

Ultracold molecule assembly

The background features a 3D visualization of an ultracold molecule assembly trap. A large, dark, cylindrical structure with a textured surface is shown. A bright green beam of light enters from the left and focuses into a blue, translucent, bowl-shaped region. Inside this region, numerous small molecular models are visible, some appearing to be trapped or moving within the light. The molecular models consist of blue and orange spheres connected by lines, representing atoms and bonds respectively.

Yichao Yu

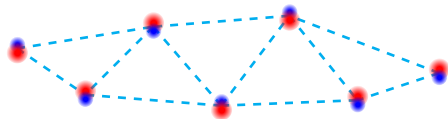
Ni Group/Harvard

Aug 11, 2017

Molecules in optical tweezer

Features

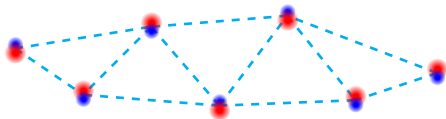
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Molecules in optical tweezer

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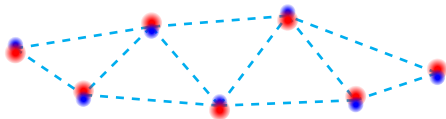
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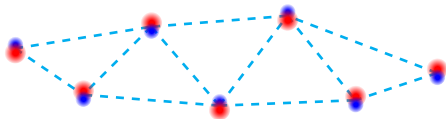
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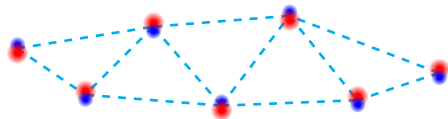
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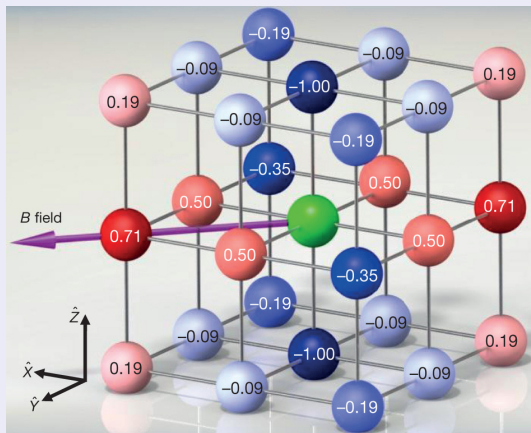
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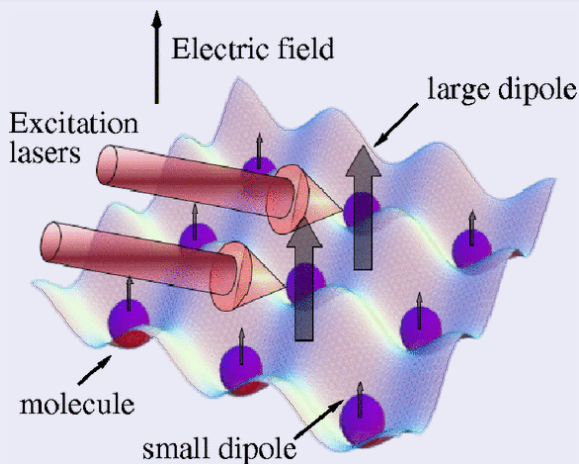
Simulation of many-body system^[1]



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

[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).

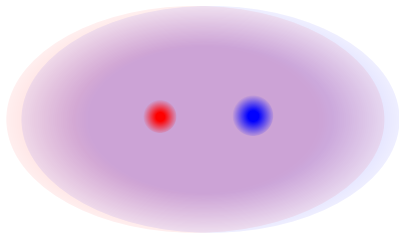
Making molecules from atoms

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



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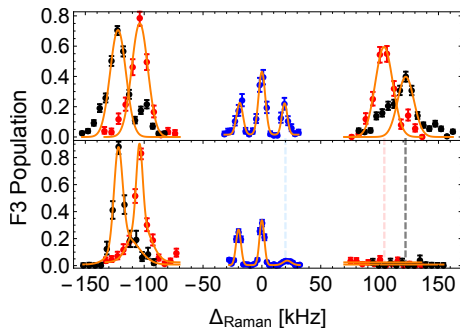
Atom loading and cooling

