

Ultracold molecule assembly

The background features a 3D visualization of an ultracold molecule assembly trap. A large, dark, cylindrical structure with a ribbed texture is shown in perspective. A bright green beam of light enters from the left and focuses into a blue, translucent, ellipsoidal region. Inside and around this region, numerous small molecular models are depicted, each consisting of blue and orange spheres connected by lines, representing atoms and bonds respectively.

Yichao Yu

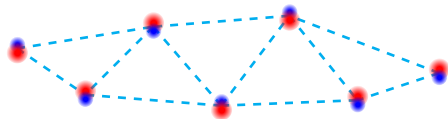
Ni Group/Harvard

Aug 11, 2017

Molecules in optical tweezer

Features

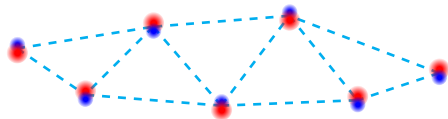
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Molecules in optical tweezer

Features

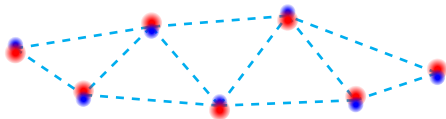
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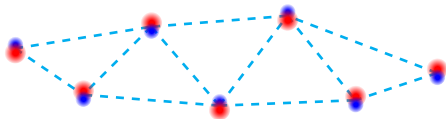
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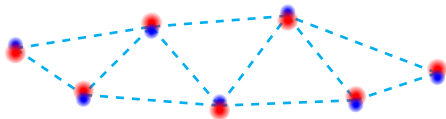
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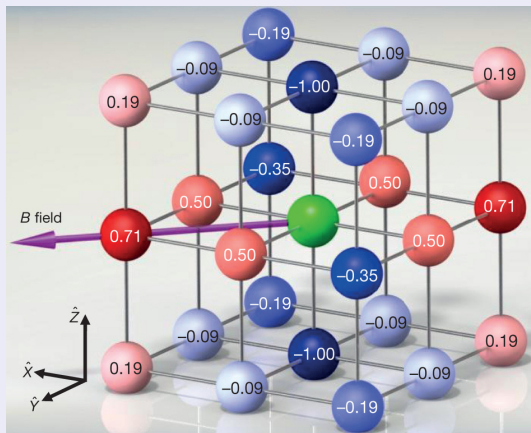
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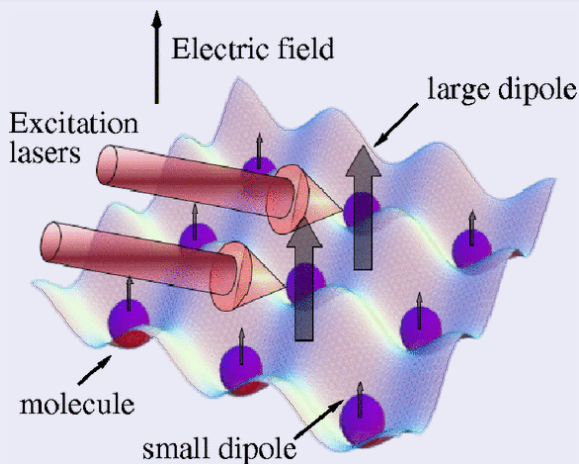
Simulation of many-body system^[1]



$$H \propto \sum V_{ij} (S_i^+ S_j^- + S_i^- S_j^+)$$

[1] B. Yan et al., “Observation of dipolar spin-exchange interactions with lattice-confined polar molecules.”, *Nature* **501**, 521–5 (2013).

Quantum computation^[2]



[2] S. F. Yelin et al., "Schemes for robust quantum computation with polar molecules", *Phys. Rev. A* **74**, 050301 (2006).

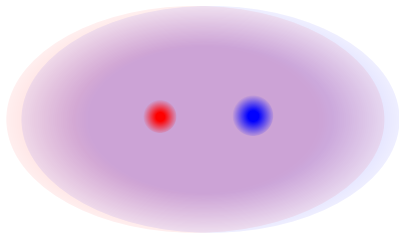
Making molecules from atoms

- MOT (Na + Cs)
- Loading single atoms
- Raman sideband cooling
- Merge traps
- Make molecules!



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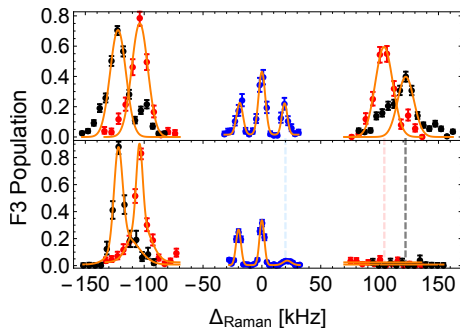
Atom loading and cooling

- Single atoms
- 85% ground state after Cesium Raman sideband cooling

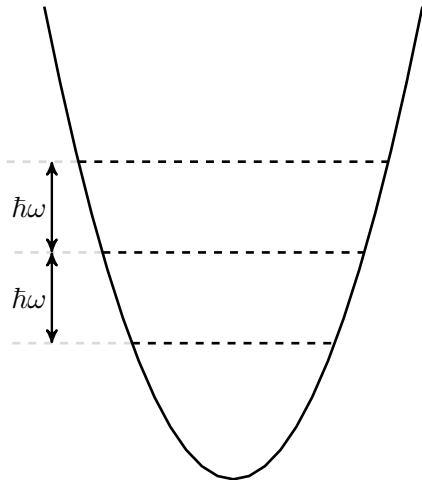


Atom loading and cooling

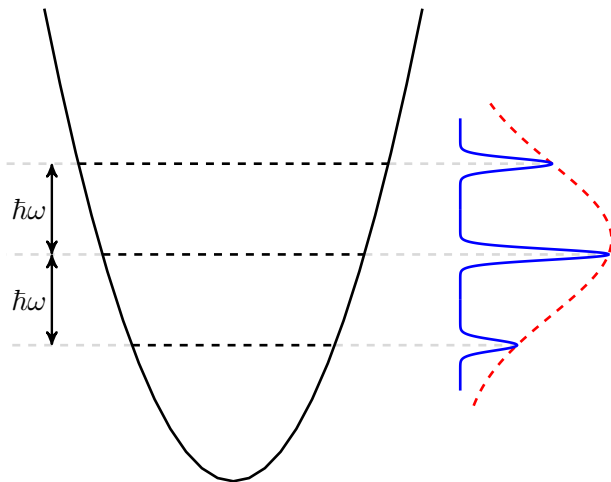
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Raman sideband cooling

