29th Young Atom Opticians Conference

Strasbourg, France

June 30 - July 16 2024

hosted by CESQ, ISIS, Fondation Jean-Marie Lehn

Conference Booklet

Strasbourg, June 2024

Welcome to YAO2024 in Strasbourg!

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 Centre Européen de Sciences Quantiques (CESQ) at the University of Strasbourg for its 29th edition, from the 30th of June to the 5th of July. 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: yao.strasbourg2024@gmail.com
- Website: https://yao2024.eu

Organisers:
Manuel Morgado, Maximilian Müllenbach, Amar Bellahsene, Swayangdipta Bera, Matteo Bergonzoni, Tatiana Bespalova, Ruben Daraban, Clément Gradziel, Tanul Gupta, Dr. Anuja Padhye, Laura Pecorari and Vineesha Srivastava.

Scientific Advisory Committee:
Prof. Guido Pupillo, Prof. Guillaume Schull and Prof. Shannon Whitlock.

We thank Anna Guyon and Laurence Schmitt for the administrative support in organising the conference. We thank the Fondation Jean-Marie Lehn for co-organizing together with us.

Conference Venue

The conference will take place in the main lecture hall of Institut de Science et d'Ingénierie Supramoléculaires (ISIS) in Esplanade, which is a Mixed Research Unit (UMR 7006) of CNRS and Université de Strasbourg.

Institut de Science et d'Ingénierie Supramoléculaires,
8 Allée Gaspard Monge,
67000 Strasbourg,
France

Hotels

We split the number of participants equally into two hotels. One of them is City Résidence Strasbourg Centre (1 Rue des Magasins, twin studios), the other one is Séjours and Affaires Strasbourg Kleber (16 Rue Hannong, twin studios).

City Résidence Strasbourg Centre,
1 Rue des Magasins,
67000 Strasbourg,
France

Séjours and Affaires Strasbourg Kleber,
16 Rue Hannong,
67000 Strasbourg,
France

Bed and breakfast are included from Sunday night until Friday morning.

Moving around

Strasbourg is not a very large city and many destinations can be reached comfortably on foot, however public transport (trams and buses) may be useful. Tickets can be purchased at the vendor machines located at many of the stops, or alternatively on the CTS Transports Strasbourg app. A single ticket costs 1,90€ and allows you to use both buses and trams for 1 hour after purchase, connections are authorised within that time range. Carnets of 10 single tickets are also available for 17,10€.

Airport - City centre:

The Strasbourg-Entzheim (SXB) airport is served up to 5 times an hour by a shuttle train, linking it to Strasbourg train station (Gare Centrale) in just 8 minutes, the cost of the TER ticket is 3,10€. A 4,90€ ticket is also available in which, in addition to the TER ticket, a single CTS ticket (for tram and buses in the city) is also included. The tram/bus ticket can be used within 1h30 after purchase. Both the two tickets can be purchased at the vendor machines. Then the station is about a 10 minutes walk away from the hotels, and 20 minute away from ISIS (the main lecture hall) by tramway (C line).

Hotel - ISIS:

From the hotel City Résidence Strasbourg Centre there is 30-40 minutes walk to ISIS (the main lecture hall) or 20 minutes by tram C (from Gare Centale to Université), other options are 2 or C9 buses. From the hotel Séjours and Affaires Strasbourg Kleber there is 20-30 minutes walk to ISIS (the main lecture hall) or 15 minutes by tram C or F (from Homme de Fer to Université).

Lunch restaurant - ISIS:
The Restaurant Universitaire de l'Esplanade (the lunch place) is less then 5 minutes walk away from ISIS (the main lecture hall).

You can find a map with the main locations of this conference at this link: map.

Social Activities

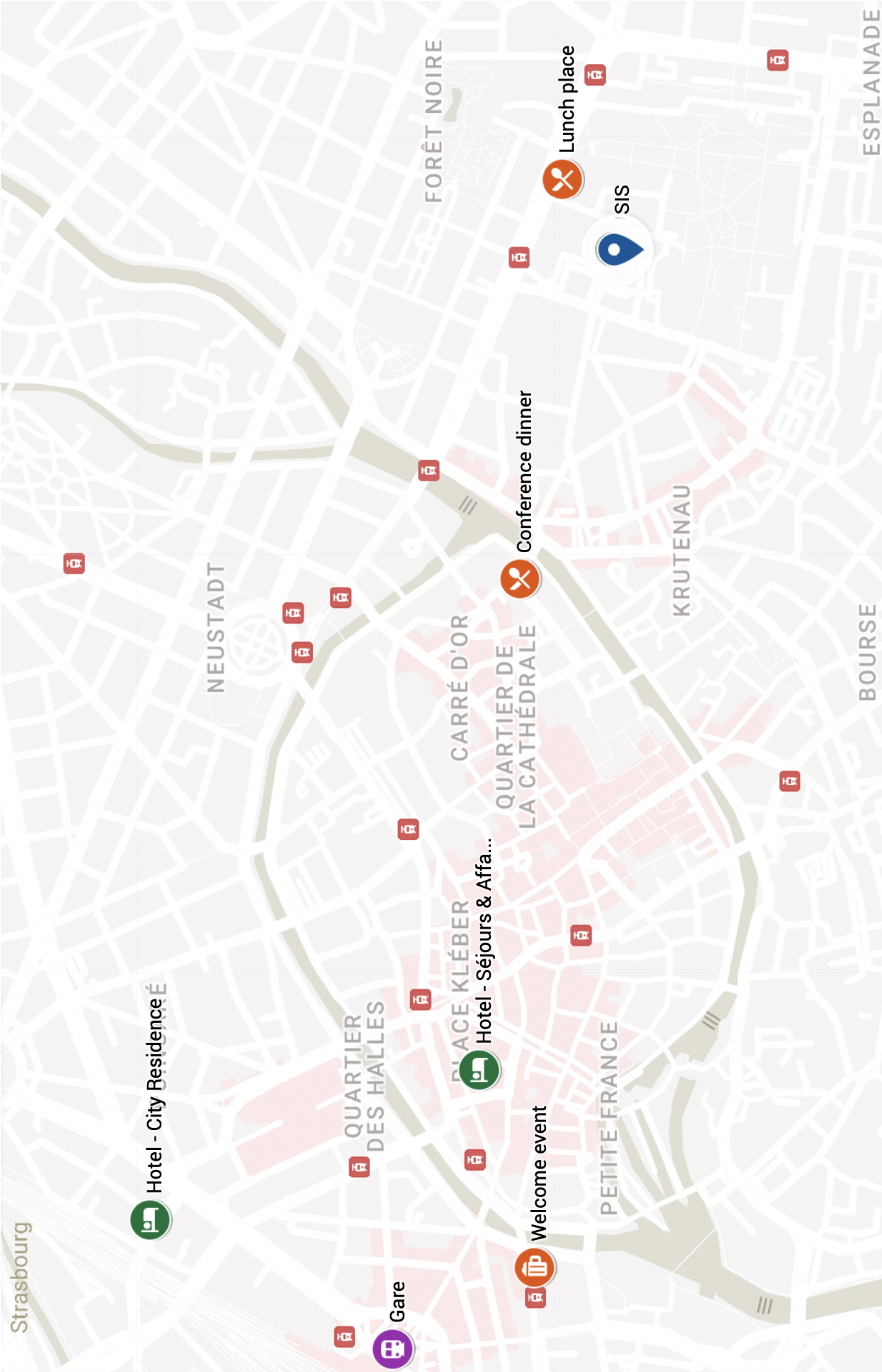
We prepared for you a range of non-scientific activities whose sole purpose is to make you socialize within and beyond the scientific context. Some people call it networking, but we think of it more as just having a fun time.

***Welcome event*:** On Sunday evening starting at 18 o'clock, we will welcome you in the historical brasserie Le Tigre (5 Rue du Faubourg National, 67000 Strasbourg). After registration, you will be able to meet and get to know eachother while enjoying varied foods (including tartes flambées) and Alsatian beers or wine.

***Boat Tour, European Parliament and Picnic*:** On Thursday July 4th, after the the lunch break, we will meet at the Embarcadère BATORAMA (Pl. du Marché aux Poissons, 67000 Strasbourg) just in front of Palais Rohan, by the Cathedral in the city center. The meeting time is 14:00 at Embarcadère. Here we will board a boat that will allow us to discover the beautiful city of Strasbourg from a unique perspective and learn more about its history. After a tour around the city island, we will then make our way up to one of the most famous buildings of Strasbourg: the European Parliament (about one hour for the total trip). Once landed, you can choose to visit the European Parliament, where an English group tour is reserved for the YAO participants, or spend some free time at the nearby Parc de l'Orangerie, where several activities will be waiting for you (music, beers, games...). Remember: if you choose to visit the European Parliament, bring a valid ID document with you!

***Conference Dinner*:** For the conference dinner, we'll do a deep dive into Alsatian cuisine. It will be held at Au Brasseur (22 Rue des Veaux, 67000 Strasbourg), a traditional restaurant still brewing their own beer, in the historic city center. We will meet there on Thursday at 19:00.

	June 30th	July 1st	July 2nd	July 3rd	July 4th	July 5th
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
8:45:00		Welcome				
9:00:00		**Antoine Browaeys**	**Stuart Adams**	**Elisa Ercolessi**	**Christiane Koch**	**Katharina Kaiser**
9:30:00						
10:00:00		Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
10:30:00					Optimal Control	
11:00:00		Quantum Simulation	Rydberg Physics	Quantum Computing and Simulation Methods	Quantum Gas Microscopy	Cold Molecules and Hybrid Systems
11:30:00					Sponsor Talk: IonQ	
12:00:00						Farewell
12:30:00		Lunch	Lunch	Lunch	Lunch	
13:00:00						
13:30:00			Sponsor Talk: Q.ANT			
14:00:00		**Giovanni Modugno**	Ultracold Fermions	**Patrick Maletinsky**		Lab Tours and Lunch
14:30:00		Coffee Break	Coffee Break	Coffee Break		
15:00:00			Atom Interferomety			
15:30:00		Bose-Einstein Condensates		Quantum Technologies		
16:00:00					Social event & Free Time	
16:30:00			Cavities			
17:00:00		Poster Session I		Poster Session II		
17:30:00						
18:00:00						
18:30:00						
19:00:00	Welcome Event & Registration					
19:30:00					Conference Dinner	
20:00:00						
...						



Strasbourg
Hotel - City Residence
Gare
QUARTIER DES HALLES
NEUSTADT
KLÉBER
Hotel - Séjours & Affa...
Welcome event
CARRÉ D'OR
QUARTIER DE LA CATHÉDRALE
Conference dinner
PETITE FRANCE
KRUTENAU
FORÊT NOIRE
Lunch place
SIS
BOURSE
ESPLANADE

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Conference Schedule

Monday, 1 July

8:45 **Welcome**, Conference Venue: ISIS, 8 Allée Gaspard Monge

9:00 **Invited Speaker:**
Many-body physics with arrays of individual atoms and optical dipoles
Antoine Browaeys, Institut d'Optique, CNRS, France

10:00 **Coffee Break**

10:30 **Session - Quantum simulation**

Dipolar XY magnetism in a two-dimensional Rydberg atom array
Bastien Gély, Laboratoire Charles Fabry, Institut d'Optique Graduate School, Palaiseau, France

Experimental Observation of Quantum Criticality in a 4D Quantum Disordered System
Farid Madani, PhLAM (Laboratoire de Physique des Lasers, Atomes et Molécules)

Ground-state cooling of Yb atoms in hybrid lattice-tweezer quantum simulator
Leonardo Bezzo, Ludwig-Maximilians Universität München

Direct laser cooling of Rydberg atoms with an isolated-core transition
Alisée Bouillon, UCLouvain

Interacting Laser-Trapped Circular Rydberg Atoms for Quantum Simulation
Aurore Young, Laboratoire Kastler Brossel

Highly Scalable Quantum Processing Architecture using Neutral Atom Arrays in a Microlens-based Integration
Lukas Sturm, TU Darmstadt

12:00 **Lunch Break at Restaurant Universitaire de l'Esplanade**

13:30 **Invited Speaker:**
Exploring the supersolid phase of matter with dipolar quantum gases
Giovanni Modugno, LENS, Università di Firenze, Italy

14:30 **Coffee Break**

15:00 **Session - BEC**

Towards superfluids and supersolids in a ring
Niccolò Preti, Università degli studi di Firenze

Observation of superthermal correlations at the Superfluid to Mott transition with ultracold bosons
Géraud Dupuy, Laboratoire Charles Fabry

Observation of vortices in a dipolar supersolid
Eva Casotti, University of Innsbruck, IQOQI

Loss features in ultracold 162Dy gases : pairwise versus three-body processes
Maxime Lecomte, Laboratoire Kastler-Brossel, ENS-PSL, Collège de France

Active magnetic field stabilization for cold atom spin mixture experiments
Sara Tiengo, Institut d'Optique, Palaiseau, France

Measurement of the excitation spectrum of a recoil-resolved atom-cavity system at the boundary between the normal and self-organized phases
Anton Bölian, Universität Hamburg

16:30 **Poster Session I**

Tuesday, 2 July

9:00 **Invited Speaker:**
From atom optics to Rydberg quantum optics
Stuart Adams, Durham University, England

10:00 **Coffee Break**

Schedule

10:30 **Session - Rydberg Physics**

Rydberg Blockade in Atomic Arrays
Felix Russo, TU Wien

Strong photon-photon interactions mediated by Rydberg polaritons in ultracold Ytterbium gases
Florian Pausewang, University Bonn

From one to two superatoms in an optical cavity
Antoine Covolo, Collège de France

Characterization of a state-insensitive optical trap for long coherence time of Rydberg superatoms
Jan de Haan, Institute of Applied Physics, University of Bonn

Multiparameter quantum sensing with a hybrid rf-dc optically pumped magnetometer at Earth's magnetic field
Diana Méndez Avalos, ICFO

Room Temperature Quantum Memory for light using the Atomic Frequency Comb protocol
Zakary Schofield, University of Southampton

12:00 **Lunch Break at Restaurant Universitaire de l'Esplanade**

13:30 **Sponsored talks** Industry Partner: Q.ANT (Company introduction and current research)

14:00 **Session - Ultracold Fermions**

Cooling of fermionic Lithium in a 2D optical lattice
Luca Muscarella, Max Planck Institute of Quantum Optics

Self-organisation dynamics in strongly interacting ultracold fermions
Gaia Stella Bolognini, IEcole Polytechnique Fédérale de Lausanne

14:30 **Coffee Break**

15:00 **Session - Atom Interferometry**

Multi- species cold atom interferometry for inertial measurements
Mal Landru, ONERA DPHY - SLM

Dark energy search using atom interferometry in the Einstein-Elevator
Magdalena Misslisch, Institut fur Quantenoptik, Hannover

High-performance two axis cold-atom gyroscope for rotational seismology
Nathan Marliere, LNE-SYRTE

Optimal Floquet Engineering for Large Scale Atom Interferometers
Léo Calmels, Laboratoire Collisions Agrégats Réactivité (LCAR), Université Toulouse III Paul Sabatier, Toulouse, France

16:00 **Session - Cavities**

Standard quantum limits for cavity-enhanced optical readout methods of hot atomic vapor quantum sensors
Hana Medhat, ICFO

Cavity-based non-destructive detection in ultracold gases
Gokul Vengillasery Illam, Raman Research Institute

An Optical Cavity-Atom Array System for Quantum Computing
Michelle Chong, Massachusetts Institute of Technology

A cavity-microscope for micrometer-scale control of atom-photon interactions
Ekaterina Fedotova, EPFL

Wednesday, 3 July

9:00 **Invited Speaker:**
Hybrid Variational Algorithms on a neutral atom platform
Elisa Ercolessi, University of Bologna, Italy

10:00 **Coffee Break**

10:30 **Session - Quantum computing**

Few-body Forster resonances in Rydberg atoms for quantum gate protocols
Ivan Ashkarin, Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton, 91405 Orsay, France

Optimisation of weighted graphs using neutral atom arrays
Max Wells-Pestell, University of Strathclyde, Glasgow

Cryogenic strontium quantum processor
Valerio Amico, University of Tübingen

11:15 **Session - Numerical Methods and Simulations**

Continuous Coherent Quantum Feedback with Time Delays: Tensor Network Solution
Kseniia Vodenkova, University of Innsbruck

Lissajous figures in a quantum walk on a lattice
Grzegorz Jaczewski, University of Warsaw

Finite-temperature Rydberg atom systems: quantum phases and entanglement characterization
Nora Reinić, University of Padova, INFN Padova

12:00 **Lunch Break at Restaurant Universitaire de l'Esplanade**

13:30 **Invited Speaker:**
Photophysics and quantum optics of solid-state quantum sensors
Patrick Maletinsky, Universität Basel, Switzerland

14:30 **Coffee Break**

15:00 **Session - Quantum Technologies**

Strongly Interacting Photons in 2D Waveguide QED
Matija Tečer, University of Padua

Development of a transportable optical cavity for a portable trapped ion atomic clock
Rishabh Pal, Indian Institute of Technology Tirupati

Manufacturing Q-optimized polymer-based mechanical resonators for cavity optomechanics with 3D-direct laser writing
Daniel Stachanow, University of Bonn

Enabling atomic systems with fully integrated photonics from UV to IR
Sophie Cavallini, ETH Zurich

Shallow, optically coherent SiV centers in diamond nanopillars for quantum sensing
Marina Obramenko, University of Basel

Characterizing single photon from an atom array via optical fiber
Yuya Maeda, Osaka university

Thursday, 4 July

9:00 **Invited Speaker:**
Training Schrödinger's Cat: Quantum Control in Molecular Physics and Quantum Information Science
Christiane Koch, Freie Universität Berlin, Germany

10:00 **Coffee Break**

10:30 **Session - Optimal Control**

Fast and robust cat state preparation utilizing higher order nonlinearities
Suocheng Zhao, IIQMT, KIT

Optimal control of quantum systems: Applications to the control of Bose-Einstein Condensates
Etienne Dionis, Laboratoire Interdisciplinaire Carnot de Bourgogne

11:00 **Session - Quantum Gas Microscopy**

A strontium quantum-gas microscope
Carlos Gas Ferrer, ICFO

Towards a quantum gas microscope with programmable lattices
Sarah Jane Waddington, TU Wien

11:30 **Sponsored talks** Industry Partner: IonQ (Company introduction and current research)

12:00 **Lunch Break at Restaurant Universitaire de l'Esplanade**

13:30 **Social Event and Free Time** Batorama tour, European Parliament and picnic at Parc de l'Orangerie

19:30 **Conference Dinner** Au Brasseur, 22 Rue des Veaux

Friday, 5 July

9:00 **Invited Speaker:**
Optoelectronics on the atomic scale – what we can learn from STM on single molecules
Katharina Kaiser, Unversität Göttingen, Germany

10:00 **Coffee Break**

10:30 **Session - Molecules**

Compact high-precision microwave spectrometer based on FID measurements

Hemanth Dinesan, CNRS, Laboratoire de Physique des Lasers, Universite Sorbonne Paris Nord and CNRS, Laboratoire Aime Cotton, France

Experiments with ultracold atoms and molecules

Lukas Leczek, TU Wien

Ultracold molecules: how not to lose them - A step towards larger molecular quantum computers

Etienne Walraven, IMM, Radboud University

11:15 **Session - Hybrid Systems**

Vibrationally coupled Rydberg atom-ion molecules

Ilango Maran, Universiteit van Amsterdam

Trapped ions in optical tweezers

Nella Diepeveen, University of Amsterdam

Interfacing Rydberg atoms with an electromechanical oscillator in a cryostat

Julia Gamper, University of Bonn

12:00 **Farewell** Closing remarks

12:30 **Lab tours** At the laboratory of CESQ and IPCMS on the Cronenbourg Campus. Lunch is included.

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: Antoine Browaeys

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Many-body physics with arrays of individual atoms and optical dipoles

Antoine Browaeys - Laboratoire Charles Fabry, Institut d'Optique, CNRS, 2 avenue A. Fresnel, 91127 Palaiseau, France

This talk will present our recent work on the control of interactions between cold atoms to implement spin Hamiltonians useful for quantum simulation of many-body problems, or quantum optics situations. We rely on laser-cooled atomic ensembles of Rb, consisting either of individual atoms in tweezer arrays, or dense elongated atomic gases.
By exciting arrays of up to 100 atoms into Rydberg states, we make the atoms interact by the resonant dipole interaction. The system implements the XY spin ½ model, which exhibits various magnetic orders depending on the ferromagnetic or antiferromagnetic nature of the interaction. When the system is placed out of equilibrium, the interactions generate scalable spin squeezing. Analyzing the spread of correlations across the system, we measure the dispersion relation and observe the predicted anomalous behavior in the ferromagnetic case, a consequence of the dipolar interactions.
Using an elongated dense atomic ensemble driven on an optical transition, we rely on the collective coupling of many atoms to a single mode of the electromagnetic field to observe driven superradiance and demonstrate the generation of non-classical light.

Antoine Browaeys is an experimental physicist at the Laboratoire Charles Fabry , leading the group "Optique quantique – Atomes" and he is specialised in the laser manipulation of atoms. He received his Ph.D in 2000 at the Université Paris-Sud, now the Université Paris-Saclay (Charles Fabry Laboratory). In 2003 he joined CNRS - Research Fellow at the Charles Fabry Laboratory. In 2007 he received the Aimé Cotton Prize from the French Physical Society. In 2013 he became Research Director at the Charles Fabry Laboratory and in 2019 he co-found the start-up Pasqal.

Monday

Talks: Quantum Simulation

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Dipolar XY magnetism in a two-dimensional Rydberg atom array 10:30

Bastien Gély, *Laboratoire Charles Fabry, Institut d'Optique Graduate School, Palaiseau, France*

Quantum simulation of interacting many-body spin Hamiltonians with Rydberg atom array and construction of a new experiment.

Quantum simulation, Rydberg, Atomic array

Experimental Observation of Quantum Criticality in a 4D Quantum Disordered System 10:45

Farid Madani, *PhLAM (Laboratoire de Physique des Lasers, Atomes et Molécules)*

Anderson metal-insulator transition is one of the few known phenomena that maintain their non-mean-field character in high dimensions, posing great challenges for traditional theoretical approaches. In this work, engineering synthetic dimensions in an ultracold atoms experiment, we observe the Anderson transition in 4D and probe its critical behavior. We measure the critical exponents, which are in agreement with Wegner's scaling law, and confirm the non-mean-field character of the transition.

Ultracold Atoms, Bose-Einstein Condensate, Quantum Simulation, Anderson Transition, Quantum Phase Transition

Ground-state cooling of Yb atoms in hybrid lattice-tweezer quantum simulator 11:00

Leonardo Bezzo, *Ludwig-Maximilians Universität München*

Quantum gas microscopes offer crucial insights into quantum many-body systems, essential for validating theoretical models and exploring new phases of matter. Achieving the ground state, together with large, tunable tunnelling rates are key challenges, traditionally addressed through evaporative cooling and adiabatic loading in optical lattices, which lack the flexible and precise control over atoms offered by tweezers. By combining optical lattice and tweezer technologies, alongside novel state-dependent control methods, a hybrid quantum simulator is being developed using Yb atoms, promising alternative routes for simulating complex Hubbard-type models.

Quantum Simulation, Optical Lattice, Optical Tweezers, Ytterbium

Direct laser cooling of Rydberg atoms with an isolated-core transition

11:15

Alisée Bouillon, *UCLouvain*

We present a scheme to directly laser cool alkaline-earth metal Rydberg atoms, using an isolated-core transition. We show that, while the presence of the Rydberg electron complexifies the energy-level structure of the ion core compared to the isolated-ion case, a closed cooling cycle can be found and laser cooling achieved. The effects of a small magnetic field on the population dynamics are also detailed.

Rydberg physics, Cold atoms, Cold gases, Alkaline-earth atoms

Interacting Laser-Trapped Circular Rydberg Atoms for Quantum Simulation

11:30

Aurore Young, *Laboratoire Kastler Brossel*

Circular Rydberg atoms, atoms with maximal orbital momentum, have a natural lifetime 100 times longer than Rydberg atoms, which makes them well suited to the quantum simulation of the dynamics of interacting quantum systems. To benefit from it, we trap them in individual optical bottle beams, characterize their interactions and demonstrate the expected coupling between spin and motional degrees of freedom in a Rydberg-atom system.

Circular Rydberg atom, Quantum simulations

Highly Scalable Quantum Processing Architecture using Neutral Atom Arrays in a Microlens-based Integration

11:45

Lukas Sturm, *TU Darmstadt*

Tweezer arrays of neutral atoms provide a versatile platform for quantum information technologies. We realize an architecture with 3000 qubit sites and more than 1000 atomic qubits. Supercharging the array with reservoir atoms increases the initial filling fraction, enabling defect-free assembly of up to 441 qubits. Addressing atom loss, we implement a modular scheme that facilitates continuous operation. The presented results on highly scalable quantum arrays foster future advances in quantum science with tweezer arrays.

