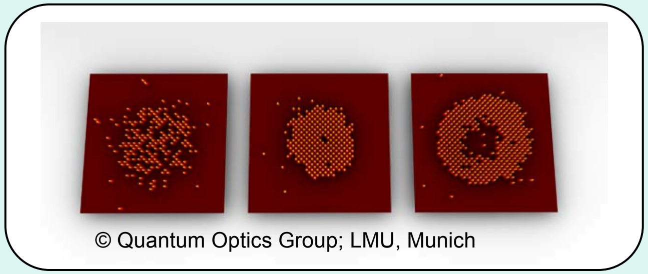
Studies of Ultracold Ytterbium and Lithium

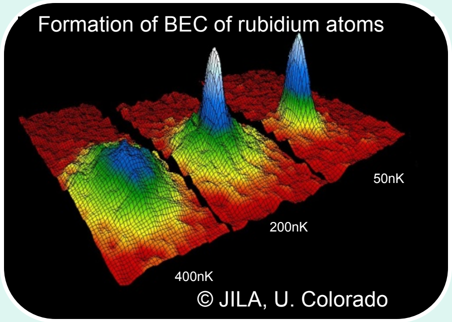
Anders H. Hansen
University of Washington Dept of Physics

U. Washington CDO Networking Days 11/18/2010

Why Ultracold Atoms?



- Young, active discipline
  - Two Nobel prizes in the past 15 years
    (1997: Chu, Cohen-Tannoudji, Phillips; 2001: Cornell, Wieman, Ketterle)
- Study exotic quantum behavior in ensembles of particles
  - Bose-Einstein Condensation, Fermi Superfluidity, Mott Insulators…
- Simulate many-body physics
  - Condensed matter / semiconductor physics
    - Greatly magnified systems, $\lambda_{dB} \approx 1000\ a_B$
    - High degree of impurity control
    - Easy to manipulate
  - Nuclear physics / Neutron stars
- Synthetic molecules
  - Building blocks of quantum computers



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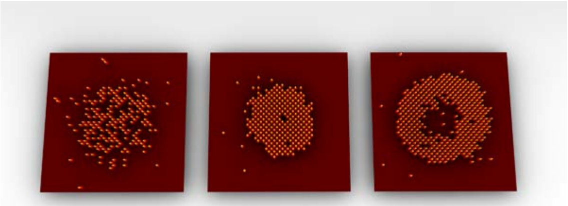
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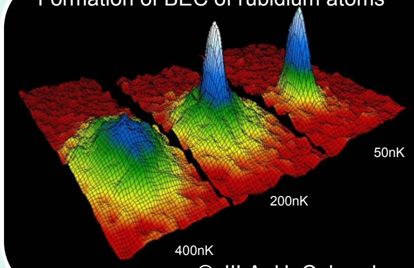
- High-precision atomic Clocks (J. Ye; C.W. Oates)
- Precision gravimetry (M. Kasovich; S. Chu; F.P. Dos Santos)
- Fundamental tests of constants & symmetries (E.S. Hinds; D.E. Pritchard; E.N. Fortson)
- Molecular synthesis & Ultracold chemistry (D.S. Jin; D. DeMille)

