

# Ultracold molecule assembly

Yichao Yu

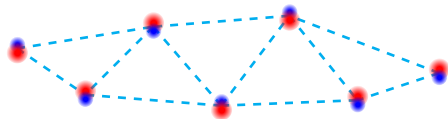
Ni Group/Harvard

Aug 11, 2017

# Molecules in optical tweezer

## Features

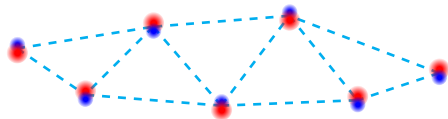
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



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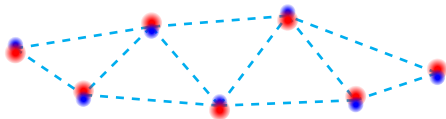
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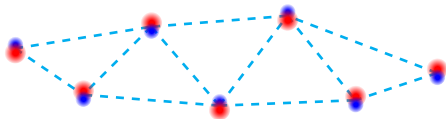
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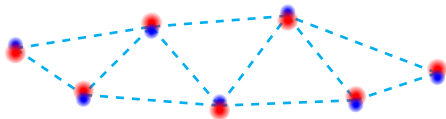
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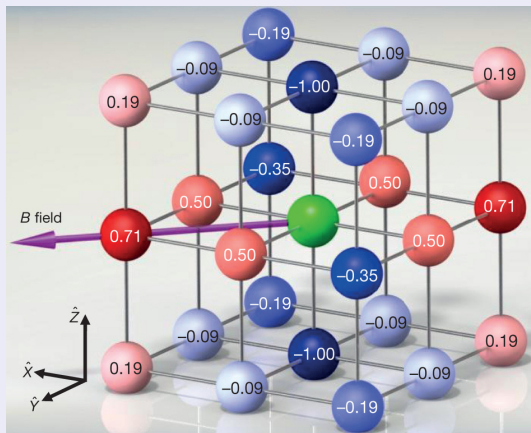
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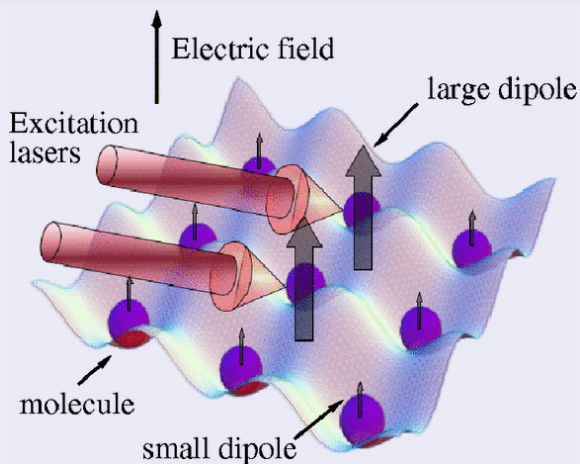
## Simulation of many-body system<sup>[1]</sup>



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

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

## Quantum computation<sup>[2]</sup>



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



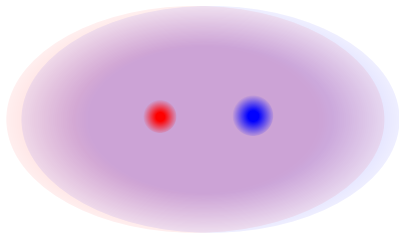
# Making molecules from atoms

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



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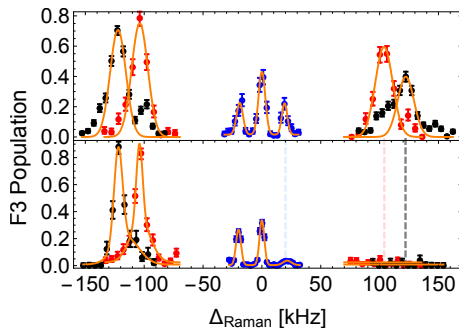
# Atom loading and cooling

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



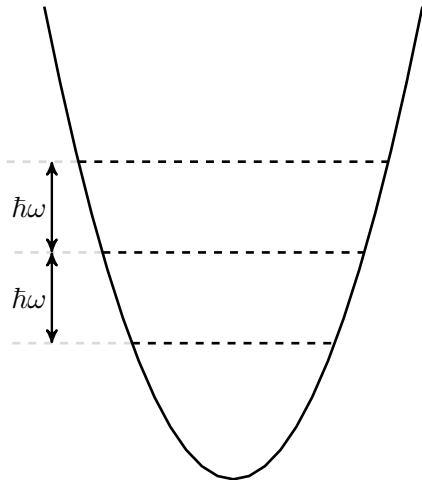
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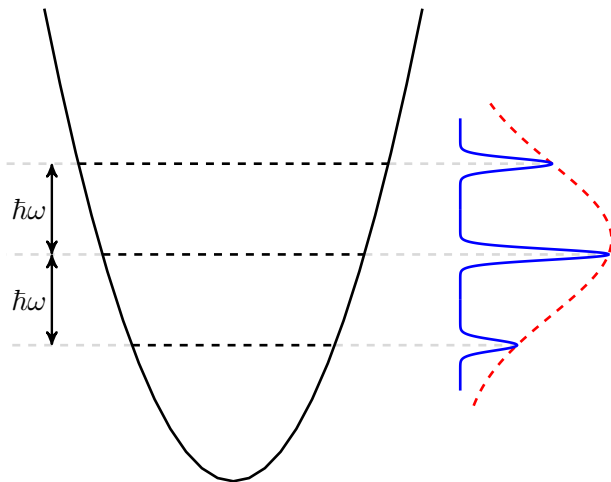