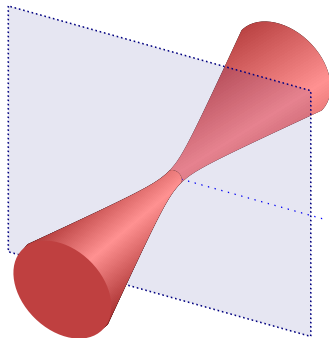
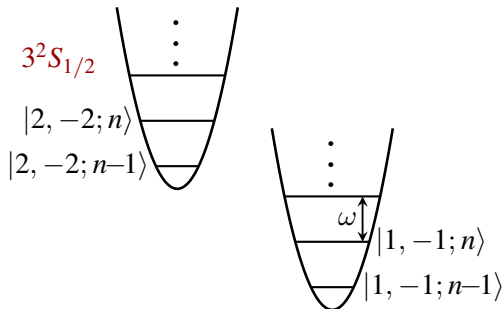


Raman sideband cooling

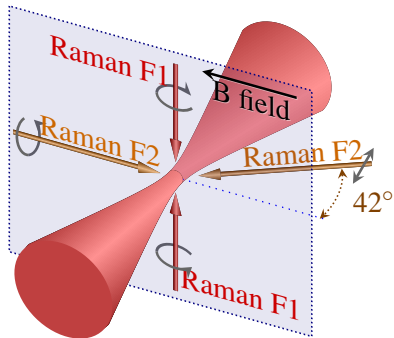
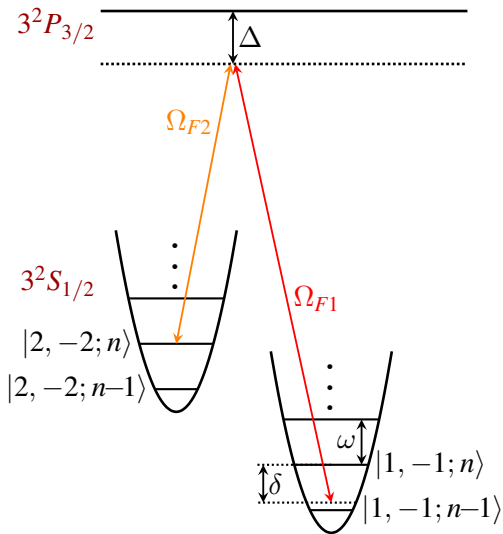


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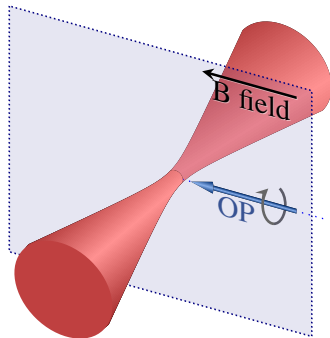
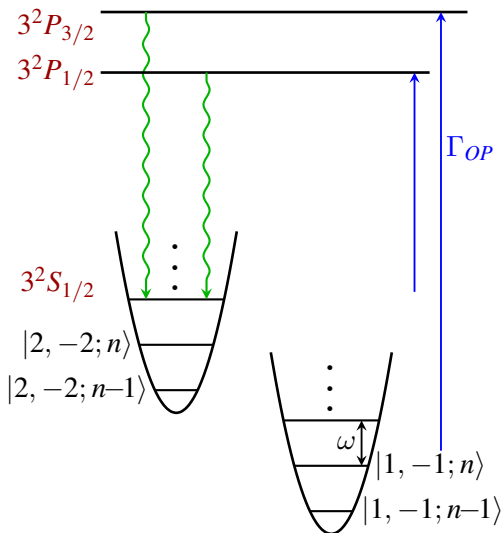
$3^2P_{3/2}$



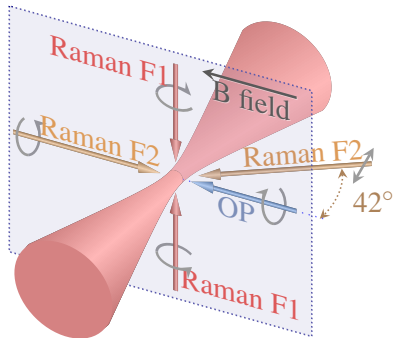
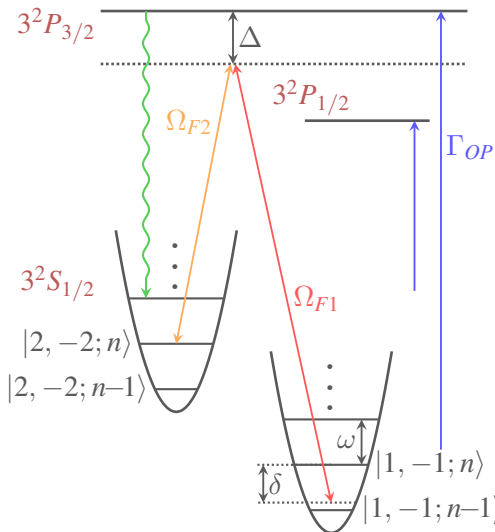
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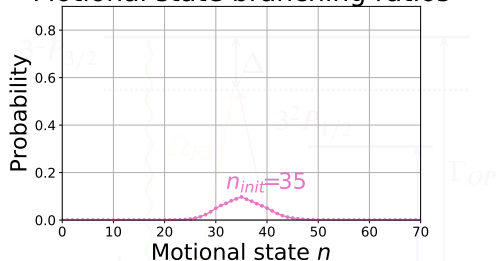


