Strongly Interacting Regimes in the Lithium-Ytterbium System

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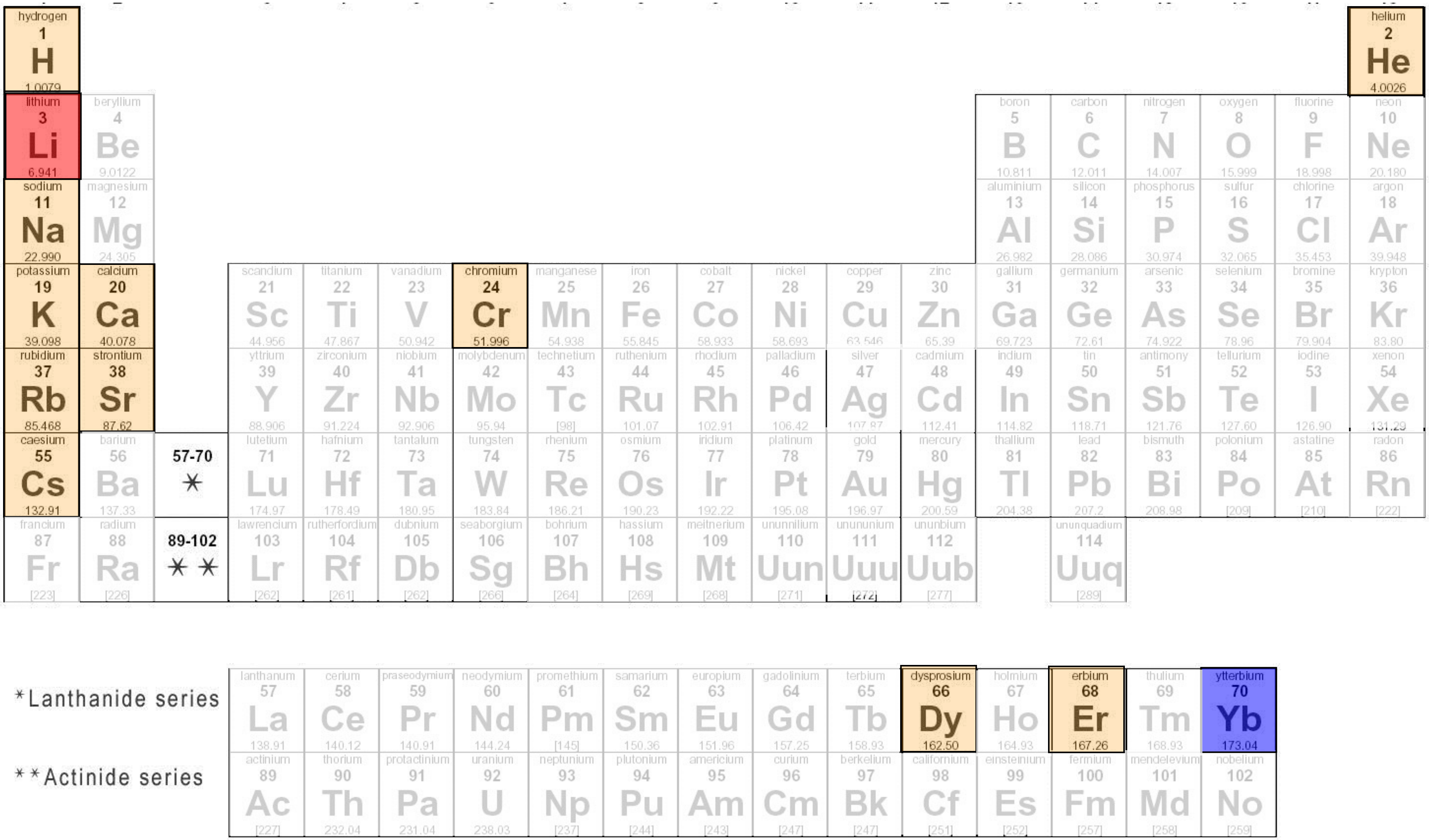
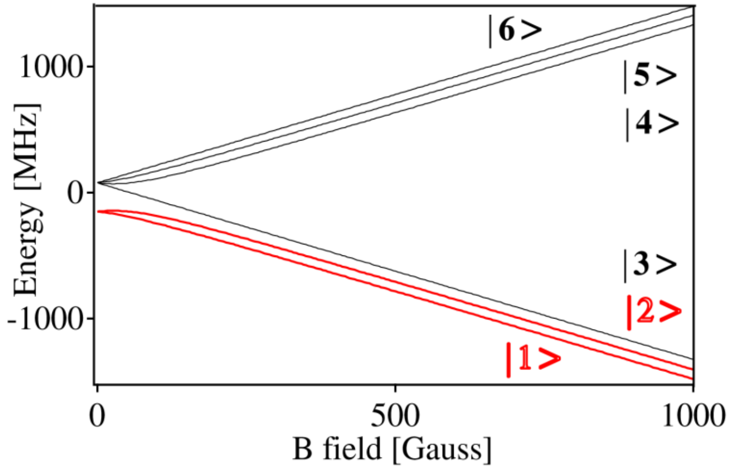
UW INT Workshop, 12th May 2014

Dilute Quantum Degenerate Gases

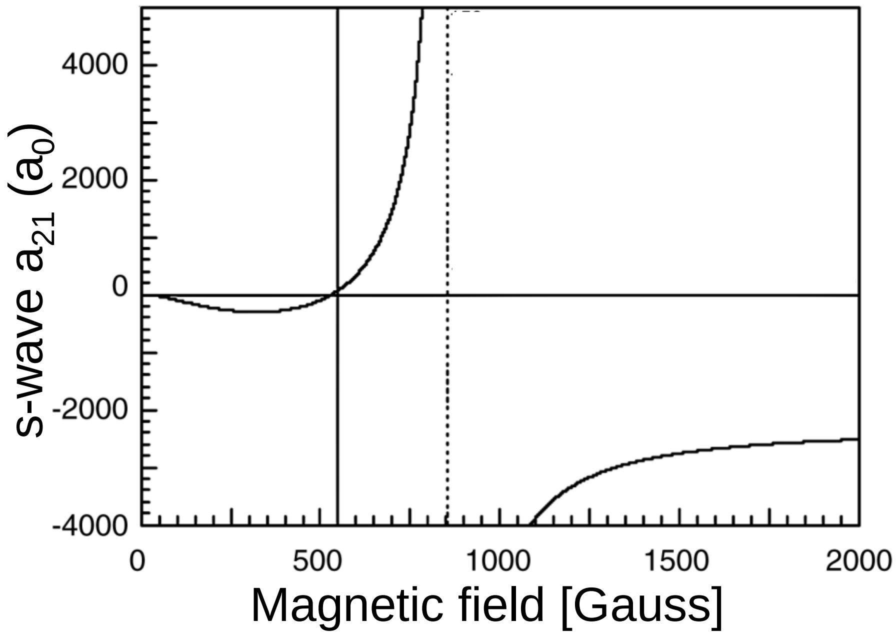


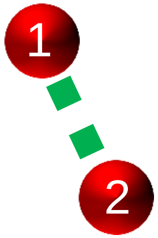
^{6}Li Fermi system

Ground State



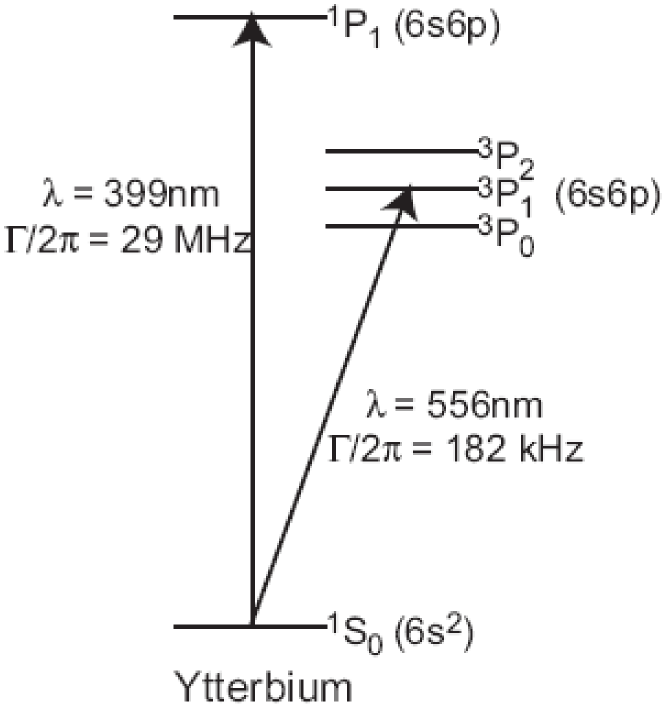
Magnetic Feshbach Resonance





Strongly interacting fermions
BEC of molecules
Fermi superfluid

Ytterbium: Heavy, 2-Electron Atom

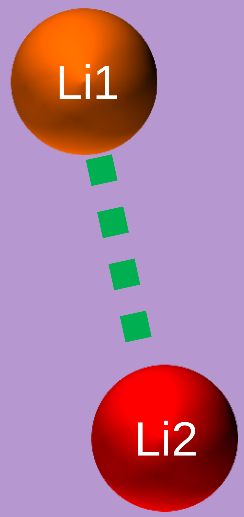


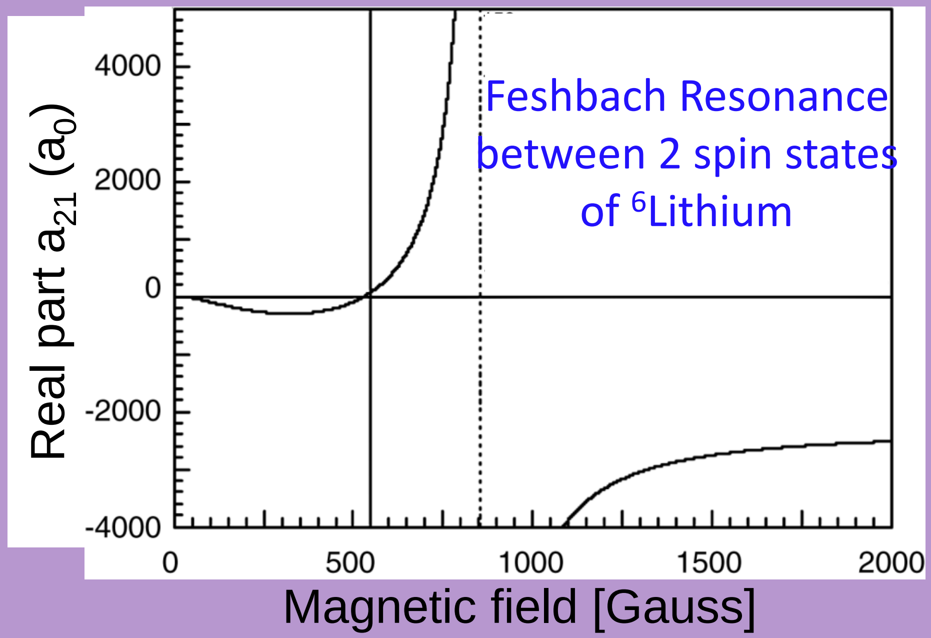
Isotope	Natural Abundance		Nuclear spin	
^{168}Yb	0.0013		0	
^{170}Yb	0.0305		0	
^{171}Yb	0.143		1/2	F
^{172}Yb	0.219		0	
^{173}Yb	0.161	a=10.55nm	5/2	F
^{174}Yb	0.318	a=5.55nm	0	
^{176}Yb	0.127		0	

