Quantum Mixtures of Lithium and Ytterbium

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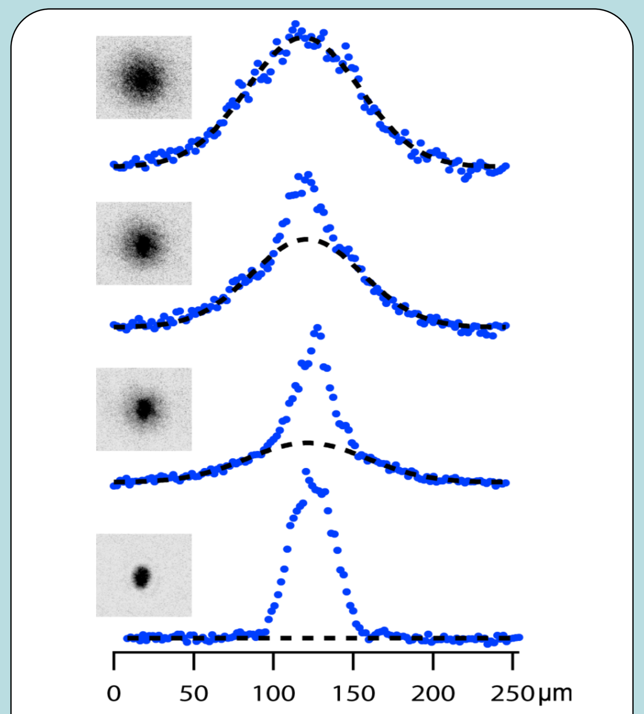
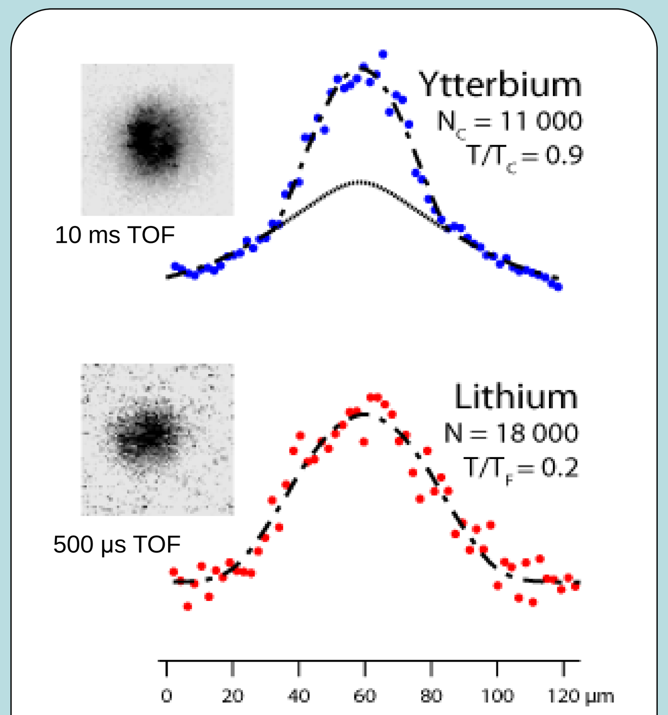
Quantum Degenerate Mixtures

We evaporatively cool Yb in an optical trap; Li is cooled sympathetically. We achieve Bose-Einstein condensation in Yb and deep Fermi degeneracy in ^{6}Li.

A. Hansen *et al.*; PRA 84, 011606(R) (2011)



^{174}Yb absorption images after 12ms expansion time. We achieve pure BECs of $> 2 \times 10^5$ atoms (the pure BEC in this image is 160 000 atoms).