## Raman sideband cooling

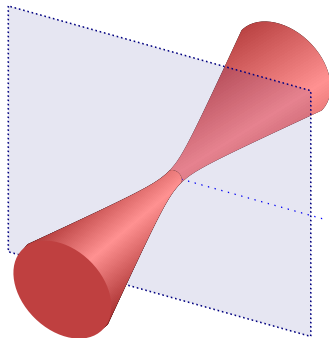
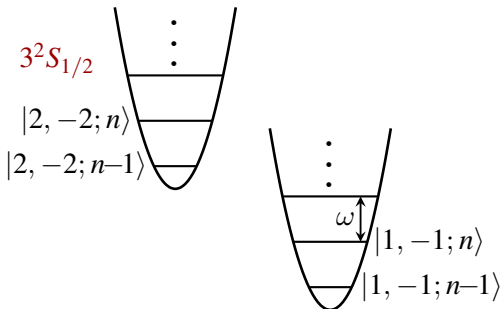


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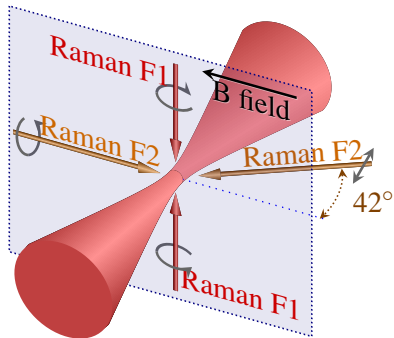
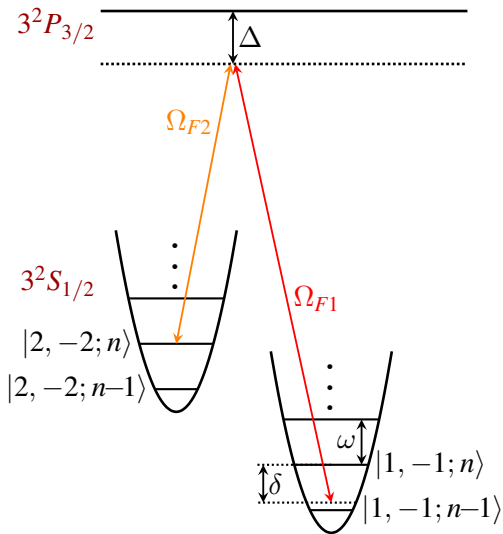


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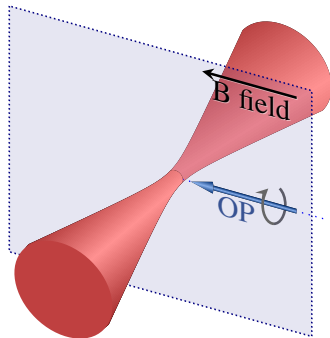
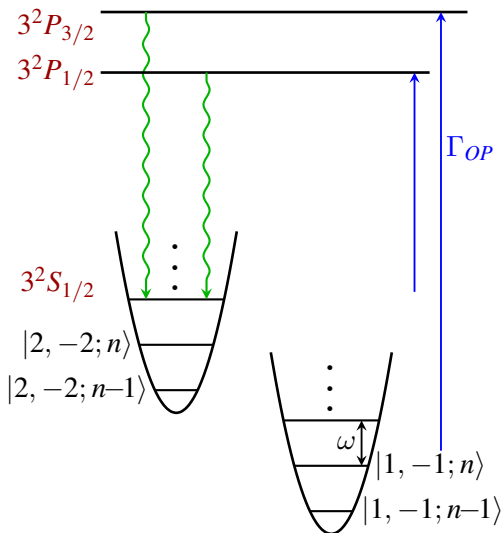
$3^2P_{3/2}$



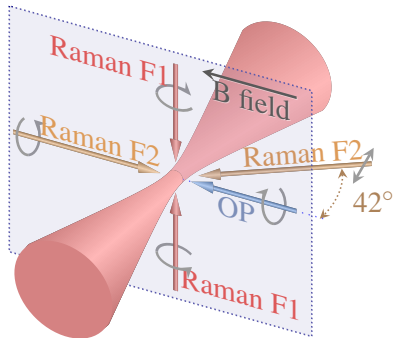
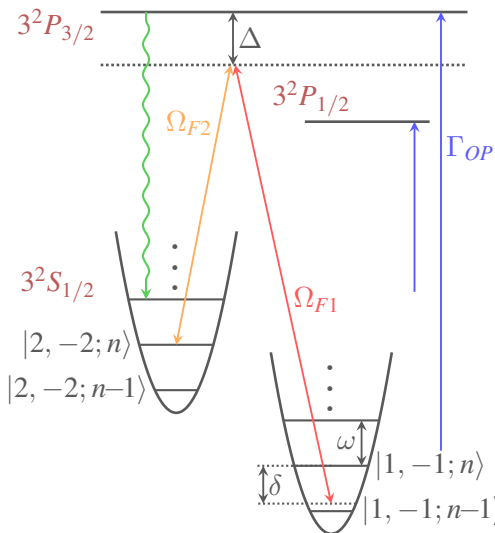
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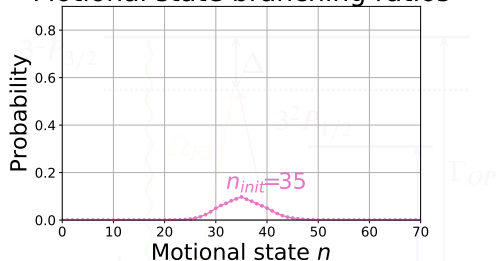


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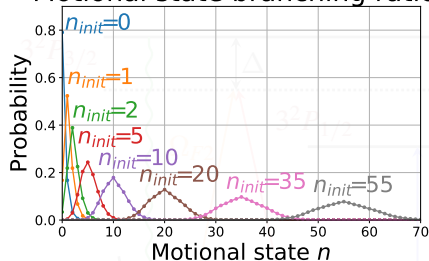
- High initial temperature ( $70\mu K$ )
- High Lamb Dicke parameter  
 $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering  
 $\approx 3 \sim 15\text{kHz}$