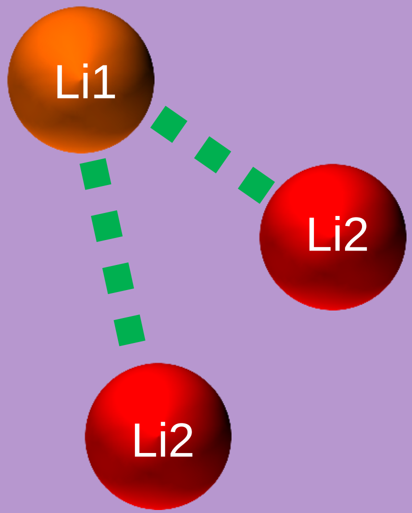
Precision expts, Atomic clock on $^1S_0 \rightarrow {}^3P_0$.
Yb fermions for quantum simulation [SU(N)].

+ Li: Coolant, heavy-light mix, Fermi bath/probe, $^2\Sigma$ molecule.

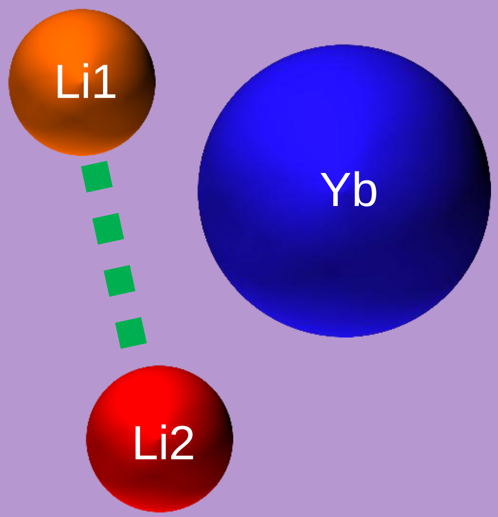
Strongly Interacting Regime I



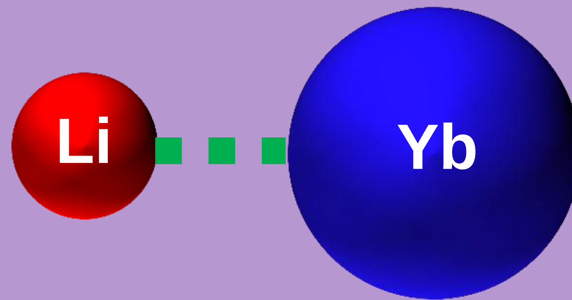




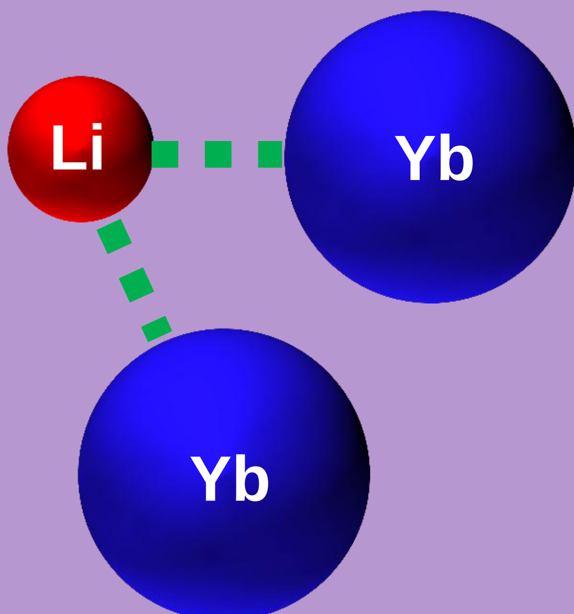
Questions of 3 particle stability
Can modify/probe resonance
Coolant/Thermometry



Strongly Interacting Regime II



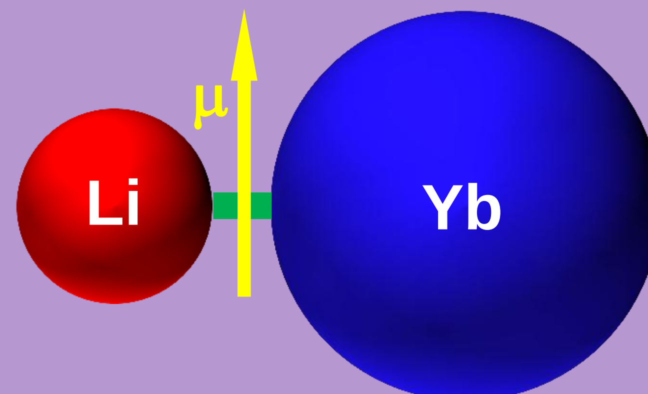
Feshbach Resonance
between Li and Yb.



