

# Ultracold molecule assembly

Yichao Yu

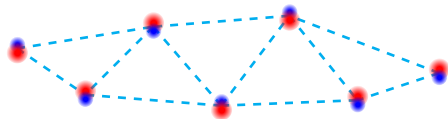
Ni Group/Harvard

Aug 11, 2017

# Molecules in optical tweezer

## Features

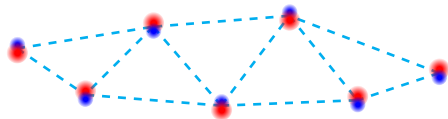
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



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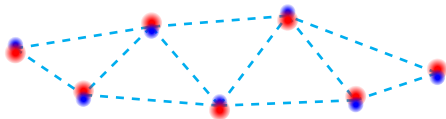
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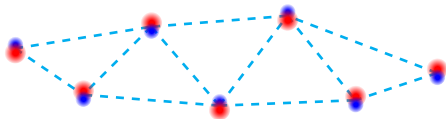
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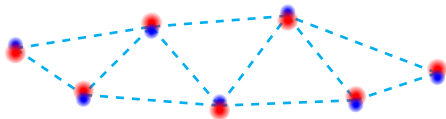
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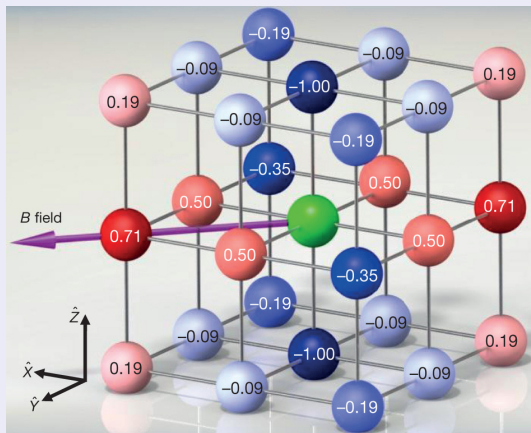
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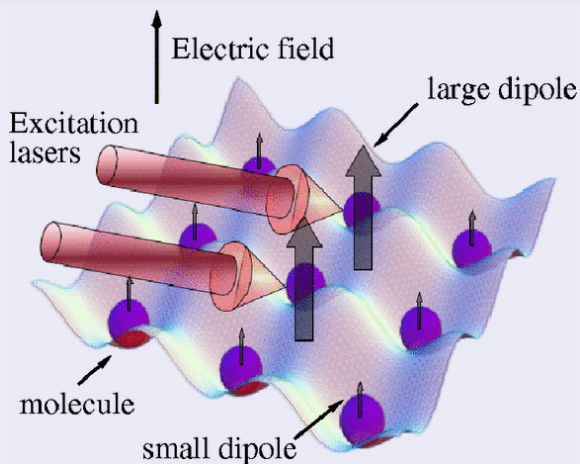
## Simulation of many-body system<sup>[1]</sup>



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

[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).



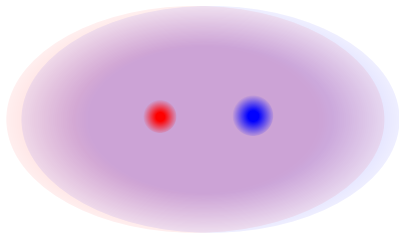
# Making molecules from atoms

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



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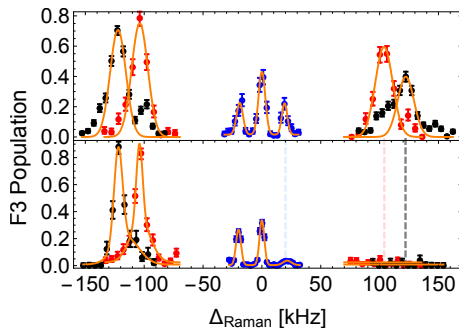
# Atom loading and cooling

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



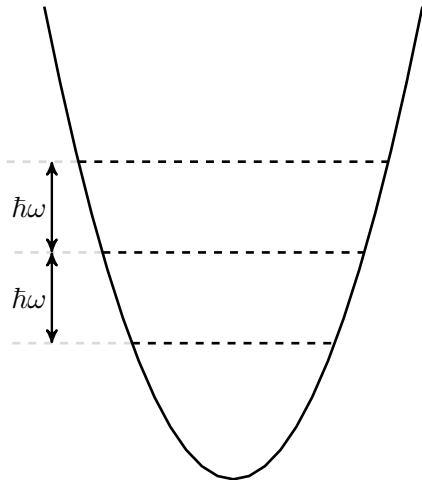
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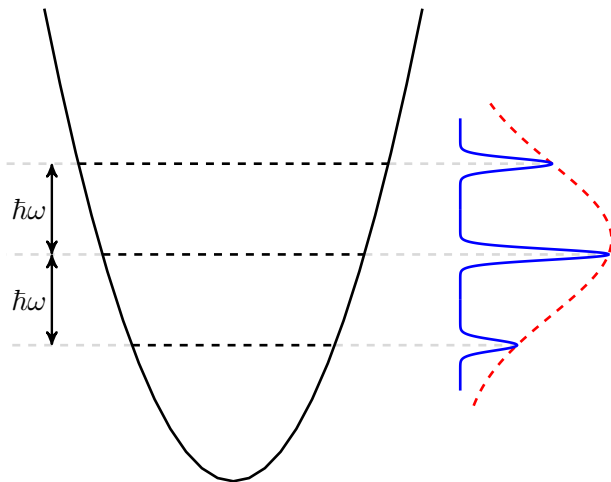




