Dipolar Quantum Gases

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Institute for Experimental Physics and IQOQI

Theory Experiments

3 LABS and a THEORY TEAM

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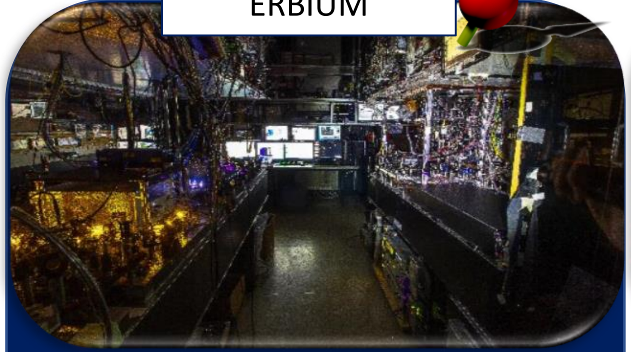
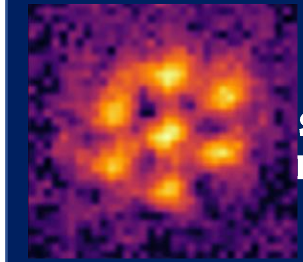
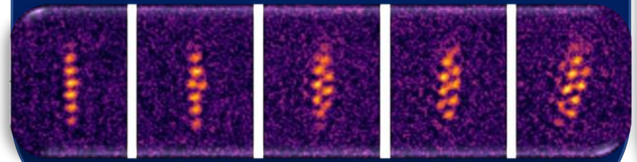
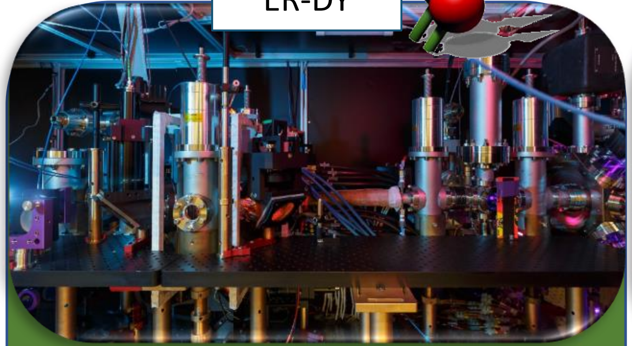