Efimov Trimers

Heavy/light combinations

Bose/Fermi combinations

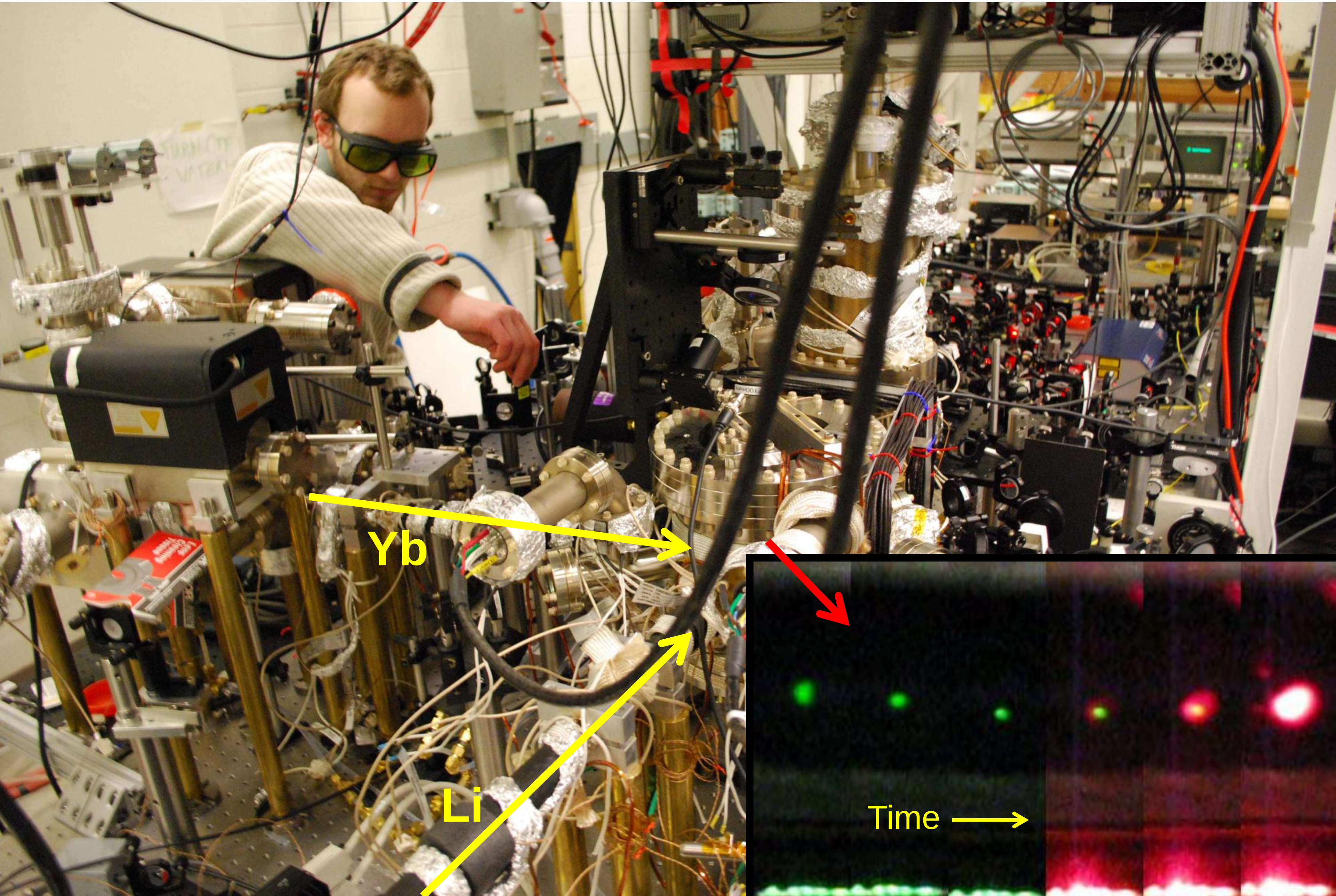


Paramagnetic Polar Molecule

Spin-controlled chemistry

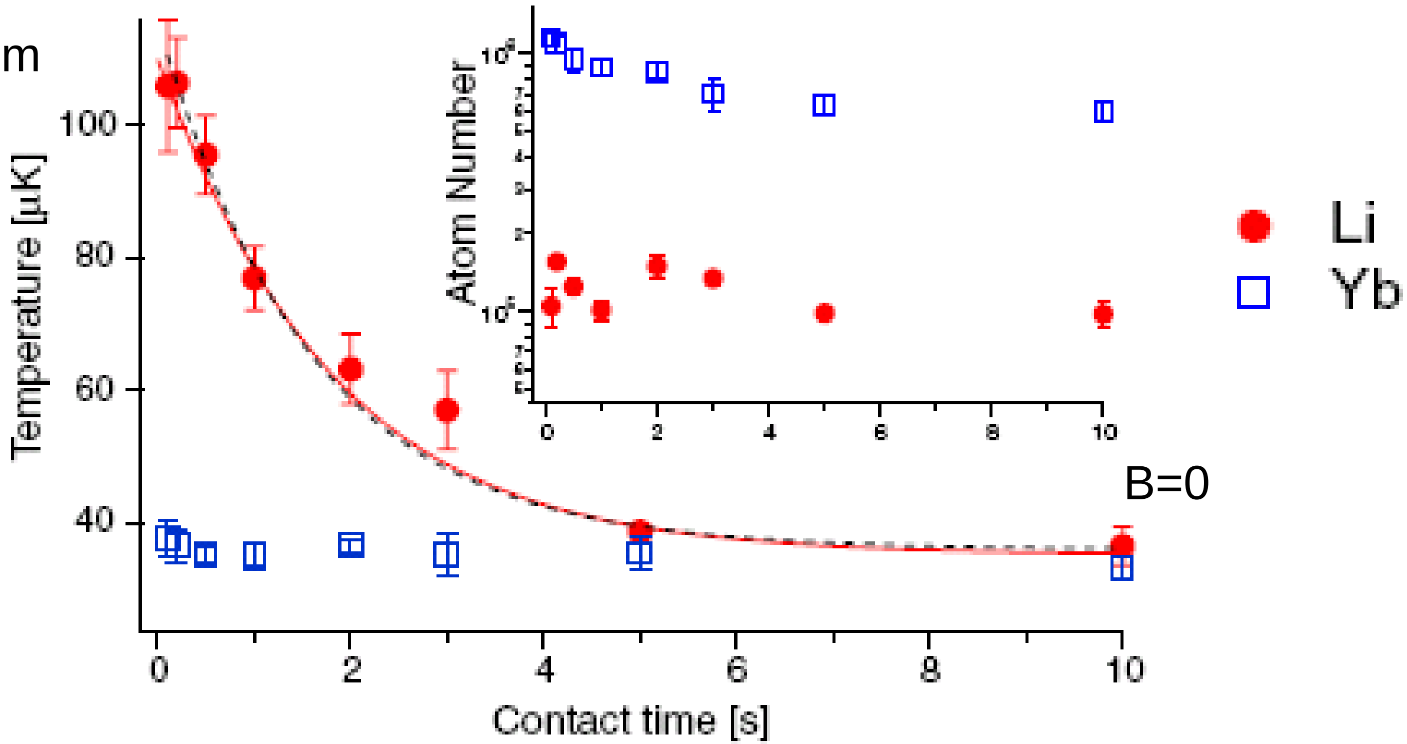
Quantum Simulation, spins on lattice

Li-Yb Apparatus



Combining Ground State ^{6}Li-^{174}Yb

Combined optical dipole trap at 1064nm



It's stable!

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

Other Yb isotopes + Li: similar weak interactions

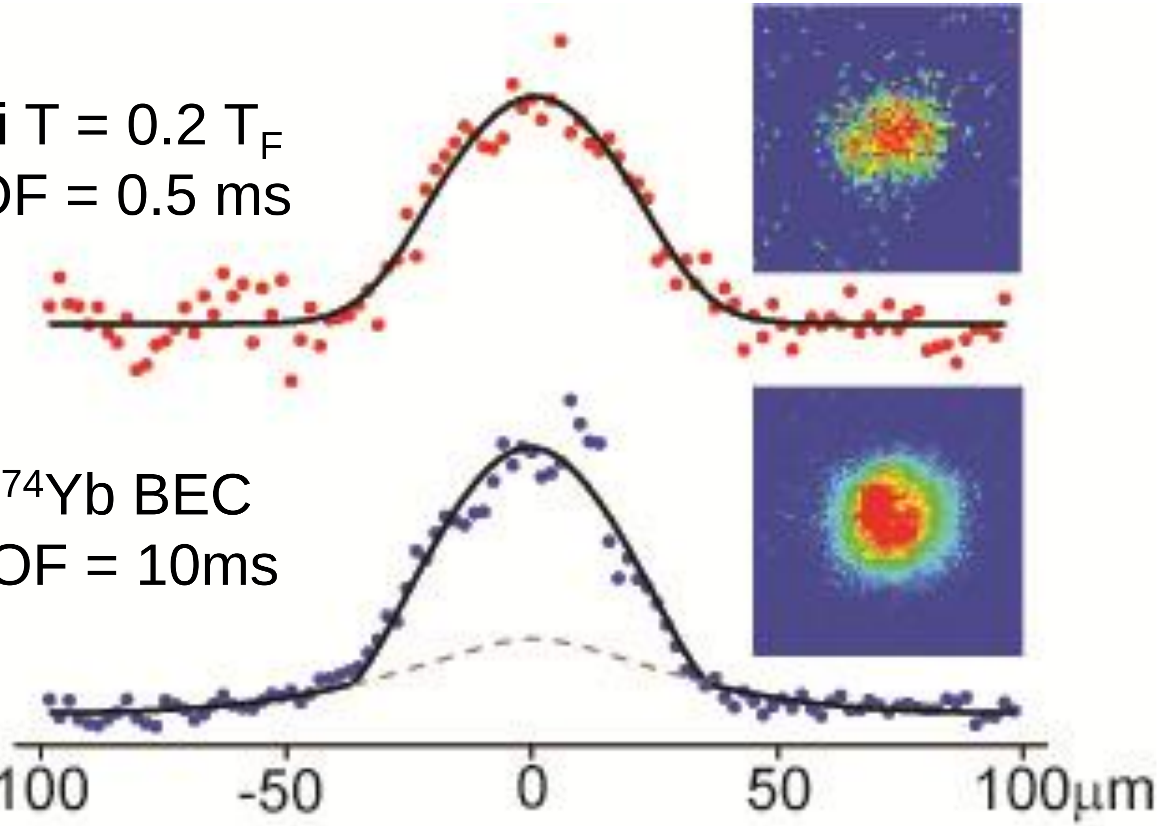
V. Ivanov et al.
PRL **106**, 053201 (2011)

Quantum Degenerate Li-Yb mixture

0.1 T_F with further cooling

^{6}Li T = 0.2 T_F
TOF = 0.5 ms

^{174}Yb BEC
TOF = 10ms



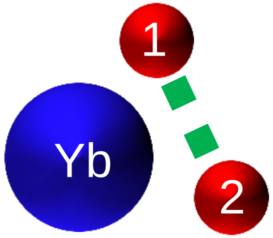
Evaporative cooling of Yb
Sympathetic cooling of Li

Similar results in Kyoto group (2011)

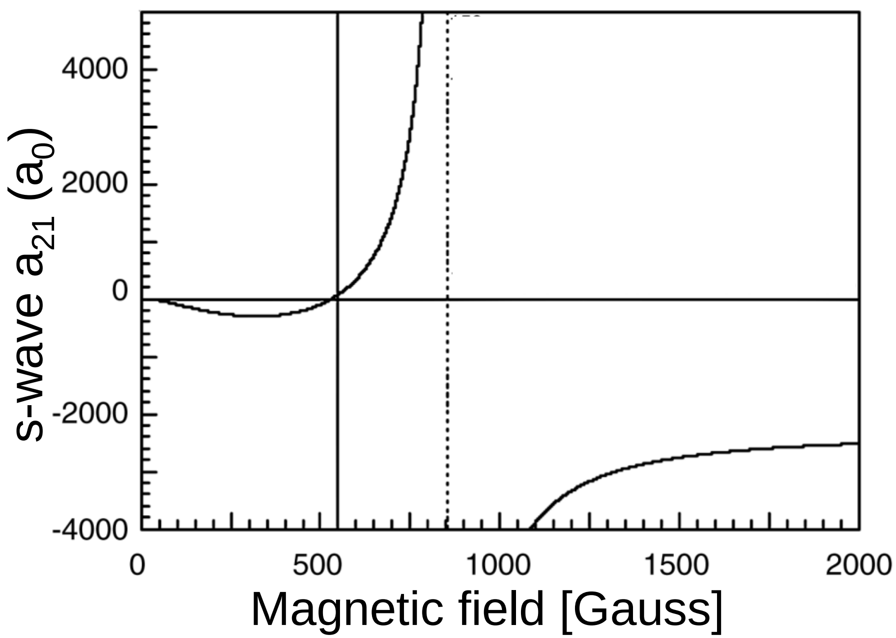
A. Hansen et al.
PRA **84**, 011606(R) (2011)

