Ultracold Mixtures of Lithium and Ytterbium Atoms

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Why Lithium and Ytterbium?

1) Lithium is a fermion*
2) Ytterbium is a boson*
3) They have a large mass mismatch
4) They respond very differently to magnetic fields

*This is a lie. In fact lithium and ytterbium both come in both fermionic and bosonic isotopes. We just happen to use fermionic lithium and bosonic ytterbium.

Fermions and Bosons

Two fermions *cannot* both have identical properties; they must differ in position, velocity or internal state.

Bosons *can* have identical properties; in fact one boson in a particular state makes it *more* likely for another boson to be in that state!.

Masses and Magnetic Fields

We plan to make molecules of ytterbium and lithium; these molecules are expected to have interesting electronic properties, partly because ytterbium has 29 times the mass of lithium.

Ytterbium is completely insensitive to magnetic fields while in its ground state; lithium is not. This gives us a way to independently control the two ground state atoms.

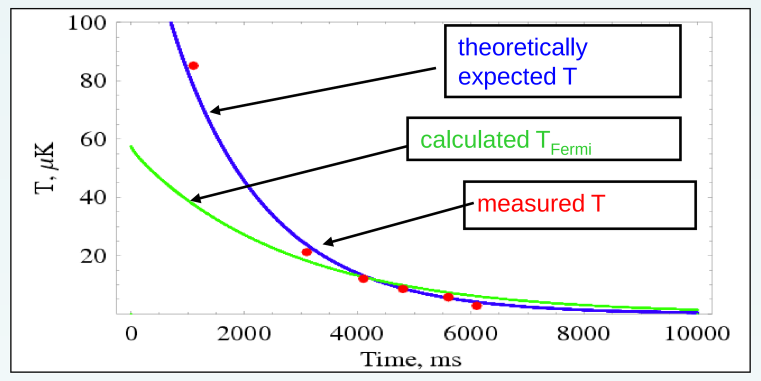
Why Ultracold?

Matter displays interesting properties at very low temperatures: Bose-Einstein condensates, degenerate fermi gases, Bardeen-Cooper superconductivity, and mott insulator phases to name a few. We'd like to investigate many of these behaviors, thus we require ultracold temperatures.

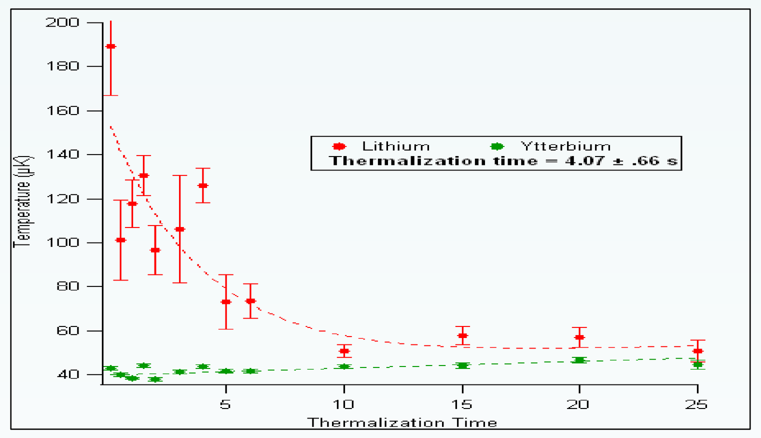
We'd also like to perform a variety of precision experiments: the search for an electron electric dipole moment, and variations in the fine structure constant. These experiments require ultracold temperatures in order to see any appreciable effects.

How to Get Ultracold?

