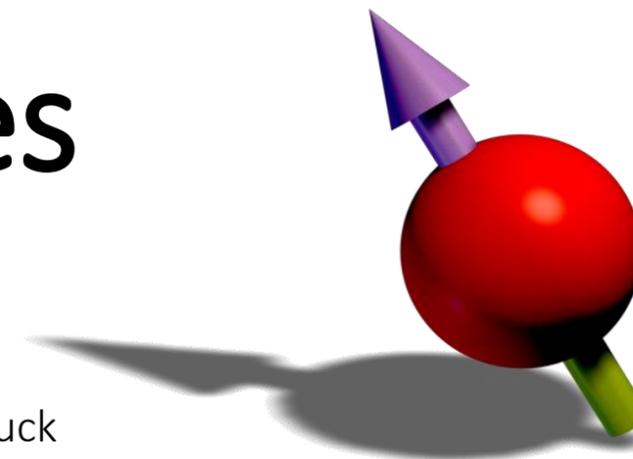




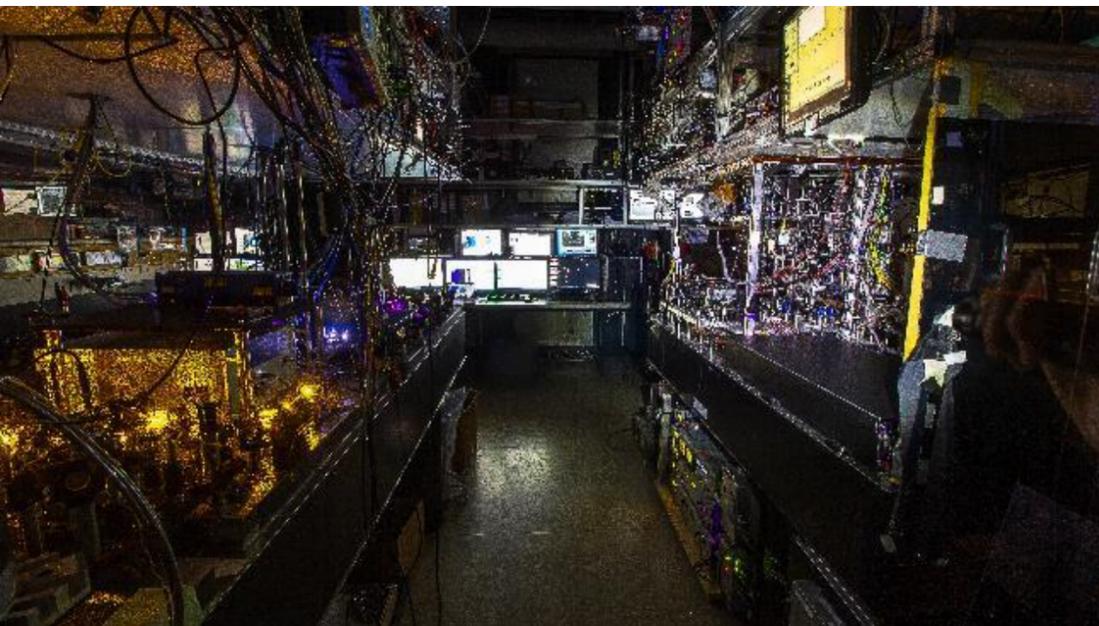
# Dipolar Quantum Gases

WWW.ERBIUM.AT

Center for Ultracold Atoms and Quantum Gases, IExp and IQOQI, Innsbruck



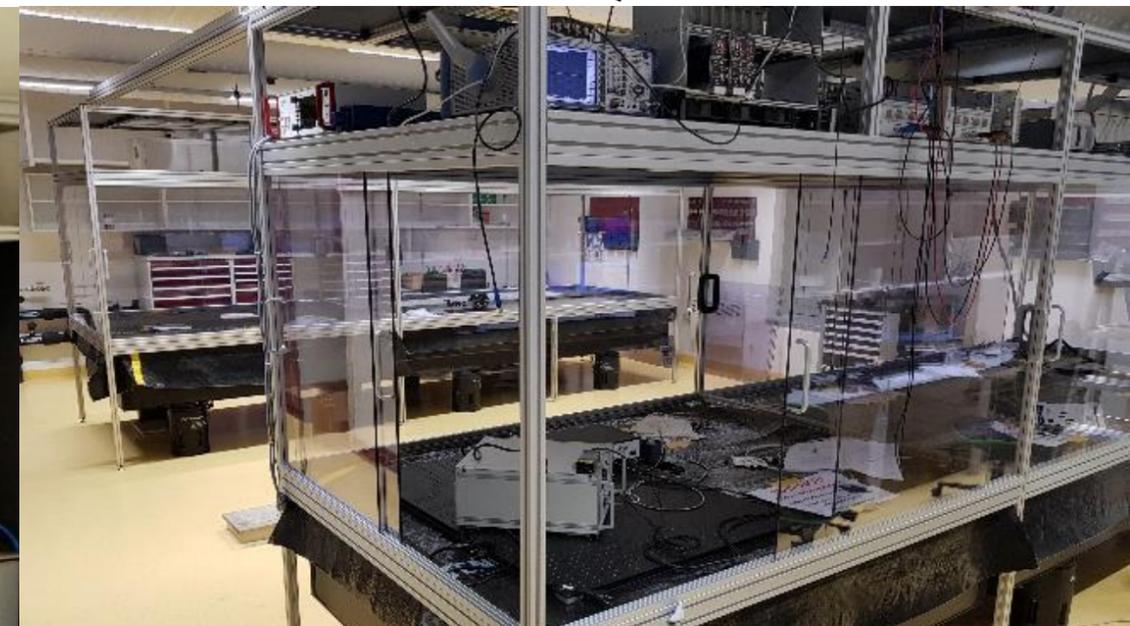
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ER-DY



