

Ultracold molecule assembly

Yichao Yu

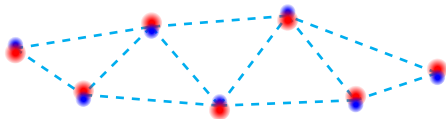
Ni Group/Harvard

Aug 11, 2017

Molecules in optical tweezer

Features

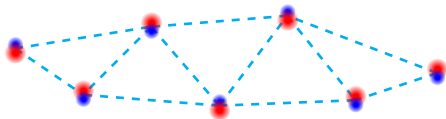
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Molecules in optical tweezer

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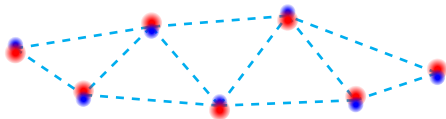
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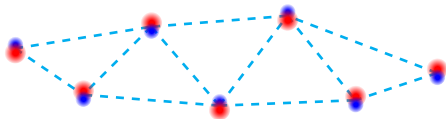
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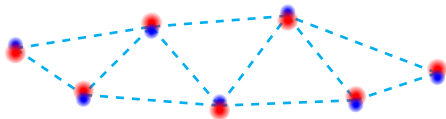
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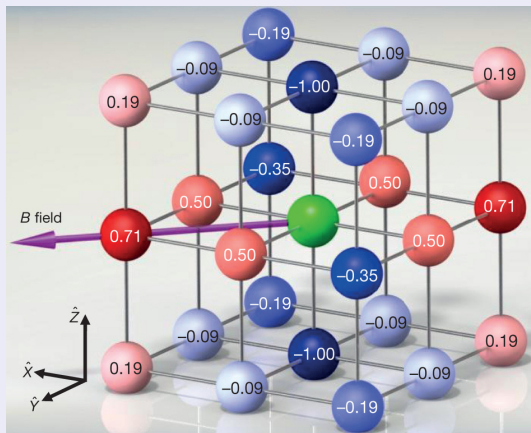
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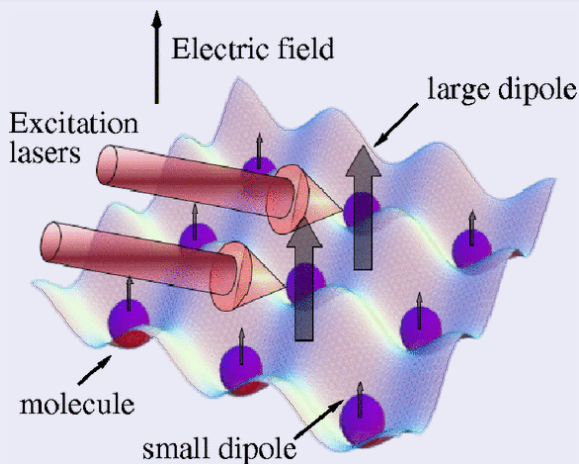
Simulation of many-body system^[1]



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

[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).

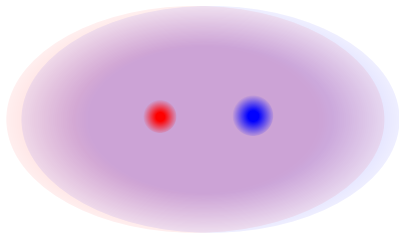
Making molecules from atoms

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



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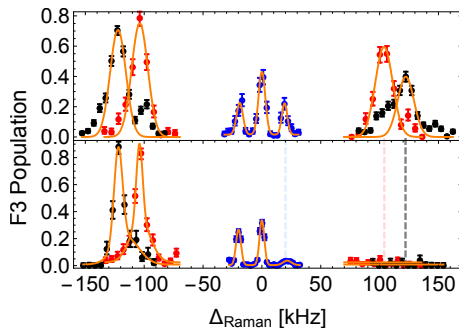
Atom loading and cooling