Optical Tweezer Arrays, Continuous Operation , Scalability, 1000 Atomic Qubits

Invited Speaker: Giovanni Modugno

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Exploring the supersolid phase of matter with dipolar quantum gases

Giovanni Modugno - LENS and Dipartimento di Fisica e Astronomia, Università di Firenze, and CNR-INO, Pisa

Supersolids are a fundamental quantum phase of matter combining properties of crystals and of superfluids. A supersolid phase was recently discovered in Bose-Einstein condensates of strongly magnetic atoms. I will discuss the exceptional properties of dipolar supersolids, spanning from double symmetry breaking to mixed superfluid and classical dynamics. I will in particular show how a supersolid can behave as a self-induced Josephson junction array, and how it is possible to deduce from the Josephson dynamics the superfluid fraction, which is the universal property quantifying the deviation of supersolids from both crystals and superfluids.

Giovanni Modugno has been conducting experimental research since 1999 aimed at studying fundamental physics phenomena with ultracold quantum gases. He has conducted frontier experiments in the fields of quantum mixtures, quantum transport, quantum disordered systems and quantum few-body phenomena. He received his Ph.D. in Physics with honours at the Scuola Normale Superiore in Pisa in 1999. In 1999 he became a Research Fellow and TD Researcher at the LENS laboratory of the University of Florence and CNR. In 2005 he become Associate Professor of Physics of Matter at the Department of Physics and Astronomy, University of Florence and from 2022 he is a Full Professor of Physics of Matter at the Department of Physics and Astronomy, University of Florence.

Talks: BEC

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Monday

Towards superfluids and supersolids in a ring 15:00

Niccolò Preti, *Università degli studi di Firenze*

I will report on an ongoing experiment regarding the superfluid nature of the supersolid. Our aim is to trap the supersolid in an optical potential shaped as a ring. Moving from the supersolid to a standard superfluid through a reversible quantum phase transition, we will be able to test for the first time the seminal theory by the Nobel laureate A. Leggett.

Supersolids, Superfluids, Dysprosium

Observation of superthermal correlations at the Superfluid to Mott transition with ultracold bosons 15:15

Géraud Dupuy, *Laboratoire Charles Fabry*

To accurately describe strongly-correlated quantum systems, one needs to account for the non-trivial correlations induced by interactions between individual particules. Our experiment aims to observe such correlations in momentum with an original electronic detection device using metastable ultracold helium-4. Here we report our observation of many-body correlation function becoming super-thermal at the Mott transition, suggesting the presence of non-gaussian correlations.

Ultracold atoms, Strongly-correlated systems, Non-Gaussian correlations

Observation of vortices in a dipolar supersolid 15:30

Eva Casotti, *University of Innsbruck/IQOQI*

We report on the theoretical study and experimental observation of vortices in a dipolar supersolid, an exotic phase of matter that spontaneously breaks two simmetries: phase and translational invariance. Our observations, revealing a fundamental difference between modulated and unmodulated quantum matter, open the way to study the peculiar properties of vortices in supersolids and further applications to the study of other systems with multiple broken simmetry, such as neutron stars.

Dipolar gases, Supersolidity, Vortices

Loss features in ultracold 162Dy gases : pairwise versus three-body processes

15:45

Maxime Lecomte, *Laboratoire Kastler-Brossel, ENS-PSL, Collège de France*

In (ultra)cold atomic gases experiments, Fano-Feshbach resonances turned out to be a major tool to tune the interactions between particles. Understanding their nature and properties allow a better control of such dilute systems. We investigated low-field Fano-Feshbach resonances in a dipolar gas, whose interactions are long-range and anisotropic.

Fano-Feshbach resonances, Pairwise, Three-body processes, Dipolar gas.

Active magnetic field stabilization for cold atom spin mixture experiments.

16:00

Sara Tiengo, *Institut d'Optique, Palaiseau, France*

The popularity of Feshbach resonances as a tool for manipulating atomic interaction strength has led to an increasing demand for generating large and highly stable magnetic fields. Our experiment, concerning the study of effective three-body interactions in radio-frequency coupled spin mixtures, requires magnetic field stability at the ppm-level. We propose an easy-to-implement active feedback method to stabilize the magnetic field, which has been proved via Ramsey spectroscopy on the K39 magnetic sub-levels to stabilize a magnetic field of 57 G with a rms noise reduced 2.5 ppm.

Magnetic field stabilization, Feedback loop circuit, Coupled spin-mixtures

Measurement of the excitation spectrum of a recoil-resolved atom-cavity system at the boundary between the normal and self-organized phases

16:15

Anton Bölian, *Universität Hamburg*

We study the exciation spectrum of a transversely pumped Bose- Einstein-condensate coupled to a single mode of a recoil-resolved cavity. We measure the softening of the lowest polariton mode induced by the external pump, and observe the emergence of an excitation gap when measuring with a pump near detuned to the cavity resonance, caused by the significant contribution of the long-lived cavity field to the polariton mode.

Cavity QED, Quantum phase transition, Bosonic quantum gases

Invited Speaker: Stuart Adams

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From atom optics to Rydberg quantum optics

C. Stuart Adams - Durham University, England

Three decades ago when the Young Atom Optics conference series began, atom optics, the control of atomic centre-of-mass was an emerging field [1]. In those three decades we have seen remarkable progress including developments such as Bose-Einstein condensation and optical tweezing of individual atoms. In this talk, I will focus on another unforeseen development, the flourishing of atomic and optical physics exploiting highly-excited Rydberg states [2]. In addition to the strong-switchable interactions that are useful for quantum simulation and quantum computation, Rydberg atoms allow us to connect six orders of magnitude in the electromagnetic spectrum [3]. For example, terahertz-to-optical conversion using Rydberg atoms enables fast imaging in the terahertz region for the first time [4]. The strong interactions between Rydberg atoms also have implication for sensing [5], and result in rich dynamics such as synchronisation [6].

[1] CS Adams, M Sigel and J Mlynek, *Phys Rep* **240**,143 (1994).

[2] CS Adams, JD Pritchard and J Shaffer, *J Phys B* **53**, 012002 (2019).

[3] G Allinson et al., arXiv:2311.11935, Phys Rev Res accepted (2024).

[4] L Downes et al., *Phys Rev X* **10**, 011027 (2020).

[5] DS Ding et al., *Nature Phys* **18**, 1447 (2022).

[6] K Wadenpfuhl and CS Adams, *Phys Rev Lett* **131**, 143002 (2023).

Charles Stuart Adams studied Physics at Hertford College, Oxford University, he obtained a Masters by Research from McMaster University in Canada followed by a PhD from Strathclyde University in Glasgow. After post doctoral work in Germany and the US, he began a research group at Durham in October 1995. His main interests are in experimental quantum optics, in particular light-matter interactions in strongly-interacting atomic systems. He was awarded the Thomson medal by the IOP in 2014 and the Holweck Prize by the French Physical Society and IOP in 2020 for pioneering work on quantum optics.

Tuesday

Talks: Rydberg Physics

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Rydberg Blockade in Atomic Arrays 10:30

Felix Russo, *TU Wien*

Subwavelength atomic arrays have emerged as a versatile platform for realizing strong light-matter coupling. I will discuss their potential to create quantum states of light via the Rydberg-blockade mechanism. Understanding the nonlinear dynamics of atomic Rydberg arrays is crucial for realizing their promising prospects, e.g., in photonic quantum information processing.

Rydberg blockade, Atomic arrays, Quantum nonlinear optics

Strong photon-photon interactions mediated by Rydberg polaritons in ultracold Ytterbium gases 10:45

Florian Pausewang, *University Bonn*

I present the progress towards the demonstration of strong interaction between photons, mediated by Yb-174 Rydberg excitations formed in a 1D ultracold Ytterbium gas. Our experimental apparatus has a two-chamber design featuring dispensers and a 2D MOT providing transversally cooled Yb atoms and a two-color 3D MOT and a dipole trap in the science chamber. Using a 2-photon excitation EIT scheme the interaction strength for Rydberg s-states in dissipative and attractive interaction regimes can be quantified.

Rydberg polaritons, Ytterbium, Two-color MOT

From one to two superatoms in an optical cavity 11:00

Antoine Covolo, *Collège de France*

For quantum simulations and computing, scalability in optics relies on deterministic photon gates. Our system utilizes a small atomic cloud within a cavity, driven to a Rydberg state, acting as a collective superatom. With 60% efficiency, we achieve deterministic preparation of non-Gaussian Wigner-negative optical quantum states. Expanding our setup, we incorporate an additional atomic cloud, laying the groundwork for advanced protocols and quantum optics applications.

Collective excitation, Rydberg, Optical cavity

Characterization of a state-insensitive optical trap for long coherence time of Rydberg superatoms 11:15

Jan de Haan, *Institute of Applied Physics, University of Bonn*

To increase the coherence time of Rydberg superatoms in our setup by reducing the motion of the constituent atoms and by reducing differential light shifts due to the confining trap, we have implemented a 1D-lattice state-insensitive optical trap for ground and Rydberg states. For different trap geometries, I present measurements of wavelengths giving the best coherence time in a photon storage experiment, and compare them to spectroscopic measurements of magic wavelengths.

Magic wavelength trap, Rydberg superatoms, Ponderomotive potential

Tuesday

Multiparameter quantum sensing with a hybrid rf-dc optically pumped magnetometer at Earth's magnetic field 11:30

Diana Méndez Avalos, *ICFO*

We describe a hybrid optically pumped magnetometer (hOPM) that simultanously measures the dc magnetic field and one quadrature of the rf magnetic field, operating around Earth's magnetic field with only one atomic spin ensemble. We demonstrate sub$-pT/Hz^{1/2}$ quantum-noise-limited sensitivity, for frequency and amplitude modulation schemes.

Magnetometers, Metrology, OPM, Multiparaneter estimation

Room Temperature Quantum Memory for light using the Atomic Frequency Comb protocol 11:45

Zakary Schofield, *University of Southampton*

Quantum memories are devices that allow for the on-demand storage and retrieval of photonic quantum information. The Atomic Frequency Comb (AFC) protocol is a rephasing memory based on the spectral shaping of an inhomogenoulsy broadened transition into a frequency comb with periodic spacing Δ. This is demonstrated with short pulses of light attenuated to the single photon level in warm Rubidium vapour with a storage time of 7.5ns and an efficiency of 9%.

Quantum Memory, Warm Rubidium Vapour, Frequency Comb

Talks: Ultracold Fermions

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Cooling of fermionic Lithium in a 2D optical lattice 14:00

Luca Muscarella, *Max Planck Institute of Quantum Optics*

We present our advancements towards achieving Raman cooling of Fermionic Lithium confined in a 2D optical lattice. Following trapping in a MOT, we proceed to direct loading into the lattice and we employ Raman cooling to drive the atoms into their motional ground state. In the future we aim to load this sample into a superlattice that we intend to use as a hybrid digital/analog quantum processor.

Laser cooling, Optical lattice, Lithium

Self-organisation dynamics in strongly interacting ultracold fermions 14:15

Gaia Stella Bolognini, *Ecole Polytechnique Fédérale de Lausanne*

The talk presents an experimental setup which combines a degenerate Fermi gas of 6Li with a high-finesse optical resonator, providing full control over both short and long range interparticle interactions. We study the dynamics of the superradiant phase transition which emerges upon driving the system from the side, for which the atoms self-organise into a crystalline structure. A universal response is observed, suggesting the existence of a new universality class emerging in far-from-equilibrium, strongly interacting systems.

Ultracold fermions, Cavity-Quantum Electrodynamics, Light induced Phase transitions

Talks: Atom Interferometry

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Multi- species cold atom interferometry for inertial measurements 15:00

Mal Landru, *ONERA DPHY - SLM*

Cold atom interferometry based on a single atomic species (usually Rubidium) can give rise to very stable and absolute gravity sensors, but this technology suffers from dead times and a limited measurement range. However, manipulating 3 atomic species instead of 1 reveals new potential of cold atom gravimeters. A triple-species gravimeter (Rb85, Rb87 and Cs133) could present fewer dead times and a better measurement range, or could even enable simultaneous 3D acceleration measurements.

Cold atoms, Atom Interferometry, Inertial sensor, Multi-species

Dark energy search using atom interferometry in the Einstein-Elevator 15:15

Magdalena Misslisch, *Leibniz Universitat Hannover*

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. Multi-loop atom interferometry is used to search for phase contributions induced by chameleon scalar fields with a specially designed test mass that suppresses gravitational effects from self-mass and its environment.

Atom interferometry, Dark energy search, BEC, Microgravity

High-performance two axis cold-atom gyroscope for rotational seismology 15:30

Nathan Marliere, *LNE-SYRTE*

The SYRTE cold-atom gyroscope represents the state-of-the-art in atomic gyroscopes. Using atomic interferometry, it achieves measurements of the Sagnac effect with exceptional sensitivity and stability. I will present our recent work on enhancing sensitivity through no dead-time sequences, enabled by double diffraction. This aims to minimize noise and improve performance, ultimately reaching standard quantum projection noise levels.

Atomic Inferometry, Gyroscope, Sagnac effect

Optimal Floquet Engineering for Large Scale Atom Interferometers

15:45

Léo Calmels, *Laboratoire Collisions Agrégats Réactivité (LCAR), Université Toulouse III Paul Sabatier, Toulouse, France*

Atom interferometry is a very promising tool for metrology and exploration of quantum physics at the macroscopic scale, but requires highly efficient atom manipulations processes. We present a new method, based on Floquet's theory, for accelerating atoms in an optical lattice, resulting in the largest momentum transfer ever achieved in atom interferometry so far.

Atom interferometry, Large momentum transfer, Floquet engineering

Tuesday

Talks: Cavities

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Standard quantum limits for cavity-enhanced optical readout methods of hot atomic vapor quantum sensors 16:00

Hana Medhat, *Institut de Ciències Fotòniques (ICFO)*

We derive the standard quantum noise limits of different optical readout techniques for monitoring the collective spin variables of a hot atomic ensemble with high number density placed inside a resonant cavity structure. The techniques included in our analysis are Homodyne and Heterodyne interferometric readout methods as well as the Pound-Drever-Hall readout method.

Cavity-Enhancement, Optical readout methods, Standard quantum noise limits

Cavity-based non-destructive detection in ultracold gases 16:15

Gokul Vengillasery Illam, *Raman Research Institute*

To demonstrate rapid, continuous cavity-based measurement, we experimentally measure time evolution in a multilevel system and show the potential of cavity-based measurements for state detection, even when there are many participating energy levels. To illustrate the range of applications of the cavity-based detection scheme, we also use the cavity to detect photoassociation in a dark MOT where a direct fluorescence measurement is not possible and use this to determine PA rates in the system.

Cavity QED, Quantum optics, Non-destructive detection

An Optical Cavity-Atom Array System for Quantum Computing 16:30

Michelle Chong, *Massachusetts Institute of Technology*

Atom arrays are a promising platform for quantum computing but it will be difficult to scale system size using the standard readout technique of fluorescence imaging. We present cavity-mediated readout as a scalable alternative. We present progress on error detection and correction of an atom array using an optical cavity.

Optical cavity, Atom array, Quantum computing

A cavity-microscope for micrometer-scale control of atom-photon interactions 16:45

Ekaterina Fedotova, *EPFL*

We present our cavity-microscope device allowing for spatio-temporal programming of the light-matter coupling of atoms in a high finesse cavity, which provides a spatial resolution an order-of-magnitude lower than the mode waist. We illustrate this capability by engineering micrometer-scale coupling, using cavity-assisted atomic measurements and optimization. This technique opens a wide range of perspectives from ultra-fast, cavity-enhanced readout to the quantum simulation of quantum matter.

QED, microscope, aberration correction, SYK

Invited Speaker: Elisa Ercolessi

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Hybrid Variational Algorithms on a neutral atom platform

Elisa Ercolessi - University of Bologna, Italy

Quantum Computing is seen as a potential breakthrough for the study of hard classical problems as well as for quantum many body systems. However, we are in the era of NISQ devices and still far away from fault-tolerant machines.

This leads us to consider the possibility of hybrid classical-quantum protocols of variational type: they exploit quantum resources to efficiently prepare states that depend on a suitable chosen set of variational parameters, which can then be determined by means of optimization algorithms to be run on a classical computer. The choice of such classical optimizer schemes is to be guided by compatibility requirements with respect to current available quantum platforms.

To evaluate the feasibility of such an approach, we present an application of the Quantum Approximate Optimization Algorithm to a typical classical hard combinatorial problem, that has been emulated and tested on the Rydberg atom quantum machine Fresnel of Pasqal.

Elisa Ercolessi is an Associate professor of Theoretical Physics, Models and Mathematical Methods at the Department of Physics and Astronomy since 2005. After the Laurea Degree in Physics at the University of Bologna, she obtained the PhD in Physics at Syracuse University (NY, USA). Her research develops in the field of quantum statistical mechanics, working with several national and international groups, focussing mainly on models for many body systems in low-dimensions, which exhibit topological and exotic phases of matter, and on quantum information and computation theory. Author of more than 80 papers in international journals and of 3 books.

Talks: Quantum Computing

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Few-body F¨orster resonances in Rydberg atoms for quantum gate protocols 10:30

Ivan Ashkarin, *Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton, Orsay, France*

Due to the dramatic size increase of available neutral-atom-based quantum registers, the implementation of long-range multi-qubit quantum gates is essential to maintain interconnectivity and improve computational efficiency in near-term NISQ devices. Stark-induced Förster transitions provide a promising approach for realizing multi-qubit gates between distant atomic qubits. We present results of research on the applicability of Förster interactions to Rydberg quantum computing applications, and propose high-fidelity three-qubit quantum gate protocols based on such transitions.

Multiqubit gate, Quantum gate, Förster resonance, RF induction

Optimisation of weighted graphs using neutral atom arrays 10:45

Max Wells-Pestell, *University of Strathclyde, UK*

Neutral atom quantum computers show promise in finding solutions for combinatorial optimisation problems. Here we show first experimental results of solving an optimisation problem on a weighted graph using local light-shifts, extending the class of problems that can be solved with neutral atom tweezers and providing a route to scaling to solutions of real-world problems. An example 2D MWIS problem was solved by coherent quantum annealing for the first time, where a five vertex graph was encoded into a nine qubit array.

Quantum information processing, Rydberg atoms, Quantum computing

Cryogenic strontium quantum processor 11:00

Valerio Amico, *University of Tübingen*

We work to realise an optical tweezer lattice in a cryogenic environment at 4K. This will allow us to shield the environment (black body radiation), reach stronger vacuum regimes, and thus get high-performance qubits.

Cryostat, Quantum computer, Strontium87, Rydberg atoms, Optical tweezers.

Talks: Numerical Methods and Simulations

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Continuous Coherent Quantum Feedback with Time Delays: Tensor Network Solution 11:15

Kseniia Vodenkova, *University of Innsbruck*

We present a new method for solving quantum optical systems with coherent feedback loops with time delays. We map these non-Markovian problems to Markovian quantum many-body problems, enabling efficient numerical solutions using tensor network methods. Our approach handles long time delays and arbitrary excitations in delay lines, providing solutions for real-time dynamics and steady states. We also propose a mean-field approach that offers semi-analytical solutions.

Quantum optics, coherent feedback, tensor networks

Wednesday

Lissajous figures in a quantum walk on a lattice 11:30

Grzegorz Jaczewski, *University of Warsaw*

The dynamics of a quantum particle on a square lattice subjected to an external constant force is numerically studied. In one dimension, if the wave packet is wide enough, the average position over time will evolve in an oscillatory manner, while the shape of the wave packet is pre- served. We mainly focus on showing that it is possible through a combination of Bloch oscillations in both directions to obtain trajectories of a wave packet center analogous to classical Lissajous figures.

Quantum walk, Bloch oscillations, Lissajous figures

Finite-temperature Rydberg atom systems: quantum phases and entanglement characterization 11:45

Nora Reinić, *University of Padova, INFN Padova*

Ultracold Rydberg atoms are a promising quantum computing and simulation platform. However, considering that a realistic experimental setup can never be cooled down to a zero temperature, it is important to understand how robust to the temperature these systems really are. For this purpose, we develop a tensor network algorithm for studying quantum many-body systems at thermal equilibrium, and use it to extract the finite temperature phase diagrams and entanglement properties of Rydberg chains.

Rydberg atoms, Tensor networks, Finite temperature, Entanglement

Invited Speaker: Patrick Maletinsky

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Photophysics and quantum optics of solid-state quantum sensors

Patrick Maletinsky - Department of Physics, University of Basel, Switzerland

Quantum two-level systems offer remarkable opportunities for sensing minute physical quantities and enabling high-resolution imaging at the nanoscale [1]. While atomic and molecular systems excel in quantum coherence and record sensitivities [2], solid-state quantum emitters are more conducive to device development [3] and provide access to nanoscale imaging in both physical and life sciences [4]. In this talk, I will present the foundational principles [5] and key engineering challenges in the field of solid-state quantum sensing [6]. I will describe their basic operational principles and highlight selected key applications in mesoscopic, condensed-matter physics [7]. The focus will then shift to the (quantum)-optical properties of solid-state quantum sensors. I will discuss the photophysics of a leading platform in quantum sensing - the Nitrogen- Vacancy center in diamond [8] - and present recent advancements towards utilizing coherent optical control of Silicon-Vacancy center spins for quantum sensing under extreme conditions [9]. The talk will emphasize the importance of spectroscopy and quantum optics in quantum sensing. An in-depth understanding of the (quantum)-optical properties of solid-state quantum centers is not only crucial for developing and optimizing such sensors, but also holds significant potential for discovering novel sensing modalities, which could unlock new scientific insights across various disciplines.

[1] B. Chernobrod and G. Berman, J. of Applied Physics 97, 014903

[2] M W. Mitchell and S. P. Alvarez, Rev. Mod. Phys. 92, 021001

[3] www.qnami.ch

[4] G. Balasubmaranian et al., Nature 455, 644

[5] C. L. Degen, F. Reinhard, and P. Cappellaro RMP 89, 035002

[6] P. Appel et al., Rev. Sci. Instr. 87, 063703; N. Hedrich et al. Phys. Rev. App., 14, 064007

[7] L. Thiel et al., Science 364, 973 and Nature Nano. 11, 677

[8] J. Happacher et al., PRL 128, 177401 and PRL 131, 086904

[9] J. A. Zuber et al., Nano Lett. 23, 10901; Z.-H. Zhang et al., PRL 130, 166902

Patrick Maletinsky was born in 1979 in Baden, AG and grew up in the town of Schaffhausen, Switzerland. He studied Physics at ETH Zurich with stays at the Ecole Normale Supérieure Paris and at JILA in Boulder, Colorado. For his doctoral studies, he returned to ETH Zurich, where he graduated under the supervision of Prof. Atac Imamoglu on optical studies of hyperfine-interactions in individual, self-assembled quantum dots. His doctoral thesis was awarded the Schläfli-prize of the Swiss Academy of Sciences in 2010. From 2008 to 2011, he was a postdoc in the group of Amir Yacoby at Harvard University, where he developed and applied novel, highly precise methods for nanoscale magnetic field sensing. In 2012, Patrick Maletinsky assumed the Georg-H.-Endress-Professorship as an Assistant Professor at the Department of Physics of the University of Basel; he was promoted to Associate Professor in February 2017.

Talks: Quantum Technologies

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Strongly Interacting Photons in 2D Waveguide QED 11:30

Matija Tečer, *University of Padua*

The occurrence of strong photon-photon interactions in 1D waveguide quantum electrodynamics has been studied extensively in the last few decades. However, the question of its occurrence in higher dimensions is not trivial since photons can be emitted within a larger phase space. We positively answer this question for the case of a 2D square array of atoms coupled to the light confined into a 2D waveguide by demonstrating the existence of long-lived two-photon repulsive and bound states.

Quantum optics, Collective effects in atomic physics, Light-matter interaction, waveguide QED, Photonic Crystals

Development of a transportable optical cavity for a portable trapped ion atomic clock 11:45

Rishabh Pal, *Indian Institute of Technology Tirupati, India*

Portable all optical atomic clocks, reliant on dipole forbidden optical clock transition are crucial in modern applications. Coherent probing of optical clock transition necessitates ultra-stable narrow linewidth laser, feasible using ultra-stable high finesse cavity. Designing such cavity involves meticulous selection of cavity length and materials. This presentation focuses on Airy point identification of cavity and how cavity length and mirror curvature impact fundamental thermal noise floor.

High finesse cavity, Portable optical clock, Finite element analysis, Airy Point

Manufacturing Q-optimized polymer-based mechanical resonators for cavity optomechanics with 3D-direct laser writing 12:00

Daniel Stachanow, *University of Bonn*

Optomechanical platforms with high-quality mechanical and optical resonators have a wide application potential ranging from quantum limited sensing to long-lived storage of quantum information. Recent developments in polymer-based 3D direct laser-written structures allow for new paradigms in manufacturing micromechanical bridge-like resonators, but so far suffer from strong mechanical dissipation. We show viable routes for improving this platform.

Optomechanics, Nanoscribe, Direct Laser Writing, Fiber Cavity, Dissipation Dilution

Enabling atomic systems with fully integrated photonics from UV to IR 12:15

Sophie Cavallini, *ETH Zurich*

Integrated photonics have demonstrated substantial benefits in chip-scale atomic systems, including stability, convenience, and scalability. Recent advances in alumina waveguide fabrication have opened the door to trapped ion and neutral atom systems with all wavelengths of light integrated on chip. Our work targets more generally photonic integrated circuits, for example, structures like low-loss bends and power splitters, and we present ongoing work towards self-injection locking on a chip for a UV diode laser using a thermally tunable ring resonator.