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

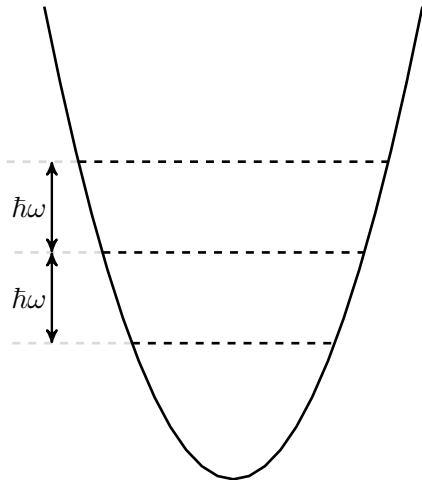


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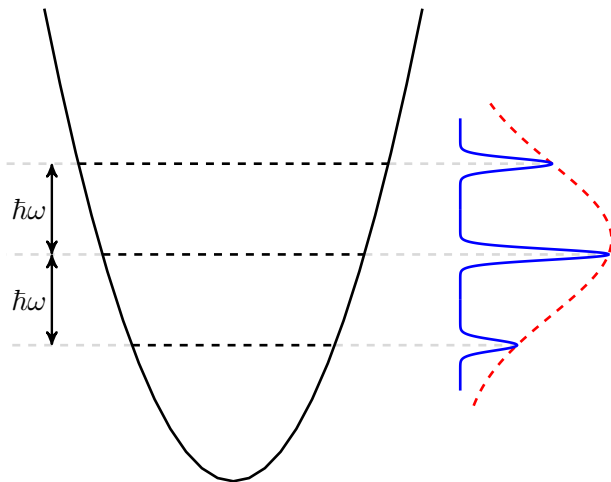
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Raman sideband cooling

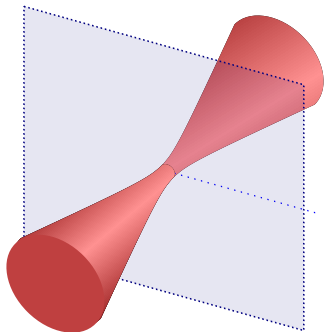
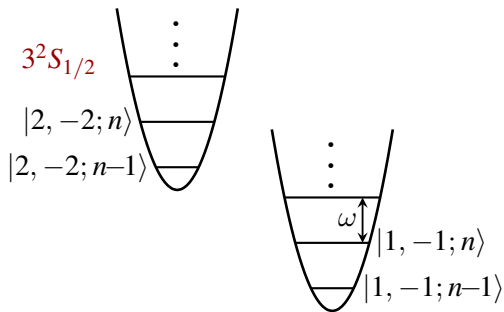


Raman sideband cooling

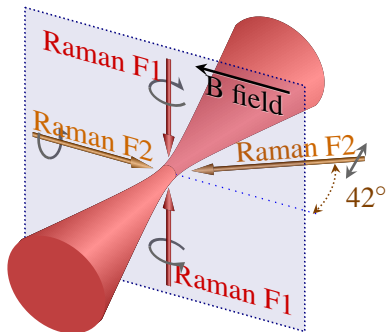
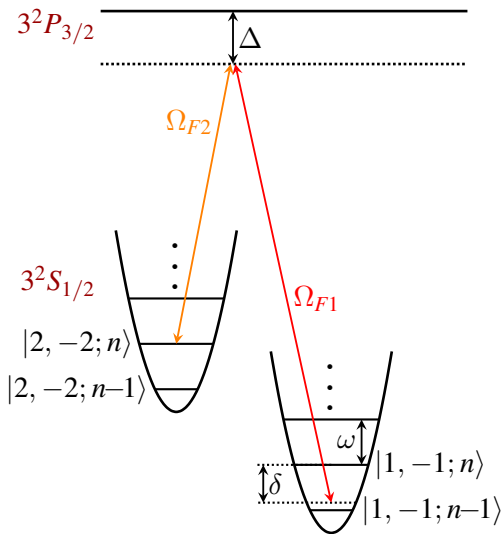


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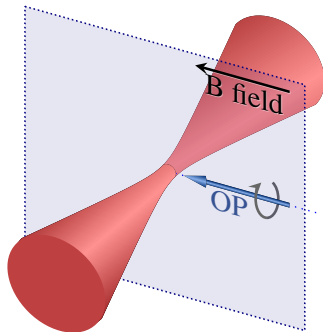
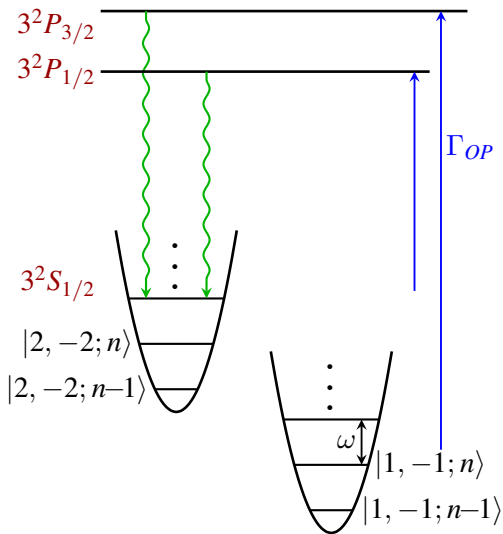
$3^2P_{3/2}$



