform for the study of many-body physics. In the last decades, however, an emergent platform which combines excited atoms to Rydberg states and the capability of individually addressing them in optical tweezers has caught a lot of attention [1]. The magnitude and tuneability of their interactions makes them excellent to implement spin Hamiltonians, which is the long-term goal of our experiment.

In this poster, we describe the first steps towards the construction of a new ultracold atom experiment in which strontium Rydberg atoms will be trapped in a programmable tweezer array. Firstly, we motivate the interest in strontium Rydberg atoms. Then, we present an overview of the current status of the design of the experiment including the vacuum system, the electromagnetic field control and the system for laser cooling and trapping. Finally, we discuss future plans on the construction of the apparatus and its applications.

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Ultracold & Ultrafast: Towards probing ultrafast electron and ion dynamics of ionized ultracold quantum gases

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Ultrashort laser pulses provide new pathways for manipulating quantum gases on femtosecond timescales. A single femtosecond laser pulse can ionize up to several thousand atoms in a ^{87}Rb Bose-Einstein condensate, thus triggering the formation of a strongly coupled ultracold plasma. The large atomic densities combined with low ion temperatures (below 40 mK) result in an ultrafast electron cooling from initially 5250 K to about 10 K within a few hundred nanoseconds [1].

To further investigate these complex many-body systems as well as hybrid quantum systems involving few ions, electrons and atoms a novel coincidence unit consisting of an ion microscope and a velocity map-imaging (VMI) spectrometer has been developed [2]. With this detector, the ionization products can be simultaneously detected with spatial resolution of the ions and the momentum resolution of the photoelectrons. Simulations for the ion microscope suggest a resolution in the 100nm range, surpassing the optical resolution limit of quantum gas microscopes.

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Optimizing Faraday Rotation Measurements on BECs: Enhancing Precision through Frequency Control and Noise Reduction

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Faraday rotation measurements (FRM) are highly valuable due to their potential to behave as quantum non-demolition measurements under certain conditions. This unique property enables a wide range of applications, including magnetic field sensing, material characterization, optical isolation, and quantum information processing. Moreover, applying FRM to Bose-Einstein condensates (BEC) offers significant insights into the magnetic properties, dynamics, and quantum phenomena of the condensate.

To optimize FRM on a BEC, we have implemented an optical cavity that maximizes the interaction between atoms and light. The cavity incorporates lasers of two different wavelengths, namely 780nm and 1560nm. While the stability of the optical cavity is maintained through the Pound-Drever-Hall (PDH) technique using the 1560nm laser, the cavity itself is influenced by environmental conditions due to a piezoelectric control mechanism. These environmental variations introduce additional noise to the system by altering the resonator frequency for the 780nm laser.

To address this challenge, we have developed a frequency locking system controlled by an Arduino and equipped with a maximum search algorithm (MSA). The implementation of this system has yielded promising results, reducing the noise after the cavity by 15% compared to the system without the algorithm. Consequently, we can approach the shot noise limit more closely, enhancing the precision and sensitivity of our measurements.

By combining Faraday rotation measurements, optical cavities, and advanced control techniques, we aim to advance our understanding of magnetic phenomena, enable precise measurements, and explore the potential applications of BEC in diverse fields of research.

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Variational Quantum states for Eigenstate Thermalization Hypothesis violation in NISQ-era.

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This project investigates Quantum Many-Body Scars (QMBS) in a PXP Model, capturing the Rydberg blockade phenomenon in a Rydberg chain. QMBS has been shown to exhibit weak ergodicity breaking, indicating a weak violation of the Eigenstate Thermalization Hypothesis (ETH). The project utilizes hybrid quantum-classical machine learning techniques, specifically applying automatic differentiation methods and gradients of objective functions. This allows for the discovery of the parametrized quantum circuit expression of these states. The Variational Quantum Eigensolver (VQE) serves as an example of such techniques. The project aims to find the optimal set of rotation gates and parameters defining the target state, enabling their implementation on a quantum computer. This work can be the first step in further studies in order of understanding the thermalization dynamics of local observables and the violation of the Eigenstate Thermalization Hypothesis.

