Loading and Cooling of Single Sodium and Cesium Atoms

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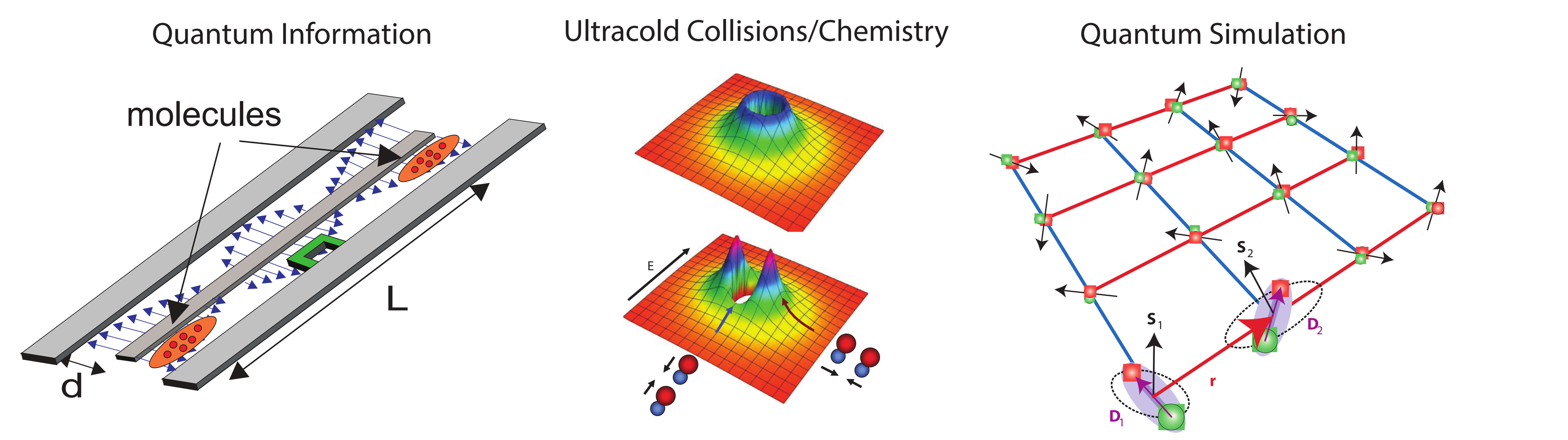
Harvard-MIT Center for Ultracold Atoms

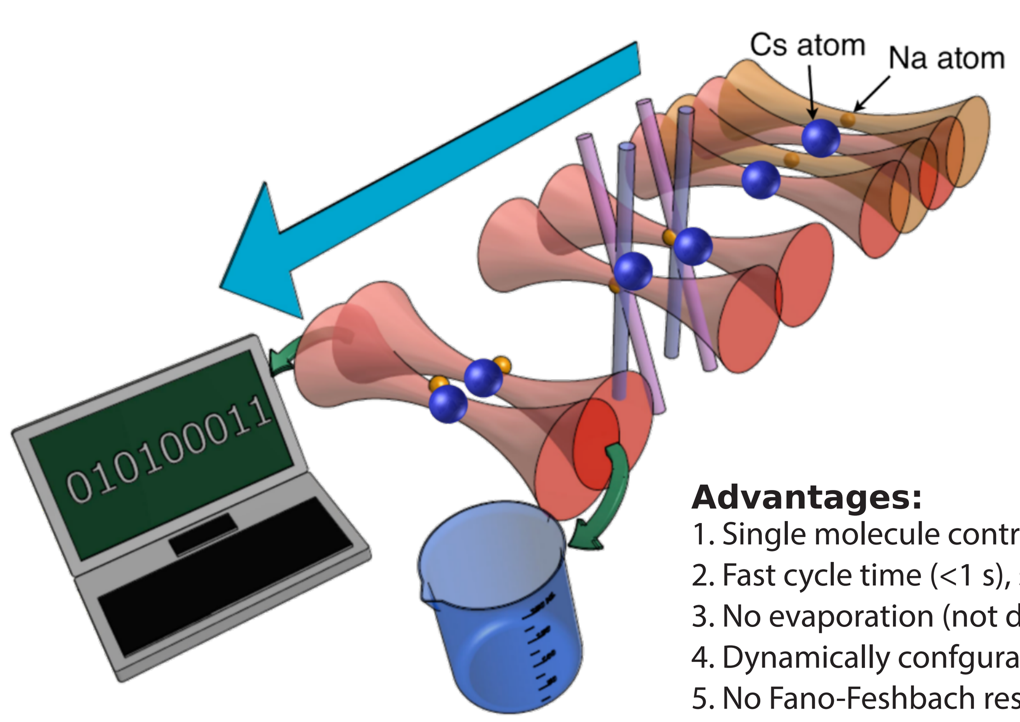
Why Ultracold Molecules?