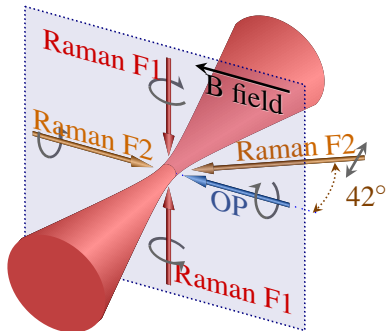
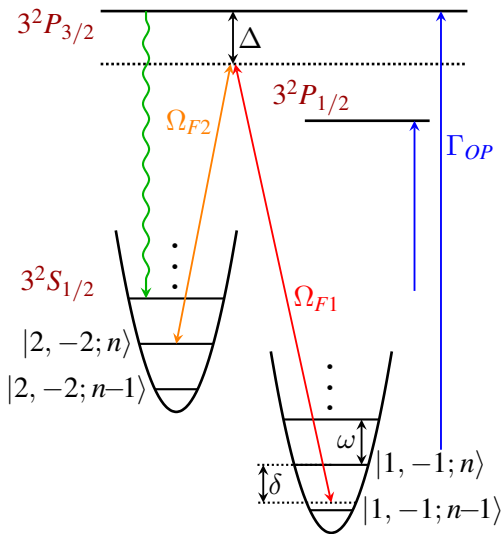
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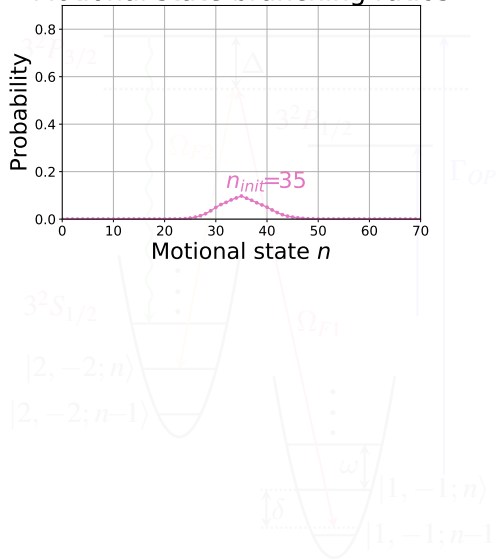


Raman sideband cooling



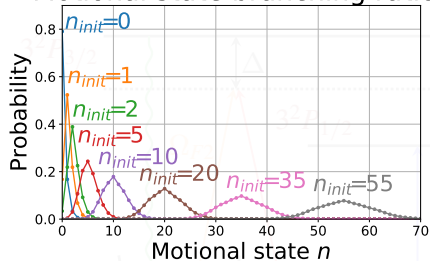
- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter
 $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering
 $\approx 0.2 \sim 0.5\text{kHz}$

Motional state branching ratios



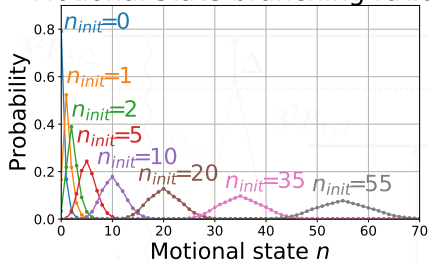
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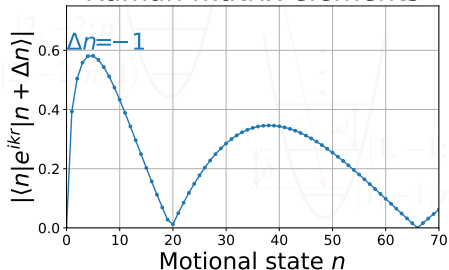


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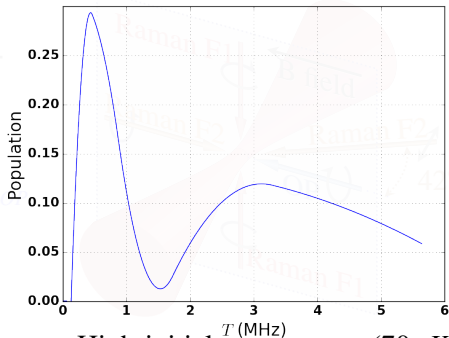
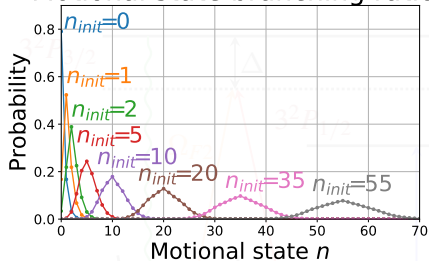
Raman matrix elements



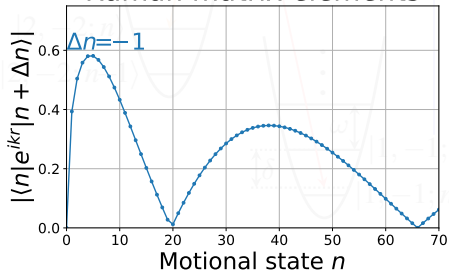
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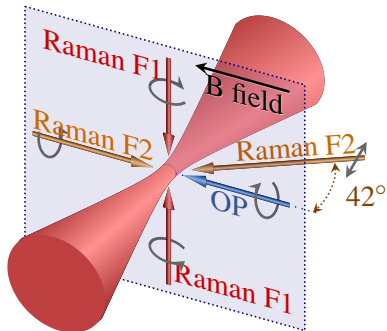
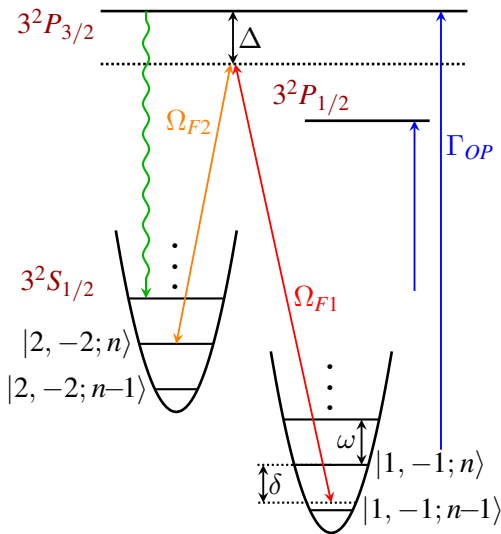


