

Strongly Interacting Regimes in the Lithium-Ytterbium System



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Dilute Quantum Degenerate Gases

hydrogen 1 H 1.0079																	helium 2 He 4.0026	
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180	
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948	
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80	
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29	
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

* Lanthanide series

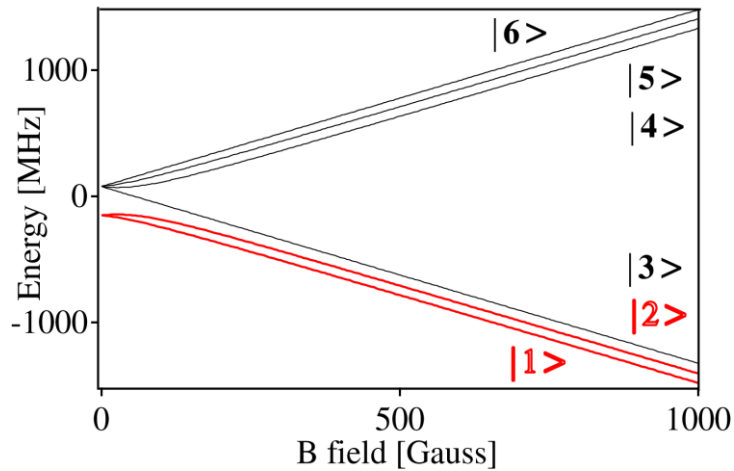
lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
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** Actinide series

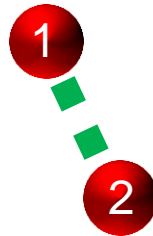
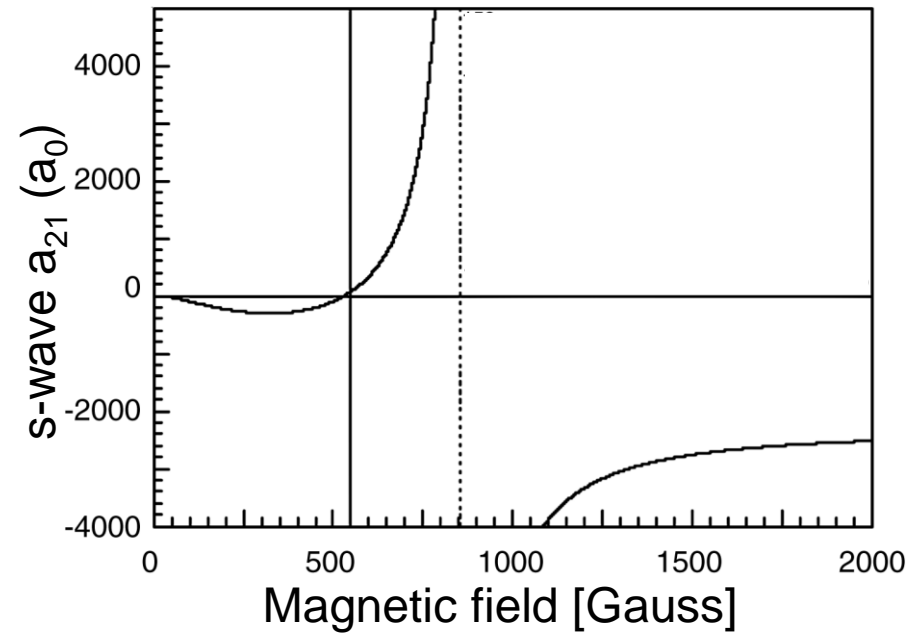
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]
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^6Li Fermi system

Ground State

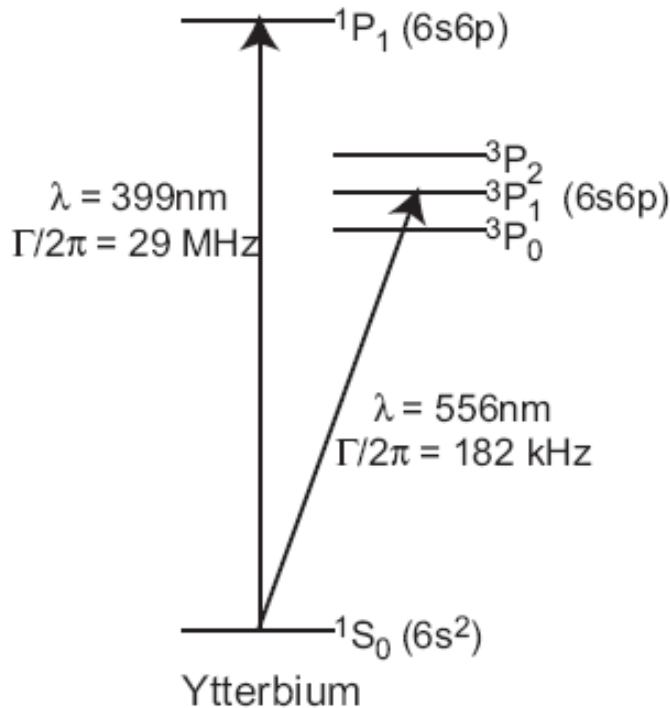


Magnetic Feshbach Resonance



Strongly interacting fermions
BEC of molecules
Fermi superfluid

Ytterbium: Heavy, 2-Electron Atom

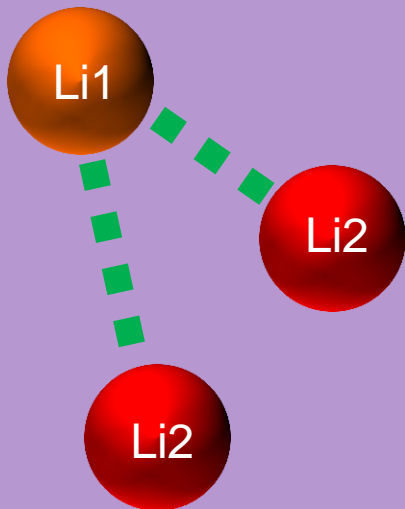
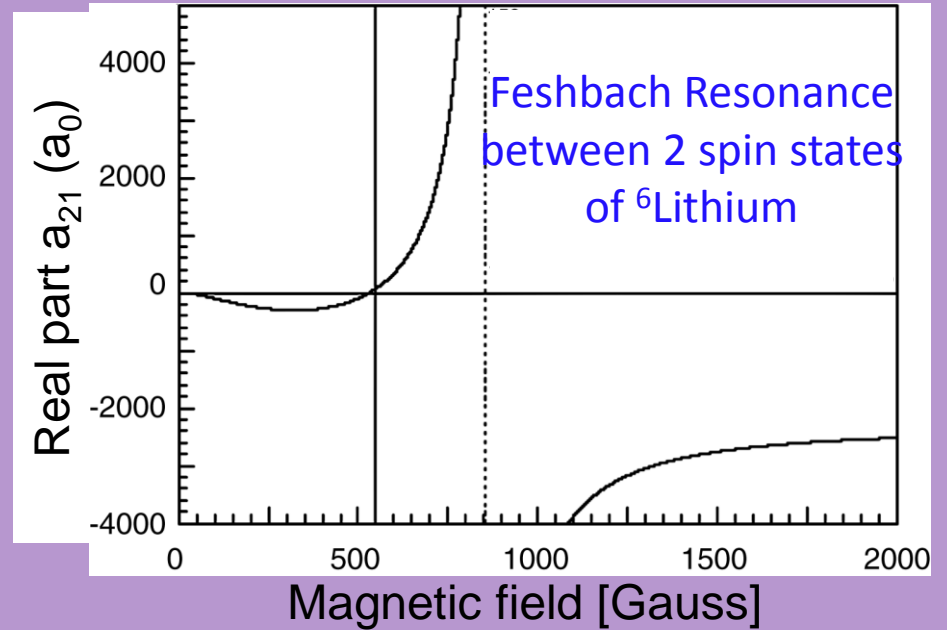
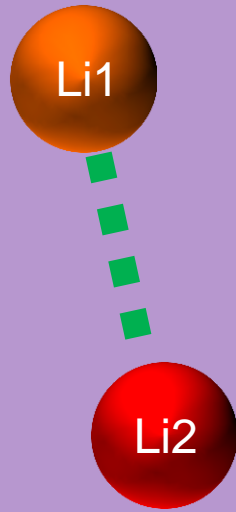


Isotope	Natural Abundance	Nuclear spin
^{168}Yb	0.0013	0
^{170}Yb	0.0305	0
^{171}Yb	0.143	1/2 F
^{172}Yb	0.219	0
^{173}Yb	0.161	$a=10.55\text{nm}$ 5/2 F
^{174}Yb	0.318	$a=5.55\text{nm}$ 0
^{176}Yb	0.127	0

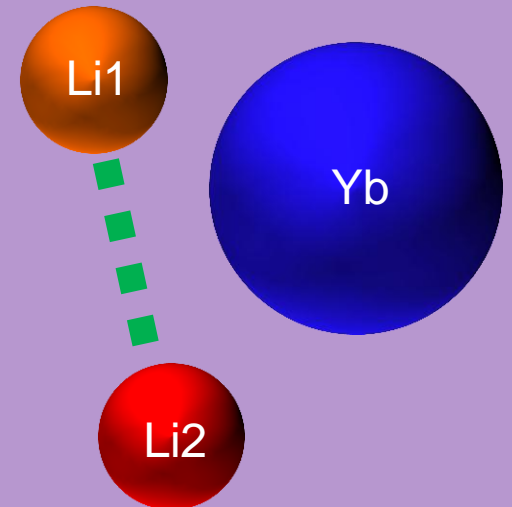
Precision expts, Atomic clock on $1S_0 \rightarrow 3P_0$.
 Yb fermions for quantum simulation [SU(N)].