T-REQS



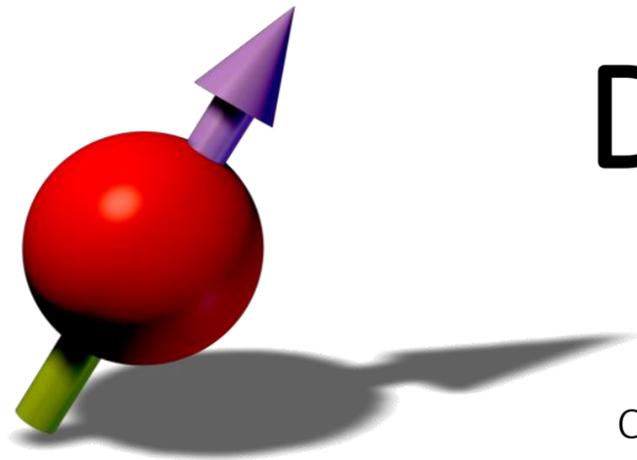
PI: Prof. Francesca Ferlino

2 Post-Docs  
10 PhD-Students  
4 Master-students



Senior Scientist: Dr. Manfred Mark

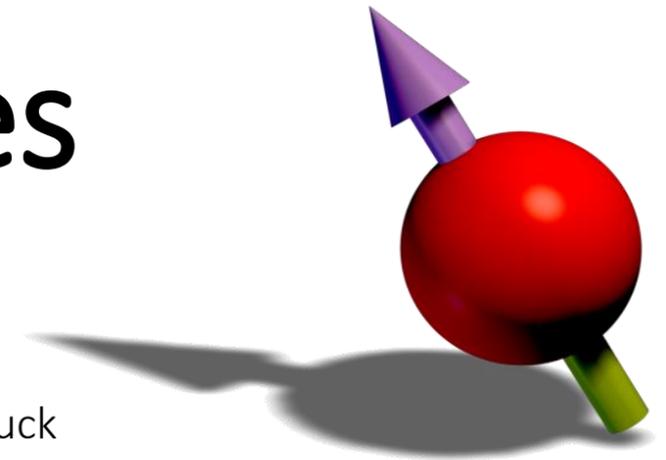




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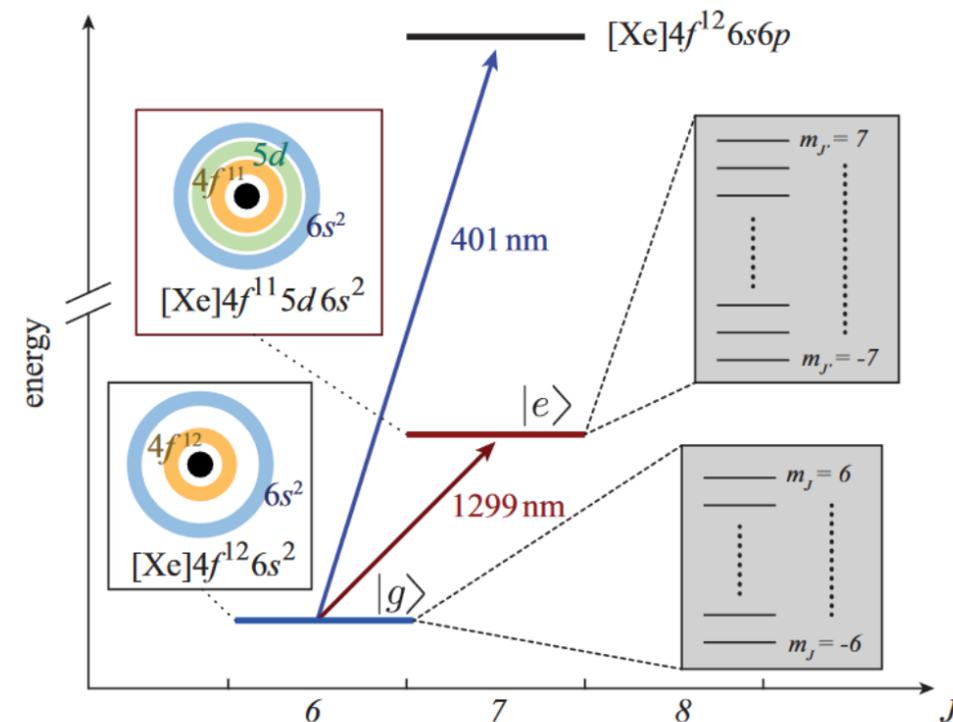
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Observation of a narrow inner-shell orbital transition in atomic erbium at 1299 nm

A. Patscheider, B. Yang, G. Natale, D. Petter, L. Chomaz, M. J. Mark, G. Hovhannesian, M. Lepers, and F. Ferlaino  
Phys. Rev. Research **3**, 033256 – Published 17 September 2021