Chip-scale atomic system, Integrated photonics, Aluminium oxide waveguides

Shallow, optically coherent SiV centers in diamond nanopillars for quantum sensing 12:30

Marina Obramenko, *Department of Physics, University of Basel, CH-4056 Basel, Switzerland*

In our work, we present a way of creating individual SiV centers at the depth of approximately 50 nm. We introduce a novel charge stabilization method through extended 445 nm laser exposure, which enables resonant excitation without a charge-repump pulse. Our results constitute a key step towards single SiV quantum sensing under extreme conditions and offer a powerful tool for charge stabilisation of various solid state spin.

Colour centers, Quantum sensing, SiV centers

Characterizing single photon from an atom array via optical fiber 12:45

Yuya Maeda, *Osaka University*

The system of atom arrays, containing a large number of computable qubits and offering the potential for photonic links, is also showing promising features as quantum nodes. In this talk, we report the experiment of fiber coupling of the photons emitted from a single site in an atom array and the measured results of nonclassical second-order correlation.

Atom arrays, Quantum communication, Quantum optics

Invited Speaker: Christiane Koch

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Training Schrödinger's Cat: Quantum Control in Molecular Physics and Quantum Information Science

Christiane Koch - Freie Universität Berlin, Germany

Control refers to the ability to steer a dynamical system using external fields; quantum control does so by exploiting quantum coherence. One way to think of it is in terms of constructive and destructive interference between different quantum pathways, all connecting the same initial and final states. The desired interferences can be designed spetrally, temporally, or using the picture of dressed states. If the dynamics of the quantum system is too complex to design the interferences by hand, optimal control theory comes to rescue. I will showcase recent applications of these concepts to chiral molecules and AMO platforms for quantum information.

Thursday

Christiane Koch studied physics at the Humboldt University of Berlin from 1992 to 1998, during which she was a Fulbright Scholar at the University of Texas at Austin. She did her doctoral studies in chemical physics through Humbold University at the Fritz Haber Institute of the Max Planck Society, completing her Ph.D. in 2002. After postdoctoral study at the University of Paris-Sud and The Hebrew University of Jerusalem, she became an Emmy Noether Independent Junior Researcher at the Free University of Berlin in 2006. She became a professor at Kassel in 2010, and moved to the Free University of Berlin in 2019. Christiane's researches involve quantum mechanical versions of control theory, including the use of lasers to achieve coherent control of chemical reactions. She has also performed research on efficiently testing the accuracy of quantum computing devices.

Talks: Optimal Control

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Fast and robust cat state preparation utilizing higher order nonlinearities

10:30

Suocheng Zhao, *IQMT, KIT*

Coherent cat states can be prepared using multiple order nonlinearities and optimal control, protected from noise using optimal squeezing, and realized using Rydberg ensemble.

Cat state, quantum control, Rydberg atom, Squeezed cat state

Optimal control of quantum systems: Applications to the control of Bose-Einstein Condensates

10:45

Etienne Dionis, *Laboratoire Interdisciplinaire Carnot de Bourgogne*

Quantum control techniques applied to manipulate Bose-Einstein condensate in optical lattice. Demonstrated precise control using modified GRAPE algorithms to meet experimental constraints.

Optimal Control, Quantum Control, BEC

Talks: Quantum Gas Microscopy

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A strontium quantum-gas microscope 11:00

Carlos Gas Ferrer, *ICFO*

A quantum-gas microscope of strontium is introduced and results on single-atom imaging of a superfluid of bosonic strontium (^{84}Sr) are presented. Finally, efforts towards efficient cooling and single-atom imaging of the fermionic isotope (^{87}Sr) are described.

Quantum gas microscope, Strontium, Quantum simulation

Towards a quantum gas microscope with programmable lattices 11:15

Sarah Jane Waddington, *TU Wien*

Our poster will present the ongoing design and development of a Lithium quantum simulator. A reconfigurable lattice potential will allow site-resolved state preparation and evolution, and imaging will be achieved through a microscope objective. Research goals include the Fermi-Hubbard model, but also more unconventional phases allowed by the dynamic lattice shaping.

Lattice, Simulation, Microscope

Invited Speaker: Katharina Kaiser

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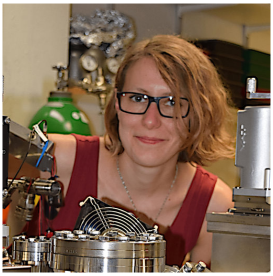
Optoelectronics on the atomic scale – what we can learn from STM on single molecules

Katharina Kaiser - Unversität Göttingen, Germany

When we talk about molecules in scanning tunneling microscopy (STM), we typically refer to a geometry that essentially consists of a molecule that is sandwiched between two tunnel barriers and metal electrodes. Basically, this corresponds to the geometry of an organic resonant tunnel diode, or photodiode, if dyes are used instead of just any molecule. Only in this case, instead of a huge ensemble of molecules arranged in a thin film, we have a single molecule. And instead of a plate capacitor-like arrangement of electrodes, one electrode is an atomically sharp tip that allows us to observe and manipulate the molecule with atomic resolution and precision.
In my talk, I will show you how this allows us to understand what happens during charge transport through a molecule and what possibilities there are to actively control the light emission from such a single-molecule tunnel photodiode.



Professor Katharina Kaiser studied physics at the Georg-August-Universität in Göttingen, Germany, and obtained her Ph.D. in 2022 from Regensburg University generating and characterizing single molecules by atomic force and scanning tunneling microscopy at IBM Research. Afterwards she continued her research on single molecules using scanning tunneling microscopy at IPCMS in Strasbourg. Since January she is a junior professor at the Georg-August-University in Göttingen and leads a group on atomic scale optoelectronics and STMs

Talks: Molecules

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Compact high-precision microwave spectrometer based on FID measurements 10:30

Hemanth Dinesan, *CNRS, Laboratoire de Physique des Lasers, Université Sorbonne Paris Nord, Villetaneuse, France and CNRS, Laboratoire Aimé Cotton,Orsay, Saclay, France*

We present a simple, compact, microwave spectrometer based on Free Induction Decay measurements of molecules confined in a microwave waveguide at room temperature. The test measurments on OCS the transition at 12.163 GHz yielded a notably high SNR ($> 10^7$) which is well above the state-of-the-art commercial instruments and laboratory measurements in this frequency range. Extending the technology to the measurements at cryogenic temperatures should allow us to significantly improve the SNR.

Free induction decay, Signal-to-Noise Ratio, Microwave

Experiments with ultracold atoms and molecules 10:45

Lukas Leczek, *TU Wien*

I will report on two experiments that use the unique properties of different atomic and molecular quantum gases. First, I present the design and realization of an optical system that combines an adjustable ring pattern created by axicon lenses and tailored light patterns created by a digital micromirror device, which will be used in an experiment with strongly interacting quantum gas of lithium-6 atoms. Second, I discuss a new experiment that aims to use ultracold calcium monofluoride molecules to study supersolid phases of matter.

Ultracold quantum gas, Axicon lens, Digital micro-mirror device, Ultracold molecules

Ultracold molecules: how not to lose them - A step towards larger molecular quantum computers 11:00

Etienne Walraven, *IMM, Radboud University*

Ultracold molecules trapped by an optical tweezer array are a powerful platform for quantum computing. However, the typical loading efficiency of 50% limits the scalability to larger systems. We propose a novel scheme to increase this efficiency to 80% by using rotationally excited states that show lower collisional loss.

Dipolar molecules, Optical tweezers, Ultracold collisions

Talks: Hybrid Systems

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Vibrationally coupled Rydberg atom-ion molecules 11:15

Ilango Maran, *Universiteit van Amsterdam*

We use a hybrid atom-ion system to create a linear ion crystal in a Paul trap with Rydberg atom ion molecules at its ends to generate ion-mediated Rydberg-Rydberg interactions. We propose a scheme that uses motional modes of the ion chain to enhance or suppress the formation of two RAIMs at its ends, effectively extending the blockade radius. We use detailed Floquet analysis and the Landau-Zener criterion to provide a qualitative test for the RAIM's survival in the Paul trap's rf potential.

Rydberg atom-ion molecules, Floquet formalism, Rydberg blockade

Trapped ions in optical tweezers 11:30

Nella Diepeveen, *University of Amsterdam*

We plan to combine 2-dimensional Yb+ ion crystals in a Paul trap with optical tweezers to create a novel platform for quantum simulations. Our experimental work demonstrates an optimisation routine for resonant tweezers and observation of coherent population trapping of the ion states. Looking ahead, since we need a deep trapping potential while minimising photon scattering for quantum simulation, we outline future plans to align and optimize non-resonant tweezers.

Quantum simulation, Optical tweezers, Trapped ions

Interfacing Rydberg atoms with an electromechanical oscillator in a cryostat 11:45

Julia Gamper, *University of Bonn*

We are interested in interfacing optically controlled Rydberg atoms with an electromechanical oscillator and will explore the possibility to cool a mechanical oscillator mode to its quantum mechanical ground state by extracting phonons via a coherent exchange of microwave photons with the atoms. Here, we present our design of how to implement this hybrid system and present our progress on the construction. Moreover, we show in detail the optimisation and characterisation of the atom preparation.

Rydberg Atoms, Hybrid System, Electromechanical Oscillator

Posters

Posters: Session Monday (1)

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Atom Interferometer Observatory and Network: towards enhancement of large momentum transfer for fundamental physics

Upasna Chauhan, *University of Birmingham*

The Atom Interferometer Observatory and Network (AION) project, is an atom interferometry project in the UK to detect ultra -light dark matter, mid-frequency gravitational waves and explore other fundamental physics. In my poster, I will provide an overview of the work towards AION at Birmingham, with a focus on both the laboratory progress and the theoretical exploration of LMT. An analysis of wavefront aberration effect in LMT atom interferometers, and a scheme for compensation will also be discussed.

Cold atoms, Quantum sensing, Atom interferometry, Atom optics, Large momentum transfer

High-resolution spectroscopy of the lowest energy levels in the b3Π0 potential of 87Rb133Cs for magic wavelength trapping

Albert Li Tao, *Durham University*

High-resolution spectroscopy of the lowest three rovibrational levels of the $b^3\Pi_0$ potential of ultracold RbCs molecule are conducted. Though this, the rotational constant, the partial linewidths, the natural linewidths and the magnetic moments of the excited states are measured. These parameters are crucial for an improved model of a rotationally magic wavelength of RbCs molecules.

Ultracold RbCs molecules, High-resolution spectroscopy, Magic trapping

A progress report on the isotopic comparison of parity violation in Yb

Iraklis Marios Papigkiotis, *University of Crete*

The development of our newly built precision measurement tabletop apparatus will serve as a novel platform for fundamental tests in nuclear and particle physics. By studying the isotopic variation of atomic parity violation in the ytterbium atom we aim to gain knowledge regarding the neutron distribution of neutron-rich nuclei and delve into physics that extend beyond the Standard Model.

Precision measurements, Atomic parity violation, Neutron skin distribution

Atom-light Crystals in Photonic Crystals: cold Rb atoms in Hollow Core Photonic Crystal Fibres (HCPCF)

Matteo Marchesini, *Alma Mater Studiorum - University of Bologna*

Atom interferometry allows to build gravimeters and gyroscopes of unprecedented precision. Our aim is to realise a setup that is more compact, economic and easily transportable compared to commercial instruments. Our experiment is composed of a Magneto Optical Trap of Rb atoms in proximity of the tip of a Hollow-Core Photonic Crystal Fiber, in which we plan to confine the cold atoms to reduce encumbrance while still attaining state-of-the-art sensitivities ($10^-7m/s^2$).

Laser cooling and trapping, Atom-ligh Crystals, Hollow Core Photonic Crystal Fibers, Quantum sensors, Magnetometry, Interferometry

Quantum interference measurement of the free fall of anti-hydrogen

Joachim Guyomard, *Laboratoire Kastler Brossel*

In order to improve the accuracy of the measurement of the gravitational force between matter and anti-matter, we are studying new interferometric schemes in the special case of a very small sample of atoms. Using optical analogies, we find for bouncing wave packets a behaviour similar to the caustic phenomenon. Finally, we study the resonances in the cavity created between the force of gravity and the bouncing potential.

Interferometry, Gravity

Floquet operator engineering for quantum state stroboscopic stabilization

Nicolas Ombredane, *Toulouse*

We use Quantum Optimal Control (QOC) to manipulate a Bose-Einstein condensate in a shaken optical lattice, and prepare a wide range of states (arbitrary momentum superpositions, squeezed gaussian states...). A complete state reconstruction is performed via tomographic measurements to certify the preparation with high fidelities and purities. We also report on the efficient design of QOC protocols to engineer a Floquet operator, allowing for the stroboscopic stabilization of any desired state.

Floquet, Stroboscopic

Scaling Beyond Grids of 1000 Optical Tweezers with Dynamic Manipulation in Real-time

Marcel Mittenbühler, *TU Darmstadt / Atoms - Photons - Quanta*

Optical tweezers have become the standard for moving atoms in stochastically loaded optical lattices and tweezer arrays to construct structures required for subsequent experiments. However, using a single tweezer becomes a bottleneck for scaling to ever larger systems. Our setup overcomes several challenges in controlling multiple tweezers with strict real-time requirements, achieving various movement patterns, including grids of up to 40x40 tweezers for atom transport.

Optical Tweezers, Scalable Atom Transport, Multi-tone Signal Generation, Real-time Control

Engineering Atomic Frequency Distributions for Atomic CQED Experiments

Clément Raphin, *Laboratoire Kastler Brossel*

The paradigm of N single neutral atoms coupled to the resonant mode of a Fabry-Perot cavity allows the study of transport properties in long-range interacting spin chains. When the emitter frequency distribution is inhomogeneous, the competition between light-matter coupling and disorder leads to a quantum phase transition. We discuss an experimental technique that allows controllable broadening of the atomic frequency distribution using elliptically polarized dipolar traps (optical tweezers).

Cavity Quantum Electrodynamics, Optical Tweezers, Light Shifts, Polaritons, Quantum Simulation, Single Atom Array

Microfabricated alkali cells for atomic devices

Linda Péroux, *Centrale Lille - IEMN*

Miniature atomic devices rely on microfabricated alkali vapor cells. We replicate the glass-blowing technique used in the fabrication of macro-cells on wafer-integrated microstructures. We report on our first results of migration of cesium inside the cells using this method.

Vapor cell, Atomic device, Microfabrication

Realising fast readout for Rydberg arrays

Mehmet Öncü, *Max Planck Institute of Quantum Optics*

In this work, we present our progress on an experimental platform aimed at achieving cavity-assisted, non-destructive, local readout of dual-element tweezer arrays. Long-range and tunable interactions between highly-excited Rydberg states make the platform suited to simulate spin models and form the architectural basis for the realisation of a scalable error-corrected quantum computing platform.

Neutral atom quantum computing, Rydberg atom arrays, Fast cavity readout, Dual-element tweezer arrays

Two-qubits entanglement and quantum gate operations using trapped neutral atom

Diksha Thapliyal, *Indian Institute Of Technology Roorkee, India*

This work thoroughly compares and analyses the impact of Doppler dephasing and decoherence originating due to the finite Rydberg state lifetimes across existing Rydberg protocols. These insights are crucial for designing a novel and robust gate protocol. Additionally, it presents a idea of implementing Controlled-Z and swap gates using amplitude and phase-modulated pulse waveform. Furthermore, it outline our experimental strategy to achieve the objective of high-fidelity gate implementation.

Trapped neutral atom, Quantum entanglement, High-fidelity quantum gates, Rydberg blockade

Picosecond imaging of both the phase and amplitude of an out of equilibrium 2D quantum gas

Kayce Ouahrouche, *Université de Lille*

We propose a new experimental scheme to investigate quantum turbulence at the picosecond time scale and perform single shot measurement of both the phase and amplitude of a turbulent polaritons fluid.

Quantum Turbulence, Polaritons Fluids, Ultrafast Imaging

Sensing Interactions in Atomic Quantum Systems

Luc Verwaal, *Eindhoven university of technology*

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 state-to-state quantum chemistry. At TU/e a new setup is being built to exploit the novel combination of Yb+ and Dy offering the opportunity to investigate the effects of dipole-dipole interactions in hybrid ion-atom systems.

Quantum sensing, Dipolar, Hybrid ion-atom system

Towards a Dual-Species Dipolar Quantum Gas Microscope

Clemens Ulm, *Institute for Quantum Optics and Quantum Information*

Ultracold atoms in optical lattices have been established as a powerful toolbox for quantum simulation, enabling the study of many-body physics and strongly correlated condensed matter. In the last decade, single-site imaging and addressing of these lattice-confined atoms has been achieved by the experimental realization of quantum gas microscopes. Here, we report on the progress towards a quantum gas microscope utilizing the highly dipolar species erbium and dysprosium, which will allow the study of both single- and dual-species physics on the single-atom level.

Ultracold, Dipolar Atoms, Quantum Gas Microscope

Cold Rydberg atoms for Strontium Optical Clock thermometry

Hugo Tortel, *SYRTE / Laboratoire Aimé Cotton - CNRS*

We propose a method for an in-situ, independent evaluation of the blackbody radiation frequency shift of the clock by exciting the clock atoms into a Rydberg state, therefore significantly increasing their BBR sensitivity.

Optical Lattice Clocks, Blackbody Radiation, Rydberg atoms.

Quantum simulation using Bose Einstein Condensates

Morten Strøe, *Aarhus University*

Using BECs as a quantum simulator for electron-phono quasiparticles (phonons) in a solid

Polarons, Quantum-Simulation, many-body physics

Studying Ultra-cold Collisions in Hg-Rb Mixture

Archita Sahu, *Nicolaus Copernicus University in Torun*

We developed an experimental set-up to perform ultra-cold collisions in sympathetically cooled ultra-cold Hg+Rb mixture in a two-species magneto-optical trap (MOT). We use the Time of Flight method and absorption imaging technique to measure the temperature of the atomic Rb cloud in the presence and absence of Hg atoms We also check the cooling efficiency for all five prominent Hg isotopes.

Ultra-cold atoms, Rubidium, Mercury, Collision, Sympathetic cooling, Magneto-optical trap

Exploring Kitaev model with Rydberg atoms: Probing exotic spin states through dipole-dipole interactions

Sakthikumaran Ravichandran, *Faculty of Physics, University of Warsaw*

We study the prospects for realizing Kitaev-type interactions through the utilization of Rydberg atoms, capitalizing their dipole-dipole interactions to engineer specific quantum spin dynamics. By combining theoretical analysis and numerical simulations, the research maps these interactions onto an effective spin-1/2 model, enabling the exploration of quantum phases with potential topological properties through precise control via external electromagnetic fields.

Rydberg atoms, Kitaev model, Quantum spin dynamics

Experimental setup to investigate fundamental interactions in ultra-cold mercury atoms.

Indrajit Nandi, *Nicolaus Copernicus University*

We developed an experimental system based on ultra-cold Hg atoms to explore the possibilities for new interactions beyond the Standard Model. Two-color photo-association spectroscopy will be performed at nm range near the dissociation threshold limit of Hg-Hg molecules. The Hg-Hg molecules will also be used to explore possibility of realization of optical molecular clock.

Ultra-cold mercury, Photo-association, Optical Feshbach resonance, Optical molecular clock

Toward microwave-induced Feshbach resonance

Bastien Mirmand, *Laboratoire de Physique des Lasers*

We are currently investigating a microwave-induced Feshbach resonance which has been theoretically predicted for all alkaline atoms in 2010. Relying on a coplanar waveguide, we induce a strong microwave field at the position of a sodium BEC, which is magnetically trapped on top of an atom chip. We have observed the different spin states of the molecular bound state involved in this Feshbach resonance and have obtained preliminary results on the modification of the interatomic interactions.

Feshbach-microwave-BEC

An accordion optical lattice for the realization of Hofstadter ladders with bosonic mixtures

Andreas Meyer, *ICFO - The Institute of Photonic Sciences*

Strong interactions among charged particles in two-dimensional lattices in the presence of a magnetic flux give rise to fractional quantum Hall physcis. We report on our progress in realizing a minimal representation of this many-body system with mixtures of Bose-Einstein condensates through the implementation of a two-dimensional accordion optical lattice.

Optical lattices, Synthetic gauge fields, Fraction qantum Hall effect, Bose-Einstein condensates

Chip-Scale Quantum Gravimeter

Julian Lemburg, *Leibniz Universität Hannover, Institut für Quantenoptik*

Atom interferometry with Bose-Einstein condensates promises very precise, absolute and drift-free measurements of gravity with residual uncertainties on the order of nm/s^2. To be applicable in ground or space-borne geodesy quantum gravimeters have to be compact, lightweight and energy-efficient . To tackle those challenges, we designed a novel atom chip that is equipped with a grating and a wavelength dependent mirror, which allows us to perform cooling and atom interferometry on a single axis.

Atom Chips, Gravimetry, Compactification

Quench induced chaotic dynamics of Anderson localized interacting Bose-Einstein condensates in one dimension

Swarup Sarkar, *Indian Institute of Technology, Guwahati*

In this work, we establish a possible connection between the delocalized condensate with temporal chaos, which is captured using the time correlator function as the post-perturbed dynamics of the condensate. Although, the dynamics in the delocalized region is chaotic with time but in the localized region the time correlator remain periodic, and quasiperiodic in nature. This investigation enables us to develop a characterization technique between localization and delocalization by studying the dynamics of the condensate, which remains consistent across various trap geometries.

Ultracold atoms: BEC, atomic clocks, Rydberg physics, ...

Posters: Session Wednesday (2)

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Emergence of Synchronisation in a Driven-Dissipative Hot Rydberg Vapour

Karen Wadenpfuhl, *Physikalisches Institut, Heidelberg University*

Synchronisation has first been studied by Huygens, who observed out-of-phase synchronisation of two pendula fixed to the same support, and has since been employed to explain a wealth of phenomena in nature, and physics in particular. We show theoretically that strong interactions via a Rydberg density mean field facilitates synchronisation in a thermal gas and report on the experimental observation of synchronisation emerging in a driven-dissipative hot Rydberg vapor. This system provides an ideal testbed for a fundamental study of synchronisation in ensembles of nonlinear, coupled oscillators due to the large number of constituent oscillators and tunability of the system's parameters.

Rydberg atoms, Hot vapour, Synchronisation, Nonlinear driven-dissipative system

Towards a Grating MOT for Calcium Atoms

Pavel Filippov, *Eidgenössische Technische Hochschule Zürich, ETH Zurich*

We present the latest results of our experiment with the goal of using circular Rydberg states of calcium as qubits. In particular, this work focuses on the implementation of a grating magneto-optical trap (gMOT). This technology allows for a simplified implementation into a cryogenic apparatus and opens new integration possibilities, such as waveguides integration into the grating and a compact source of quadrupole magnetic field.

Rydberg, MOT, Calcium

Driving Raman transitions using a nano-structured atom chip

Kai-Christian Bruns, *Leibniz Universität Hannover*

Grating atom chips simplify and enhance quantum sensing devices by trapping atoms in a MOT with a single beam. This advancement promises compact, portable, and efficient quantum sensors. The poster demonstrates Raman transition measurements on such a chip, supported by simulations. Utilizing the diffracted beams, multi-axis atom interferometers could be constructed, with implications ranging from fundamental research to practical geodesy applications.

Interferometry, Atom chips, Raman transitions

Closed loop correction for laser pulse envelope imperfections based on Compact-Optimized optical modulator

Shuzhe Yang, *University of Strasbourg*

Optimal pulses featuring specific amplitude and phase envelopes have been investigated to achieve high-fidelity quantum operation in neutral atom or ions trap based quantum processor. However, the generated laser pulse usually suffers from distortions induced by experimental devices, which will have a detrimental effect on fidelity of quantum operations. Here, we present a method to correct the distortion in laser's amplitude and phase simultaneously. By estimating the complex-value impulse response function characterized by the Volterra series, we are able to obtain pre-distorted amplitude and phase envelope from optimization algorithm , which enables us to compensate for the distortion induced from experimental devices. Our method is effective in addressing the errors that arise from the laser pulse envelope imperfections on ions trap or neutral atom-based quantum processor.

QI technology: quantum computers, Sensors, Simulators, Communications

Quantum Simulation and Quantum Computing using trapped ^{88}Sr atoms

Jan Geiger, *Max Planck Institute of Quantum Optics*

Here, we present the coherent excitation of the ultranarrow $^1S_0$–$^3P_2$ transition in ^{88}Sr with excitation fractions of 97(1)%. Building on these results, we demonstrate the implementation of a fine-structure qubit encoded in the metastable $^3P_2$ and $^3P_0$ states of ^{88}Sr promising fast single- and two-qubit gates. Our results pave the way for fast quantum information processing and highly tunable quantum simulators with two-electron atoms.

Quantum simulation, Quantum computing, Optical lattice, Strontium

A miniature atomic magnetometer prototype

Arthur Dewilde, *Centrale Lille - IEMN*

We report on the ongoing development of a miniature atomic magnetometer at IEMN. These sensors must contain a VCSEL, the optics (quarter-wave plate, lens and prisms), the alkali vapor cell and the coils, in the most compact design possible.

