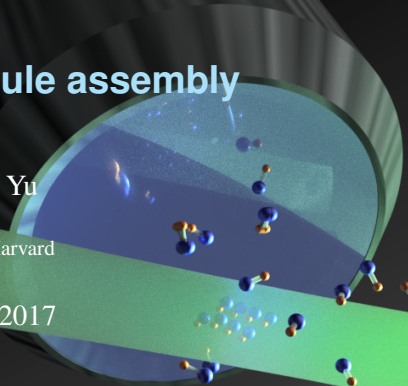


# Ultracold molecule assembly

Yichao Yu

Ni Group/Harvard

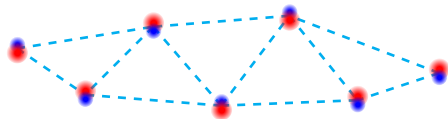
Aug 11, 2017



# Molecules in optical tweezer

## Features

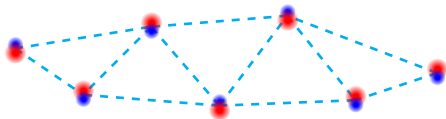
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



# Molecules in optical tweezer

## Features

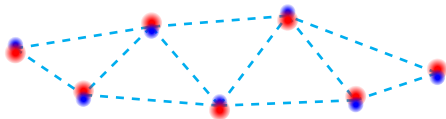
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# Molecules in optical tweezer

## Features

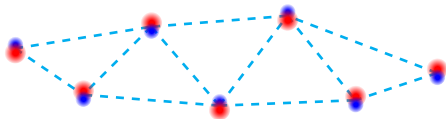
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# Molecules in optical tweezer

## Features

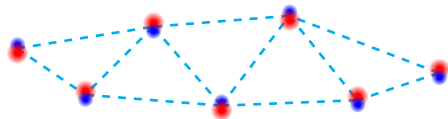
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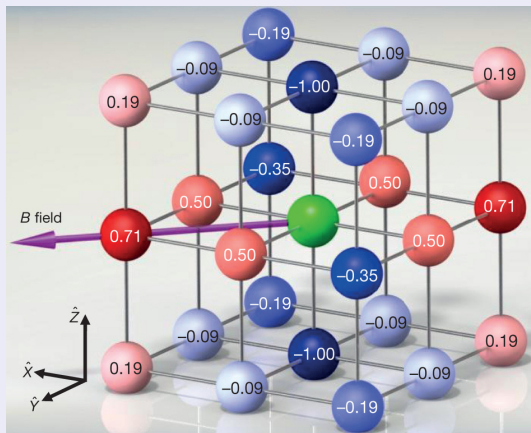
# Molecules in optical tweezer

## Features

- Strong and tunable interaction
- Rich internal energy levels
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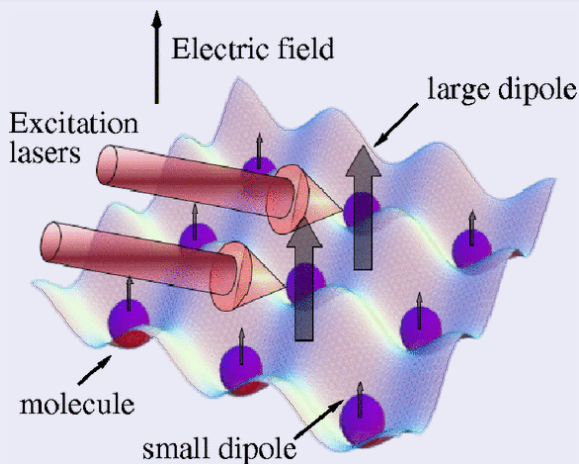
## Simulation of many-body system<sup>[1]</sup>



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

[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).



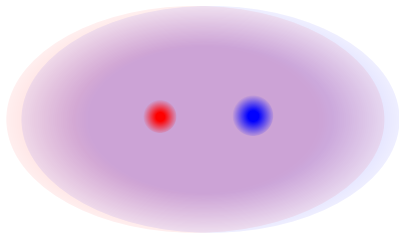
# Making molecules from atoms

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



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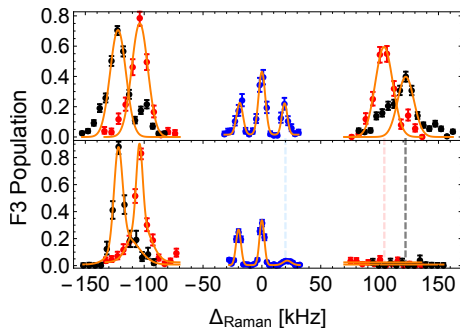
# Atom loading and cooling