## Raman sideband cooling

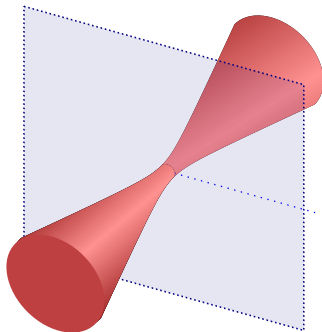
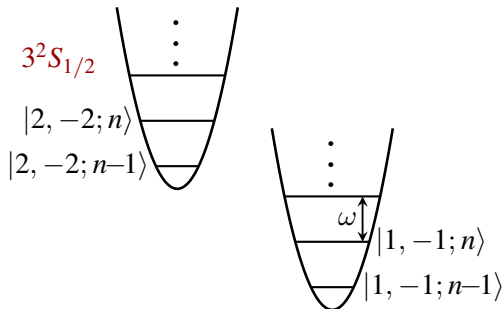


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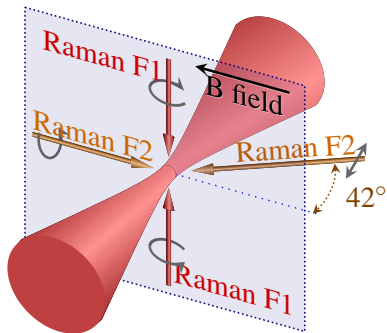
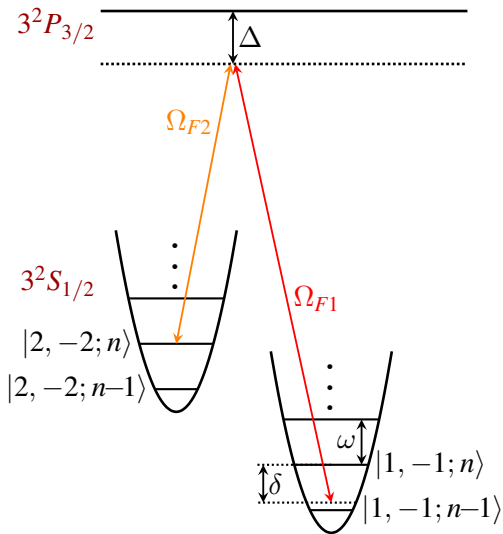


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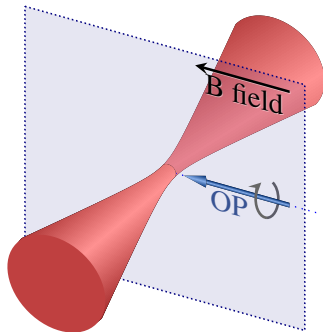
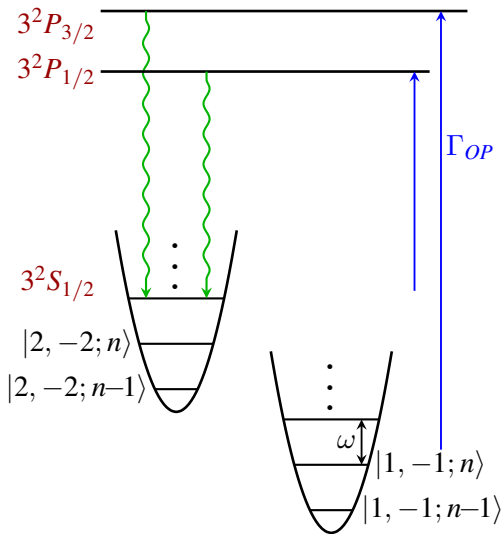
$3^2P_{3/2}$



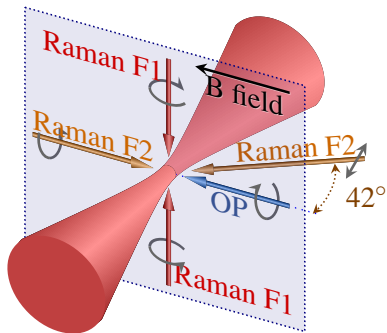
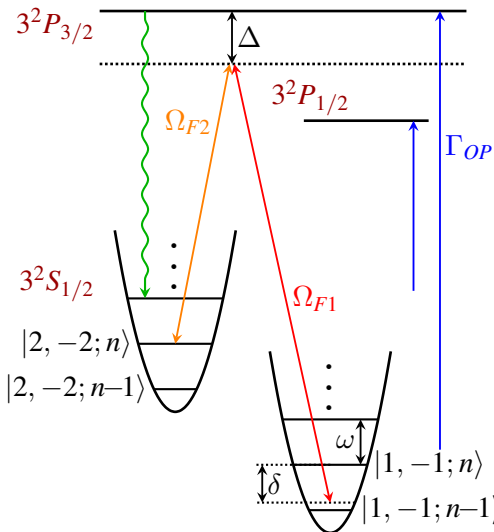
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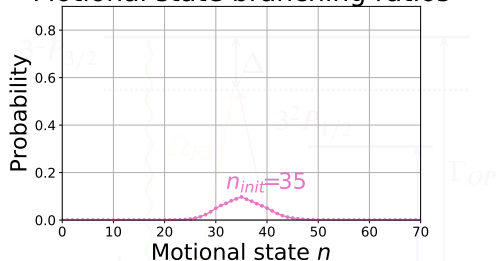


## Raman sideband cooling



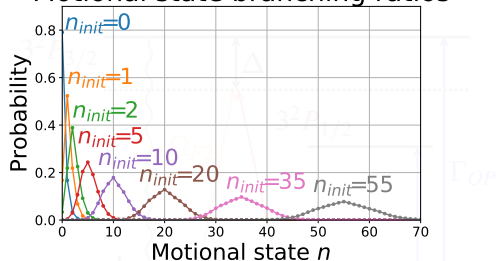
- High initial temperature ( $70\mu K$ )
- High Lamb Dicke parameter  
 $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering  
 $\approx 3 \sim 15\text{kHz}$