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

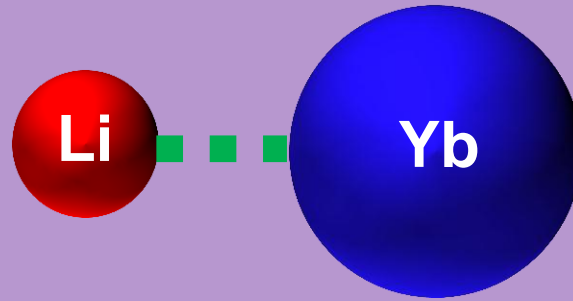
Strongly Interacting Regime I



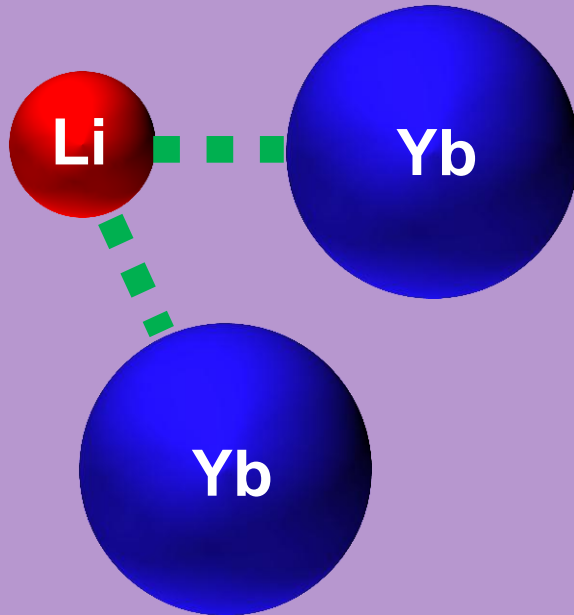
Questions of 3 particle stability
Can modify/probe resonance
Coolant/Thermometry



Strongly Interacting Regime II

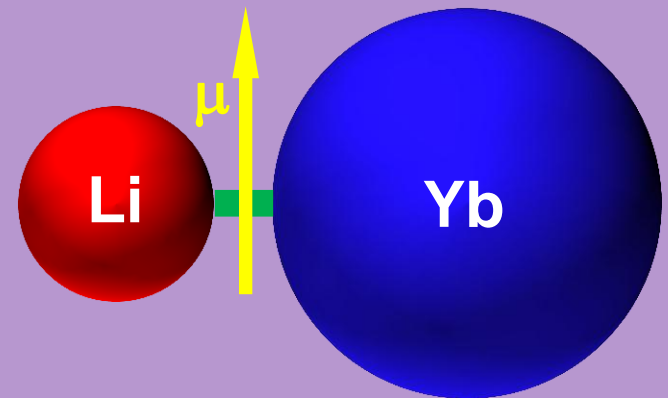


Feshbach Resonance
between Li and Yb.



Efimov Trimers

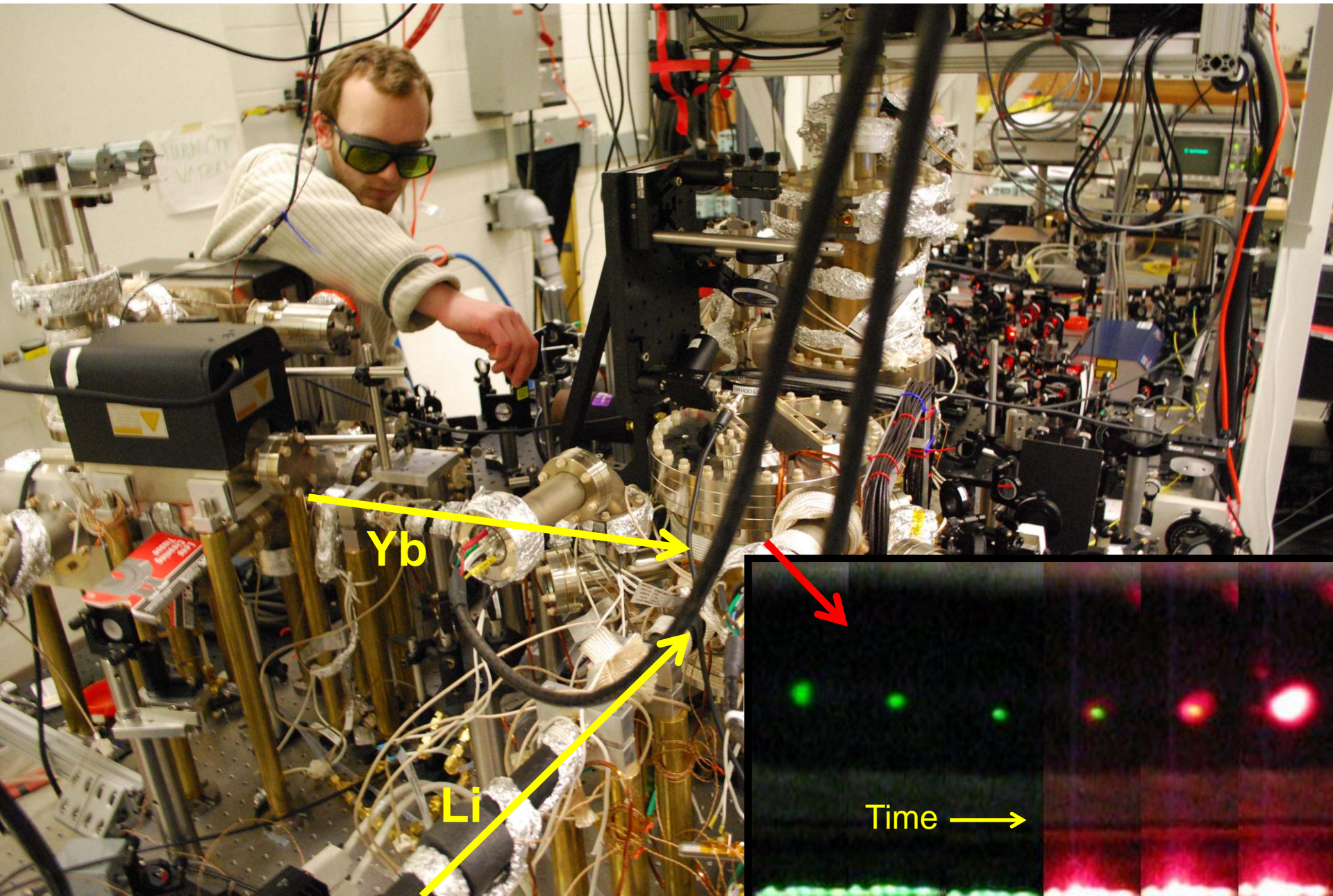
Heavy/light combinations
Bose/Fermi combinations



Paramagnetic Polar Molecule

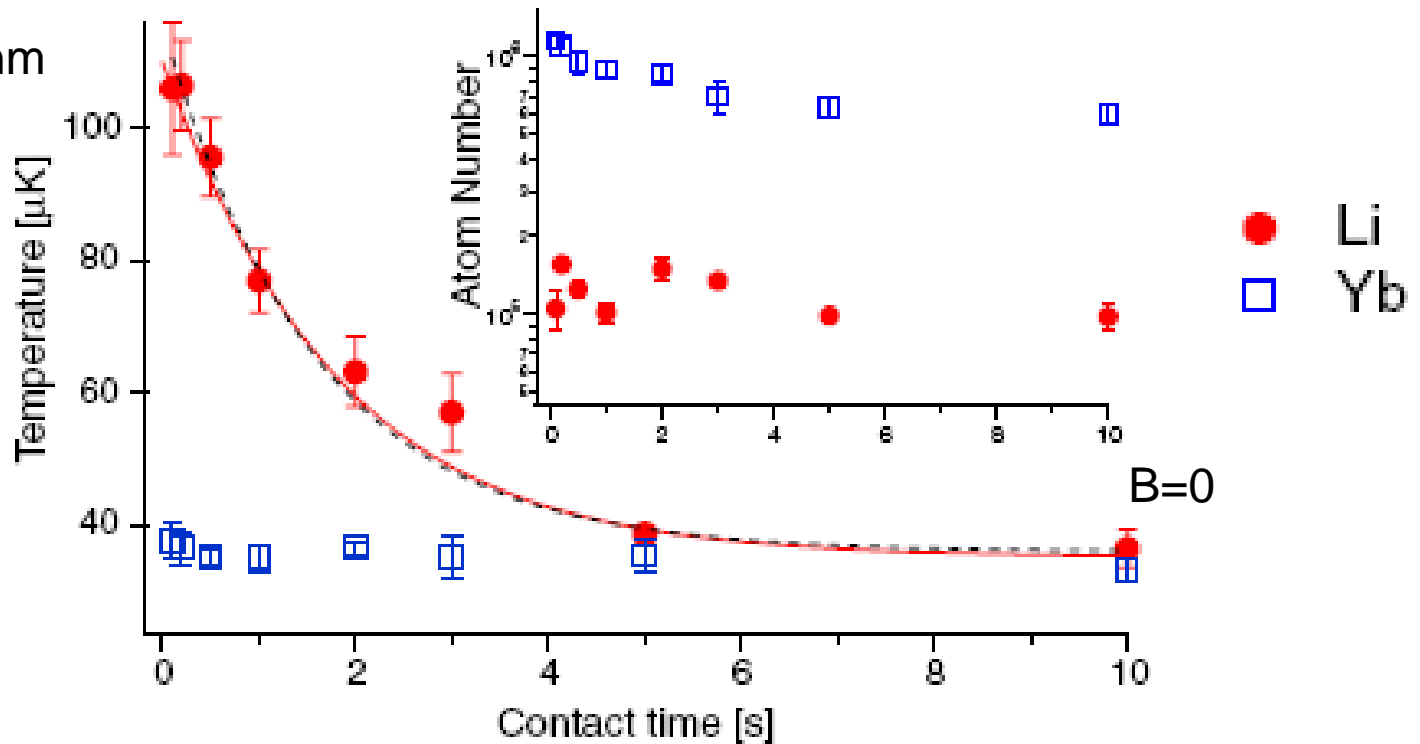
Spin-controlled chemistry
Quantum Simulation, spins on lattice