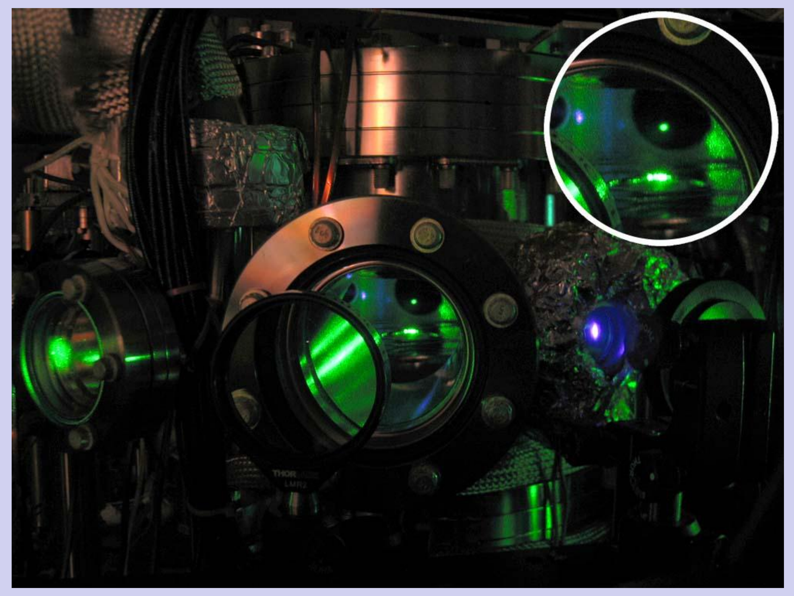
Simultaneous degeneracy. Insets - integrated density profiles. Plots - narrow cross-sections, fit to Thomas-Fermi model.

We also cool ^{173}Yb to Fermi degeneracy; make Fermi-Fermi mixture of Li & Yb.

Introduction

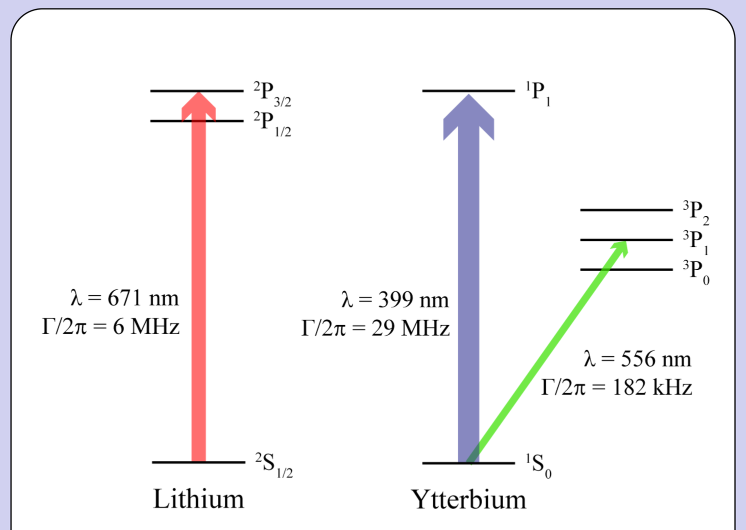
We simultaneously trap ultracold clouds of lithium and ytterbium atoms, and cool both species into the quantum degenerate regime.

We measure interspecies interactions and study superfluid properties. We also aim to prepare and study paramagnetic, polar Li-Yb molecules.

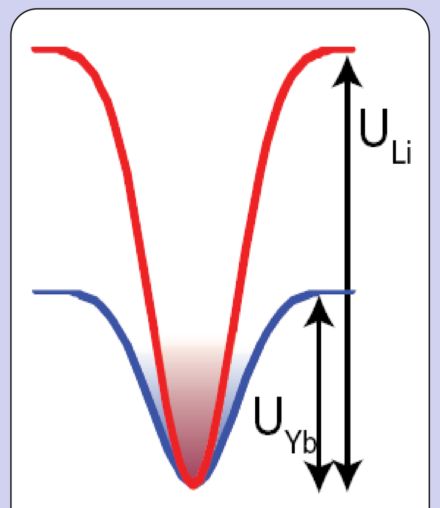


Yb magneto-optical trap (MOT) (green dot at center)