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Quantum Rayleigh-Taylor instability in two dimensional Bose gases

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Hydrodynamic instabilities are present in a wide variety of everyday phenomena. Ocean waves, the organization of water droplets into a spider's web, and the mushroom clouds resulting from volcanic eruptions are all examples of such instabilities. In the case of quantum fluids, quantum hydrodynamic instabilities, analogous to those of classical fluids, are related to the superfluid properties of these systems. An example in this direction is the quantum Rayleigh-Taylor instability that can be systematically studied in ultracold gas systems thanks to the high level of control and detection of these systems. [1] In this project, we propose to excite the quantum analogue of the Rayleigh-Taylor instability in a two-dimensional degenerate Bose gas and the subsequent study of the dynamics of the excitations arising from this instability. For this purpose, a new experimental system will be built combining the latest technologies used in this type of experimental [2] system in order to enable the creation of two-dimensional gases with tunable interaction and subject to arbitrary potentials and perturbations, guaranteeing the necessary conditions for the unprecedented observation of the Rayleigh-Taylor in this context.

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Dark Energy search using atom interferometry in microgravity

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The nature of Dark energy is one of the biggest quests of modern physics. It is needed to explain the accelerated expansion of the universe. In the chameleon theory, a hypothetical scalar field is proposed, which might affect small test masses like dilute atomic gases. In the vicinity of bulk masses, the chameleon field is hidden due to a screening effect making the model in concordance with observations. Dark Energy Search using Interferometry in the Einstein-Elevator(DESIRE) studies the chameleon field model for dark energy using Bose-Einstein Condensate of ^{87}Rb atoms as a source in a microgravity environment. Einstein-Elevator provides 4 seconds of microgravity time for multi-loop atom interferometry to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity. This method suppresses the influence of vibrations, gravity gradients and rotations via common mode rejection. The specially designed test mass suppresses gravitational effects from self-mass and its environment[1]. This work will further constrain thin-shell models for dark energy by several orders of magnitude.

[1] Sheng-wey Chiow, Nan Yu *Phys. Rev. D* **97**, 044043 (2018).

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Waveguide QED with Rydberg superatoms

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The field of waveguide QED investigates how light in a single mode propagates through a system of localized quantum emitters. Such systems offer an interesting platform for quantum nonlinear optics. We work towards realizing a cascaded system in free space by using Rydberg superatoms as directional effective two-level systems.

We realize these Rydberg superatoms by exploiting the Rydberg blockade effect of atomic ensembles. By confining $N \approx 10.000$ atoms to a single blockaded volume, the ensemble only supports a single excitation creating an effective Rydberg superatom. Due to the collective nature of the excitation, the superatom effectively represents a single emitter coupling strongly to single photons. The directional emission of the superatom into the initial probe mode realizes a waveguide-like system in free space without any actual light-guiding elements [1].

On this poster we demonstrate how a single Rydberg superatom strongly couples to an incident low-photon light field and how the chain of such superatoms can be used as a few-photon absorber in the fast dephasing regime [2]. We show our progress towards implementing a magic-wavelength optical lattice that will enable us to reduce the motional dephasing of the collective excitation. This in turn will give us an opportunity to measure cascaded interaction between Rydberg superatoms mediated by single photons [3].

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Strapdown multi-axis inertial quantum sensor

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The Joint Laboratory iXAtom (Bordeaux, France) brings together the knowledge of Exail, an industrial expert in inertial navigation and industrial quantum sensors, and the LP2N, a public laboratory specialized in atom interferometry. The goal is to perform technological advances using cold atoms to develop the next generation of inertial sensors for geophysics and navigation applications. We build a compact and transportable 3-axis Raman interferometry sensor. Our goal is to validate a "strapdown" strategy by tackling the issues of vibrations and rotations using hybridization.[1](FIG. 1)

I work on the hybridization of the inertial sensor with gyroscopes to compensate rotation effects. We are performing a mirror orientation correction stage and a phase correction stage to retrieve the atomic fringes and make reliable acceleration measurements.[2]