Li-Yb Apparatus



Combining Ground State ${}^6\text{Li}$ - ${}^{174}\text{Yb}$

Combined optical
dipole trap at 1064nm

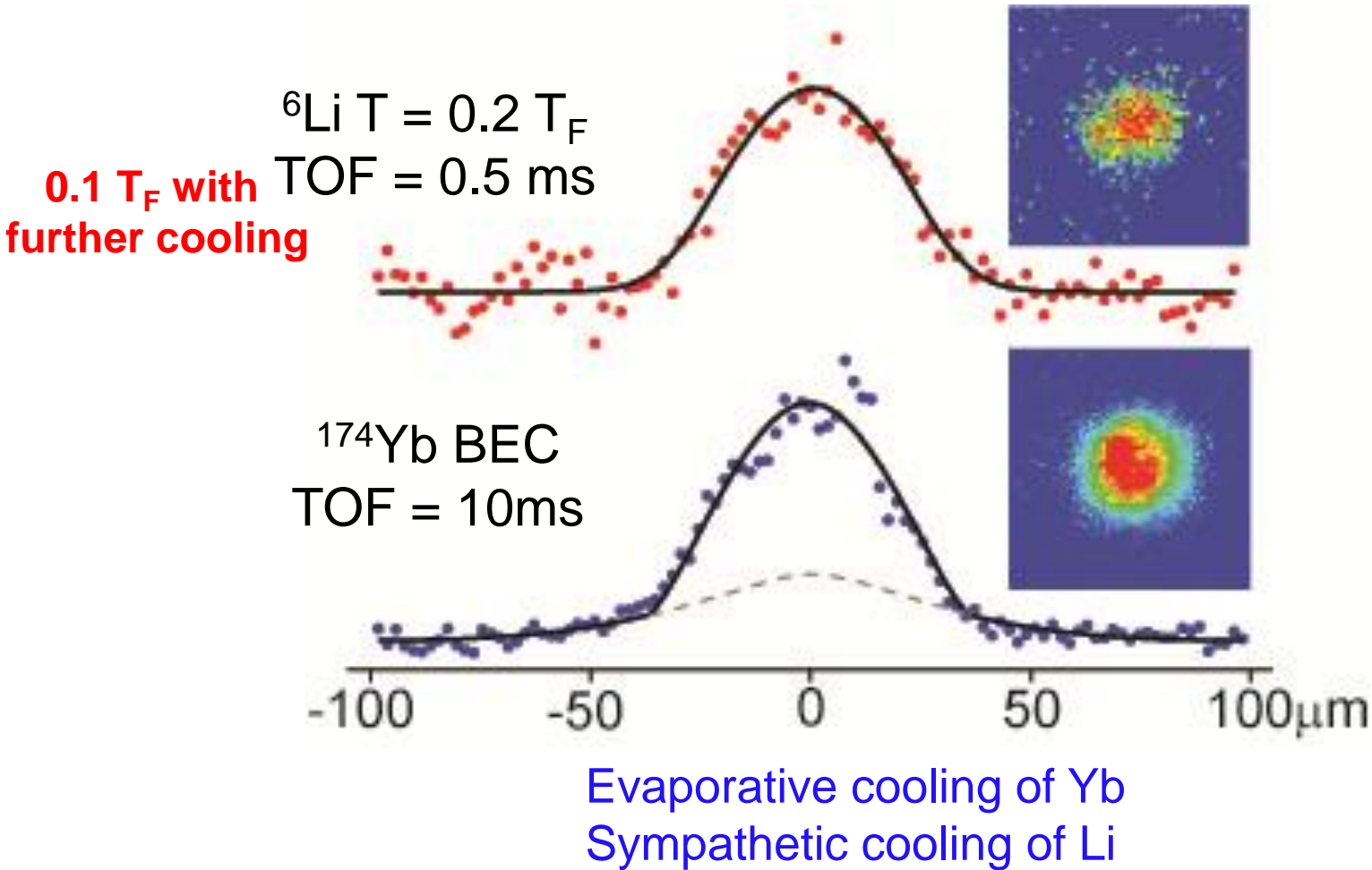


It's stable!

Extract $|a| = (13 \pm 3) a_0$ ($\sim 0.7\text{nm}$)

Other Yb isotopes + Li: similar weak interactions

Quantum Degenerate Li-Yb mixture

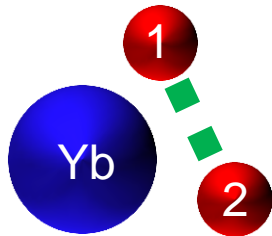


Similar results in Kyoto group (2011)

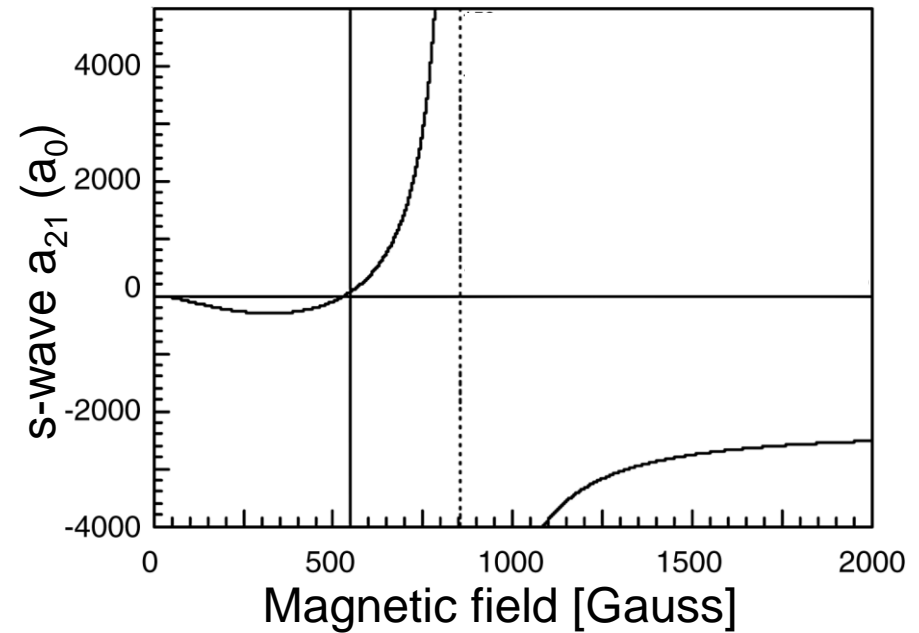
A. Hansen et al.
PRA **84**, 011606(R) (2011)

Yb+Li1+Li2 near Li Feshbach

Yb +



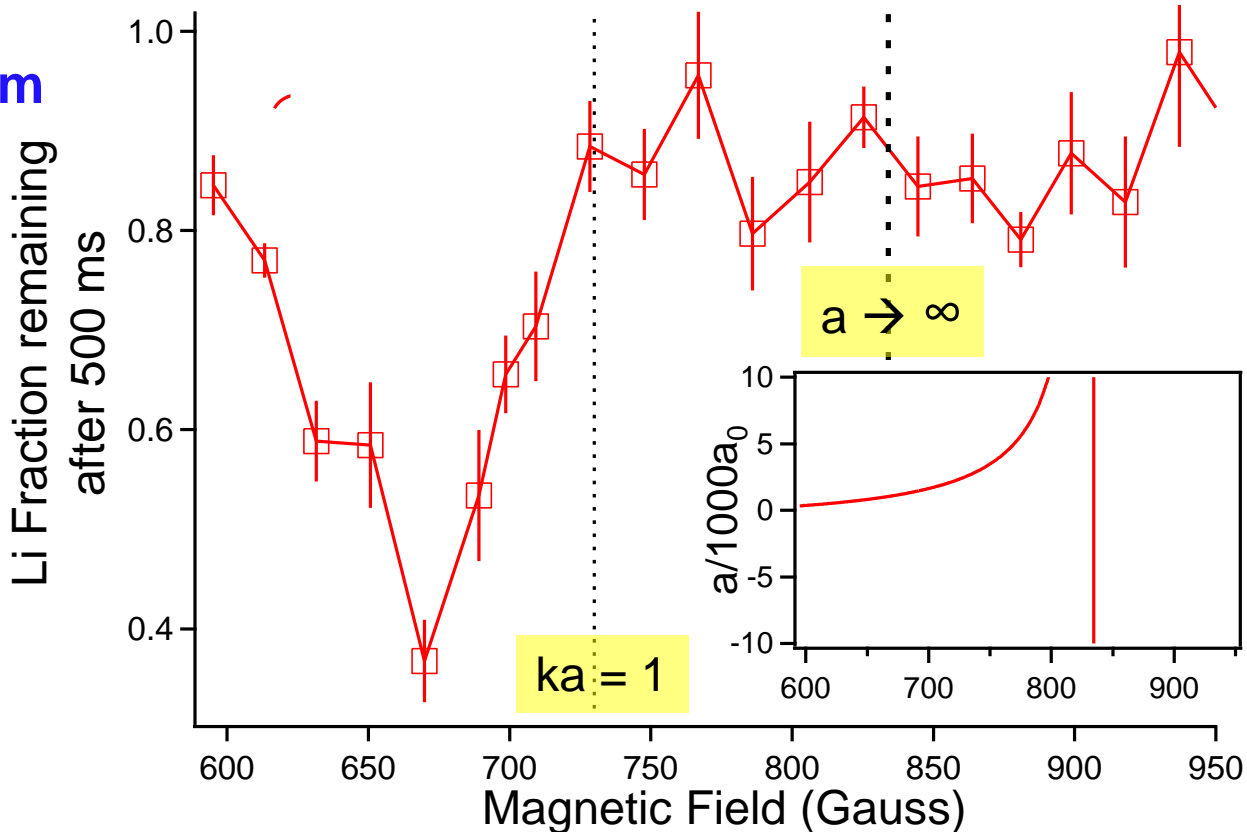
Magnetic Feshbach Resonance



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)