Formation of BEC of rubidium atoms



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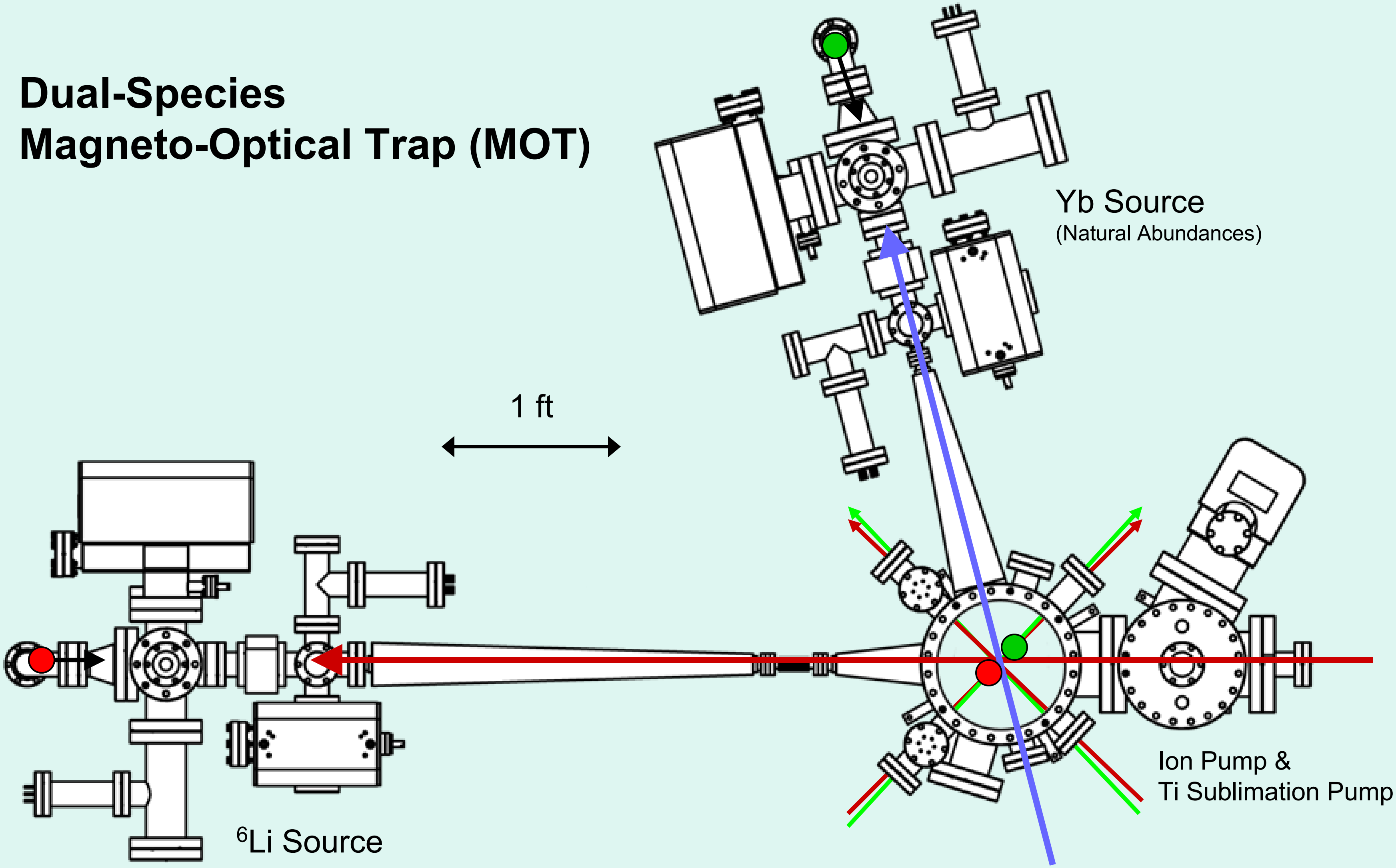
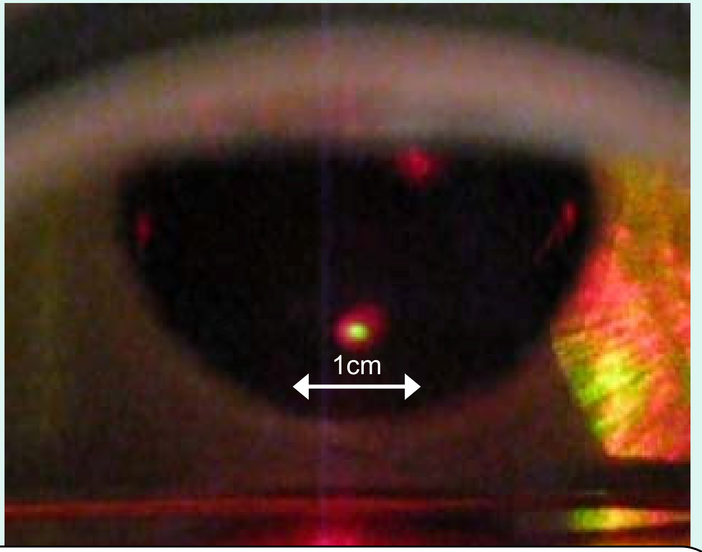
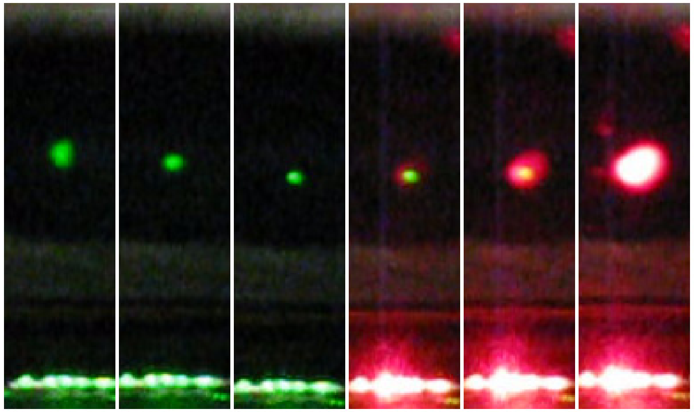
Dual-Species Magneto-Optical Trap (MOT)