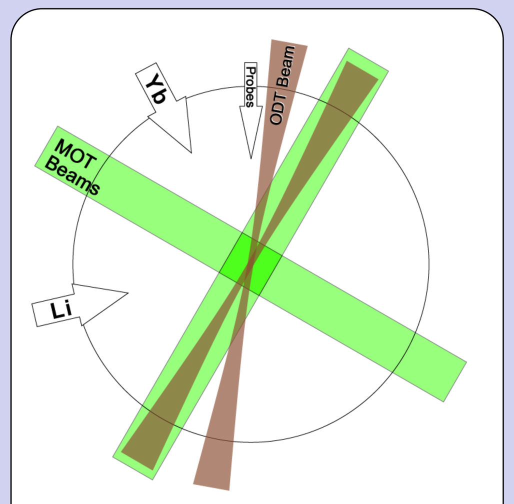
Experimental Setup



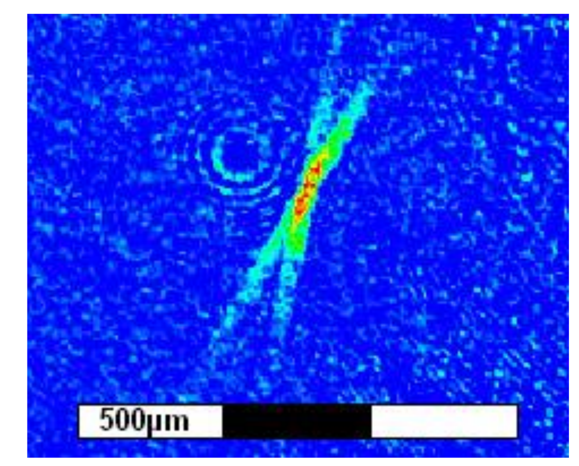
Energy levels of lithium and ytterbium relevant for laser cooling and absorption imaging. We routinely use ^{173}Yb (fermion) or ^{174}Yb (boson)



Optical potentials for Li and Yb at equal (high) trap power. U_{Li}/U_{Yb}= 2.3, ω_{Li}/ω_{Yb}= 8



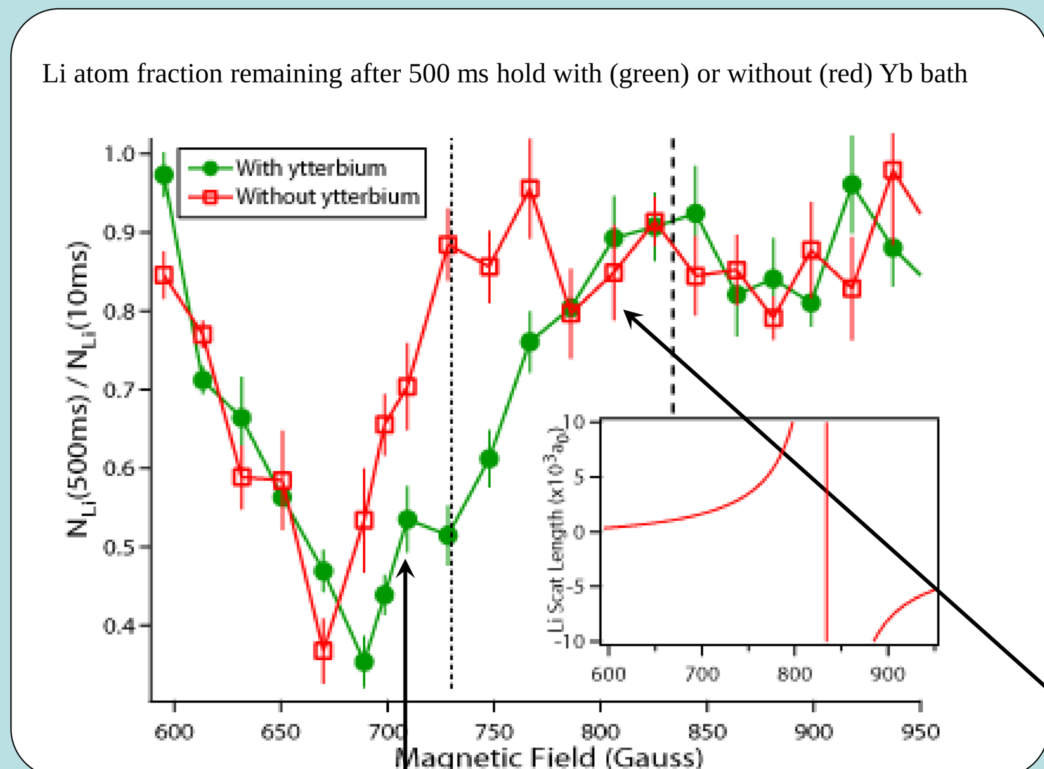
Top-down schematic of vacuum chamber (vertical beams omitted for clarity).