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



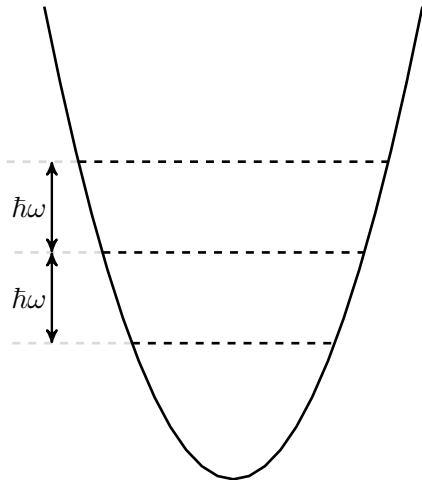
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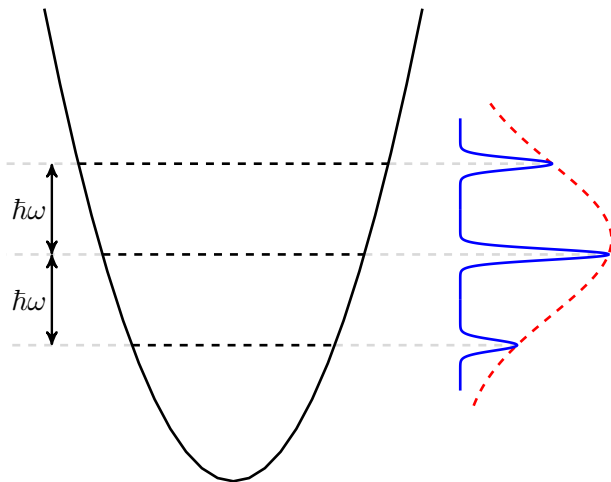




## Raman sideband cooling



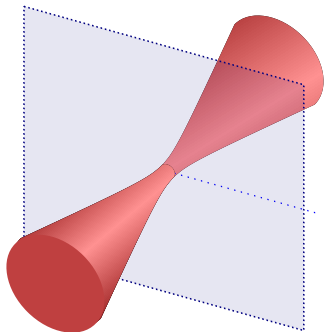
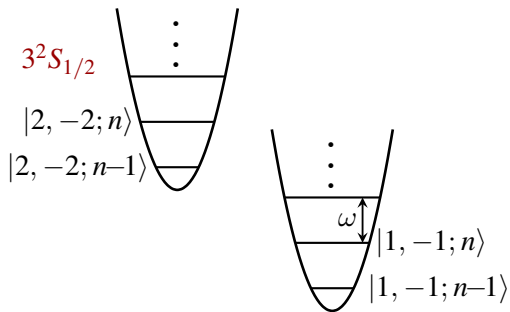
## Raman sideband cooling



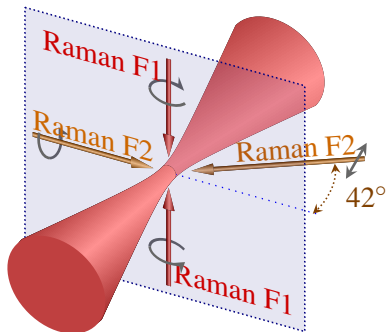
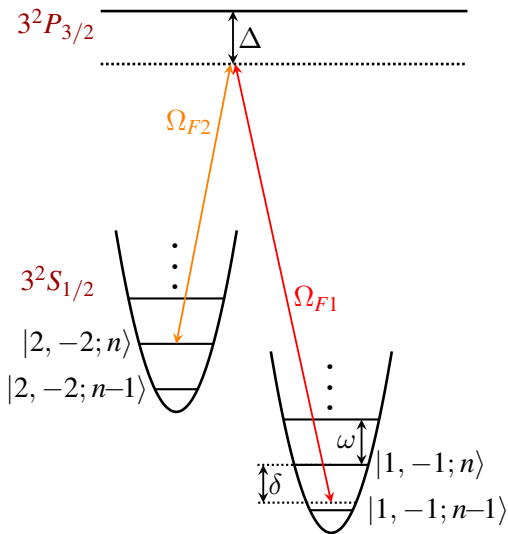
## Raman sideband cooling

$3^2P_{3/2}$

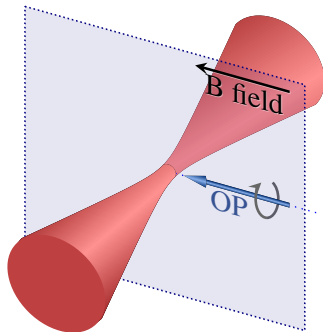
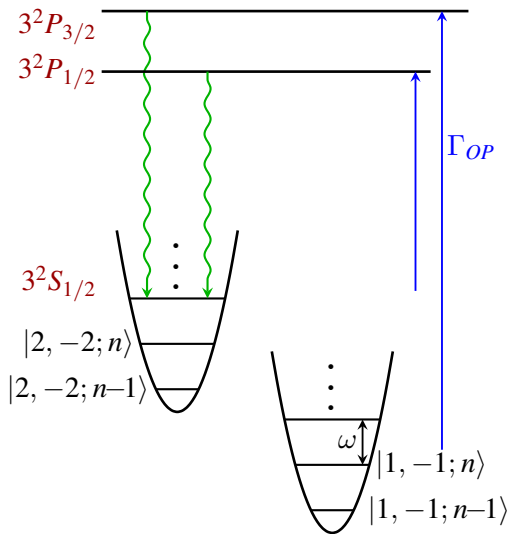
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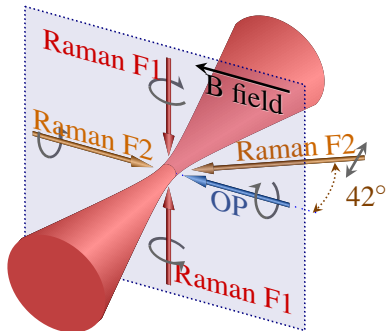
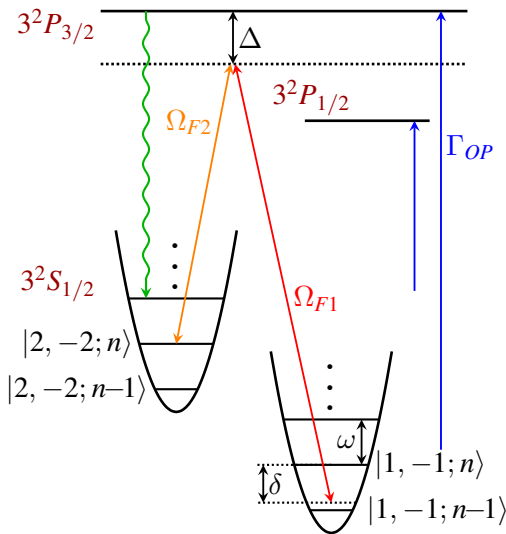
## Raman sideband cooling