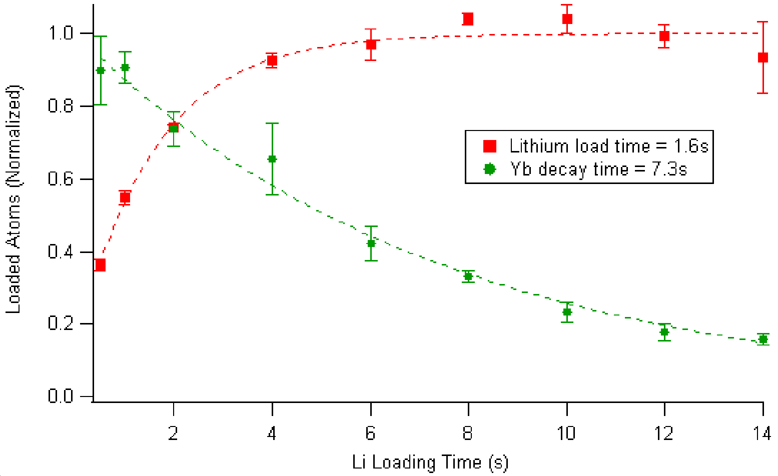


Simultaneous MOTs of Li and Yb

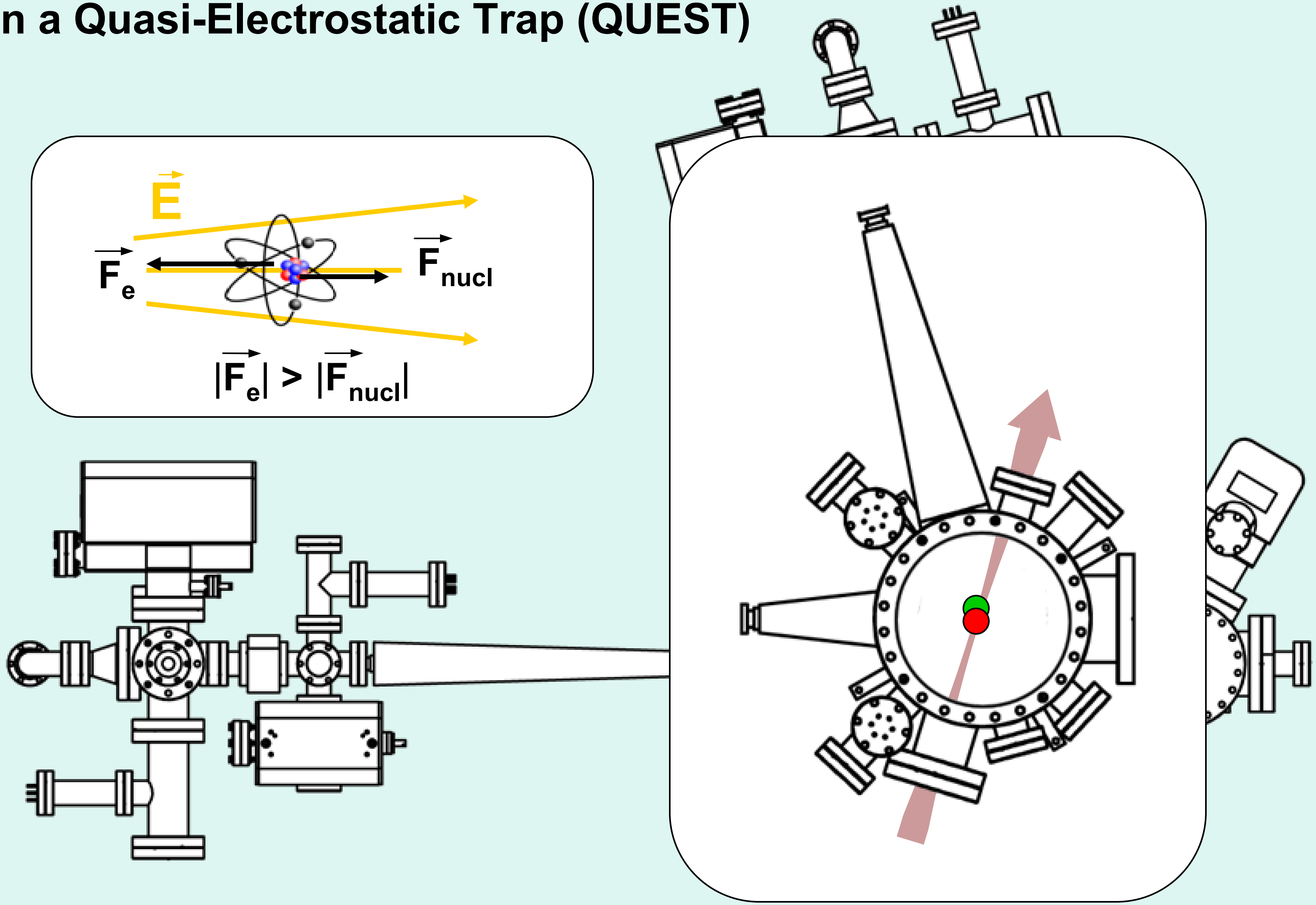




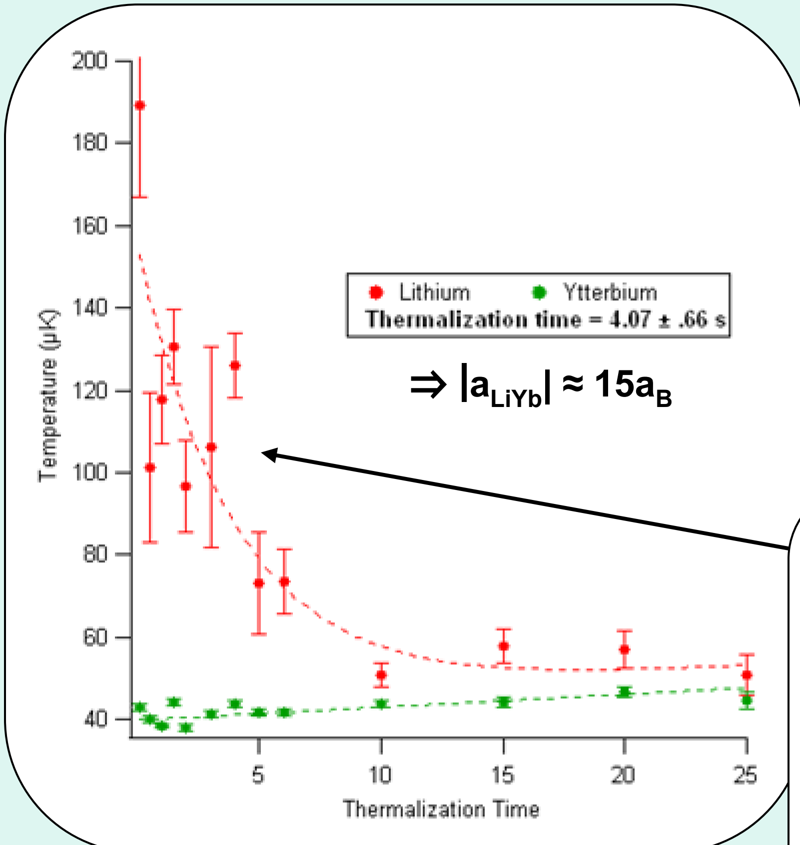
- Simultaneous trapping of Li and Yb
- Ability to trap