P. Rabl, et al., Phys. Rev. Lett. 97, 33003 (2006).
K.-K. Ni et al., Nature 464, 1324 (2010).
A. Micheli, G. K. Brennen, and P. Zoller, Nat. Phys. 2, 341 (2006).

Our Approach

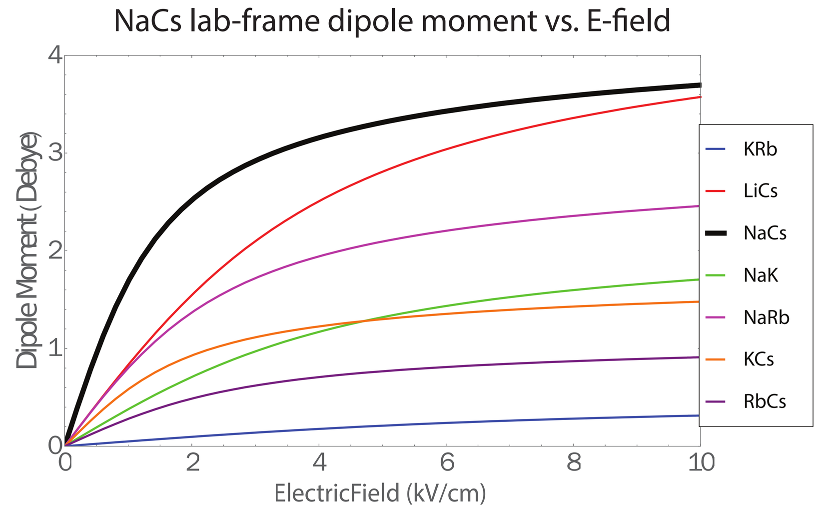
We aim to assemble and trap individual ultracold polar molecules in optical tweezers from laser-cooled atoms



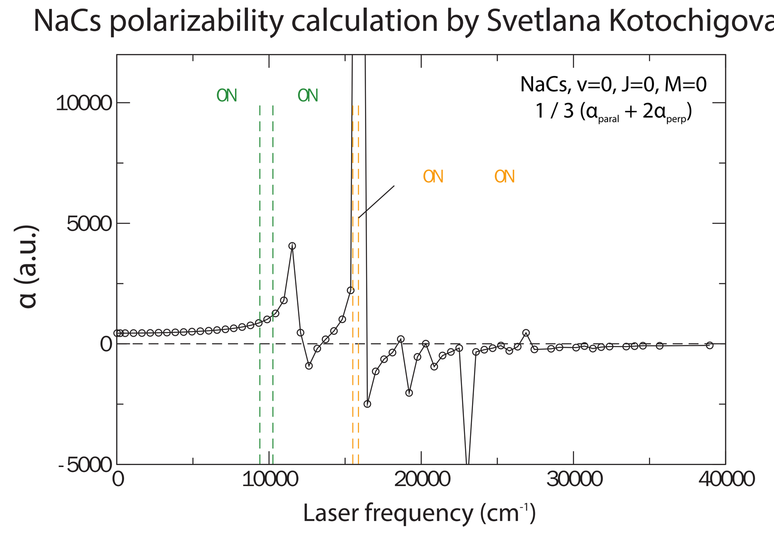
Choice of Molecule:
NaCs (4.6 Debye)

Advantages:
1. Single molecule control
2. Fast cycle time (<1 s), small vacuum chamber
3. No evaporation (not dependent on dual-species atomic collisions)
4. Dynamically confgurable trapping geometry
5. No Fano-Feshbach resonance required (relaxes B-field control)
6. No atomic three body losses