Atomic magnetometer, VCSEL, Vapor cell

Quantum computing with mixed qubit types in ^{137}Ba$^+$

Sophie Decoppet, *University of Oxford*

We present an initial toolbox for trapped ion quantum computing with mixed qubit types. In particular, we demonstrate a novel state preparation and measurement protocol and entangling gates between ground and metastable qubits.

Trapped ion quantum computers, omg architecture, Mixed qubit types

Cold ytterbium Rydberg atoms source

Jawad Cheayto, *Quantum Information Master- Laboratoire Aime Cotton*

Mounting a new atomic source constituted of an ytterbium oven, a Zeeman slower collecting most of the velocity classes, followed by a Magneto-Optical Trap (MOT) in 2 dimensions to redirect the atomic flux towards a 3D MOT.

Quantum Simulations, Rydberg Atoms, Quantum Computers

Quantum Simulations using potassium-40

Paul Catterson, *University of Strathclyde*

Quantum gas microscopes allow for single-atom-imaging within an optical lattice, allowing for the study of meany-body quantum systems with applications within solid state, and fundamental physics.

Quantum simulation, Quantum gas microscope, Optical lattices

Lowering entanglement in quantum trajectory unravelings of noisy quantum circuits

Ruben Daraban, *University of Strasbourg*

The evolution of quantum states quantum circuits subjected to dissipation can be simulated by unraveling the dynamics into quantum trajectories. Here, we introduce strategies to optimize those unravelings by leveraging the unitary degree of freedom in defining the Kraus operators. With analytical arguments and large-scale numerical simulations we demonstrate that standard representations of Kraus operators lead to almost worst-case scenario entanglement growth, and introduce a novel way to limit the entanglement growth.

Matrix Product States, Random quantum circuits, Monte Carlo wavefunction, Quantum Trajectories, Measurement induced phase transition

Energy levels in a 2D spin dependent optical lattice

Kamil Dutkiewicz, *University of Warsaw*

Investigation of energy levels in a 2D spin dependent, rectangular optical lattice. Type of boundary condition is discovered to influence the topological behavior of the energy levels as a function of the extertal magnetic field. Wave functions are investigated to show the difference in energy comes from interaction with the Dirichlet walls.

Optical lattices, Band structure, Edge states

Scale-invariant phase transition of disordered bosons in one dimension

Tanul Gupta, *University of Strasbourg*

This study investigates disorder-induced quantum phase transitions in one-dimensional bosonic systems, challenging the conventional expectation of a Berezinskii-Kosterlitz-Thouless (BKT) transition. Using hard-core lattice bosons with power-law hopping, a non-BKT continuous phase transition is revealed, contrary to expectations. Exact quantum Monte Carlo methods are employed to explore the phase diagram for different power-law exponents, highlighting scale-invariant behavior for $\alpha \leq 3$. Additionally, the data suggest a correlation length exponent consistent with the Harris bound, unveiling a new universal behavior for disordered bosons in one dimension.

Quantum Monte Carlo, Bose-Hubbard Model, Power-law hopping

Energy Damping of a Jones-Roberts Soliton: Analytical and Numerical Results

Nils Krause, *University of Otago*

We investigate the thermally induced decay of Jones-Roberts solitons in the framework of the stochastic projected Gross-Pitaevskii equation. Our findings suggest that the dominant damping mechanism is energy damping. While in the vortex dipole regime the characterising property of a Jones-Roberts soliton is the distance between the vortices, we identify the interaction energy as the relevant quantity in the rarefaction pulse regime.

Damping, BEC, Soliton

Assembled Arrays of Rydberg-interacting Atoms with Single-site Control

Justus Götzinger, *Technische Universität Darmstadt*

Neutral atoms in optical tweezer arrays are a well-controlled and scalable platform for quantum science. We extend the typical 2D setup to the third dimension at no additional cost, using a microlens-generated Talbot tweezer lattice. In-plane atom transport enables the deterministic preparation of defect-free configurations of naturally identical atomic qubits. We apply this platform to quantum sensing of magnetic fields and quantum information science with Rydberg-mediated interactions.

Optical tweezers, Quantum sensing, Rydberg interactions

Towards cavity-control of ultracold chemical reactions in molecular quantum gases

Marian Dürbeck, *Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany*

Understanding and controlling chemical reactions at ultralow temperatures is crucial for unlocking the potential of molecular quantum gases and for engineering new molecular species. We report on our efforts to create a Bose-Einstein Condensate of dysprosium atoms and preliminary spectroscopy characterization of the target dysprosium dimers.

Molecular quantum gases, Dysprosium, BEC, Ultracold chemistry, Cavity

Quantum Simulation of Ultra-Cold Atoms

Zoubair Daouma, *Université de Lille*

In my theoretical study, I explore the dynamics of the quantum kicked rotor, a fundamental system for studying quantum chaos and Anderson localization, by introducing spin-orbit coupling. This advanced model allows me to examine time-reversal symmetry and to develop an experimental protocol aimed specifically at studying the three Wigner-Dyson symmetry classes: symplectic, orthogonal, and unitary. A novel aspect of this work lies in the study of Hamiltonians belonging to the symplectic symmetry class, which, to our knowledge, have never been experimentally realized before.

Quantum kicked rotor, Ultracold atoms, Time-reversal-symmetry

Hydrodynamic Instabilities in Quantum Droplets

Luca Cavicchioli, *University of Florence*

We report on a hydrodynamic instability of a 41K-87Rb quantum droplet, which causes the break-up of the atomic cloud into smaller droplets. The phenomena seen can be explained by a conceptual framework analogous to that of the capillary instability in classical fluids, where the surface tension causes the fragmentation of a liquid filament. This opens new possibilities in the investigation of multicomponent superfluids.

Quantum droplets, Superfluids, Hydrodynamic Instability

Bragg-spectroscopy of a dissipation induced instability

David Baur, *ETH*

In our Experiment, we investigate two roton-like excitation modes, induced by the long-range interactions of our coupled BEC-cavity system. We make use of Bragg-Spectroscopy to simultaneously measure these two low-lying excitations and find the individual softening of the two modes as they approach their respective phase. We can explore a parameter regime, where the two modes coalesce, observing an exceptional point and the associated dynamical instability.

Cavity physics, Long-Range order, Roton-mode softening, Dynamical instability, Exceptional point

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

Omar Abdel Karim, *Università degli Studi di Napoli, Federico II*

Neutral atoms trapped in arrays of optical tweezer microtraps have recently emerged as a promising platform for quantum science. Optical tweezers enable the manipulation, control, and detection at the single-atom level. Moreover, the dynamic rearrangement of tweezer traps allows the generation of large-scale defect-free atom arrays in arbitrary geometric configurations. This, together with the possibility of directly implanting reordered arrays in optical lattice traps allows to combine the precise control provided by tweezers and the versatility provided by optical lattices making possible the realization of new generation quantum simulators.

Tweezers, Ytterbium, Simulator

High-rate quantum LDPC codes for long-range-connected neutral atom registers

Laura Pecorari, *University of Strasbourg*

We discuss the possibility of realizing a family of high-rate Low-Density Parity-Check (LDPC) codes in neutral atom quantum computers. We present results for their encoding and error correction capabilities, by focusing on codes that may be realized in near-term experiments with Rydberg atoms trapped in a two-dimensional array. We conclude by discussing in what situations these codes offer advantages over the standard surface code approach.

Rydberg Physics, Quantum Error Correction, Quantum Computing

Towards optical dipole trapping of Feshbach molecules with infrared light near $2\mu m$

Viviana Lippolis, *University of Innsbruck*

We are building an optical parametric oscillator, realized with a periodically poled lithium niobate crystal (PPLN). This is used to generate a tunable infrared light beam, with wavelength around 2 μm, that can be used to realize an ODT trap for the Dy-K Feshbach molecules.

Ring Cavity, Infrared light, Optical Dipole Trap

Perfect ring-shaped Bose Einstein Condensation

Vishal Pathak, *ITE Heraklion*

Ring-shaped Bose-Einstein condensates are created using timme-averaged adiabatic potentials (TAAPs) trap from the application of oscillating magnetic fields to a rf dressed quadrapole trap. A study is carried out for the coherence and superfluidity nature of the atoms making a testbed for fundamental quantum physics. The stability of the ring-shaped BECs is being studied by analyzing the effects of perturbations and fluctuations and precise control over cooling and confinement. By controlled manipulation of the trapping potentials, the dynamic excitations of the condensates is also studied. Ring-shaped BECs also offer possibilities for mater wave interferometry, and in atomtronics.

BEC, Ring-shape, Superfluidity

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 2024 conference is arranged by PhD students from CESQ and will take place in Strasbourg from June 30th to July 5th 2024.

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1997:	Parco dell'Orecchiella, Italy	2012:	Krakow, Poland
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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
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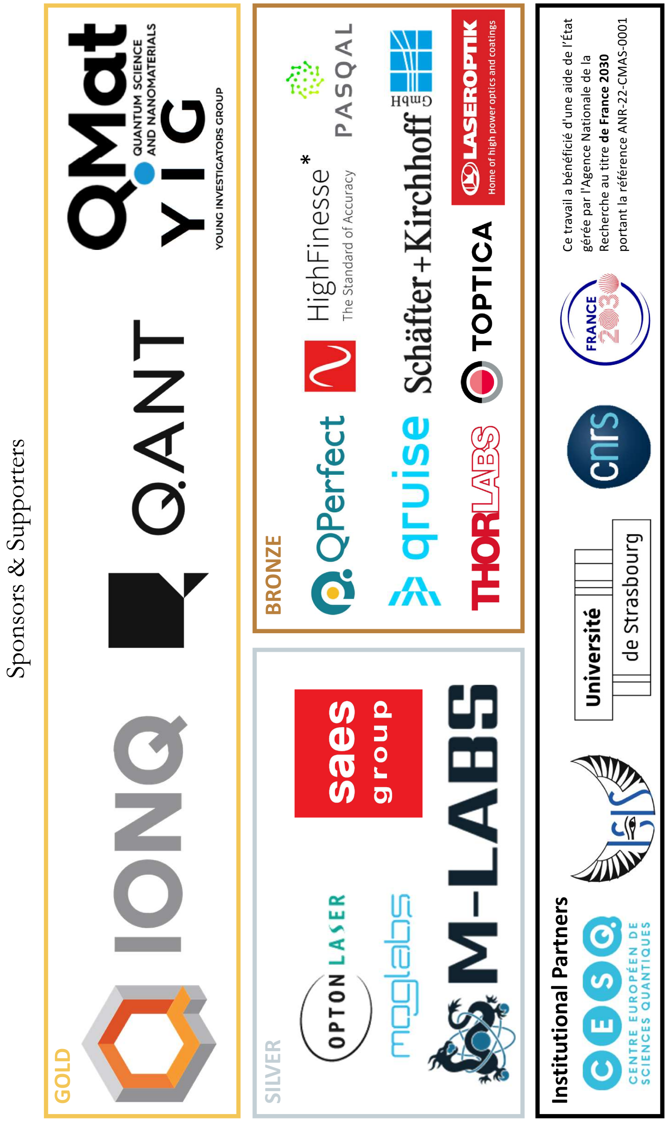

Dipolar XY magnetism in a two-dimensional Rydberg atom array

Bastien Gély,[1,*] Guillaume Bornet,[1] Cheng Chen,[1] Gabriel Emperauger,[1] Mu Qiao,[1] Lukas Klein,[1] Thierry Lahaye,[1] and Antoine Browaeys[1]

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I will present our Rydberg atom array experiment, our latest results on the study of interacting spin models, and our plans to build an improved version of this experiment.

In the context of quantum simulation of many-body spin Hamiltonians, we have developed a method called quench spectroscopy [1], which allows us to extract the dispersion relation of elementary excitations in many-body systems. We also have extended the range of systems we can study by implementing arbitrary local control in arrays of dipolar Rydberg atoms [2].

In parallel, we are building an improved version of this experiment. The main upgrade consists in using under-vacuum microscope objectives, enabling us to manipulate larger arrays of atoms with less optical aberration and larger field of view.

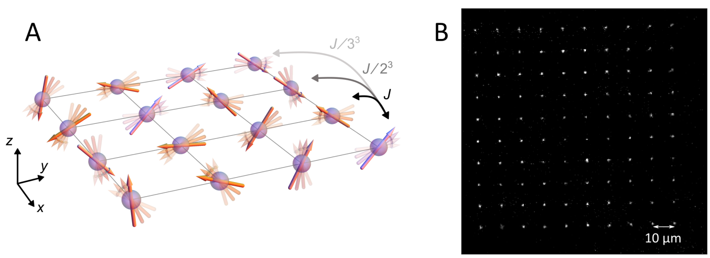

FIG. 1. **A**: Schematic representation of a square array of spins interacting under the dipolar XY model. The red arrows depict the average direction of the spins, and the black arrows represent the coupling between the spins, which decays as $1/R^3$ with R the inter-spin distance. **B**: Fluorescence image of an assembled atomic array.

[1] C. Chen *et al.* Spectroscopy of elementary excitations from quench dynamics in a dipolar XY Rydberg simulator. *ArXiv 2311.11726* (2023).

[2] G. Bornet *et al.* Enhancing a many-body dipolar Rydberg tweezer array with arbitrary local controls. *ArXiv 2402.11056* (2024).

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Experimental Observation of Quantum Criticality in a 4D Quantum Disordered System

Farid Madani,[1,*] Maxime Denis,[1] Pascal Szriftgiser,[1] Jean Claude Garreau,[1] Adam Rançon,[1] and Radu Chicireanu[1]

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Phase transitions are ubiquitous in natural sciences, from magnets, liquid crystals, superfluids, to nuclear matter and the electroweak transition in high-energy physics. These critical systems display emergent phenomena, with scale invariance –common to fractals– and universality –the independence on microscopic details– being the most striking examples. Furthermore, their fate is inherently tied to dimensionality: low-dimensional systems often exhibit suppression of phase transitions, while high-dimensional systems generally have simpler behaviors, with mean-field theories suitable to fully describe critical phenomena. However, a few notable exceptions are known to exist, like the Kardar-Parisi-Zhang equation –describing interface growth– and the stochastic Navier-Stokes equation describing turbulence– in classical physics, and the Anderson metal-insulator transition in quantum systems [1]. These systems maintain their non-mean-field character even in high dimensions, posing great challenges for traditional theoretical approaches. Excitingly, engineering synthetic dimensions in quantum simulations can open new ways to emulate and explore complex, high-dimensional phase transitions. In this work, using such an approach in an ultracold atoms experiment [2][3], we observe the Anderson transition in 4D and probe its critical behavior. We fully characterize the universal scaling emerging in the vicinity of the critical point and measure the critical exponents describing the scale-invariant properties of the critical dynamics. Our results confirm the non-mean-field character of the transition in 4D. The measured exponents are shown to be in good agreement with Wegner's scaling law in dimension four. This work opens a paradigm for experimentally exploring non-trivial critical phenomena in higher dimension.

[1] F.Evers and A.D.Mirlin, *Rev. Mod. Phys.* **80**, 1355-1417 (2008).
[2] F.L.Moore *et al.*, *Phys. Rev. Lett.* **75**, 4598 (1995).
[3] G.Casati *et al.*, *Phys. Rev. Lett.* **62**, 345 (1989).

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Long Abstracts

Ground-state cooling of Yb atoms in hybrid lattice-tweezer quantum simulator

Leonardo Bezzo,[1,*] Tim O. Höhn,[1,2] Etienne Staub,[1,2] René A. Villela,[1,2] Ronen M. Kroeze,[1,2] and Monika Aidelsburger[1,2,3]

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Quantum gas microscopes provide unique microscopic insights into quantum many-body systems, which is of paramount importance for testing theoretical models in condensed matter physics and probe new phases of matter. The basic ingredients needed are the ability to cool and trap atoms with high fidelity, as well as large and tunable tunnelling rates, e.g., to study Hubbard-type physics. Optical lattices are extremely well suited for achieving large homogeneous arrays of itinerant particles. The traditional approach to reach the ground state has been to perform evaporative cooling followed by an adiabatic loading of the lattice. However, this typically results in long cycle times and the initial-state fidelities are limited by the imperfect adiabatic loading. On the other hand, optical tweezer arrays offer extreme flexibility, dynamical rearrangement and local control. Unfortunately, the spacing between neighbouring traps is too large and sufficient tunnelling rates can only be realized for extremely light atoms. However, the combination of optical lattice and tweezer technologies, along with wisely employed magic and tune-out potentials enabling state-dependent control, provides alternative pathways for simulating complex Hubbard-type models. We report on our progress in building such a hybrid quantum simulator using Yb atoms and discuss novel methods for state preparation and ground-state cooling.

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Direct laser cooling of Rydberg atoms with an isolated-core transition

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Whereas ground-state atoms and small molecules have already been laser cooled, direct laser cooling of Rydberg atoms has never been achieved. This is explained by the absence of a suitable cooling cycle for the Rydberg electron. Instead, we theoretically propose to laser cool the ion within the Rydberg electron orbit, motivated by the fact that the ion core can be, to a good approximation, isolated from the Rydberg electron [1]. We illustrate our scheme with the Ca atom, using the $4s_{1/2} - 4p_{1/2}$ isolated-core transition to achieve cooling and the $3d_{3/2} - 4p_{1/2}$ one to close the cooling cycle.

When the ion core of an atom in a Rydberg state is excited, its energy lies above the first ionization threshold and the atom can therefore autoionize. For sufficiently high orbital-angular-momentum l values of the Rydberg electron ($l > 10$), it is however possible to suppress autoionization far below the radiative lifetime of both the ion core and the Rydberg electron. In this case, the lifetime of the states is extended to > 100 μs, which makes it possible to realize many isolated-ion-core cooling cycles.

To demonstrate the feasibility of our scheme, we first calculate the energy-level structure of the states involved in the cooling cycle. Their number is increased and their energies split, compared to the isolated ion, by the residual Coulomb interaction between the ion-core electrons and the Rydberg one. We then examine population dynamics over the 200 states of the cooling cycle and demonstrate that an ion-core photon scattering rate of $\sim 10^7$ s^{-1} can be achieved, and, in the presence of a small magnetic field, maintained over more than 100 μs [2]. Our Rydberg-atom laser cooling scheme offers the possibility to optically cool Rydberg atoms without significantly perturbing the Rydberg electron and paves the way to exploring the properties of cold Rydberg gases for a broad range of temperatures.

[1] H. Lehec *et al.*, *Phys. Rev. A* **103** 022806 (2021).
[2] A. Bouillon *et al.*, *Phys. Rev. Lett.* (2024). In press.

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Long Abstracts

Interacting Laser-Trapped Circular Rydberg Atoms for Quantum Simulation

A. Young Y. Machu A. Durán Hernández G. Creutzer
P. Méhaignerie J.M. Raimond C. Sayrin M. Brune

Abstract

Rydberg-atom based quantum simulators have proven their ability to emulate large systems of interacting spins in two dimensions. Their operation time, however, is limited to a few microseconds by the lifetime of the commonly used laser-accessible Rydberg levels. Circular Rydberg atoms, namely Rydberg atoms with maximal orbital momentum, have typically 100 times longer natural lifetimes, of a few 10 ms. This makes them well suited to the quantum simulation of the dynamics of interacting quantum systems. To benefit from these long lifetimes, we trap individual circular Rydber atoms in optical bottle beams based on the ponderomotive force. In addition, we implement an optical detection method capable of distinguishing the different energy levels and spatially resolving the array. I will report on our recent experimental activities, in which we measure the dipole-dipole interaction between two circular Rydberg atoms. We characterize it through microwave spectroscopy, and we can both control the geometry of the pair and dynamically tune the interaction strength via the surrounding electric field. Finally, we record oscillations which demonstrate for the first time the expected coupling between spin and motional degrees of freedom in a Rydberg-atom system.

Highly Scalable Quantum Processing Architecture using Neutral Atom Arrays in a Microlens-based Integration

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As inherently non-interacting particles with identical intrinsic properties, arrays of neutral atoms offer a versatile platform for quantum technologies. We present the realization of a large-scale quantum processing architecture surpassing the tier of 1000 atomic qubits. By combining two separate tweezer arrays, we achieve 2D configurations comprising 3000 sites, providing an average of 1167 single atoms [1]. In addition, by supercharging one array designated as the quantum processing unit with atoms from the secondary array, we significantly increase the initial filling fraction. This advancement enables defect-free assembly of clusters containing up to 441 qubits (see Fig. 1) with persistent stabilization at near-unity filling fraction over multiple detection cycles. To address immanent atom loss, we introduce a modular scheme incorporating an additional cold-atom reservoir and an array of buffer traps. This approach decouples cold-atom accumulation from the operation of the quantum register, resulting in increased data rates and paving the way for continuous operation of individual-atom tweezer arrays in quantum science [2]. These methods advance neutral atom quantum science by facilitating the continuous operation of highly scalable and configurable quantum registers, with immediate applications in Rydberg-mediated quantum simulation, computing, sensing, and metrology.

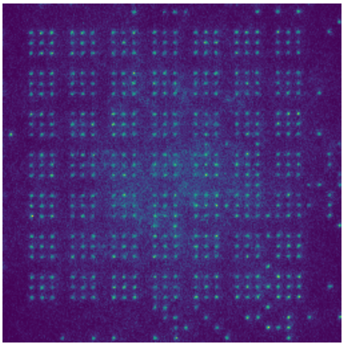

FIG. 1. Defect-free assembly scores target patterns with up to 441 qubits.

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Towards superfluids and supersolids in a ring

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In the mid 90's the experimental realization of BEC in ultracold atoms opened the way to a series of ground-breaking discoveries. Among them, an important recent achievement has been the observation of a new phase of matter, the supersolid, about 50 year since its first theoretical proposals. Previous results in the supersolid community proved that this newly discovered phase of matter indeed possesses the properties of both a superfluid, showing coherence and a reduced moment of inertia when rotated, and of a solid, featuring a spontaneous density modulation. I will report on an ongoing experiment regarding the superfluid nature of the supersolid. Our aim is to trap the supersolid in a repulsive optical potential shaped as a ring, made through the use of a digital micromirror device. By doing so we will be able to study its rotation properties in the same configuration used in the past for standard superfluids and superconductors. Moving from the supersolid to a standard superfluid through a reversible quantum phase transition, we will be able to test for the first time the seminal theory by the Nobel laureate A. Leggett.

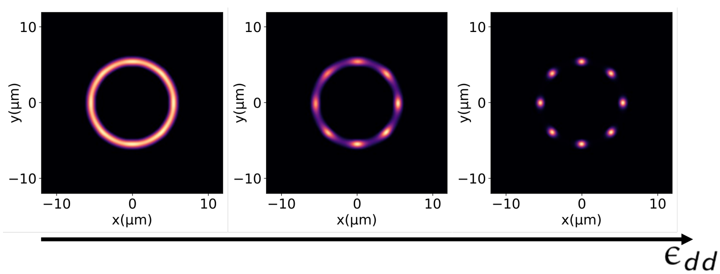

FIG. 1. Numerical simulation of the superfluid to supersolid phase transition in a ring shaped potential, explored by changing the parameter ϵ_{dd}, which controls the relative strength of dipolar and contact interactions.

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Observation of superthermal correlations at the Superfluid to Mott transition with ultracold bosons

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Over the past decades, experimental platforms with ultracold atoms have proven their usefulness for studying quantum many-body physics [1]. The description of strongly-correlated quantum states necessitates to go beyond Gaussian theories and linearised fluctuations, in order to account for the non-trivial correlations induced by interactions between individual particules. To reveal these non-trivial correlations in an experiment, our group studies ultracold gases of metastable helium-4 atoms, an atom whose large internal energy (~ 20 eV) enables a single-atom-resolved electronic detection after a long time-of-flight (~ 300 ms). This approach yields the three-dimensional momentum distribution of individual atoms [2] from which atom correlations can be measured [3].

Here we report our measurement of momentum correlations in interacting lattice bosons across the phase transition from a Superfluid to a Mott insulator. Deep in the Superfluid regime, we observe many-body correlations up to the sixth order ($n = 6$) compatible with those of a coherent state, $g^{(n)}(0) \simeq 1$, while in the Mott insulator we find a thermal statistics with $g^{(n)}(0) \simeq n!$ [4]. Somewhat surprisingly, many-body correlations become super-thermal with $g^{(n)}(0) > n!$, in the vicinity of the phase transition. This observation suggests the presence of non-Gaussian correlations at the Mott phase transition [5].

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Observation of vortices in a dipolar supersolid

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Supersolids are an exotic state of matter that spontaneously break two symmetries: gauge invariance by phase-locking of the single-particle wavefunction and translational symmetry due to the emergence of a crystalline structure. Originally predicted for solid helium, they have recently been observed in ultracold atoms, one of the most successful examples being dipolar atoms[1]. The crystalline structure can be probed directly by observing the density modulation of the gas, and phase-locking of the single-particle wavefunction emerges from self-interference. What has not yet been observed are quantized vortices, a hallmark of superfluidity. Bolstered by the recent realization of two-dimensional supersolids[2–4], we report on the theoretical study and experimental observation of vortices in a dipolar supersolid of Dysprosium[5]. Our work shows how supersolids, encompassing both crystalline and superfluid properties, show a mixture of rigid-body and irrotational behavior, revealing a fundamental difference between modulated and unmodulated quantum fluids. These observations open the way to study the peculiar properties of vortices in supersolids: their reduced angular momentum, the effect of the crystalline structure on the vortex dynamics and further applications to the study of other systems with multiple spontaneously broken symmetries, such as neutron stars[6].