Raman sideband cooling



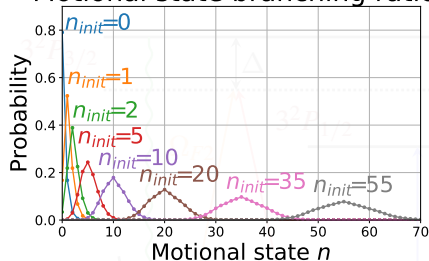
- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter
 $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering
 $\approx 3 \sim 15\text{kHz}$

Motional state branching ratios



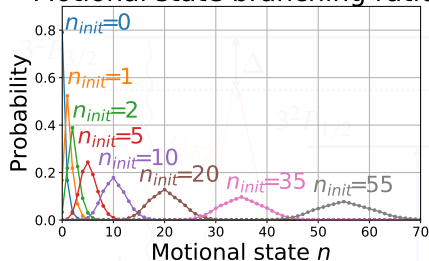
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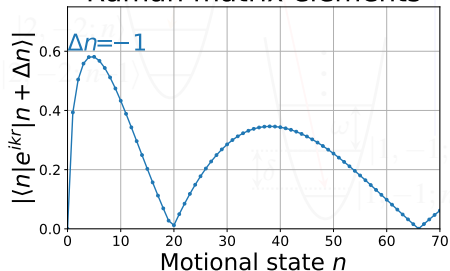


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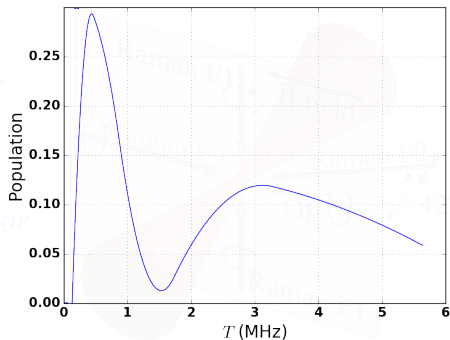
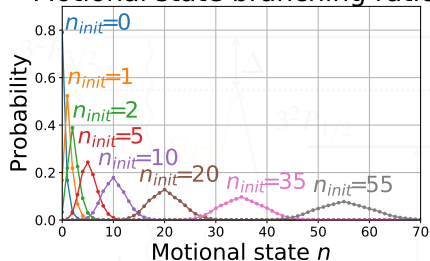
Raman matrix elements



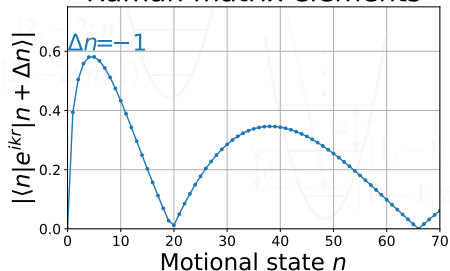
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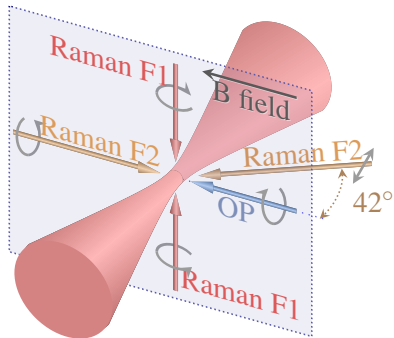
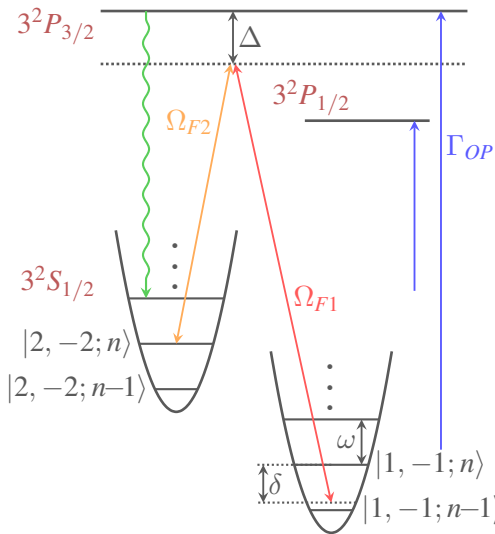