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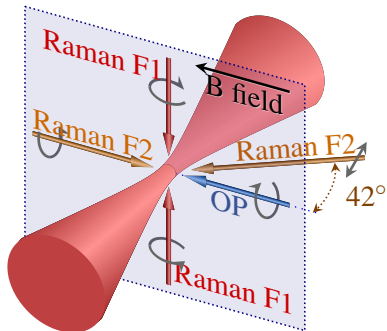
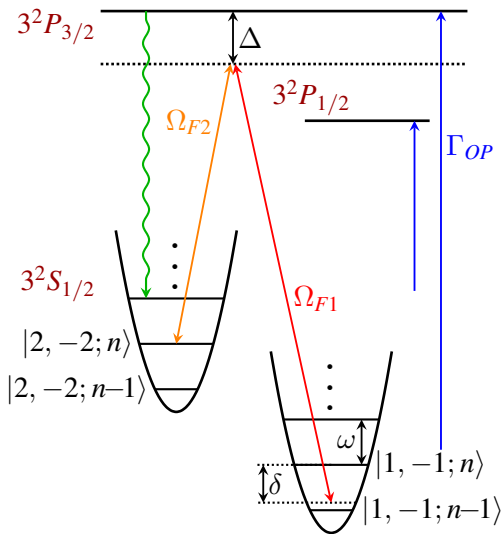
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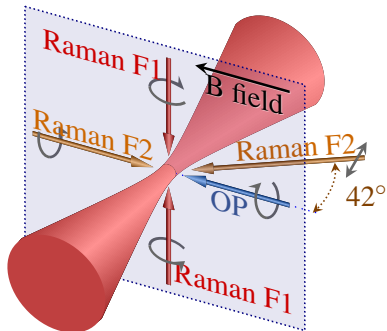
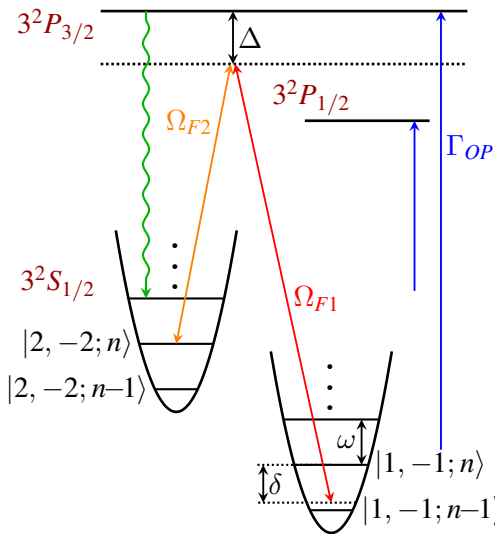
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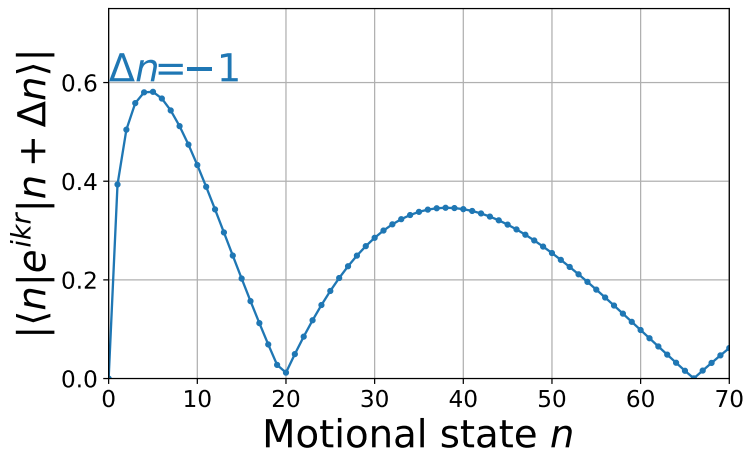
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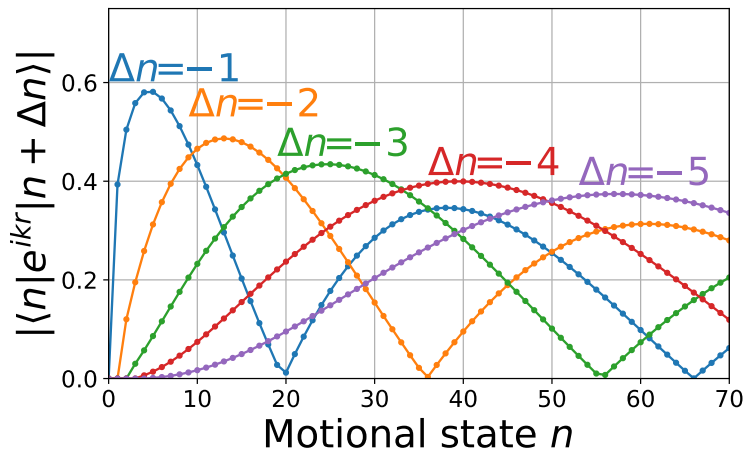