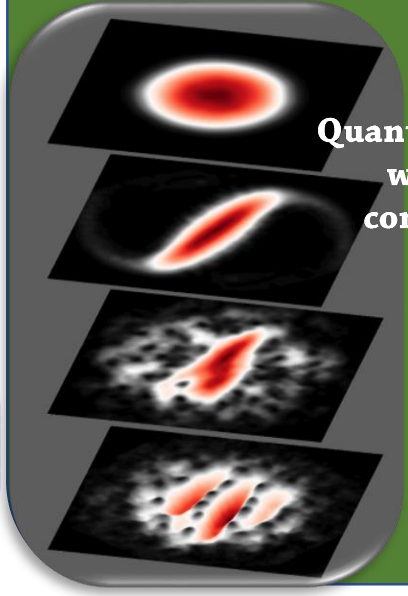


The discover of Supersolidity and Bloch Oscillations



ER-DY

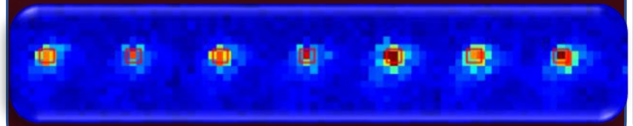




Quantum Vortices with high connectivity

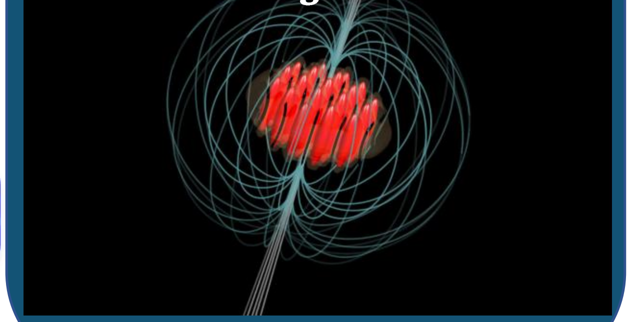
T-REQS

Single atomic magnet in an array of tweezers for quantum info



Theory

Simulation of the behavior of dipolar quantum gases



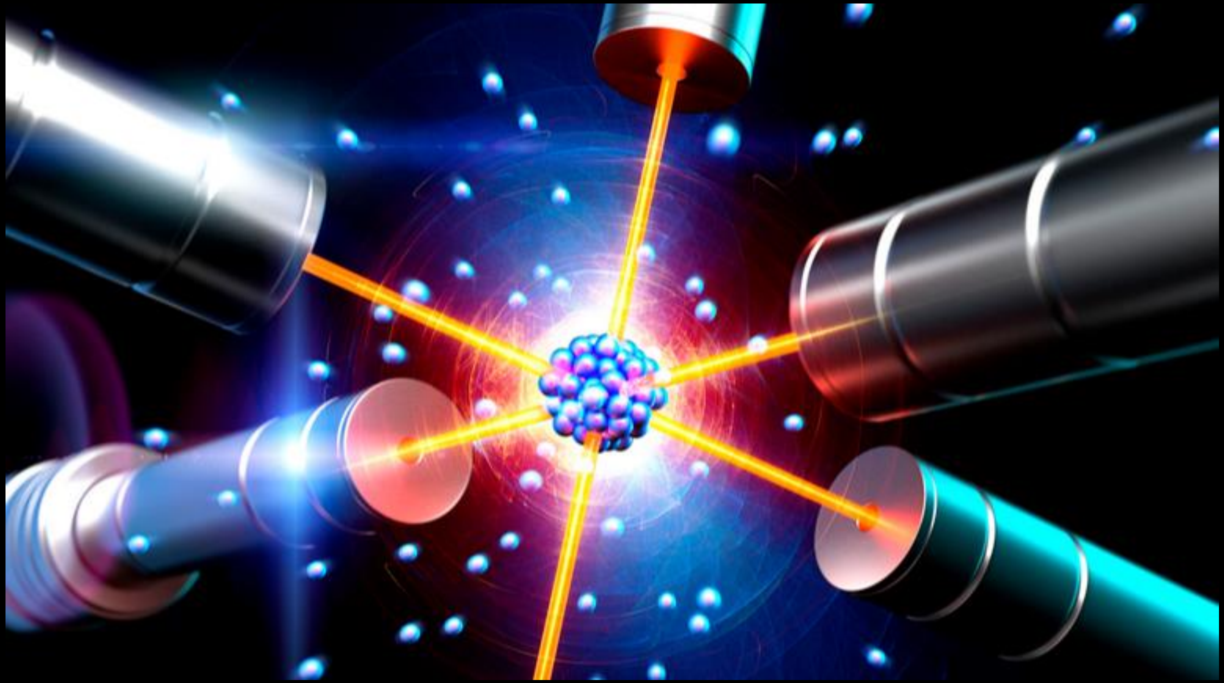
Bachelor Project

1. Ultra-fast production of degenerate gases

The exploration of the rich and novel properties of quantum gases such as Bose-Einstein condensates and Fermi gases critically depends on the capability of experiments to produce and study these gases. Quantum gases are extremely sensitive to perturbations, and measurements techniques are most often destructive, so that acquiring relevant data requires to repeat the experiment many times. While the standard procedure to produce Bose-Einstein condensates relies on thermalization process that last multiple seconds, cutting-edge techniques enable sub-second production of degenerate gases, which effectively enhances dramatically the quality and reliability of statistical measurements. The Bachelorarbeit will work out the basic principles of production of degenerate gases, from the standard evaporation in optical-dipole traps, to the sub-second production of BECs with narrow-line cooling. The Bachelorarbeit will also set-up and test a tunable and controllable frequency generator to optimize the production of a condensate of Dysprosium atoms.

You will learn:

- How evaporative and narrow-line cooling are used to create degenerate quantum gases
- How conservative and dissipative atom-light interactions co-exist in atomic gases
- How the interplay between two interactions can be tuned and controlled in the laboratory by setting up a tunable frequency generator



Credit: VENTRIS/Science Photo Library via Getty Images

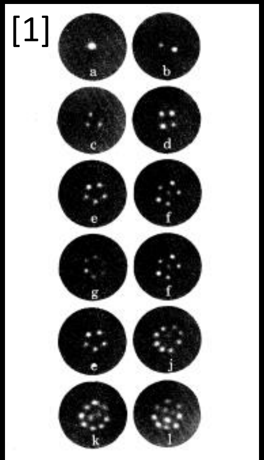
Bachelor Project

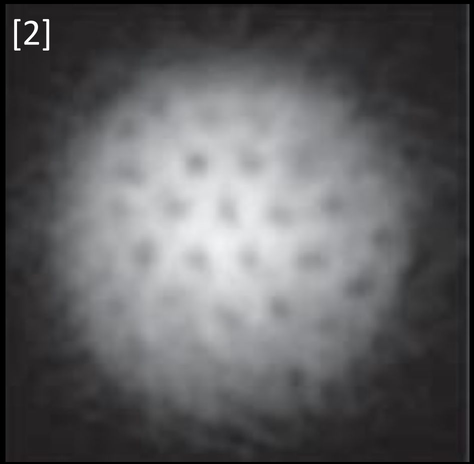
2. Understanding Vortices in Superfluid Systems

