Ultracold Atoms - Thywissen Group

Summer 2026 Undergraduate Research Projects

Overview

Our research group strives to address fundamental questions about many-body physics by studying a model system: neutral atoms at nanokelvin temperatures. A collection of thousands or millions of atoms are manipulated and probed while they are levitated inside a vacuum system by magnetic or optical traps.

To create an ultracold sample, we employ a wide range of techniques: lasers locked to an atomic resonance, high-power fibre lasers, electromagnets to produce magnetic traps, fast electronics, microwaves and radio waves, optical modulators of various types, and imbedded computing for sequencing. Data taken comes in the form of images: see the example below.

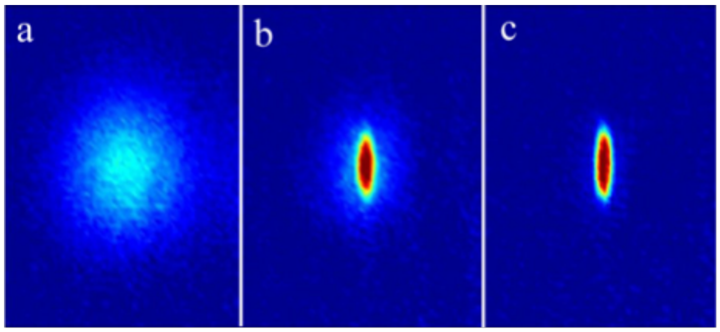

Figure 1. Absorption images of (**a**) a thermal gas; (**b**) a Bose gas at a phase transition; and (**c**) a nearly pure Bose-Einstein Condensate.

Project 1: Construction of a new BEC machine

We are looking for one or two summer students to help build a new experimental apparatus. This experiment will study tunnelling of atoms through barriers and probe how superfluids move in optical lattices. As a summer student in the group, you would learn about lasers, vacuum systems, electronics, and imaging systems. Your daily work would be under the guidance and supervision of graduate students. The goal of the summer would be to progress as far as possible towards Bose-Einstein condensation.

The regime we intend to study is deeply quantum-mechanical, so coursework in quantum physics would be required. Most important is a strong interest in experimental work. Laboratory work in an atomic physics lab involves intense hands-on experimental work; this project may involve vacuum systems, optics, CAD design, programming, high-current electronics, and testing. All summer students will be enrolled in the basic training course of the physics machine shop, if they have not already taken it for prior summer work.

Project 2: Phase-locked optical lattice

Overlapping laser beams make interference patterns, whose structure is controlled by the geometry, polarization, and relative phase of the beams. This project aims to move beyond the basic "square lattice" geometry to more interesting hexagonal order. The new technical aspect of a controlled hexagonal lattice is that the relative phase of perpendicular laser beams needs to be stabilized, thereby eliminating drift caused by the thermal fluctuations in optical fibres. Figure 2 shows an example of such a lattice; the exciting physics that results from it can be found here [on the arXiv].

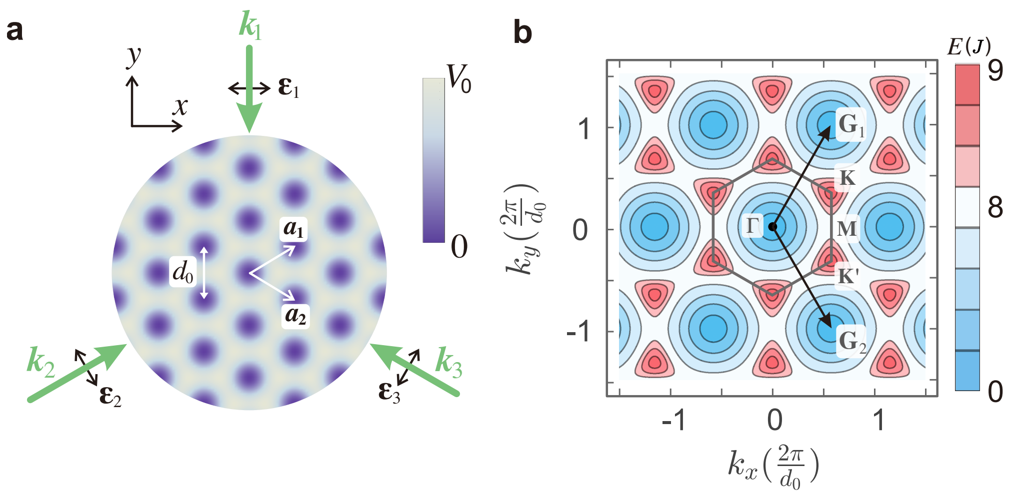

Figure 2. a, Three interfering blue-detuned laser beams create a triangular lattice with lattice spacing; the wave vectors of the beams are shown by the green arrows while the black arrows indicate the in-plane polarizations. In this blue-detuned lattice, the atoms sit around the zero-intensity points (purple regions). **b**, Tight-binding dispersion relation of the lowest band, with the hexagon outlining the first Brillouin zone. The inherent geometric frustration of the triangular lattice leads to two non-equivalent degenerate maxima at the K and K′ points. [from Hasan et al, arXiv: 2509.20352].

Project 3: Correlations between fermions in a lattice

Since 2015, we have been able to image individual fermions in a single plane of an optical lattice. For various measurements (such as conductivity), we have taken thousands of images such as the one shown in Figure 3 below. However, only a rudimentary analysis has been made: we have quantified the dynamics of average atom positions and have fit the overall shape of the cloud to a thermal model to determine the temperature of the cloud. This USRA project is an opportunity to "data mine" our image bank for further information. For example, atoms may tend to avoid each other due to Pauli pressure; or conversely, tend to "clump" due to attractive interactions. Is there a signal? The goal of your project would be to find out, understand the limitations of data so far, and help point us towards new measurements.

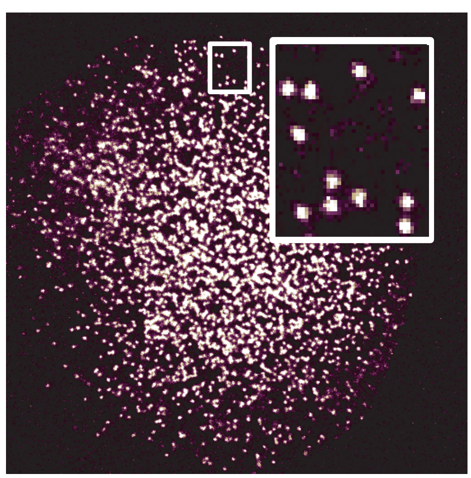

Figure 3. In-situ image of fermionic potassium atoms in an optical lattice. The overall scale of this image is roughly 100μm. **Inset**: a magnified portion of the image shows more clearly that each individual atom appears as distinct object in the image.

Contact & additional information

For more information, visit https://www.thywissenlab.ca/, which includes recent publications, a list of former summer students (and what they are doing now), current group members, and contact information.