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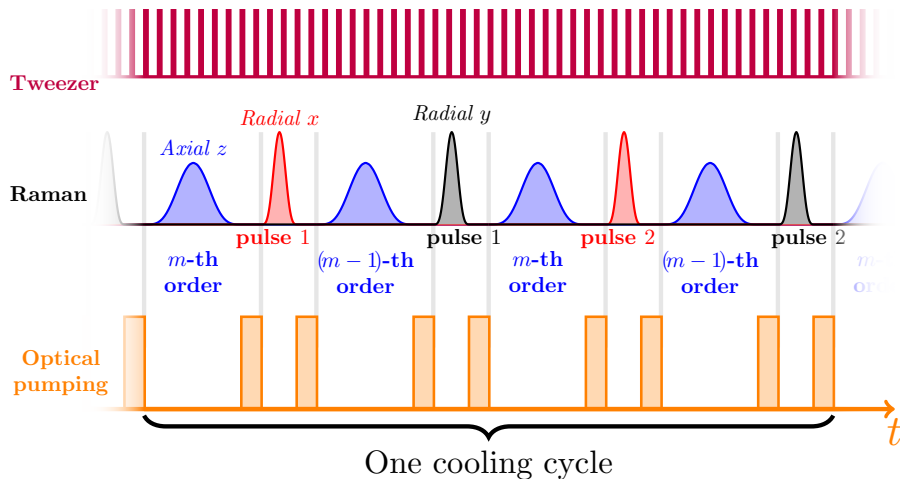
Raman matrix elements



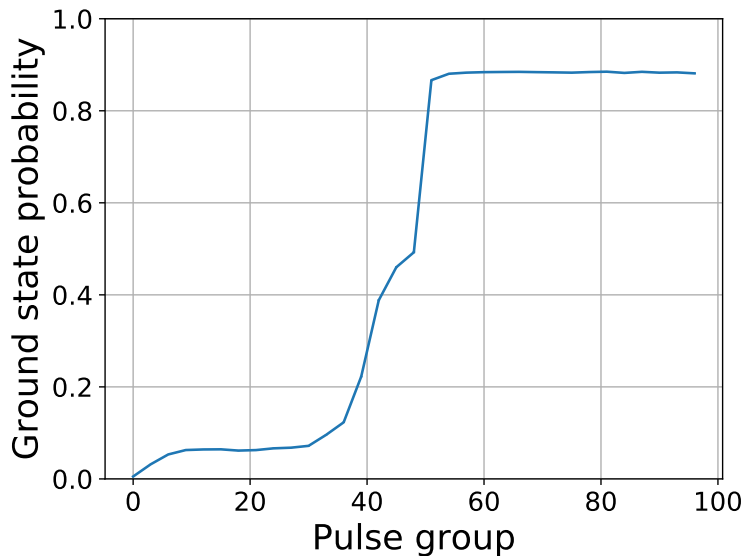
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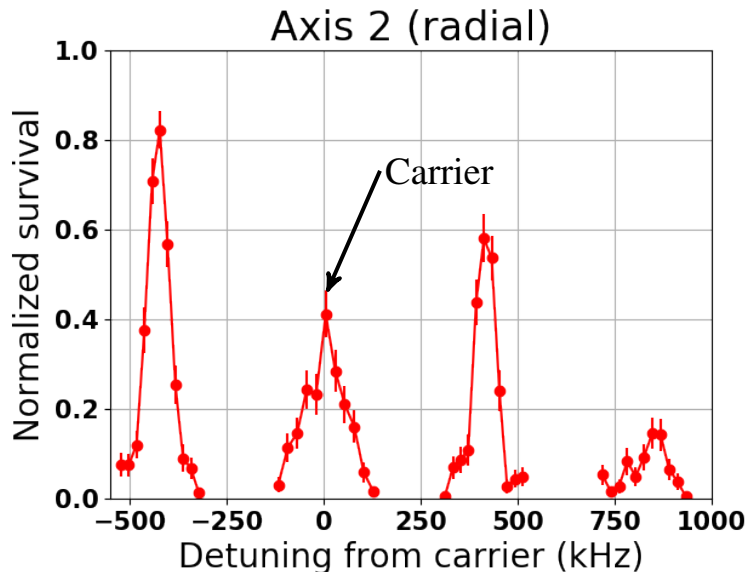