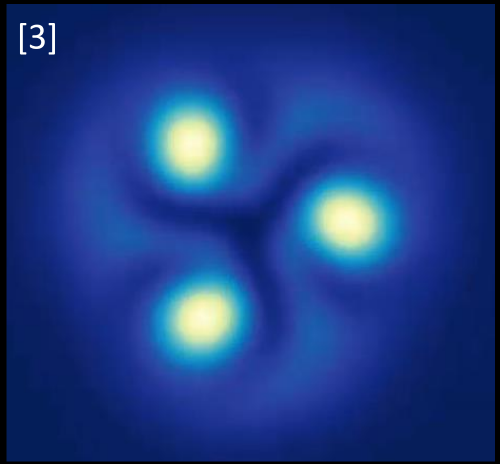
Superfluid systems, ranging from liquid helium to ultracold atomic gases, exhibit remarkable quantum phenomena such as frictionless flow and quantized vortices. These vortices, the superfluid analogs of tiny whirlpools, arise due to the quantum nature of these systems and serve as powerful probes of their underlying physics. This project focuses on exploring vortices in diverse superfluid platforms, including liquid helium, Bose-Einstein condensates, fermionic superfluids, and supersolids. The goal is to understand the similarities and differences in vortex formation, dynamics, and stability across these systems.

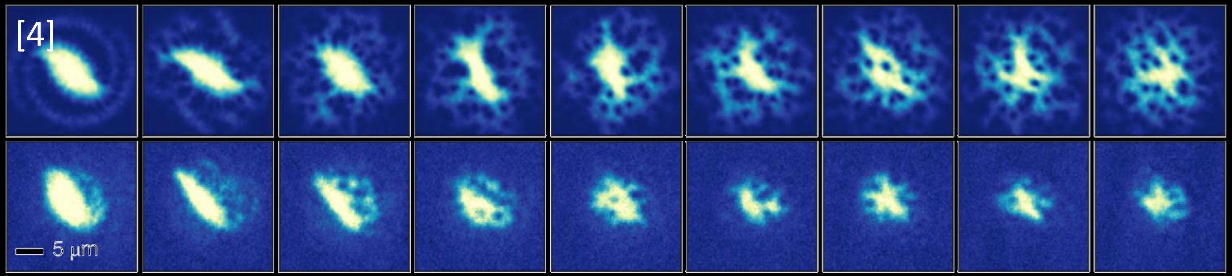
You will learn:

- The key properties of superfluid systems and how vortices arise from their quantum nature.
- The different vortex dynamics between liquid helium, ultracold bosonic/fermionic gases, and supersolids.
- The experimental and theoretical tools used to study and characterize vortices









[1] Yarmchuk, E., Gordon, M. & Packard, R., *Phys. Rev. Lett.* **43**, 214 (1979).
[2] Zwierlein, M., Abo-Shaeer, J., Schirotzek, A. *et al., Nature* **435,** 1047-1051 (2005)
[3] Casotti, E., Poli, E., Klaus, L. *et al., Nature* **635**, 327–331 (2024).
[4] Klaus, L. et al., *Nat. Phys.* **18**, 1453–1458 (2022)

