Quantum Degenerate Mixtures of Lithium and Ytterbium

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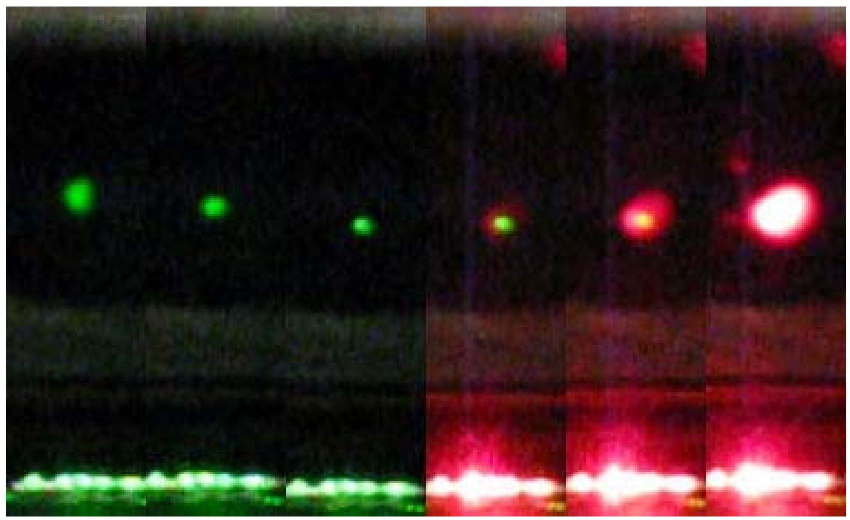
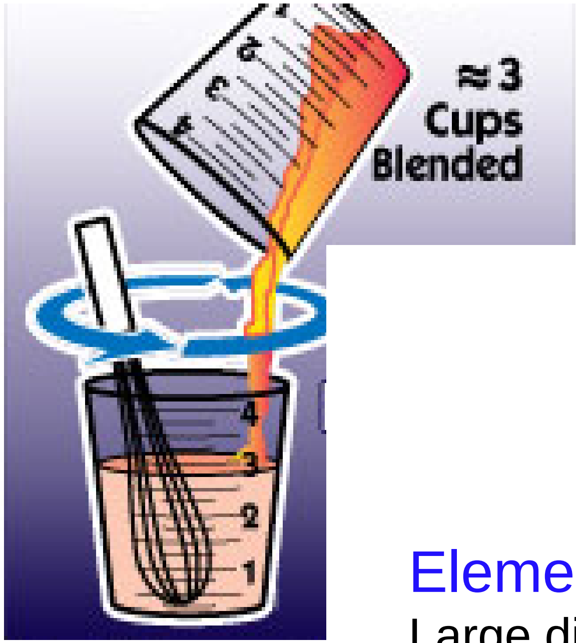


Mixtures

Spin Mixtures

Distinguishability for technical (cooling) and scientific (strong interactions & polarized gases)



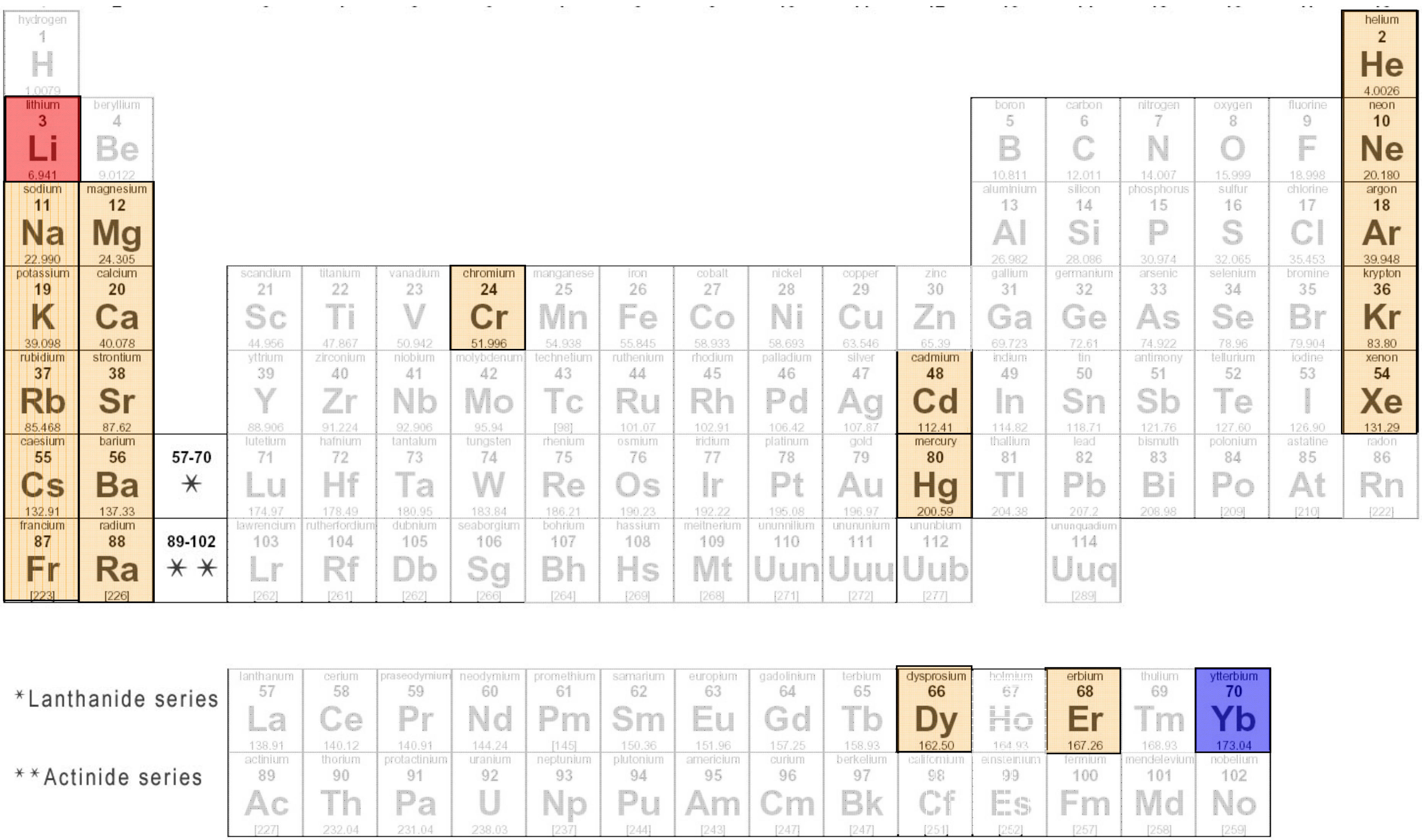
Isotopic mixtures

Further ease of cooling
Different statistics
(slightly) heteronuclear

Elemental Mixtures

Large differences in mass, electronic structure.
Heteronuclear – dipolar molecules
Species selective techniques

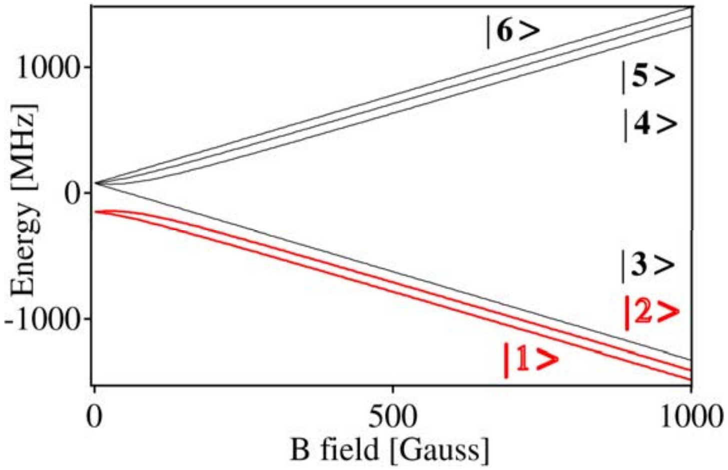
Colds Atoms Menu



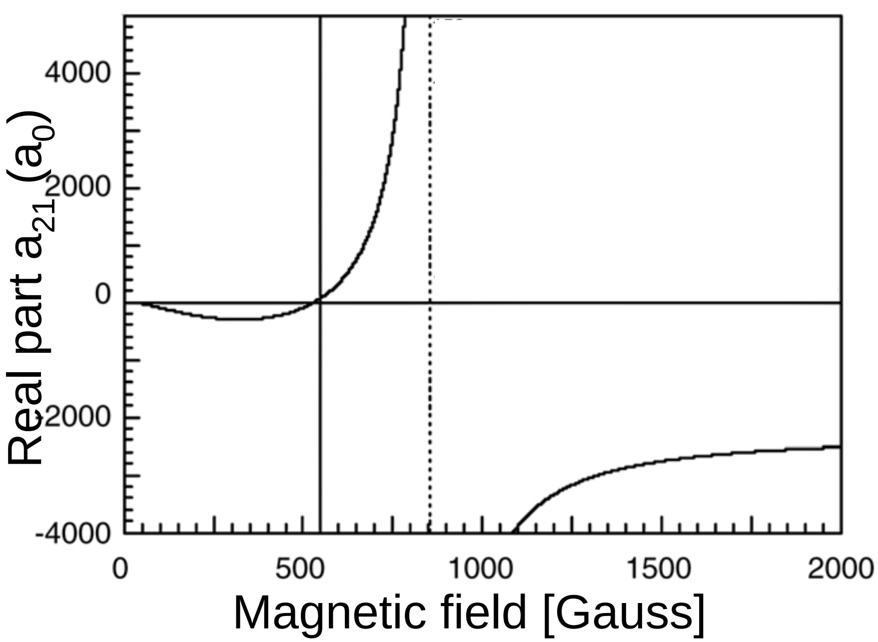
Li and Yb have different electronic structure and very different mass

