Ultracold Atoms -- Thywissen Group

NSERC Undergraduate Student Research Award (USRA) positions - Summer 2021

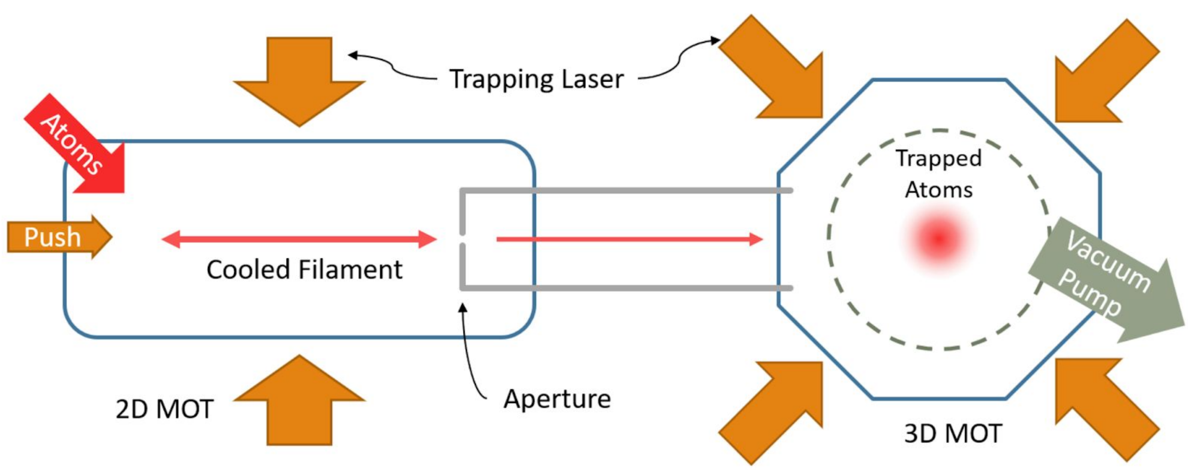
Project overview

We have a fantastic summer USRA project this year! We are looking for one or two students who want to dive into the technical development of a laser cooling and trapping experiment.

Over the last two years, a series of great undergraduates have built a new laser cooling setup in our lab. Those students have all graduated (and gone onto physics graduate programs around the world), so we now have an opening on this experiment! Your project would be to recover an operational status of the machine (more details on this below), assess the performance, design the next-generation upgrade, and start towards the implementation of that upgrade.

In the long term, this experiment would eventually study the way superfluids move in optical lattices. In the shorter term, we are using it as a testbed to advance the way in which ultracold atoms are produced in our lab, by using enhanced laser cooling.

The 2D MOT experiment



Schematic diagram of the laser cooling experiment for this USRA project.
[source: Hanzhen Lin, B.A.Sc. thesis]

The illustration above shows a diagram of the system at the heart of this project. Atoms are collected from teh background vapour in the 2D MOT chamber, forming a filament of cold atoms. The atoms in this filament have a temperature of less than 1 millikelvin, because of the laser cooling in the MOT (which stands for <u>m</u>agneto-<u>o</u>ptical <u>t</u>rap). The atoms are pushed through a small aperture into a second chamber, in which they are re-trapped into a 3D MOT.

The vacuum pressure in the second chamber is lower so that the atoms are further decoupled from the walls, and can stay trapped longer.