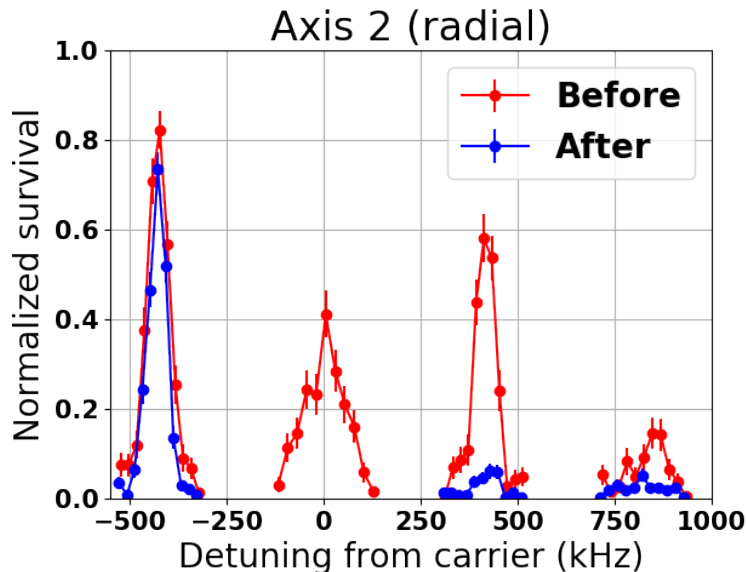
Sequence and simulation

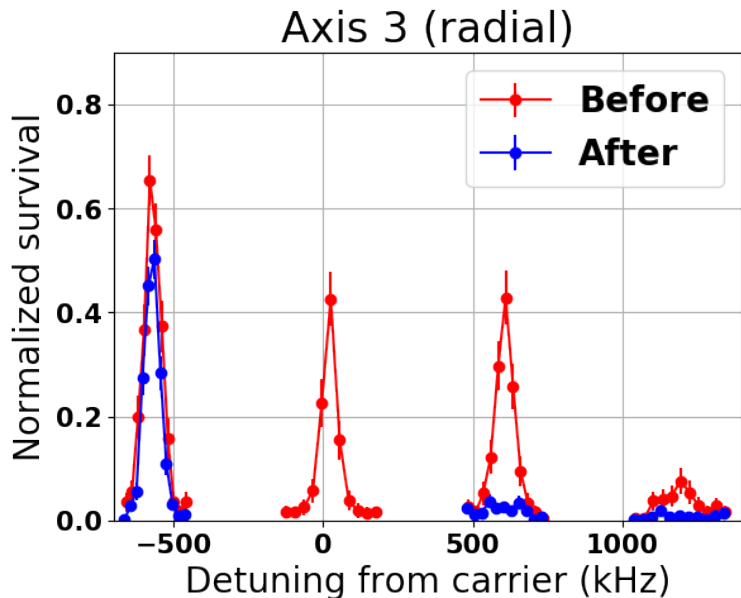


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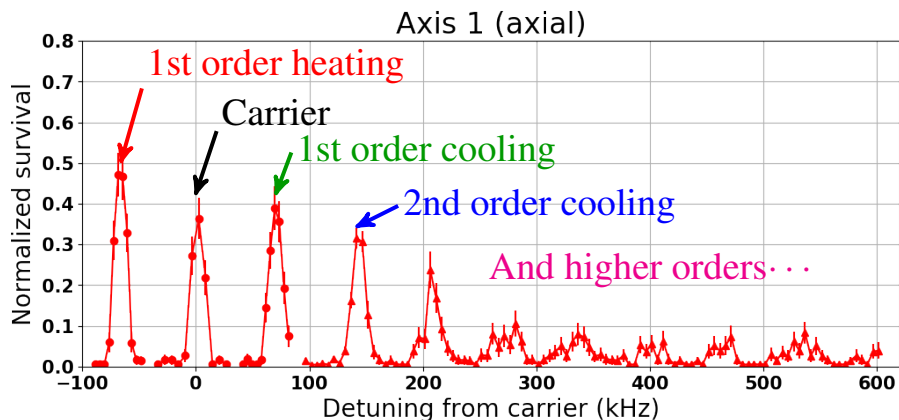