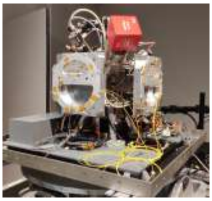

FIG. 1. The inertial sensor

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Quantum Thermodynamics in Ultracold Mixtures - Towards Single Atom Quantum Heat Engines

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Our experiment is devoted to the study of quantum thermodynamics and aims to realise a single atom quantum heat engine. We take advantage of low-field interspecies Feshbach resonances to control the interactions between an ultracold atomic bath of ^{87}Rb and a single ^{41}K atom which is trapped within a species-selective optical tweezer. Engine cycles, including the Carnot, Otto and Diesel engine can then be achieved by the implementation of basic quantum thermodynamic transformations using these tunable interactions [1]. Our current research probes how the feshbach resonances may behave differently under our experimental parameters, and how these affect the thermalisation of the single atom within the bath [2], alongside its uses in thermometry [3]. [4].

[1] G. Barontini *et al.*, *New J. Phys.* **21**, 063019 (2019).
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[4] J. Mũnoz *et al.*, *Phys. Rev. Lett.* **125**, 020403 (2020).

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A dipolar quantum gas microscope

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We present the progress of our quantum gas microscope which offers access to study complex many-body quantum systems. The setup is capable of single-site detection of ultra cold atoms in a two-dimensional optical lattice and will enable quantum simulations of a wide variety of phenomena ranging from quantum magnetism to lattice spin models. The single-site resolution of our quantum gas microscope is combined with the long-range and anisotropic interaction between higly magnetic dysprosium atoms, enabling a detailed study of novel, strongly correlated phases. A high numerical aperture and a spin and energy resolved super-resolution imaging technique allow us to achieve single-site detection with 180 nm resolution. The short spacing of the ultraviolet optical lattice increases the nearest neighbor dipolar interaction strength significantly to be on the order of 200 Hz (10 nK) and allows us to enter the regime of strongly interacting Bose- and Fermi-Hubbard physics where next nearest neighbor interactions could become visible.

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Towards a Sr Optical Lattice Clock

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As the Designated Institute for Time and Frequency Metrology in Spain, ROA has recently started building up an optical lattice clock based on ^{87}Sr atoms. In this way, an entirely new optical infrastructure has been constructed to host this new frequency standard where a frequency chain between the new optical oscillators and the microwave frequency standards has already been built and stays operational. We have also implemented a second ultra-stable laser at 1396 nm setup that is locked to a very high finesse ($> 400\,000$) cavity equipped with crystalline mirrors. This constitutes the future clock laser at 698 nm (once frequency doubled) and features a fractional stability $< 2 \times 10^{-15}$ at 1 s. Moreover, the first actions are currently being carried out to face the coming cold atom stages. The characterization of the Sr oven is presented. Finally, we present a preliminary model for the atom loading via a permanent magnets Zeeman slower to the understudy magneto-optical trap.

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Theoretical and experimental developments for a continuous superradiant laser

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Frequency standards based on atomic transitions in the optical domain can reach remarkable fractional frequency stabilities of 10^{-17} at one second of integration [1]. Here, we present developments towards the realization of an ultra-stable laser based on the phenomenon of superradiance [2]. An ultra-stable superradiant laser consists of cold atoms confined within a mode of a high-finesse optical cavity [3]. We present a theoretical description of the system of atoms confined within the cavity using the open quantum systems formalism. We also discuss preliminary numerical simulations exploring the steady-state superradiance in the parameter space [4]. We finally report on the preparation of cold ^{171}Yb atoms and discuss current developments for an optical transport of the atoms to a high-finesse Fabry-Perot cavity.