A little about ^{6}Li

Ground State of ^{6}Li



Magnetic Feshbach Resonance (MFR)



Established cooling methods:

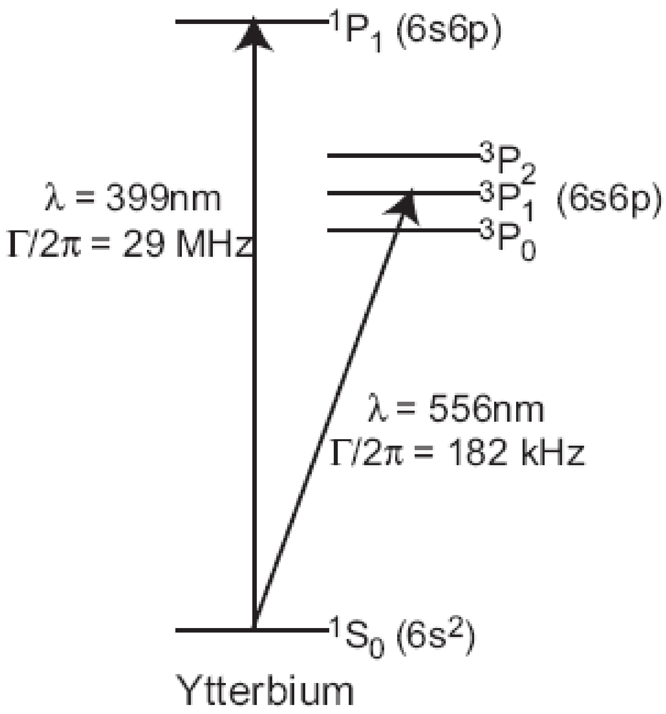
Red laser cooling line at 671nm

Evaporative cooling to degeneracy
2-spin states at a convenient B
in an optical trap

Sympathetic cooling by a boson
(^{7}Li, ^{23}Na, ^{87}Rb) in a magnetic trap

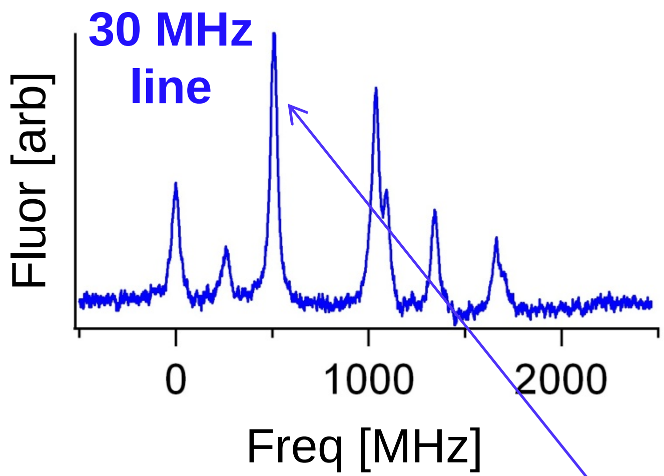
Molecular BEC/Fermi Superfluid/
Universal Physics/ BEC-BCS crossover
near Feshbach Resonance at 834G.

A little about Yb

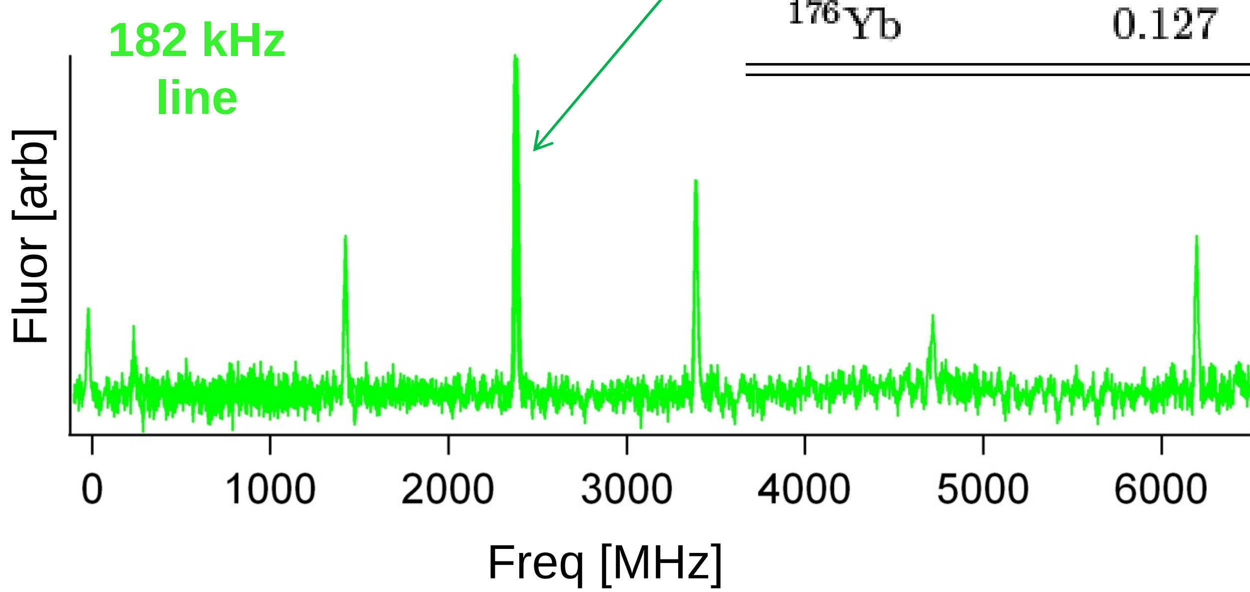


Isotope	Natural Abundance	Nuclear spin
^{168}Yb	0.0013	0
^{170}Yb	0.0305	0
^{171}Yb	0.143	1/2
^{172}Yb	0.219	0
^{173}Yb	0.161	5/2
^{174}Yb	0.318	0
^{176}Yb	0.127	0

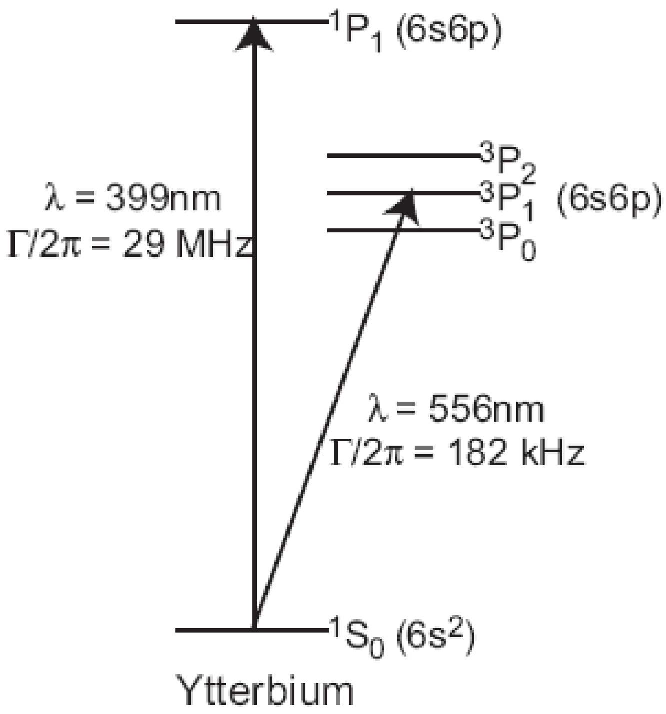
A little more about Yb



Isotope	Natural Abundance		Nuclear spin	
^{168}Yb	0.0013		0	
^{170}Yb	0.0305		0	
^{171}Yb	0.143		1/2	F
^{172}Yb	0.219		0	
^{173}Yb	0.161	10.55nm	5/2	F
^{174}Yb	0.318	5.55nm	0	
^{176}Yb	0.127		0	



A little more about Yb



Many isotopes cooled to degeneracy (Kyoto)

Atomic clock on $^1S_0 \rightarrow {}^3P_0$ (NIST, others)

Heavy – useful for precision measurements
eg. e-EDM search in $^3P_2$

Yb fermions in optical lattice
Quantum simulation, quantum computation

<u>When mixed with alkali:</u>
Good collisions only - spin-zero ground state
Additional species selectivity with B field gradient

Possibility of paramagnetic polar molecules

The Li-Yb combination

Ground States: Collisionally stable mixture expected. However very small thermalization factor (~ 21 collisions per particle for thermalization).