nature

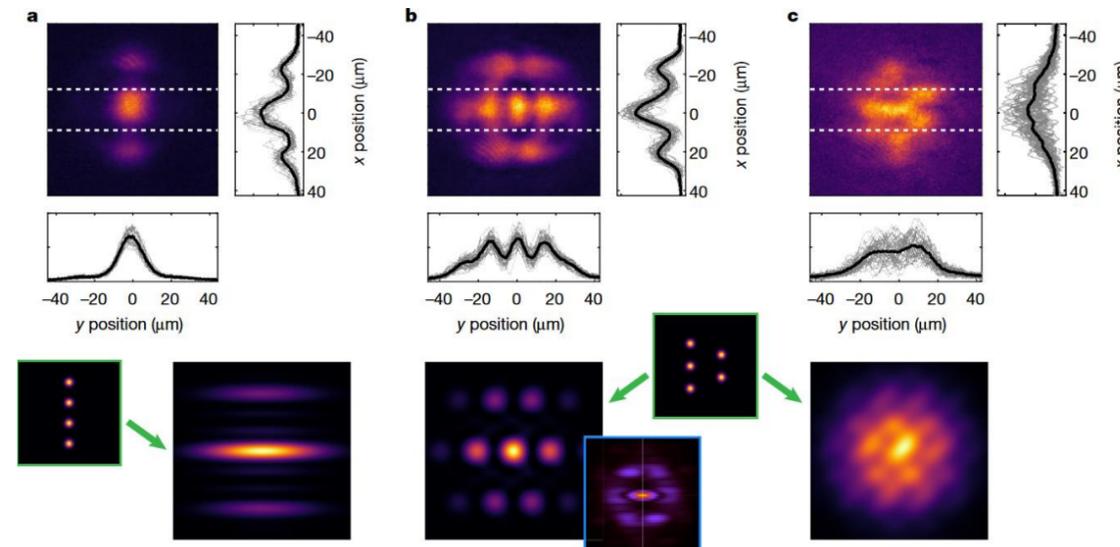
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Article | Published: 18 August 2021

## Two-dimensional supersolidity in a dipolar quantum gas

Matthew A. Norcia, Claudia Politi, Lauritz Klaus, Elena Poli, Maximilian Sohmen, Manfred J. Mark, Russell N. Bisset, Luis Santos & Francesca Ferlaino



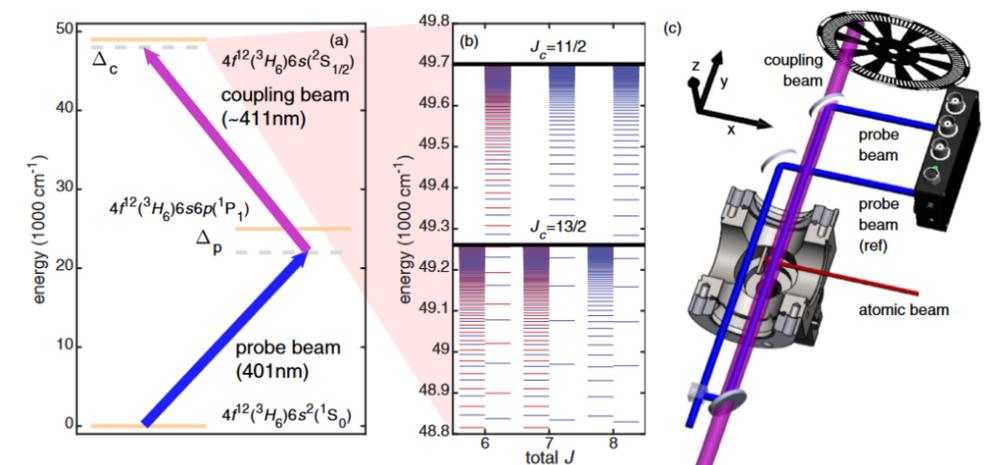
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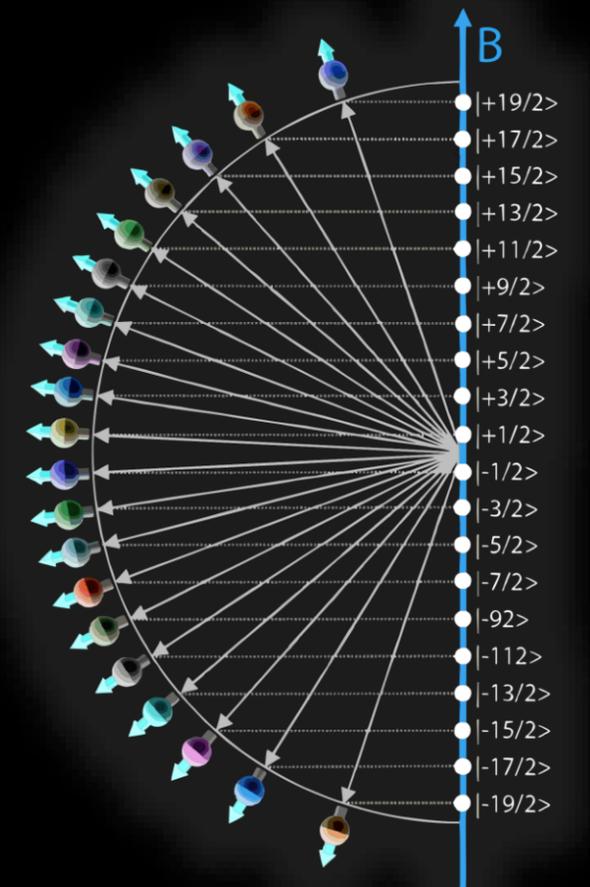
Spectroscopy of Rydberg states in erbium using electromagnetically induced transparency

A. Trautmann, M. J. Mark, P. Ilzhöfer, H. Edri, A. El Arrach, J. G. Maloberti, C. H. Greene, F. Robicheaux, and F. Ferlaino  
Phys. Rev. Research **3**, 033165 – Published 19 August 2021