Yb+Li1+Li2 near Li Feshbach

Yb +



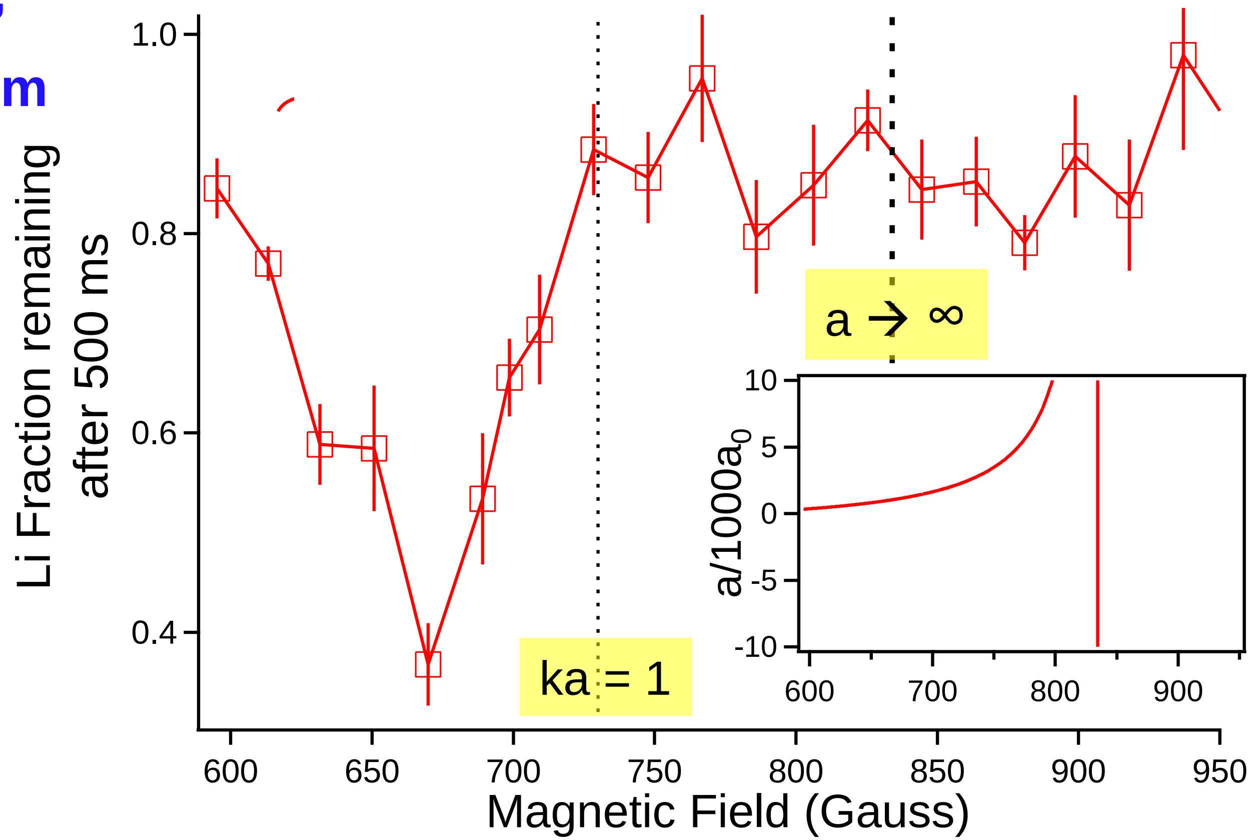
Magnetic Feshbach Resonance



Stability/reactivity of FB molecules
Yb as a bath or probe

Collisional Stability near Li Feshbach

"Loss" Spectrum



Li only

($T_F/2$)

Faster dimer formation (a^6)

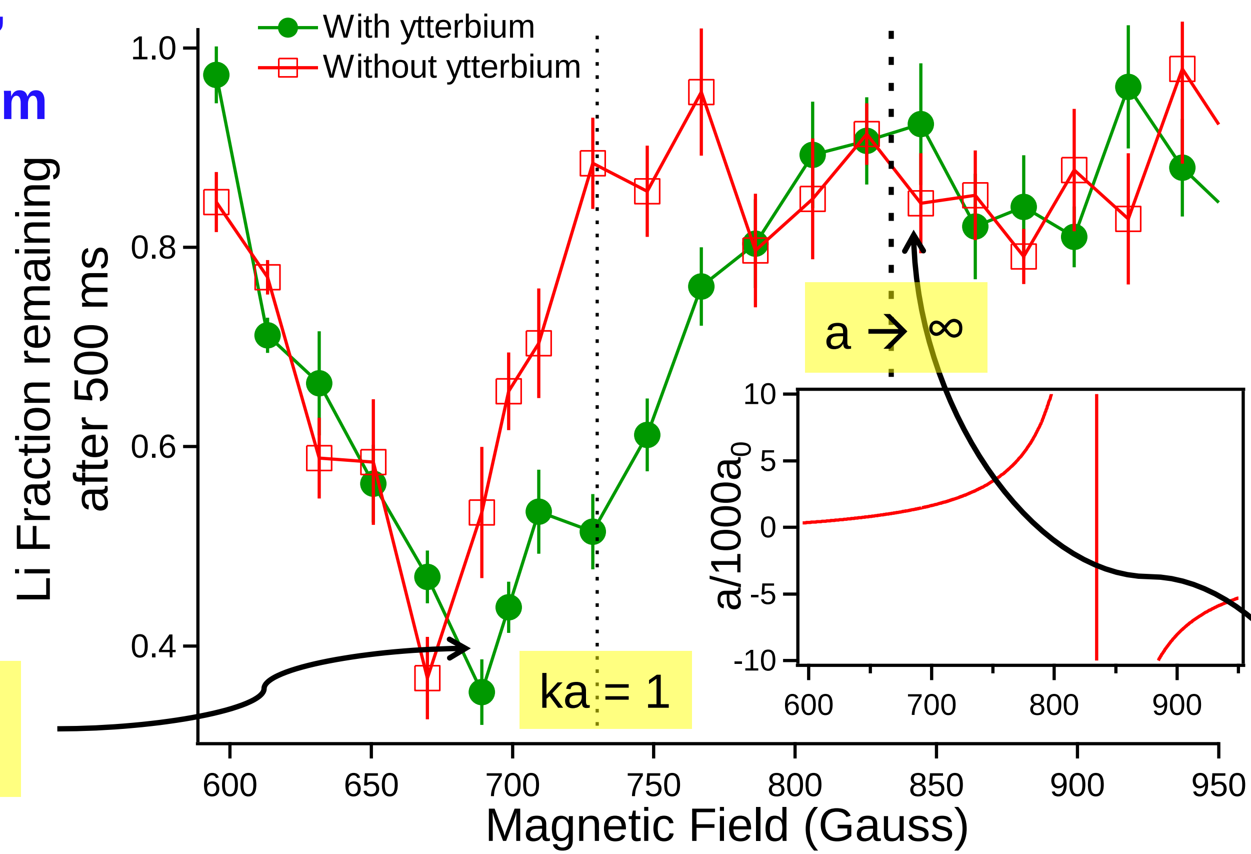
Increased dimer stability ($a^{-3.3}$)

Earlier experiments: Ketterle/Salomon/Grimm/Hulet/Thomas (2002/2003)

Theory: Petrov, Shlyapnikov, Salomon, Kokkelmans, Chin, Grimm, Ho, others

Collisional Stability near Li Feshbach

"Loss" Spectrum



Lossy Region

Stable Region (at unitarity)

a^6 $\quad \mathrm{Li}|1\rangle + \mathrm{Li}|2\rangle + \mathrm{Li} \rightleftharpoons \mathrm{Li}_2^s + \mathrm{Li} \quad (+\epsilon_\mathrm{B}) \qquad (\mathrm{I})$

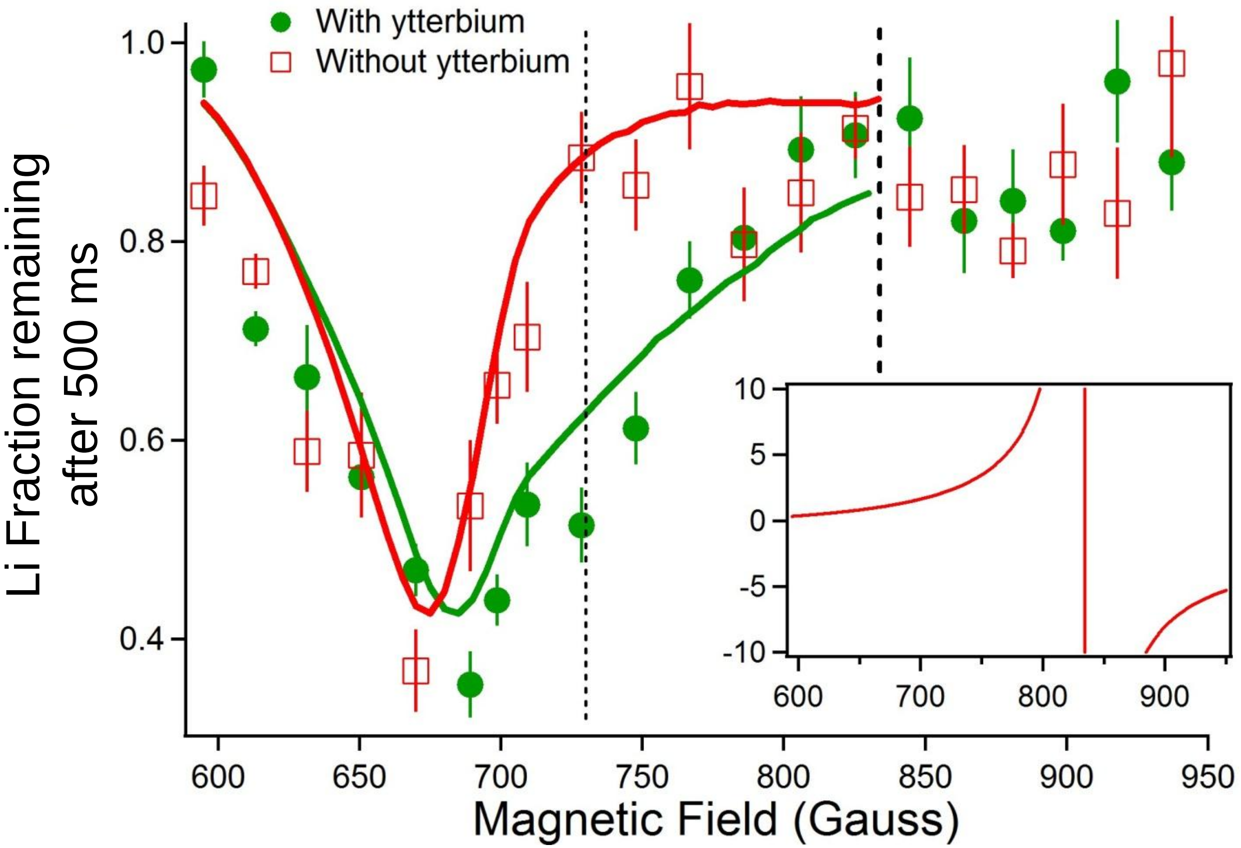
$a^{-3.3}$ $\quad \mathrm{Li}_2^s + \mathrm{Li} \rightarrow \mathrm{Li}_2^d + \mathrm{Li} \quad (+\epsilon_\mathrm{D}) \qquad (\mathrm{II})$

a^4 $\quad \mathrm{Li}|1\rangle + \mathrm{Li}|2\rangle + \mathrm{Yb} \rightleftharpoons \mathrm{Li}_2^s + \mathrm{Yb} \quad (+\epsilon_\mathrm{B}) \qquad (\mathrm{III})$

a^{-1} $\quad \mathrm{Li}_2^s + \mathrm{Yb} \rightarrow \mathrm{Li}_2^d + \mathrm{Yb} \quad (+\epsilon_\mathrm{D}) \qquad (\mathrm{IV})$

a^2 $\quad \mathrm{Li}|1\rangle + \mathrm{Li}|2\rangle + \mathrm{Yb} \rightarrow \mathrm{Li}_2^d + \mathrm{Yb} \quad (+\epsilon_\mathrm{D}) \qquad (\mathrm{V})$