## Motional state branching ratios



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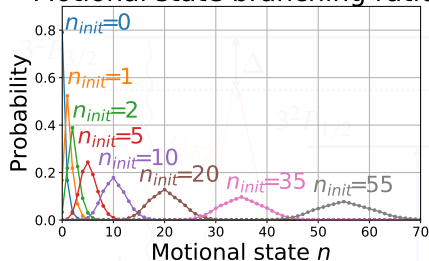
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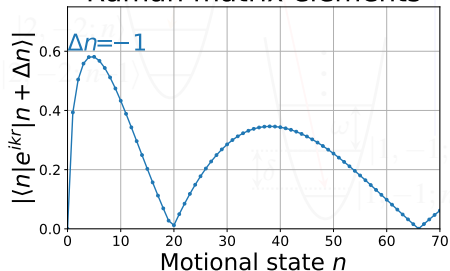
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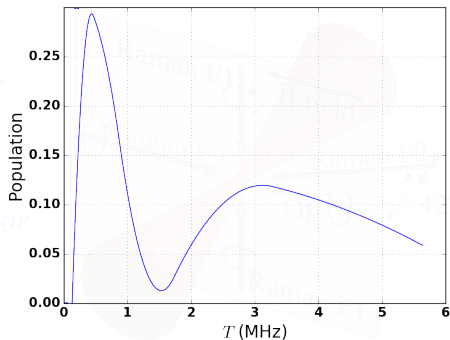
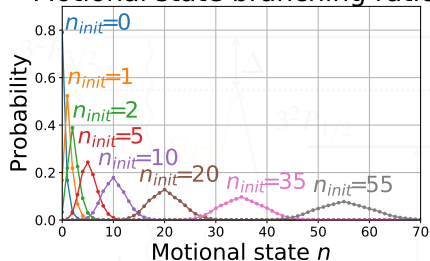
## Raman matrix elements



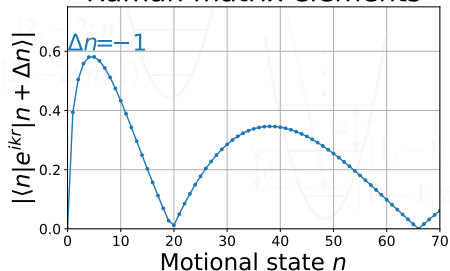
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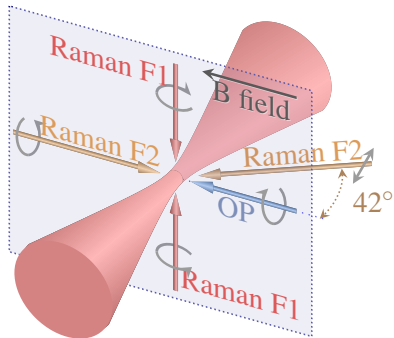
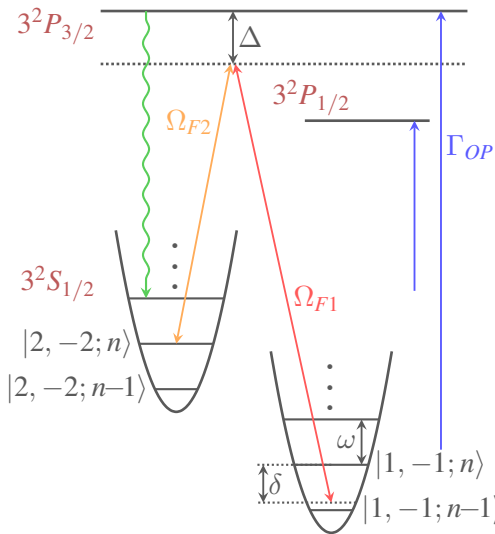