# Bachelor & Master Projects

ERBIUM



# Bachelor Project

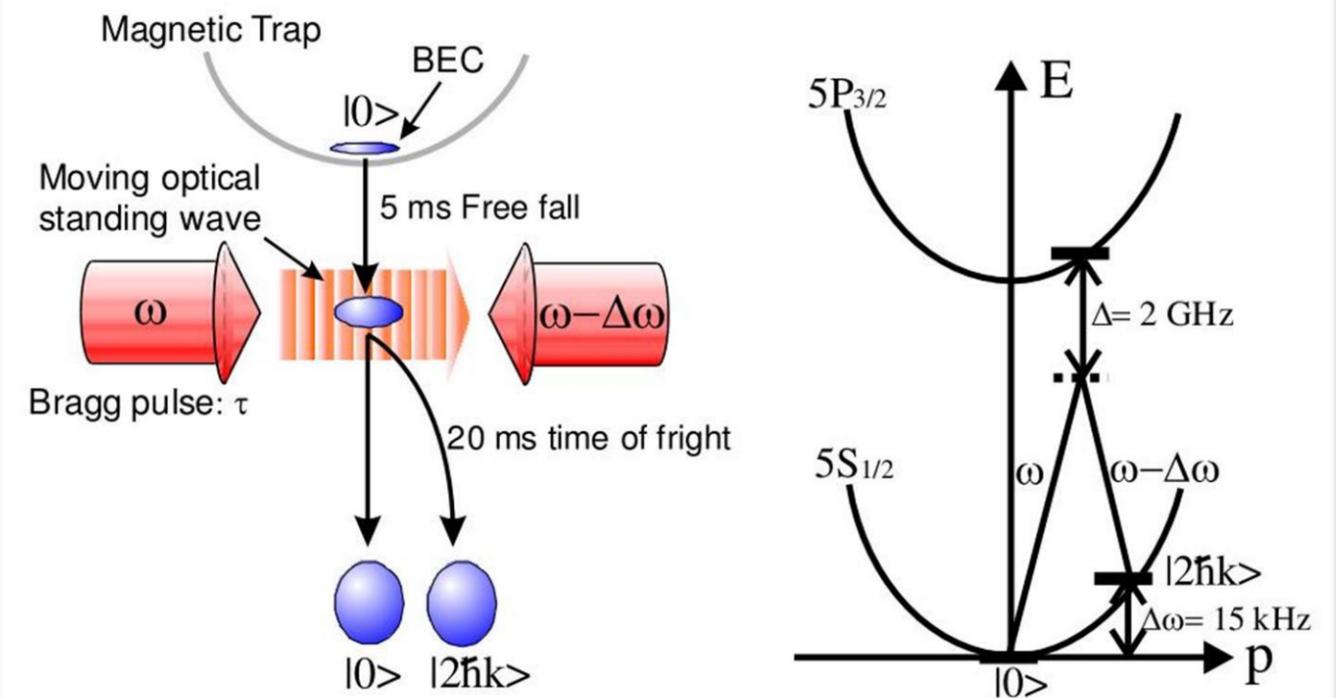
1. Elementary excitations : testing 1940's theory via photon Bragg scattering on gaseous Bose-Einstein condensates

Reaching ultralow temperatures, the quantum nature of a large assembly of particles becomes manifest macroscopically and a phase transition to a quantum degenerate state occurs. For bosonic particles, a Bose-Einstein condensate (BEC) is formed. While interparticle interactions are not needed for a BEC to form, they will lead to superfluidity. The understanding of these effects traces back to Landau's works in the 1940's on elementary excitations, i.e. intrinsic modes of oscillation on top of the quantum fluid. Landau's picture was substantiated by Bogoliubov. The advent of ultracold gases in experiments hence directly enables us to test Bogoliubov theory in a clean setting. A powerful technique to test Bogoliubov theory on quantum gases relies on Bragg scattering, using potentials created by light. Over the years, Bragg spectroscopy has been widely used in cold-atom experiments demonstrating effects predicted by Bogoliubov as well as others.

This bachelor thesis should work out the basic description of quantum Bose gases and their elementary excitation within the Bogoliubov theory, the concept of Bragg scattering excitation and its various implementations on ultracold atom experiments. In addition, software implementation of tunable Bragg spectroscopy laser beams using a Digital Micromirror Device can be performed within the framework of an optical laboratory internship.