## Raman sideband cooling

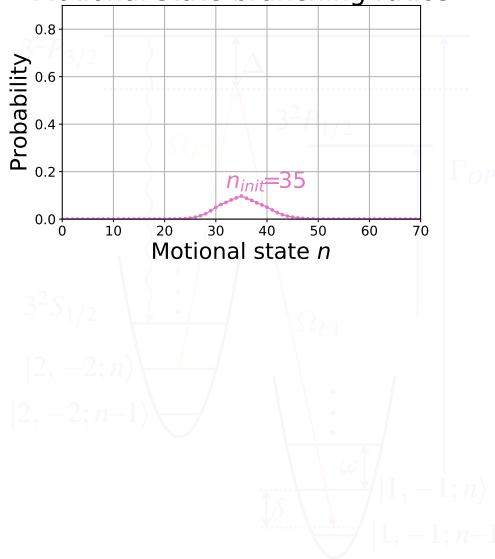


## Raman sideband cooling



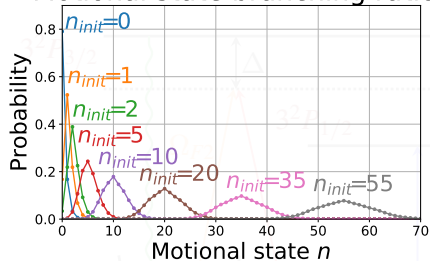
- High initial temperature ( $70\mu K$ )
- High Lamb Dicke parameter  
 $\eta \equiv k z_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering  
 $\approx 0.2 \sim 0.5\text{kHz}$

## Motional state branching ratios



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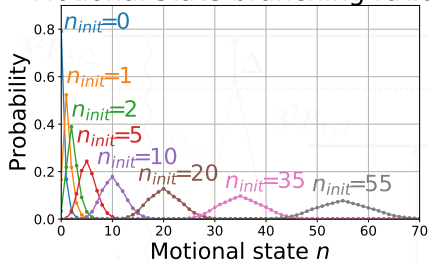
## Motional state branching ratios



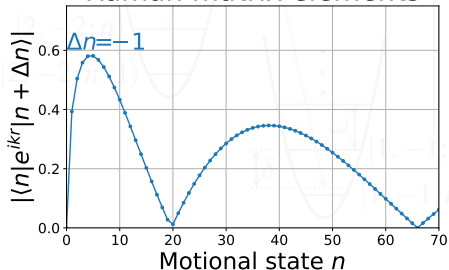
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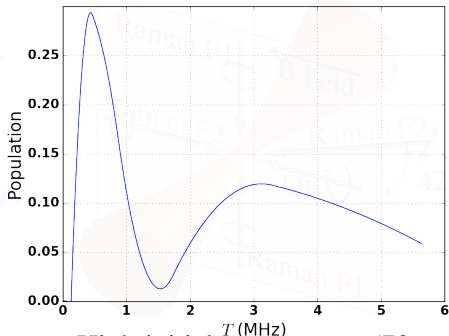
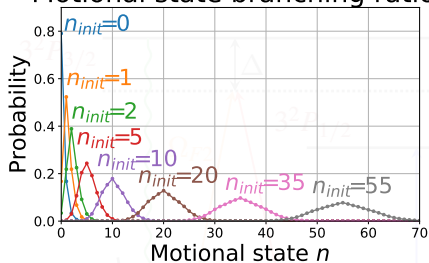