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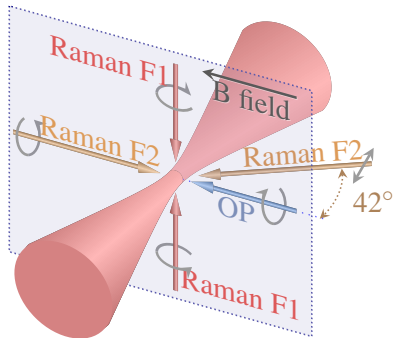
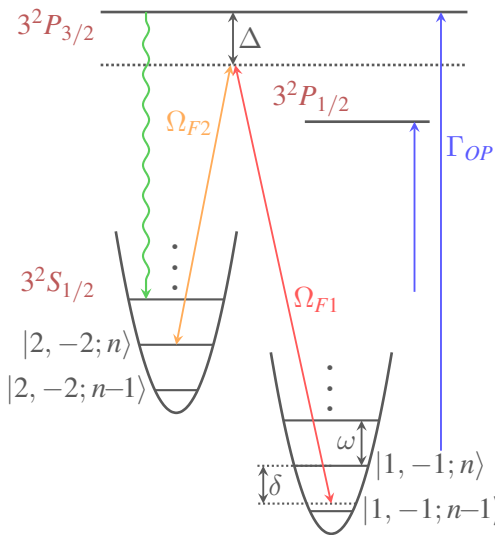
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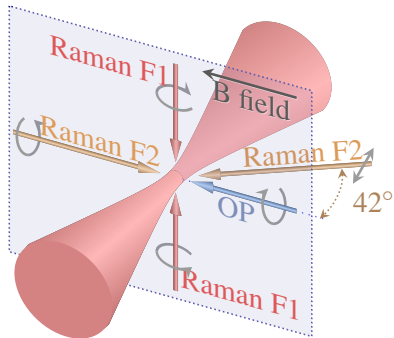
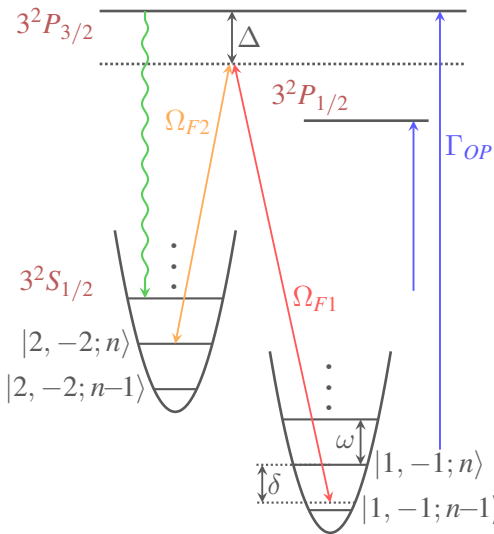
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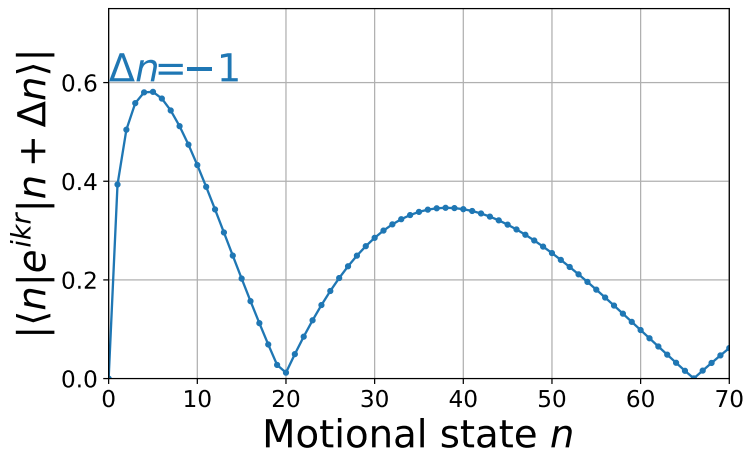
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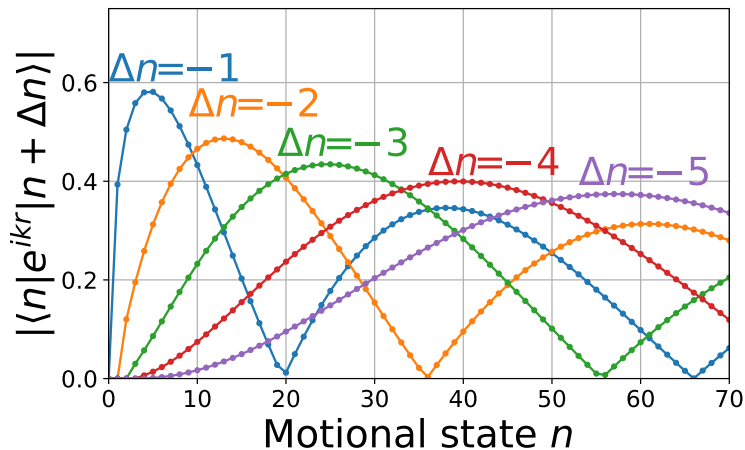


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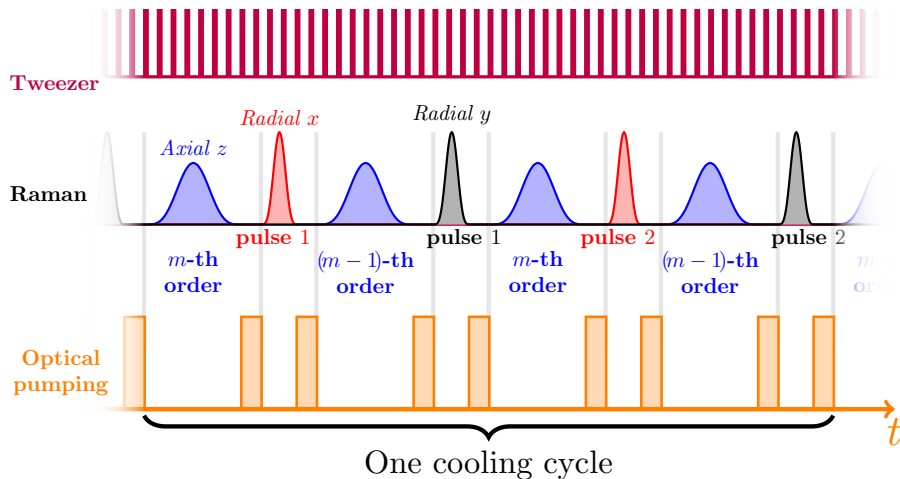
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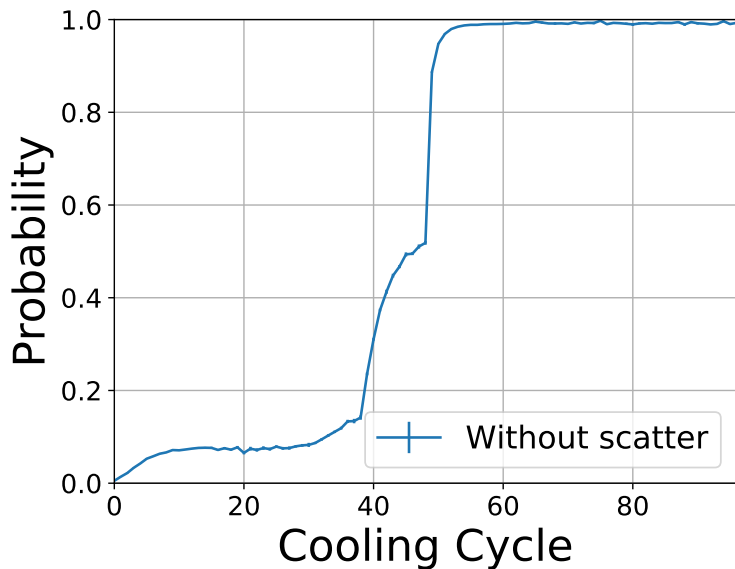