  - 2×10^8 Li atoms at 150μK
  - 10^7 Yb atoms at 40μK
  - …or a linear combination of the two



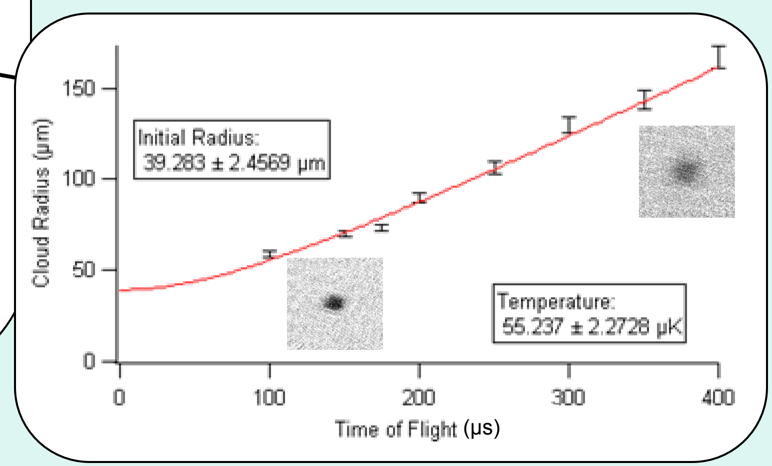
Optical trapping of Neutral Atoms in a Quasi-Electrostatic Trap (QUEST)