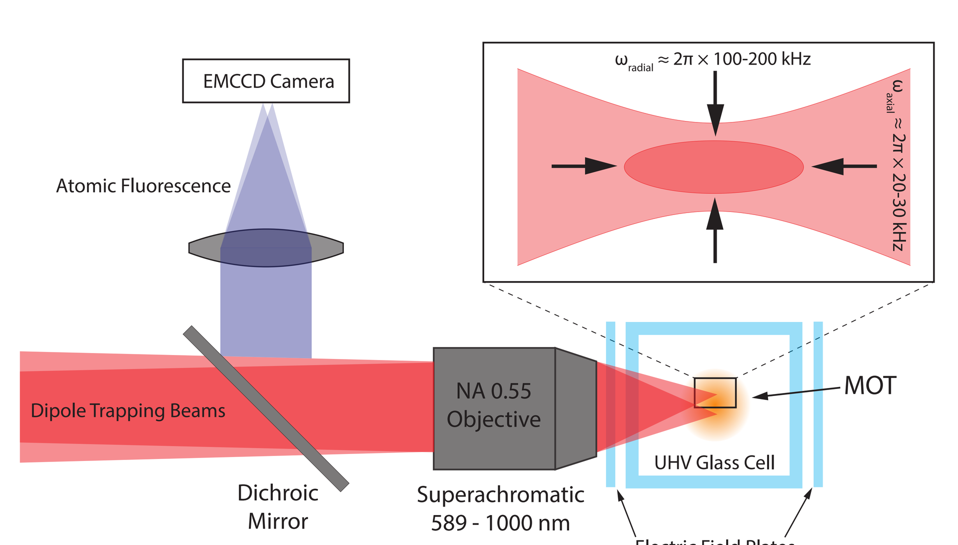
NaCs lab-frame dipole moment vs. E-field

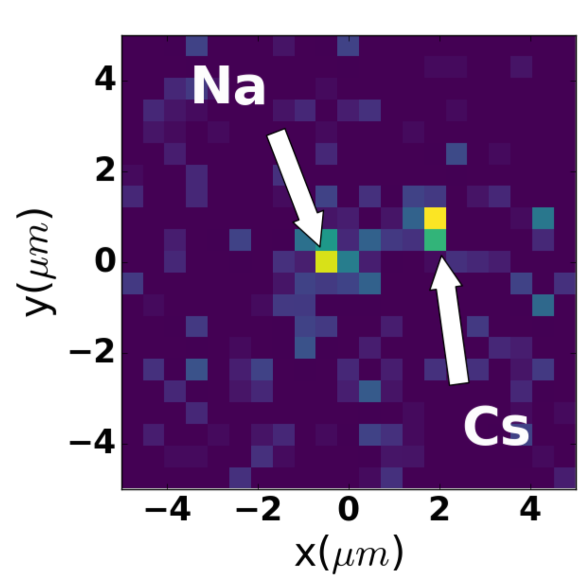


NaCs polarizability calculation by Svetlana Kotochigova



Step 1: Trapping Individual Atoms in Optical Tweezers

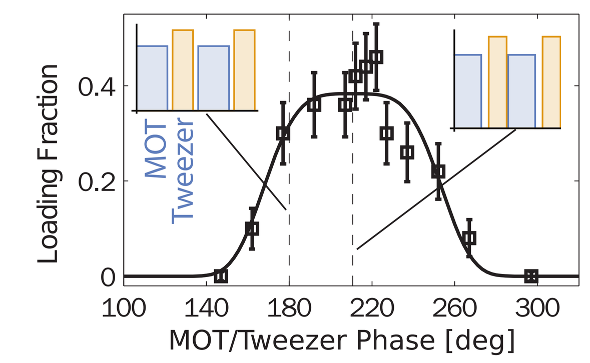




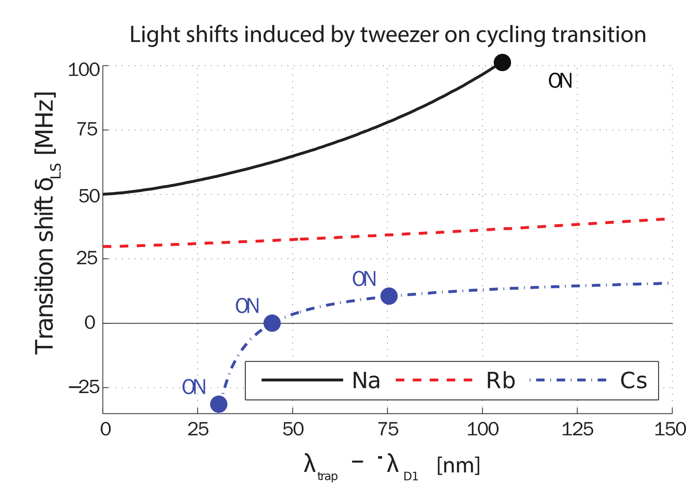
Modulation of tweezer and MOT/imaging light

AC Stark shifts can prevent atom loading, as is the case with Na atoms in tweezers at convenient wavelengths.