# Sequence and simulation

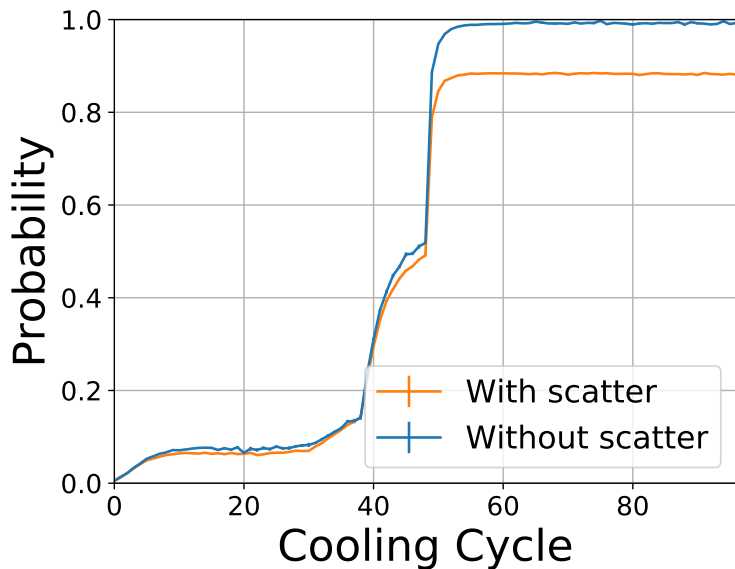




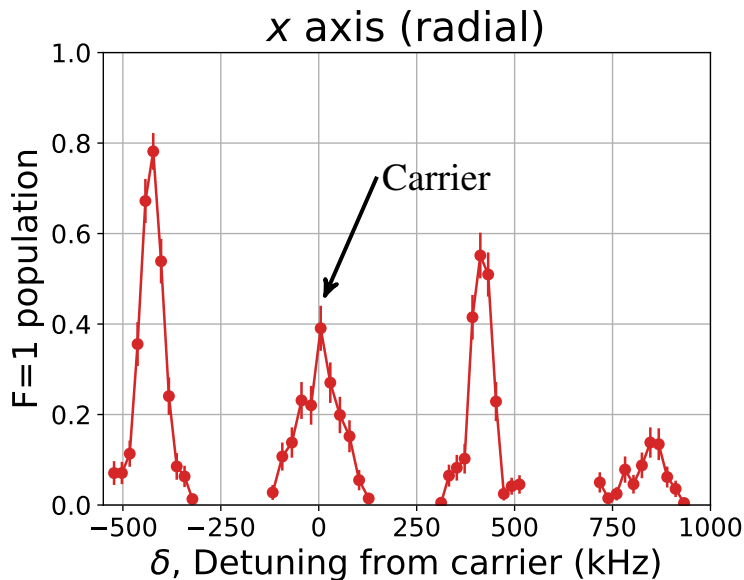
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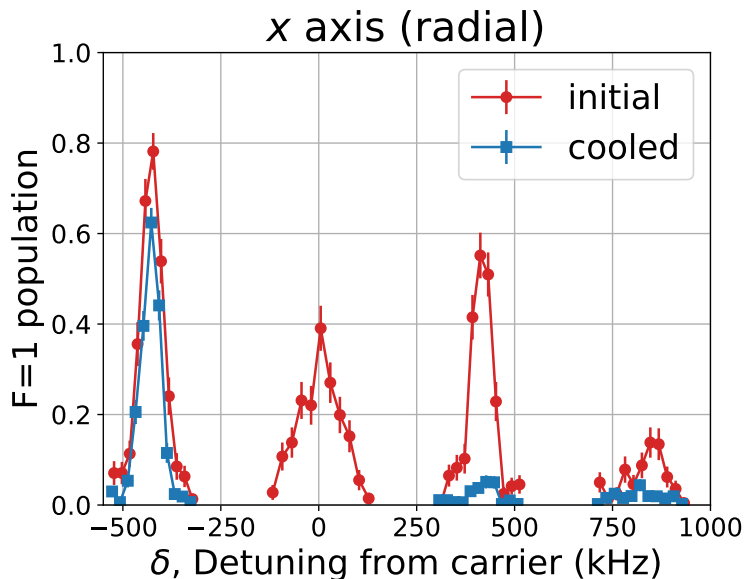


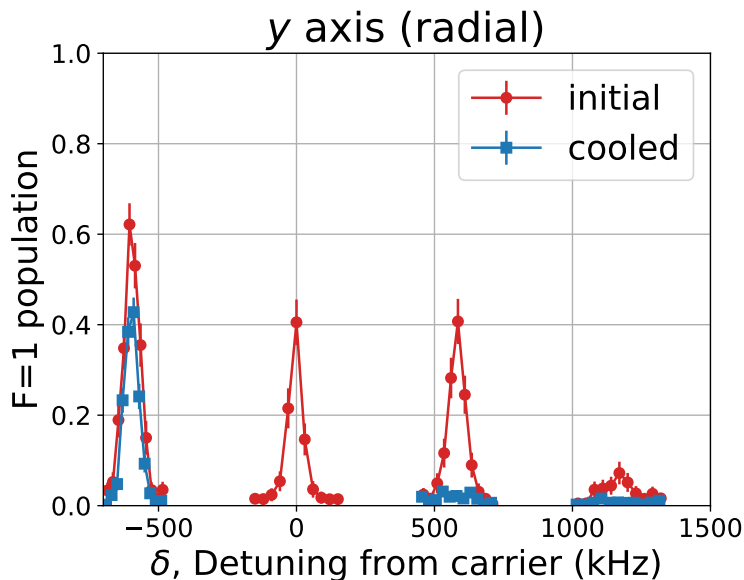
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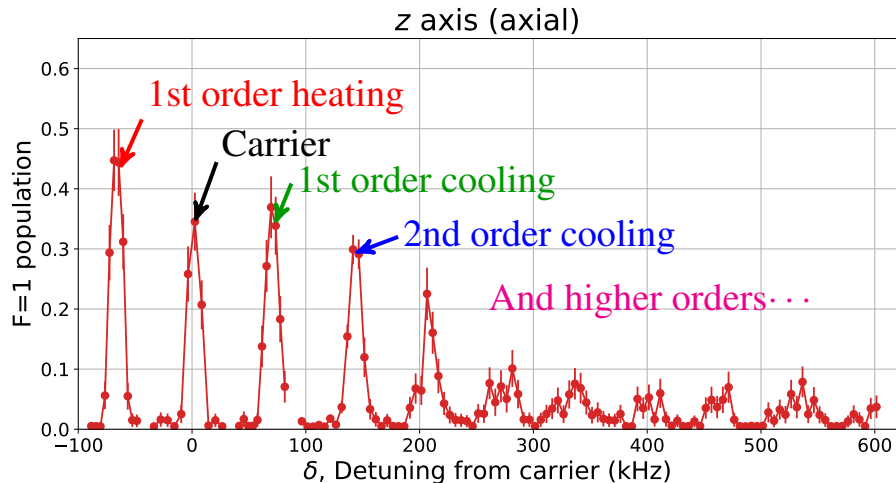
## Raman sidebands