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

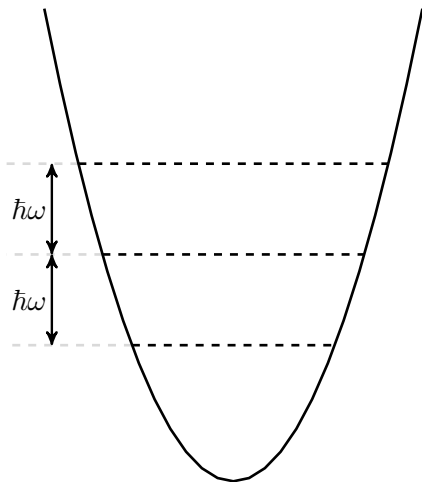


Atom loading and cooling

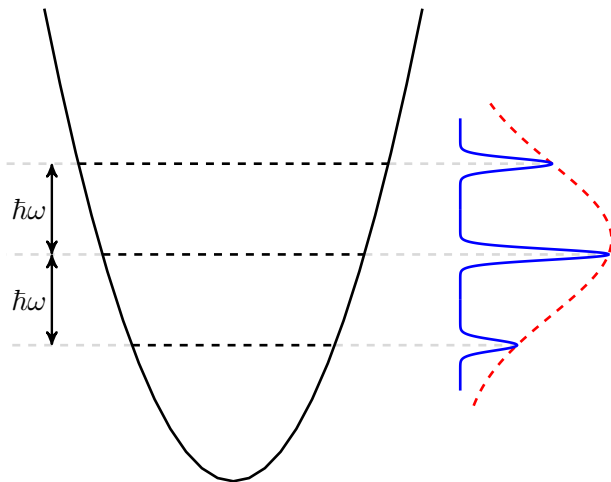
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Raman sideband cooling

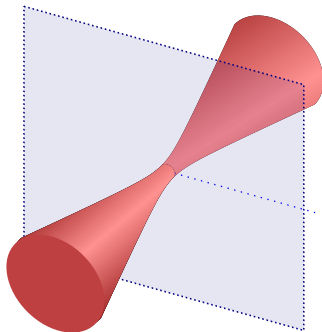
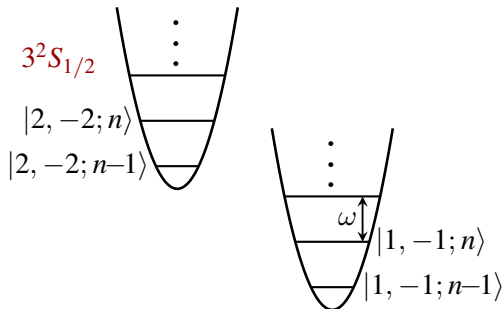


Raman sideband cooling

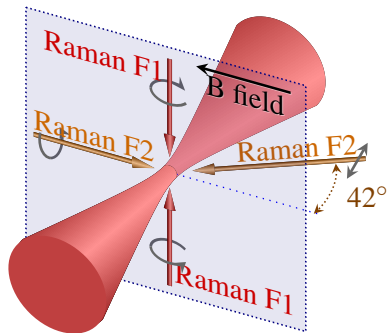
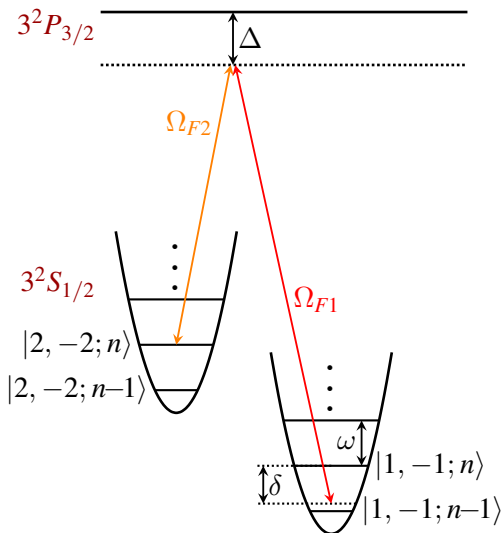