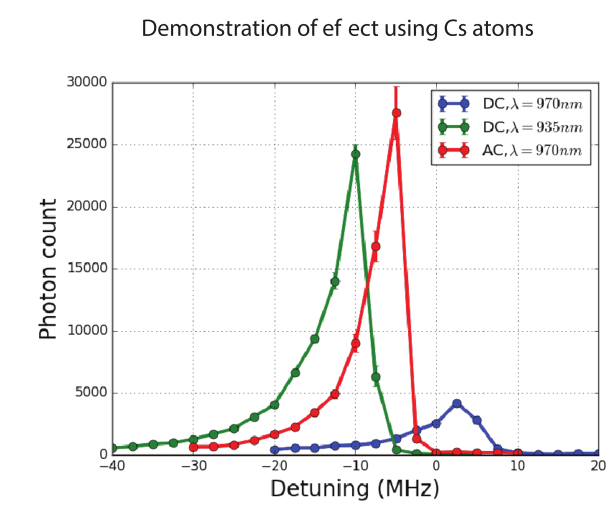
Our solution: rapidly modulate the intensity of the MOT, cooling, imaging, and tweezer beams. Light shifts are effectively eliminated, and Na atoms can be loaded.



Light shifts induced by tweezer on cycling transition

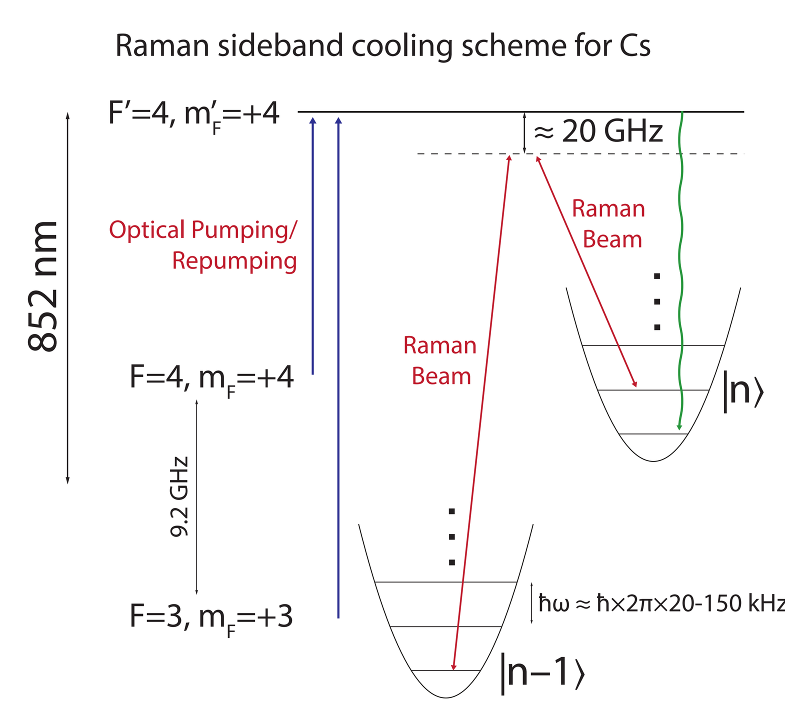