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Spin- and momentum-correlated atom pairs mediated by photon exchange

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Quantum correlations among the constituents of many-body systems determine their fundamental properties. With their pristine control over external and internal degrees of freedom, Quantum gases offer a versatile platform to manipulate and detect such correlations at a microscopic level. Here, we report on observing correlated atomic pairs in specific spin and momentum modes. Our implementation relies on Raman scattering between different spin levels of a spinor Bose-Einstein condensate induced by the interplay of a running-wave transverse laser and the vacuum field of an optical cavity. Far-detuned from Raman resonance, a four-photon process gives rise to collectively-enhanced spin-mixing dynamics. We investigate the statistics of the produced pairs and explore their non-classical character through noise correlations in momentum space. Our results demonstrate a new platform for the fast generation of correlated pairs in a quantum gas and provide prospects for matter-wave interferometry using entangled motional states. [1].

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Characterization of a new dual-species atomic source for lithium and potassium

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Mixtures of ultracold atoms in the quantum degenerate regime offer a great testbed to probe interacting many-body systems. An inevitable ingredient for preparing these ultracold samples is an atomic source providing the desired species within an atomic beam. Here, we present a new home-built dual-species atomic source for our ultracold atom experiment working with lithium and potassium. We characterize its functionality by exciting the emitted atoms and detecting the resulting fluorescence photons with a photomultiplier tube. To conclude on the absolute number of emitted atoms we take transverse spectra of the atomic beam. For both species we observe good agreement with predictions from theory [1]. In addition to the flux we measure the spatial intensity distribution of the atomic beam. For increasing temperature we observe the transition from the transparent into the opaque regime where collisions amongst the atoms decrease their intensity on the center-line [2]. In order to get a quantitative measure about the efficiency of our oven we compare the atomic intensity on the center-line with the total number of emitted atoms.

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Rydberg spectroscopy in the strong driving limit for atoms and molecules

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We experimentally deform the 5S-6P potential of ^{87}Rb atoms at large interatomic distances, creating new bound molecular states. To achieve this, we couple off-resonantly to an ultra-long range Rydberg molecule potential using strong laser driving. Properties that are commonly associated with Rydberg molecules are optically admixed to the 5S-6P pair state.

Another effect we investigate is the Autler-Townes splitting in multilevel systems. The strong coupling lifts degeneracies and mixes closely-spaced states. This results in complex spectra deviating from the symmetrical two-level Autler-Townes splitting. We experimentally investigate these spectra in a thermal cloud of ^{87}Rb atoms by resonantly coupling the $6P_{3/2}, F = 3$ state to a Rydberg state with varying Rabi frequency.

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Construction of a versatile Rydberg atom platform

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In recent years, atomic arrays emerged as a ground-breaking platform in quantum physics. These setups do not only feature single-atom control, additionally exciting addressable atoms to Rydberg states introduces further possibilities to study physical problems in different geometric configurations.

We plan to realize arbitrarily arranged two-dimensional arrays with up to 100 lattice sites, each of them containing one or a few atoms. The arrays are holographically generated by an SLM in combination with a 1064 nm YAG-laser. Via a two-photon Rydberg transition, we collectively excite the atoms to Rydberg states. Due to the long-range character of the resulting Rydberg interactions, an interaction of the atoms in and between lattice sites is also intrinsically given. This setup is a prime candidate to investigate both topological systems of single atoms as well as effects arising from many-body properties in a controlled manner.

Adding controlled microwave transitions between different Rydberg states and the incorporation of a second atomic species open up possibilities to study even more complex physical systems in future research.

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Trade off-free microfabricated cells for atomic devices

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Miniature atomic devices such as clocks and magnetometers rely on microfabricated alkali vapor cells [1]. Several techniques have been proposed to make such cells but they often entail specific advantages and drawbacks [2–4]. We recently demonstrated an alternative technique mimicking the approach found in the fabrication of standard glass-blown cells. It consists in wafer-integrated make-seal structures that can be closed locally with a CO_2 laser [5, 6]. Here, we report on recent work to extend this concept further by connecting the wafer to a vacuum chamber filled with the desired chemical species before sealing the cells as shown in Fig. 1. This method benefits from microfabrication in terms of cost, reproducibility and mass fabrication.