## Bragg scattering of BEC

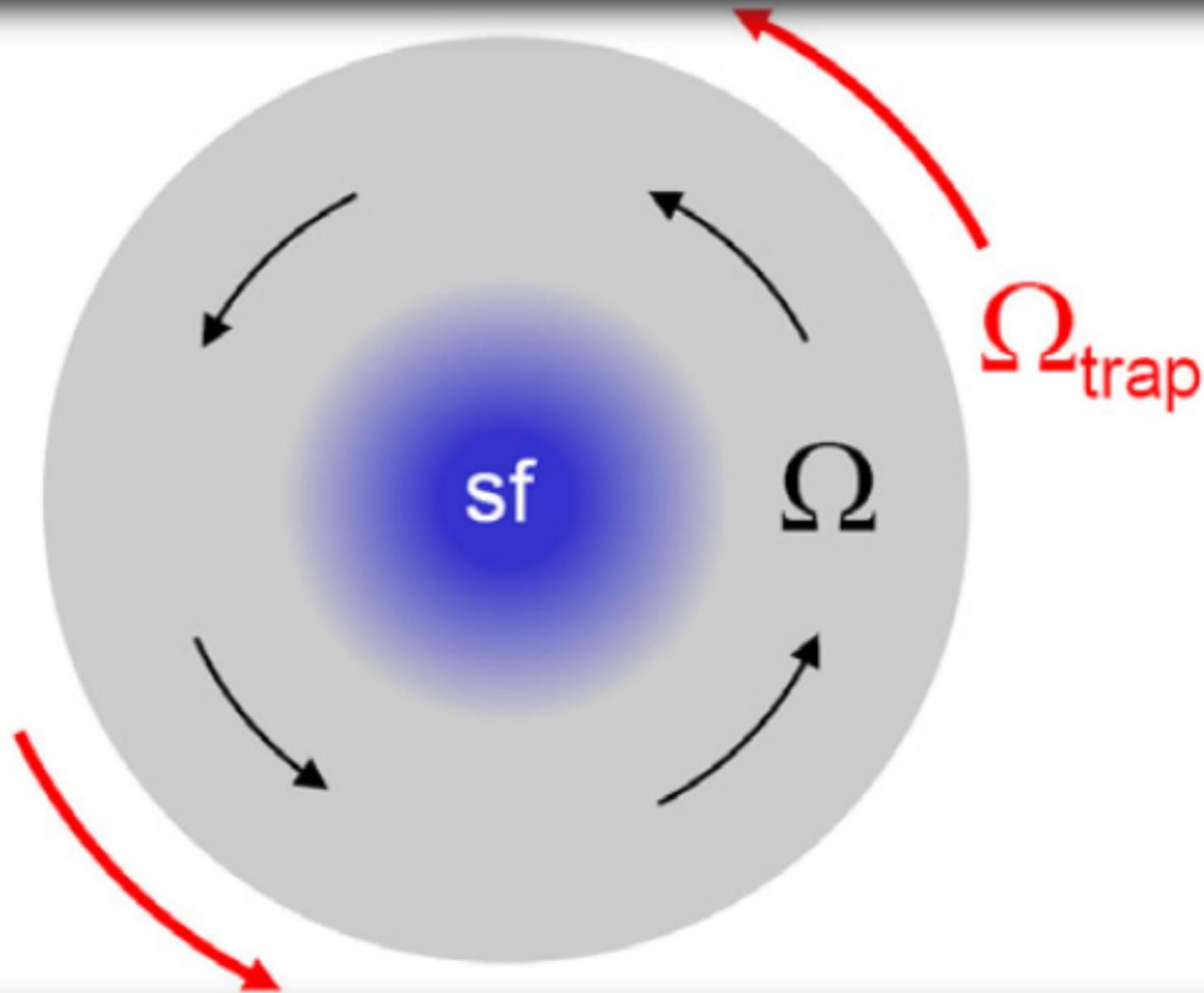
[M. Kozuma et. al. Phys. Rev. Lett. **82**, 871 (1999)]



# Bachelor Project

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2. Is it really superfluid? The challenge of testing superfluidity in ultracold quantum gases



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For a long time, the only known superfluid in nature was Helium liquid. The fascinating ability of the helium superfluid to flow without any friction has stunned scientists all around the world. In 1995, scientists have produced in laboratory a new system: quantum gases of ultracold neutral atoms. Central to the understanding of the physics of ultracold gases are the concepts of Bose-Einstein condensation and superfluidity. The two concepts have been conceptually linked ever since the discovery of superfluidity in liquid helium in 1937, but they are nevertheless clearly distinct and their exact quantitative connection is often elusive or given for granted.

The Bachelorarbeit will focus on few experimental techniques employed to study superfluidity in Bose of ultracold atoms in search of unambiguous evidences of superfluidity. Particular emphasis will be given to superflow and non-classical moment of inertia.

# Bachelor Project

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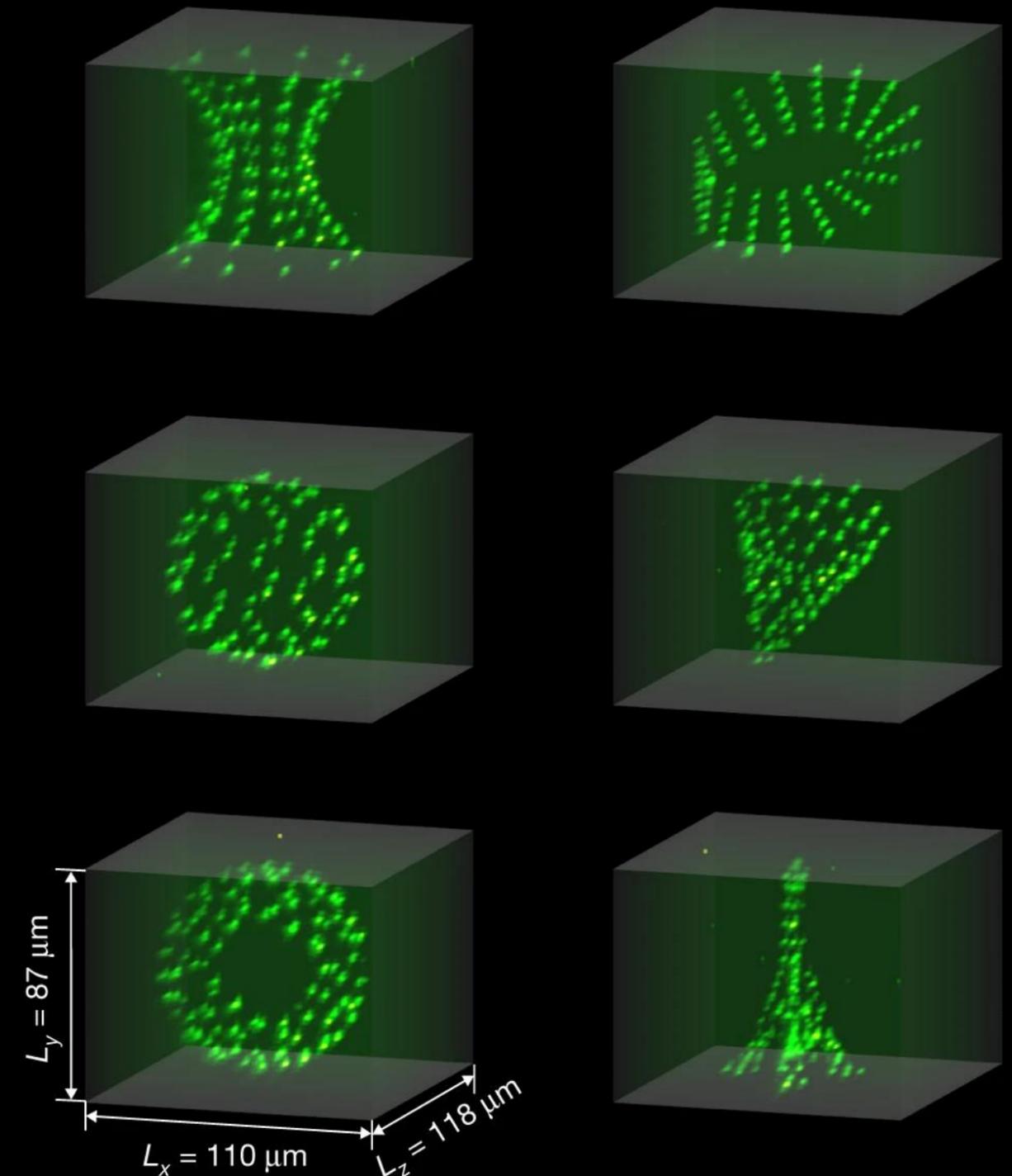
## 3. Quantum simulation with neutral atoms in optical tweezers