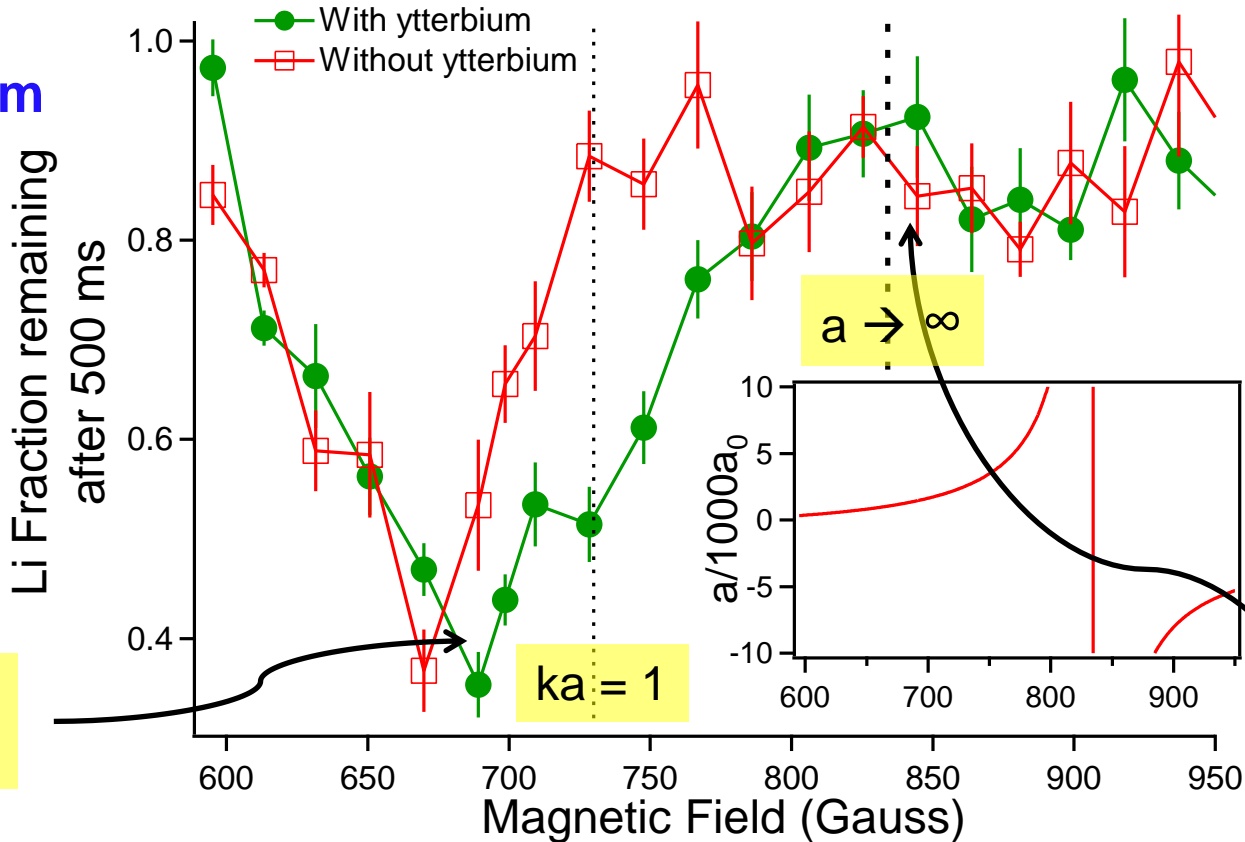


Increased dimer stability ($a^{-3.3}$)

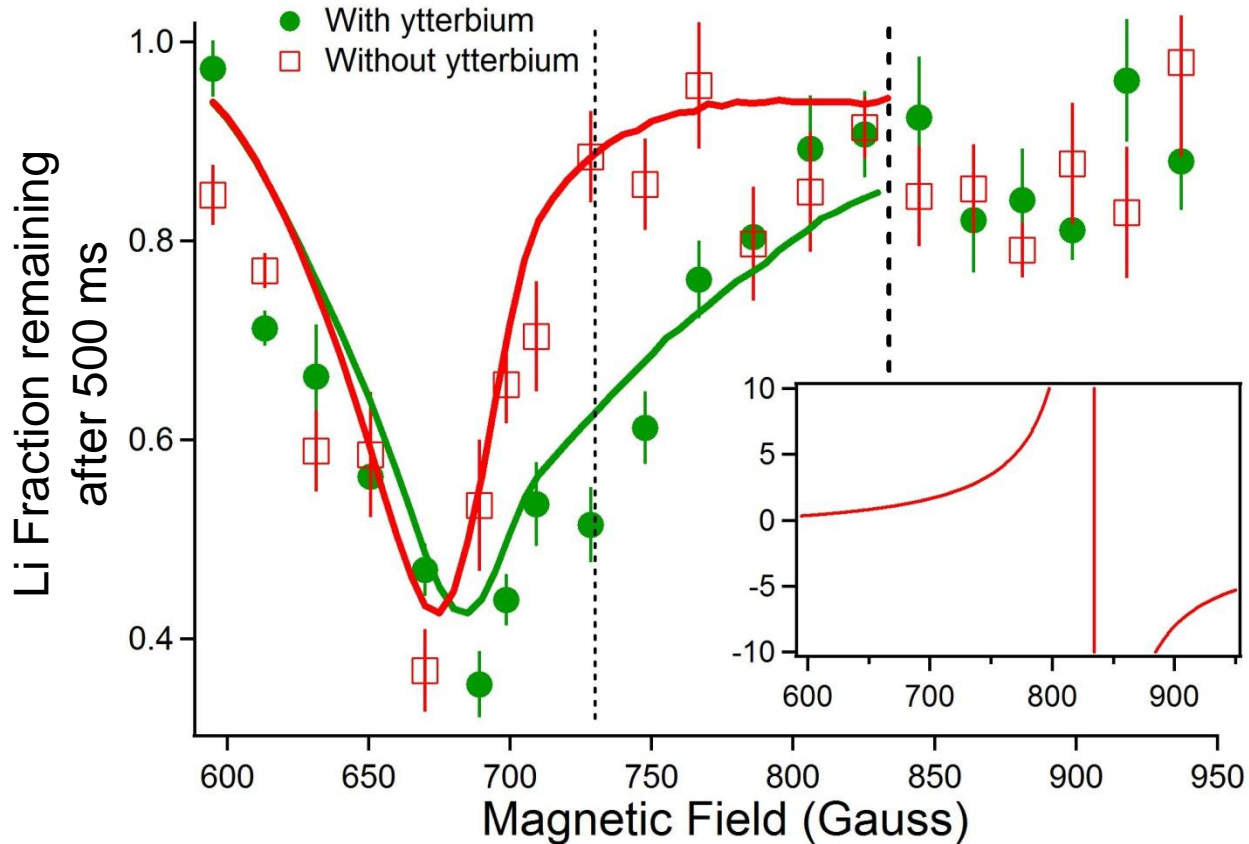
Earlier experiments: Ketterle/Salomon/Grimm/Hulet/Thomas (2002/2003)
Theory: Petrov, Shlyapnikov, Salomon, Kokkelmans, Chin, Grimm, Ho, others

Collisional Stability near Li Feshbach

“Loss”
Spectrum



Scaling to Other Fields

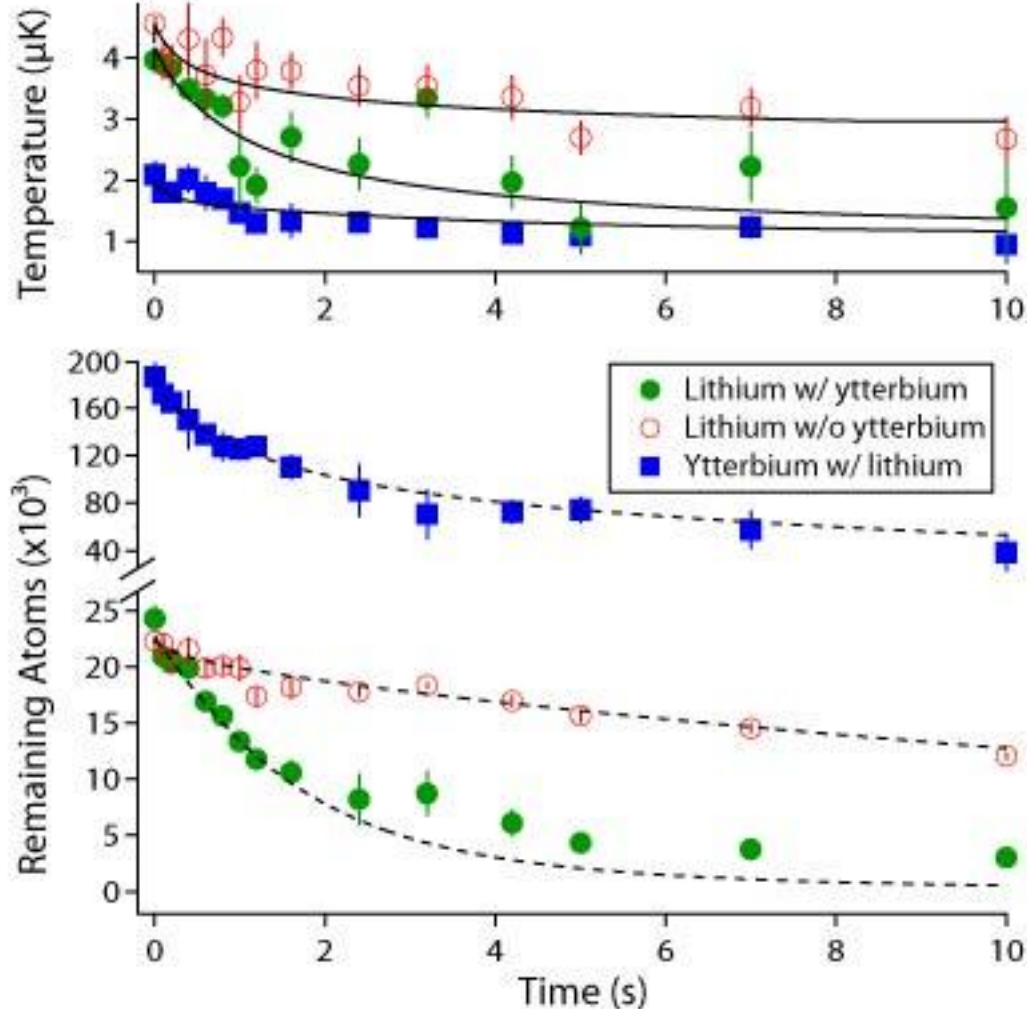


Scaling from rate constant measurements at 710 G

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

Evolution at unitarity

(810 G, $k_a=+6$)