## Motional state branching ratios



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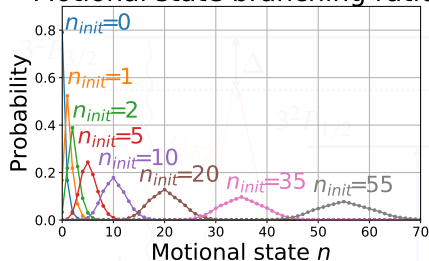
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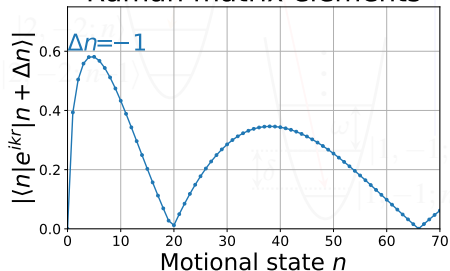
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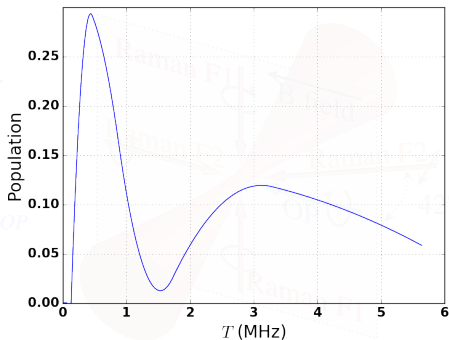
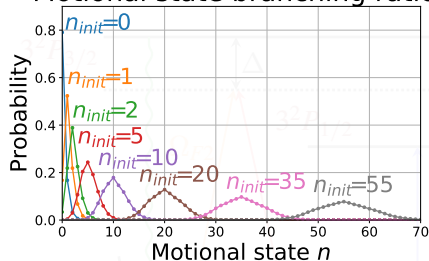


## Raman matrix elements

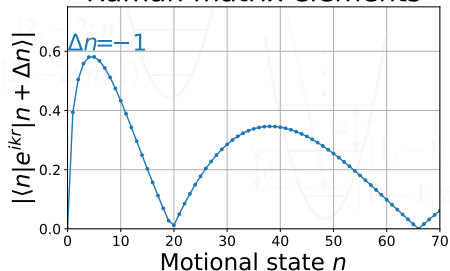


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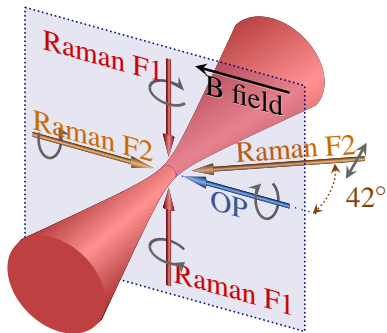
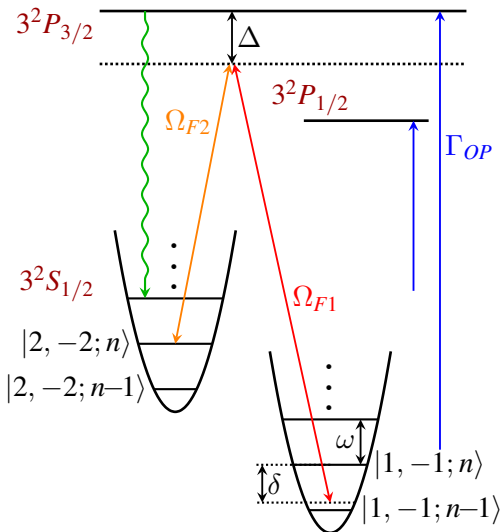