Scaling to Other Fields

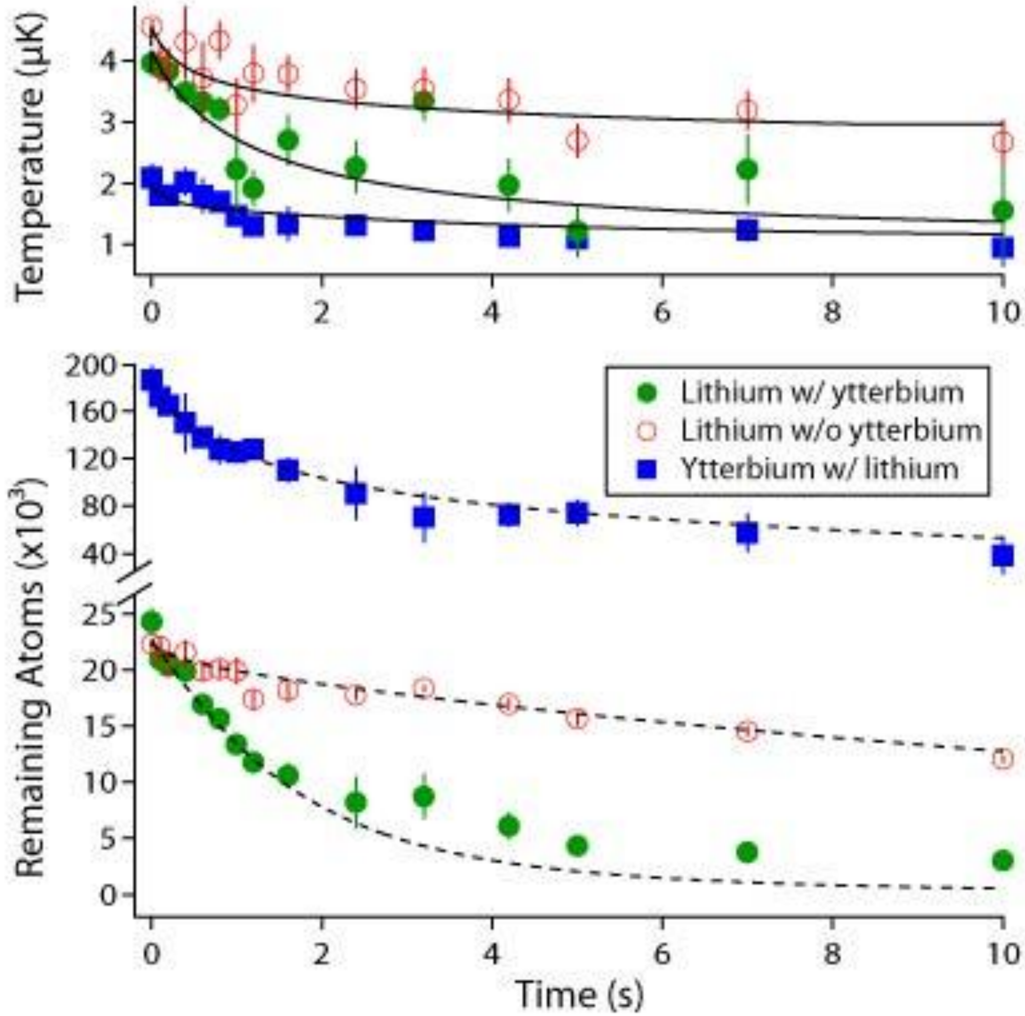


Scaling from rate constant measurements at 710 G

Scaling laws: Petrov/Shlyapnikov, D'Incao/Esry, others (2003 onwards)

Evolution at unitarity

(810 G, ka=+6)

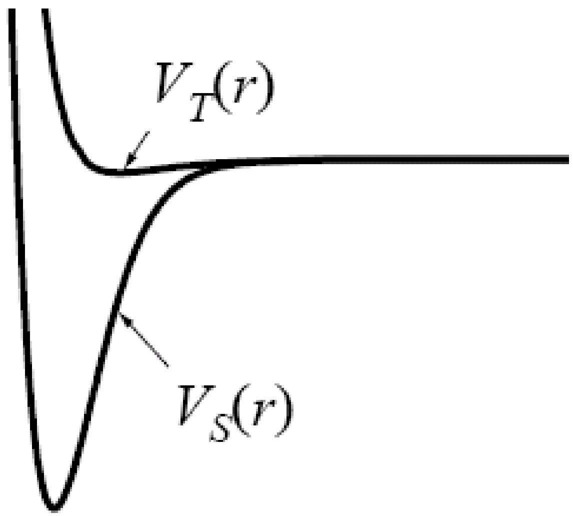


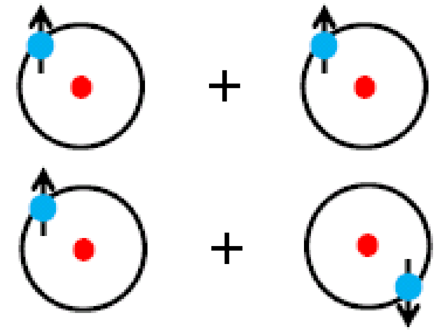
Good collisional stability with Yb
Clear inter-species thermalization.

A. Khramov et al
PRA **86**, 032705 (2012)

Related work in Innsbruck on K-Li: PRL **103**, 223203 (2009)

Feshbach Resonance in Li-Yb?

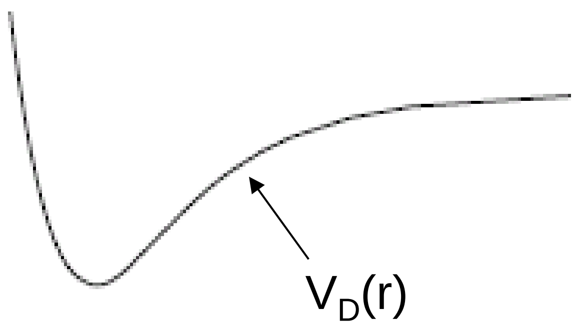


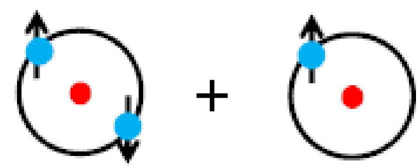


triplet

singlet

Collisions in a bi-alkali system.
Supports strong Fesbach resonances





doublet

Collisions in a spin-zero+alkali system.
“Usual” Feshbach resonance not supported

No resonances seen yet in
expts with spin-zero +alkalis

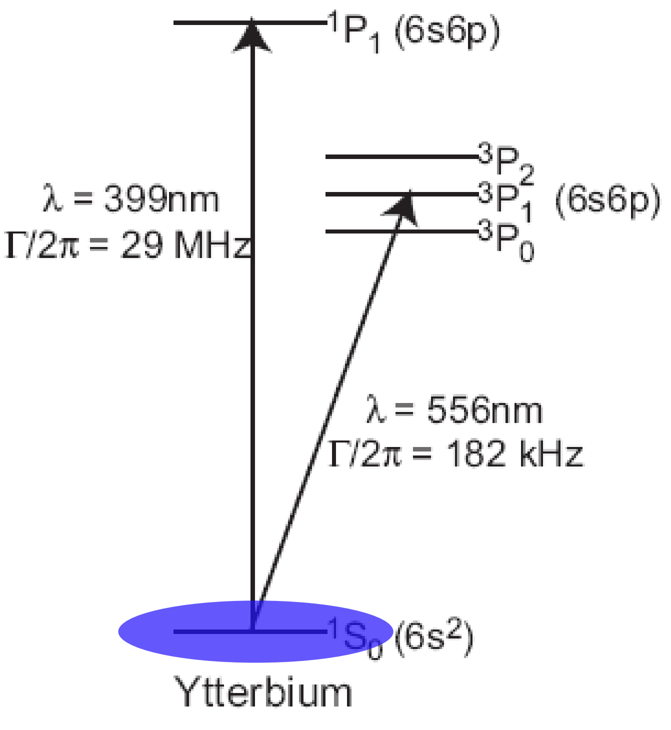
Coupling through Li hyp const
and Yb nuclear spin.
Predicted width of ~ 1 μ/mG at > 1kG

Brue and Hutson, PRL **108**, 043201 (2012)

Feshbach Resonance in Li-Yb?

(Too?) Narrow Feshbach resonance with *ground* Yb

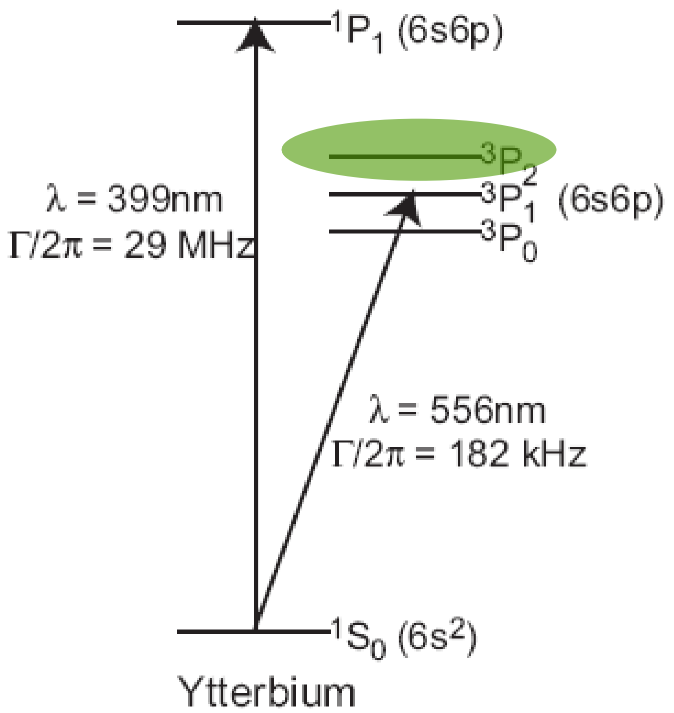
Li +



Feshbach Resonance in Li-Yb?