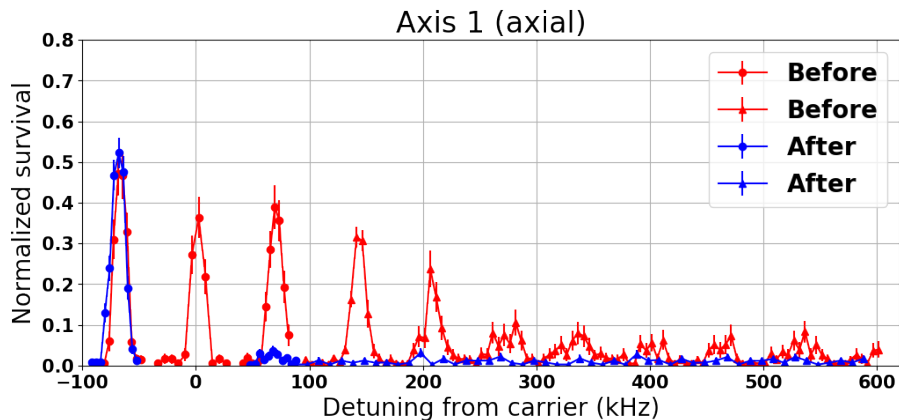




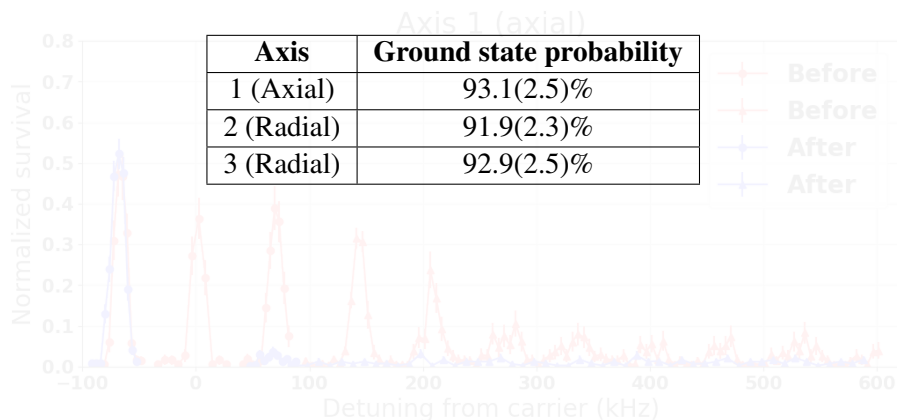
Raman sidebands



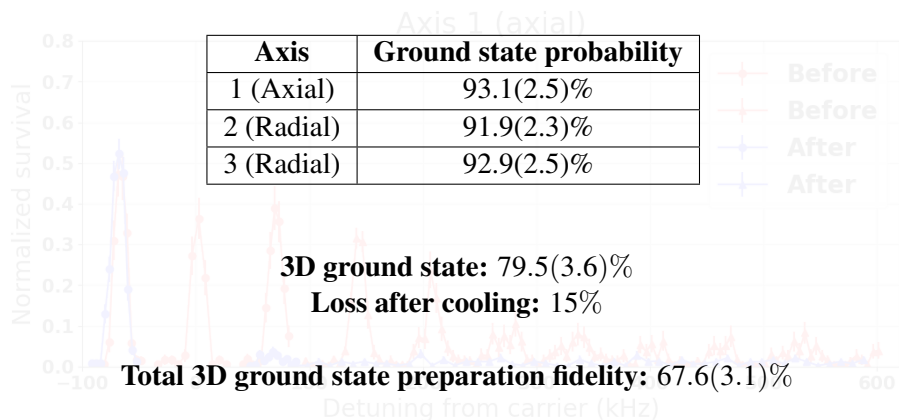
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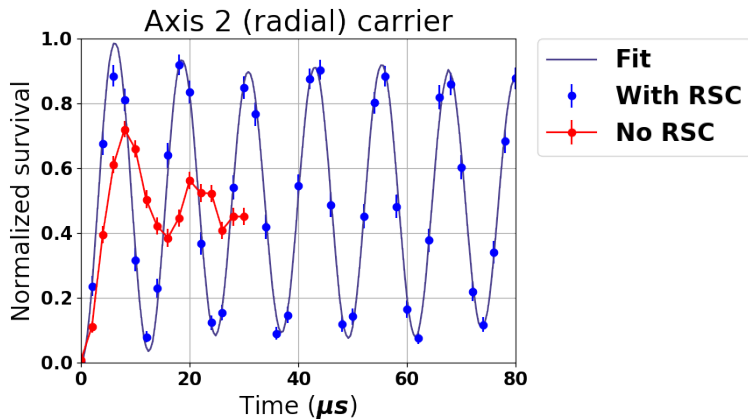
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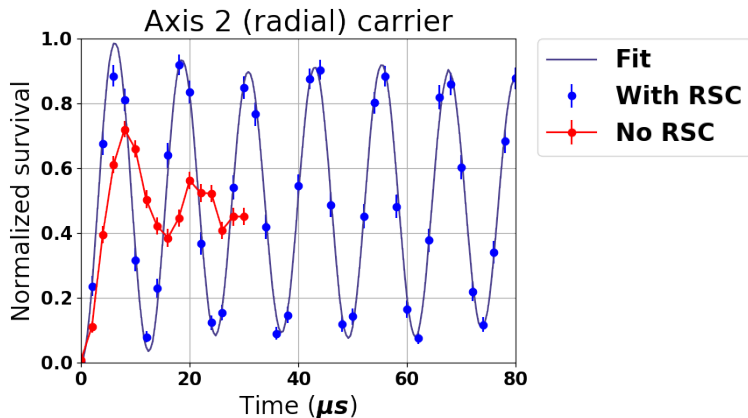
Raman sidebands



Rabi flopping (radial)

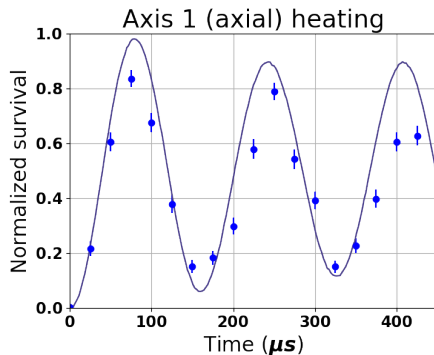
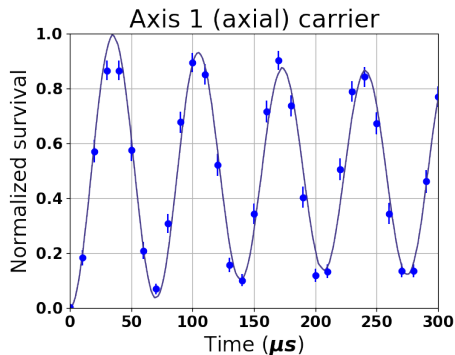