The good news is that this experiment works! Here is an image of the 2D MOT:

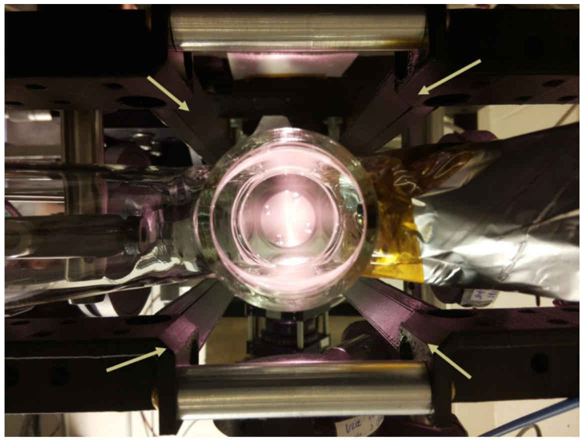
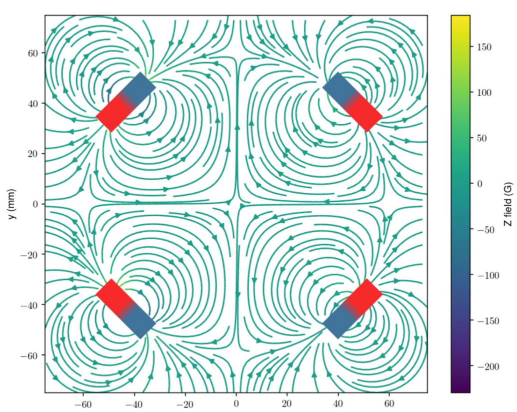


Image of the 2D MOT from the “push” window. The pink-ish glow is from potassium atoms that are fluorescing in the vacuum. [source: Hanzhen Lin, B.A.Sc. thesis]

Experience

This project requires the integration of several systems, whose variety provides a great laboratory experience. The 2D MOT and 3D MOT traps require a combination of correct magnetic fields and correct laser light. That atoms must be trapped in sufficiently good vacuum so that they are laser cooled faster than they are sand-blasted by background gas impurities. There are electronics behind everything: laser servo locks, microcontrollers for sequencing, power supplies and frequency generators. Shaping and control of light uses lenses, waveplates, optical isolators, and modulators. Data is taken using a triggered camera, analyzed with image processing code. Of course, we write all this code ourselves :-)

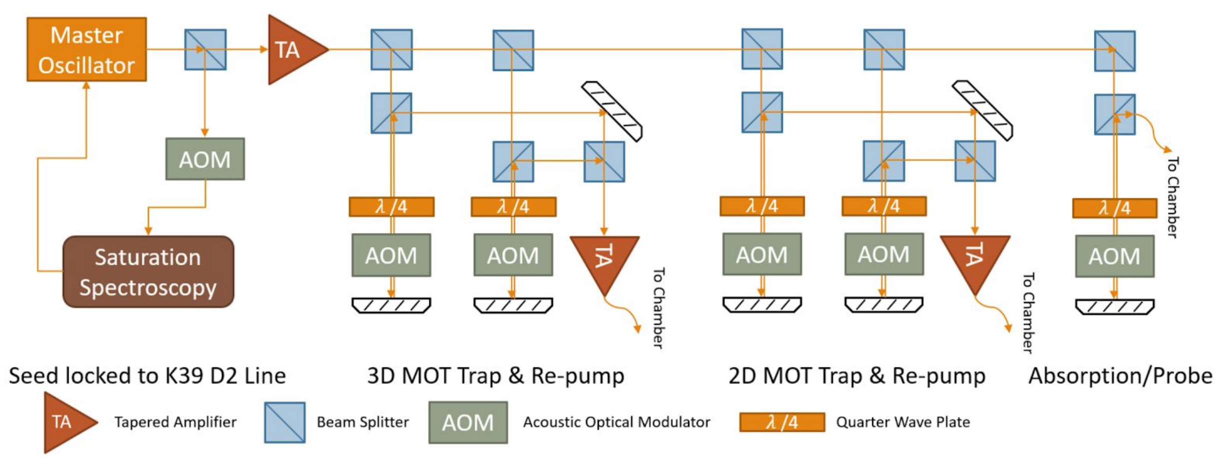


Magnetic field lines for the 2D MOT
[source: Hanzhen Lin, B.A.Sc. thesis]

The following paragraphs give a bit more detail on two aspects of the machine. The M in “MOT” is “magneto-”, and refers to the magnetic fields that tune atoms so that they are pushed by laser beams into the middle of the field. When combined with the cooling action of the lasers, this produces clouds that are both dense and cold (compared to the background vapour). “Dense” is a relative term however: here we mean that there is an atom in every cubic micron, i.e. one atom per cubic wavelength of light. That is still extremely dilute when compared to a solid, which would put 10 billion atoms in the same volume.