Raman matrix elements



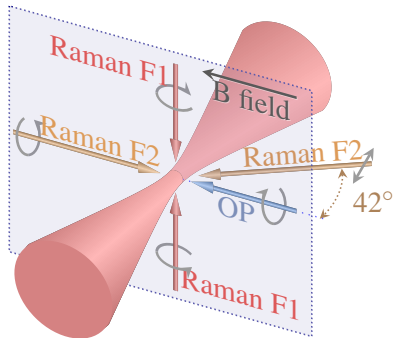
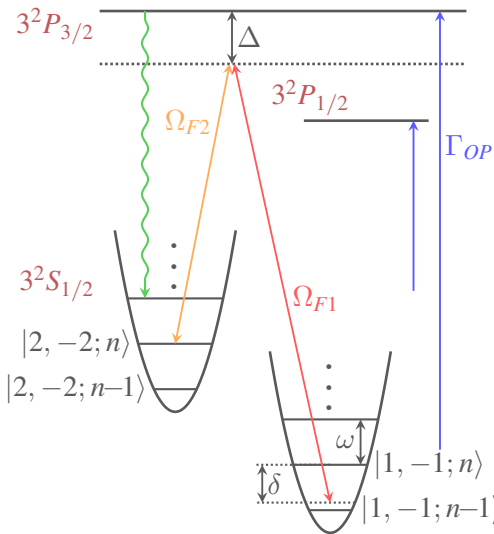
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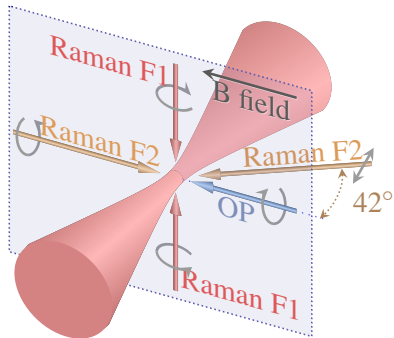
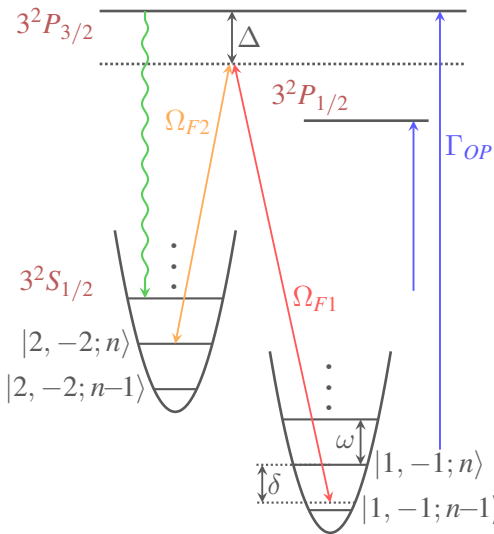
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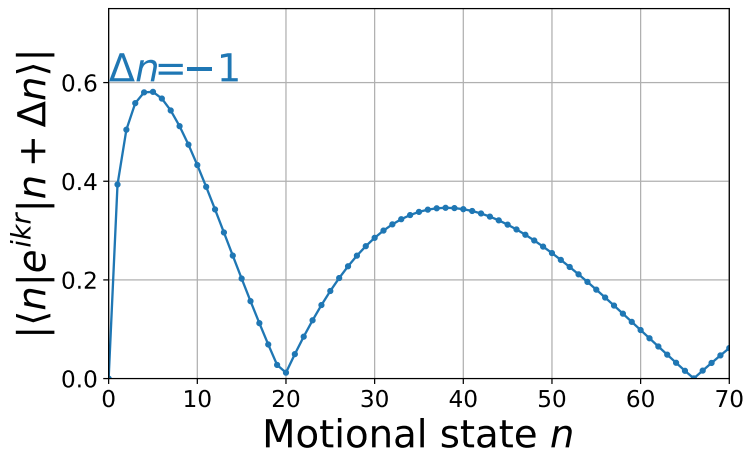
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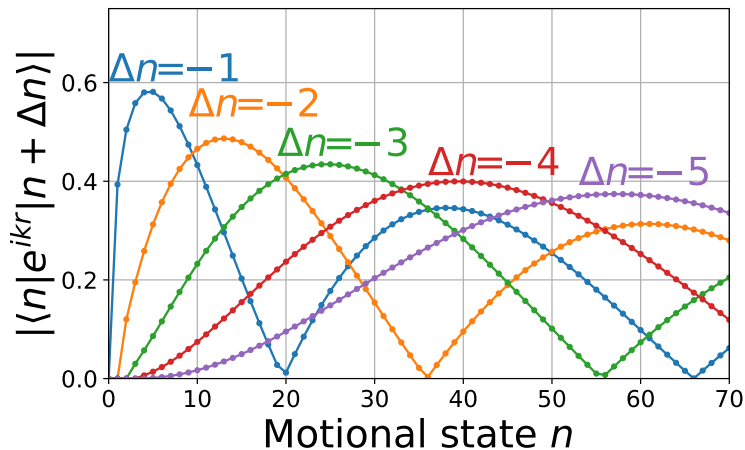


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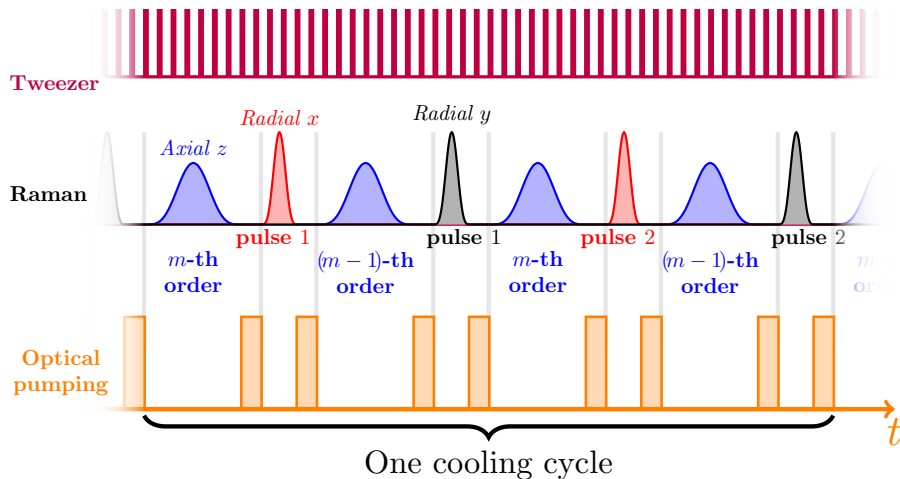
Raman matrix elements