Demonstration of ef ect using Cs atoms

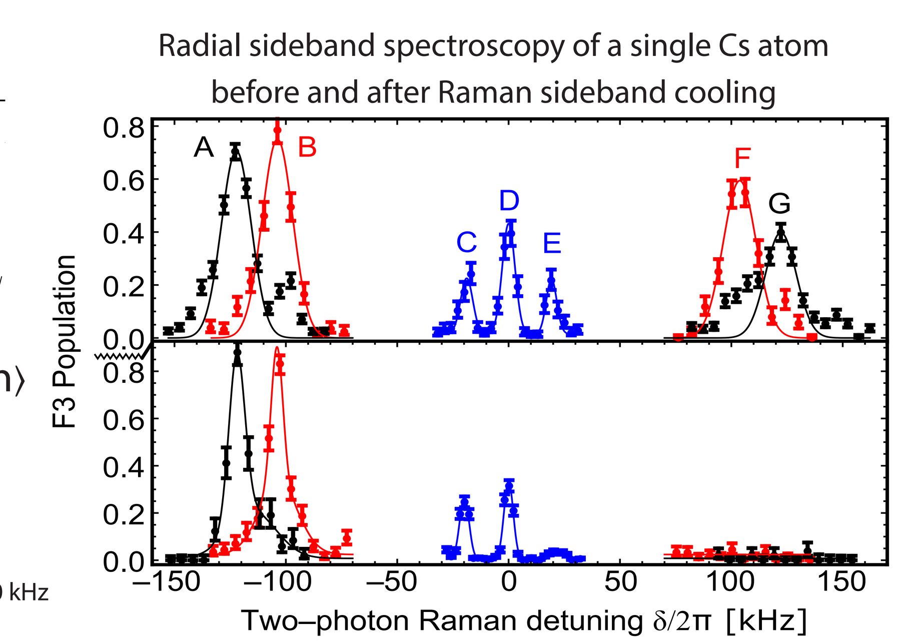


Step 2.1: Cooling Cesium Atoms to the Motional Ground State

Raman sideband cooling scheme for Cs



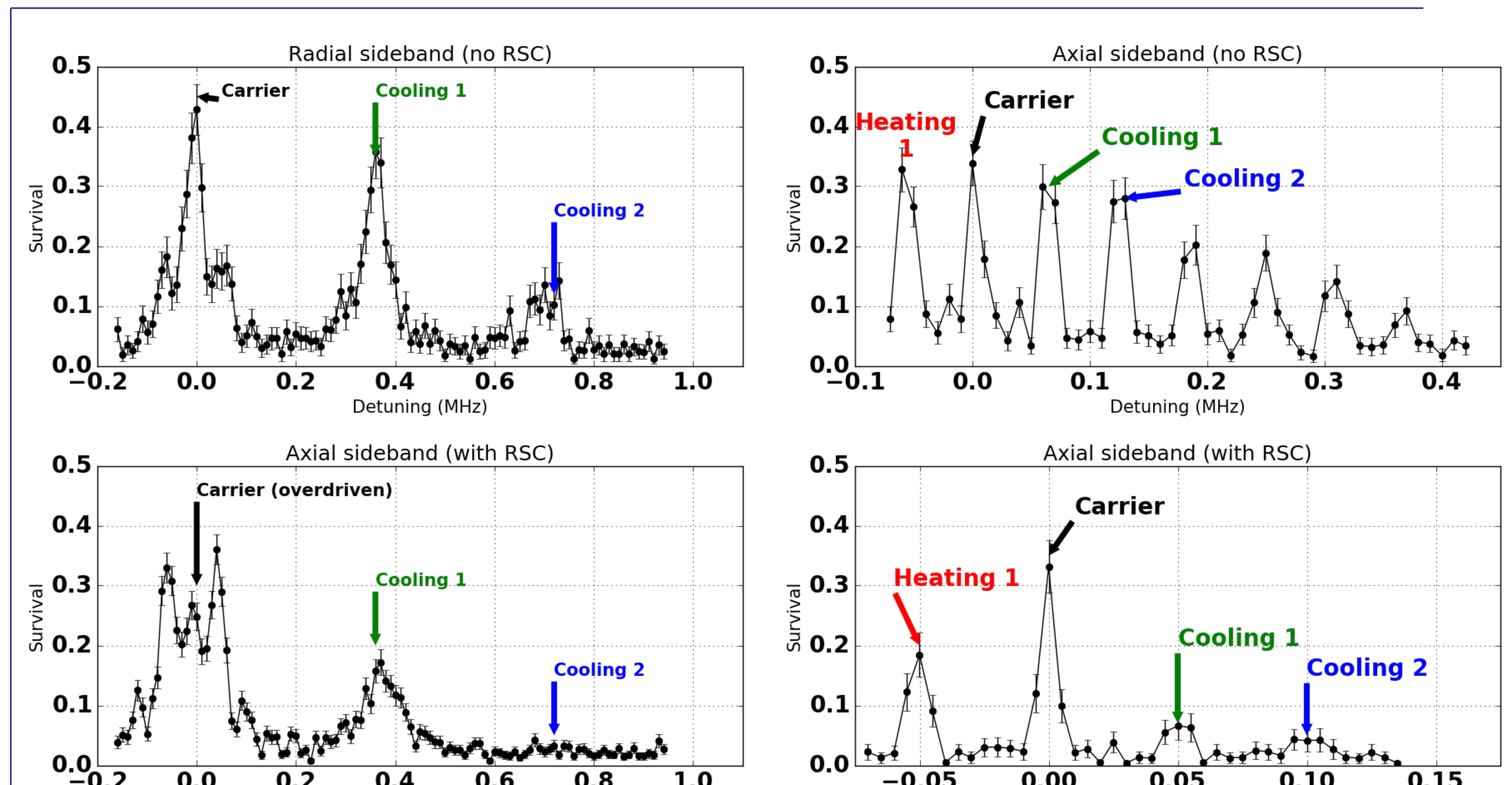
Radial sideband spectroscopy of a single Cs atom before and after Raman sideband cooling