Mass Ratio = 29, B-F and F-F combos available
    new collisional regime (> 13.6)
    new many-body regime (highly mismatched Cooper pairs?)

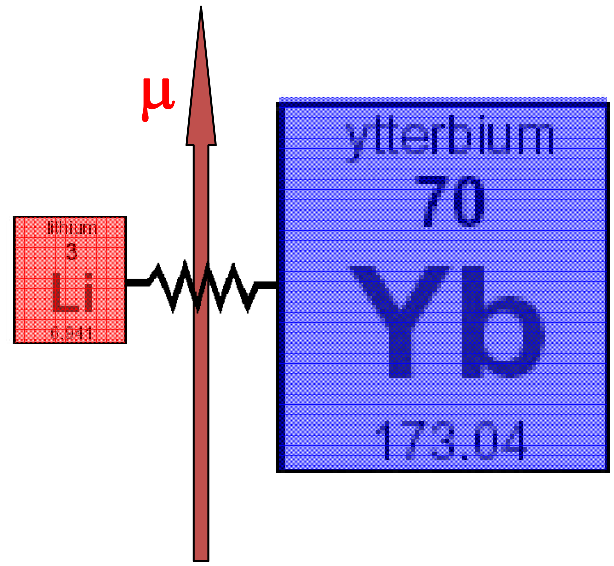
Tunable interactions
    Magnetic Feshbach resonances – available?
    Optical Feshbach resonances – usable?

Microscopic/Impurity probe of the ^{6}Li superfluid

Other similar mixtures:
Rb+Yb (Dusseldorf, NIST), Li+Yb (Kyoto), Rb+Sr (Innsbruck)

The Li-Yb combination

A paramagnetic polar molecule
with electronic degree of freedom



Dipolar physics

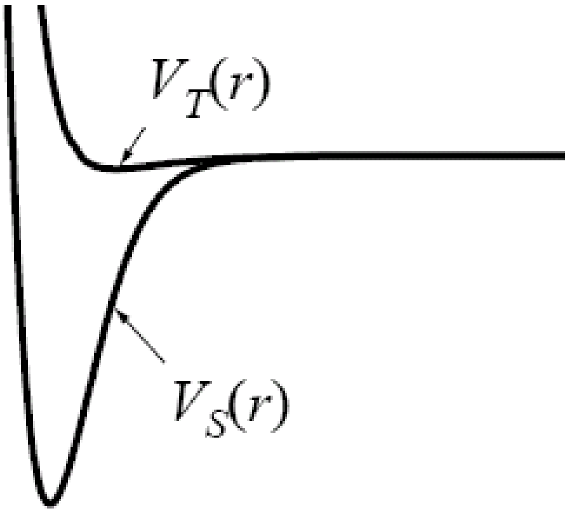
Quantum simulation of lattice spin models

Quantum computing

Sensitive test of fundamental symmetries (e-EDM)

Ground state molecule production by ultracold atom association in Jin/Ye group (KRb),
Weidemuller (LiCs), DeMille (RbCs), Nagerl (Cs_2),..

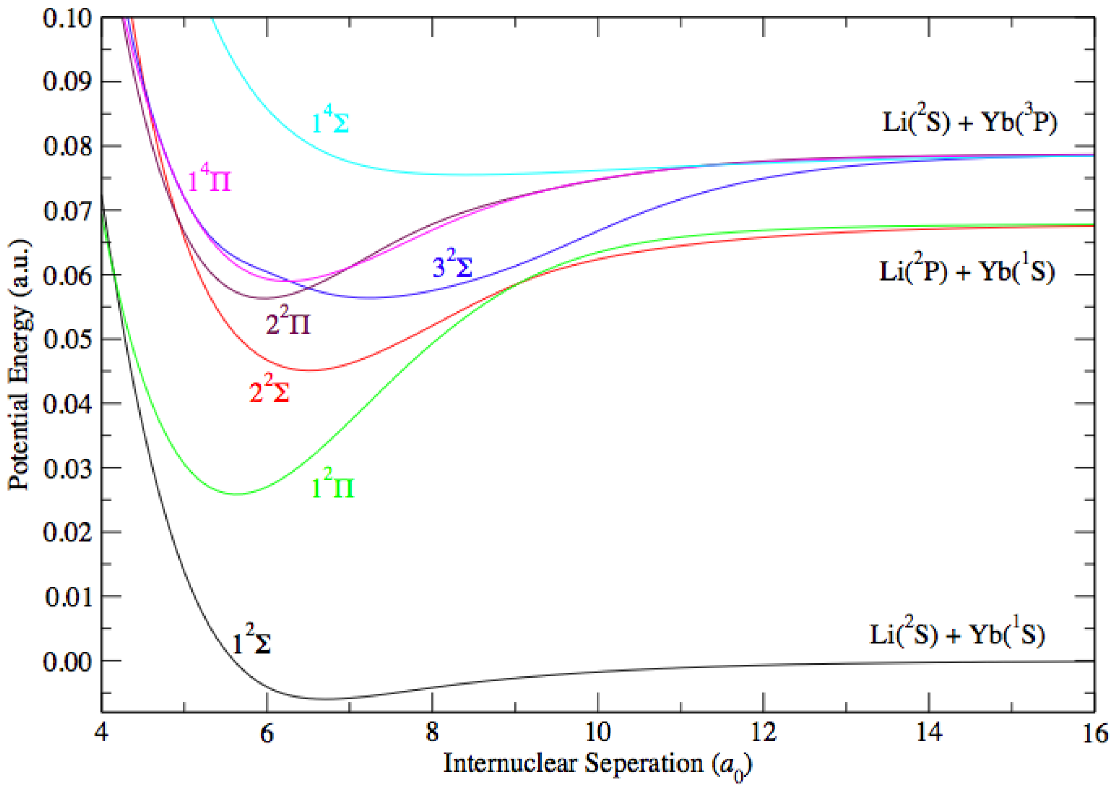
Feshbach resonance in LiYb?



MFR through coupling between singlet and triplet ground state potentials in alkali+alkali collisions

Only doublet-sigma ground state potential for alkali+spin-singlet collisions. No “usual” MFR.

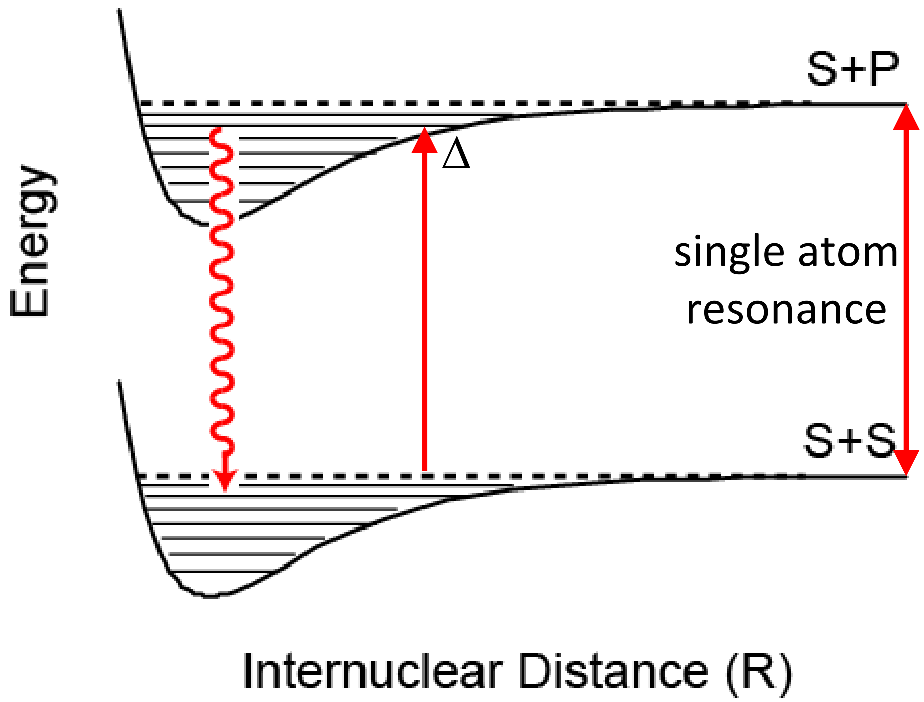
Weak MFRs may exist [Hutson and co-workers, PRL 105, 153201 (2010)]



Ab-initio Li-Yb potentials from Zhang et al. JCP 133, 044306 (2010).

Optical Feshbach Resonance

Optically connect free particles with an excited molecular state.
Initial proposal by Shlyapnikov and others [PRL 77, 2913 (1996)].