## Raman matrix elements

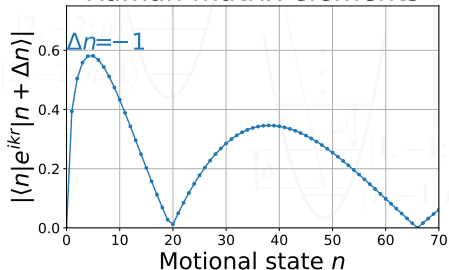


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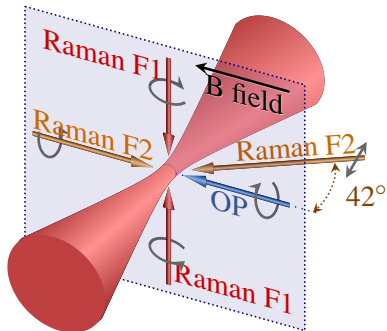
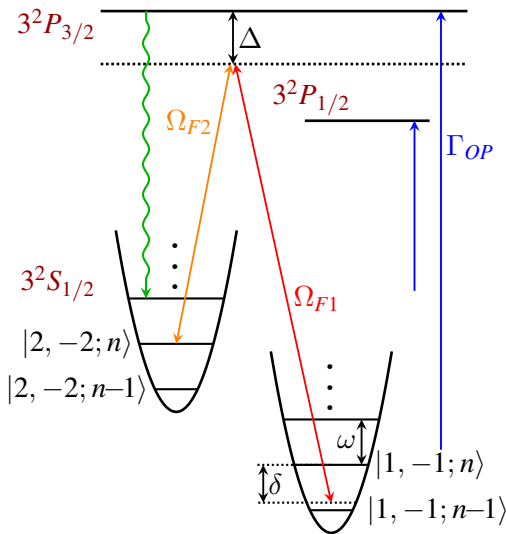


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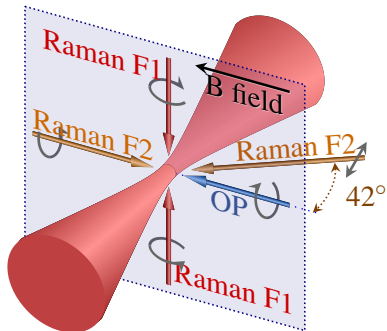
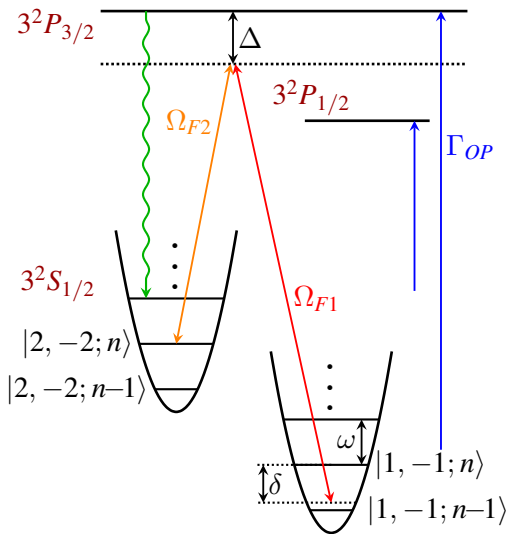
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## Raman sideband cooling



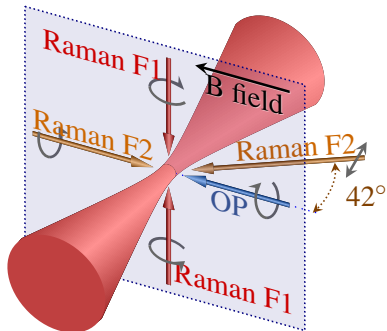
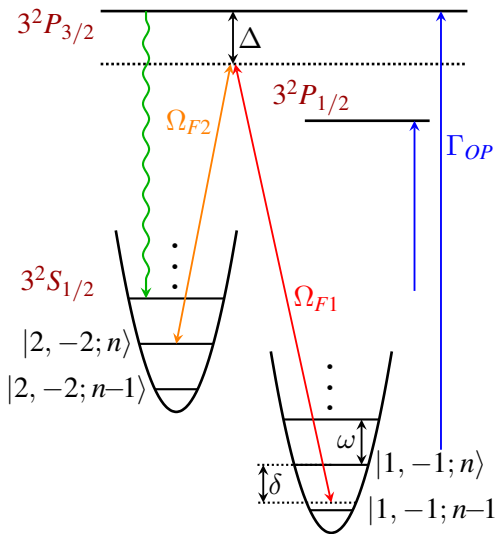
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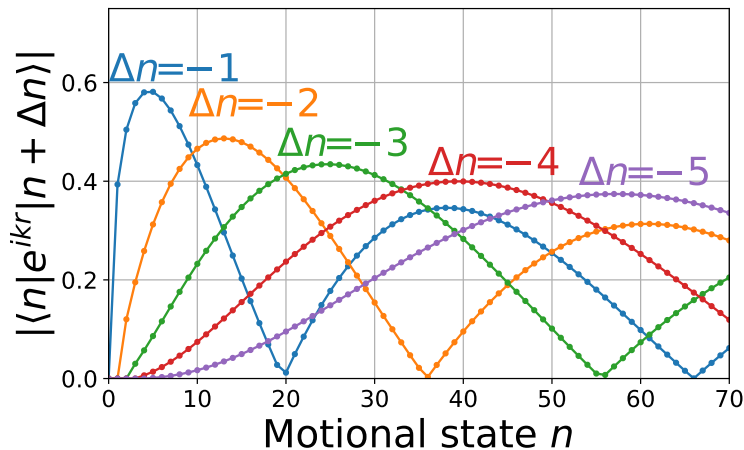
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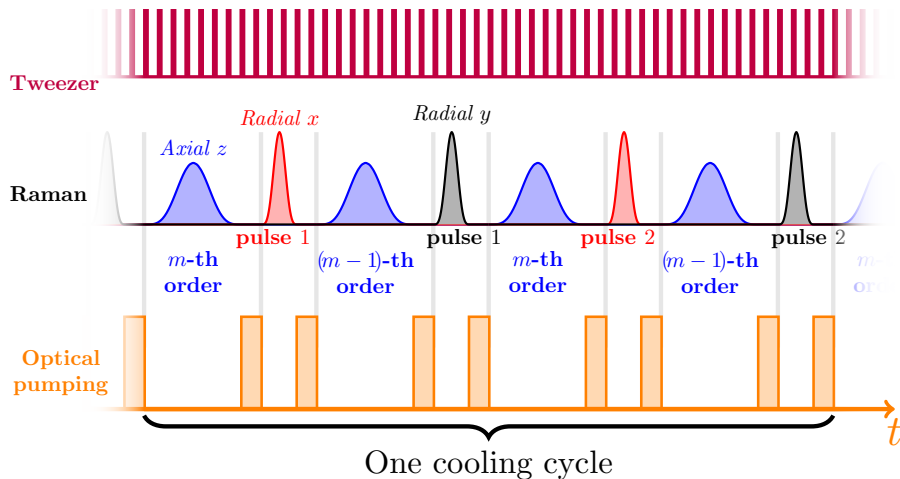