Early Studies of Heteronuclear Interactions



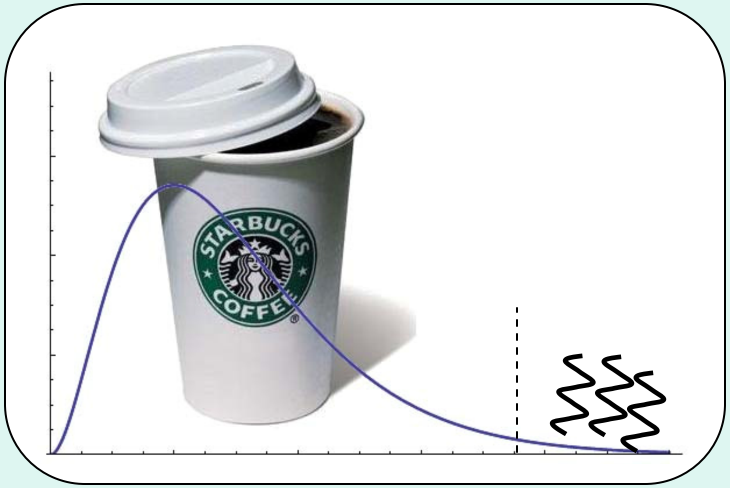
$\Rightarrow |a_{LiYb}| \approx 15a_B$



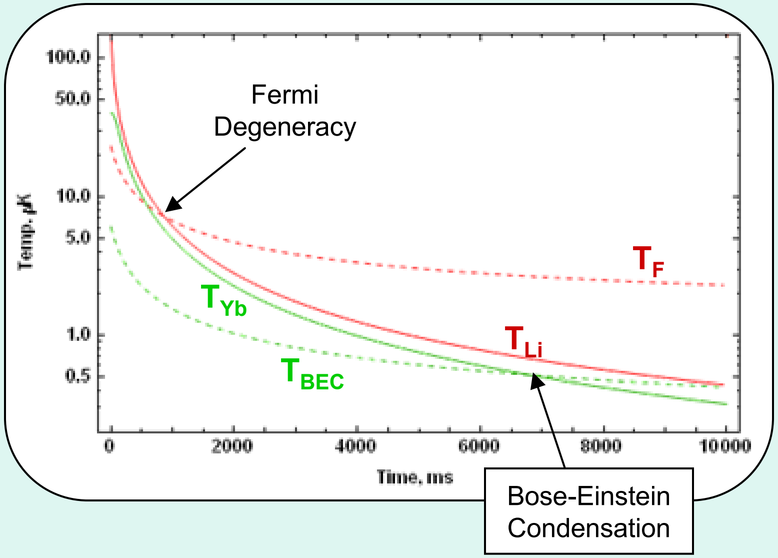
- Species load into ODT at different temperatures
- Thermalization time reveals info about collision rate
- Can extract cross-species s-wave scattering length a_{LiYb}

Planned Studies: Getting to Quantum Degeneracy

- **Evaporative cooling paves the way**
  - Analagous to hot coffee: only the molecules energetic enough to break surface tension will escape
  - Can imagine "forced evaporation" of cold coffee by reducing energy barrier at surface