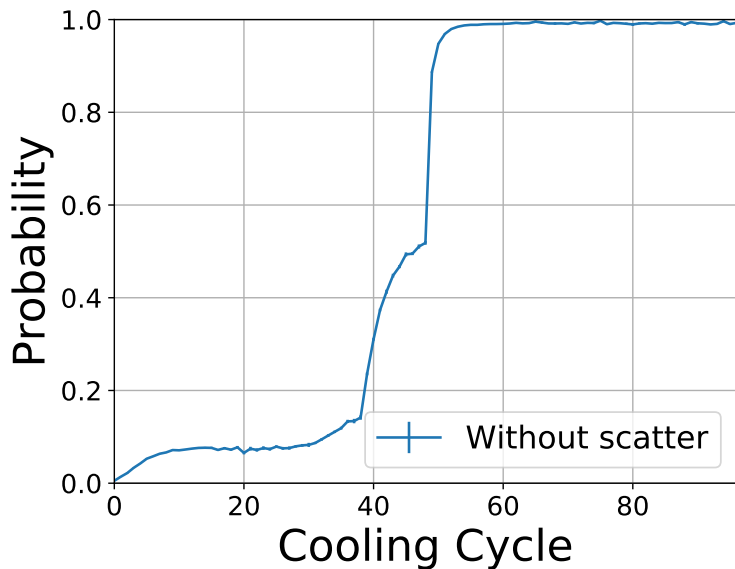
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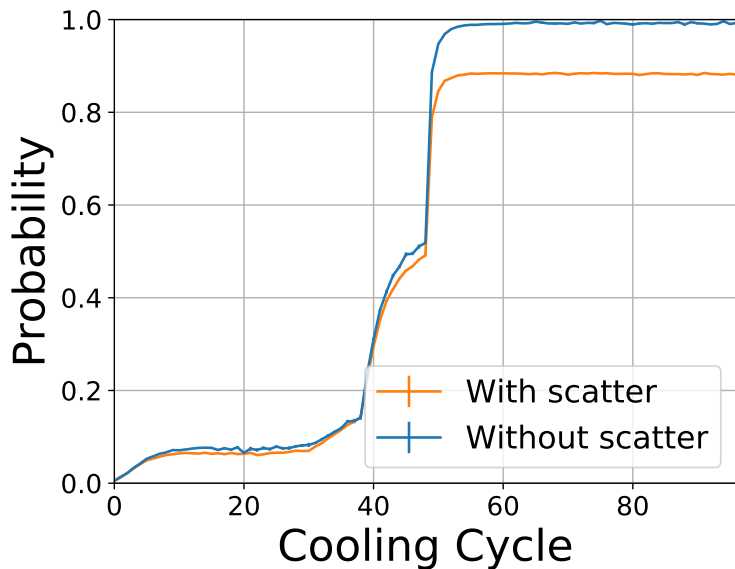
Sequence and simulation

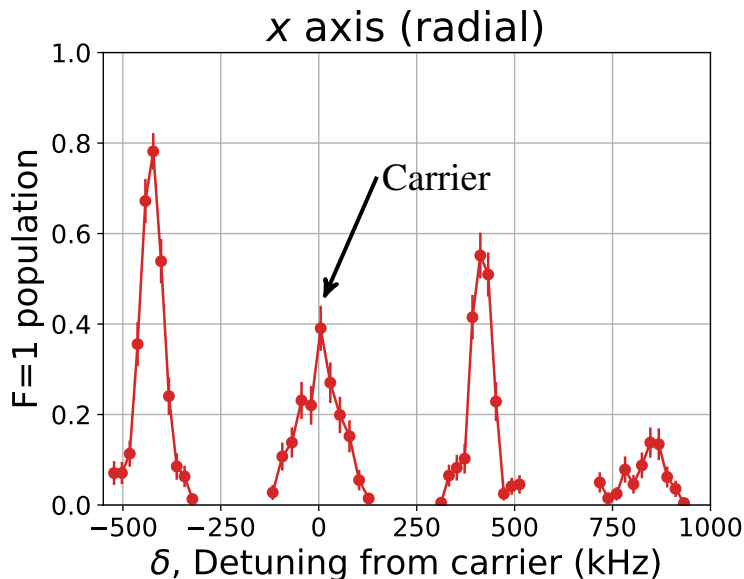


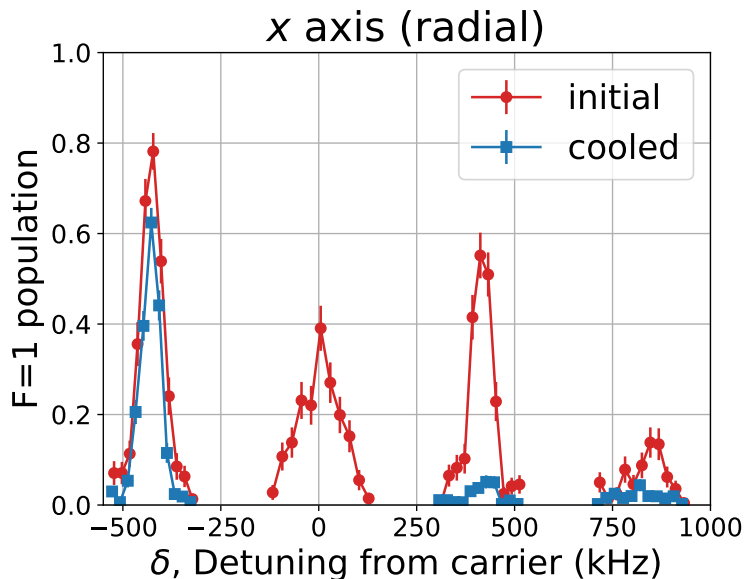
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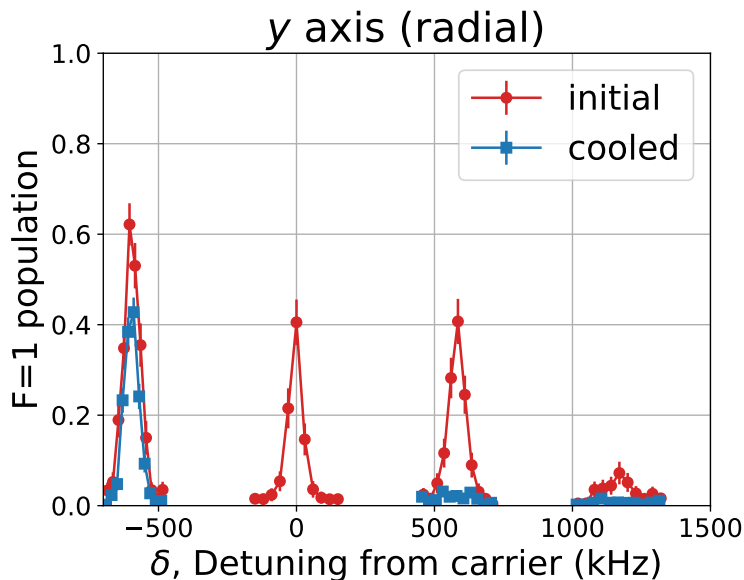