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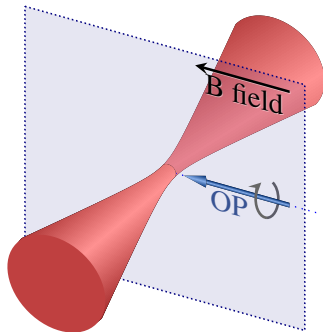
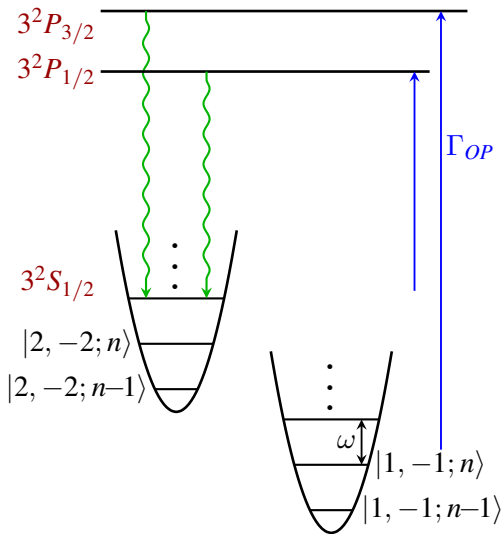
$3^2P_{3/2}$



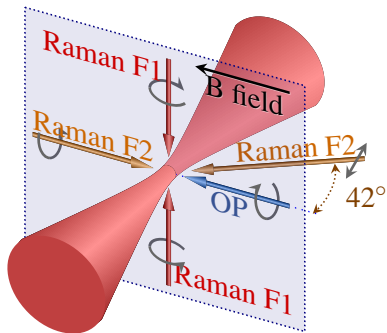
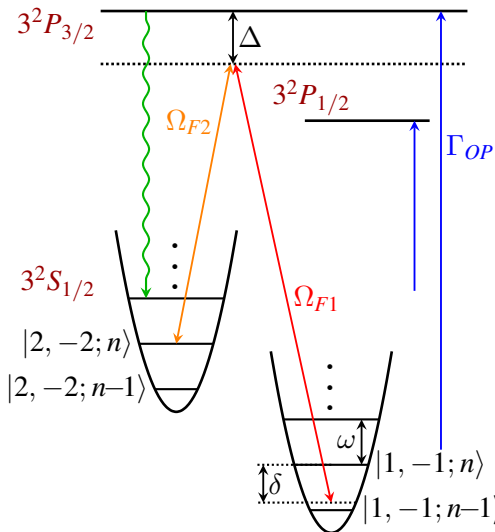
Raman sideband cooling



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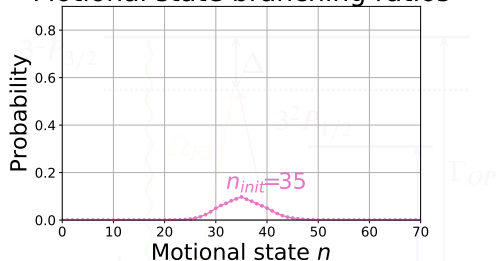


Raman sideband cooling



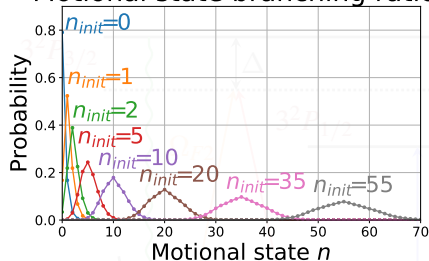
- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter
 $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering
 $\approx 3 \sim 15\text{kHz}$