(Possible) broad Feshbach resonance with *metastable* Yb*

Li +



15s natural lifetime

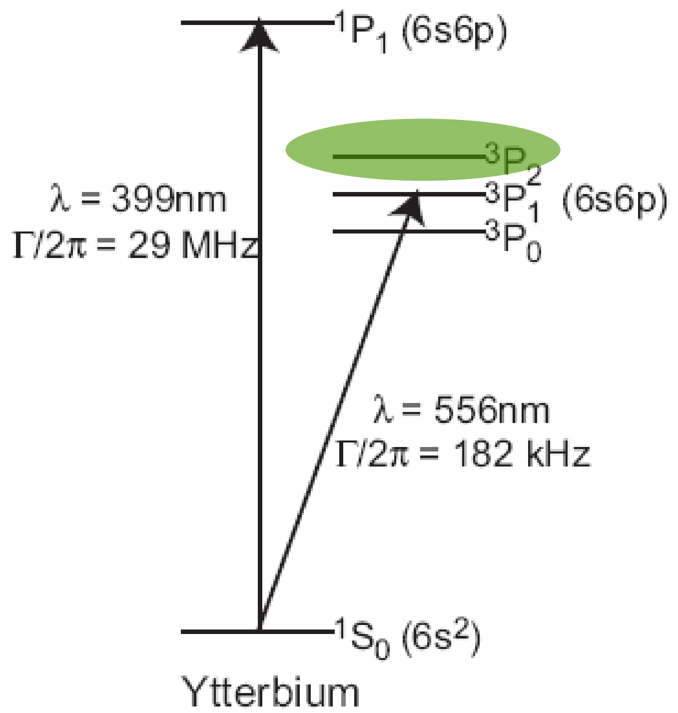
Resonances in Yb+Yb*: Takahashi group - PRL **110**, 173201 (2013)

Coupling through anisotropic interactions: S. Kotochigova group - PRL **109**, 103002 (2012)

Feshbach Resonance in Li-Yb*

Broad Feshbach resonances with *metastable* Yb* (Kotochigova; Hutson)

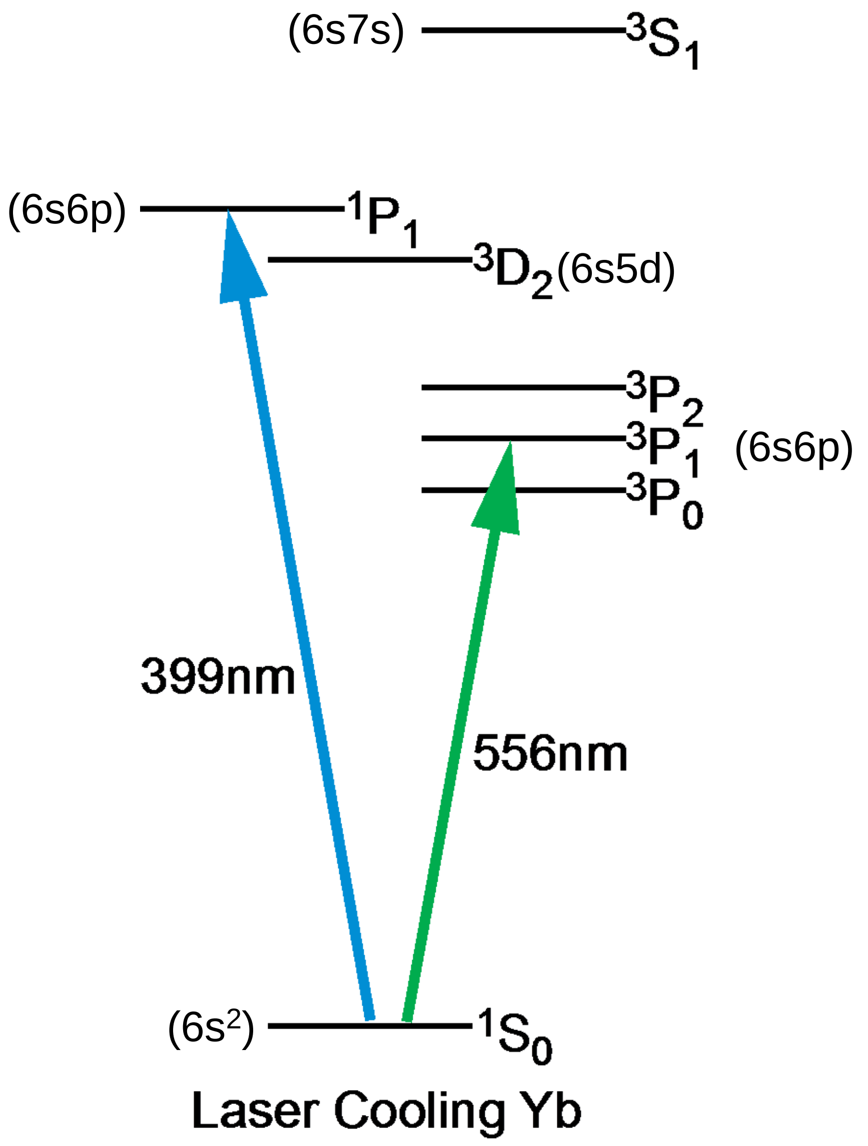
Li +



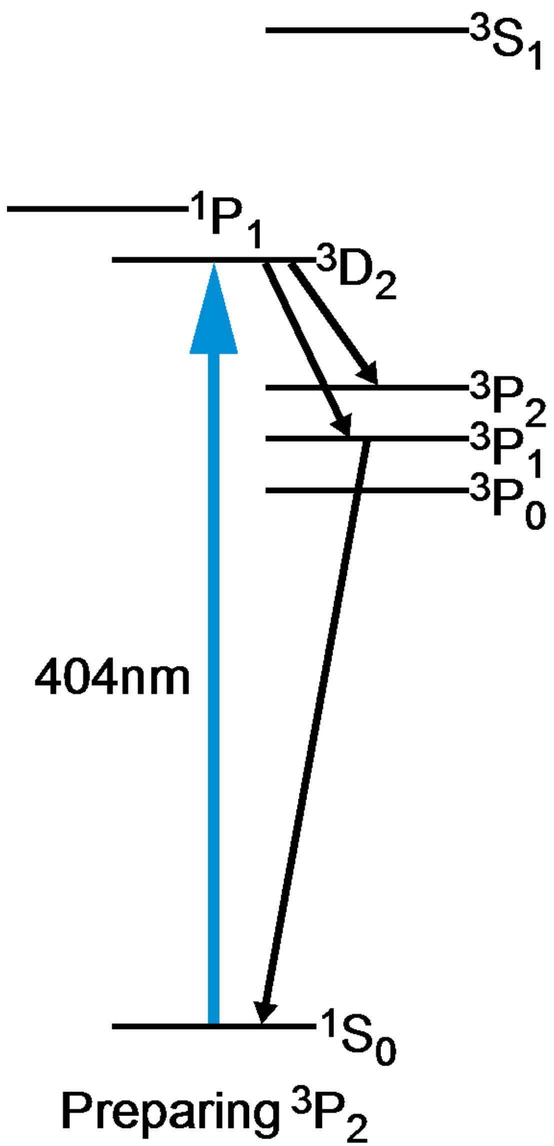
These resonances can also be lossy.

Gonzalez-Martinez and Hutson, PRA **88**, 020701R (2013).
Parallel calculations in S. Kotochigova group