- Raman sideband ground state cooling for neutral atoms
  - » Demonstrated for single Rb atoms in tight tweezer traps
  - » A. Kaufman, B. Lester, and C. Regal, PRX 2, 041014 (2012)
  - » J. D. Thompson et al., PRL 110, 133001 (2013)

- Initially cool using polarization gradient cooling in tweezer
  - » Can cool single Cs atom to 15 uK in 3 ms
- Follow with pulsed Raman sideband cooling (RSC)
  - » Alternate cooling beams between three axis.
  - » Use Blackman shape Raman pulse to reduce off-resonance coupling to carrier and heating sidebands.
  - » Sweep Raman pulse time to address different vibrational states with different matrix elements.
  - » Achieve 3D ground state with probability 84^{+7}_{-12}%

Step 2.2: Cooling Sodium Atoms to the Motional Ground State



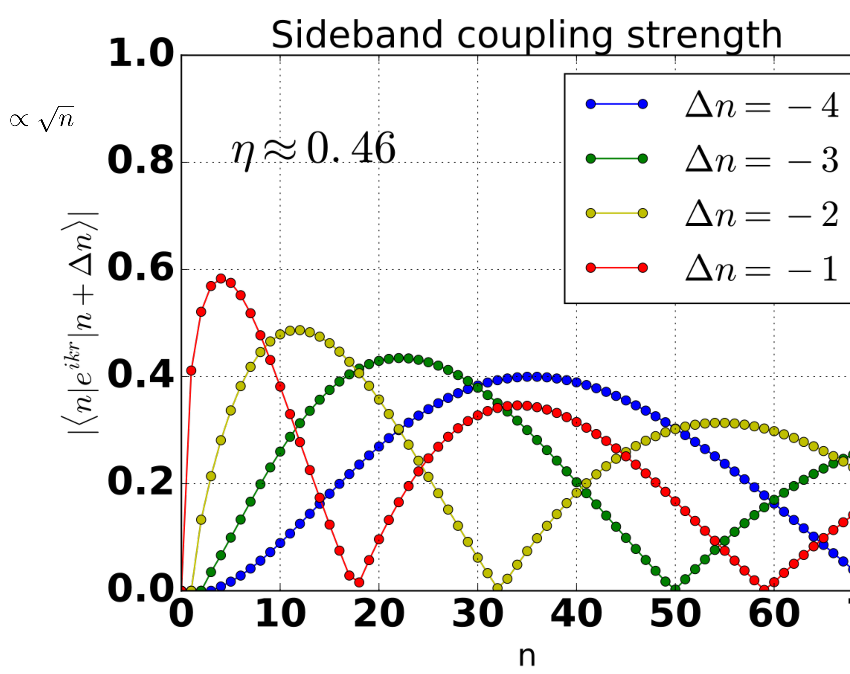
Measuring "high" axial temperature

Normal sideband thermometry relies on $\left|\langle n|\mathbf{e}^{\mathbf{i}kr}|n-1\rangle\right| \propto \sqrt{n}$