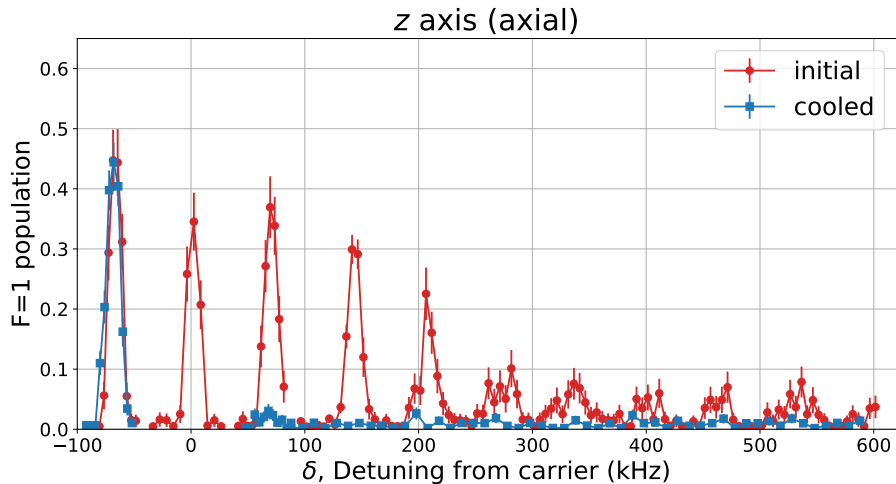




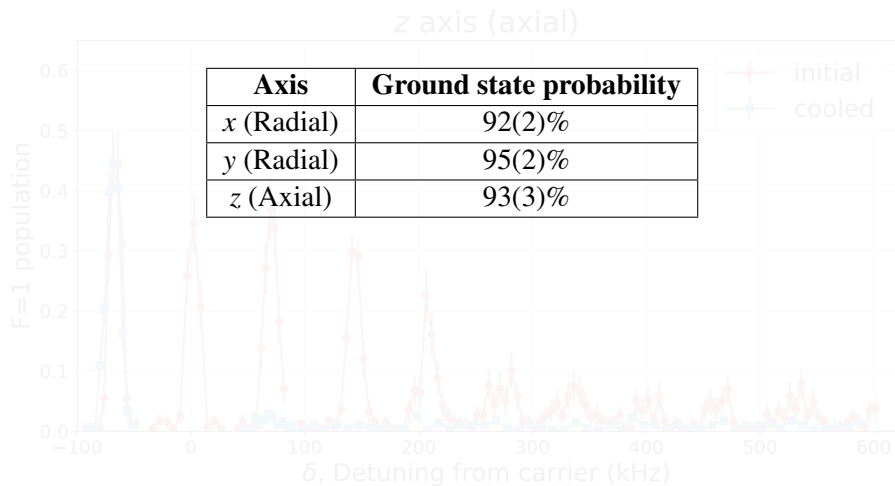
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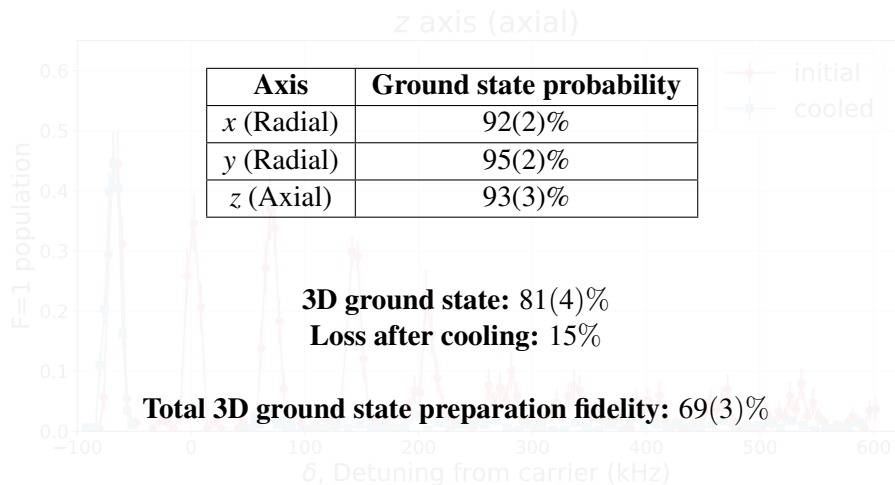


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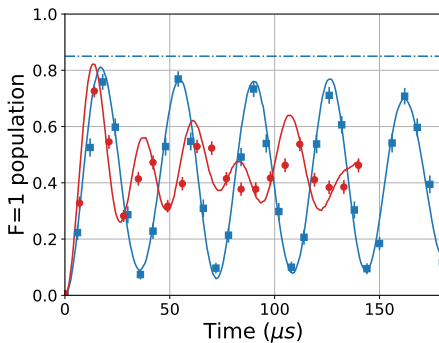
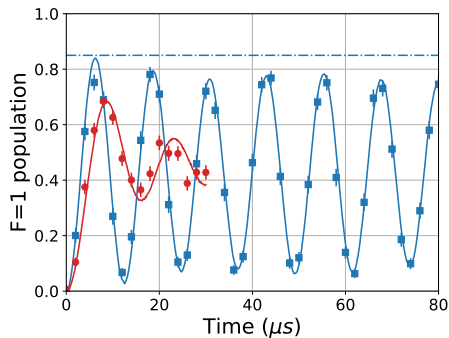