In the 2D MOT part of this experiment, the magnetic fields are produced by permanent magnets, placed in 3D-printed holders The calculated fields are shown on the previous page. Although you will not be asked to replace these magnets (they work very well), they are a nice example of a USRA project that used first-principles design to make fabrication plans, test the object made, and implement the solution.

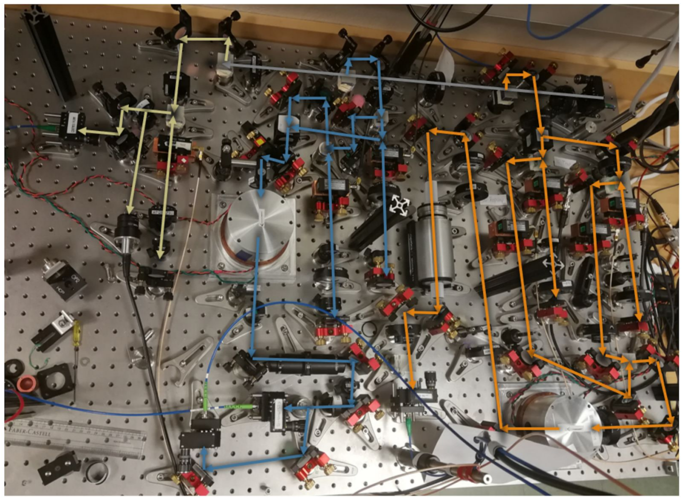
The laser system is the most demanding aspect of the experiment, but also the source of the revolutionary ability of lasers to cool things. This may seem contradictory at first: after all, sunlight and fire light clearly warm our skin, and in sci-fi movies, lasers blow things up. (They don’t, really.) So, how could lasers cool things? The reason is that all the photons in a laser beam are identical: the same frequency, polarization, and direction. Just as heat=entropy=randomness, cold=order. Laser cooling works by transferring some of the randomness in the atomic velocity distribution to the light field, leaving a more ordered (and therefore colder) system of atoms. The second law of thermodynamics is not violated because the entropy of the photons was increased. A schematic diagram of the system we use for light generation is shown here:



Schematic of the laser system
[source: Hanzhen Lin, B.A.Sc. thesis]

The oscillator source (“master oscillator”) is one of the elements of this system which needs to be replaced. Under the supervision of graduate students and postdocs in the group, you would learn how to build a laser and assess its performance and power output. The key to stability is a feedback servo (a “laser lock”) that compares the laser frequency to an atomic reference, and then applies a correcting voltage back to the laser, in order to keep it at the desired wavelength. Once swapped into this experimental setup, it would be able to use the already existing amplifiers etc to generate the correct light for the 2D MOT and 3D MOT.

In reality, there are a lot of lenses and mirrors not shown in the schematic: see image below. Learning how to align such a system is one of the things you'll learn on this project.



Optical table for injection of Tapered Amplifiers (TAs)

Level

Students at any level are welcome. The regime we study is deeply quantum-mechanical, so some background in quantum would be helpful, but not required. More important is a strong interest in experimental work. Daily work in a lab involves electronics, optics, design work, programming, construction, and testing. All USRA students in the group will be enrolled in the basic training course of the physics machine shop, assuming they are available; as well as all requisite safety training for working in a lab.

The Thywissen group

Our research group tries to understand fundamental questions about materials by studying a model system -- neutral atoms at nanokelvin temperatures. A collection of thousands to millions of atoms are manipulated and probed while they are held in either magnetic or optical traps, inside an ultrahigh-vacuum system.

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