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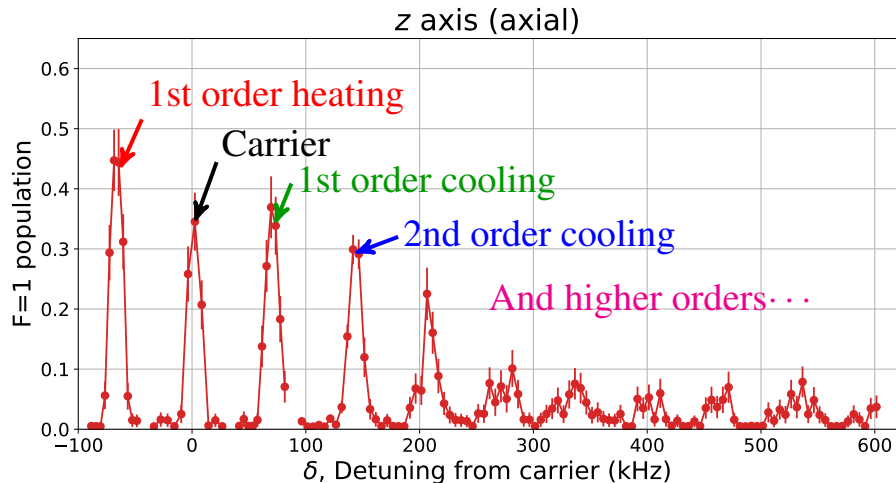




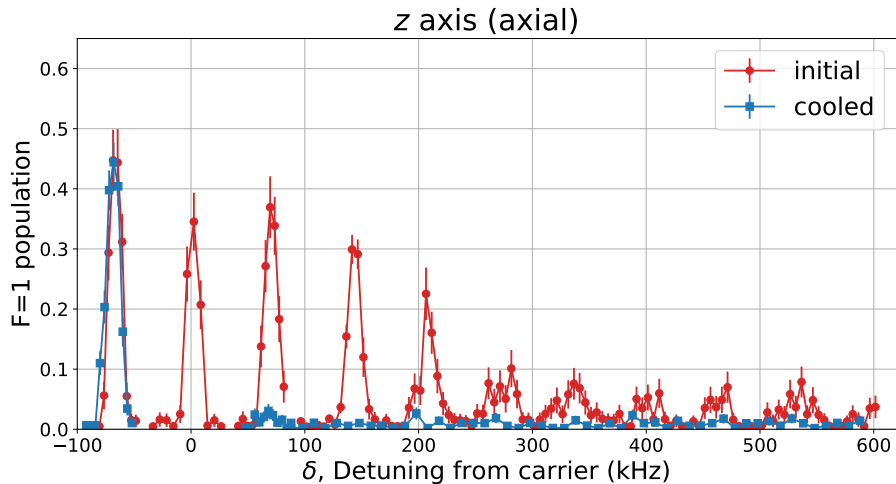




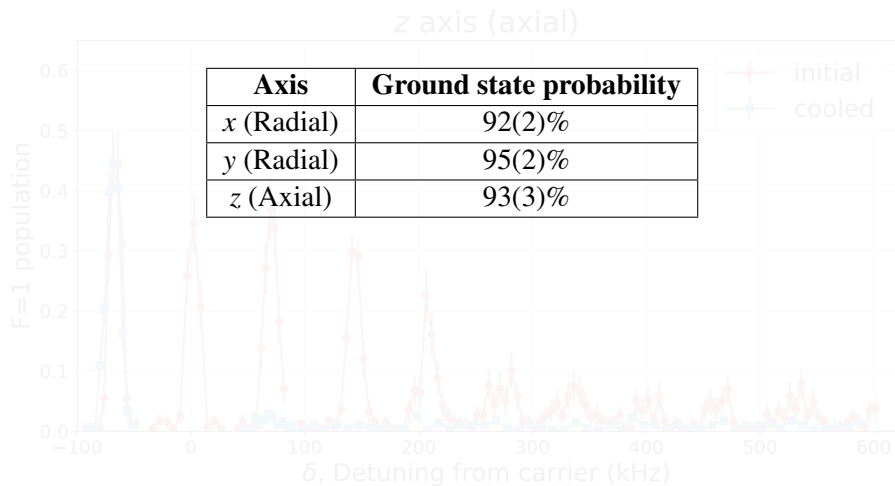
Raman sidebands



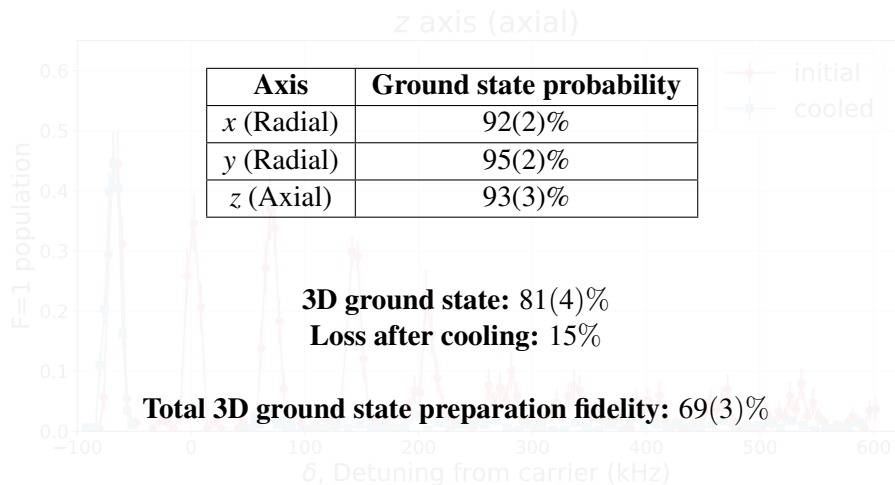
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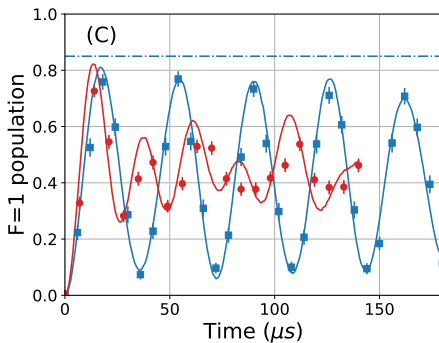
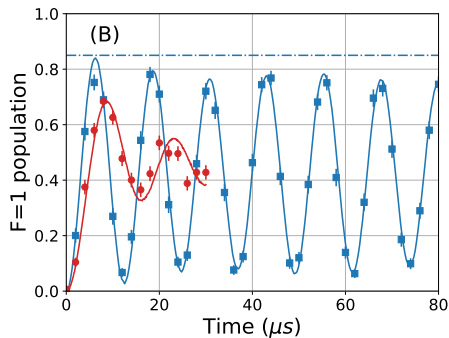
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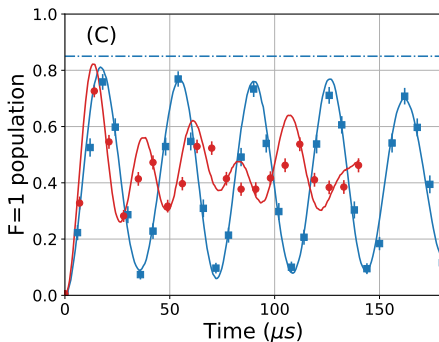
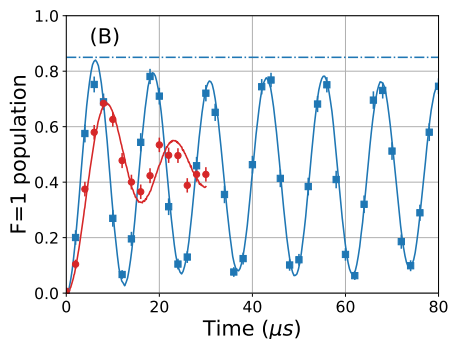
Raman sidebands