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Simulating physics with computers has been a long standing challenge, the notion of a quantum computer or a quantum simulator was suggested in the 1980s and sparked an ongoing technological and theoretical effort to fulfill these aspirations. Simulating quantum systems is a formidable problem, Richard Feynman put it in memorable words: “Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical and by golly it's a wonderful problem, because it doesn't look so easy.”

Quantum simulators, where synthetic systems are built and studied to gain insight into complicated, many-body real-world problems have been developing rapidly over the last two decades. Systems of individually controlled neutral atoms, interacting with each other when excited to Rydberg states, have emerged as a promising platform for quantum simulation, particularly for the simulation of spin systems.

The Bachelorarbeit will focus on the assembly and control of neutral atom arrays, Rydberg states and interactions between them and combining these two elements to simulate Ising spin models.



# Bachelor Project

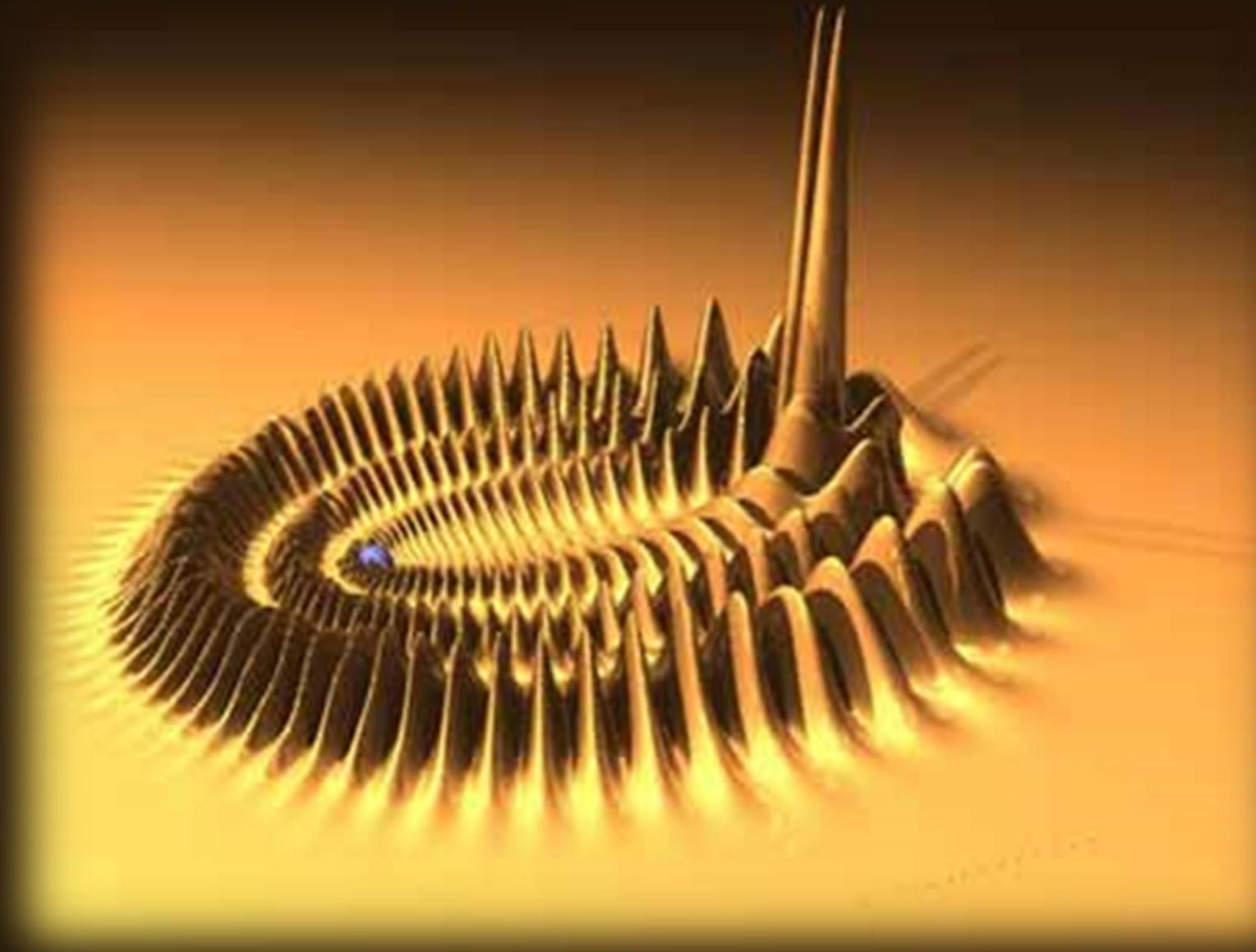
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## 4. Ultralong-range Rydberg Molecules – From Trilobites to Butterflies

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Rydberg atoms, i.e. electronically highly excited atoms, have brought new insights to the field of atomic physics since its origins. Their extreme properties make them very interesting as building blocks in recent efforts on quantum simulation and quantum computation.