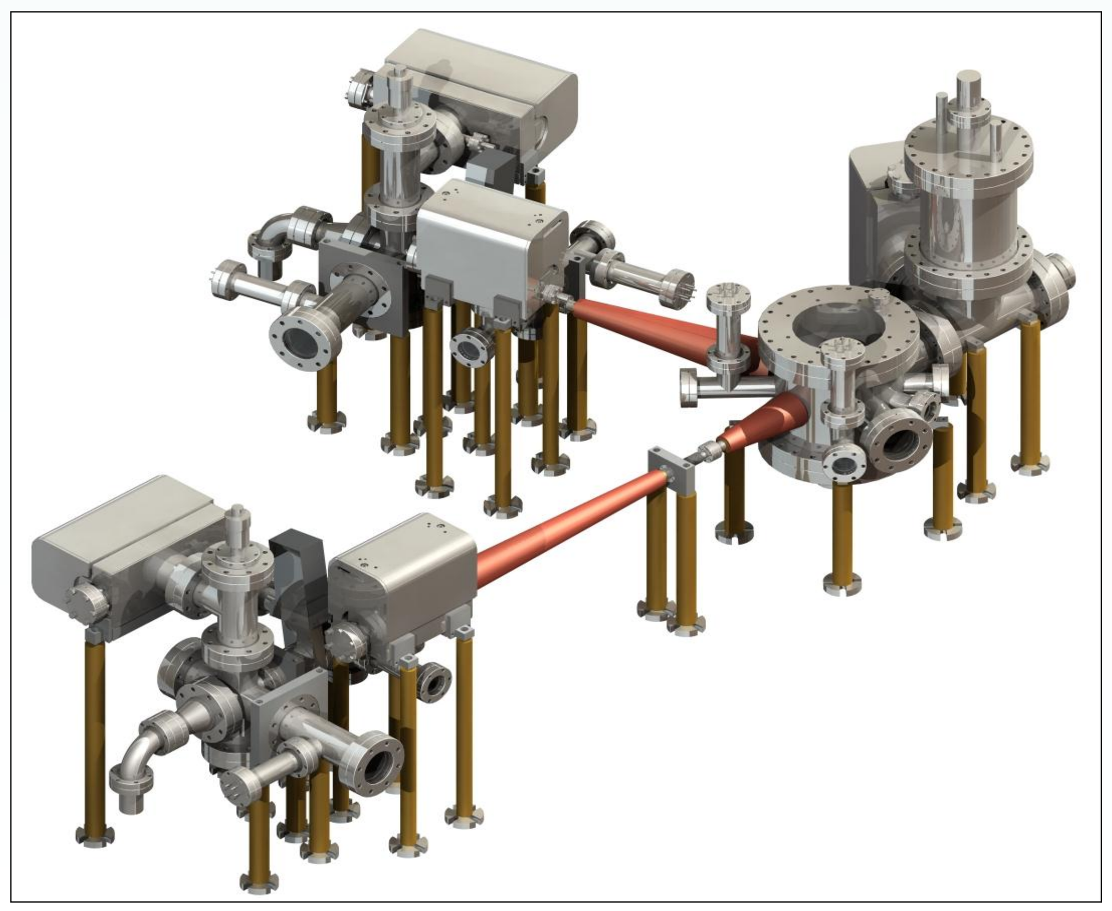
To get ultracold lithium and ytterbium, we start with an ultra-high vacuum chamber (10^{-10} Torr) to reduce collisions with hot background gases. The vacuum is fed by ovens (~400°C) of gaseous lithium and ytterbium. These beams are cooled from 1500m/s to 50m/s by a Zeeman slower. 50 million (3 million) Lithium (Ytterbium) atoms are then trapped in a Magneto-Optical Trap at 400 (30) microkelvin. Finally, the atoms are transferred to an optical dipole trap. We can then forcefully evaporate the sample to achieve nanokelvin temperatures (at the cost of total atom number).