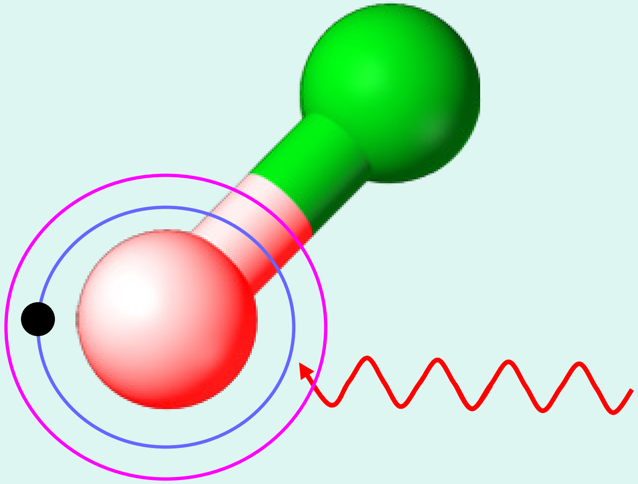


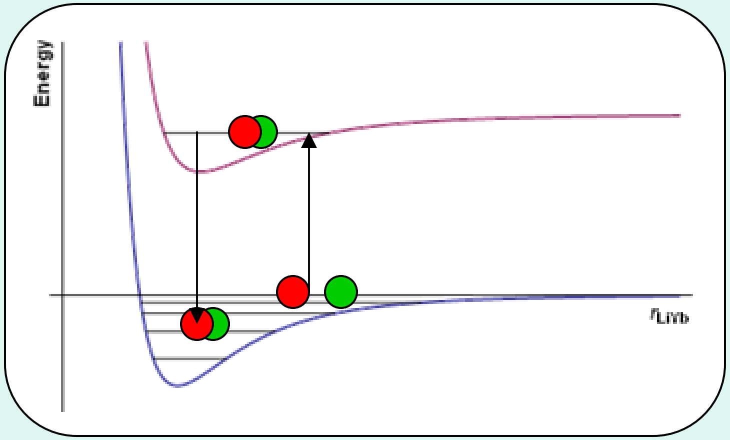
- **Realization of forced evaporation in ultracold atomic physics:**
  - Energetic atoms evaporate from ODT
  - Keep evaporation going by reducing power of trapping laser
  - Standard procedure to cool atoms to quantum degeneracy



Toward Ultracold Molecules

- **One-Photon photoassociation**
  - Excite colliding pair into electronically excited molecule
  - Unstable configuration: quickly decays into kinetic pair
- **Two-Photon photoassociation**
  - Puts molecule in electronic ground state
  - Typically ends up in vibrationally excited state
  - Search for the *absolute* ground state currently a major force in ultracold physics
- **The real challenge is precisely locating the molecular bound state energies!**





Our Group at UW Physics

- **PI: Subhadeep Gupta**
- Post-Doc: Vlad Ivanov
- Grad Students:
  - Alex Khramov
  - Will Dowd
  - Alan Jamison
  - Frank Münchow
    (Uni. Düsseldorf)
- Undergraduates
  - Jiawen Pi
  - Jason Grad
  - Eric Lee-Wong

Please visit our poster at today's poster session 2:20-3:30pm

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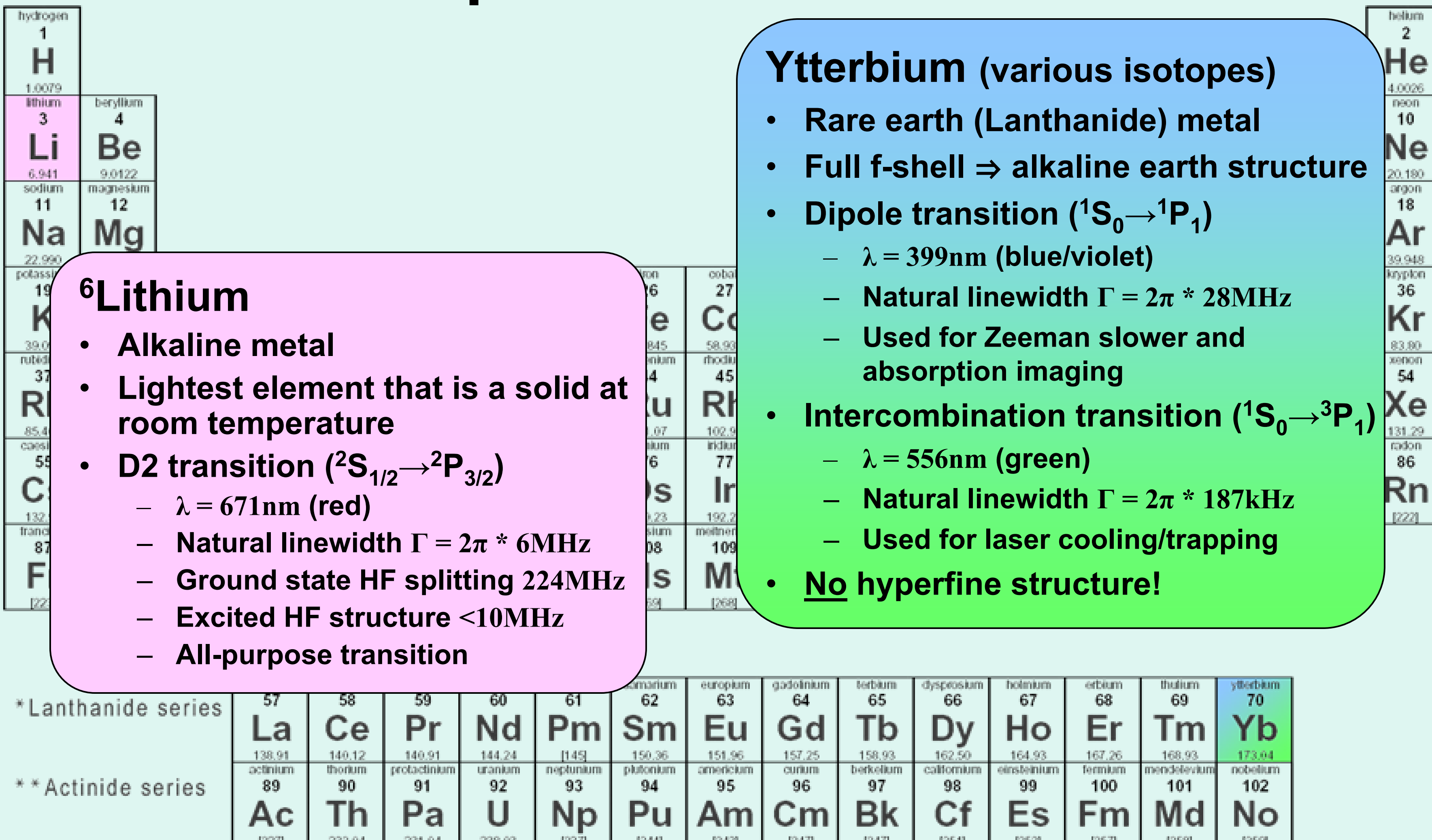
Secret Slide!
Properties of ^{6}Li and Yb