Rabi flopping (radial)

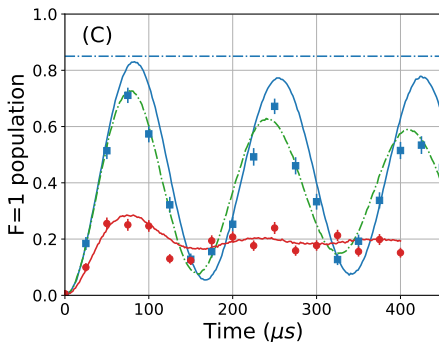
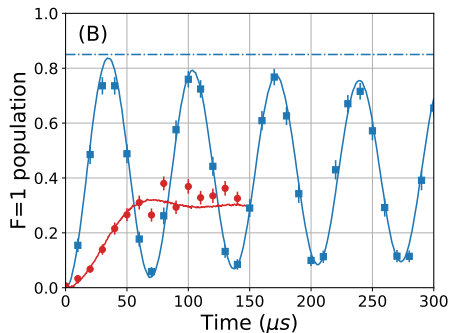


Rabi flopping (radial)



Good agreement in ground state probability
between spectrum and Rabi flopping data.

Rabi flopping (axial)



Decoherence caused by technical noise.
E.g. 1.5 mG of magnetic field noise.

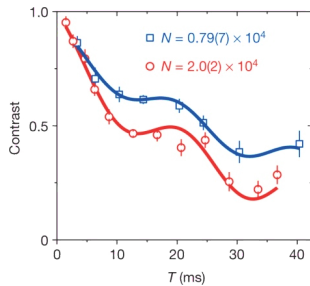
Conclusion

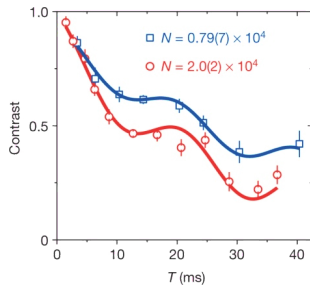
- Trapping of Na and Cs atoms
- Ground state cooling of Na^[3] and Cs

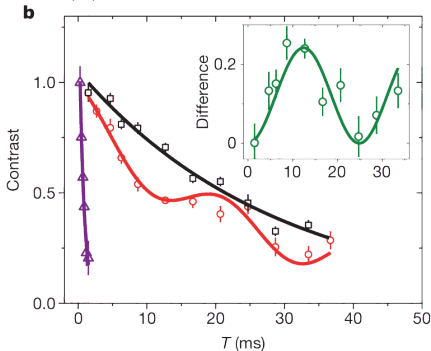
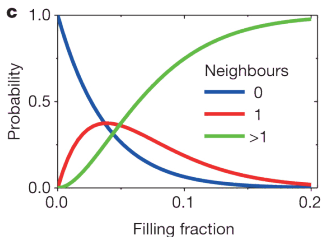
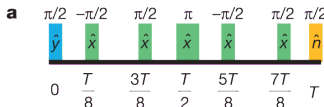
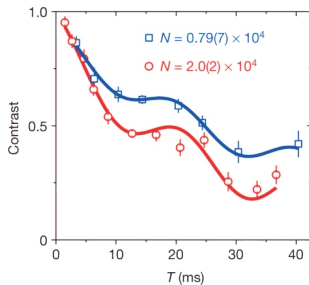
In progress

- Merge trap
- Photoassociation spectroscopy
- Make molecules

[3] Y. Yu et al., “Motional ground state cooling outside the lamb-dicke regime”, [arXiv 1708.03296](#) (2017).