Photoassociation Resonance

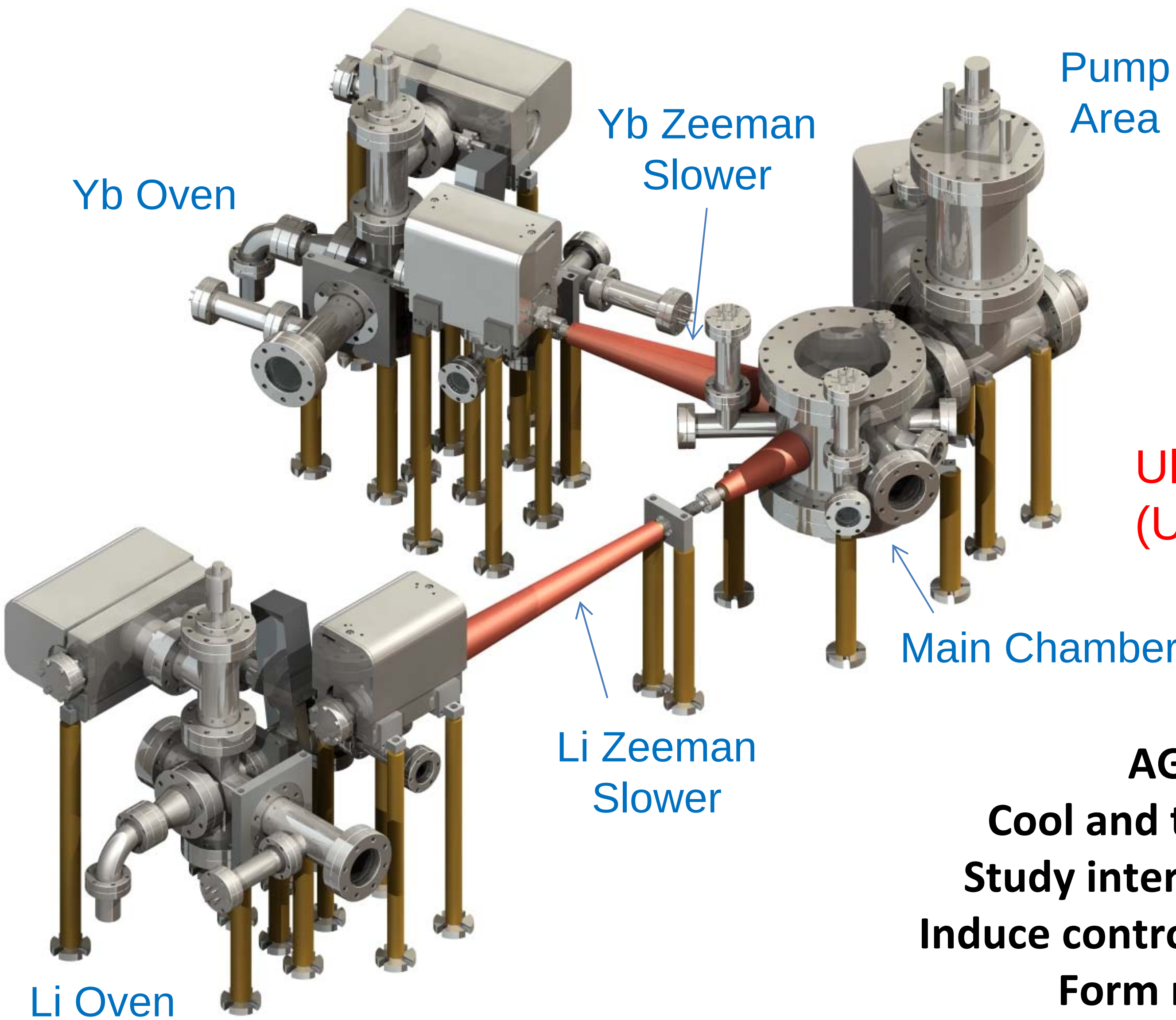
[First observation in Grimm group Theis et al, PRL **93**, 123001 (2004)]

Optical Feshbach Resonance

[Grimm, Takahashi, Killian, Jun Ye]

Further theory work by Bohn, Julienne, co-workers
More applicable with narrow optical transitions

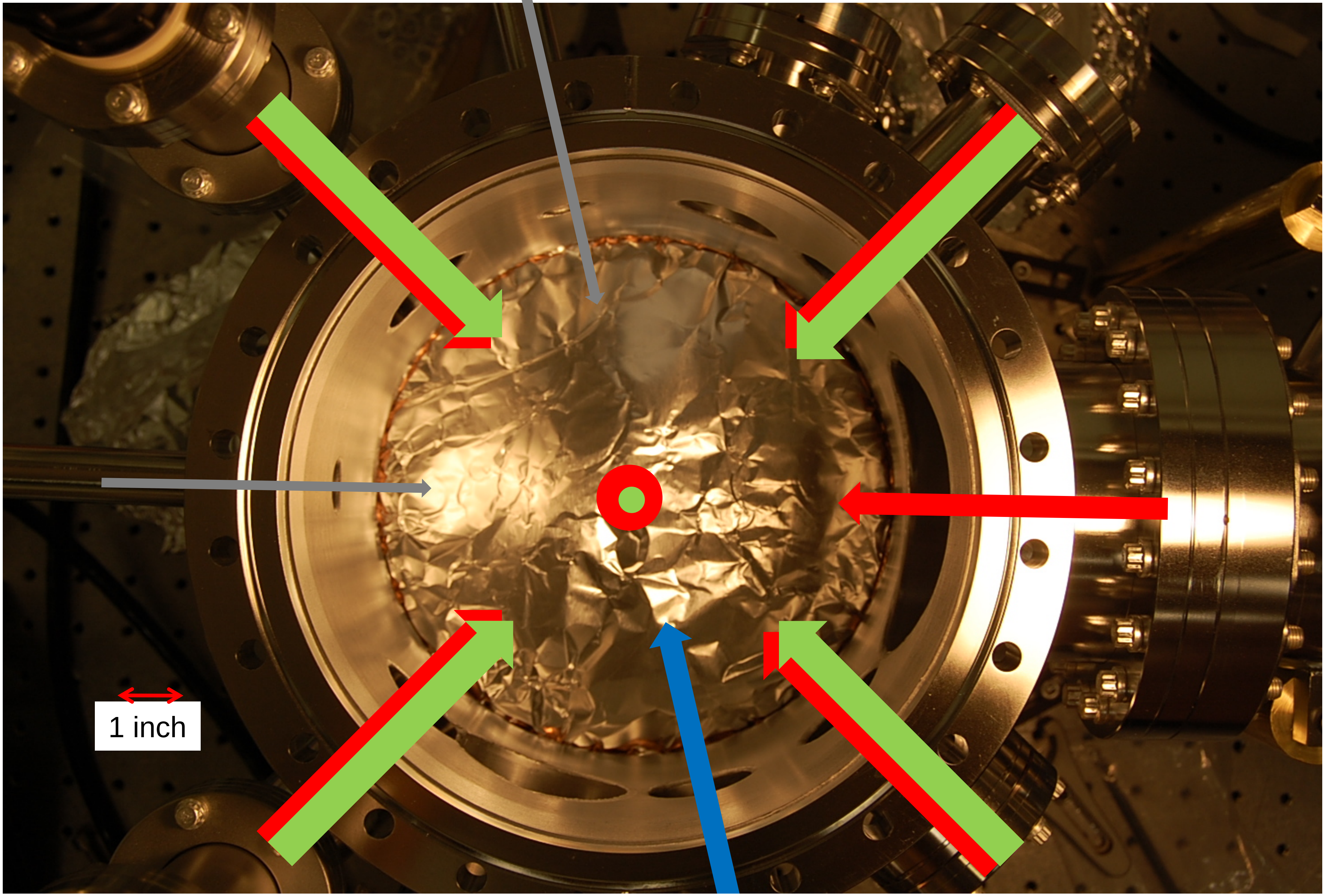
Co-trapping of Li and Yb



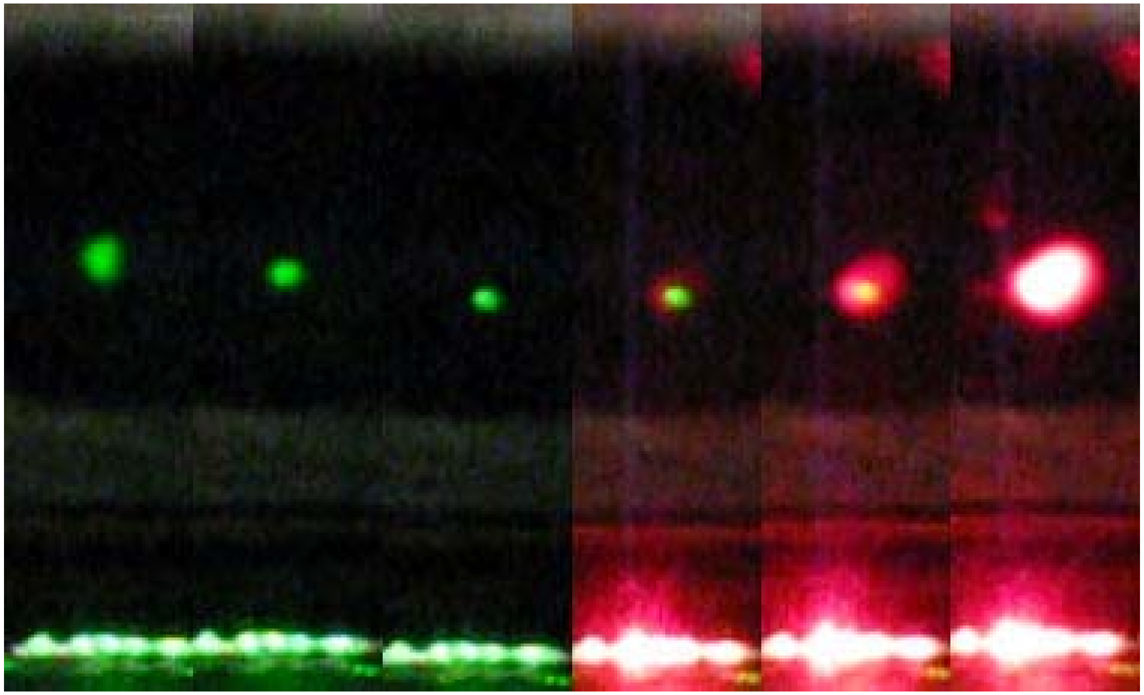
Ultrahigh Vacuum
(UHV < 10^{-10} Torr)