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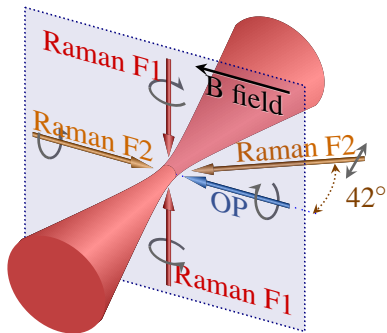
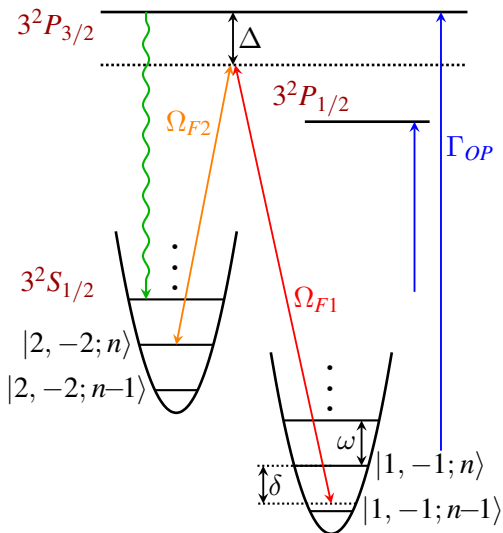
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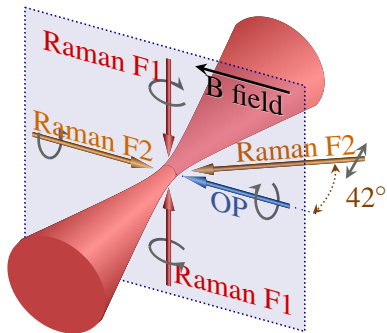
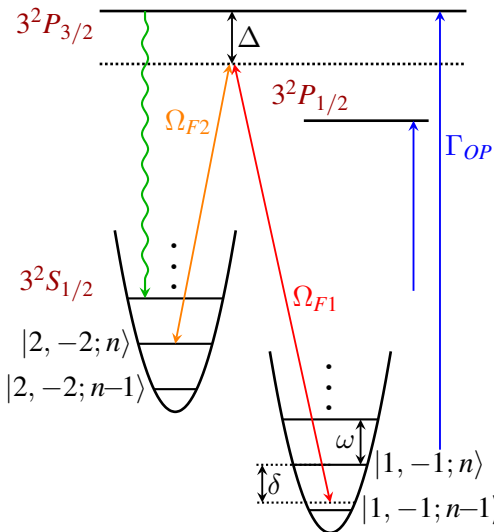
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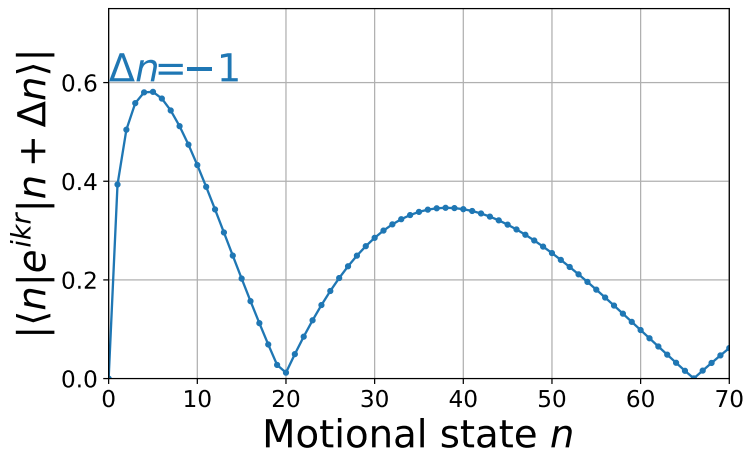
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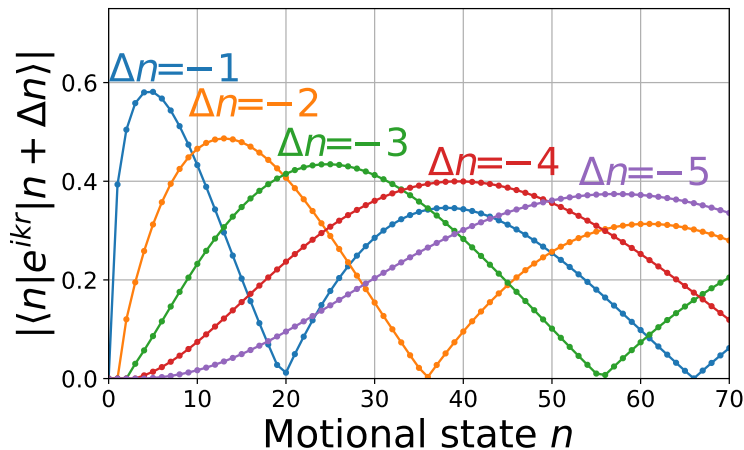


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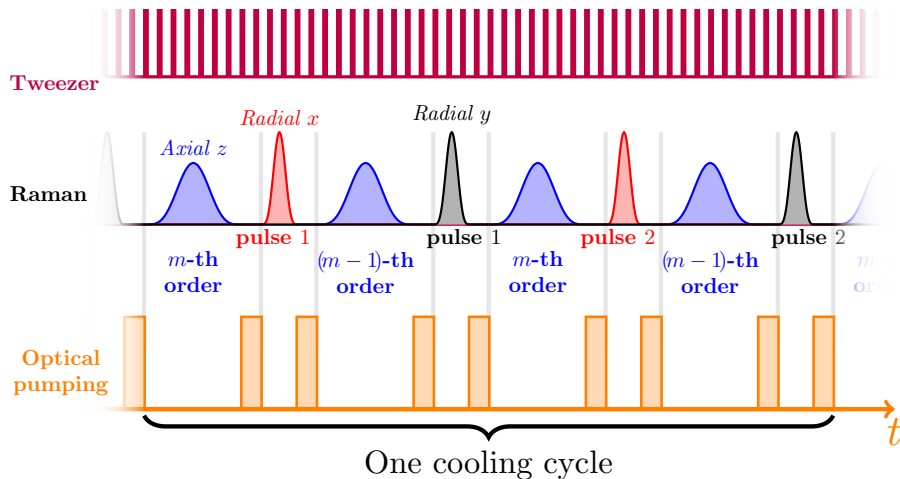
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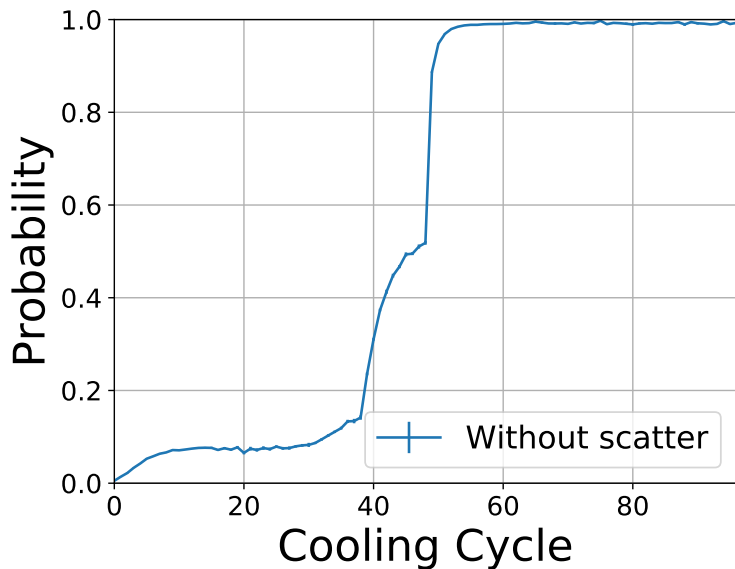