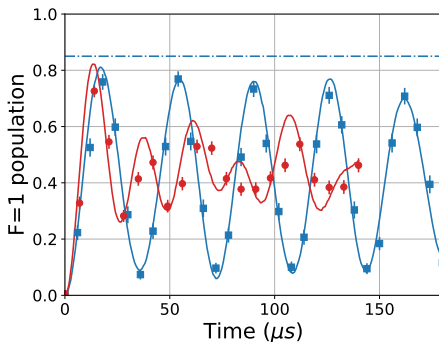
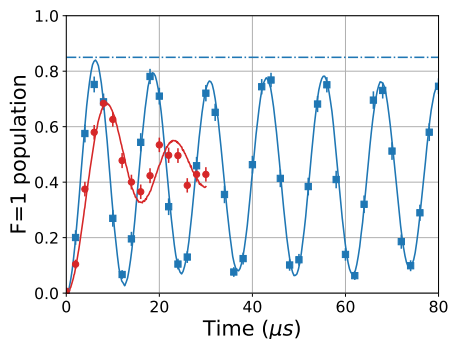
## Raman sidebands



## Rabi flopping (radial)

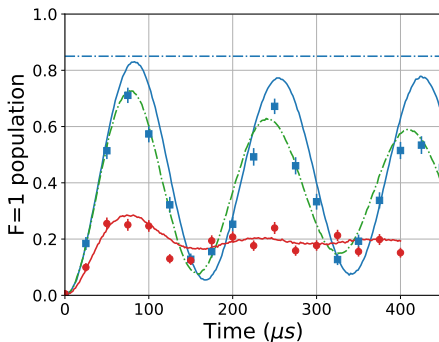
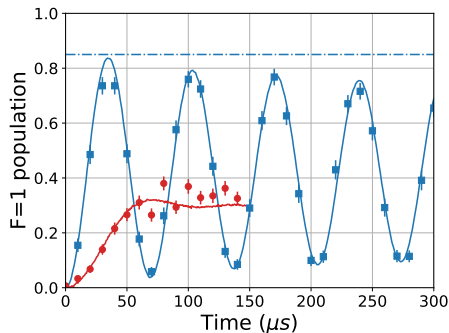


## Rabi flopping (radial)



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<sup>[3]</sup> and Cs

## In progress

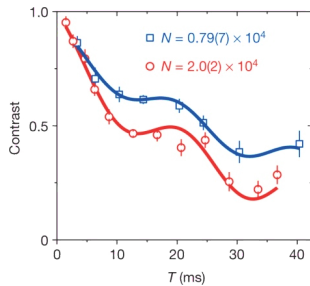
- Merge trap
- Photoassociation spectroscopy
- Make molecules

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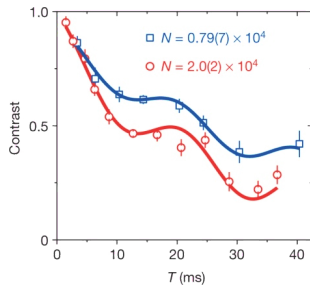
[3] Y. Yu et al., “Motional ground state cooling outside the lamb-dicke regime”, [arXiv 1708.03296](#) (2017).

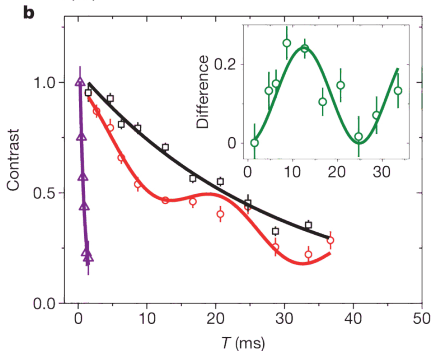
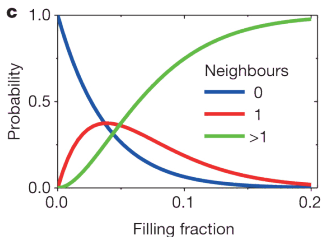
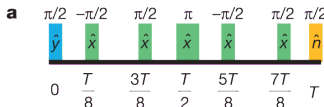
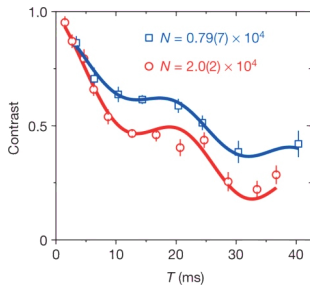












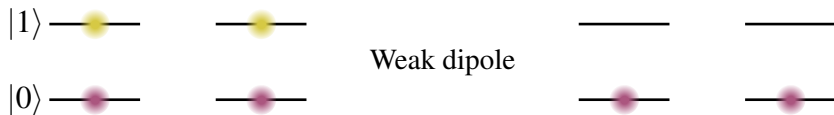
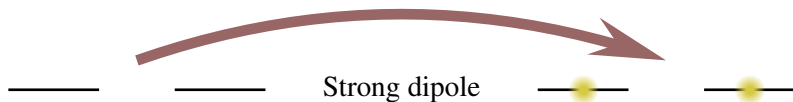