AGENDA
Cool and trap Li and Yb
Study interacting mixture
Induce controlled interactions
Form molecules

Dual Species Apparatus



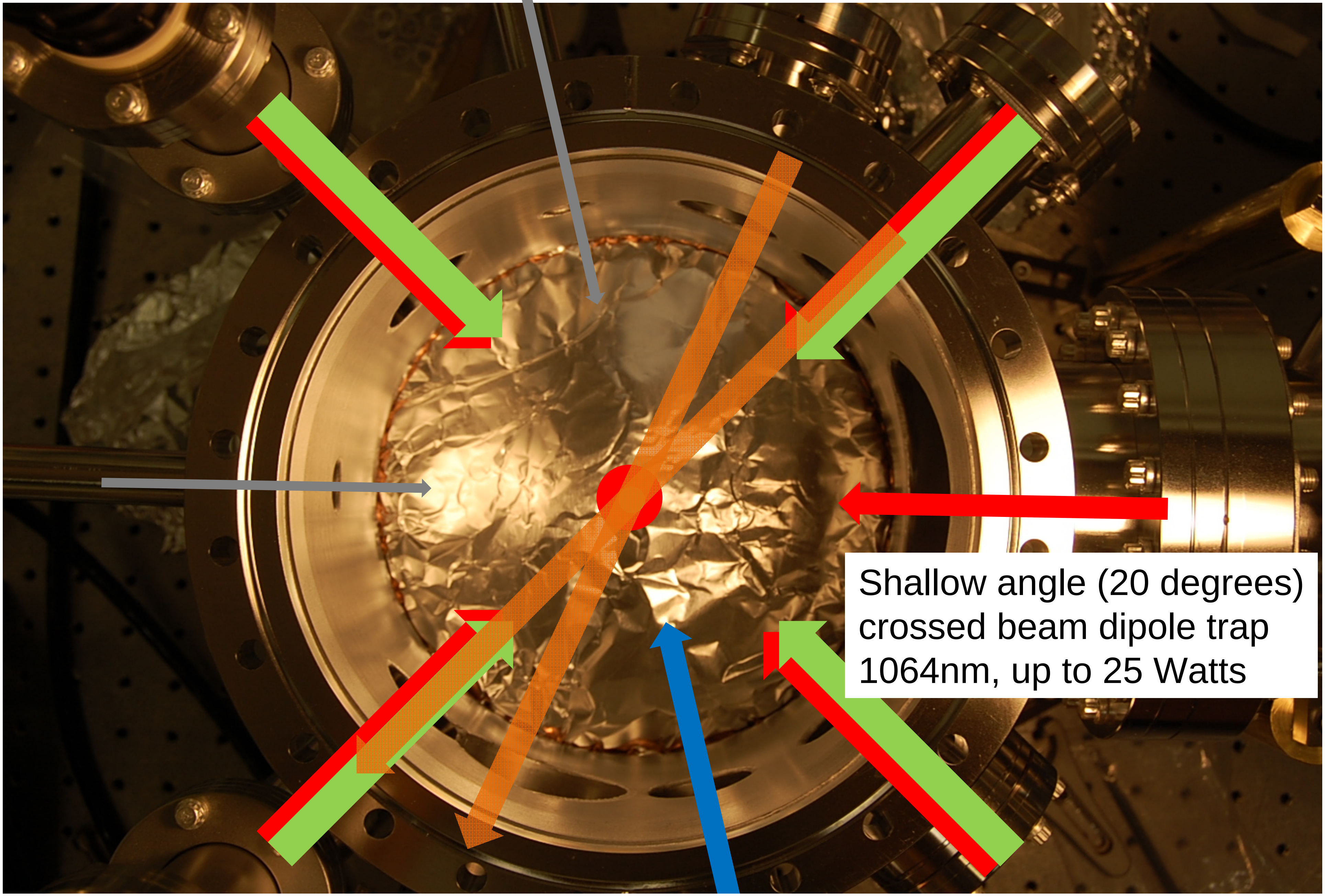
Yb MOT and double MOT



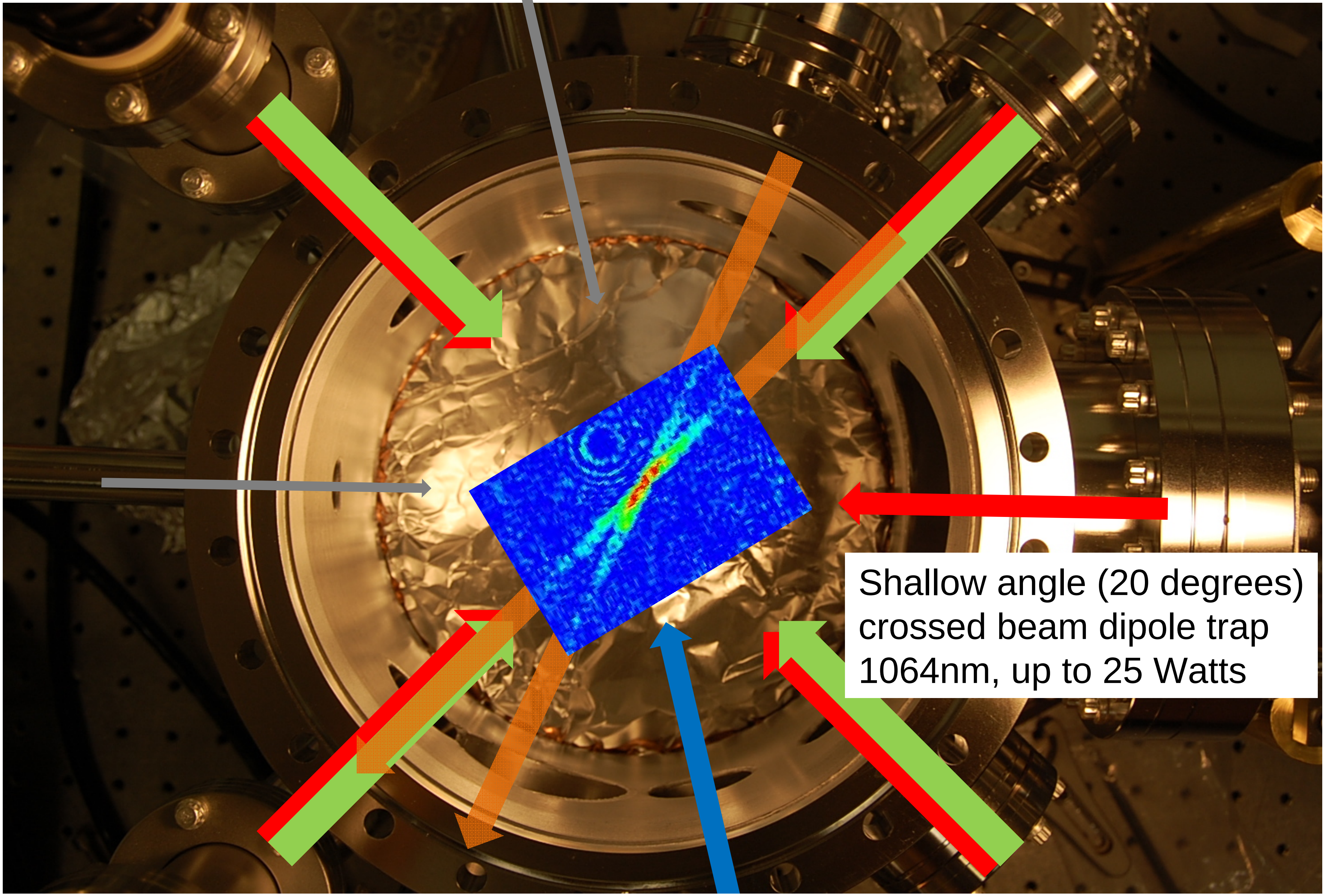
Sequential Loading

The 2 MOTs are optimized at different parameters of magnetic field gradient and also exhibit inelastic interactions