False-color image of ^{174}Yb immediately upon load into crossed ODT.

Li Feshbach molecules in a Li-Yb Mixture

We investigate the effect of a third, non-resonant component in a 2-spin-state Feshbach-resonant mixture.

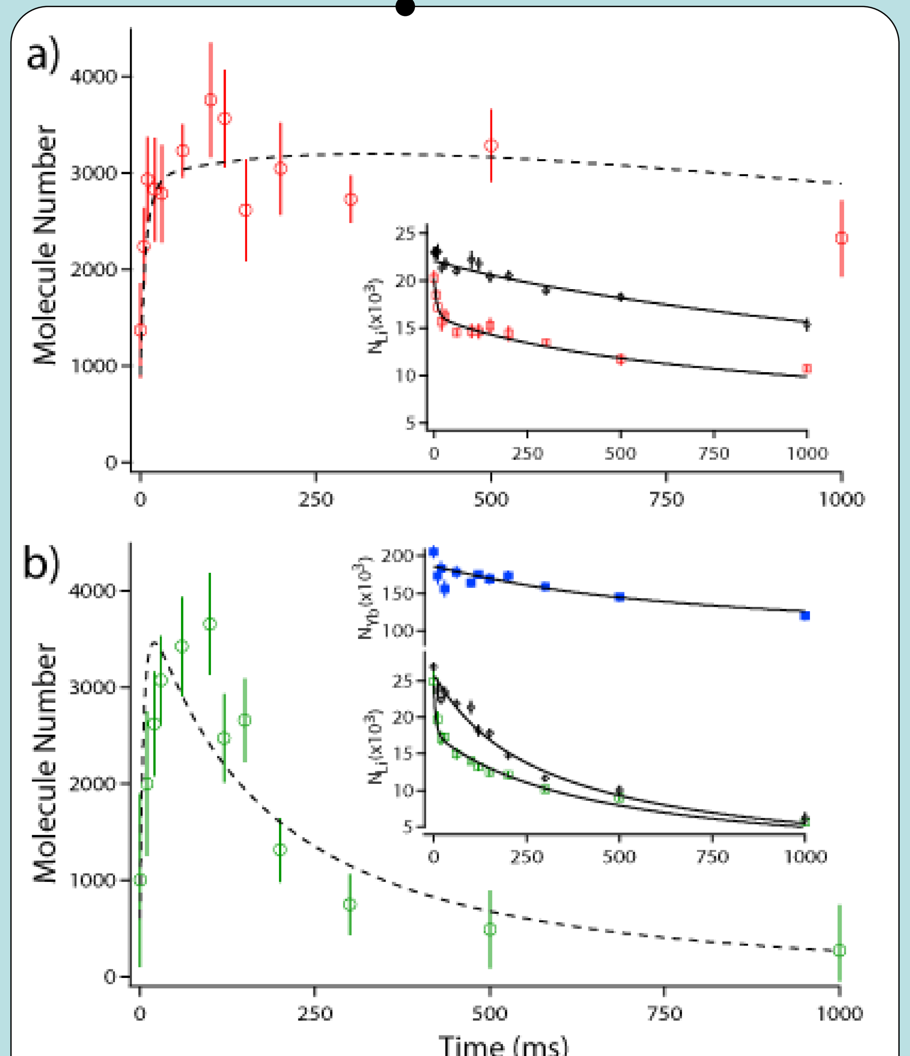


We study the formation and stability of weakly bound Feshbach molecules in the presence of a bath of Yb atoms at a range of magnetic fields, and compute the rates of the chemical processes involved.