# Quantum computation

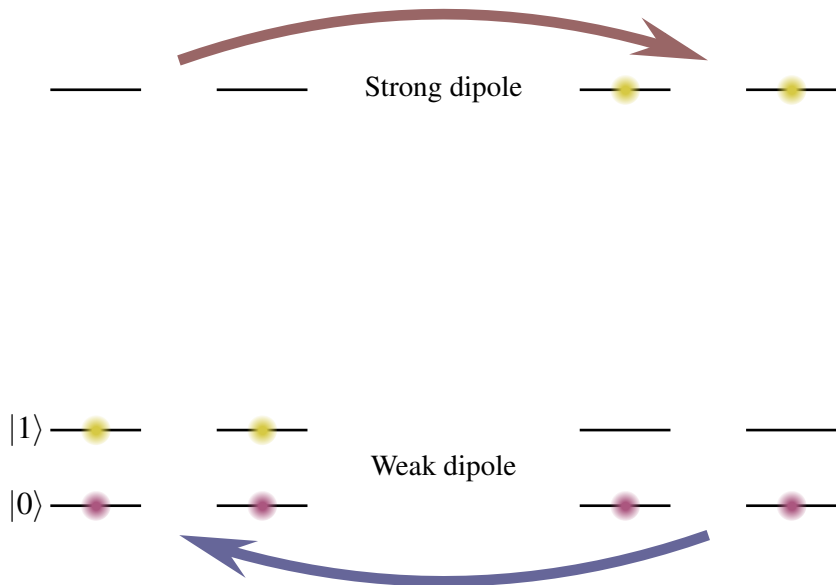
———— Strong dipole

$|1\rangle$  ———  $|1\rangle$   
 $|0\rangle$  ———  $|0\rangle$   
Weak dipole

# Quantum computation

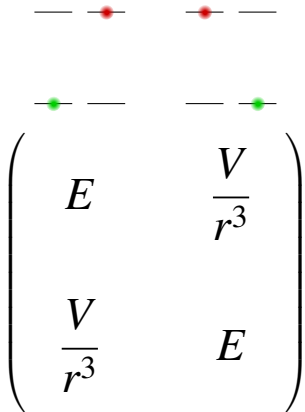


# Quantum computation





# Quantum computation

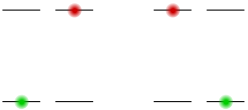


The diagram illustrates a two-qubit system. At the top, there are two horizontal lines representing energy levels. The left line has a red dot in the middle, and the right line has a red dot in the middle. Below these, there are two more horizontal lines. The left line has a green dot in the middle, and the right line has a green dot in the middle. Below the green dots is a large matrix representing the system's Hamiltonian or coupling matrix. The matrix is a 2x2 block with elements  $E$ ,  $\frac{V}{r^3}$ ,  $\frac{V}{r^3}$ , and  $E$ .

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



## Quantum computation

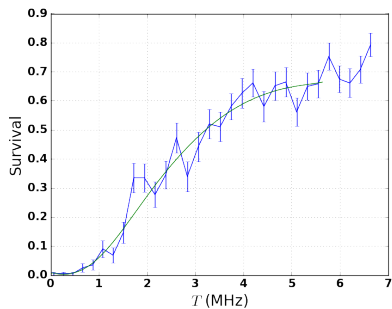


The diagram shows two horizontal lines representing energy levels. The top line has two red dots, and the bottom line has two green dots. This represents a system with two states, each having two degenerate sub-states.

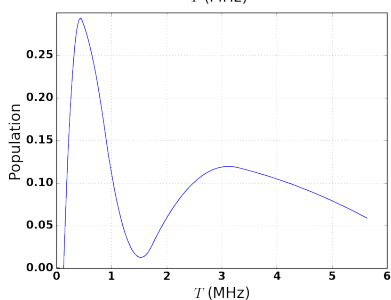
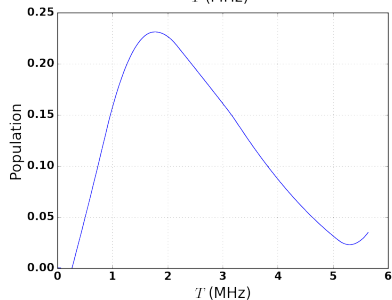
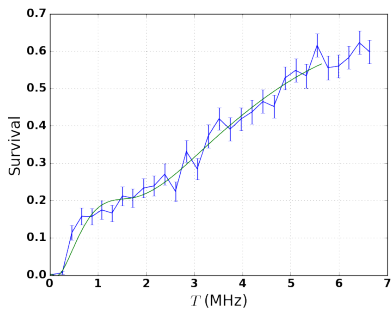
$$\begin{pmatrix} E & \frac{V}{r^3} \\ \frac{V}{r^3} & E \end{pmatrix} \rightarrow \begin{pmatrix} E - \frac{V}{r^3} & \\ & E + \frac{V}{r^3} \end{pmatrix}$$



Before cooling

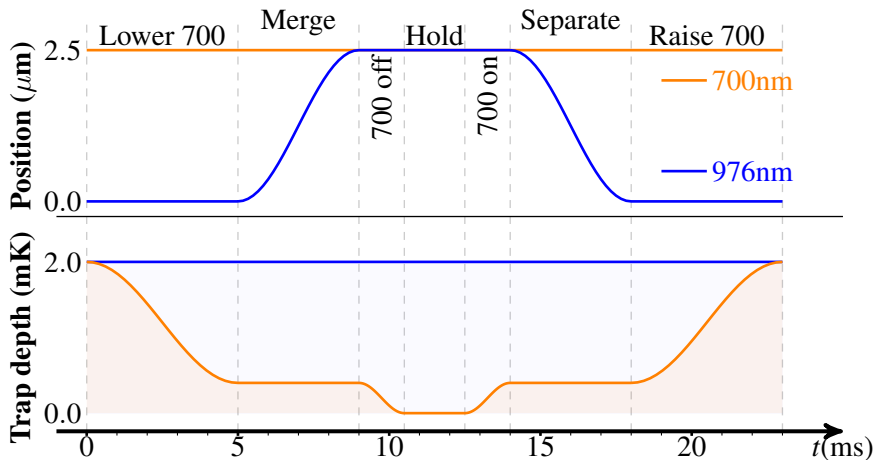


After cooling





## Merge trap





# Making molecule