^{6}Lithium

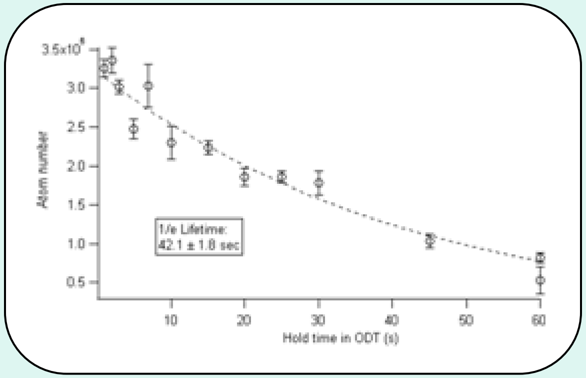
- Alkaline metal
- Lightest element that is a solid at room temperature
- D2 transition ($^2S_{1/2} \rightarrow {}^2P_{3/2}$)
  - $\lambda = 671\text{nm}$ (red)
  - Natural linewidth $\Gamma = 2\pi * 6\text{MHz}$
  - Ground state HF splitting 224MHz
  - Excited HF structure $<10\text{MHz}$
  - All-purpose transition

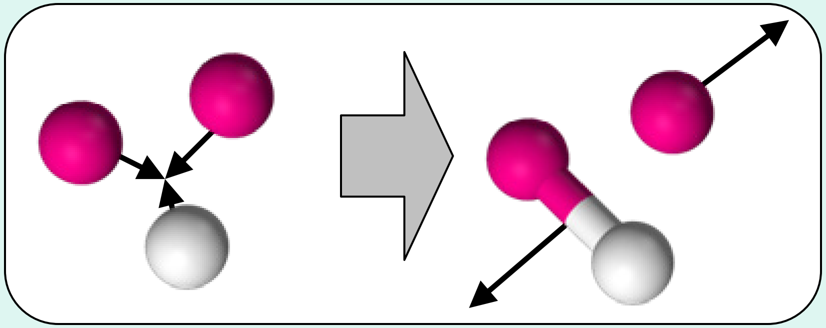
Ytterbium (various isotopes)

- Rare earth (Lanthanide) metal
- Full f-shell ⇒ alkaline earth structure
- Dipole transition ($^1S_0 \rightarrow {}^1P_1$)
  - $\lambda = 399\text{nm}$ (blue/violet)
  - Natural linewidth $\Gamma = 2\pi * 28\text{MHz}$
  - Used for Zeeman slower and absorption imaging
- Intercombination transition ($^1S_0 \rightarrow {}^3P_1$)
  - $\lambda = 556\text{nm}$ (green)
  - Natural linewidth $\Gamma = 2\pi * 187\text{kHz}$
  - Used for laser cooling/trapping
- No hyperfine structure!