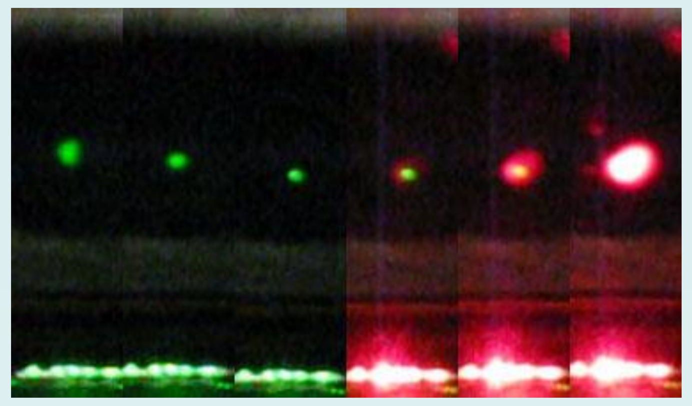
Li evaporation in the ODT



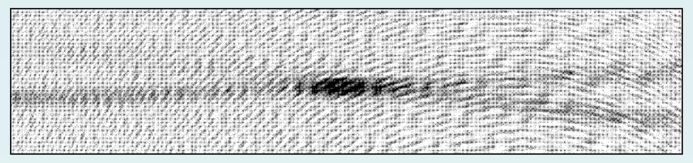
Thermalization of Li and Yb in the ODT



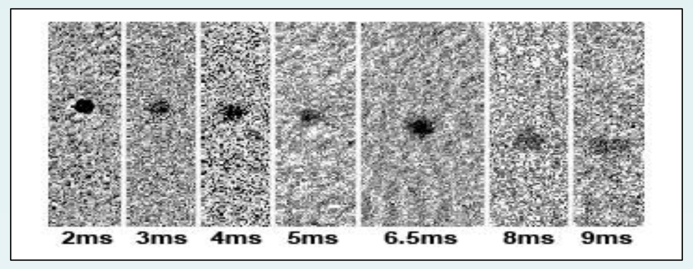
A model of the apparatus we use.



Loading the ytterbium and lithium MOTs



Absorption Image of the ODT



Temperature measure by time of flight

Magneto-Optical Traps

A MOT uses six slightly detuned laser beams pointed at the center of the vacuum chamber from the top, bottom, left, right, front, and rear. If an atom moves away from the center of the trap, a magnetic field causes the laser beam coming from that direction to come into resonance with the atom; the atom absorbs a photon from that beam, and gets kicked back towards the center of the trap.

Optical-Dipole Traps

An optical-dipole trap functions by using the focus of a powerful laser to create a strong electric field. The electric field polarizes the atoms, which are then attracted to the most intense location of light.

Absorption Imaging

Shining resonant light on the atoms causes some of that light to be absorbed; we can take a picture of that light and see the shadow cast by the atoms. How dark that shadow is determines how many atoms there are.

Measuring Temperature

Temperature can be measured by a time of flight experiment. The atoms are dropped out of the trap and allowed to expand freely for some amount of time after which we take a picture of them. The size of the atom cloud as a function of the expansion time gives the temperature.

Evaporation

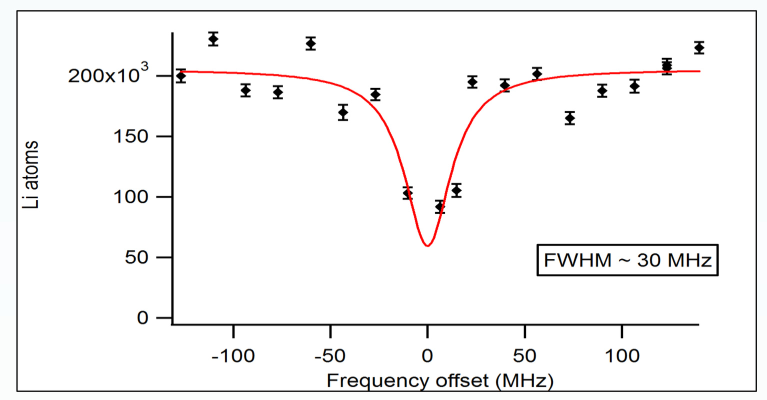
By reducing the power in the optical-dipole trap, atoms are less strongly attracted to the focus of the laser beam, and the more energetic (hotter) atoms escape the trap leaving the cooler atoms behind.

Thermalization

Li and Yb are loaded into the ODT at different temperatures. After a while, they will thermalize with each other and become the same temperature. How long this takes gives us important information about the interactions between the atoms.

Making Molecules

A photon of a precise frequency excites two ground state atoms into a high vibrational state of a molecule. Finding the frequency of these photons is the first step to further work with molecules. These excited molecules rapidly decay into lower energy states and become lost from the trap. Therefore, we can find these resonances by scanning the frequency of the light and looking for atom loss in our trap.



Resonance shape for a Li_2 molecule; LiYb molecules are next.

The group of intrepid physicists