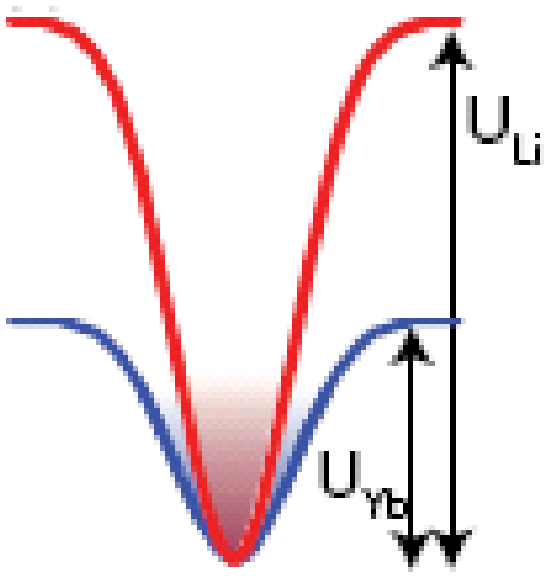
Optical Dipole Trap



Optical Dipole Trap



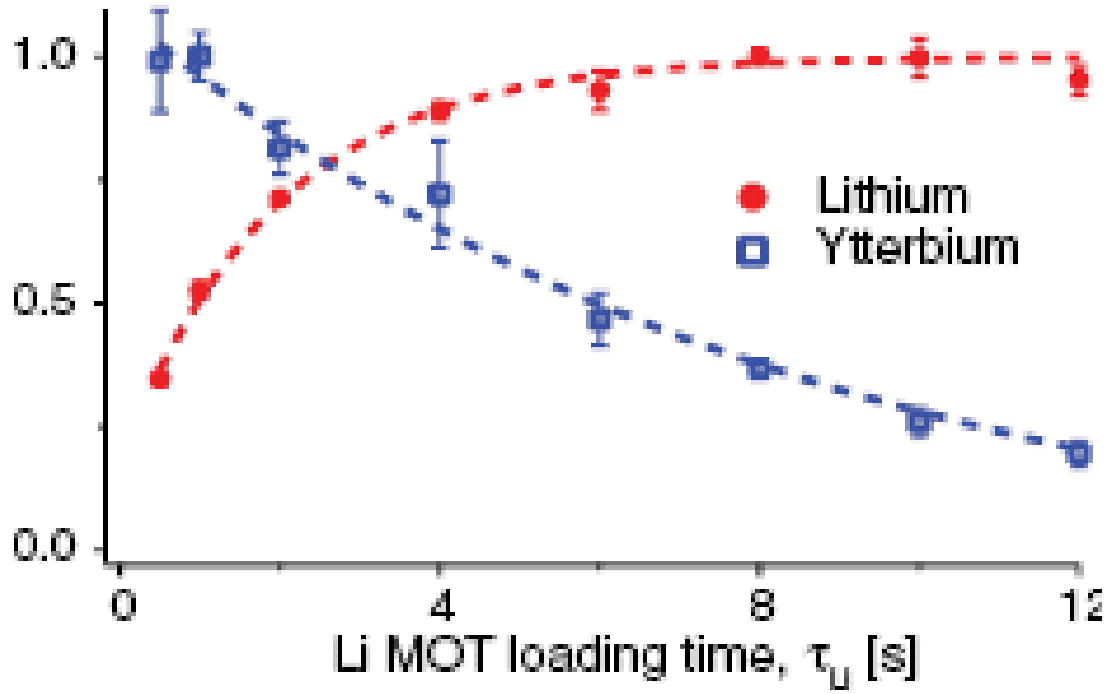
Co-trapping of Lithium and Ytterbium



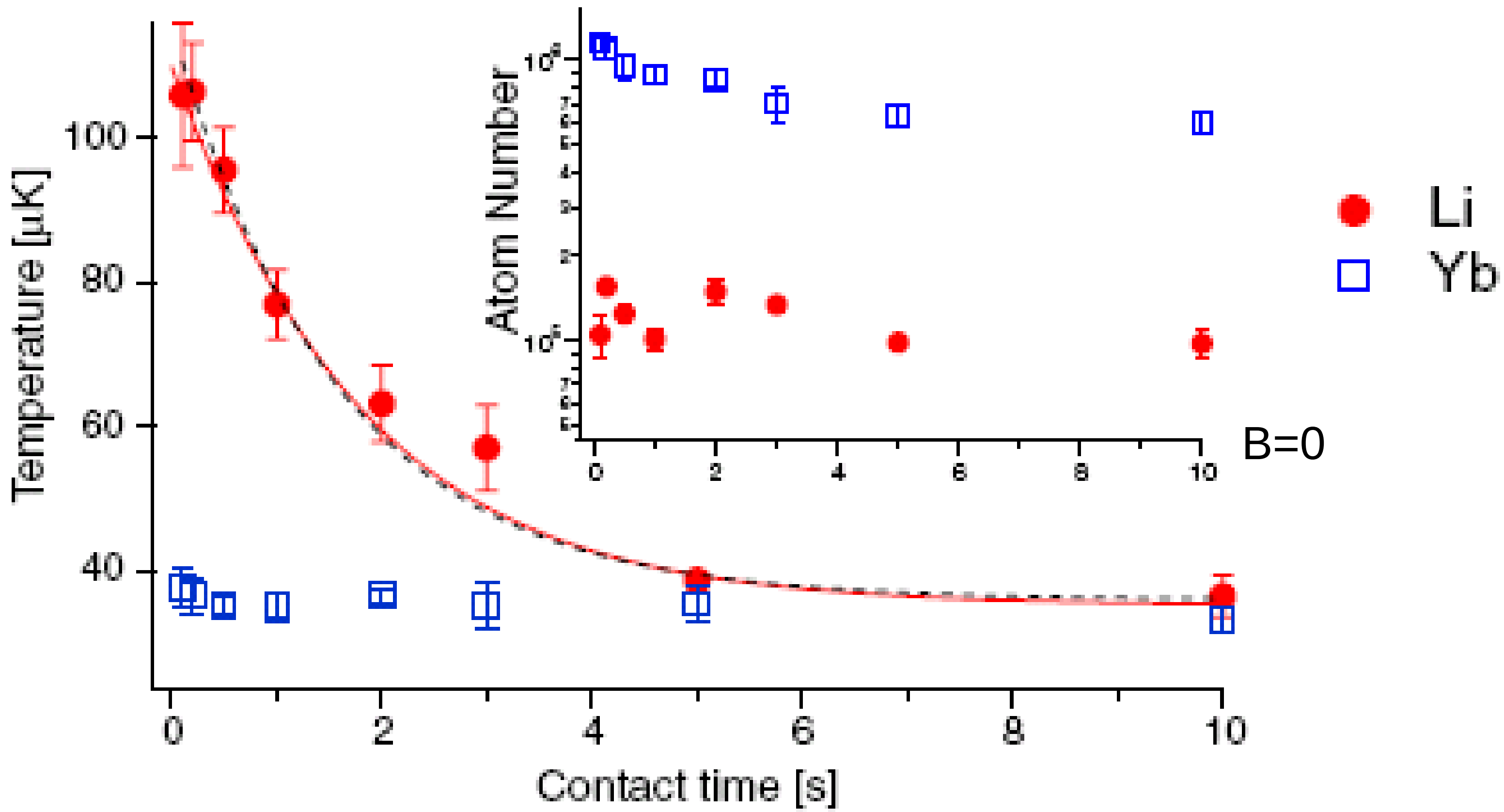
1064nm optical trapping potentials for Li and Yb.