This thesis will look at the basic properties of Rydberg atoms and then especially focus on the interactions between the Rydberg electron and neutral disturber atoms, leading to the possibility of forming giant molecules. Finally recent experimental progress on the detection and characterization of those molecular states will be discussed.



# Master Project

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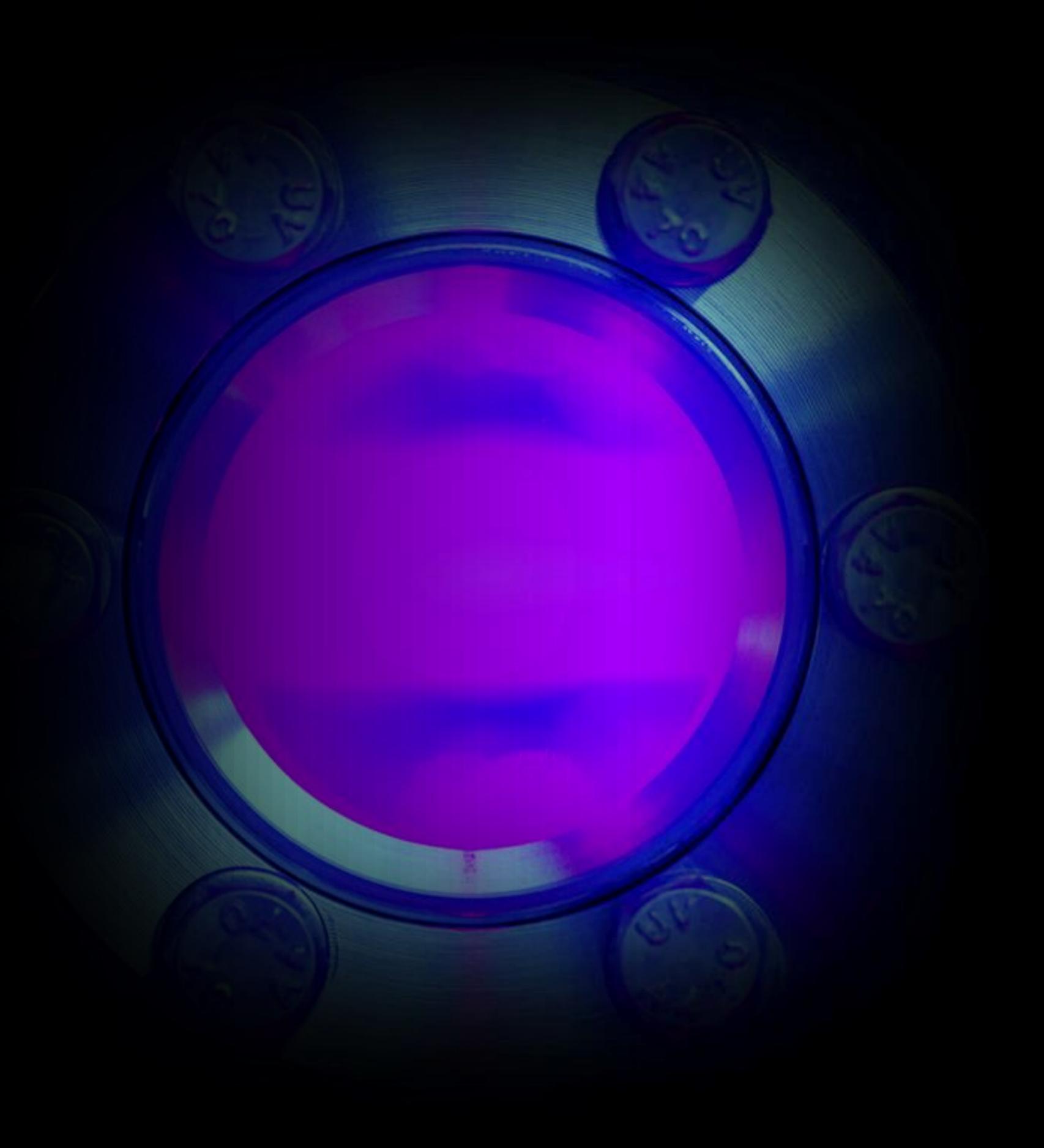
1. Build-up and implementation of a 401nm laser system for transversal cooling of erbium

---

This project aims to improve on our existing experiments by improving part of the very first stage in the process of cooling atoms to quantum degeneracy. In particular, the student will develop and implement a laser at the broadest closed transition for erbium: 401nm.

You will learn:

- Laser Physics and how to build one
- How to build a stable optical setup
- Electronic control and stabilization



# Master Project

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2. Tunable 2D lattice for quantum gas microscopy at 532nm

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This project aims to improve on our existing experiments by adding a 2D lattice with tunable periodicity using the “accordion” technique. In particular, the student will use an existing off-resonant laser at 532nm to build and implement an optical setup to create these tunable lattices.