# Sequence and simulation

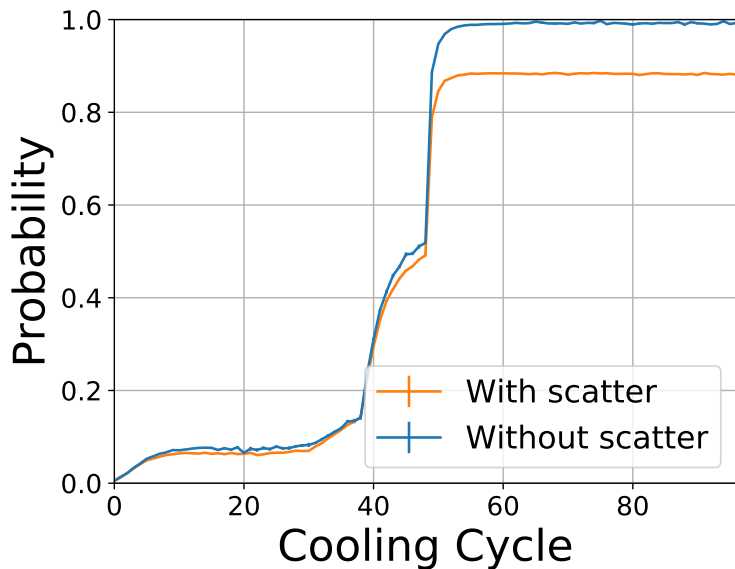


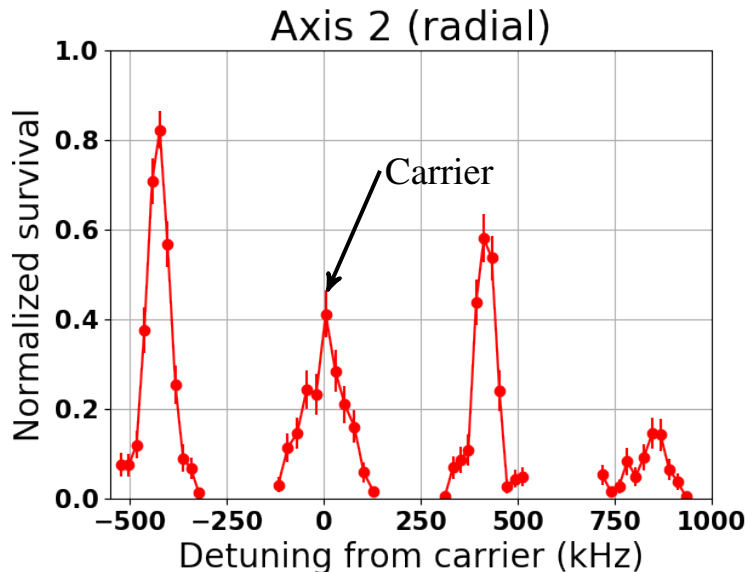


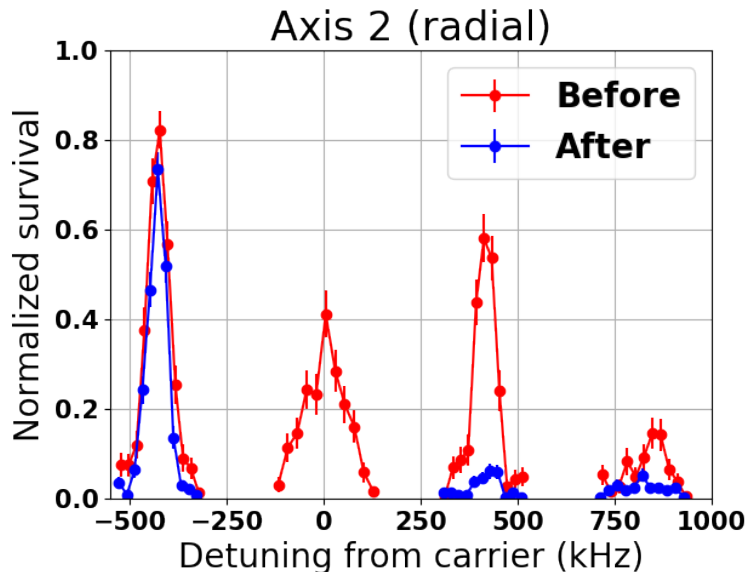
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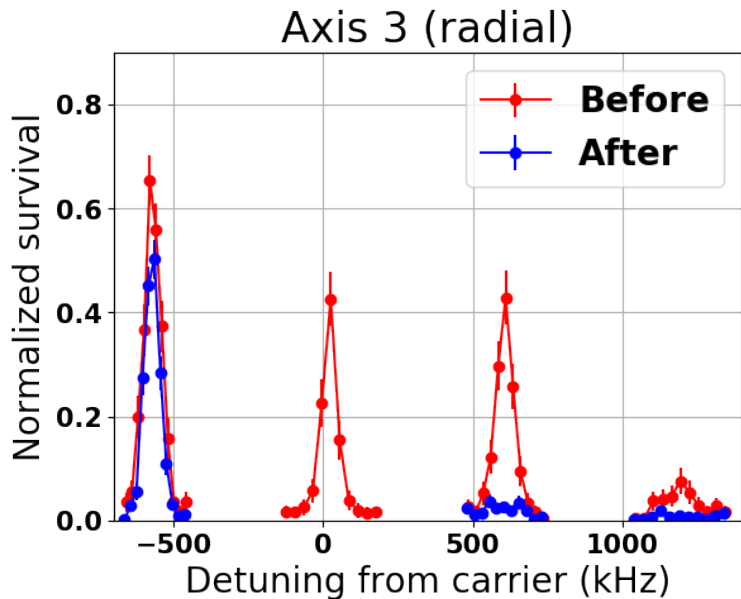