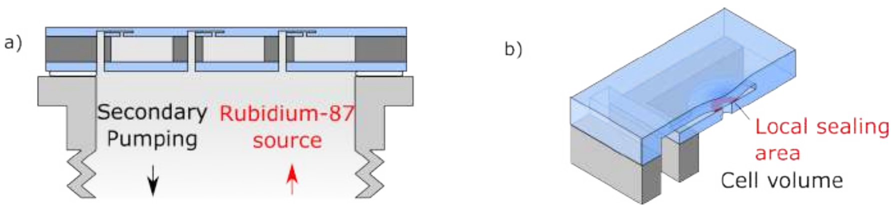

FIG. 1. *a)* A wafer of cells placed on a vacuum chamber to fill the cell with rubidium-87 *b)* Local sealing using a CO_2 laser.

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Delta-Kick Collimation of quantum mixtures for dual species atom interferometry in space

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Dual species atom interferometry under microgravity is a promising tool to precisely test the Einstein's Equivalence Principle (EEP). MAIUS-2 (Matter wave interferometry under microgravity) focuses on understanding the dynamics of K-41 and Rb-87 quantum mixtures in microgravity and preparing the system to perform a test of EEP during MAIUS-3. The sensitivity of a Mach-Zehnder atom interferometer is quadratically proportional to the interrogation time. This could be achieved by further reducing the momentum spread of the ensembles. Magnetic Delta-Kick Collimation (DKC) is a suitable tool to collimate atomic ensembles down to temperature equivalents below Nanokelvin. In this contribution, we concentrate on studying and optimizing the time steps, number of kicks [2] of DKC required to collimate both species simultaneously based on harmonicity and isotropic natures of the trap. Simulations based on two different methods are performed and compared. One on the classical equations of motion and the other on scaling approach [3] which gives a classical interpretation of the dynamics.

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A ytterbium source for quantum-clock interferometry

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Quantum-clock interferometry (QCI) is a promising approach to test general relativistic effects in the quantum regime [1, 2]. In QCI a sequence of light pulses is used to split, redirect and recombine coherent wave packets and drive transitions between the internal degrees of freedom of a quantum system. Choosing an appropriate configuration, the phase shift between the interferometer arms is sensitive to gravitational time dilation effects.

To improve the sensitivity of phase shift detection, one can either increase the delocalization of wave packets using large momentum transfer techniques or extend their free evolution time. The Very Long Baseline Atom Interferometry facility in Hannover takes advantage of the latter. It is a state-of-the-art, 10-meter-long facility designed for highly sensitive measurements [3]. It is designed to operate with two different atomic sources and features a magnetic shield and a seismic attenuation system to mitigate external noise sources. This makes it an ideal environment to perform QCI experiments.

Due to its long-lived clock state, ytterbium is an appealing candidate to measure differences in proper time [4]. We present the current status of our high-flux source of laser-cooled ^{174}Yb atoms [5]. To drive the clock transition, a highly stable laser source of at least 10 W and a line width of less than 1 kHz is required [4]. We present the frequency stabilization of an 1156 nm laser to an external cavity and discuss the future implementation to enable the E1-M1 optical transition.

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Long Abstracts

Local periodic driving in optical lattices

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The ability to locally tune the parameters of a tight-binding model is a highly sought-after goal which would allow for the simulation of a wide range of quantum phenomena. Motivated by recent advances in realising quantum gas microscopes as well as highly versatile optical tweezers, we demonstrate that local control in an optical lattice can be achieved in ultracold-atom experiments by incorporating a local, time-periodic potential. We employ Floquet theory to capture the dynamics of locally driven optical lattices and investigate applications of this technique for non-interacting particles in one dimension to engineer various configurations. Extending to two dimensions, we show that local periodic driving in a three-site plaquette allows for full control of Hamiltonian parameters including tunneling amplitudes and flux values piercing the plaque. Our results demonstrate the vast array of phenomena that can be accessed by periodically driving a system locally.

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Momentum-space correlations of lattice Bose gases close to the Mott transition

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We study interacting Helium-4 Bose gases in an optical lattice, realising the 3D Bose-Hubbard hamiltonian [1]. This hamiltonian holds a quantum phase transition, from a superlfuid to a Mott insulator, and we report our on-going efforts to characterise many-body correlations in the vicinity of this transition. To this aim, we use a unique experimental probe which consists in detecting metastable Helium-4 atoms one by one after a long time-of-flight to measure atom correlations in momentum space [2].