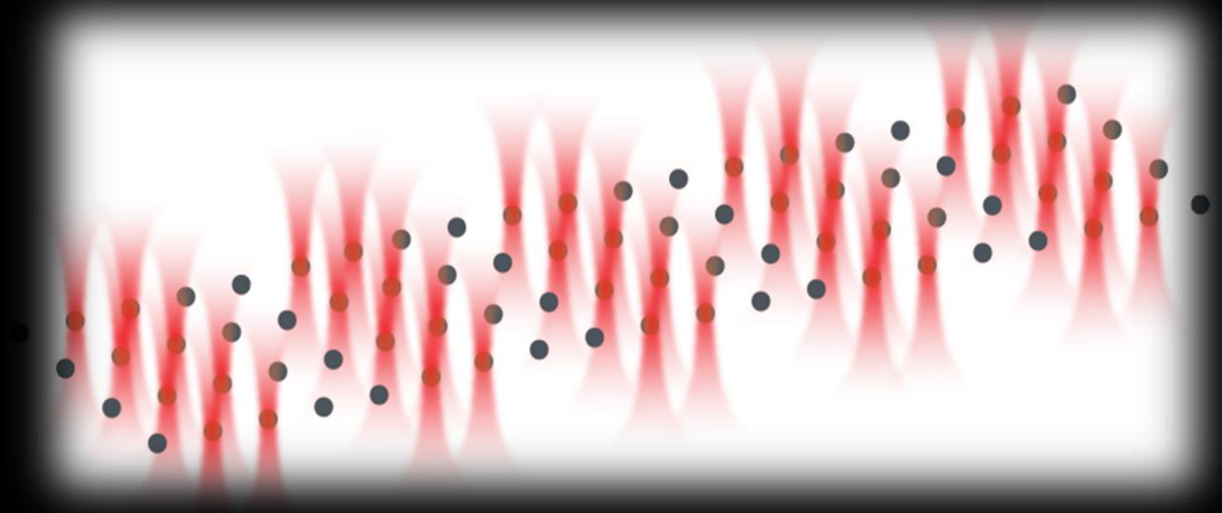
Bachelor Project

3. Quantum computing with neutral atoms in optical tweezers.

Quantum computing aims at solving computational problems that are intractable for classical processors, exploiting the quantum nature of atoms and of artificial systems with a similar internal energy structure. This project focuses on a specific platform, neutral atoms trapped in optical tweezers, and explores the implementation of qubits and qudits up to the state of the art achieved by recent experiments.

You will learn:

- What the building blocks of a quantum computer are, such as qubits, qubit gates, entangling gates and readout protocols.
- How those building blocks can be implemented in neutral atoms in optical tweezer arrays.
- How the performance of a quantum computer can be quantified and benchmarked.



Picture from Evered et al., 2023 (Nature)

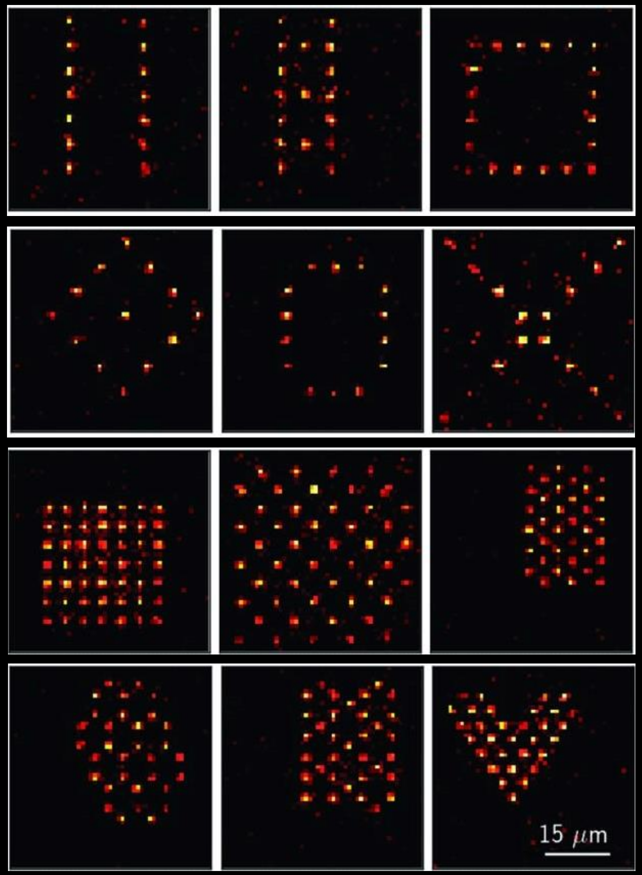
Bachelor Project

4. Controlling reconfigurable tweezer arrays

Tightly focused beams of light, known as optical tweezers, have fast become a leading method for trapping and moving single atoms, with broad applications in particular in the fields of quantum computing and simulation. This project focuses on the techniques to create and control reconfigurable tweezer arrays in 1D, 2D and 3D. The goal is to learn and understand the current state-of-the-art methods for single atom control as well as their concrete implementations into experiments.

You will learn:

- The various methods to prepare optical microtrap arrays in 1D, 2D and 3D.
- How to load single atoms into such tweezer arrays.
- How to dynamically rearrange single atoms to create defect-free configurations.



Picture from Barredo et al. Science (2016)

Bachelor Project

5. The dipolar supersolids: how solid are they?

Dipolar supersolids are quantum states of matter which have the frictionless flow of a superfluid while also behaving like a crystalline solid. These elusive states have had their superfluid nature rigorously tested, while its solid properties remain mostly unknown.

Classical solids can be characterized by their elastic moduli; quantities which measure the force required to elastically deform the solid. This project will explore the elastic moduli of the dipolar supersolids, and the associated elastic waves which propagate within them.

You will learn:

- How solids are defined, and the theory of elasticity used to characterize them.
- How supersolids differ from classical solids, and the equations which govern the behaviour of a supersolid.
- How to numerically simulate the propagation of elastic waves in ultracold dipolar supersolids.