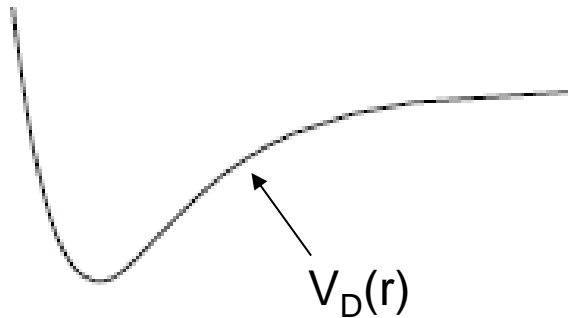
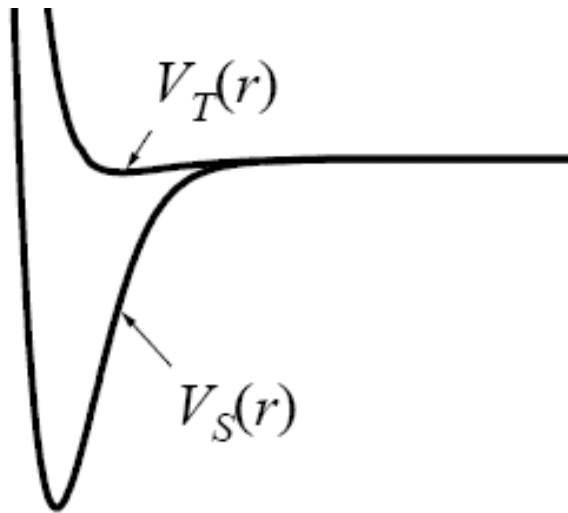


Good collisional stability with Yb
Clear inter-species thermalization.

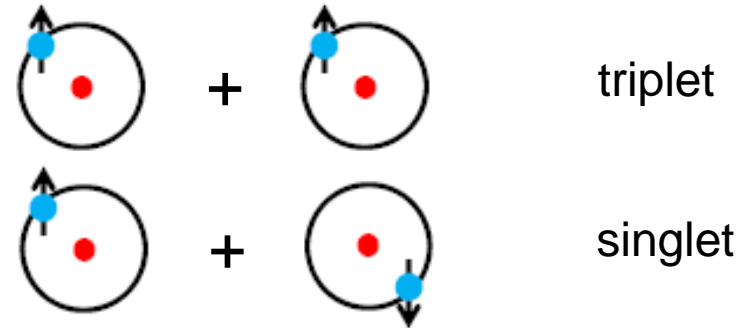
A. Khramov et al
PRA **86**, 032705 (2012)

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

Feshbach Resonance in Li-Yb?



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



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



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

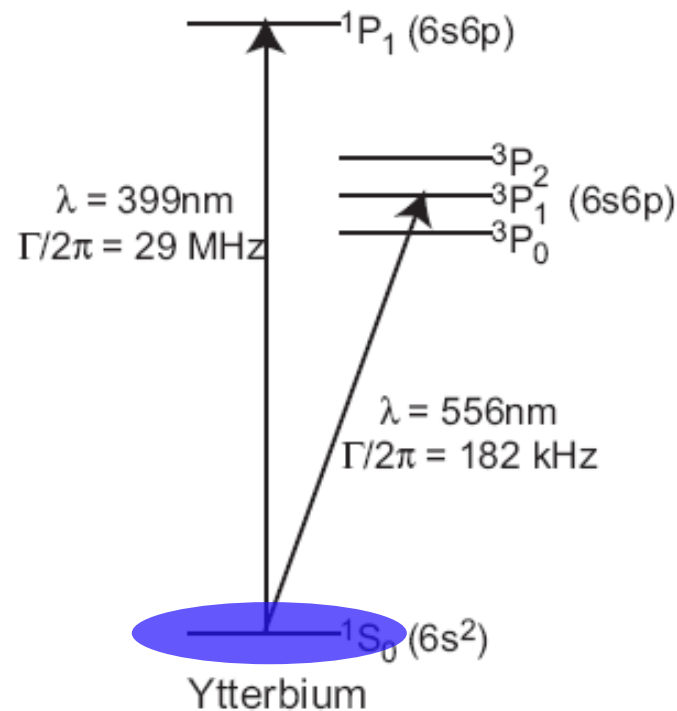
Coupling through Li hyp const
and Yb nuclear spin.
Predicted width of $\sim 1 \mu\text{mG}$ at $> 1\text{kG}$

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

Feshbach Resonance in Li-Yb?

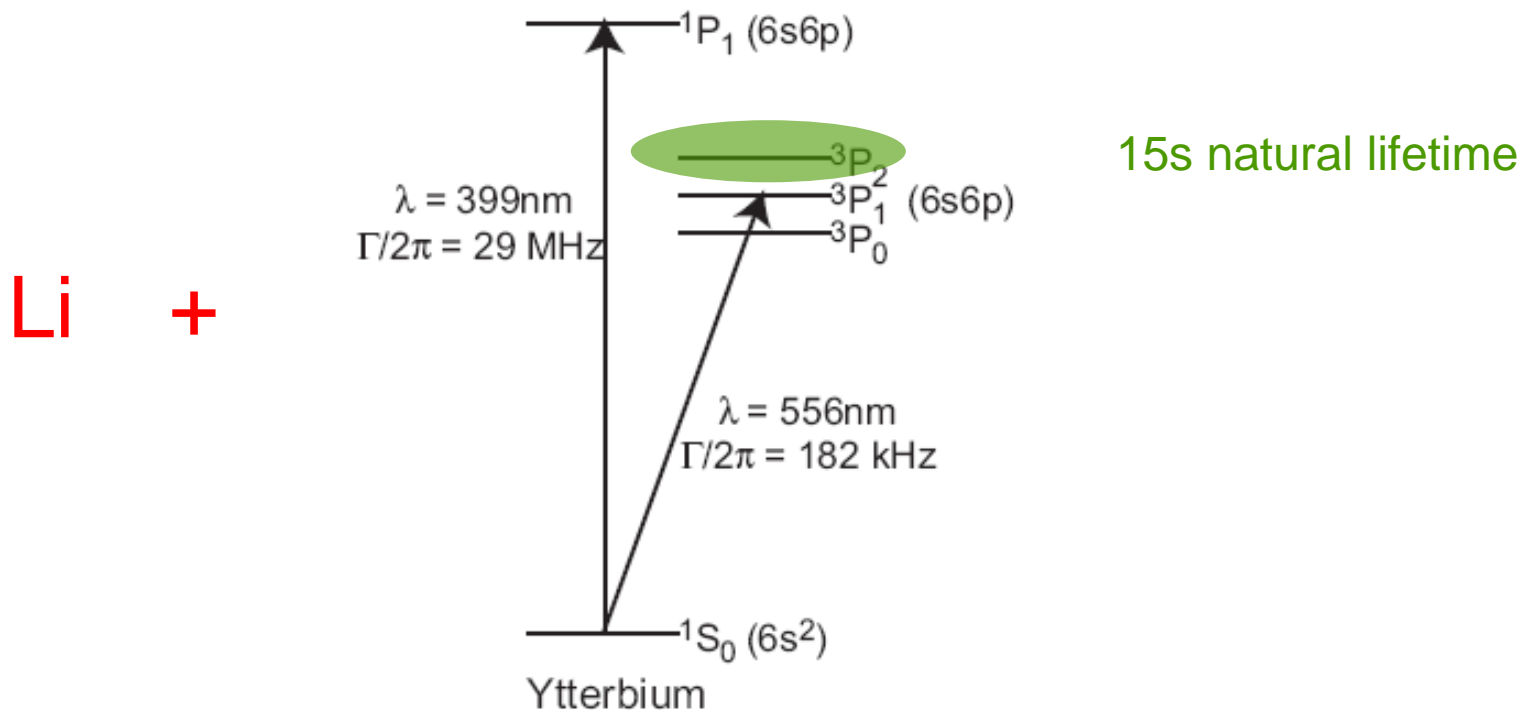
(Too?) Narrow Feshbach resonance with *ground* Yb

Li +



Feshbach Resonance in Li-Yb?