Secret Slide!
Trap Lifetimes & 3-Body Inelastics

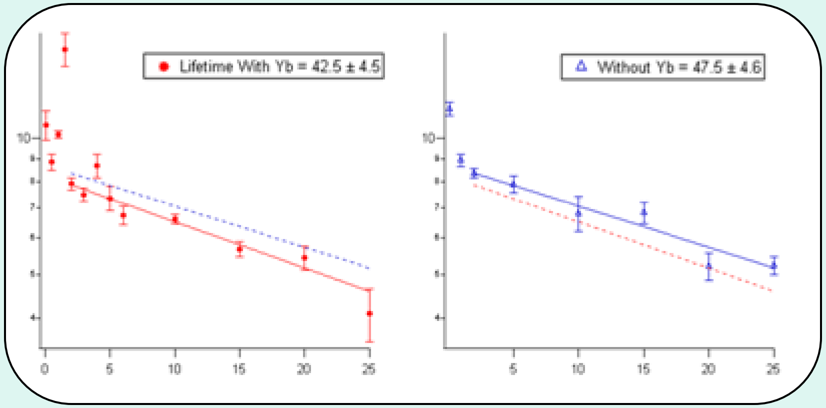
- Measure lifetime τ by plotting N_{atoms} vs Δt, and fit exponential curve
- At pressures ~10^{-10} Torr, expect upper bound $\tau \leq 30$s
- We observe lifetimes of up to 40s at our lowest pressures (~7×10^{-11} Torr) for single-species traps.



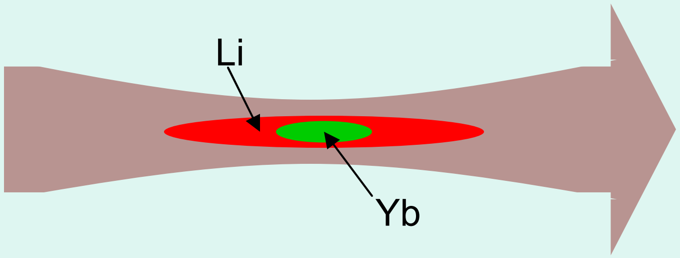


- 3-Body recombination possible in single-species and two-species systems
- Formation of bound pair, with third atom present to conserve energy, momentum
- Covalent bond energy converted to kinetic energy, leading to trap losses

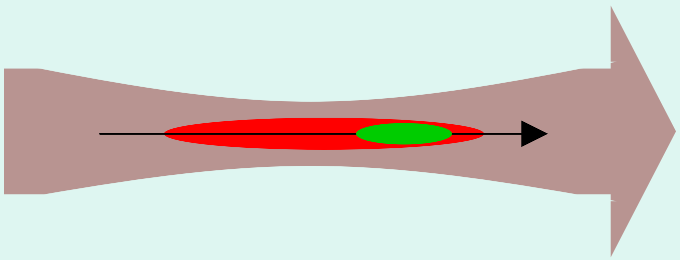
- Lifetime measurements of Li in a reservoir of Yb show no adverse effects on τ from the presence of Yb.
- Good news for experiments that depend on long lifetime of either species, but suggests deeply bound Feshbach state of LiYb



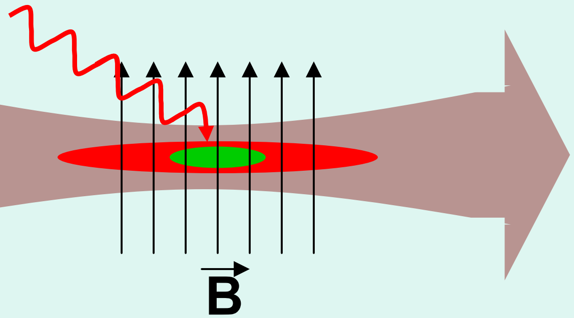
Secret Slide!
Yb as an Impurity Probe of ^{6}Li Superfluid



- Yb as static impurity
- Observe perturbative effect on Li wavefunction, Fermi energy, etc.



- Yb as “projectile”
- Measure critical velocity of Li superfluid
- Improvement over similar experiments with magnetically sensitive probe species



- Search for Feshbach resonances (FBR)
- Magnetic FBR to search for cross-species hyperfine interactions
- Optical FBR as path toward LiYb molecules