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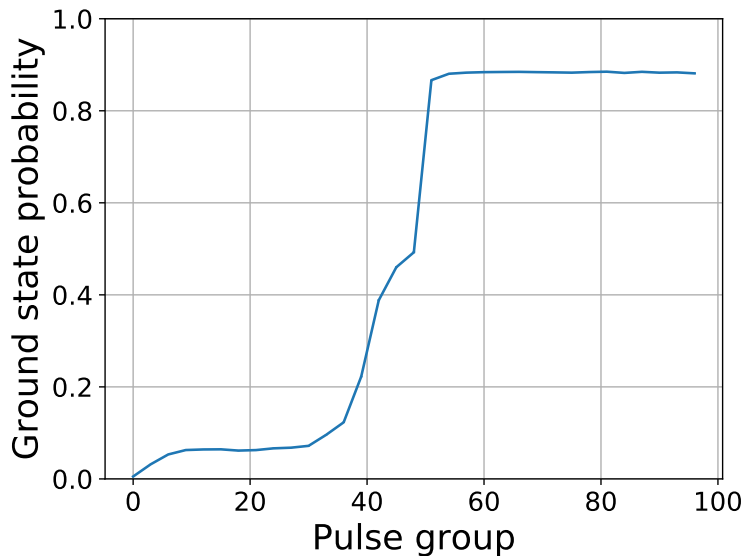
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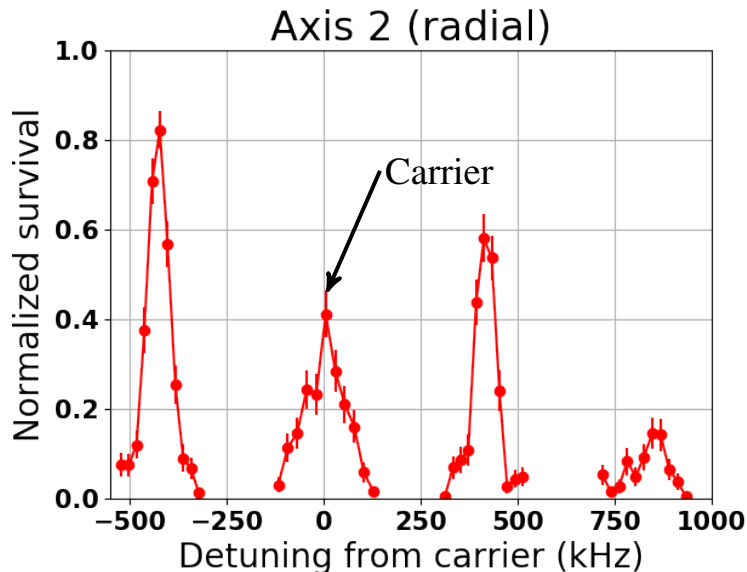
# Sequence and simulation