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

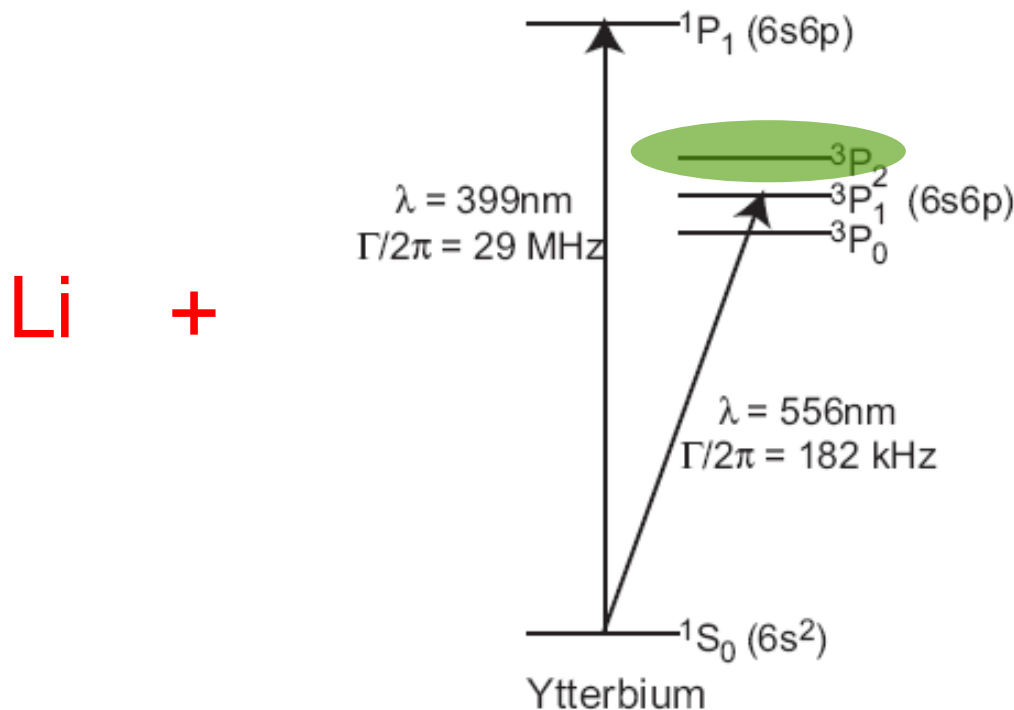


Resonances in Yb+Yb*: Takahashi group - PRL **110**, 173201 (2013)

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

Feshbach Resonance in Li-Yb*

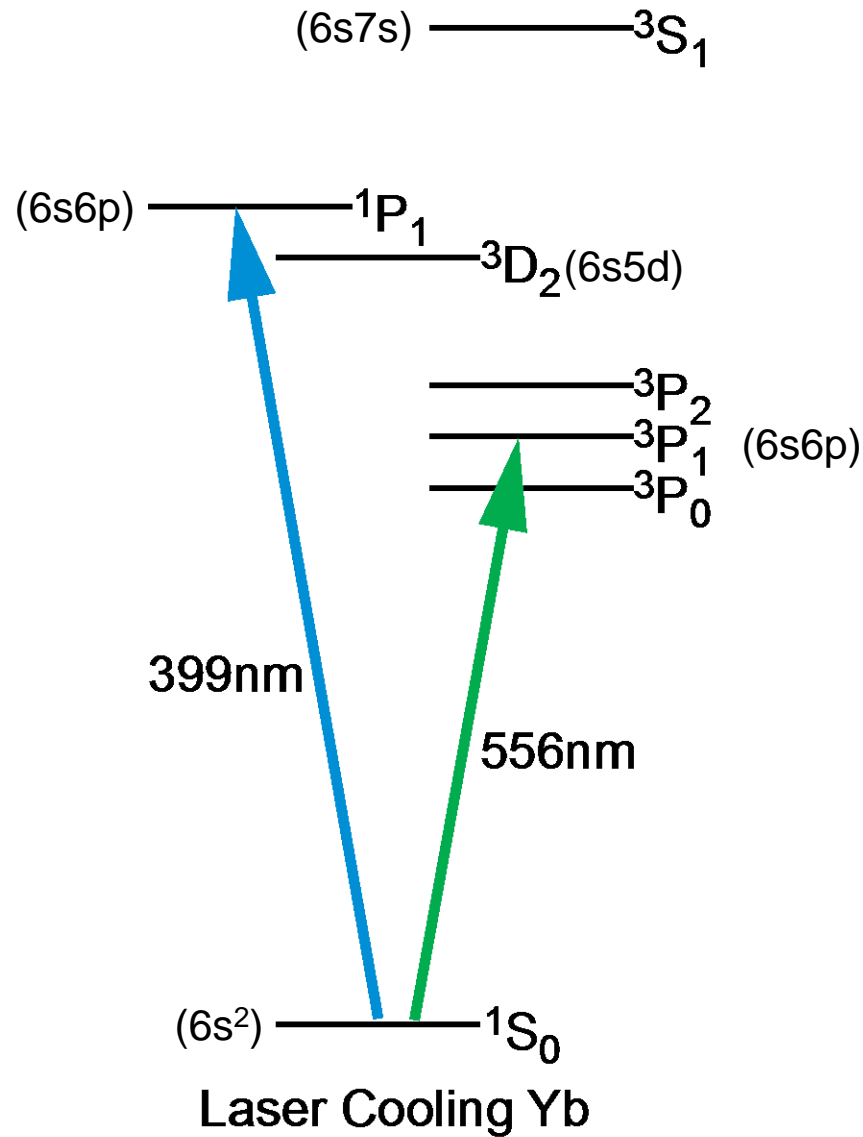
Broad Feshbach resonances with
metastable Yb* (Kotochigova; Hutson)



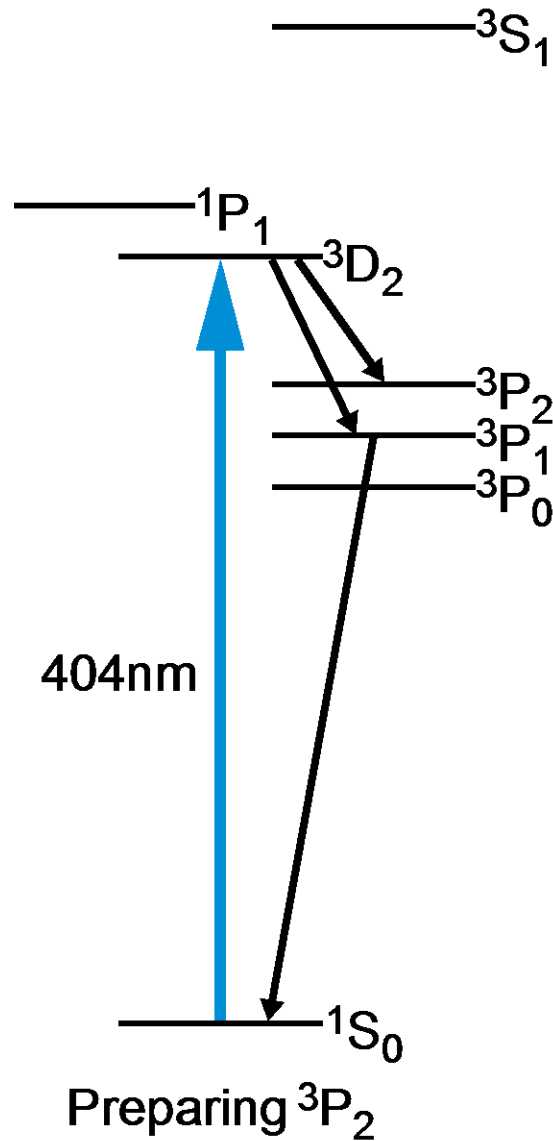
These resonances
can also be lossy.