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Loss features in ultracold ^{162}Dy gases : pairwise versus three-body processes

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Dipolar gases, like erbium and dysprosium, have a dense spectrum of resonant loss features associated with their strong anisotropic interaction potential. These resonances display various behaviours with density and temperature, implying diverse microscopic properties. Here, we quantitatively investigate the low-field ($B < 6$ G) loss features in ultracold thermal samples of ^{162}Dy, revealing two- and three-body dominated loss processes. We investigate their temperature dependence and detect a feature compatible with a d-wave Fano-Feshbach resonance, which has not been observed before. We also analyse the expansion of the dipolar Bose-Einstein condensate as a function of the magnetic field and interpret the changes in size close to the resonances with a variation in the scattering length.

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Active magnetic field stabilization for cold atom spin mixture experiments

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The popularity of Feshbach resonances as a tool for manipulating atomic interaction strength has led to an increasing demand for generating large and highly stable magnetic fields. In our experiment, we study radio-frequency dressing in potassium spin mixtures in order to induce effective three-body interactions in ultracold gases [1]. In this context, precise control requires magnetic field stability at the ppm-level. Feshbach magnetic fields are typically produced using coils in the Helmholtz configuration, driven by currents of the order of 100 A. As commercially available current supplies do not guarantee ppm precision, researchers often employ active feedback correction for current control and ambient noise stabilization [2][3]. We propose a novel easy-to-implement stabilization method, which has been tested to stabilize a magnetic field of 57 G with a rms noise reduced to 0.14 mG (2.5 ppm). A transducer measures the current flowing through the coils, and an error signal is generated by comparing the latter with an ultra-stable reference. The magnetic field is then stabilized supplying a compensation coil around the experiment. The residual rms noise is measured via Ramsey spectroscopy on the ^{39}K magnetic sub-levels. This method does not require sophisticated circuit architectures or the installation of magnetic field sensors in close proximity to the atoms, making it highly adaptable to various cold atom experiments.

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Measurement of the excitation spectrum of a recoil-resolved atom-cavity system at the boundary between the normal and self-organized phases

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In ultracold quantum gases, long-range interactions can give rise to a roton-like excitation spectrum comparable to those measured previously in liquid helium. We study the exciation spectrum of a transversely pumped Bose-Einstein-condensate coupled to a single mode of a recoil-resolved cavity. The cavity mediates an all-to-all interaction between the atoms. As the transverse pump strength increases, we observe a softening in the lowest polariton mode, leading to a transition to a self-organized state beyond a critical pump strength. Our cavity operates in the recoil-resolved regime, where the cavity photon lifetime and atomic recoil frequency are of the same order of magnitude. This leads to polariton modes with comparable contributions from the light and matter components. In our excitation spectrum, this causes regions in which the excitation energy is zero, but the excitation rate is negative. Despite zero excitation energy, a negative excitation rate prevents the system from entering self-organisation due to the long lifetime of the cavity field and its significant contribution to the polariton mode.

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Rydberg Blockade in Atomic Arrays

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During the last years, subwavelength atomic arrays have emerged as a versatile platform for realizing strong light-matter coupling [1–3].

Recently, it was demonstrated experimentally that a single Rydberg "ancilla" atom can be used to spatially control the optical response of these arrays [4]. When the ancilla is in the ground state, the atomic array exhibits electromagnetically induced transparency; when the ancilla is in the Rydberg state, the atomic array becomes opaque in the ancilla's vicinity due to the Rydberg blockade mechanism.

The nonlinearity induced by the Rydberg-Rydberg interaction renders atomic arrays a promising candidate for creating quantum states of light. Intuitively, Rydberg blockades are created as a function of the incoming light's intensity, altering the scattering environment and thus inducing an effective photon-photon interaction. A theoretical understanding of this nonlinear behavior is vital to further realize the promising prospects of atomic arrays, e.g., in photonic quantum information processing.

In my talk, I will introduce a framework to calculate the optical response of an array of Rydberg atoms. I will give insight into the underlying theory and discuss a numerical approach using the cumulant expansion [5]. Furthermore, I will present simulation results and compare them to experimental data [4].

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Strong photon-photon interactions mediated by Rydberg polaritons in ultracold Ytterbium gases

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Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons. Demonstrations of photon-photon gates or multi-photon bound states based on this concept have so far exclusively employed ultracold alkali atoms. Two-valence electron species, such as Ytterbium, offer unique novel features such as narrow-linewidth laser-cooling and new optical detection schemes. Especially for Yb-174 a longer coherent time is expected compared to previous experiments with Rubidium due to the zero nuclei spin and singlet spin state in bivalent structure.

In this contribution, I present the progress towards the demonstration of strong interaction between photons, mediated by Yb-174 Rydberg polaritons formed in a one-dimensional ultracold Ytterbium gas. Our experimental apparatus has a two-chamber compact design featuring dispensers and a four-beam 2D MOT as the source of transversaylly cooled Yb atoms in the first chamber and a two-color 3D MOT for further cooling in the science chamber. This design enables the fast production ($\sim$ 4s) of elongated one-dimensional ultracold Yb gases in a crossed dipole trap, followed by the generation of Rydberg polaritons using a 2-photon excitation EIT scheme.

An important next step is quantifying the interaction strength for Rydberg s-states with the principal quantum numbers $n = 60...120$ in dissipative and attractive interaction regimes. We plan to demonstrate the mapping of the dynamics in a microscopic, strongly interacting quantum system onto freely propagating photons emerging from the optical medium.

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From one to two superatoms in an optical cavity

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For quantum simulations and quantum computing applications, scalability is paramount. Achieving scalability in quantum optics hinges on the development of photon gates or photon sources capable of deterministic behavior.

Our system is based on a small atomic cloud, placed inside a medium finesse optical cavity and driven to a highly-excited Rydberg state. The number of atoms enhances the coupling between the cloud and the cavity, while Rydberg interactions prevent double excitation within the cloud. Consequently, the atomic assembly acts as a single two-level collective superatom. We coherently control its state and optically detect it in a single shot with 95% efficiency[1]. With this setup, we achieve the first fully deterministic preparation of non-Gaussian Wigner-negative free-propagating optical quantum states[2]. The photonics states are generated in the desired spatio-temporal mode with a high 60% efficiency.

Building on these achievements, we expand our experimental setup by incorporating an additional atomic cloud within the cavity, drawing inspiration from prior experiments involving single atoms [3]. We introduce one excitation into a superatom and transfer it through the cavity into the other one. We measure the population in each atomic cloud by probing the Rydberg blokade, while employing Electromagnetically Induced Transparency (EIT) in a lambda configuration on the other superatom to render it transparent. These results represent the initial phase towards implementing more complex protocols, such as entanglement protocols[3], or applications in quantum optics[4].

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Characterization of a state-insensitive optical trap for long coherence time of Rydberg superatoms

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The long-range interaction between Rydberg atoms has been shown to enable manipulation of few-photon light pulses. One way of using the interaction for this are so called Rydberg superatoms: Ensembles of ultracold atoms confined to a volume smaller than the Rydberg blockaded volume. The ensemble is excited collectively, giving enhanced coupling between light and superatom, and the superatom acts as a two-level system emitting into the mode of the exciting field.

By measuring the effect of a cascade of these superatoms on few-photon light pulses, we want to realize a chiral waveguide QED system with large light-emitter coupling. To do this, the coherence time of our superatoms must be increased. In our setup, this coherence time is limited by differential light shifts due to the optical trap confining the ensembles, and motional dephasing.

To avoid these dephasing mechanisms of the superatoms, we have implemented a state-insensitive optical trap for the ground and Rydberg states. Optical trapping of Rydberg atoms is complicated by the almost unbound electron, which experiences an anti-trapping ponderomotive potential. This makes the trapping potential for the Rydberg atom dependent on the intensity distribution of the trapping light in a region around it, and makes it impossible to completely equate the ground and Rydberg state potentials for some intensity distributions of the trapping light.

I present our characterization of the state-insensitive optical trap. We observe a difference of the wavelength for the best coherence time, as probed using a photon storage experiment, between 1D-lattice and Gaussian beam trap geometries. By spectroscopy, we measure a trapping light wavelength at which the two-photon transition frequency between ground and Rydberg state has its free-space value. The relation between that wavelength and the one giving the best coherence time is discussed.

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Multiparameter quantum sensing with a hybrid rf-dc optically pumped magnetometer at Earth's magnetic field

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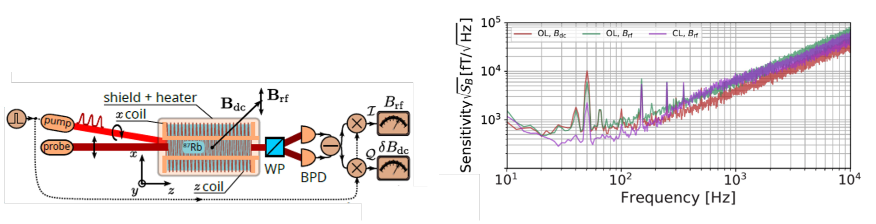
We describe a *hybrid optically pumped magnetometer* (hOPM) that simultanously measures the dc magnetic field and one quadrature of the rf magnetic field, operating around Earth's magnetic field. This hOPM measures both fields with only one atomic spin ensemble, which makes it suitable for multiparameter estimation. The experimental set-up of the hOPM is presented in figure 1a. The hOPM is a Bell-Bloom magnetometer, optically pumped in the same direction as the probe laser. The probe light is then detected with a balanced polarimeter and demodulated with respect to the optical pumping reference modulation signal. We demonstrate sub-pT/$\sqrt{\text{Hz}}$ quantum-noise-limited sensitivity, as shown in figure 1b, for frequency and amplitude modulation schemes. hOPMs have the potential to be quantum enhanced for both fields simultaneously using optical and/or spin squeezing.



(a) (b)

FIG. 1: a) Experimental setup of a Bell-Bloom optically pumped rf-dc magnetometer. The setup consists of a shielded ^{87}Rb cell through which pass the probe and the pump beams. The polarization rotation of the probe is captured via a Wollaston prism (WP) and a balanced photodetector(BPD). b) Sensitivity measurements for dc and rf quadratures of the hOPM in a frequency modulation scheme.

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Room Temperature Quantum Memory for light using the Atomic Frequency Comb protocol

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Quantum memories are devices that allow for the on-demand storage and retrieval of photonic quantum information. They are crucial devices in the realisation of quantum networks [1] and are used for the synchronisation of qubit inputs for photonic quantum computers [2].

The Atomic Frequency Comb (AFC) protocol is a rephasing memory based on the spectral shaping of an inhomogenoulsy broadened transition into a frequency comb with periodic spacing Δ [3]. 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 $2\pi/\Delta$ and the photon is re-emitted.

The AFC protocol is demonstrated with short pulses of light attenuated to the single photon level in warm Rubidium vapour with a storage time of 7.5ns and an efficiency of 9%.

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Cooling of fermionic Lithium in a 2D optical lattice

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We present our advancements towards achieving Raman sideband cooling of Fermionic Lithium confined in a deep 2D optical lattice. Following trapping in a Magneto-Optical Trap, we proceed to direct loading into the optical lattice. Subsequently, we employ Raman sideband cooling, a technique surpassing the limitations of Doppler cooling. Our objective is to drive the atoms into their motional ground state. This sample preparation facilitates loading the atoms into the subsequent phase of our experiment: a bichromatic superlattice. We intend to use this setup as a hybrid digital/analog quantum processor for quantum simulation and computing. The analog mode enables exploration of the Fermi-Hubbard model's physics, while the digital mode leverages single and two-qubit gates for basic quantum computations.

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Self-organisation dynamics in strongly interacting ultracold fermions

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The combination of quantum gases and high-finesse optical cavities allows the study of composite systems of matter and light. Many-body Hamiltonians with strong interactions can be simulated with these platforms, thanks to the high level of control and flexibility which they provide.

In this talk, I will present an experimental setup which combines a degenerate Fermi gas of ^{6}Li atoms with an high-finesse optical resonator [1]. On one hand, interparticle short-range interactions can be controlled through Feschbach resonances, exploring the physics of the BEC-BCS crossover. On the other hand, the strong coupling with the cavity field provides photon mediated long-range interactions between particles [2]. By controlling the power of a side driving field, the interaction strength can be tuned and the system undergoes a superradiant phase transition upon reaching a critical strength. In this phase, the intra-cavity field builds up and the atoms arrange into a crystalline structure, phenomenon known as self-organisation, competing with the intrinsic superfluid behaviour of the system [3].

I will discuss our latest studies on the dynamics of this ordered phase, upon quenching the long-range interaction strength. We observe an exponential rise of the order parameter, whose time scale is remarkably independent on the short-range interactions underlying the system. This universal character extends also to the response to ramps at finite speed. Evidences suggest that this dynamical instability could enter into a new universality class, emerging in far-from-equilibrium, strongly interacting systems.

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Long Abstracts

MULTI-SPECIES COLD ATOM INTERFEROMETRY FOR INERTIAL MEASUREMENTS

Mal Landru,[1,*] Noémie Marquet,[1] Malo Cadoret,[1] Yannick Bidel,[1] Alexis Bonnin,[1] Sylvain Schwartz,[1] Alexandre Bresson,[1] Nassim Zahzam,[1] and Antoine Godard[1]

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Using wave proprieties of matter, cold atoms can become tiny quantum sensors with high stability and sensitivity to inertial quantities, such as rotation or acceleration. The principle is the following: cold atoms (a few μK) free fall in an ultra high vacuum chamber, submitted to the Earth gravity g. While they're falling, one can probe the atoms with lasers in a so called interferometry sequence: carefully-tuned laser pulses will transfer momentum to the atoms which will result in the matter wave being separated, deflected and recombined. At the end of the sequence one can get the value of g by measuring the fluorescence of the atoms.

Contrary to their classical analogous, cold atom accelerometers suffer from dead times between each measurement and a limited measurement range. However, they do benefit from an unrivalled stability and allow to perform absolute measurements [1]. Since classical and atomic sensors have complementary strengths and weaknesses, they're both commonly combined to create hybrid sensors. But there could be another way to make the best of the atomic accelerometer: manipulating different atomic species simultaneously.

Indeed there are insightful configurations using 3 atomic species(Rb^{85}, Rb^{87} and Cs^{133}) instead of one. One could decrease dead times by "juggling" between the 3 species such that while one is being laser-cooled, the other is free-falling and the third species is being detected. Another configuration could enable simultaneous 3D acceleration measurements. The challenge is to imagine and set up ingenious configurations to exploit the full potential of the triple species gravimeter.

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Dark energy search using atom interferometry in the Einstein-Elevator

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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. This work will further constrain thin-shell models for dark energy by several orders of magnitude.

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High-performance two axis cold-atom gyroscope for rotational seismology

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The Sagnac effect is at the heart of the modern precision inertial sensors. An interferometer with a physical area, when spun, exhibits a phase shift at its output. Measuring this phase-shift leads to a direct measurement of the rotation rate.

The SYRTE dual-axis cold-atom gyroscope represents the state-of-art of atomic gyroscopes. With its large physical area ($11cm^2$) and a long interrogation time of 800 ms, it offers both the sensitivity and stability 3×10^{10} $rad.s^{-1}$ to push the Sagnac measurement to an unprecedented accuracy level [1]. Demonstrating such performance required the control and characterization of the experimental parameters and systematic effects and the precise knowledge of the scale factor.

The cold-atom gyroscope experiment is based on atomic interferometry, where cooled Cesium-atoms (2μK) are launched vertically ($\sim 5m/s$) to be interrogated with a sequence of four Raman pulses (allowing an internal and external control over atomic states). The pulses play the role of atomic optics by splitting and guiding the matter-waves along the arms of the interferometer. By the end, transition probability measurement gives access to the phase-shift induced by rotation.

I will present our recent work done to develop new methods that will improve the gyroscope sensitivity. The Double diffraction, atom diffraction in both $\pm\hbar\vec{k}_{eff}$ directions, should enables a measurement setup with no dead time based on the use of two correlated interleaved interferometers [2]. Thus, the vibration and rotation noises that limits the sensitivity should average to achieve the detection noise, targeting the standard quantum projection noise.

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Optimal Floquet Engineering for Large Scale Atom Interferometers

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Atom interferometry has proven to be a promising tool for metrology, enabling significative advances in inertial sensing and fundamental constant measurements. Its potential as a quantum sensor is expected to be exploited for the detection of gravitational waves and the search for dark matter, as well as for other precision measurements such as tests of the weak equivalent principle or matter neutrality. These prospects highlight the need for highly efficient atomic manipulation processes, in particular momentum separations greater than $1000\hbar k$ between the arms of the interferometer. Therefore, large momentum transfer (LMT) techniques based on Raman transition, Bloch oscillations and Bragg diffraction have been developped in the last decades, leading to a maximum momentum separation of $400\hbar k$ so far. We present here a new method, based on Floquet's theory, for accelerating atoms in an optical lattice using Bragg pulses sequences, which we have implemented in our atom interferometer. We have demonstrated an unprecedented momentum separation of $600\hbar k$ with a significant 20% visibility of the interference fringes, limited only by the size of our detection system. We strongly believe that this new LMT technique paves the way for new metrology standards in atom interferometry, and holds great potential for the exploration of quantum physics at the macroscopic scale.

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Standard quantum limits for cavity-enhanced optical readout methods of hot atomic vapor quantum sensors

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The phenomenon of Cavity Enhancement (CE) refers to the increase in the effective interaction length between a probing light beam and an atomic platform placed inside a resonant cavity structure. CE methods have been used extensively in the context of single atoms [1], cold atomic ensembles [2] and hot atomic vapors [3]. In this work, we focus on deriving the quantum noise limits of different optical readout techniques for monitoring the intra-cavity collective spin variables of a hot atomic ensemble with high number density. We provide a unified Figure of Merit which combines the sensitivity of each technique with the spin decoherence rate due to light-atom interaction. Our analysis includes the quantum noise limits of Homodyne and Heterodyne interferometric measurements as well as direct detection of phase modulated probe light followed by demodulation (the Pound-Drever-Hall readout method [4]). To highlight the enhancment factor in each of the three distinct CE readout methods presented in this work, the figure of merit of each CE method is compared against the single-pass polarimetric measurement using Faraday rotation.

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Cavity-based non-destructive detection in ultracold gases

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Cavity quantum electrodynamics studies the interaction of atoms with the electromagnetic mode of an optical cavity. Placing an atom within a cavity modifies its emission properties either by changing the spontaneous emission rates (weak coupling regime) or by coherent exchange of energy between atom and cavity mode (strong coupling regime). When there are multiple atoms (N_C) inside the cavity mode volume, collective effects emerge. As a result, the atom-cavity system shows vacuum Rabi splitting (VRS), which directly depends on the $\sqrt{N_C}$ (collective strong coupling regime).

This makes cavity a frequency-sensitive detection tool for measuring state-dependent interactions. To demonstrate rapid, continuous cavity-based measurement, we experimentally measure time evolution in a multilevel system and show the potential of cavity-based measurements for state detection, even when there are many participating energy levels. To illustrate the range of applications of the cavity-based detection scheme, we also use the cavity to detect photoassociation in a dark MOT where a direct fluorescence measurement is not possible and use this to determine PA rates in the system [1]

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Long Abstracts

An Optical Cavity-Atom Array System for Quantum Computing

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Atom arrays are a leading candidate for quantum computing but the ability to scale system size is limited by the standard readout technique of free-space fluorescence imaging. Despite impressive improvements, fluorescence imaging continues to be capped by fundamental atomic scattering and heating rates and is insensitive to atomic state without local pushout. We present cavity-mediated readout of an atom array as a scalable alternative. A high finesse cavity greatly enhances atomic emission into the cavity mode which enables high collection efficiency with little heating of the atom. In our experiment, we load and selectively couple single ^{87}Rb atoms to an optical cavity to perform repeated nondestructive readout of multiple atoms in hundreds of microseconds. We tune the narrow resonance of the cavity to detect both presence and state of an atom in a tweezer. Since atoms are selectively coupled to the cavity, measurement of one tweezer leaves others undisturbed. We describe progress towards using these capabilities to continually detect and correct errors in the atom array. We also present efforts to use holography to expand the size and reconfigurability of the atom array.

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A cavity-microscope for micrometer-scale control of atom-photon interactions

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Cavity quantum-electrodynamics enables measurements of atoms with sensitivity limited by quantum backaction. Over the last decade, the possibility to observe and control the motion of few or individual atoms using cavity-enhanced light-matter coupling has been exploited to realize various quantum technological tasks, from quantum-enhanced metrology to quantum simulation of strongly-correlated matter. A principle limitation of these experiments lies in the mode structure of the cavity, which is hard-coded in the distance and geometry of the mirrors, effectively trading spatial resolution for enhanced sensitivity.

I will present our cavity-microscope device allowing for spatio-temporal programming of the light-matter coupling of atoms in a high finesse cavity, which provides a spatial resolution an order-of-magnitude lower than the mode waist [1]. This is achieved through local Floquet engineering of the atomic structure, imprinting a corresponding light-matter coupling. We illustrate this capability by engineering micrometer-scale coupling, using cavity-assisted atomic measurements and optimization. Our system forms a single optical system with a single optical axis and has the same footprint and complexity as a standard Fabry-Perot cavities or con-focal lens pairs, and can be used for any atomic species. This technique opens a wide range of perspectives from ultra-fast, cavity-enhanced mid-circuit readout to the quantum simulation of fully connected models of quantum matter such as the Sachdev-Ye-Kitaev model [2].

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Few-body Förster resonances in Rydberg atoms for quantum gate protocols

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Reconfigurable arrays of neutral atoms arranged in individual optical tweezers provide a prospective platform for quantum computing. Nevertheless, the realisation of high-fidelity multi-qubit quantum gates in atomic registers presents an outstanding challenge, thus reducing the range of applicability of near-term NISQ devices.

A promising technique for quantum gates implementation is based on Stark-induced Förster resonances [1, 2]. The external electric field allows to compensate the Förster energy defect between the Rydberg register collective states, leading to a significant interaction enhancement. Thus, Förster resonance transfers enable the gate implementation between strongly distant qubits (with interatomic distances of $\sim 10 - 20$ µm), providing ample opportunities to increase interconnectivity in neutral-atom-based devices.

We report here on our recent research results on Förster resonances in ordered ensembles of ultracold Rydberg atoms of Rb and Cs. Stark-induced resonance transfers have been numerically demonstrated within a quasi-classical interaction model framework, taking into account finite Rydberg lifetimes, as well as estimating the influence of unwanted transitions. We have designed a number of protocols to implement high-fidelity (up to 99.7%) three-qubit Toffoli and CCPHASE gates [1, 3, 4]. We have also investigated a number of techniques to improve gate stability, including radio-frequency induced Förster resonances [4].

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Demonstration of weighted graph optimization on a Rydberg atom array using local light-shifts

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Combinatorial optimisation problems hold substantial commercial interest due to their widespread applicability across a range of research and industrial sectors from route planning to network design. For large scale problems, quantum computers may provide a route to faster and more efficient solutions.

Neutral atom arrays have emerged as a scalable platform suitable for solving optimisation problems by natively embedding a target problem onto a 2D unit disk graph and using Rydberg blockade to enforce constraints between neighbouring atoms. Early demonstrations have explored solving maximum independent set problems using purely global controls [1], however for more general problems including weighted-graphs (MWIS) or quadratic binary unconstrained optimisation (QUBO) recent work has proposed a methods to solve this on neutral atom arrays by introducing local light-shifts to implement vertex weighting [2].

We present first demonstrations of weighted graph optimization on a Rydberg atom array using annealing with local light-shifts [3]. We verify the ability to prepare weighted graphs in 1D and 2D arrays, including embedding a five vertex non-unit disk graph using nine physical qubits. We find common annealing ramps able to prepare the target ground state for arbitrary graph weightings. This work provides a route to exploring large-scale optimization of non-planar weighted graphs relevant for solving relevant real-world problems and in future we will extend this to encoding larger graph problems.

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

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Cryogenic strontium quantum processor

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Optical tweezers lattices hosting neutral Rydberg atoms are a promising platform for quantum computing and simulation. However, the most demanding challenge consists in mitigating noise due to environmental coupling. In our ongoing project, we propose a pioneering approach that involves creating optical tweezer lattices, based in fermionic strontium 87, in a cryogenic environment at 4K. The use of a closed-cycle cryostat will provide an extremely high vacuum (XHV) environment of 1e-12 mbar which will reduce atom loss due to background gas and increase the atom lifetime in trap beyond 10 min thus enabling the assembly of larger arrays. Furthermore, operating at cryogenic temperatures will markedly reduce black-body radiation (BBR) and consequently reduce BBR-induced transitions between Rydberg levels. This will increase Rydberg lifetime and improve the fidelity of entangling gates and qubit coherence. In addition to shielding provided by the 4K copper case, the cryogenic environment enables the usage of superconducting coils, which offer outstanding passive stability of the magnetic field and thereby increases the qubit coherence. In this presentation, I will showcase the design and construction of our cryogenic chamber, and our current efforts towards cooling and transporting atoms into the cryostat.