We have recently exploited this approach to reveal the Bogoliubov pairs of atoms with opposite momenta in the quantum depletion of a weakly interacting Bose gas [3] and to study the high-order correlations (between up to 6 atoms) in lattice superfluids and Mott insulators [4]. Our present efforts rely on these previous studies to quantify momentum correlations close to the Mott transition.

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Cryogenic Strontium Quantum Processor

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Neutral Rydberg atoms in optical tweezers are a promising platform for quantum computing. This platform unites fundamentally indistinguishable qubits and precise control via laser fields with scalability in the size of the qubit register.
In our project we aim at the unification of the optical tweezer technology with cryogenic technology at 4K, using fermionic strontium. This will result in record-long coherence and lifetimes of the atoms in the optical tweezer array and it will form the basis for scalability to large atom numbers. Furthermore, the intensity of black-body radiation is strongly reduced at cold temperatures. This reduces the unwanted coupling between neighboring Rydberg states, a potential source for collective decoherence in the quantum processor. Finally, the 4K environment will enable us to use superconducting coils, which will generate a ultrastable magnetic field for qubit frequency definition.

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Anderson Localization of Light by Cold Atoms

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Philip Anderson received the Nobel Prize for his theory on localization phenomena in 1977. His seminal paper explain that a phase transition occurs from conductor to insulator after a certain threshold of disorder in the system[1]. There are various theories and experiments to determine Anderson localization of light but a clear signature of Anderson localization of light in 3D has not been reported so far because absorption complicates the interpretation of experimental results. Recent theoretical developments suggest that strong localization can be observed using a large cloud of cold atoms[2].

Here, I will present our new experimental setup aiming to study Anderson localization of light using large clouds of ^{174}Yb cold atoms in three dimensions.

The ensemble of atoms is produced in a Magneto-optical Trap (MOT) operating at 555.6 nm on the intercombination transition $^1S_0 -^3 P_1$. Its narrow linewidth ($\Gamma_{gr} = 2\pi * 182kHz$) allows cooling the atoms below $10\mu K$. This green MOT is loaded from Blue MOT at $398.9nm$ on $^1S_0 -^1 P_1$ transition. This transition has a broad linewidth ($\Gamma_{bl} = 2\pi * 28.9MHz$) which is advantageous for slowing the atomic beam over a distance of a few cm. A slowing beam is used to increase the loading rate of the blue MOT. We typically capture around 10^9 atoms in the blue MOT. We then transfer about $2.5 * 10^8$ atoms in the green MOT resulting an optical depth of 10. The temperature and atom number are determined using standard absorption imaging and time-of-flight (TOF) techniques. The obtained optical depth is not sufficient yet to observe the localization [2]. The setup is being currently improved by the implementation of the repumpers and by the precise study of the blue MOT limitations.
The production of an atomic sample is the first step toward the Anderson localization of light. The next key step will be the observation of a coherent backscattering (weak localization)[3] which can be seen as a precursor of

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Generation and control of quantum coherence in single atom mechanics

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Quantum coherence between energy eigenstates of mechanical oscillators is crucial for a wide range of applications including quantum sensing and bosonic quantum error correction protocols. A single atomic ion trapped and laser-cooled in a Paul trap provides an ideal testbed for the feasibility of generation and estimation of motional coherences. It allows for a deterministic coherent optical manipulation of the quantum motion with high fidelity by a sequence of laser pulses acting on the combined electronic-motional space. A motional Ramsey-type interferometer then allows for the precise measurement of the off-diagonal elements of the density matrix to quantify the quantum coherence. We experimentally demonstrate climbing up a hierarchy of criteria excluding the convex closure of Gaussian states of the linear oscillations by analysis of their corresponding observable coherence on a single trapped $^{40}Ca^{+}$ ion - motional oscillator. We estimate their robustness to dominant decoherence mechanisms in mechanical systems corresponding to the interaction with thermal amplitude and phase reservoirs.

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