ω_{Li}/ω_{Yb} **= 8**

Controlling the relative numbers



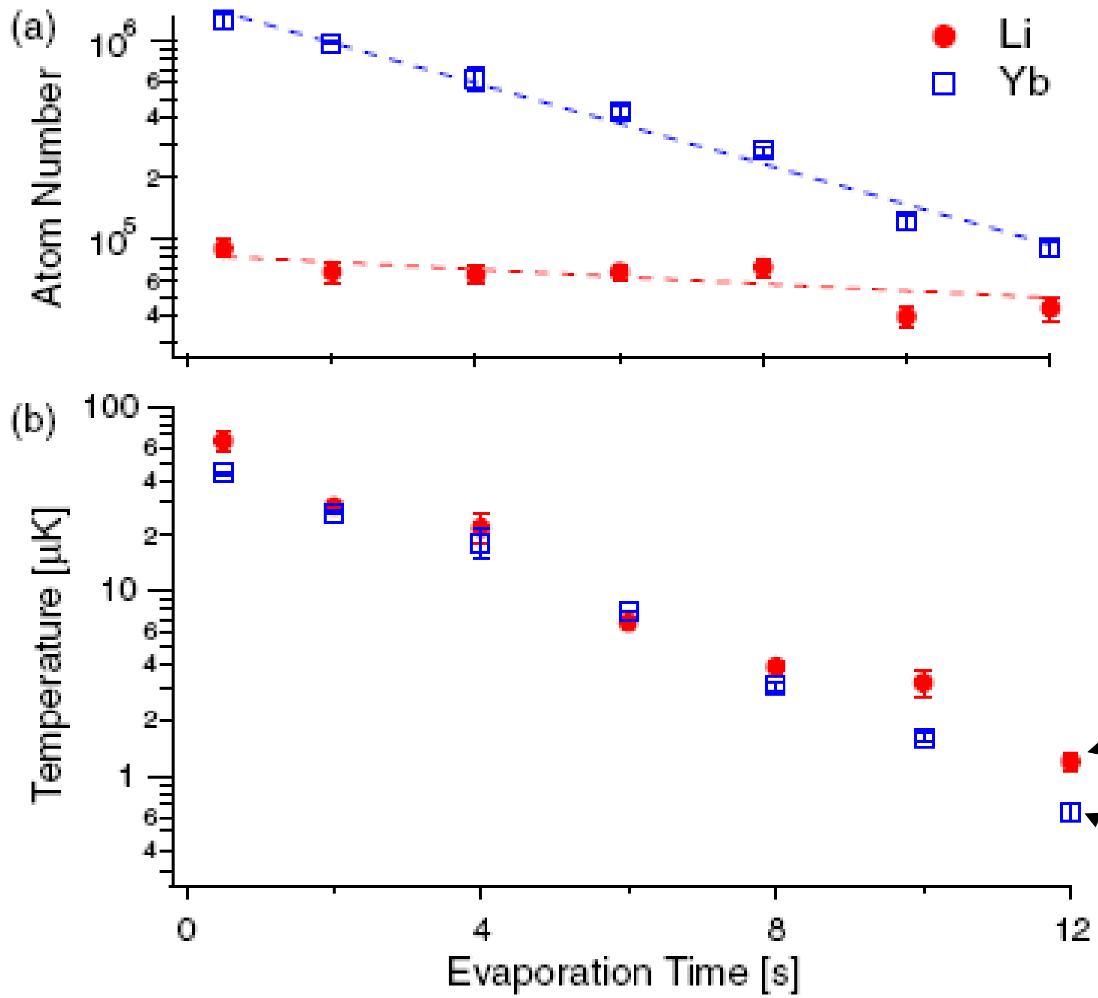
Ground State behavior of Li-Yb mixture



It's stable!

Extract $|a| = (13 \pm 3)\, a_0$ (~ 0.7nm, kind of small)

Sympathetic Cooling to below T_F



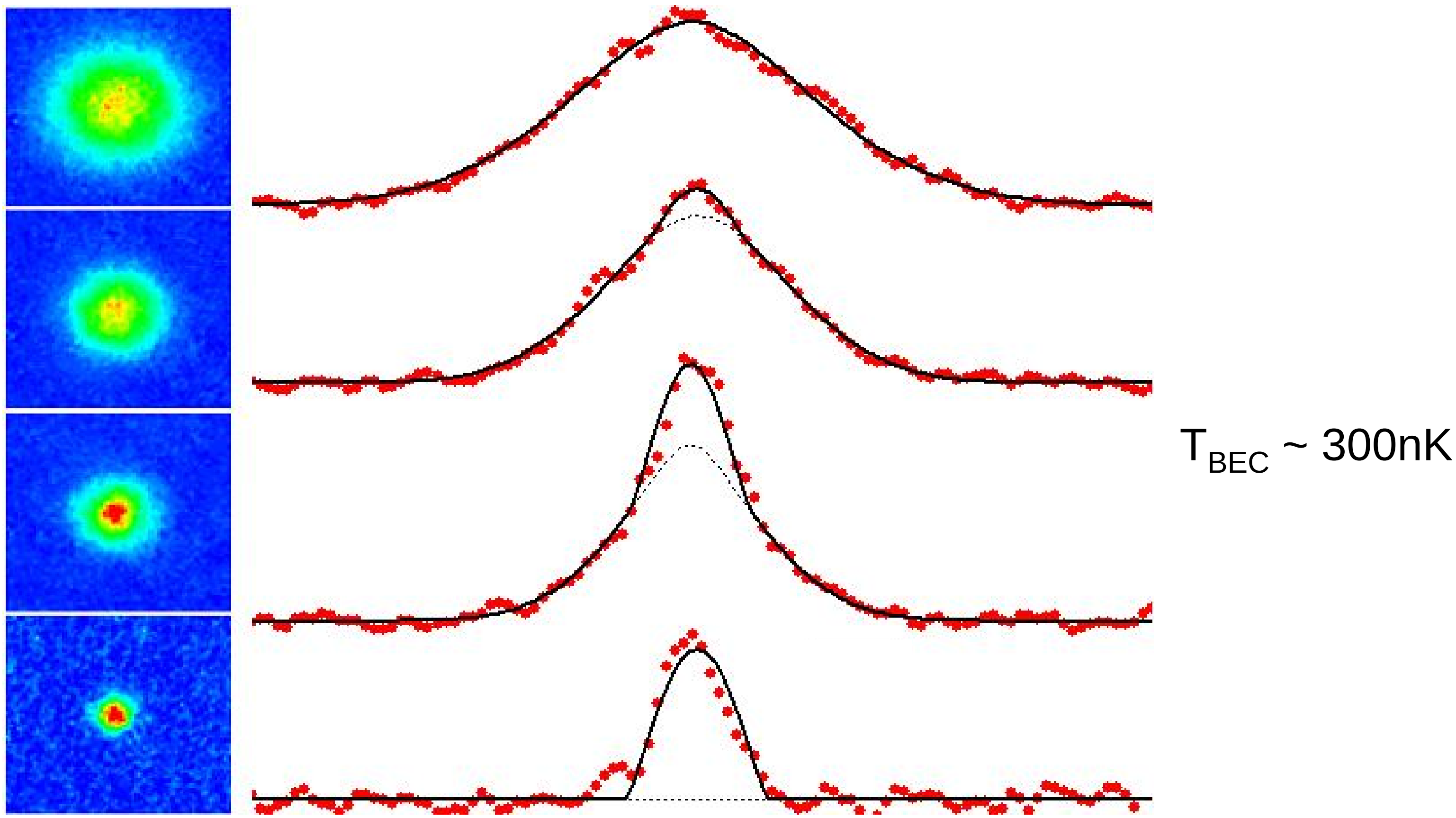
Small interspecies scattering length, but light Li provides high relative speed.

$T/T_F \sim 0.7$

$T/T_{BEC} \sim 4$

Ivanov et al, PRL **106**, 153201 (2011)

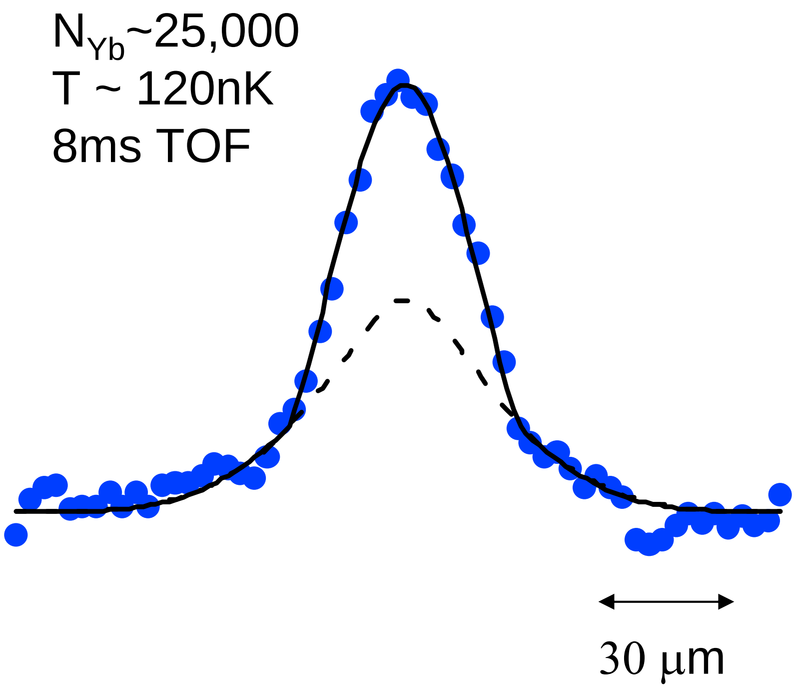
Bose-Einstein condensation of ^{174}Yb in a 1.06μm trap

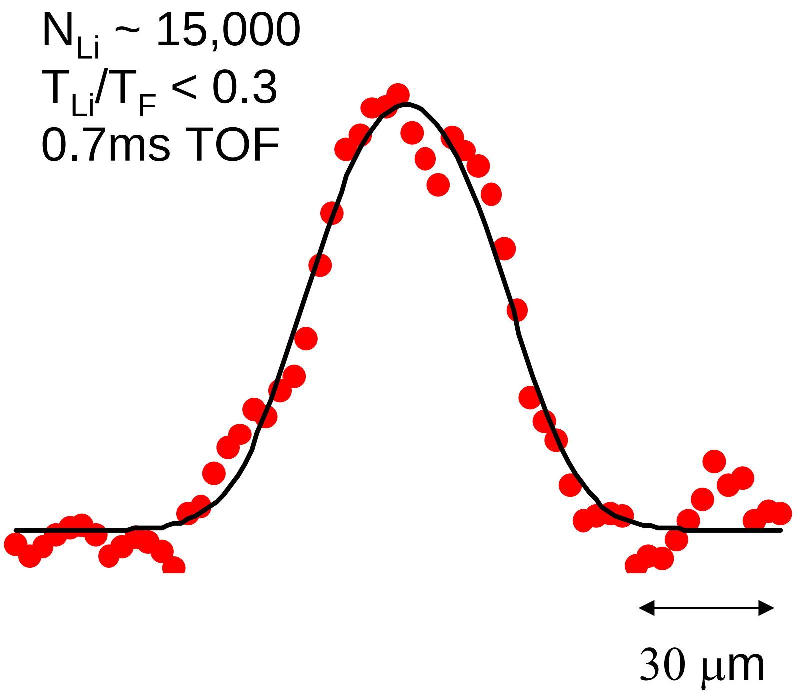


A straightforward method to create Yb BECs in 1064nm potential.
Quasi-pure BECs with up to 50,000 atoms possible

Recent technical improvements: improved laser cooling, tighter optical confinement.