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Continuous Coherent Quantum Feedback with Time Delays: Tensor Network Solution

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We develop a novel method to solve problems involving quantum optical systems coupled to coherent quantum feedback loops featuring time delays. Our method is based on exact mappings of such non-Markovian problems to equivalent Markovian driven dissipative quantum many-body problems. In this work we show that the resulting Markovian quantum many-body problems can be solved (numerically) exactly and efficiently using tensor network methods for a series of paradigmatic examples, consisting of driven quantum systems coupled to waveguides at several distant points. In particular, we show that our method allows solving problems in so far inaccessible regimes, including problems with arbitrary long time delays and arbitrary numbers of excitations in the delay lines. We obtain solutions for the full real-time dynamics as well as the steady state in all these regimes. Finally, motivated by our results, we develop a novel mean-field approach, which allows us to find the solution semi-analytically and identify parameter regimes where this approximation is in excellent agreement with our exact tensor network results.

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Lissajous figures in a quantum walk on a lattice

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The dynamics of a quantum particle on a square lattice subjected to an external constant force is numerically studied. In one dimension, it is well known that if the wave packet is wide enough, the average position over time will evolve in an oscillatory manner, while the shape of the wave packet is preserved. This phenomenon is known as Bloch oscillations and is characteristic for particles moving in periodic systems with a constant gradient. Additionally, in the case of a narrow wave packet, the position of the center does not change over time, but periodic changes in shape are observed. Such behavior is often referred to as the breathing mode. Eventually, we can observe two competing effects, where oscillations dominate for wide wave packets and breathing dominates for narrow ones. We show that for a certain class of initial states, the problem of time evolution of the two-dimensional system can be treated as two independent one-dimensional problems. We mainly focus on showing that it is possible through a combination of Bloch oscillations in both directions to obtain trajectories of a wave packet center analogous to classical Lissajous figures.

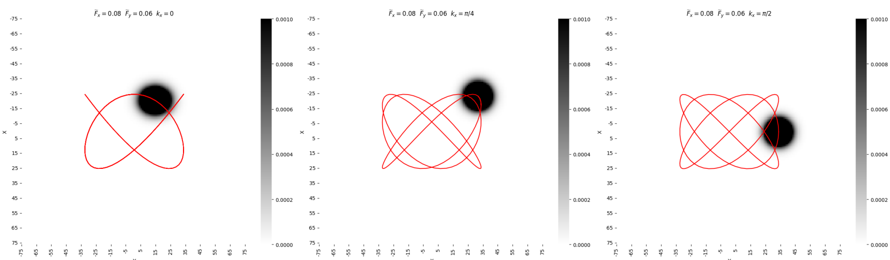

FIG. 1. Exemplary trajectories obtained for particularly chosen external force and for different initial momenta. Horizontal and vertical axes correspond to x and y coordinates. Color intensity corresponds to the density $|\psi(x, y, t)|^2$ at some time t .

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Long Abstracts

Finite-temperature Rydberg atom systems: quantum phases and entanglement characterization

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Due to the controllable interactions both among themselves and with an external field, Rydberg atoms are shown to be promising candidates for building programmable quantum devices. Considering that the practical limitations prevent any experimental setup from operating at zero temperature, the central problem of this work is assessing how robust the system remains with increasing the temperature. For this purpose, we present a tensor network-based numerical algorithm for analyzing the mixed quantum many-body states in Rydberg atom chains at thermal equilibrium. By computing the purity and von Neumann entropy, we obtain the finite-temperature phase diagrams and show how the temperature affects these properties for different system sizes. Moreover, we examine the entanglement between two halves of the system using the negativity and entanglement of formation as entanglement measures, providing the numerical evidence for the finite-temperature scaling law at conformal critical points.

Long Abstracts

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Strongly interacting photons in 2D waveguide QED

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One dimensional confinement in waveguide Quantum Electrodynamics (QED) plays a crucial role to enhance light-matter interactions and to induce a strong quantum nonlinear optical response. In two or higher dimensional settings, this response is reduced since photons can be emitted within a larger phase space, opening the question whether strong photon-photon interaction can be still achieved. In this study, we positively answer this question for the case of a 2D square array of atoms coupled to the light confined into a two-dimensional waveguide. More specifically, we demonstrate the occurrence of long-lived two-photon repulsive and bound states with genuine 2D features. Furthermore, we observe signatures of these effects also in free-space atomic arrays in the form of weakly-subradiant in-band scattering resonances. Our findings provide a paradigmatic signature of the presence of strong photon-photon interactions in 2D waveguide QED.

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Development of a transportable optical cavity for a portable trapped ion atomic clock

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Portable optical atomic clocks have emerged as a promising candidate for next-generation applications in communication, positioning, and navigation. etc[1]. These clocks have the potential to form a resilient PNT (Position Naviagation and Timing) system. Such clocks are based on narrow linewidth ($\Delta\nu$) dipole-forbidden optical transition (known as a clock transition) and thus have better stability compared to their microwave counterparts.

For coherent probing of an optical clock transition, an ultra-stable, narrow linewidth (Hz or sub-Hz) laser (clock laser) is required. This is achieved using the PDH (Pound-Drever-Hall) technique of laser frequency stabilization. In PDH technique, the fractional stability in length ($\Delta L/L$) of an ultra-stable Fabry-Perot (FP) cavity is transferred to the clock laser (oscillator) according to equation $\Delta L/L = -\Delta\nu/\nu$ [2]. However, the stability in the length of a FP cavity is limited by fundamental thermal noise and severely affected by external noises posing formidable challenges to developing an ultra-stable cavity.

In my oral presentation, we shall briefly describe the transportable, trapped ion-based optical clock project at IIT Tirupati. We shall also discuss how we identify the Airy points for a cavity (spacer constructed from ultra-low expansion (ULE) glass and mirror substrates made of fused silica). Additionally, we shall elucidate how the fundamental thermal noise floor is influenced by the cavity length and radius of curvature (ROC) of mirrors.

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Manufacturing Q-optimized polymer-based mechanical resonators for cavity optomechanics with 3D-direct laser writing

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Optomechanical platforms with high-quality mechanical and optical resonators have a wide application potential ranging from quantum limited sensing to long-lived storage of quantum information. Whilst exceptionally high quality factors have been realized with structures in thin layers of dielectric or semiconducting materials, their geometries are limited by the capacity of lithographic fabrication. Recent developments in polymer-based 3D direct laser-written structures allow for new paradigms in manufacturing micromechanical bridge-like resonators, but so far suffer from strong mechanical dissipation. We show viable routes for improving this platform.

The losses impacting the mechanical Q-factor of the resonator in vacuum are dominated by intrinsic losses within the material such as friction and thermoelastic damping. These losses, however, can be heavily reduced by introducing strain on the membrane, leading to so-called dissipation dilution, through adjusting the fabrication process. Additionally, one can engineer the geometry of the resonator for optimized aspect ratios.

To quantify the results of our methods a scannable vacuum-integrated fiber cavity setup for probing high quality-factor mechanical resonators is used. We present our first experimental results and give an outlook on our next steps going forward.

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Enabling atomic systems with fully integrated photonics from UV to IR

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Integrated photonics have demonstrated substantial benefits in chip-scale atomic systems, including stability, convenience, and scalability [1]. Much work utilizes the versatile and relatively mature photonics platform of silicon nitride, but due to becoming highly absorptive toward blue and ultraviolet (UV) wavelengths, its application remains limited to the visible and infrared (IR). In contrast, the larger bandgap of aluminum oxide allows guided light transmission at wavelengths even below 300 nm.

Recent advances in alumina waveguide fabrication have opened the door to trapped ion and neutral atom systems with all wavelengths of light integrated on chip, with the majority of applications thus far focusing on beam delivery. Our work targets more generally photonic integrated circuits, for example, focusing on the design and testing of essential components including low-loss bends and arbitrary splitting ratio splitters. Additionally, we present ongoing work done towards self-injection locking on a chip for a UV diode laser using a thermally tunable ring resonator.

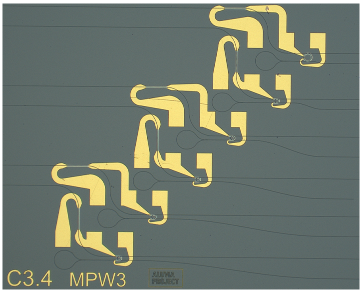

FIG. 1. Microscopic picture of the Al_2O_3 photonic chip for self-injection locking.

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Shallow, optically coherent SiV centers in diamond nanopillars for quantum sensing

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Nanoscale sensing of magnetic fields under extreme conditions such as sub-kelvin temperatures and Tesla-range magnetic fields holds promise for advancing our understanding of physics in systems like unconventional superconductors [1] and the fractional quantum Hall effect [2]. However, the implementation of NV centers for such tasks becomes challenging due to the charge state instability of shallow NV defects at mK temperature and the limitation of the sensing scheme under the strong field. SiV centers emerge as promising candidates for nanoscale single-spin quantum sensors in these extreme conditions due to their stability coming from the inversion symmetry. Another defining characteristic of SiV centers is their capability for all-optical, coherent manipulation of its electron spin.

A key requirement for such an application is the creation and resonant excitation of coherent shallow single SiV within the diamond nanopillar. In our work [3], we present a way of creating individual SiV^- centers at the depth of approximately 50 nm. We introduce a novel charge stabilization method through extended 445 nm laser exposure, which enables resonant excitation without a charge-repump pulse. Our results constitute a key step towards single SiV quantum sensing under extreme conditions and offer a powerful tool for charge stabilization of various solid state spin. Moreover, upon resonant excitation, a combination of photon bunching and antibunching observed in photon correlation measurements reveals population dynamics within the orbital levels of SiV^-, which is further modeled by a four-level system.

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Characterizing single photon from an atom array via optical fiber

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Connecting distant quantum nodes is actively investigated for realizing quantum-network protocols such as quantum repeater and distributed quantum computation. Long-distant entanglement distribution has been successfully demonstrated using diverse quantum nodes such as neutral atoms [1], ion traps [2], and NV centers [3]. In recent years, the system of atom arrays, containing a large number of computable qubits and offering the potential for photonic links, is also showing promising features as quantum nodes. In this talk, we report the experiment of fiber coupling of the photons emitted from a single site in an atom array and the measured results of nonclassical second-order correlation.

In our experiment, we prepare an ^{87}Rb single-atom array by using 852-nm holographic optical tweezers with the objective lens of NA $= 0.7$. An optical coupling between the single-mode fiber and the single atom on the array has been created through the same objective. We make the atom emit the scattered photons by imposing cooling and repumping lights to collect these photons into the optical fiber. The collected photons are split by a fiber-based half beamsplitter and then detected by two avalanche photo diodes (APDs) to measure the second-order correlation function $g^{(2)}(\tau)$. We postselect the case of trapping a single atom by measuring the photon countrates of APDs. As a result, we obtain the $g^{(2)}(0) = 0.14 \pm 0.14$, which clearly shows antibunching of the fluorescence. This is an important step toward the realization of the connection between distant quantum nodes with atom arrays.

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Fast and robust cat state preparation utilizing higher order nonlinearities

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Cat states are a valuable resource for quantum metrology applications, promising to enable sensitivity down to the Heisenberg limit. Moreover, Schrödinger cat states, based on a coherent superposition of coherent states, show robustness against phase-flip errors making them a promising candidate for bosonic quantum codes. Despite its applications, cat states are difficult to generate. A coherent state can evolve into a cat state under a single Kerr-type anharmonicity as found in superconducting devices as well as Rydberg atoms. Such platforms nevertheless exhibit only the second order anharmonicity, which limits the time it takes for a cat state to be prepared. In this talk, we will show how proper tuning of multiple higher order nonlinear interactions leads to shorter cat state preparation time. We will also discuss practical aspects including optimal control schemes and ways to mitigate decoherence. Lastly, we propose an ensemble of Rydberg atoms that exhibits higher order nonlinearities as a platform to prepare cat states in the laboratory.

Optimal control of quantum systems: Applications to the control of Bose-Einstein Condensates

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This poster will present Quantum Control [1] and its application to the manipulation of Bose-Einstein condensate (BEC). The goal is to manipulate the motional states of an atomic Bose-Einstein condensate in a one-dimensional optical lattice. This study is a joint work with the experimental group of Pr. D. Guéry-Odelin in Toulouse University (France). The protocols operate on the momentum comb associated with the lattice through its phase [2].

A precise and versatile control for a wide variety of targets has been demonstrated. Due to the large dimension of the Hilbert space, numerical algorithms such as GRAPE [3] have to be used. However in order to improve the agreement between theory and experiment, it is important to design control processes that respect experimental constraints such as robustness against a parameter whose value is not perfectly known. We show that GRAPE can be modified in order to respect those contraints [4, 5].

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A strontium quantum-gas microscope

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Quantum-gas microscopy is a powerful tool to study the behavior in quantum many-body systems at the single particle level. Realizing those systems with alkaline-earth atoms such as strontium provides new tools for quantum simulation, as shown by the existence of magic wavelengths or the ultra-narrow clock transition.

We have realized a strontium quantum-gas microscope which will allow us to study many-body systems experimentally. We produce quantum-degenerate clouds of bosonic strontium and load them into a square optical lattice of 575nm spacing operated at 813nm, the clock-magic wavelength of strontium. For imaging, we capture photons scattered at the 461nm transition with a high-NA objective while exploiting the narrow 689nm transition for efficient attractive Sisyphus cooling. This way, we obtain site-resolved images where the atoms can be imaged for several seconds.

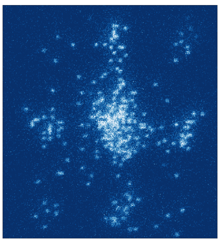

FIG. 1. Single-atom picture of the interference pattern after some expansion time of a superfluid in our optical lattice.

In my talk, I will present results on the detection of a superfluid of ^{84}Sr in the optical lattice (See FIG.1, [1]) and explain our efforts towards efficient cooling and imaging of the fermionic isotope ^{87}Sr. This is particularly challenging due to a complex hyperfine structure arising from its nuclear spin of $I = 9/2$, making harder to realize narrow-line processes such as a narrow-line MOT or Sisyphus cooling. However, this will enable the study of the SU($N \leq 10$) Fermi-Hubbard model which gives rise to exotic magnetic phases beyond the limits of natural materials.

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Towards a quantum gas microscope with programmable lattices

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Cold atoms in optical lattices are a powerful platform for investigating and simulating a wide range of physical phenomena relevant to areas from condensed matter to quantum information. We will describe the ongoing design and development of a quantum gas microscope capable of operation with Li6 (fermionic) or Li7 (bosonic) in a reconfigurable lattice potential with site-resolved state preparation, evolution, and readout. The setup is optimized to reach sub-second cycle times by removing the transport step and implementing advanced cooling techniques. Potential avenues of research for our new project include simulating and investigating phases of matter predicted by the Fermi-Hubbard model, fractional quantum Hall phases, and 'frustrated' systems with unconventional lattice shapes.

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Compact high-precision microwave spectrometer based on FID measurements

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We present a simple, compact, microwave spectrometer based on Free Induction Decay (FID) measurements of molecules confined in a microwave waveguide at room temperature. The potential of this instrument is demonstrated by doing test measurements on the $J = 0 \rightarrow J = 1$ rotational transition of OCS at 12.163 GHz with a notably high Signal-to-Noise Ratio (SNR $> 10^7$) which is well above the state-of-the-art commercial instruments and laboratory measurements in this frequency range [1–5]. With such high levels of SNR, our instrument opens perspectives for a range of applications: from (i) the determination of increasingly accurate molecular parameters and the refinement of line shape models to improve existing atmospheric and astrophysics databases to (ii) tests of fundamental physics, such as the search for new physics by providing constraints in the time variation of fundamental constants by accurately measuring microwave transition frequencies repeatedly over time. Our apparatus can also be viewed as a high sensitivity detector of internal state populations in polyatomic molecules. Extending the technology to measurements at cryogenic temperatures should allow us to significantly improve the SNR.

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Towards ultracold calcium monofluoride molecules

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The production of ultracold molecular quantum gases promises to add long-range dipolar interactions to the quantum simulation toolbox. I present a new experimental setup that aims to realize new phases of matter in bulk molecular Bose-Einstein condensates, such as droplet states and supersolids, by using calcium monoflouride molecules (CaF). These are characterized by their large electric dipole moment and well-established laser cooling strategies. In a first step to create a gas of these molecules with high phase space density, we have designed and characterized a cryogenic buffer gas beam source for CaF molecules.

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Ultracold molecules: how not to lose them – A step towards larger molecular quantum computers

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Long Abstracts

Ultracold molecules, like CaF, provide a powerful platform for quantum computing. These molecules are arranged in a grid and are trapped by an optical tweezer array. To build this up, tweezers are loaded stochastically with 50% probability, which must be followed by rearrangement of these tweezers to create defect-free arrays. However, this can take too long compared to the lifetime of the molecules, which limits the scalability of such molecular quantum computers. Deterministic loading of tweezers with single molecules at 100% success rate is therefore desirable.

We propose a novel scheme to increase the efficiency [1]: repeatedly load laser-cooled molecules into optical tweezers, and transfer them to storage states that are rotationally excited by two additional quanta. We show using quantum scattering calculations that collisional loss of molecules in these storage states is suppressed [2], and a dipolar blockade prevents the accumulation of more than one molecule. This scheme greatly improves the efficiency to 80%, leading to the possibility of creating larger molecular quantum computers.

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Vibrationally coupled Rydberg atom-ion molecules

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Recently, a new type of a long range molecule consisting of an ion and a Rydberg atom popularly known as rydberg atom-ion molecules (RAIMs) has been theoretically proposed[1, 2] and experimentally observed in an ultracold cloud of ^{87}Rb atoms[3]. We use a hybrid atom-ion system to create a linear crystal of ions in a Paul trap with RAIMs attached to its either end to generate ion-mediated Rydberg-Rydberg interactions. We propose a scheme to utilise the common motional modes of a crystal of trapped ions to enhance or suppress the probability of forming two RAIMs at the ends of the chain, replacing the typical blockade radius set by the dipole-dipole interaction by the length of the ion crystal. We use detailed Floquet analysis to demonstrate the feasibility of our scheme in the presence of the time dependent rf potential of the Paul trap and provide a qualitative test for their survival probability based on Landau-Zener criterion. Lastly, we outline future plans on how these RAIMs could potentially be detected in our hybrid atom-ion experiment[4] without the application of an ion microscope.

Long Abstracts

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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 combine 2-dimensional Yb^+ ion crystals in a Paul trap with optical tweezers to create a novel platform for quantum simulations [1, 2]. The hyperfine splitting of the ground state of the ions is used as a qubit transition and the interactions between the qubits are mediated by the phonon modes in the crystal [3]. Optical tweezers provide an additional trapping potential thereby changing the phonon mode spectrum, thus increasing the range of accessible Hamiltonians [4, 5]. We present experimental work demonstrating an optimisation routine for resonant tweezers, offering a fast and robust method for alignment on the ion. We further analyse the beam profile and observe coherent population trapping of the ion states [6]. Lastly, we outline future plans to align and optimise non-resonant tweezers, as we need a deep trapping potential while minimising photon scattering for quantum simulation.

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Interfacing Rydberg atoms with an electromechanical oscillator in a cryostat

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Rydberg atoms offer electric dipole allowed transitions over a large range of the electromagnetic spectrum which makes them interesting for hybrid quantum systems that aim at interacting quanta in vastly different frequency regimes.

We are interested in interfacing optically controlled Rydberg atoms with an electromechanical oscillator and will explore the possibility to cool a mechanical oscillator mode to its quantum mechanical ground state by extracting phonons via a coherent exchange of microwave photons with the atoms.

Here, we present our design of how to implement this hybrid system and present our progress on the construction. Our system combines a closed-cycle cryostat with vibration isolation with a classical room-temperature setup for production of ultracold atoms consisting of a 3D magneto optical trap of rubidium atoms from which ultra-cold atoms are magnetically transported into the cryo-region. There the rubidium atoms are excited to Rydberg states which will make it possible to perform experiments interfacing the atoms with a mechanical oscillator in a 4 K environment.

Moreover, we show in detail the optimisation and characterisation of the atom preparation such as magnetic trapping of the rubidium atoms and to transport them to the science region where they are excited to Rydberg state.

In the next step, the cryogenic environment together with dissipative interactions with Rydberg atoms should enable cooling the oscillator to its ground state.

Long Abstracts

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Atom Interferometer Observatory and Network: towards enhancement of large momentum transfer for fundamental physics

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In cold atom interferometry, laser pulses induce a momentum kick on atoms in a cloud in order to separate and recombine the atomic matter waves. The Atom Interferometer Observatory and Network (AION) project[1], is an atom interferometry project in the UK to detect ultra -light dark matter, mid-frequency gravitational waves and explore other fundamental physics. The sensitivity of an atom interferometer can be improved by increasing the space-time area that it encloses. Thus, by increasing the magnitude of the effective momentum kick, the sensitivity can be enhanced. As part of the AION consortium, the University of Birmingham is investigating the enhancement of large momentum transfer (LMT). The sensitivity goals for AION aim for LMT of order 40,000 $\hbar$k which is an improvement of a factor of over 500 times the current state of the art for strontium[2]. Modelling suggests that hybrid solutions are required which utilise various advanced techniques simultaneously, including composite pulses, pulse shaping and wavefront control. In my poster, I will provide an overview of the work towards AION at Birmingham, with a focus on both the laboratory progress and the theoretical exploration of LMT. An analysis of wavefront aberration effect in LMT atom interferometers, and a scheme for compensation will also be discussed.

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High-resolution spectroscopy of the lowest energy levels in the $b^3\Pi_0$ potential of ^{87}Rb^{133}Cs for magic wavelength trapping

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Long rotational coherence times of ultracold polar molecules are required for many proposed applications including quantum computation and quantum simulation [1]. In our previous work [2, 3], we have demonstrated a rotationally magic trap for ultracold ^{87}Rb^{133}Cs molecules at a detuning of 185 GHz from the transition at 1146.1 nm from the rovibrational ground state of the $X^1\Sigma^+$ potential to the lowest vibrational level of the $b^3\Pi_0$ potential. We have observed second-scale rotational coherence and detected the dipolar interactions in a dilute gas of molecules through the loss of contrast in a Ramsey sequence. Here we report high-resolution spectroscopy of the relevant transitions needed to develop an improved model of the magic conditions. We resolve rotational and hyperfine structure associated with the three lowest vibrational levels of the $b^3\Pi_0$ potential. From the spectroscopy we extract the rotational constant of ^{87}Rb^{133}Cs molecules in the $b^3\Pi_0$ state. Linear Zeeman shifts of the hyperfine states are measured across magnetic fields ranging from 181.5 G to 210.4 G, from which the associated magnetic moments are derived. We determine the transition dipole moments to the lowest two vibrational levels by directly observing the Rabi oscillations. The results indicate partial transition linewidths of $2\pi \times (3.87 \pm 0.13)$ kHz and $2\pi \times (2.48 \pm 0.05)$ kHz, respectively. We also measure excited state lifetimes of 10.3 ± 0.7 μs and 7.2 ± 0.5 μs, corresponding to natural linewidths of $2\pi \times (15.5 \pm 1.1)$ kHz and $2\pi \times (22.1 \pm 1.5)$ kHz. As an outlook, we report on-going work to load the molecules into a magic wavelength optical lattice.

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Long Abstracts

A progress report on the isotopic comparison of parity violation in Yb

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The investigation of atomic parity violation (APV), serves as a platform for fundamental tests in nuclear and particle physics. The recent experimental findings regarding the isotopic comparison of the APV effect across a series of ytterbium (Yb) isotopes [1–3] underscore the efficacy of this technique as a tool for probing the neutron distribution in the Yb nucleus. This research allows one to probe neutron skins, which are rather poorly understood and are closely related to the structure of neutron stars.

The investigation of weak-force-induced effects in atomic ytterbium is the primary field of research of our newly built laboratory at the Physics Department of the University of Crete. We are currently working on developing an atomic beam setup for the study of the isotopic variation of APV in the Yb atom. Our goal is to increase the precision of the measurement enough to check the distribution of neutrons in the ytterbium nuclei. Additionally, the methodology will act as a tool for probing for low mass Z' bosons, beyond the standard model of particle physics.

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Atom-light Crystals in Photonic Crystals: cold Rb atoms in Hollow Core Photonic Crystal Fibres

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Developed over the last 3 decades, atom interferometry, i.e. interferometry performed with atomic matter wave, has generated gravimeters and gyroscopes of unprecedented precision [1–3].

While a few commercial instruments based on atom interferometer already made their way to the market, in general the instrumentation is cumbersome, delicate and hardly movable, when realised in a "standard" way. We aim at making the experimental setups much more compact, economic and easily transportable. We plan to prepare laser-cooled atoms inside a Hollow Core Photonic Crystal Fibre (HCPCF). Once in the core, using light guided by the fibre, an Atom-light Crystal is created, where collective radiative effects can be observed and used for various purposes including interferometry [4].