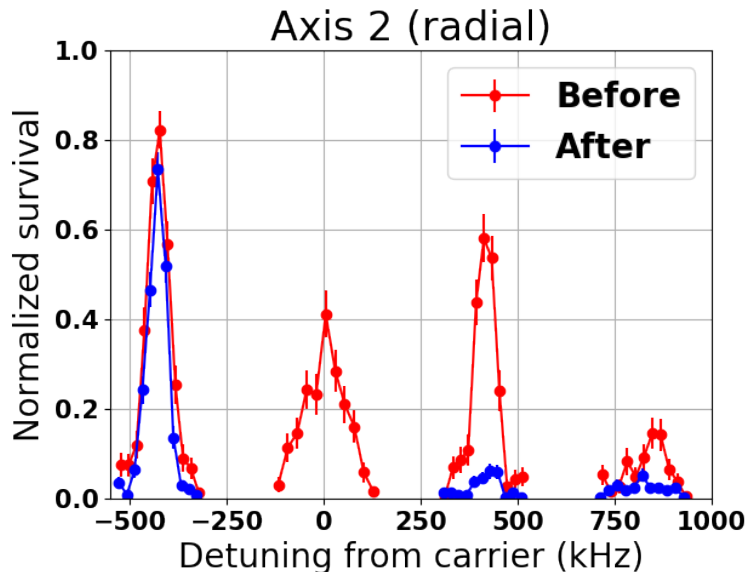


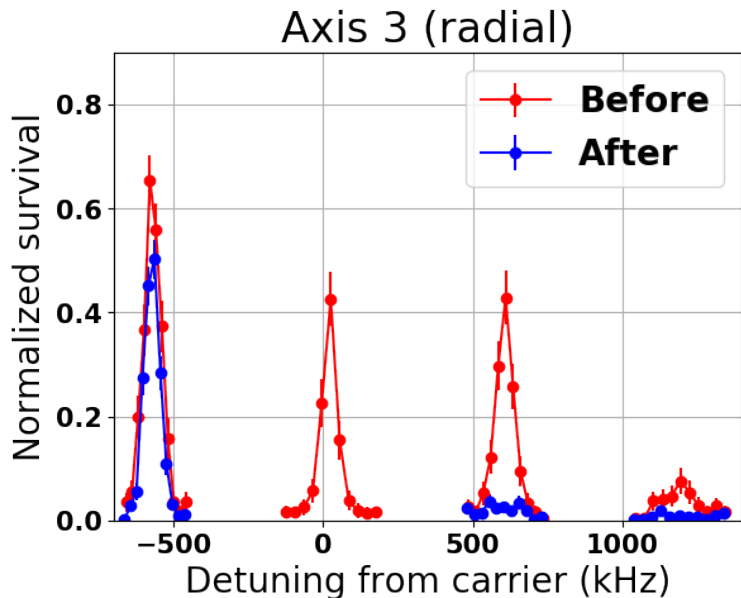
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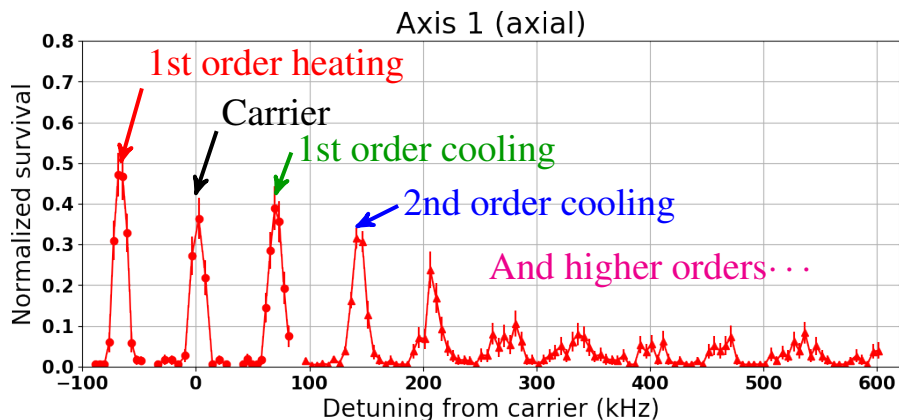