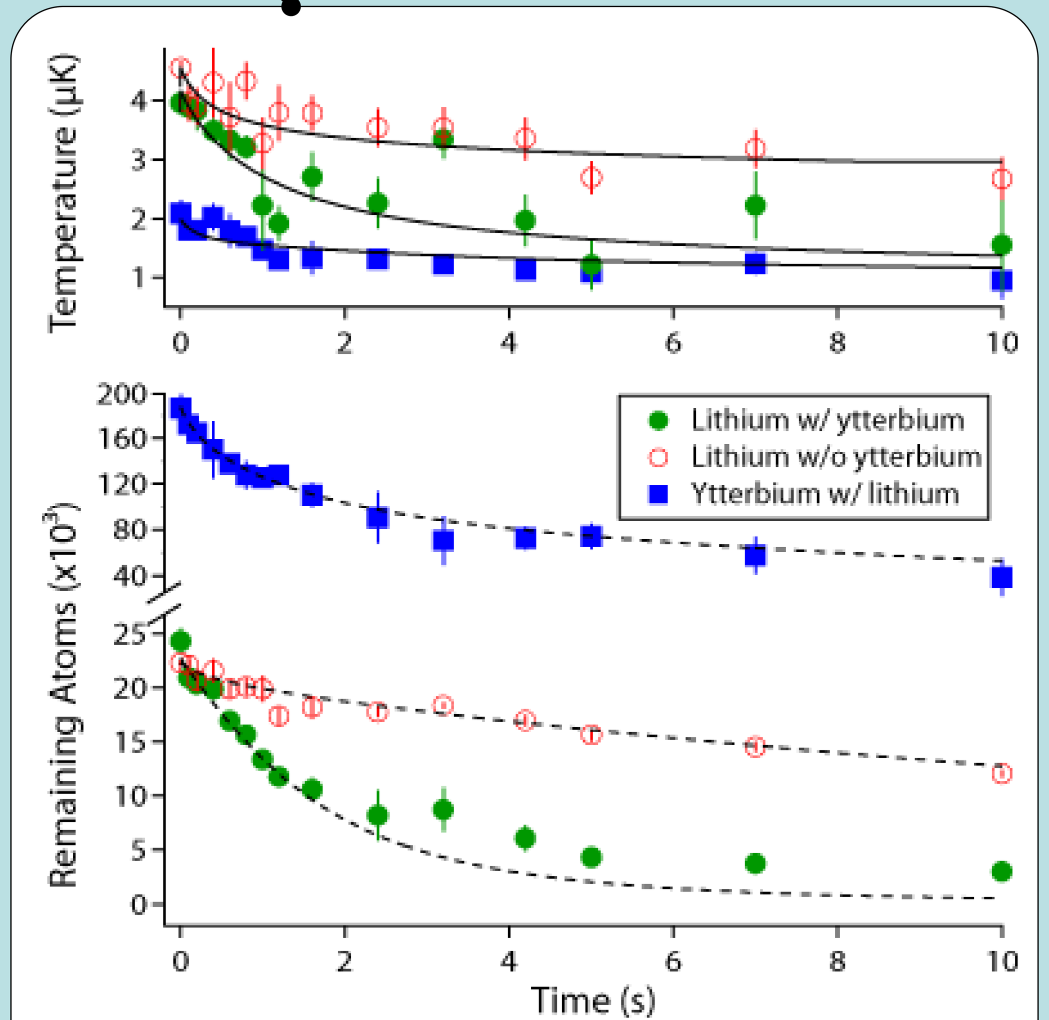
A. Khramov *et al.*; 1207.2187

$$\mathrm{Li}|1\rangle + \mathrm{Li}|2\rangle + \mathrm{Li} \rightleftharpoons \mathrm{Li}_2^s + \mathrm{Li} \quad (+\epsilon_B) \quad \text{(I)}$$
$$\mathrm{Li}_2^s + \mathrm{Li} \rightarrow \mathrm{Li}_2^d + \mathrm{Li} \quad (+\epsilon_D) \quad \text{(II)}$$
$$\mathrm{Li}|1\rangle + \mathrm{Li}|2\rangle + \mathrm{Yb} \rightleftharpoons \mathrm{Li}_2^s + \mathrm{Yb} \quad (+\epsilon_B) \quad \text{(III)}$$
$$\mathrm{Li}_2^s + \mathrm{Yb} \rightarrow \mathrm{Li}_2^d + \mathrm{Yb} \quad (+\epsilon_D) \quad \text{(IV)}$$
$$\mathrm{Li}|1\rangle + \mathrm{Li}|2\rangle + \mathrm{Yb} \rightarrow \mathrm{Li}_2^d + \mathrm{Yb} \quad (+\epsilon_D) \quad \text{(V)}$$