Preparing and Monitoring the $^3P_2$ State

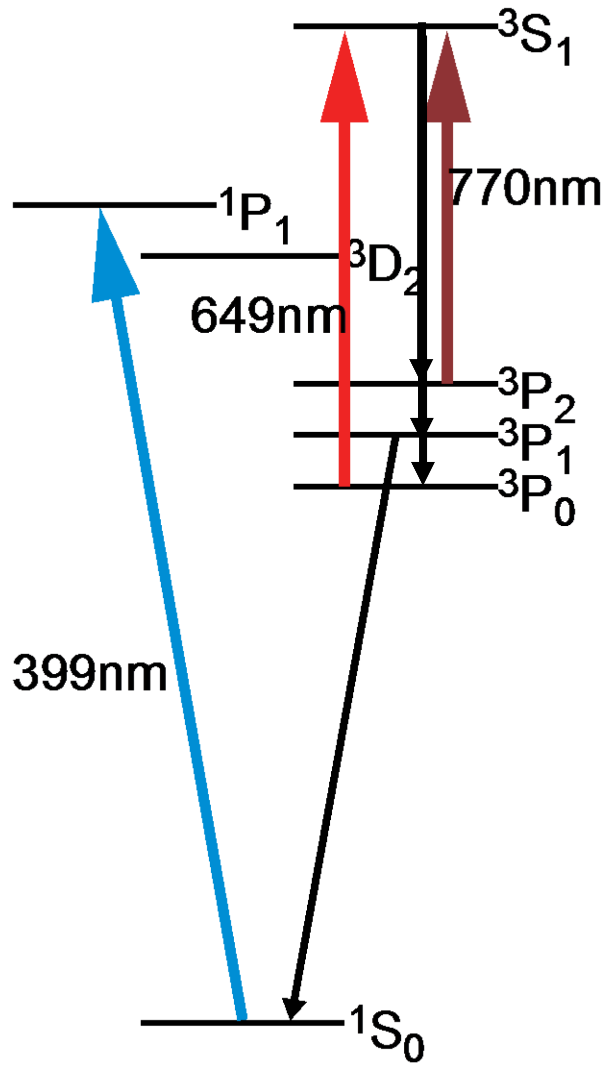


Preparing and Monitoring the $^3P_2$ State



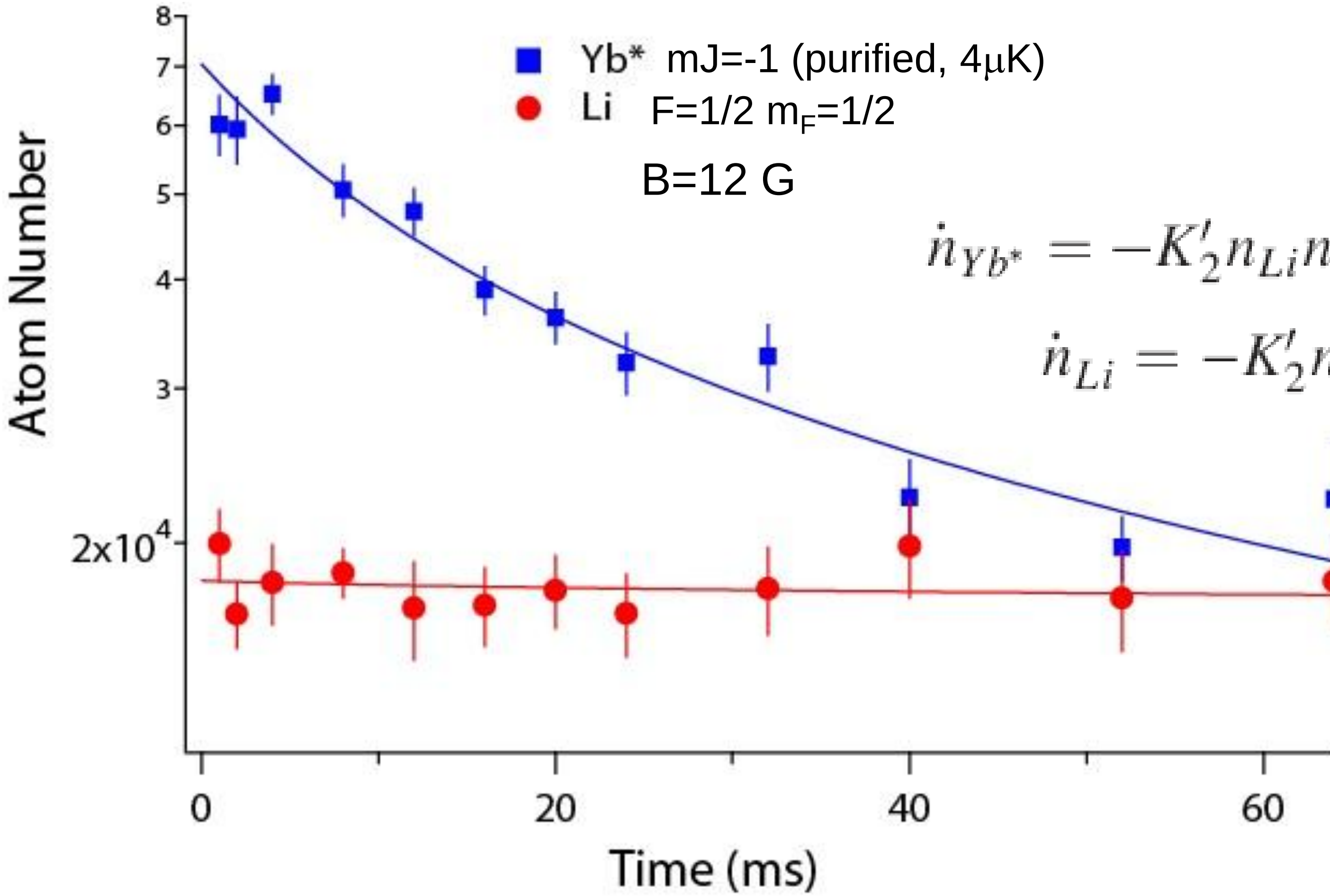
Prior 1S0→3D2 work: Bowers et al PRA **59**, 3513 (1999), Yamaguchi et al PRL (2008)

Preparing and Monitoring the $^3P_2$ State



Detecting $^3P_2$

Combining Ground Li and Excited Yb* Atoms



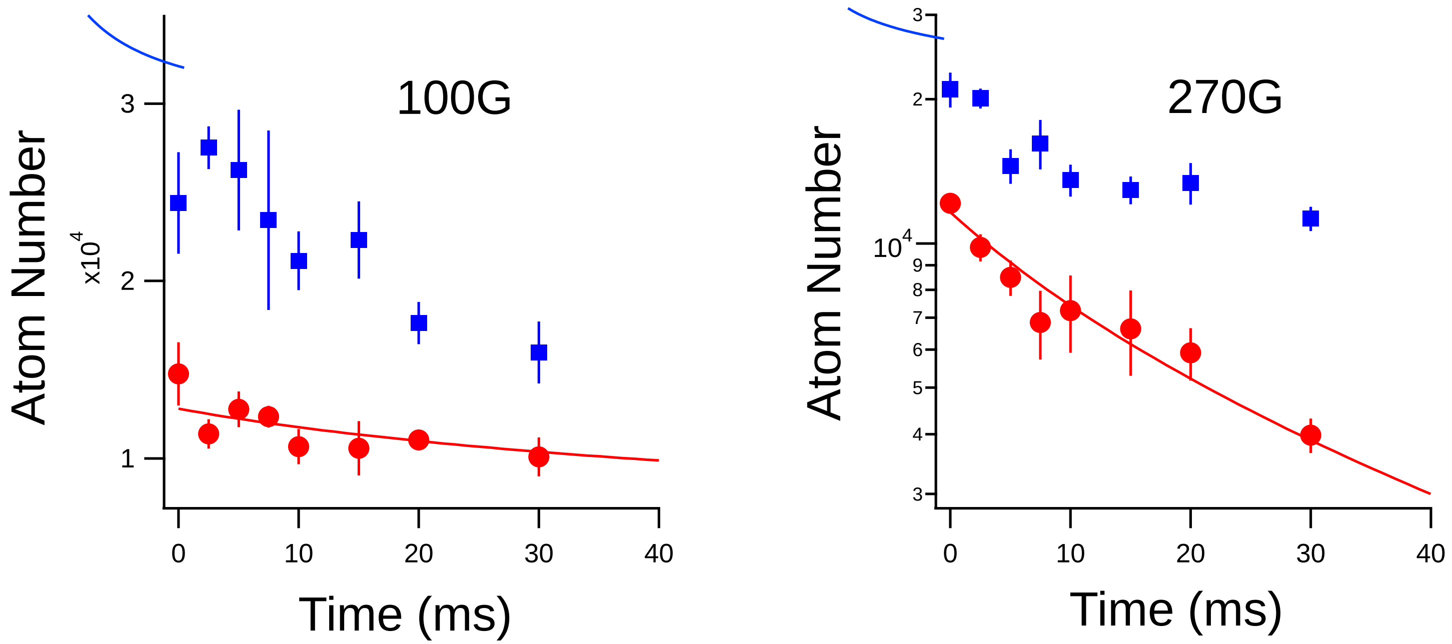
$$\dot{n}_{Yb^*} = -K_2' n_{Li} n_{Yb^*} - K_2 n_{Yb^*}^2 ,$$

$$\dot{n}_{Li} = -K_2' n_{Li} n_{Yb^*} ,$$

Yb*-Yb* 2 body decay constant K_2 = 2.5x10^{-11} cm^3/s
Yb*-Li 2 body decay constant K_2' < 3x10^{-12} cm^3/s

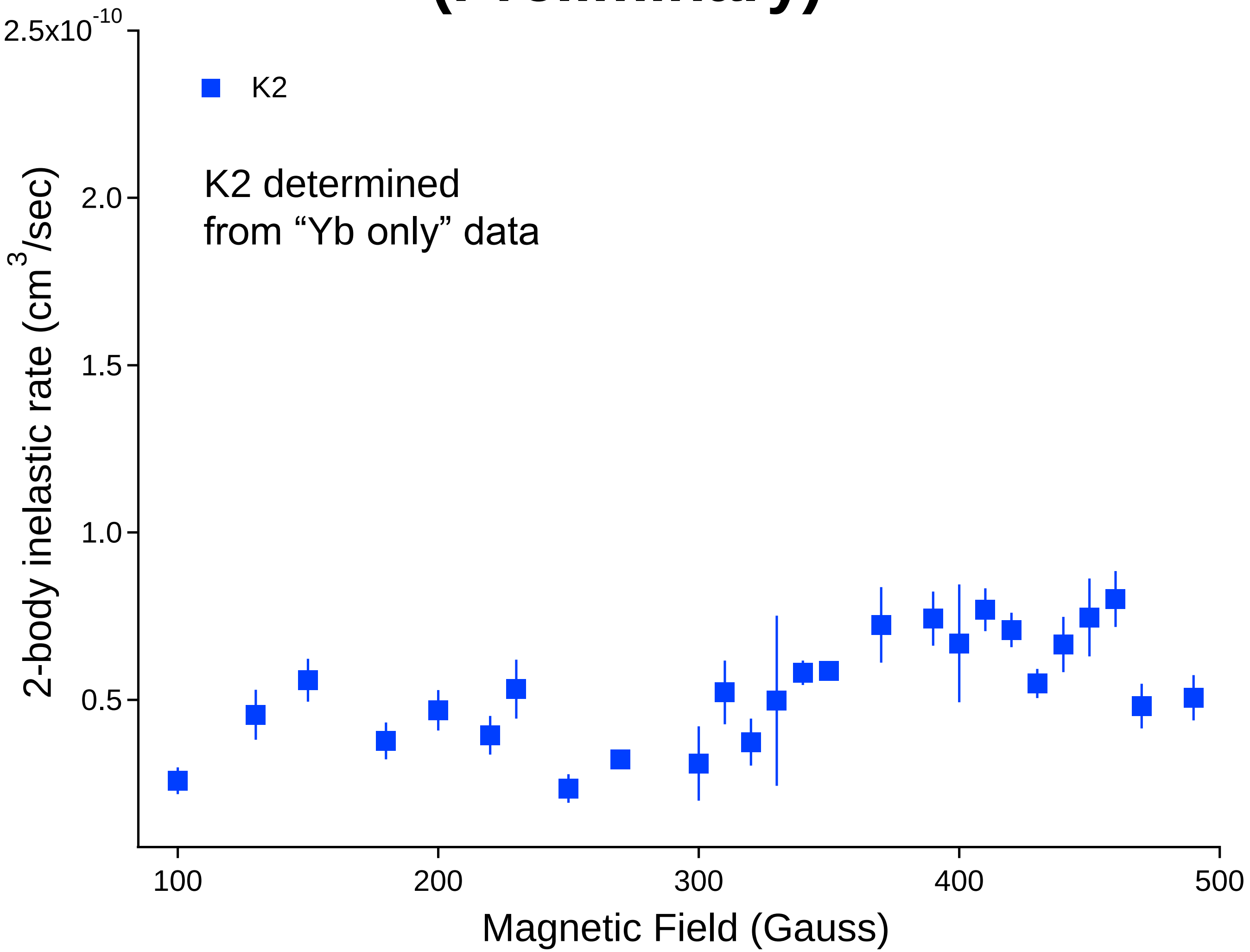
A. Khramov et al. PRL **112**, 033201 (2014)