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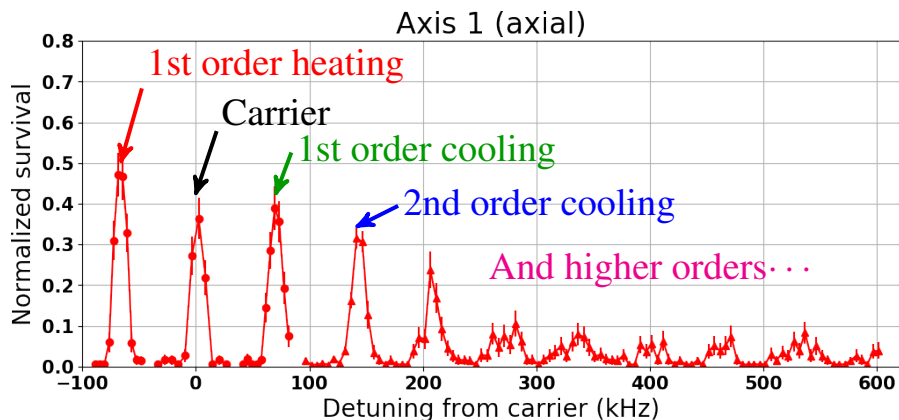




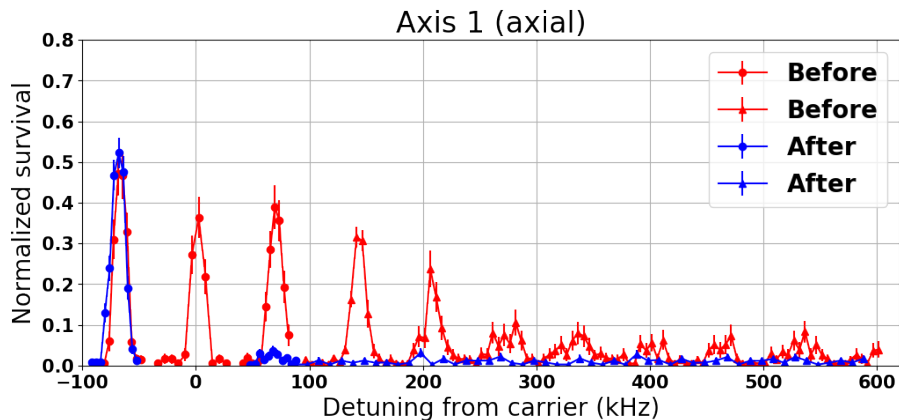




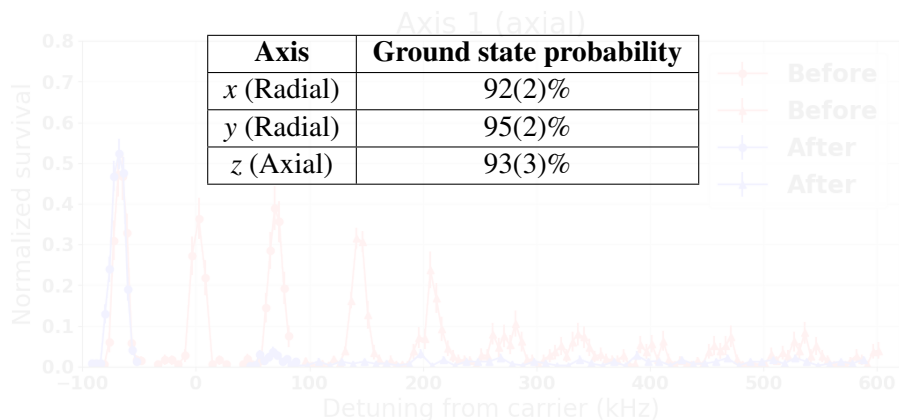
## Raman sidebands



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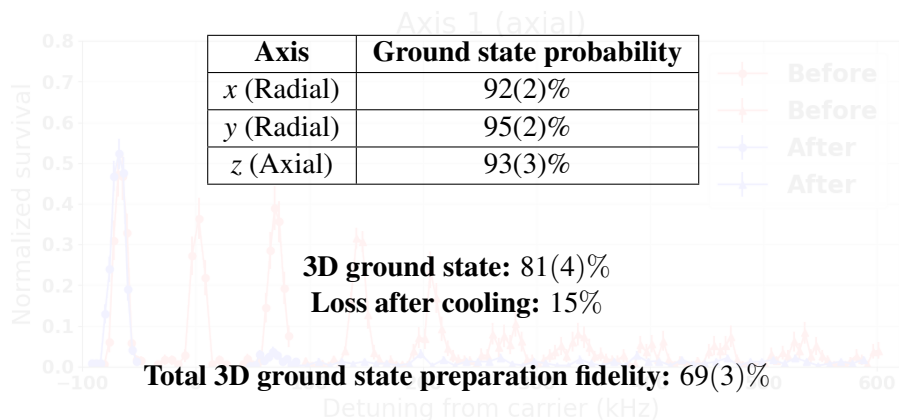


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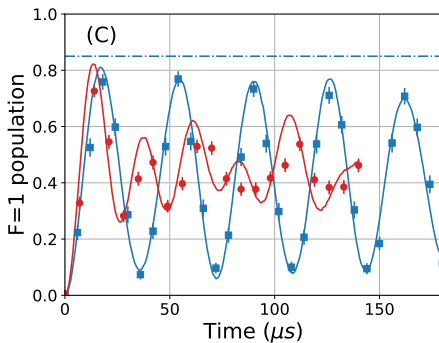
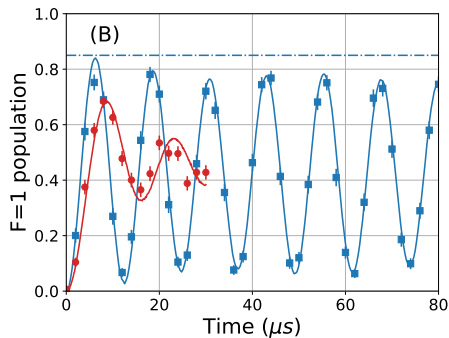