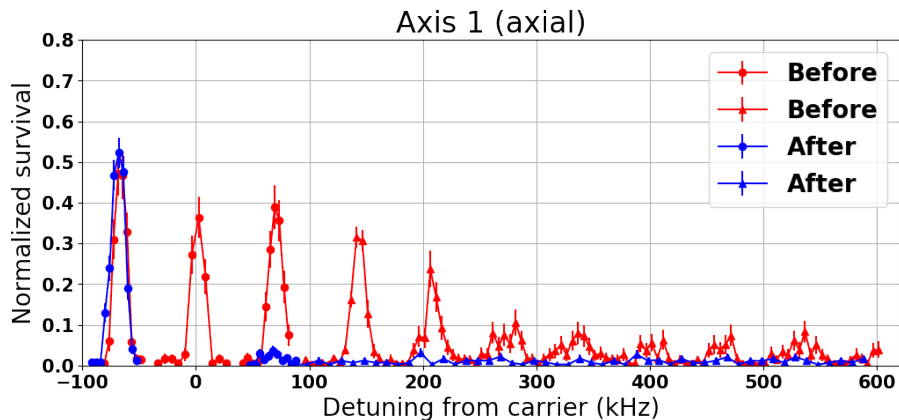




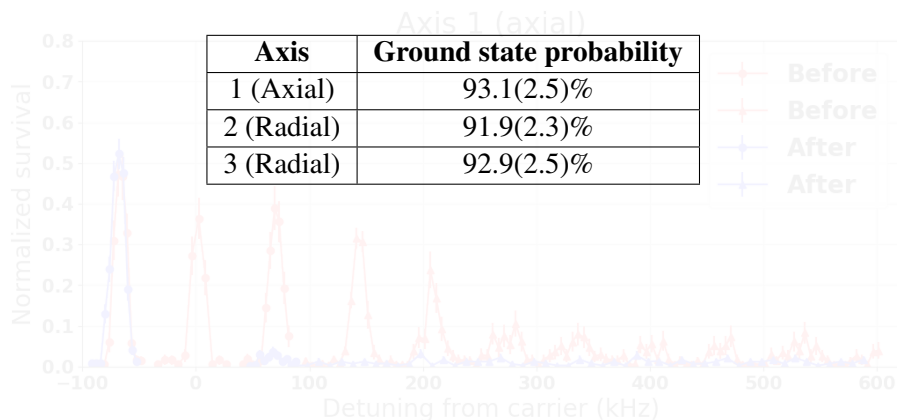
## Raman sidebands



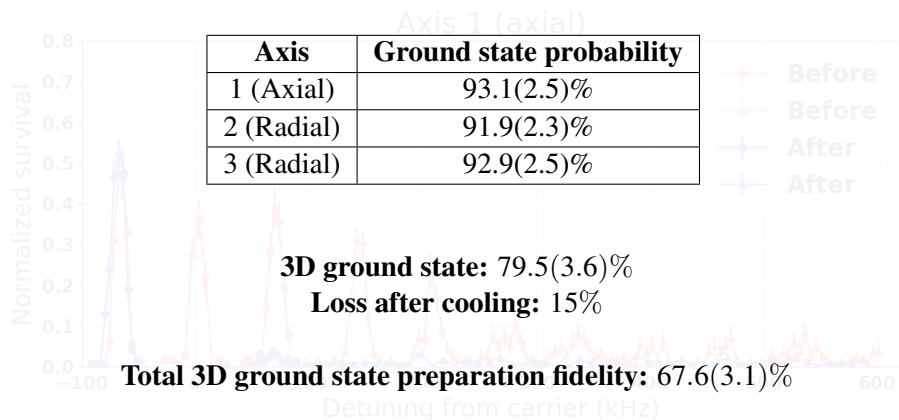
## Raman sidebands



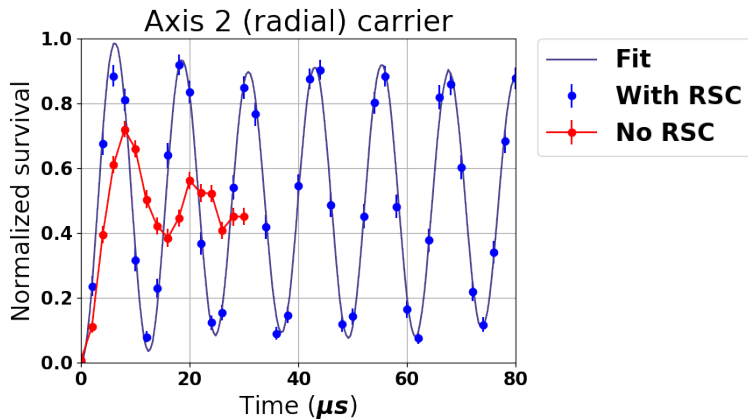
# Raman sidebands



## Raman sidebands

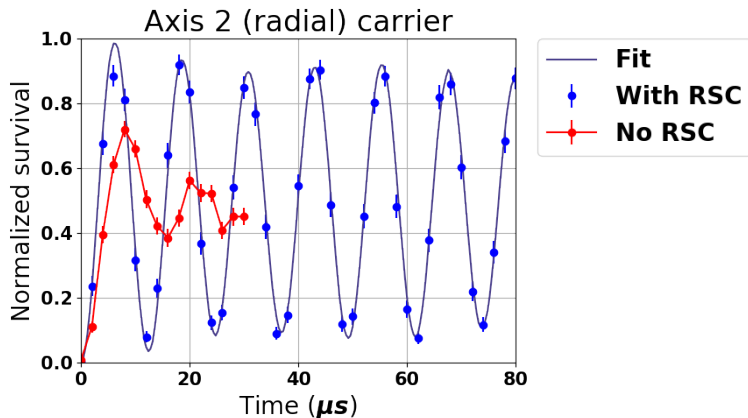


## Rabi flopping (radial)



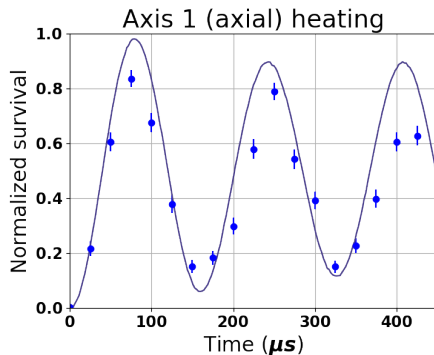
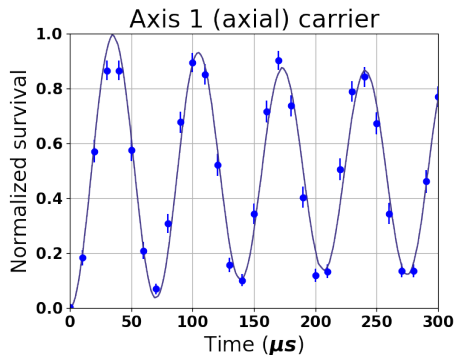