Our experimental setup is composed of a vacuum chamber to generate a magneto-optical trap (MOT) of Rb atoms in proximity of the tip of a HCPCF. The fibre has one sealed end sticking out of the chamber, for easier light-injection with and external laser source. After the atoms are in place, their interaction with the fibre will be studied in order to understand how to prevent them being adsorbed by the walls, and to ensure the realisation of a proper atom-light crystal. With such a device, gravimetry measurements could be performed with state-of-the-art sensitivity of $10^{-7}\ m/s^2$ (enough to detect a $\sim 1\ kg$ nearby mass around the fibre) [5].

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Quantum interference measurement of the free fall of anti-hydrogen

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Several experiments have been proposed with the goal of testing the Weak Equivalence Principle using anti-matter. In September 2023, the sign of $\bar{g}$, the free fall acceleration of anti-matter in the gravitational field of the Earth, has been directly measured for the first time [1]. In the GBAR project, the anti-hydrogen atom will be produced from a trapped $\bar{H}^+$ ion, for which the additional positron has been photodetached. Based on this production scheme, we have modeled a new kind of interferometer. Thanks to bounces of atoms on a flat surface, it is possible to preform numerical simulation of the evolution of the wave function, using an analogy with an optical cavity. We are able to observe a behaviour identical to the focalisation phenomenon and creat fringes of interferences in the vicinity of a cautics. With our scheme and the likelihood statistical approach, we have shown that it could be possible to measure $\bar{g}/g_0$ at the order of 10^{-5} with 100 of $\bar{H}^+$. Achieving such an accuracy with this number of $\bar{H}^+$ atoms is crucial, as the production of $\bar{H}^+$ is a true endeavor for the moment.

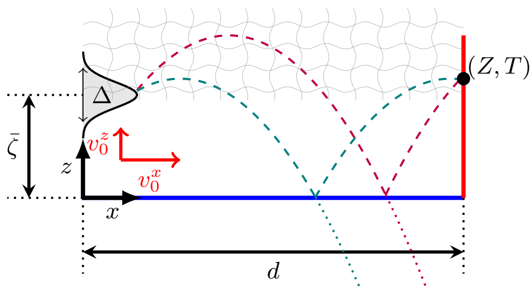

FIG. 1. This setup is made by a penetrable wall, drawn as the blue miror, and a perfect wall, the gravity field, represented by the grey sinus field. The wave packet falls and completly bounces off the mirror, to recombine at (Z, T). The dotted line passing throught the mirror plate are the loss going out of this cavity.

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Floquet operator engineering for quantum state stroboscopic stabilization

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Cold atoms constitute a highly controllable platform well suited for quantum simulations and quantum metrology. In that context, quantum optimal control (QOC) is a valuable tool allowing preparation of a wide range of states that could not be produced using standard methods. In our system, a Bose-Einstein condensate (BEC) in a 1D optical lattice, QOC is used to optimize the time evolution of the lattice phase in order to prepare specific target states of the BEC collective wavefunction. We have recently demonstrated our ability to control and prepare states that are not eigenstates of the system such as arbitrary momentum states with chosen relative phases [1], superpositions of gaussian states and squeezed states in the phase-space of each lattice cell [2]. To certify the preparation of the chosen states, we use tomographic measurements to reconstruct the final state using a maximal likelihood estimation algorithm. I will also present experimental applications of QOC to realize a stroboscopic stabilization of quantum states of the BEC by exploiting space and time symmetries or by directly generating with QOC a stabilizing Floquet operator [3].

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Scaling Beyond Grids of 1000 Optical Tweezers with Dynamic Manipulation in Real-time

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Quantum arrays of neutral atoms in regular optical potentials of multi-site tweezer configurations and optical lattices foster numerous applications in the fields of quantum optics, quantum metrology, and quantum information science, where comprehensive laser-control enables the realization of textbook examples of quantum models. For future advancements of this platform, scaled and parallelized control techniques are key.

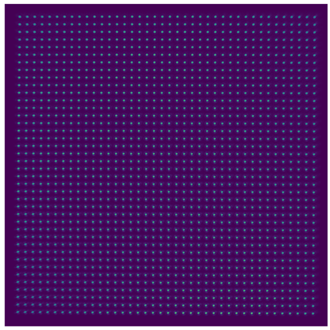

FIG. 1. Dynamically generated array of 40×40 optical tweezers.

In practice, laser cooled atoms are loaded from a magneto-optical trap, resulting in a stochastic filling of the grid of optical potentials while application-specific defect-free structures are a prerequisite. Optical tweezers have become the standard tool for relocating atoms between sites to assemble the required patterns. Each move between two sites requires time, resulting in a scalability bottleneck due to the limited residence time of the trapped atoms. We address this challenge by implementing multiple tweezers that are generated in parallel with high-bandwidth control using crossed acousto-optic deflectors (AODs).

Typically, the AODs are driven by a sinusoidal radio frequency signal. To overcome the limitation of a single tweezer, it is possible to implement a multi-tone signal, resulting in multiple tweezers. Although conceptually simple, such an approach presents multiple challenges in the RF signal generation and control setup to coordinate this many tweezers. We compute the signals using a graphics processing unit (GPU) and output them using an arbitrary waveform generator. This setup can generate various moves and span a grid with up to 40×40 tweezers at a time, as shown in Fig. 1. Furthermore, computing the signal on a GPU allows us to perform signal tuning with latencies that are suitable for real-time implementations. We present the problems we encountered, possible solutions, and our working setup.

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Engineering Atomic Frequency Distributions for Atomic CQED Experiments

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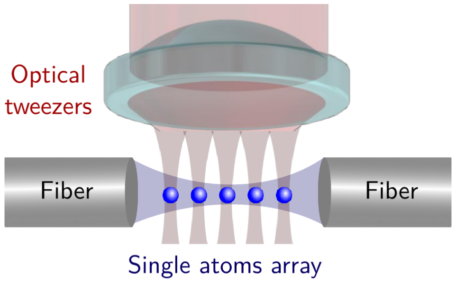

The study of N two-level systems involved in long-range interactions holds interest for quantum simulation and information. An ideal candidate would be N individually controlled neutral atoms interacting *via* the resonant photons of a Fabry-Perot cavity, in a Cavity Quantum Electrodynamics (CQED) scenario.

In our group, high-finesse Fibre Fabry-Perot Cavities (FFPCs) are made with laser-machined mirrors, allowing small mode cross-section and thus strong light-matter coupling for a single emitter. The N atoms are separately trapped using an array of far-off-resonance, tightly-focused laser beams (optical tweezers).

We are currently working on the characterization of quantum states in the low-excitation regime, which involve a hybrid light-matter mode: the polariton. This quantum state is comprised of a superposition between a single atomic excitation shared by all emitters and a single photon in the resonant field mode. It has been shown that polaritons can emerge even when the qubit frequency distribution is inhomogeneous. Experimental investigation of the transition from disordered to polaritonic regime remains mostly unexplored.

In this presentation, I will discuss a technique that allows controllable detuning of the atomic frequency distribution through the control of the polarization of the tweezers, which exert a site and position-dependent light shift on the atomic levels. The high degree of control over the frequency distribution makes this experiment a model for molecular polaritons chemistry, or quantum simulation of organic semiconductors.

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Microfabricated alkali cells for atomic devices

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Miniature atomic devices rely on microfabricated alkali vapor cells [1]. Several techniques [2–4] have been proposed to make such cells but they include a step of anodic bonding, which involves high temperatures incompatible with anti-relaxation coatings. We previously 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]. The wafer is connected to a vacuum chamber filled with the desired chemical species before sealing the cells. Here, we report on our first results of migration of cesium inside the cells using this method. The sealed cells containing cesium are characterised over time.

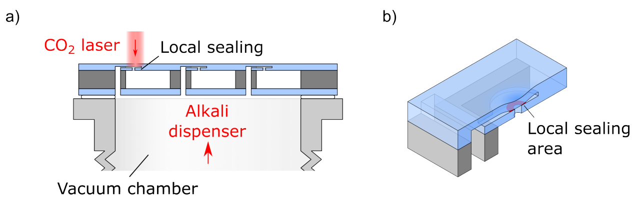

FIG. 1. *Wafer of cells placed on a vacuum chamber to fill the cell with an alkali metal.*

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Realising fast readout for Rydberg arrays

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Ordered arrays of neutral atoms provide an appealing platform for quantum simulation and quantum computation. Laser-cooled atomic gases allow for simulating quantum many-body systems with unprecedented control over microscopic degrees of freedom. The recent progress on tweezer-based atom arrays and quantum gas microscopes has enabled microscopic detection and manipulation of such systems down to the level of single atoms. Here, we present our progress on an experimental platform aimed at achieving cavity-assisted, non-destructive, local readout of dual-element tweezer arrays. Long-range and tunable interactions between highly-excited Rydberg states make the platform suited to simulate spin models and – together with the fast cavity-based readout – form the architectural basis for the realisation of a scalable error-corrected quantum computing platform.

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Two-qubits entanglement and quantum gate operations using trapped Neutral atom

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ABSTRACT:

The recent advancement in the neutral-atom platform for implementing high-fidelity gates have mainly focussed on reducing errors originating due to Doppler dephasing [1], finite Rydberg lifetime [2], and finite Rydberg blockade strength [3]. After the proposal of the Controlled-Z gate via the Rydberg blockade mechanism in Ref. 4, various protocols have been developed to create entanglement and implement robust and fast quantum gates. In the initial $\pi - gap - \pi$ pulse sequence, atoms stays in the Rydberg state for τ_{gap} time; therefore, the fidelity was limited by the ground-Rydberg decoherence. Later, with a fast protocol comprising two global pulses for ground-Rydberg coupling, the gate fidelity was improved to 97.4(3)% [1]. In a recent protocol, the "single-modulated off-resonant modulated driving," the key mechanism involved adiabatically tracking a two-atom dark state, which was implicitly initiated due to the presence of dipole-dipole exchange interaction $|rr\rangle \leftrightarrow |pp\rangle$, that minimizes the rotation error [3]. In another protocol based on Rydberg dressing techniques, the population is not actually transferred to the Rydberg state, whereas a part of the Rydberg state is admixed in the ground state, reducing the decoherences arising from the finite lifetime of the Rydberg state [2]. Our work thoroughly compares and analyses the impact of Doppler dephasing and decoherence originating due to the finite Rydberg state lifetimes across existing protocols. These insights are crucial for designing a novel and robust gate protocol. Additionally, we aim to propose our idea of implementing Controlled-Z and swap gates using amplitude and phase-modulated pulse waveform. Furthermore, we outline our experimental strategy to achieve the objective of high-fidelity gate implementation.

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Picosecond imaging of both the phase and amplitude of an out of equilibrium 2D quantum gas

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Quantum gases may exhibit macroscopic behaviors like Bose-Einstein condensation, superconductivity, superfluidity and also quantum turbulence (QT). At the microscopic scale, QT is governed by the nucleation and interactions of quantized vortices. A quantized vortex is a stable topological defect with quantized circulation, which distinguishes it from its classical counterpart. The interaction of those vortices leads to the formation of a well known macroscopic energy cascade in which energy is redistributed amongst different length scale. While the interactions of a small number of vortices has been well studied, the mesoscopic scale of vortices interaction is much less understood due to its inherent complexity.

In our study, we propose to use a polariton gas, mixed light-matter quasi particles, to study quantum turbulence. This intrinsically out-of-equilibrium system consists of an optically pumped cavity in which is embedded a quantum well. Polaritons gas provides an exciting platform to study QT, facilitating the integrated measurement of the amplitude and phase information of the fluid through the use of the optics toolbox. However the timescale of the dynamics of this system remains in the picosecond scale, rendering measurement of the dynamics challenging. We propose a new experimental scheme to investigate QT at the picosecond time scale and perform single shot measurement of both the phase and amplitude of the turbulent fluid.

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Sensing Interactions in Atomic Quantum Systems

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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 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 built to go beyond alkali and exploit the novel combination of a trapped ion – Yb+ - with dipolar atoms - Dy. This mixture offers the opportunity to investigate the effects of dipole-dipole interactions in hybrid ion-atoms systems. Here we present the progress on the design and development of the atomic-part of the setup, emphasizing our efforts towards producing a dipolar BEC.

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Towards a Dual-Species Dipolar Quantum Gas Microscope

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Ultracold atoms in optical lattices have been established as a powerful toolbox for quantum simulation, enabling the study of many-body physics and strongly correlated condensed matter. In the last decade, single-site imaging and addressing of these lattice-confined atoms has been achieved by the experimental realization of quantum gas microscopes. Until 2023, quantum gas microscopes utilized atomic species with a negligible magnetic moment, which interact exclusively via short-range contact interaction. The addition of long-range interactions in a lattice leads to new exotic phases of matter, such as the Haldane insulator, an interaction-induced topological phase. Here, we report on the progress towards a quantum gas microscope utilizing the highly dipolar species erbium and dysprosium, which will allow the study of both single- and dual-species physics on the single-atom level. With this new setup, we aim to probe extended Bose- and Fermi- Hubbard models, entering a new quantum simulation framework, beyond the capabilities of conventional short-range interaction setups.

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Cold Rydberg atoms for Strontium Optical Clock thermometry

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Optical clocks operate by locking an ultra-stable laser on a narrow atomic transition in the optical spectrum, realizing a stable and accurate frequency reference. By controlling environmental parameters and evaluating various systematic effects, the Strontium optical clock at SYRTE Laboratory currently achieves a relative frequency systematic uncertainty of approximately 1.7×10-17. At this precision, the energy shift of the clock's transition levels by the Black-Body Radiation (BBR) is a significant contribution to the clock inaccuracy, despite it being currently evaluated by calibrated thermal sensors placed around the clock vacuum system.

We propose a method for an in-situ, independent evaluation of the BBR frequency shift by exciting the clock atoms into a Rydberg state, therefore significantly increasing their BBR sensitivity [1]. The BBR will induce transitions to nearby Rydberg states, as well as photoionize the atoms, and we aim to experimentally detect this population redistribution over time[2]. By developing a theoretical model of this state redistribution as a function of BBR spectra, a comparison to our measurements would provide a precise estimation of the radiation seen by the atoms.

To ensure a stable excitation to the Rydberg states for our detection, we are currently working on locking the Rydberg excitation laser. We propose here a method based on Electromagnetically Induced Transparency (EIT) signal.

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Quantum simulation using Bose Einstein Condensates

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Throughout the last century the laws of quantum mechanics have become well understood. As a consequence the physics community has been able to understand and manipulate few body quantum systems. This can however not be said about many-body quantum systems, which often do not lend themselves to numerical or analytical solutions.

One of these many-body systems is the electron in a solid. Here the electron couples to phonon modes in the solid. This electron-phonon coupling may be seen as one collective quasi-particle called a polaron, with a different mass than the actual electron. In order to understand this system, one may use Bose-Einstein Condensates (BECs) as a quantum simulator [1]. Here I describe how we use impurities with a tuneable interaction with the surrounding media, to simulate the case of electrons in a solid material. This makes BECs a good simulator for exploring polaron physics, since one may tune the strength of the interaction, thuys the system is more accessible to manipulation and observation.

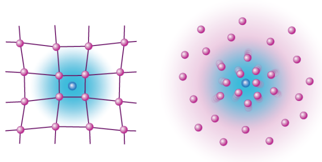

FIG. 1. Comparing polarons in a crystal lattice, and a gas. Figure taken from [2]

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Long Abstracts

Studying Ultra-cold Collisions in Hg-Rb Mixture

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We developed an experimental set-up to perform collisional studies in ultra-cold Hg+Rb mixture in a two-species magneto-optical trap (MOT) [1, 2]. One of the main motivations for developing atomic traps was investigating cold atom collisions. Adding a second atomic species opens up the possibility to sympathetically cool one atomic species through collisional energy exchange with the second one.

The temperature of the Rb cloud is determined by absorption imaging of the cloud during its ballistic expansion in free fall after abruptly turning off the trapping potential, i.e., both magnetic field and cooling laser beams. The measurement is performed with and without the presence of Hg atoms in the trap. We will verify the isotope dependence of the sympathetic cooling efficiency. Taking advantage of ultra-cold Rb-Hg in our experimental setup, we will study the collisional properties of a hetero-nuclear mixture containing ultra-cold 87-Rb and all five prominent isotopes (both fermionic and bosonic) of mercury.

[1] M. Witkowski *et al.*, *Optics Express* **25** 4 (2017).
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Exploring Kitaev model with Rydberg atoms: Probing exotic spin states through dipole-dipole interactions

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We study the prospects for realizing Kitaev-type interactions through the utilization of Rydberg atoms, capitalizing their dipole-dipole interactions to engineer specific quantum spin dynamics within a honeycomb lattice configuration. This methodology offers a pathway to explore the static as well as dynamic properties in a highly controllable experimental setting. Employing both theoretical analysis and numerical simulations, we map the dipole-dipole interactions on an effective spin-1/2 model, focusing on the realization of quantum phases that may exhibit topological properties. Utilizing external electromagnetic fields allows for precise tuning of the strength and type of relevant spin couplings. This research underscores the potential of Rydberg atoms as a versatile tool in the quest for quantum simulation of exotic states of matter.

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Experimental setup to investigate fundamental interactions in ultra-cold mercury atoms

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To experimentally investigate new hadron-hadron interactions [1], we will photo-associate mercury atoms into Hg_2, one of the heaviest two-atom molecules. The van der Waals interaction in the Hg-Hg system can be relatively well characterized [2] and this interaction is much weaker than in similar systems, like Sr_2 or Yb_2. All these give an advantage in the search for new interactions beyond the Standard Model at nm-range.

The spectroscopy of Hg_2 will be carried out with gas samples cooled to microkelvin temperatures in a dipole trap. The experiment will be conducted using the double-species experimental setup [3]. Ultraviolet two-color photoassociation [4] spectroscopy will be performed for the first time near the dissociation threshold bound states of Hg_2 molecules. The photoassociation resonances can be also understood as optical Feshbach resonances that can be used to control interaction between atoms [5]. The Hg_2 molecules will also be used to explore possibility of realization of optical molecular clock [6]. The spectroscopic measurements will be referenced to optical frequency standards [7, 8].

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Toward microwave-induced Feshbach resonance

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Controlling interatomic interactions is a powerful tool for the study of quantum phases of degenerate Bose gases. This has become accessible in experiments relying on Feshbach resonances. This phenomenon occurs as soon as the energy of two free atoms is brought to resonance with the energy of a bound state of their interaction potential. This is commonly achieved thanks to a homogeneous magnetic field relying on the Zeeman effect. In 2010, Papoular et al. [1] have proposed to realize microwave-induced Feshbach resonances for alkaline atoms.

On our experimental setup at LPL, we are currently investigating this possibility. We rely on an atom chip in order to confine extremely elongated Bose-Einstein condensates of sodium atoms. The atom chip also encompasses a coplanar waveguide allowing the production of large amplitude microwave fields at the position of the trapped atoms. In a first step, we have characterized a molecular bound state lying about 200 MHz below the hyperfine splitting energy. Microwave spectroscopy allows us to reach a much better accuracy on the measurement of the energies of the different spin states of the molecular bound state, with respect to previous results [2]. We have also been able to study the effect of large amplitudes microwave dressing on these energies.

We are currently investigating the effect of the microwave field on the scattering length of the trapped atoms. Pulsing the microwave field, we are able to excite the radial breathing mode of the condensate and observe slight differences in its characteristics across the molecular resonance.

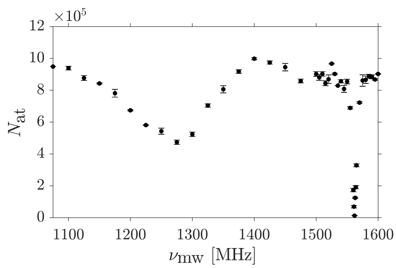

FIG. 1. molecular spectroscopy

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Long Abstracts

An accordion optical lattice for the realization of Hofstadter ladders with bosonic mixtures

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The Hofstadter model describes charged particles in a two-dimensional (2D) lattice pierced by a magnetic flux. For interacting particles, such systems give rise to exotic phenomena like the lattice analog of the fractional quantum Hall states. Realizations using cold atoms so far were limited to a few particles [1, 2].

We report on our progress towards the realization of flux ladder systems using our Raman-coupled spin mixture of Bose-Einstein condensates, which will constitute a minimal instance of the 2D Hofstadter model. We present the implementation of a 2D optical lattice, with dynamically adjustable lattice spacings. One lattice dimension together with the Raman-coupled spin states will allow us to form flux ladders [3] while the second lattice dimension will enable us to confine the atoms to reach the many-body strongly interacting regime where fractional quantum Hall physics is expected.

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Chip-Scale Quantum Gravimeter

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Atom interferometry with Bose-Einstein condensates promises very precise and absolute measurements of gravity with residual uncertainties on the order of nm/s^2. And unlike classical gravimeters, quantum gravimeter measure gravity drift-free. Unfortunately, current quantum gravimeters are still bulky, while a low size, weight, and power consumption are essential for potential applications like ground or space-borne geodesy. This challenge can be tackled by using atom chips as they offer the desired magnetic fields at low power. Additionally, the atom chip can be equipped with planar optics like a grating to facilitate the creation of a magneto-optical trap with a single beam or a mirror for Raman interferometry.
In this poster, we will present a concept for a novel atom chip that combines the features of a grating and a mirror, what allows us to use a single fiber for the cooling and interferometry beam and thus reduces the complexity of the sensor head and its dimensions to shoe-box size. With this novel atom chip and an additional relaunch scheme an innovative single-beam quantum gravimeter is envisaged. Through the miniaturization and reduction of complexity of the sensor head, the transportability and usability of the quantum gravimeter are enhanced and ease in-field operations.
This work is funded by the German Research Foundation (DFG) in the CRC 1464 "TerraQ" (Project A03) under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers" and supported by the German Space Agency (DLR) under grant number DLR 50RK1978 (QCHIP) and DLR 50WM1947 (KACTUS II).

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Quench induced chaotic dynamics of Anderson localized interacting Bose-Einstein condensates in one dimension

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(Dated: March 9, 2024)

Since the experimental realization of Anderson localization in Bose-Einstein condensates [1], it has sparked significant interest within the ultracold community owing to the adaptability of diverse trap geometries and atomic interactions. Here, we study the effect of atomic interaction on the localization and the associated dynamics of Bose-Einstein condensates in a one-dimensional quasiperiodic optical lattice and random disordered potentials. When the interactions are absent, the condensates exhibit localization, which weakens as we increase the interaction strength beyond a threshold value for both potential types. We inspect the localized and delocalized states by perturbing the system via quenching the interaction strength instantaneously to zero and studying the dynamics of the condensate, which we further corroborate using the out-of-time-order correlator. The temporal behaviour of the time correlator displays regular dynamics for the localized state, while it shows temporal chaos for the delocalized state. We confirm this dynamical behaviour by analyzing the power spectral density of the time correlator. We further identify that the condensate admits a quasiperiodic route to chaotic dynamics for both the potentials. Finally, we present the variation of the maximal Lyapunov exponents for different nonlinearity and disorder strengths that have a positive value in the regime where the time correlator function shows chaotic behaviour. Through this, we establish the strong connection between the spatially delocalized state of the condensate and its temporal chaos which can be used as a characterization technique for localized and delocalized condensates using dynamics of a condensate.

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Emergence of Synchronisation in a Driven-Dissipative Hot Rydberg Vapour

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Continuously driven, non-linear systems show interesting behaviours such as bistability and self-oscillations. An interesting question regards the interplay of many self-oscillating entities with coupled dynamics due to an interaction between the individual oscillators. A collective response of a self-oscillating ensemble has been observed in e.g. the applause of audiences, and is theoretically understood within the framework of synchronisation.

Recently, we have observed the emergence of synchronisation in a driven-dissipative hot Rydberg vapour [1]. Synchronisation occurs in a strongly-driven three-level ladder scheme in Rb where we couple the intermediate 5P3/2 state to a Rydberg state. The synchronised state manifests as oscillations of the transmission of the probe beam through the atomic vapour. Wide tunability of the system parameters as well as fast oscillation frequencies on the order of 10 kHz allow for an exploration of the synchonisation transition over a large parameter space and with many coupled oscillators.

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Long Abstracts

Towards a Grating MOT for Calcium Atoms

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Recent advancements have highlighted the potential of Rydberg atoms individually trapped in optical tweezers as a promising and scalable platform for universal quantum computing.

We present here the latest results from our experiment, aiming to use individual calcium atoms excited to circular Rydberg states as qubits. The choice of calcium is driven by the presence of two valence electrons, with the second electron providing tools for cooling, trapping, and controlling the qubit state, leveraging techniques well-established by the ion trapping community.

The realization of arrays of individual calcium atoms involves loading atoms into a magneto-optical trap (MOT), followed by cooling and subsequent trapping within tweezer arrays. Various MOT geometries exist, including mirror MOTs, pyramidal MOTs, tetrahedral MOTs, and grating MOTs (gMOTs). This work focuses on deploying a gMOT for cooling and trapping calcium atoms.

The compactness and straightforward alignment of the gMOT, along with the potential to use a single laser beam, facilitate its integration into a cryogenic apparatus. Additionally, the gMOT allows for the integration of waveguides into the grating, enabling precise and targeted delivery of additional laser light. This functionality can be exploited to implement two-photon cooling schemes, enabling the achievement of temperatures below the Doppler limit. Moreover, the grating could be integrated with a source of quadrupole magnetic field on a two-dimensional PCB, resulting in a compact cold atom source.