You will learn:

- 2D Lattice physics
- How to build a stable optical setup
- Electronic control and stabilization

# Master Project

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3. Build-up and implementation of a narrow-line laser cooling system at 841nm

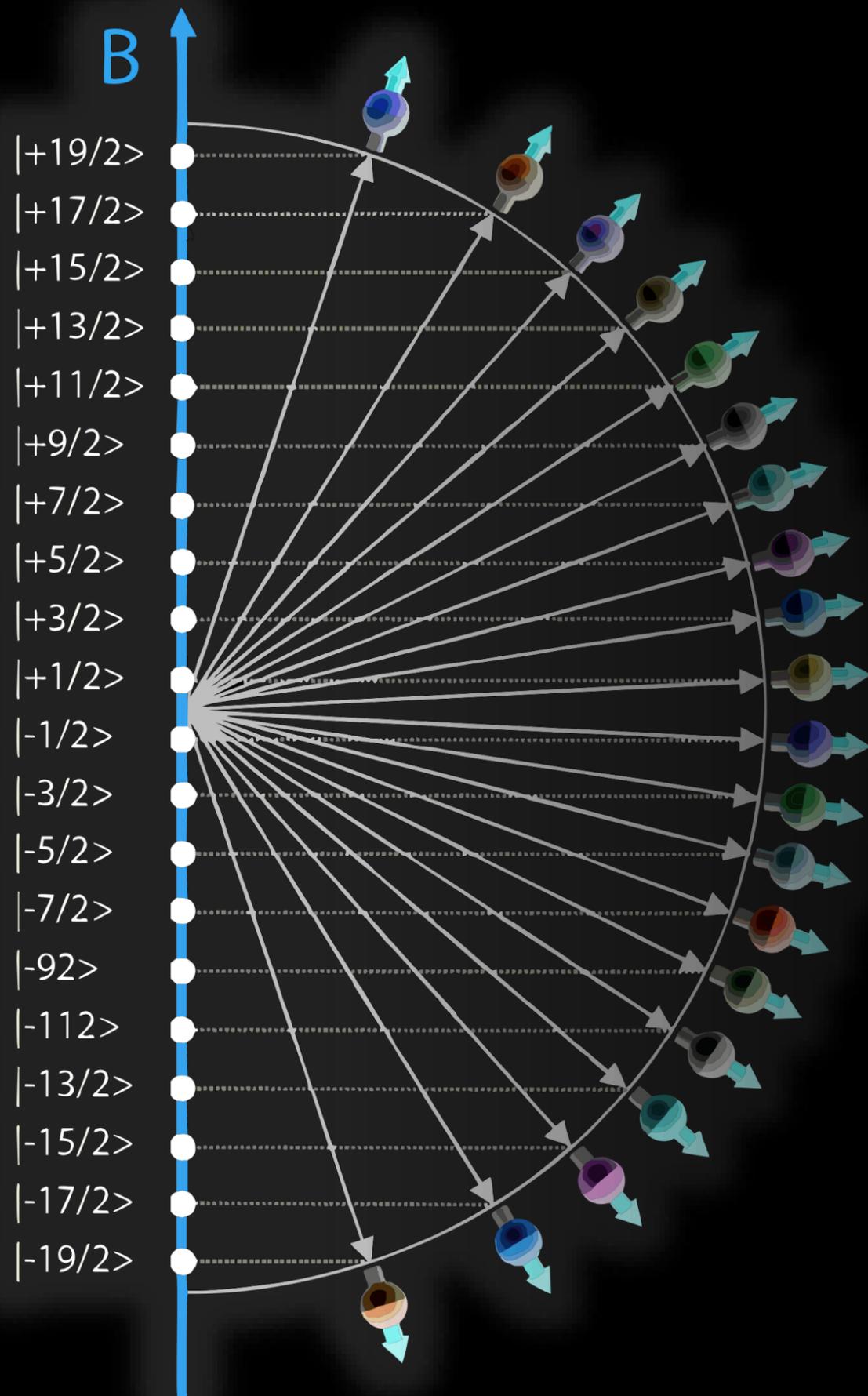
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This project aims to improve on our existing experiments by adding an extra stage in the process of cooling atoms, needed for subsecond generation of degenerate quantum gases. In particular, the student will develop and implement a laser at a narrow closed transition for erbium : 841nm.

You will learn:

- Laser Physics and how to build one
- How to build a stable optical setup
- Electronic control and stabilization





## Master Project

4. Distribution, amplification and fiber noise cancellation of a Hz-linewidth laser source at 1299nm

This project aims to interconnect our labs with an ultrastable laser working at the narrowest closed transition for erbium: 1299nm. Due to its stability and narrow linewidth, this laser can, amongst other things, be used to address any spin state within the manifold of erbium.

You will learn:

- Raman state transfer
- How to build a stable optical setup
- Electronic control and stabilization



# Contact Us

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[hagai.edri@uibk.ac.at](mailto:hagai.edri@uibk.ac.at)

## Bachelor Projects

1. Elementary excitations : testing 1940's theory via photon Bragg scattering on gaseous Bose-Einstein condensates (FF)
2. Is it really superfluid? The challenge of testing superfluidity in ultracold quantum gases (FF)
3. Quantum simulation with neutral atoms in optical tweezers (MM/HE)
4. Ultralong-range Rydberg Molecules: From Trilobites to Butterflies (MM)

## Master Projects

1. Build-up and Implementation of a 401nm laser system for transversal cooling of erbium (FF/MM)
2. Tunable 2D lattice for quantum gas microscopy at 532nm (FF/MM)
3. Build-up and Implementation of a narrow-line laser cooling system at 841nm (FF/MM)
4. Distribution, amplification and fiber noise cancellation of a Hz-linewidth laser source at 1299nm (FF/MM)