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

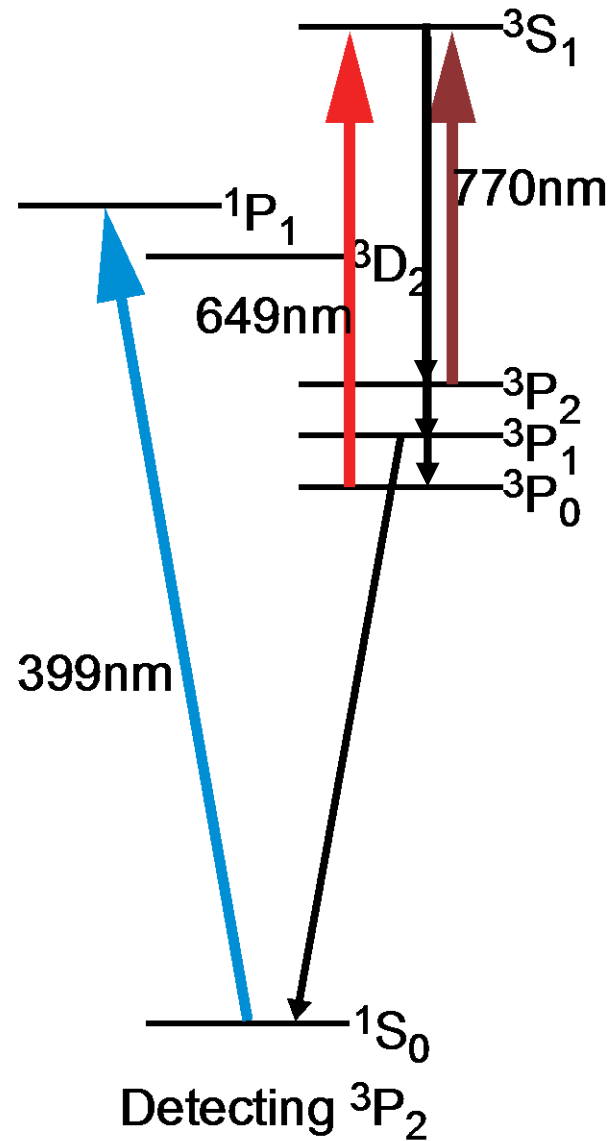
Preparing and Monitoring the 3P_2 State



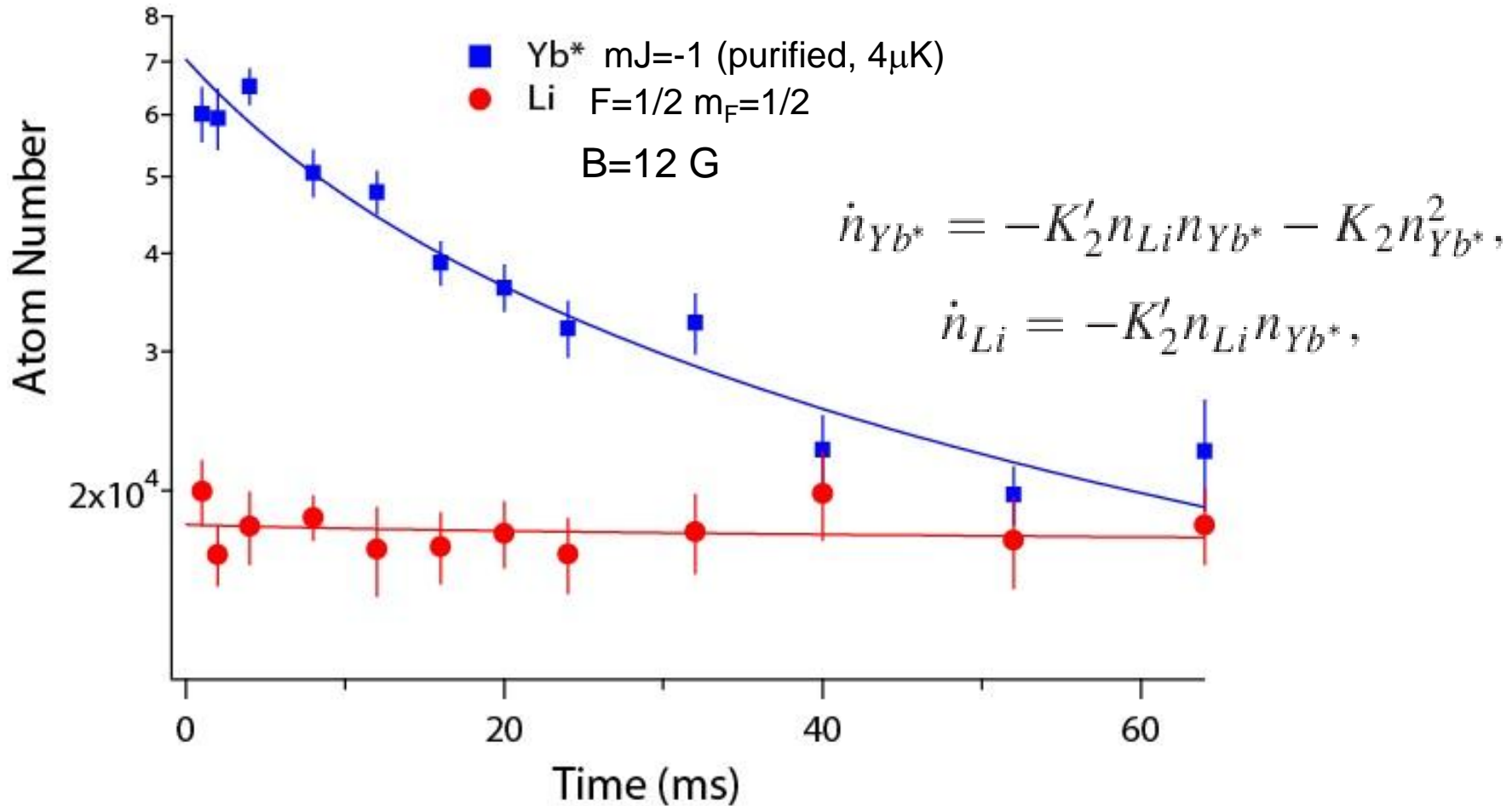
Preparing and Monitoring the 3P_2 State



Preparing and Monitoring the 3P_2 State



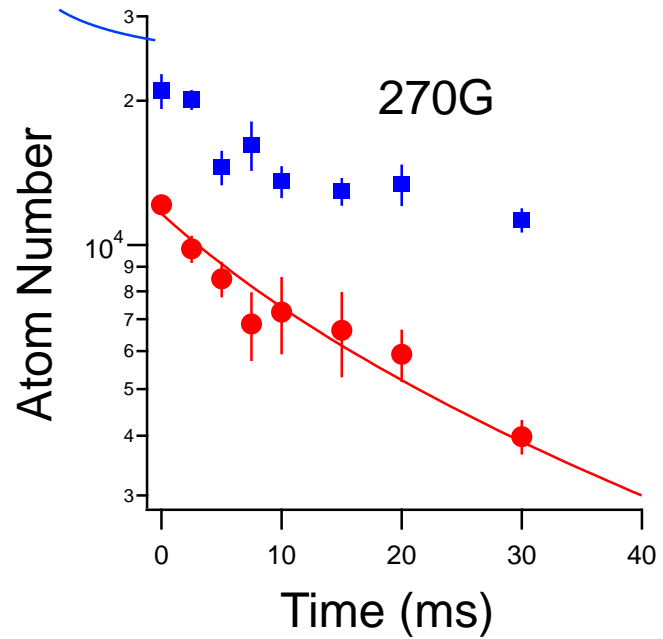
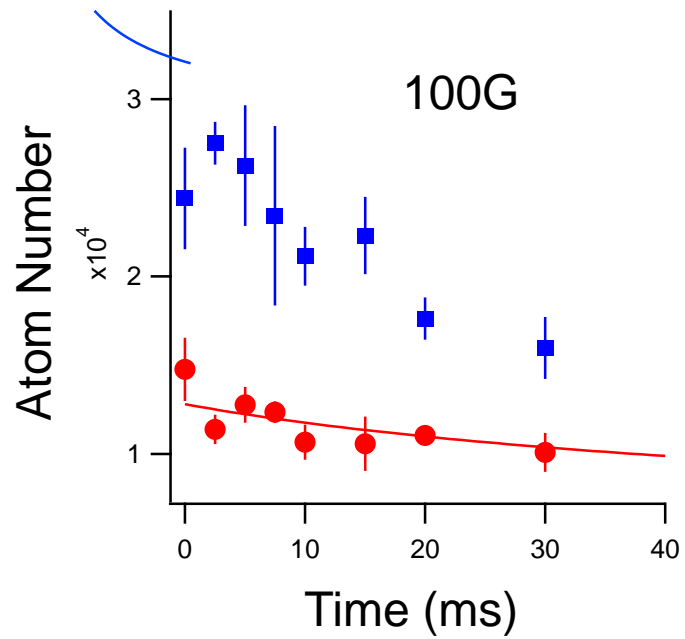
Combining Ground Li and Excited Yb* Atoms



Yb*-Yb* 2 body decay constant $K_2 = 2.5 \times 10^{-11} \text{ cm}^3/\text{s}$

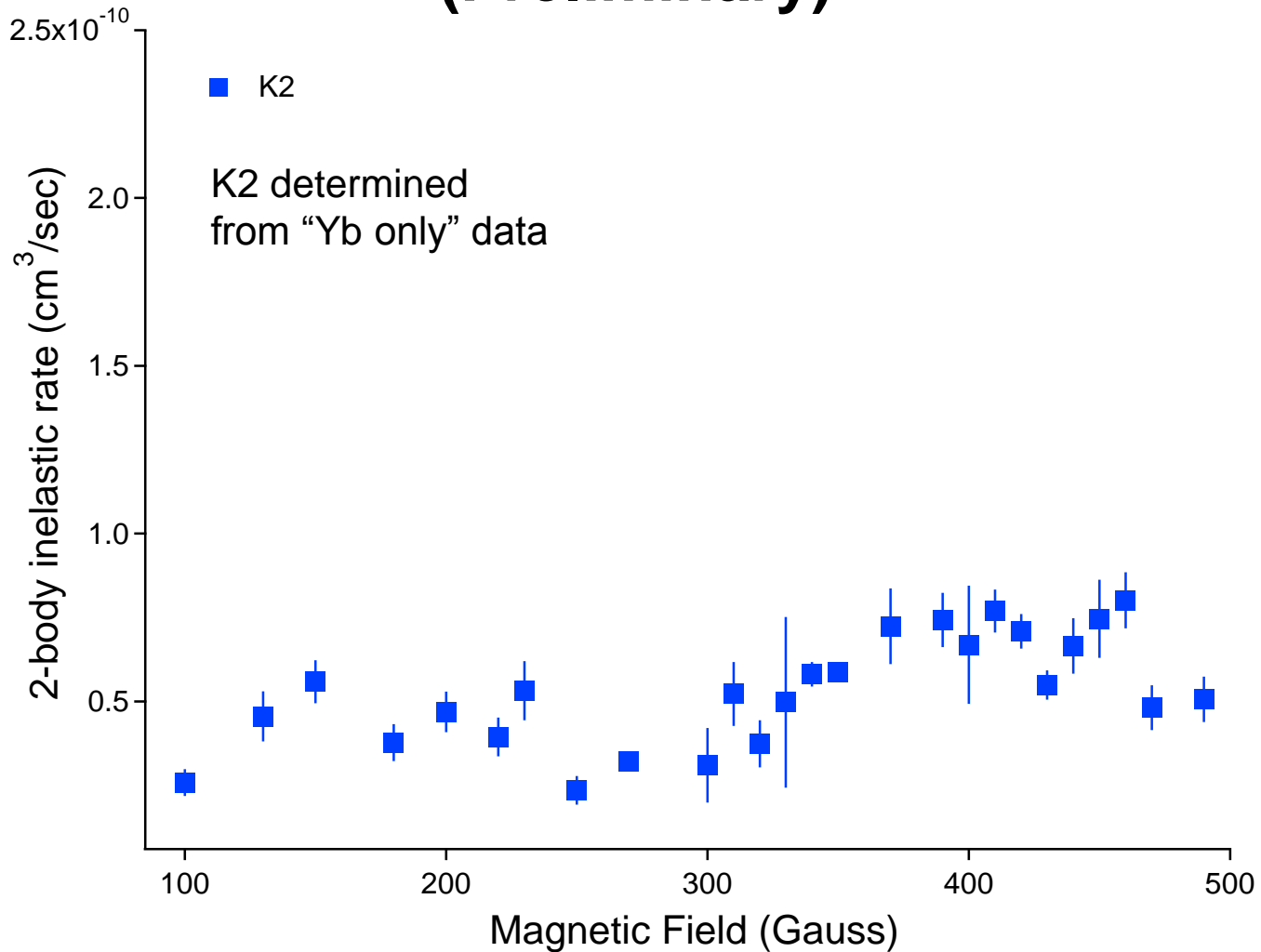
Yb*-Li 2 body decay constant $K'_2 < 3 \times 10^{-12} \text{ cm}^3/\text{s}$