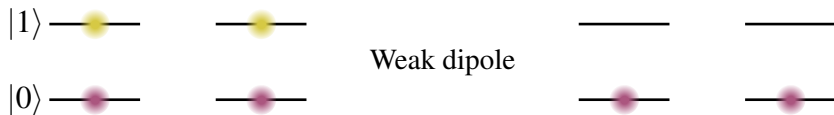
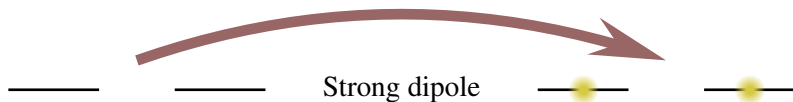
Quantum computation

_____ _____ Strong dipole

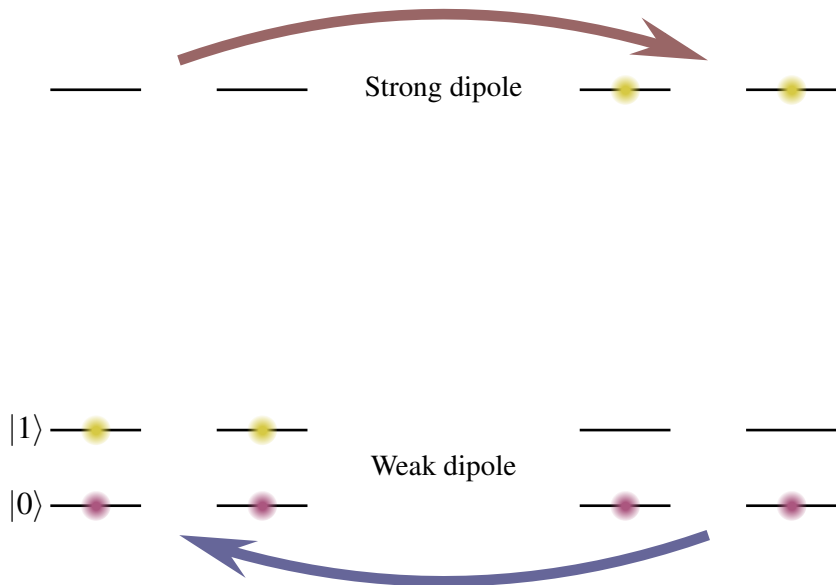
$|1\rangle$ —  — —  — Weak dipole

$|0\rangle$ —  — —  —

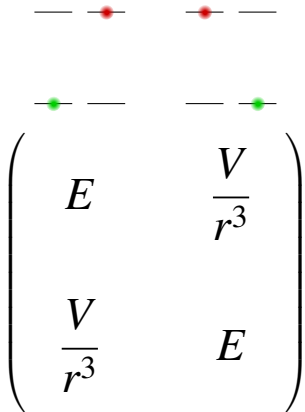
Quantum computation



Quantum computation



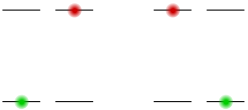
Quantum computation



The diagram illustrates a two-qubit system. At the top, two horizontal lines represent energy levels. The left line has a red dot, and the right line has a red dot. Below these, two more horizontal lines represent energy levels. The left line has a green dot, and the right line has a green dot. Below the energy levels is a large matrix representing the system's Hamiltonian:

$$\begin{pmatrix} E & \frac{V}{r^3} \\ \frac{V}{r^3} & E \end{pmatrix}$$

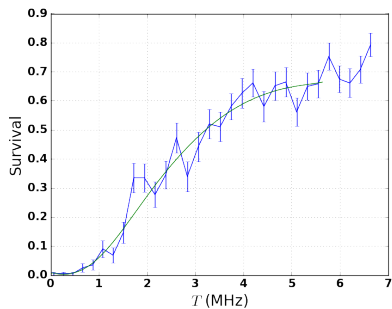
Quantum computation



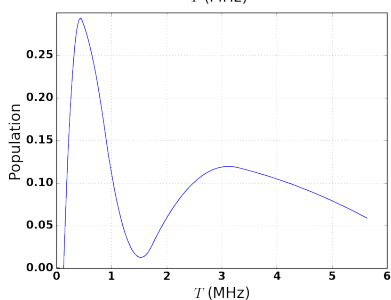
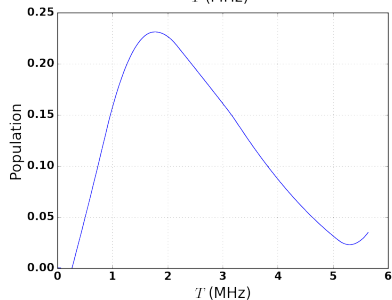
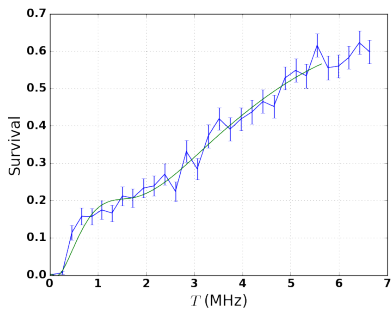
The diagram shows two horizontal lines representing energy levels. The top line has two red dots, and the bottom line has two green dots. This represents a system with two degenerate states at energy E . A large blue arrow points from this diagram to a Hamiltonian matrix.

$$\begin{pmatrix} E & \frac{V}{r^3} \\ \frac{V}{r^3} & E \end{pmatrix} \rightarrow \begin{pmatrix} E - \frac{V}{r^3} & \\ & E + \frac{V}{r^3} \end{pmatrix}$$

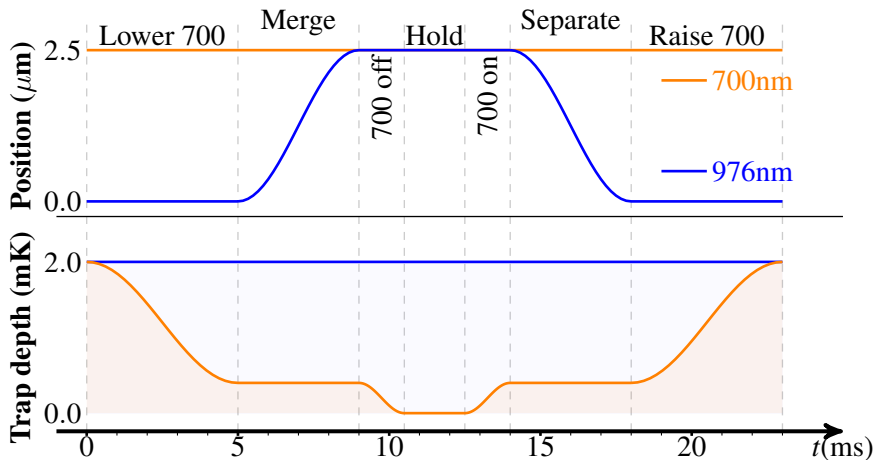
Before cooling



After cooling



Merge trap



Making molecule