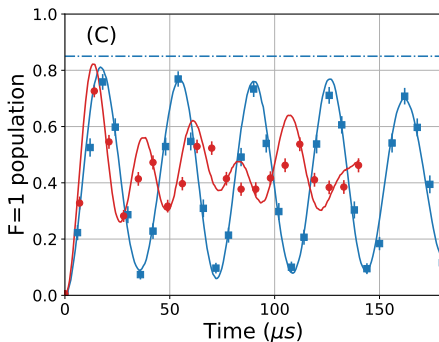
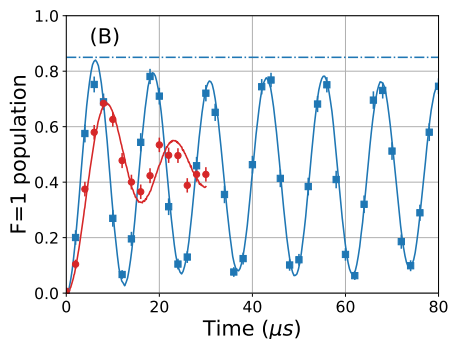
## Raman sidebands



## Rabi flopping (radial)

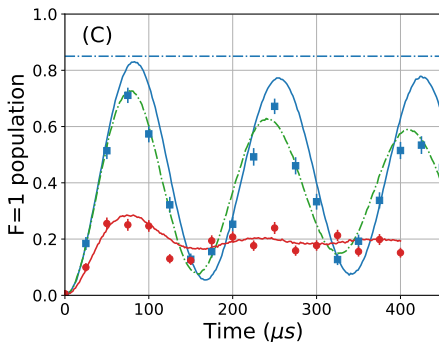
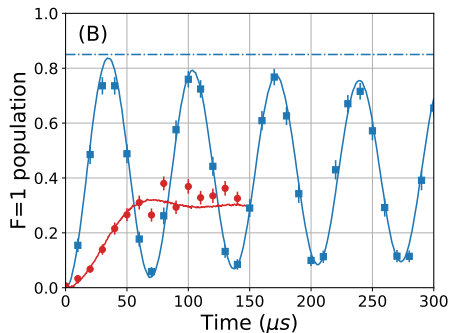


## Rabi flopping (radial)



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

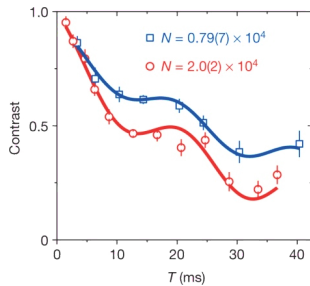
- Trapping of Na and Cs atoms
- Ground state cooling of Na and Cs

## In progress

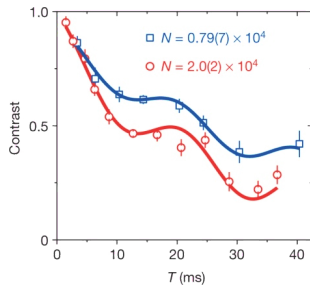
- Merge trap
- Photoassociation spectroscopy
- Make molecules

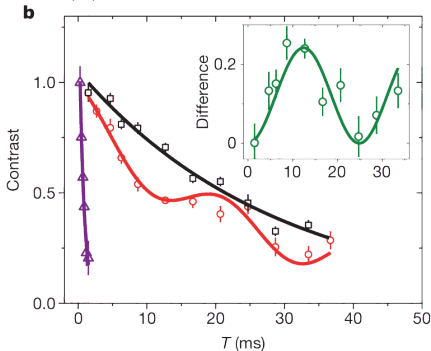
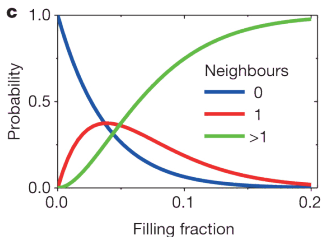
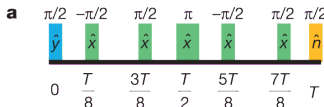
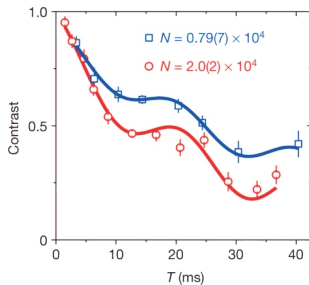
















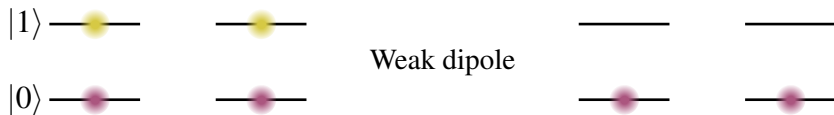
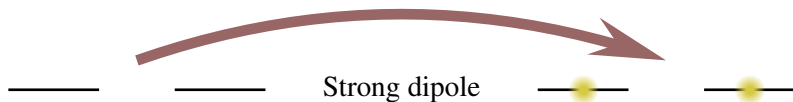
# Quantum computation