Li-Yb* Field dependent losses



Loss Spectroscopy of Li and Yb*

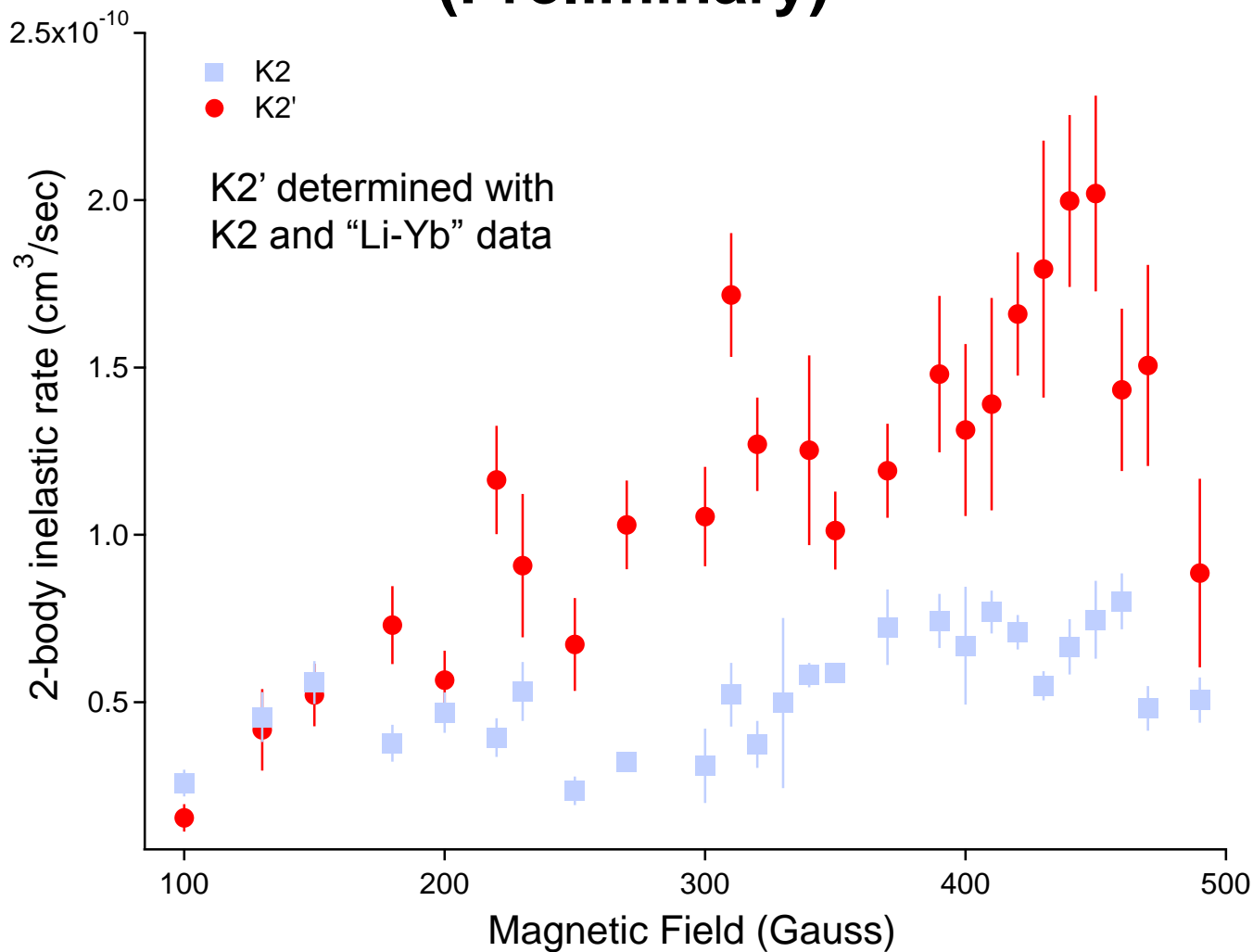
(Preliminary)



Initial peak densities: $n_{\text{Yb(Li)}} = 0.8(2.2) 10^{12}/\text{cm}^3$. Temp $\sim 1.6\mu\text{K}$.

Loss Spectroscopy of Li and Yb*

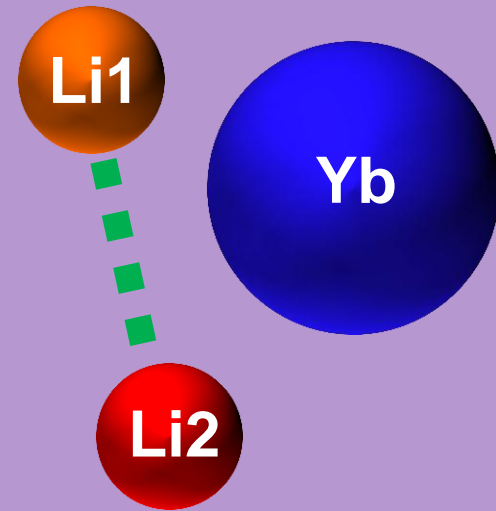
(Preliminary)



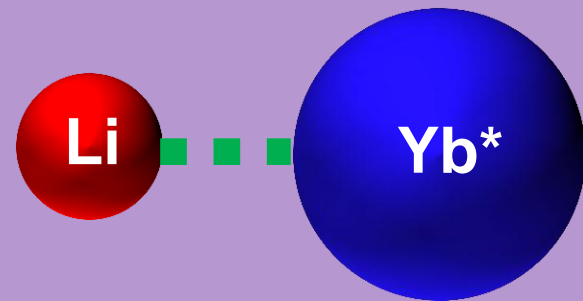
Initial peak densities: $n_{\text{Yb(Li)}} = 0.8(2.2) 10^{12}/\text{cm}^3$. Temp $\sim 1.6\mu\text{K}$.

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

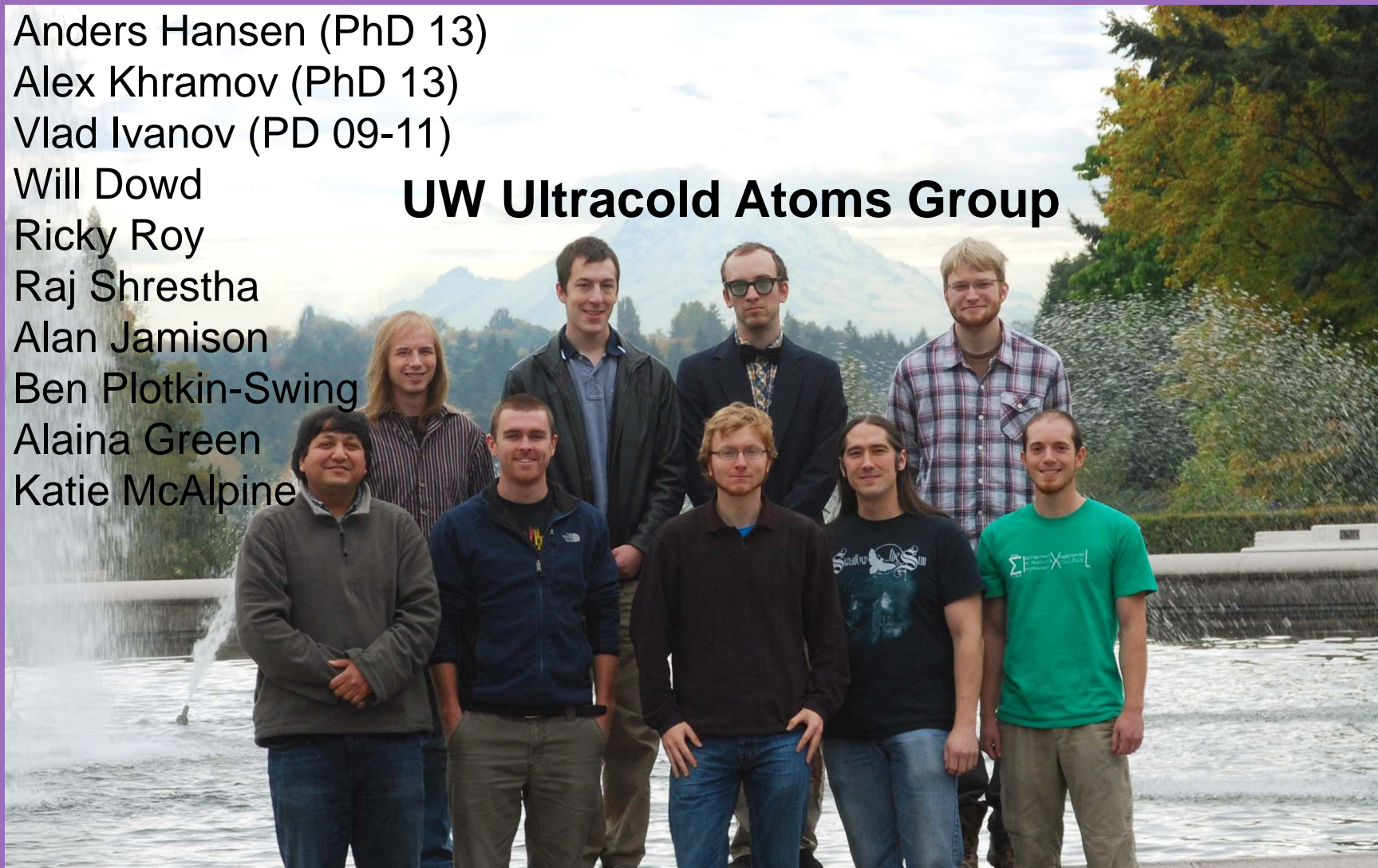
Alan Jamison

Ben Plotkin-Swing

Alaina Green

Katie McAlpine

UW Ultracold Atoms Group



ARO: MURI