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Driving Raman transitions using a nano-structured atom chip

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In the field of quantum sensing, atom interferometers are a crucial tool for high-resolution measurements. Unfortunately, current systems remain bulky and power consuming making them unreliable for terrestrial and space-born missions alike. Grating atom chips simplify quantum sensors by enabling the trapping of atoms in a MOT with a single incident beam. Additionally, the use of grating atom chips not only simplifies the setup but also enhances the scalability and portability of quantum sensing devices. This advancement holds promise for a wide array of applications, from fundamental research in equivalence principle tests [1] to practical implementations in geodesy [2].

In this poster, we show measurements of Raman transitions on an atom chip with a grating with a single incident modulated laser beam as well as simulations, which support the results. Using the diffracted beams from the grating in combination with the incoming beam, we can drive Raman transitions along different axes which is a prerequisite for the construction of a compact multi- axis atom interferometer.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate protection (BMWK) due to the enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS II), by the German Research Foundation (DFG) in the CRC 1464 'TerraQ' (Project A03) and from 'QVLS-Q1' through the VW foundation and the ministry for science and culture of Lower Saxony.

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Closed loop correction for fast laser pulse envelope imperfections based on Compact-Optimized optical modulator

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Optimal pulses featuring specific amplitude and phase envelopes have been investigated to achieve high-fidelity quantum operation in neutral atom or ions trap based quantum processor. However, the generated laser pulse usually suffers from distortions induced by experimental devices, which will have a detrimental effect on fidelity of quantum operations. Moreover, We notice that the way of amplitude modulation by varying the amplitude acoustic wave going through AOM for generating fast laser pulse also causes unignorable quadrature distortion. Here, we present a method to correct the distortion in laser's amplitude and phase simultaneously. By directly measuring the amplitude and phase from beat note signal obtained from heterodyne detection within our new-generation compact optical modulator, we are able to reconstruct I and Q components to estimate the complex-value impulse response function characterized by the Volterra series, thereby obtaining pre-distorted amplitude and phase envelope from optimization algorithm enable us to compensate for the distortion induced from experimental devices. Our method is effective in addressing the errors that arise from the laser pulse envelope imperfections on ions trap or neutral atom-based quantum processor.

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Quantum Simulation and Quantum Computing using trapped ^{88}Sr atoms

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The coherent excitation of ultranarrow optical transitions between long-lived atomic states is fundamental for optical atomic clocks, quantum information processing, and quantum simulation. Due to its rich level structure, neutral strontium in particular offers the opportunity to build precise atomic clocks, quantum computers, and quantum simulators.

Here, we present the coherent excitation of the ultranarrow $^1S_0$–$^3P_2$ transition in ^{88}Sr. We are able to coherently drive this transition with excitation fractions of 97(1)% and observe coherence times of up to 266(36) ms using a spin-echo technique. We measure the transition rate and confirm the long-standing prediction of the ultranarrow transition linewidth of 24(7) µHz establishing an additional clock transition in strontium.

Building on these results, we demonstrate the implementation of a fine-structure qubit encoded in the metastable $^3P_2$ and $^3P_0$ states of ^{88}Sr promising fast single- and two-qubit gates. We present fast high-fidelity Rabi oscillations with pi-pulse times in the µs regime lasting for more than 60 cycles. Using an echo sequence, we measure coherence times of tens of ms. Our results pave the way for fast quantum information processing and highly tunable quantum simulators with two-electron atoms.

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Long Abstracts

A miniature atomic magnetometer prototype

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We report on the ongoing development of a miniature atomic magnetometer at IEMN. Such sensors benefit from chip-integrated lasers such as VCSELs to probe atoms in physical packages with a high degree of integration [1]. While bare VCSEL chips are commercially available, turn-key and standalone laser sources meeting the requirements for atomic devices are still lacking.

A prototype of an electronic card for the control of a laser diode was designed, taking into account the different characteristics imposed by the VCSEL. The choice of each component and its justification are presented and thermal and electrical simulations were carried out. This board has three main parts: a current source, a heating source, and temperature control.

Besides the VCSEL, the miniature magnetometer must contain the optics (quarter-wave plate, lens and prisms), the alkali vapor cell and the coils. To reduce the volume, the photodiode and the VCSEL are placed on the same PCB. The alkali vapor cell needs to be heated and is placed on a PCB containing the thermistor and the heating resistor. The PCB also supports the optical elements. The cell is microfabricated, which supports large-scale production and miniaturization. The magnetometer must operate in a magnetic shield but the residual field must be compensated. Helmholtz coils are made on PCB for compensation and calibration.

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Quantum computing with mixed qubit types in $^{137}Ba^{+}$

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Low error rates and long coherence times make trapped ions a promising platform for quantum computing. A major challenge of such systems is individual addressing of each ion, a necessary tool for advanced control schemes such as in-sequence cooling and mid-circuit measurements for error correction. Common schemes such as QCCD architectures and mixed species [2] create such environments where some qubits are insensitive the light field applied to others, but they are often very complex systems. The *omg* architecture [1] is a recently proposed alternative where quantum information is stored and manipulated in *o*ptical, *m*etastable, and *g*round level qubits of the same species.

Barium ions are a compelling platform for an *omg* architecture, as they have a long-lived metastable level compared to other atomic species. The ^{137}Ba isotope with nuclear spin 3/2 also possesses 'clock' transitions in both the ground and metastable levels that can be used as magnetic field insensitive qubits.

We present an initial toolbox for mixed qubit registers using $^{137}Ba^{+}$ ions. We demonstrate a novel protocol for high fidelity state preparation and measurement which exploits the benefits of mixed qubit registers to implement erasure conversion. We also present an implementation of entangling gates between mixed qubit registers which can be realized both between qubits in the same level and between a ground and a metastable qubit. This type of interaction is particularly advantageous in the *omg* architecture, as it allows for mixed qubit interactions without requiring conversion between qubit types.

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Long Abstracts

Cold ytterbium Rydberg atoms source

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My internship, which we plan to prolong for a PhD, consists in mounting the new atomic source constituted of a ytterbium oven, a Zeeman slower collecting most of the velocity classes, followed by a Magneto-Optical Trap (MOT) in 2 dimensions to redirect the atomic flux toward a 3D MOT.

To explain our experiment in simple words, the atomic source emits atoms with high speed reaching almost 300 m/s, such high speed of atoms prevents us from trapping them immediately, that's why we need a Zeeman slower which reduces the speed of the atoms up to almost 10 m/s making it possible for them to get caught by the last phase which is the MOT that cools them even more and trap them. After that, our atoms can be placed in a high vacuum regime to prevent blackbody radiations and optical tweezers can be applied in order to trap atoms individually and apply Quantum information processes on them, including quantum gates, computations, and much more. The source that already exists in our experiment has a lot of malfunctioning, which is preventing us from getting better efficiency in trapping our atoms in the MOT. Since such experiments with different phases contain lots of challenges and losses already, having a source that can provide us with a good atomic flux and atomic density which we lack in our current experiment is a must. By mounting a new atomic source, we will guarantee that more atoms will reach the next level which is the Zeeman slower. Going into the Zeeman slower, we need to find the best configuration that we can according to our new atomic source in order to make sure that most of the atoms reach the capture velocity of the MOT. Reaching the MOT, atoms that have speeds higher than the capture velocity of the MOT won't be trapped which introduces more losses to the experiment. After all, different configurations are going to be done to make our experiment function better and move to the next phase.

Our plan later on is placing optical tweezers and start applying quantum gates at first and then move to the most important part which is Quantum Simulations.

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Quantum Simulations using potassium-40.

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Quantum simulators offer a unique approach to study complex many-body quantum systems, particularly systems with a large number of particles. Due to their complexity, classical computers are not suited to deal with such systems, as the Hilbert space grows exponentially as the system increase in size. Quantum simulators overcome this challenge, and in particular quantum-gas microscopes allow for single-atom-resolved imaging within an optical lattice [1]. In our experiment we implement Raman-sideband cooling to image individual fermionic potassium atoms [2].

During my time working on the experiment, I've further improved a technique for sub-Doppler gray molasses cooling [3], lowering the temperature of the atoms and increasing the phase-space density prior to loading into the optical lattice. To propel the experiment further, a Digital Micromirror Device (DMD) is currently being incorporated, allowing for the creation of interesting geometries such as the Lieb lattice [4], or other super lattice structures. Dynamically varying potentials will also allow us to improve the cooling of the atomic sample [5], or control the commensurability of our quantum systems [6].

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Lowering entanglement in quantum trajectory unravelings of noisy quantum circuits

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The evolution of quantum states in open quantum circuits subjected to dissipation and decoherence can be simulated by unraveling the dynamics into quantum trajectories. Such an unraveling is not unique. Here, we introduce strategies to minimize entanglement in quantum trajectories using the unitary degree of freedom in defining the Kraus operators. We consider random benchmark circuits that lead to (on-average) linear increase of bipartite entanglement entropies with circuit depth, but are subjected to single-qubit noise channels of amplitude damping or phase-flip. With analytical arguments and large-scale numerical simulations we demonstrate that standard representations of Kraus operators lead to almost worst-case scenario entanglement growth, while optimized Kraus operators allow to reduce entanglement growth to a logarithmic scaling (in the case of amplitude damping) or constant scaling (in the case of phase-flip). This has important consequences for classical simulations of open quantum circuits with matrix product states (MPS), which provides an efficient representation for quantum states with low entanglement entropies.

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Energy levels in a 2D spin dependent optical lattice

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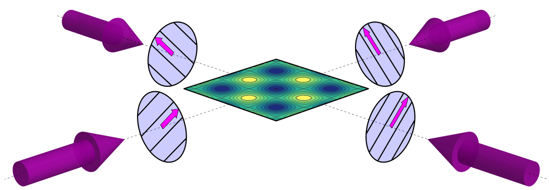

FIG. 1. Periodic potential formed by 4 counter-propagating, polarized laser beams.

In this study the energy levels of a ^{87}Rb atom in a 2D spin dependent optical lattice are examined. Four counter-propagating laser beams produce a periodic scalar potential, as depicted on Fig 1. As shown by Le Kien *et al.* [1], polarizing the beams by 45° results in an additional, spin dependent vector potential, that can be expressed through a fictitious magnetic field $\mathbf{B}_{\text{fic}}$.

The spectrum of energy levels is analyzed as a function of the external magnetic field $B_{\text{ext}}\hat{e}_z$, in lattice cells of various $n \times m$ sizes, with either Dirichlet (DBC) or periodic (PBC) boundary conditions. It is found that avoided crossing between multiplets of eigenstates occurs only for cells larger than 1 by 1 with DBC. Szulim *et al.* [2] also observed level crossing in a 1 by 1 DBC cell of a honeycomb lattice and suggested hexagonal symmetry as the cause. Rectangular cells are studied by varying the angle between the laser beams and it is shown that even with the loss of rotational symmetry, avoided crossing does not occur with PBC or in a 1 by 1 cell with DBC.

Furthermore, eigenstates are discovered in DBC cells, with energies lying outside the bands computed for a PBC cell. Analysis of the probability density of their wave functions reveals that they are hinge states. It is further demonstrated how the states localized near the Dirichlet walls tend to have higher energies than corresponding states localized in the center of the cell.

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Scale-invariant phase transition of disordered bosons in one dimension

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Bosonic particles with local interactions in one dimension (1D) are described by a universal harmonic theory, known as Luttinger liquid (LL). Diagonal disorder induces an instability in LL towards a non-superfluid Bose glass (BG) phase – a compressible insulator displaying exponential decay of off-diagonal correlations. The disorder-induced quantum phase transition between superfluid and non-superfluid states of bosonic particles in one dimension is generally expected to be of the Berezinskii-Kosterlitz-Thouless (BKT) type [1, 2]. In this work [3], we consider the disorder-induced localization transition in 1D superfluids of bosons with power-law hopping decaying with distance as $1/r^{\alpha}$. Here, we show that hard-core lattice bosons with integrable power-law hopping decaying with distance as $1/r^{\alpha}$ – corresponding in spin language to a XY model with power-law couplings – undergo a non-BKT continuous phase transition instead. We use exact quantum Monte-Carlo methods to determine the phase diagram for different values of the exponent α, focusing on the regime $\alpha > 2$. We find that the scaling of the superfluid stiffness with the system size is scale-invariant at the transition point for any $\alpha \leq 3$ – a behavior incompatible with the BKT scenario and typical of continuous phase transitions in higher dimension. By scaling analysis near the transition point, we find that our data are consistent with a correlation length exponent satisfying the Harris bound $\nu \geq 2$ and demonstrate a new universal behavior of disordered bosons in one dimension. For $\alpha > 3$ our data are consistent with a BKT scenario where the liquid is pinned by infinitesimal disorder.

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Energy Damping of a Jones-Roberts Soliton: Analytical and Numerical Results

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Non-linear, form preserving waves known as Jones-Roberts solitons are a class of universal phenomena described by the two-dimensional Gross-Pitaevskii equation. Encompassing vortex dipoles as well as rarefaction pulses, they feature prominently in the dynamics of Bose-Einstein condensates (BECs). As they prove to be stable against perturbations, finite temperature effects can be expected to have a major influence on their damping. We investigate the thermally induced decay of Jones-Roberts solitons in the framework of the stochastic projected Gross-Pitaevskii equation. Our findings suggest that the dominant damping mechanism is energy damping, stemming from the scattering between atoms in the thermal cloud and the condensate region without the exchange of particles between them. While in the vortex dipole regime the characterising property of a Jones-Roberts soliton is the distance between the vortices, we identify the interaction energy as the relevant quantity in the rarefaction pulse regime. We present analytical and numerical results demonstrating the decay behaviour of these parameters for different kinds of damping expected in thermal BECs. A comparison of these decay processes than reveals the dominance of energy damping for experimentally relevant parameters.

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Assembled Arrays of Rydberg-interacting Atoms with Single-site Control

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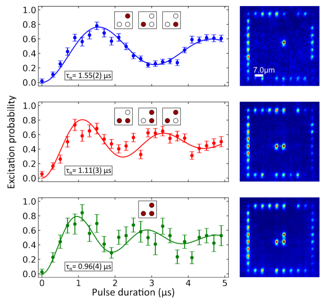

FIG. 1. Collective enhancement of the Rabi frequency through Rydberg blockade.

Optical tweezer arrays of neutral atoms are a promising platform for quantum technologies. Based on comprehensive quantum control via laser pulses, many-body quantum systems can be created and studied at the single-particle level. We report on the advancement of a novel platform for the creation of large-scale 3D multilayer configurations of planar arrays of neutral atom qubits: a microlens-generated Talbot tweezer lattice that extends 2D tweezer arrays to the third dimension at no additional cost, accessing 10000 sites in the current setup. In-plane atom transport enables the deterministic preparation of defect-free configurations of naturally identical atomic qubits [1]. Targeting applications in quantum sensing, we use the individual-atom sensor grid of a selected planar array to map an externally applied DC gradient magnetic field up to submicron resolution [2]. While well-isolated arrays of effectively non-interacting atoms form the basis of sensing and metrology, neutral atoms exhibit controllable interactions when excited to Rydberg states, a prerequisite for quantum simulation and computing. By tuning the geometry and the addressed Rydberg state, a parameter regime ranging from weak interactions to strong coupling can be accessed (see Fig. 1) [3]. Real-time control of quantum states and interactions is achieved by fast laser addressing with single-site resolution, opening up the prospect of parallelized universal quantum operations in large-scale quantum arrays.

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Long Abstracts

Towards cavity-control of ultracold chemical reactions in molecular quantum gases

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Understanding and controlling chemical reactions at ultralow temperatures is crucial for unlocking the potential of molecular quantum gases and for engineering new molecular species. Recently, the development of several shielding methods relying on DC or AC electric fields has enabled the stabilization of molecular quantum gases against chemical reactions and the attainment of quantum degenerate molecular gases. However, understanding the microscopic mechanisms that govern ultracold chemistry remains an open challenge. In Berlin, we are building a new setup to directly control the reaction pathway of ultracold molecules. A high-finesse optical cavity will be the fulcrum for chemical-reactions control. Strong light-molecule coupling will create new hybrid light-molecule states, so called molecular polaritons, that will display a new electronic structure and different chemical stability. By controlling the molecule-cavity resonance, we will steer the reaction dynamics at will and control the reaction product distribution with the cavity vacuum, thus realizing a fully quantum-mechanical catalysis method for controlling the transformation of molecular materials. We report on our efforts to create a Bose-Einstein Condensate of dysprosium atoms and preliminary spectroscopy characterization of the target dysprosium dimers.

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Effects of Time Reversal Symmetry on Localization in Disordered Quantum Systems

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In this poster, I present some of our theoretical results: I explore the dynamics of the quantum kicked rotor, a fundamental system for studying quantum chaos and Anderson localization, by introducing spin-orbit coupling [2, 3]. This advanced model allows me to examine time-reversal symmetry and to develop an experimental protocol aimed specifically at studying the three Wigner-Dyson symmetry classes: symplectic, orthogonal, and unitary. A novel aspect of this work lies in the study of Hamiltonians belonging to the symplectic symmetry class, which, to our knowledge, have never been experimentally realized before.

The distinction between these symmetry classes in our model is based on the analysis of three principal signatures. The first involves observing the probability density in the momentum space at moments preceding the localization time, to identify the presence or absence of coherent backscattering (CBS) or anti-CBS around the origin. This approach directly reveals the effect of spin-orbit coupling on the localization behavior in the system. The second signature focuses on the Thouless scaling function, $\beta(g)$, which characterizes the transport behavior of the system in terms of its dimensionless conductance g. By comparing numerical results with analytical functions valid for small values of $1/g$ [4].

Finally, the third signature examines the statistics of the quasi-energies of the Floquet operator, offering a comparative perspective with the predictions of random matrix theory. This analysis allows for the precise classification of the studied Hamiltonian into one of the three Dyson-Wigner symmetry classes [1], based on the nature of the fluctuations observed in the quasi-energy spectrum.

In summary, my research makes a significant contribution to the understanding of quantum chaos and localization phenomena in systems with spin-orbit coupling.

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Long Abstracts

Hydrodynamic Instabilities in Quantum Droplets

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In our most recent work, we report on hydrodynamical instabilities of a ^{41}K-^{87}Rb quantum droplet: after preparation in an elongated trap, the droplet is kept in a waveguide, where the collective modes excited during the preparation cause it to elongate up to a certain critical length, after which the sample splits into two or more smaller droplets; an example of this can be seen in Figure 1.

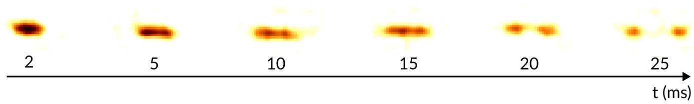

FIG. 1. Break-up of a quantum droplet into multiple droplets, mediated by a hydrodynamic instability. The images are obtained by in-situ absorption imaging of the ^{41}K atomic cloud. The times reported on the x axis of the figure are referred to the beginning of the evolution in the waveguide.

This behaviour, as well as its dependence on the interspecies interaction strength and the number of atoms, is consistent with what is expected for a kind of hydrodynamic instability known as capillary instability, where the surface tension of a liquid causes the break-up of a filament into smaller droplets; such a phenomenon is observed in classical liquids, and is also expected in their quantum counterparts [1].

With these results, we can begin to explore the new and relatively undiscovered phenomena related to quantum liquids, in general, and of quantum droplets, in particular, opening new possibilities in the improvement of our understanding of multi-component superfluids.

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Bragg-spectroscopy of a dissipation induced instability

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The study of collective excitations is a powerful tool to get insights into a many-body system. Having access to the low-lying energy spectrum and its modes, can herald imminent phase transitions and shed light on the nature of different phases. In our experiment, we load a BEC into a high-finesse cavity. The coupling of BEC and cavity results in long-range interactions, which can give rise to two roton-like excitation modes. These modes, when fully softened, correspond to two superradiant phases previously observed and studied in [1]. The dissipation, inherent to our system leads to the coupling of these two modes, when their energies are close [2]. At this exceptional point, the eigenvalues and eigenvectors related to the two modes are expected to coalesce.

We make use of Bragg-spectroscopy to simultaneously measure these two low-lying excitations. We find the individual softening of the two modes as they approach their respective phase along with diverging susceptibility. Leveraging the full tuneability of our system, we can explore a parameter regime, where the two modes coalesce, observing an exceptional point and the associated dynamical instability.

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Long Abstracts

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

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Neutral atoms trapped in arrays of optical tweezer microtraps have recently emerged as a promising platform for quantum science. Optical tweezers enable the manipulation, control, and detection at the single-atom level. Importantly, the dynamic rearrangement of tweezer traps allows the generation of large-scale defect-free atom arrays in arbitrary geometric configurations. Here, we present a new ytterbium experimental setup capable of realizing one-dimensional (1D) and two- dimensional (2D) systems of atomic arrays both in optical tweezer arrays and in optical lattices. This allows to combine the precise control provided by tweezers and the versatility provided by optical lattices, realizing a system where it's possible to directly implant reordered arrays in optical lattice traps. In such system, ytterbium atom's wide range of spectral lines opens up new avenues for the study of complex quantum phenomena, from the exploration of impurity problems to the study of cooperative light-atom interactions, giving rise to e.g. sub- and super-radiance in densely packed arrays. The presence of inter-orbital Feshbach resonances in fermionic isotopes at accessible magnetic fields enables to adjust the interaction between the impurity and the environment, making both repulsive and attractive Fermi polaron branches accessible. Moreover, tuning the trapping wavelength, it's especially possible to control the nature of the atomic trap. Atomic states with different polarizability can be selectively trapped in state-dependent optical potentials, introducing a new kind of control knob over different atomic states. Importantly, this set of features allows to investigate a large variety of quantum impurity problems using a single atomic species.

High-rate quantum LDPC codes for long-range-connected neutral atom registers

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High-rate quantum error correcting (QEC) codes with moderate overheads in qubit number and control complexity are highly desirable for achieving fault-tolerant quantum computing [1, 2]. Recently, quantum error correction has experienced significant progress both in code development and experimental realizations, with neutral atom qubit architecture rapidly establishing itself as a leading platform in the field. Scalable quantum computing will require processing with QEC codes that have low qubit overhead and large error suppression, and while such codes do exist, they involve a degree of non-locality that has yet to be integrated into experimental platforms. In this work, we analyze a family of high-rate Low-Density Parity-Check (LDPC) codes with limited long-range interactions and outline a near-term implementation in neutral atom registers. By means of circuit-level simulations, we find that these codes outperform surface codes in all respects when the two-qubit nearest neighbour gate error probability is below $\sim 0.1\%$. We show how these codes can be natively integrated in two-dimensional static neutral atom qubit architectures with open boundaries, where the desired long-range connectivity can be targeted via Rydberg-blockade interaction. Our protocol solely requires multiple laser colors to enable transitions to different Rydberg states for different interatomic distances.

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[3] L. Pecorari *et al.*, arXiv:2404.13010 (2024).

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Towards optical dipole trapping of Feshbach molecules with infrared light near 2μm

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In the Dy-K experiment, we study Fermi-Fermi mixtures in the strongly interacting regime. Around the Feshbach resonance at 7G [1] weakly bound dimers we have successfully created and trapped in an optical dipole trap.
We have experimentally shown [2, 3] that the light used to realize optical dipole trap (ODT) for Feshbach molecules induces losses of the molecules in the mixture. Such losses in the mixture have also been observed in a related experiment in Florence.
We are building a single resonant optical parametric oscillator, realized with a periodically poled lithium niobate crystal (PPLN) and a bow-tie cavity [4]. This will generate a tunable infrared light beam, with wavelength in the range 1.7 μm-2 μm, that can be used to realize an ODT trap.
The pump is a 1064 nm high-power laser. The PPLN crystal converts the pump light in two beams: the signal and the idler beams. The cavity is designed to be resonant with a signal wavelength, in order to achieve higher powers. Due to energy conservation considerations the wavelength of the beams is larger that the pump one. Changing the temperature of the PPLN crystal is then possible to modify the signal and idler wavelengths.
Our work is funded by the European Union within the ERC project SuperCoolMix.

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[3] Finelli, S. *et al.*, arXiv:2402.08337v1 (2024).
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Perfect ring-shaped Bose Einstein Condensation

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Bose-Einstein condensates (BECs) confined in ring-shaped geometries have attracted significant attention due to their unique properties and potential applications. We investigate the methods employed to create a stable ring-shaped BEC, including the use of time averaged adiabatic trapping potentials (TAAPs) and precise control over cooling and confinement parameters. By such methods, a highly homogeneous and stable condensate can be achieved. Next, we look at the stability of the ring-shaped BECs by examining the effects of perturbation and fluctuations on its persistent currents and coherence. Through experimental measurements and theoretical analysis, we explore the conditions for the condensate to maintains its integrity and coherence, providing insights into the robustness of the system. Furthermore, we look at the dynamics of excitations within the ring-shaped BEC, by introducing controlled manipulation of the trapping potentials, we investigate the behavior or response of the atoms within the condensate. The ring-shaped BEC presents a way to implement on mater wave interferometry and the very development of novel atom laser and in atomtronics. The research is ongoing for further investigations into unique phenomena exhibited by ring-shaped BECs, paving the way for their potential impact across various scientific disciplines.

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