Chemical processes near 700G. Processes (1, 3) yield trapped Feshbach molecules, while (2, 4, 5) lead to highly energetic products, which escape the trap.

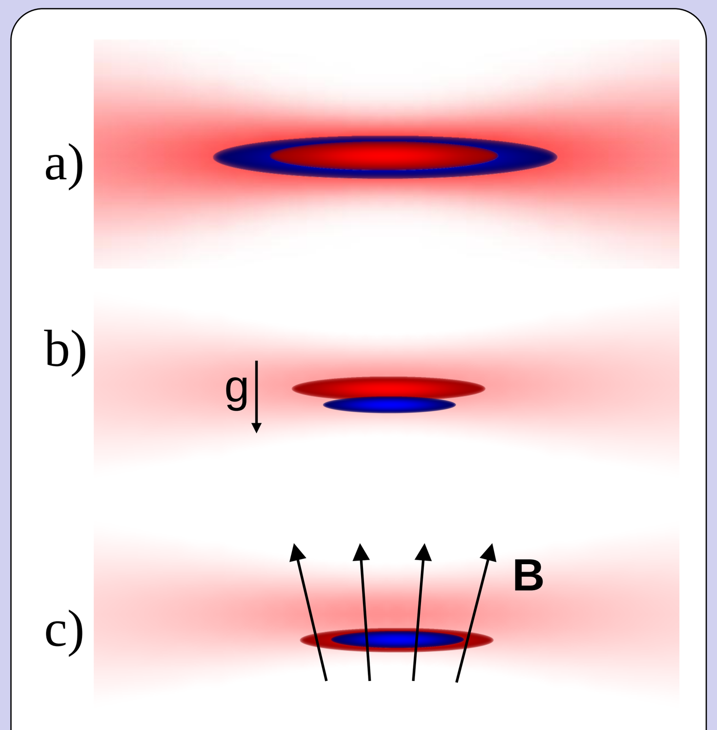


708 G: Feshbach molecule number vs time for Li, without (a), or with (b) presence of Yb bath. Insets show behavior of Li atoms+molecules (black), atoms only (red, green) and Yb atoms (blue).



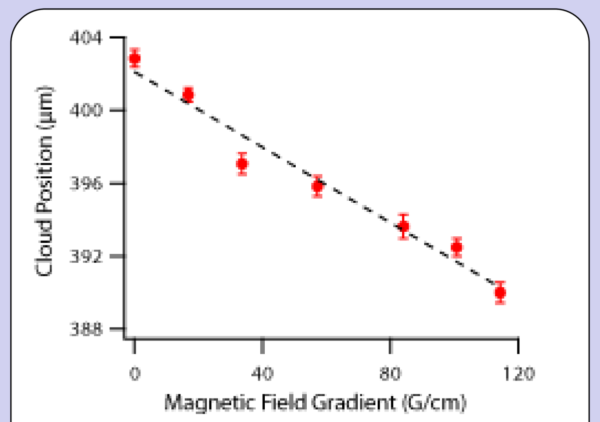
810 G: atom number evolution for Yb (blue), and Li in presence (green) or absence (red) of Yb bath. Temperatures in inset. Slow inelastic loss rate allows Li and Yb to thermalize