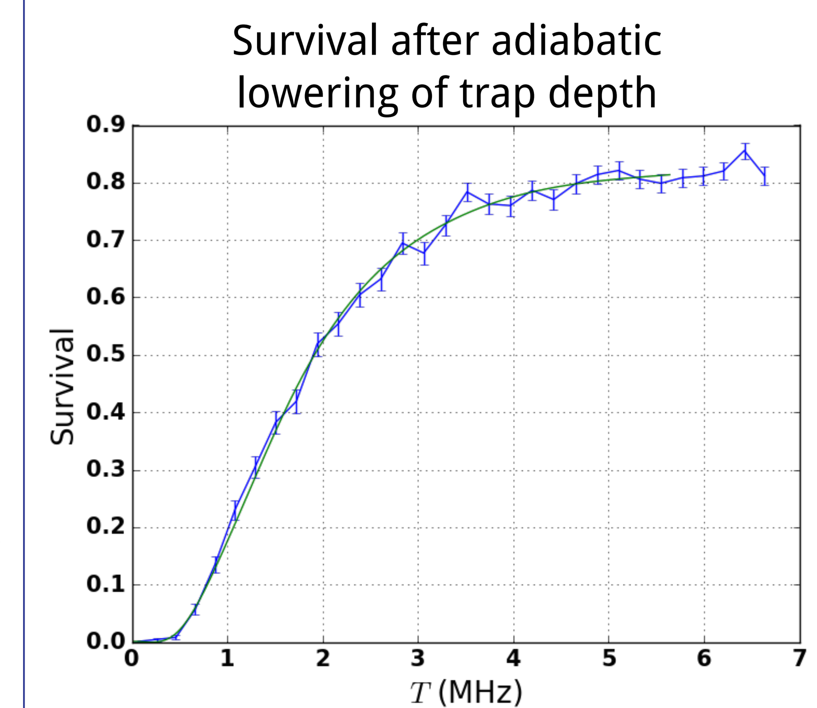
This is only valid when $\eta \ll 1$ ($\eta \equiv [\omega_{recoil}/\omega_{trap}]^{1/2}$),

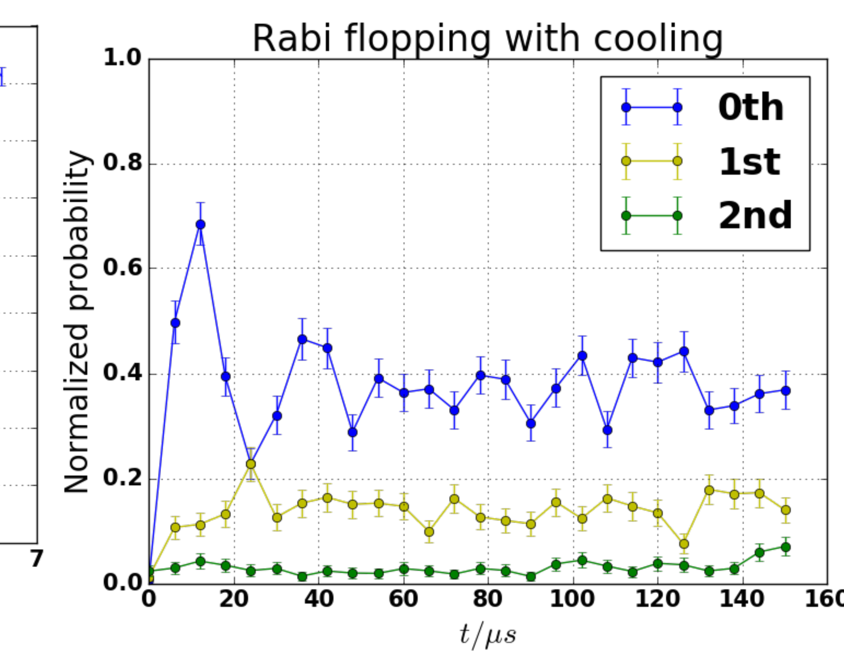
which is not the case for sodium.