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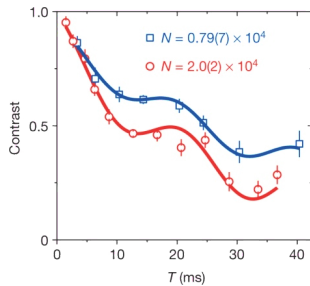


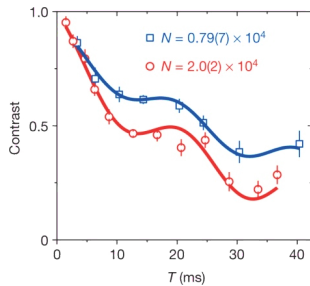
Good agreement in ground state probability between spectrum and Rabi flopping data.

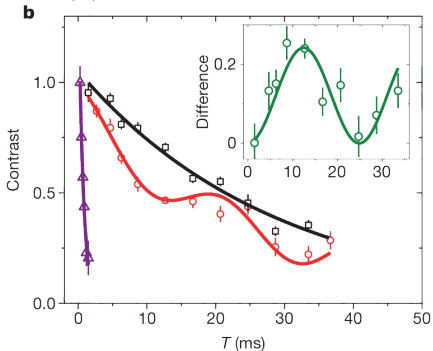
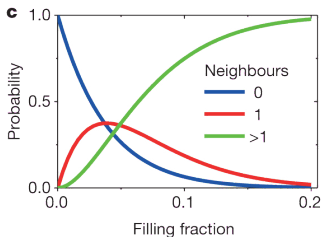
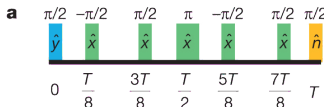
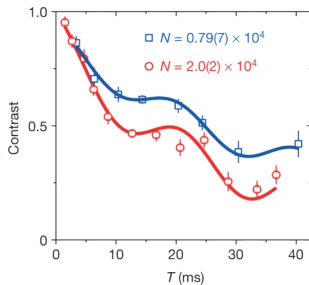
Rabi flopping (axial)



In progress





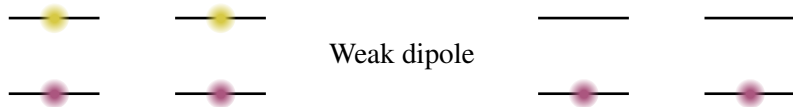
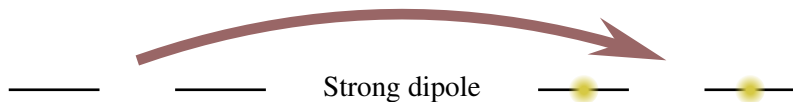


Quantum computation

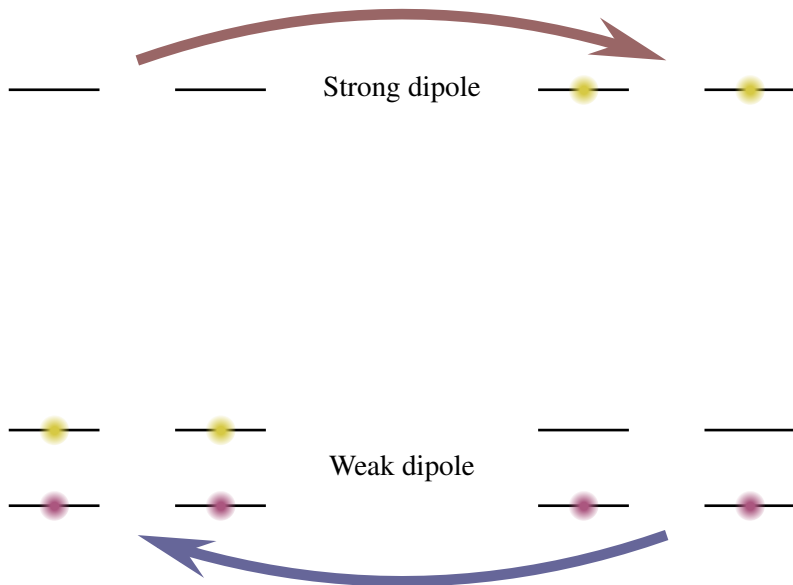
— — Strong dipole

— —
— — Weak dipole

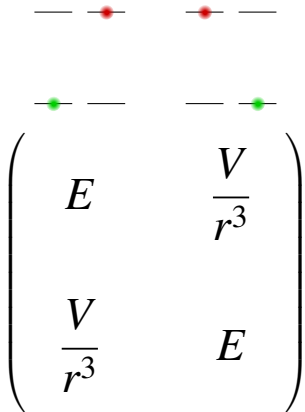
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Quantum computation



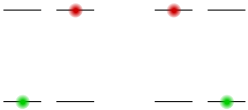
Quantum computation



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, and the right line has a red dot. Below these, there are two more horizontal lines, each with a green dot. The coupling between the two qubits is represented by a 2x2 matrix:

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

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, each split into two sub-states by a perturbation.

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

Merge trap