Species-selective Control

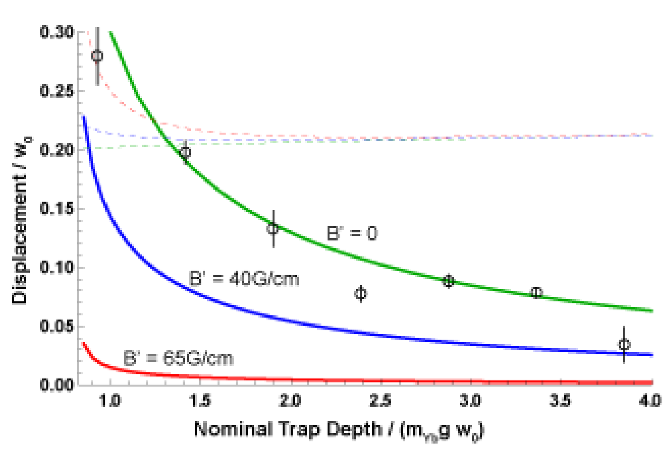


a) Li (red) and Yb (blue) collocated at high ODT powers.
b) At low powers Yb experiences gravitational sag.
c) A magnetic gradient shifts Li to overlap with Yb.

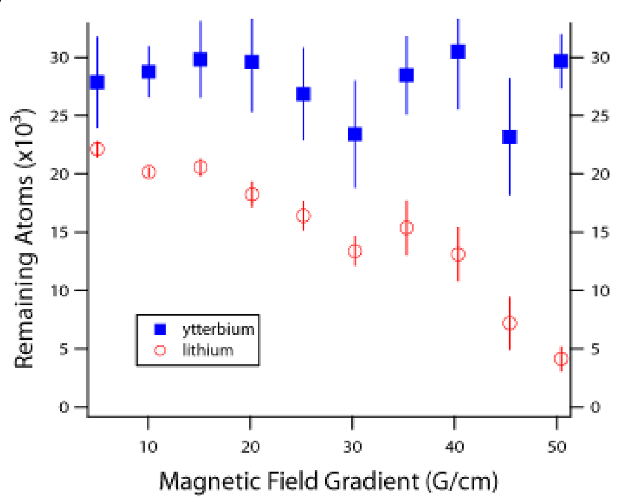
Cloud separation due to gravity at low trap depths reduces inter-species interactions we wish to use and study. We are able to compensate by species-selective spatial control of the clouds with a magnetic gradient. This technique may also be used to microscopically probe properties of the ^{6}Li Fermi gas with a small Yb sample.



Movement of ^{6}Li cloud with gradient at 530 G, intermediate trap depth



Relative displacement of ^{6}Li and ^{174}Yb (solid lines) and sum of individual cloud sizes (dashed lines) versus nominal trap depth. Black circles indicate measurement of ^{174}Yb sag relative to unshifted ^{6}Li cloud. Axes are scaled by w_0 (waist), 26 µm



Fermi-degenerate ^{6}Li in a tilted trap with low trap depth (red). Atoms are rapidly lost as the trap depth U decreases below E_F. Yb (blue) is unaffected

Future Experiments

Interspecies Feshbach Resonances

- Narrow Feshbach resonances have been predicted for the ^{6}Li-^{173}Yb combination (D. Brue and J. Hutson, (**PRL 108, 043201 (2012)**).
- Predicted position (width): 960 G (0.8 mG) or 1600 G (2.8 mG) depending on sign of scattering length
- Our apparatus allows bias fields up to 1700 G atom lifetimes of ~30s. We have initiated preliminary atom loss spectroscopy in the predicted regions.
- Explore combination of Li and a metastable magnetic state of Yb ($^3P_2$)

Mixtures and Molecules

- Search for photoassociation resonances and optical Feshbach resonances in the Li-Yb system
- Tunable Li-Yb interactions may allow for studies of new Efimov states and strongly interacting mass-mismatched fermions
- Yb as an impurity probe of the BEC-BCS crossover in Li

LiYb on a Lattice

- Create gas of polar molecules in optical lattice
- Investigate the collisional and chemical properties of LiYb. Role of the electronic spin degree of freedom.
- Quantum simulation of lattice spin models. (**A. Micheli *et al.* Nature Physics 2, 341 (2006)**)
- LiYb may be a good candidate for an electron electric dipole moment search, providing a sensitive test of time-reversal symmetry.
- Lattice-confined quantum bits for scalable quantum computing schemes (**L. Carr *et al.* New J. Phys 11, 055049 (2009)**)

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