For sodium, we have $\eta_{axial} = 0.46$, $\eta_{radial} = 0.35$



Alternative thermometry





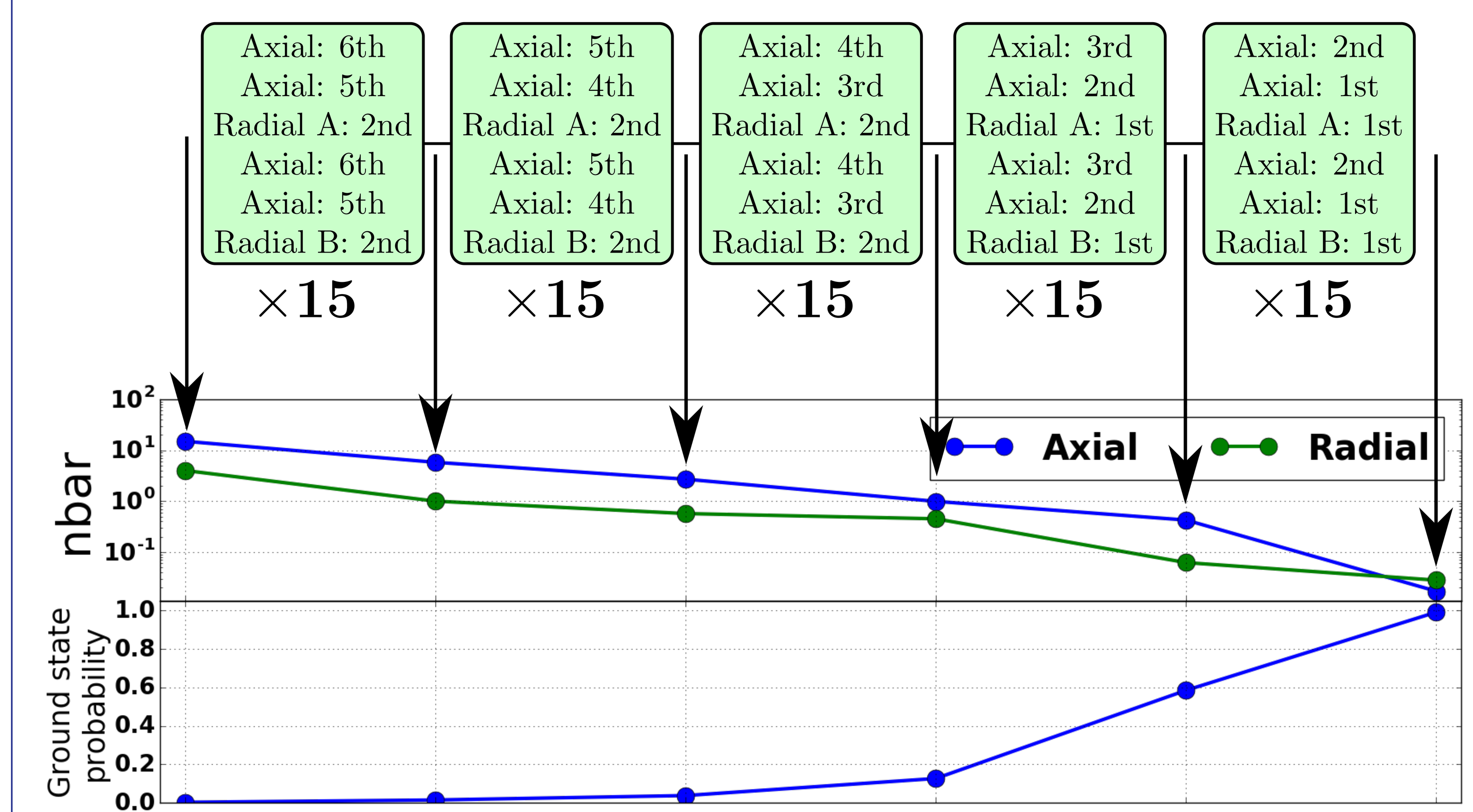
Optimizing and simulating RSC sequence

Known challenges for RSC of Na compared to Cs (or Rb)
1. ~2x higher Doppler temperature and ~10x larger recoil temperature ⇒ large initial vibrational quanta, n_{axial} ~ 15
2. Larger η causing more heating during optical pumping

We use simulation to help cooling sequence optimization

Simulation of a typical RSC sequence

The axis and order of sidebands in the cooling sequence.
Each group of pulses is repeated the specified number of times before continuing to the next group.



Preliminary similation shows that the high initial temperature and the high recoil aren't fundamental problems.
In an ideal system, the atom can be cooled to the 3D ground state with > 99% probability with 360 Raman cooling pulses.

Imperfections to be taken into account in the simulation:
- » Dark state fidelity
- » Off resonance Raman coupling
- » Off resonance scattering from the Raman beams