## Rabi flopping (radial)



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

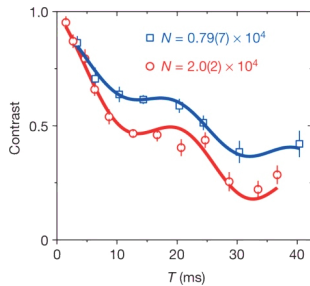
## Rabi flopping (axial)

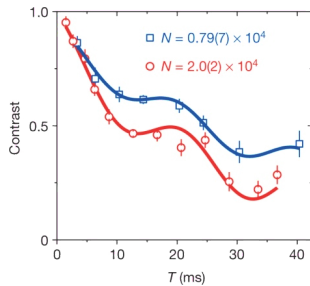


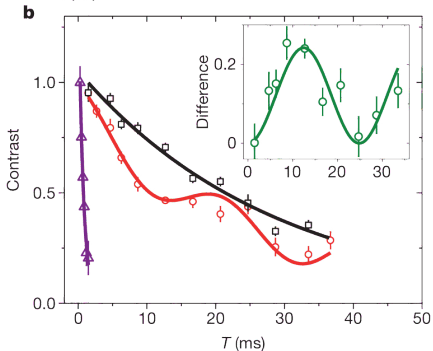
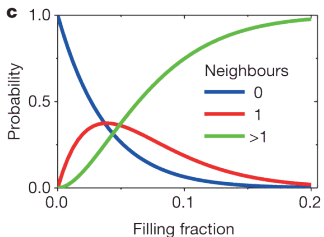
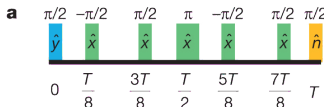
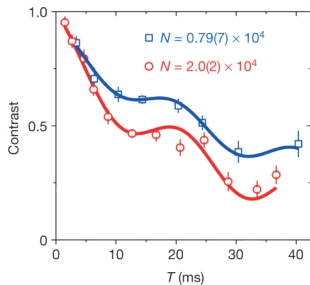
# In progress













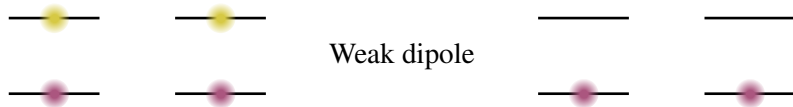
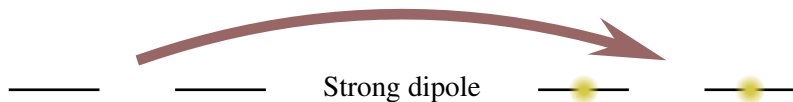


# Quantum computation

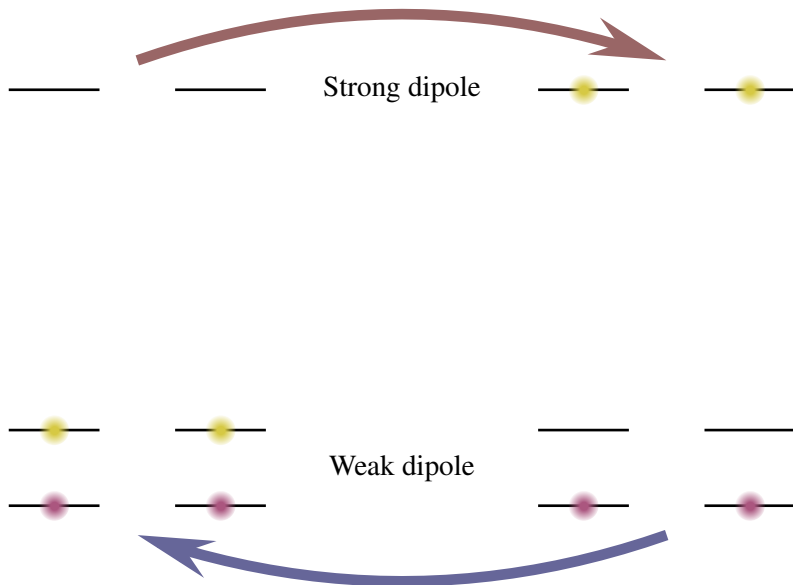
— — Strong dipole

— —  
— — Weak dipole

# Quantum computation

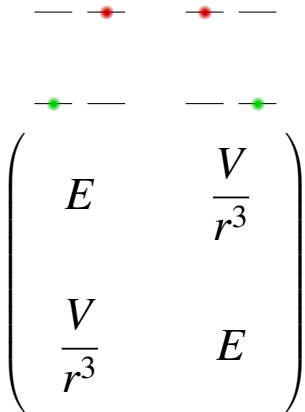


## Quantum computation





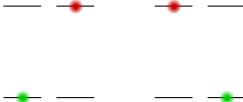
# Quantum computation



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 on its right half, and the right line has a red dot on its left half. Below these, there are two more horizontal lines. The left line has a green dot on its left half, and the right line has a green dot on its right half. Below the diagram is a 2x2 matrix representing the Hamiltonian:

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

## Quantum computation



The diagram illustrates a quantum system with two energy levels, represented by red and green dots. The red dots are at a higher energy level, and the green dots are at a lower energy level. The interaction between the two levels is represented by the potential  $V/r^3$ . The matrix representation of the system is shown as a 2x2 matrix, which is then transformed into a diagonal form.

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





## Merge trap