Simultaneous Quantum Degeneracy
in alkali + spin-zero system





Recent similar results in Takahashi/Doyle collaboration

Implications for other Li-Yb combinations

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^{172}Yb	0.219		0	
^{173}Yb	0.161	10.55nm	5/2	F
^{174}Yb	0.318	5.55nm	0	
^{176}Yb	0.127		0	

+ ^{6}Li

Should all be stable with near identical value of scat length
^{173}Yb + ^{6}Li gives most promising degenerate Fermi-Fermi mixture.

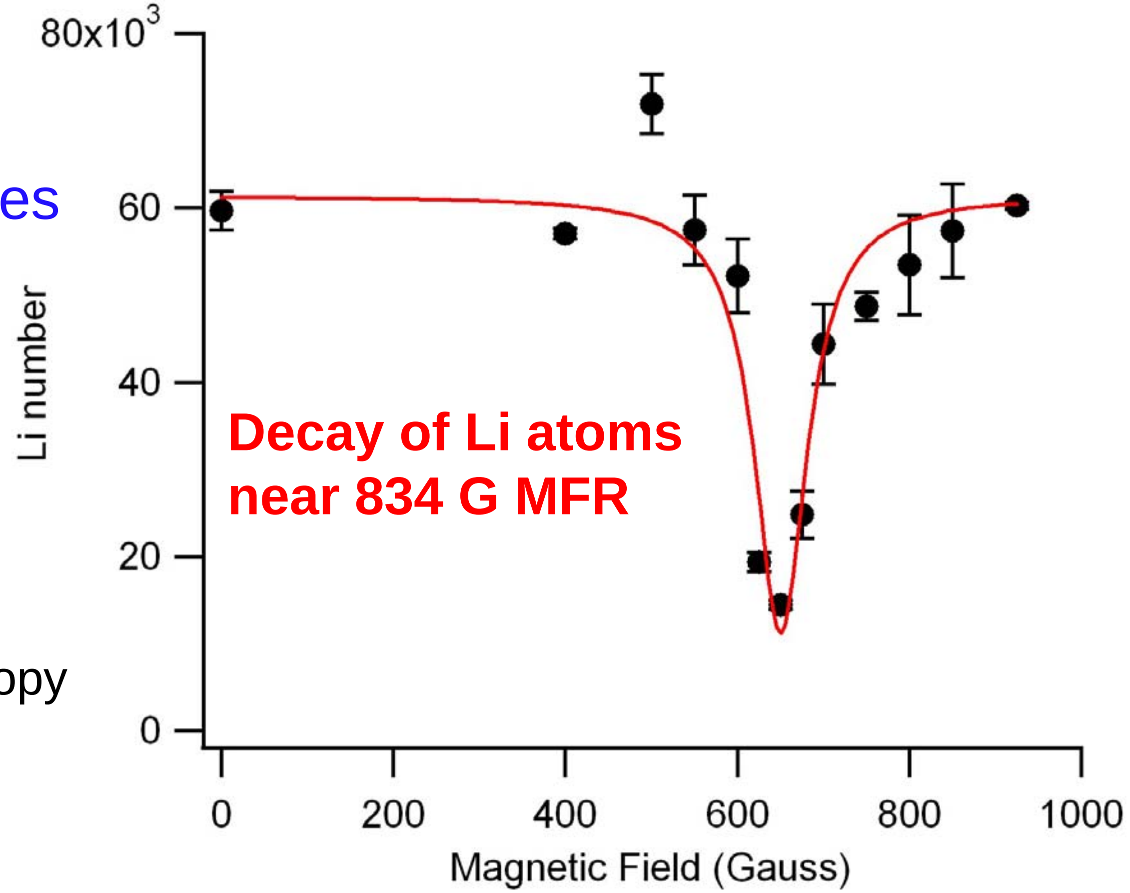
+ ^{7}Li

Should all have near identical value of scat length, different from above.

What Next?

Search for Magnetic
Feshbach Resonances

Atom loss
spectroscopy



(seen earlier in several expts.)

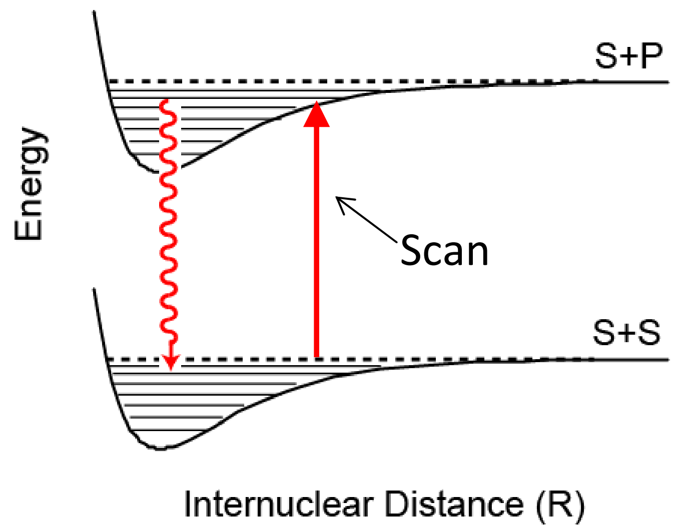
Li MFR in the presence of Yb.

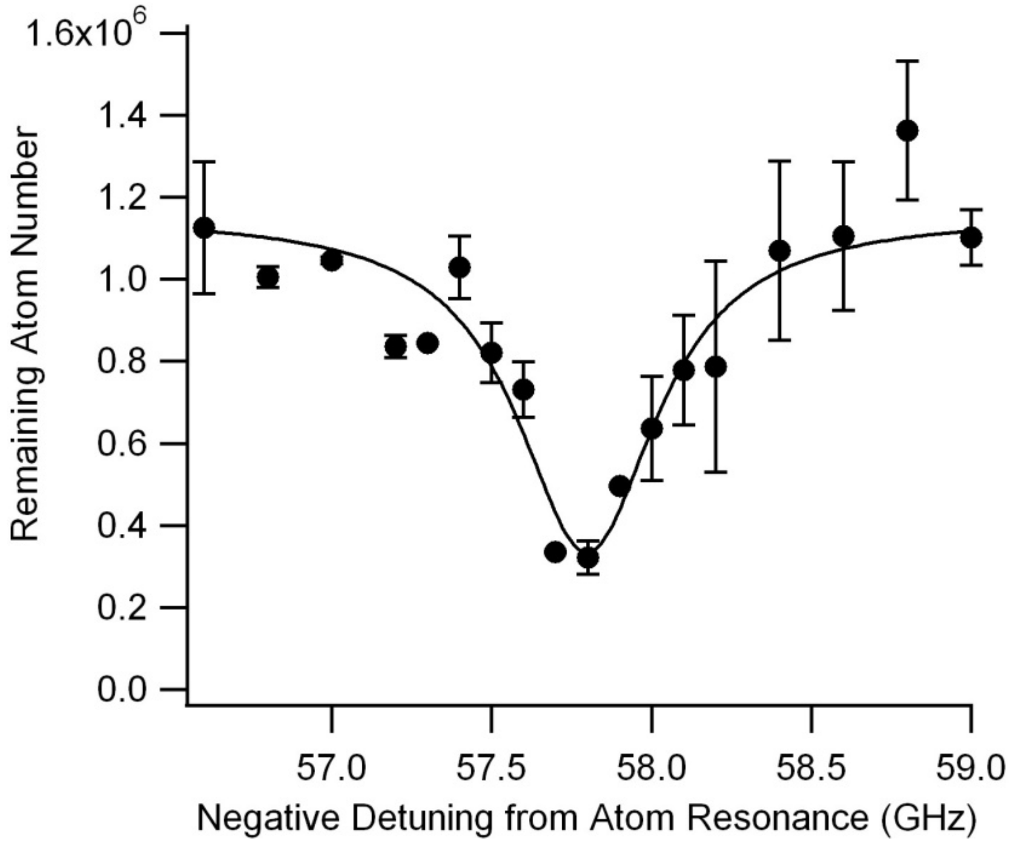
Collisions with distinguishable 3rd component (heavy, boson/fermion)

Impurity/microscopic probe of ^{6}Li superfluid

What Next?

Photoassociation Spectroscopy





Trap loss measurement in the ^{6}Li system

Provides information on excited potential
Key step towards LiYb molecule
Key step towards Optical Feshbach Resonance

UW Ultracold Atoms Team

Grad Students: Will Dowd, Anders Hansen, Alan Jamison, Alex Khramov,
Ben Plotkin-Swing

Undergrad: Ben Schwyn

Post-doc: Vlad Ivanov (now at UW Madison)

$$$ - NSF, Sloan Foundation, UW RRF, NIST