Li-Yb* Field dependent losses



Loss Spectroscopy of Li and Yb*

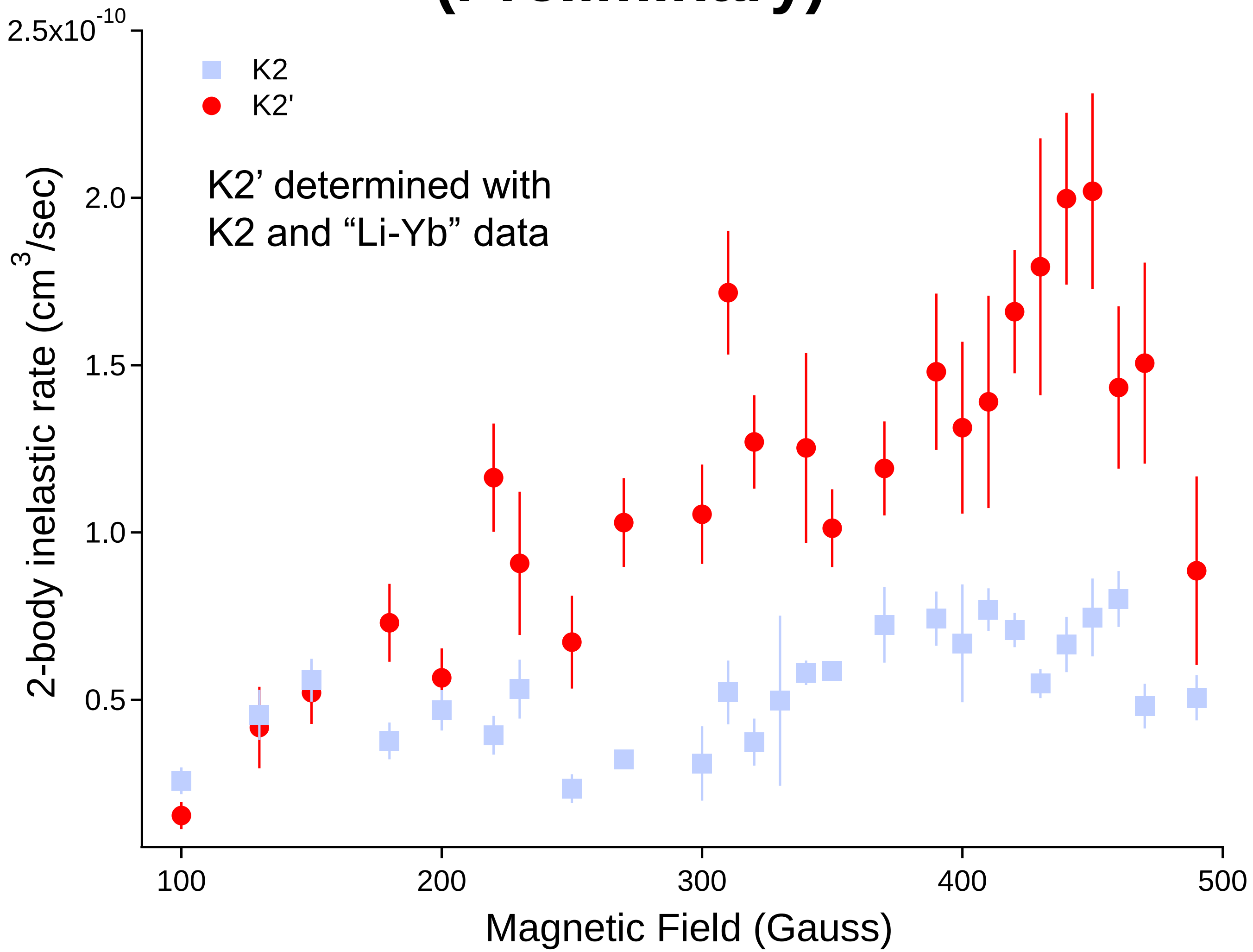
(Preliminary)



Initial peak densities: $n_{Yb(Li)}$ = 0.8(2.2) $10^{12}/cm^3$. Temp ~ 1.6μK.

Loss Spectroscopy of Li and Yb*

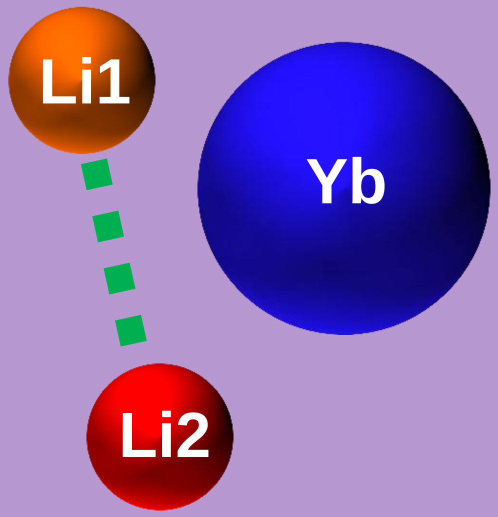
(Preliminary)



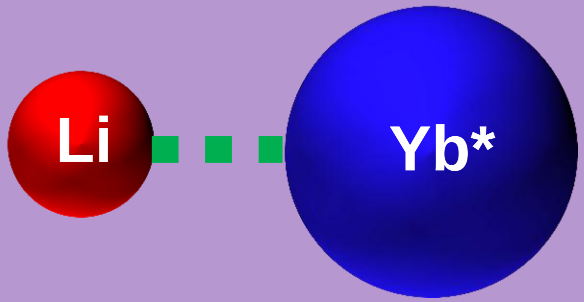
Initial peak densities: $n_{Yb(Li)}$ = 0.8(2.2) $10^{12}/cm^3$. Temp ~ 1.6μK.

Summary and Outlook

Yb as a bath or probe
with strongly-interacting
Lithium fermions



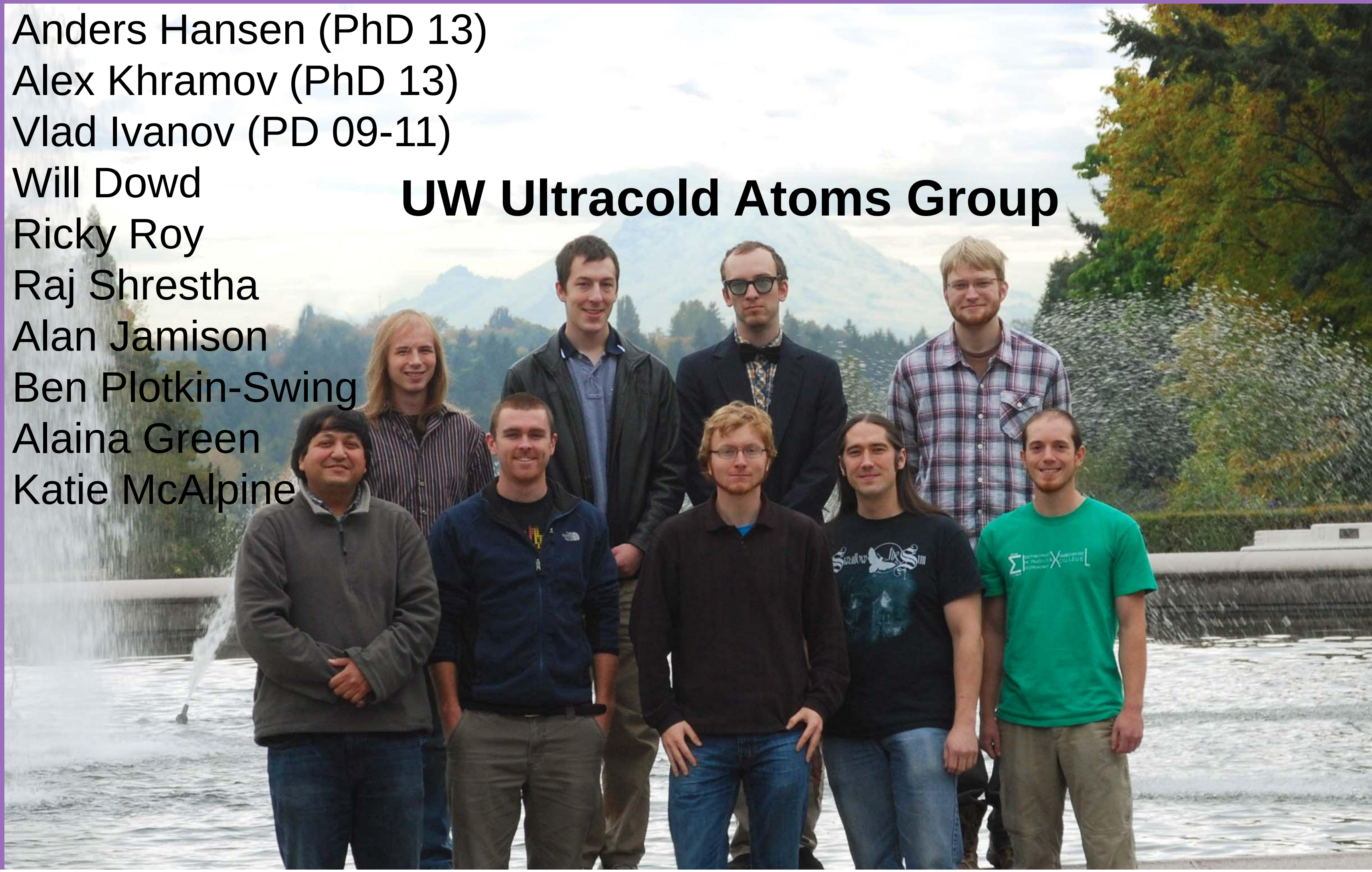
Li+Yb* system inelastics:
different spin states
2 vs 3-body evolution
LiYb molecules



Optical Lattice

Anders Hansen (PhD 13)
Alex Khramov (PhD 13)
Vlad Ivanov (PD 09-11)
Will Dowd
Ricky Roy
Raj Shrestha
Alan Jamison
Ben Plotkin-Swing
Alaina Green
Katie McAlpine

UW Ultracold Atoms Group



ARO: MURI