\_\_\_\_\_      \_\_\_\_\_      Strong dipole

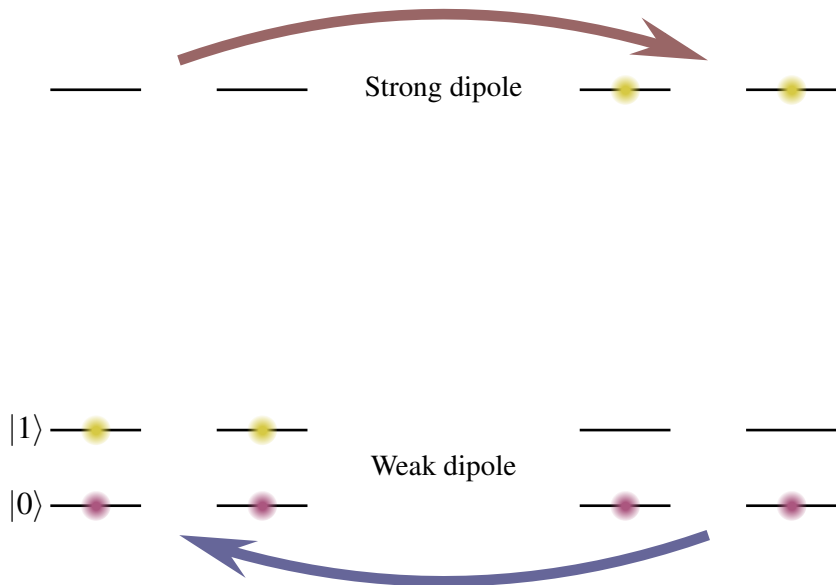
$|1\rangle$  —  —      —  —      Weak dipole

$|0\rangle$  —  —      —  —

# Quantum computation

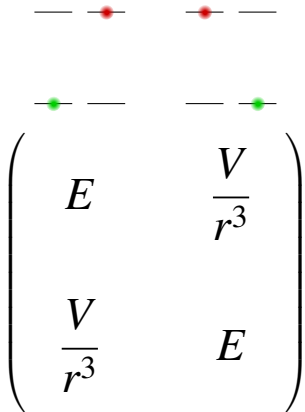


# Quantum computation





# Quantum computation

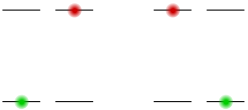


The diagram illustrates a two-qubit system. At the top, two horizontal lines represent energy levels. The left line has a red dot, and the right line has a red dot. Below these, two more horizontal lines represent energy levels. The left line has a green dot, and the right line has a green dot. Below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

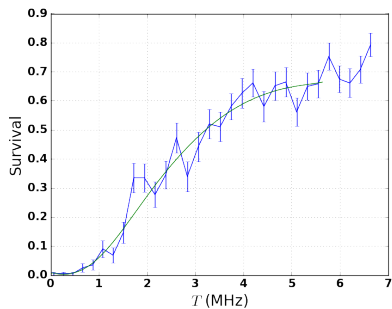


The diagram shows two horizontal lines representing energy levels. The top line has two red dots, and the bottom line has two green dots, indicating a two-level system with two states each.

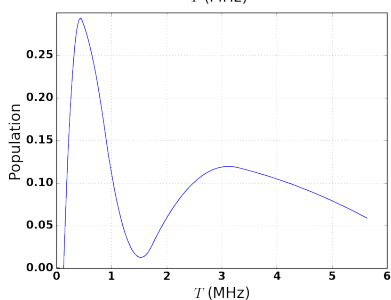
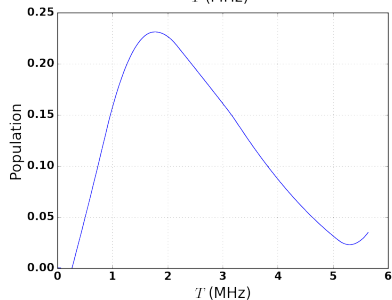
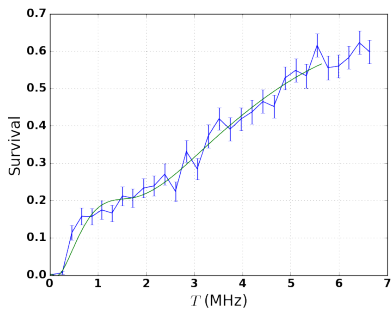
$$\begin{pmatrix} E & \frac{V}{r^3} \\ \frac{V}{r^3} & E \end{pmatrix} \rightarrow \begin{pmatrix} E - \frac{V}{r^3} & \\ & E + \frac{V}{r^3} \end{pmatrix}$$



# Before cooling

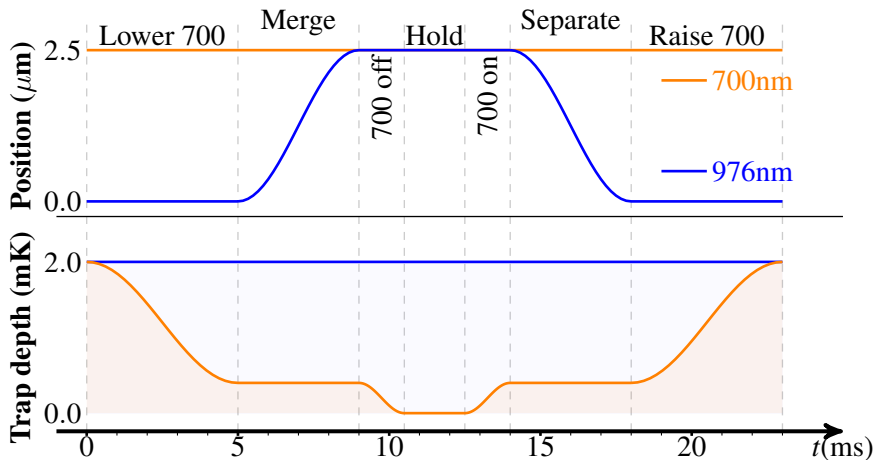


# After cooling





## Merge trap





# Making molecule