Motional state branching ratios



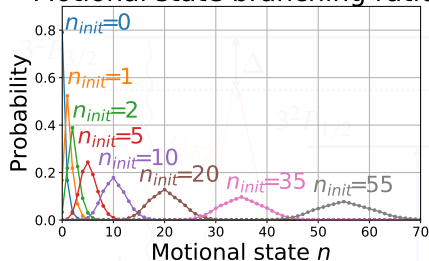
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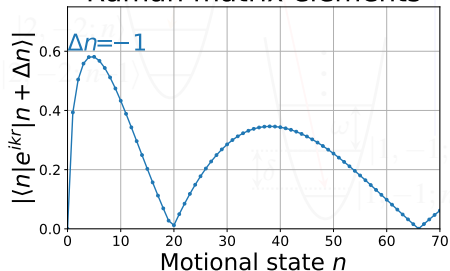


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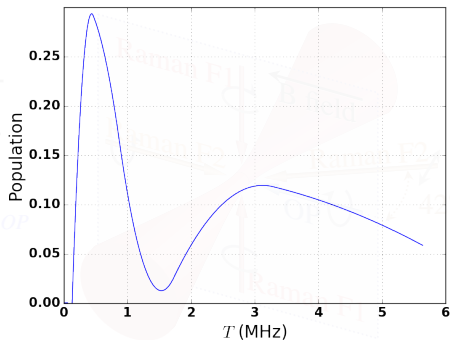
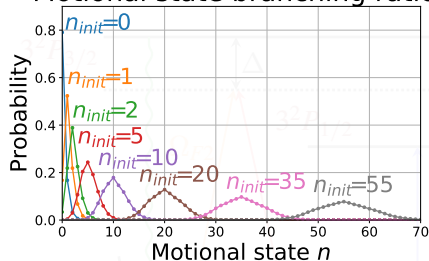


Raman matrix elements

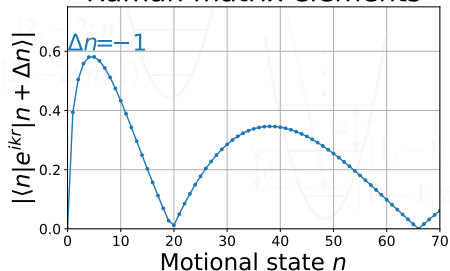


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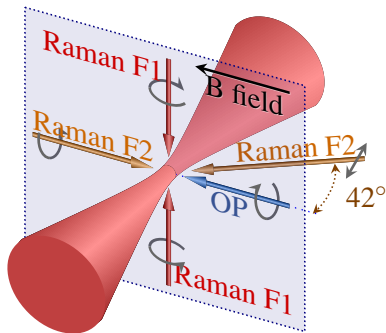
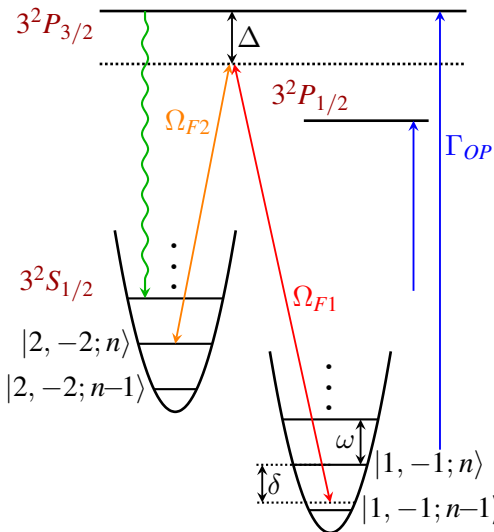


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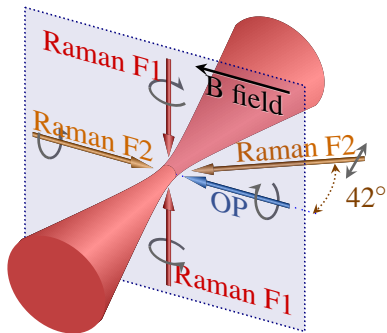
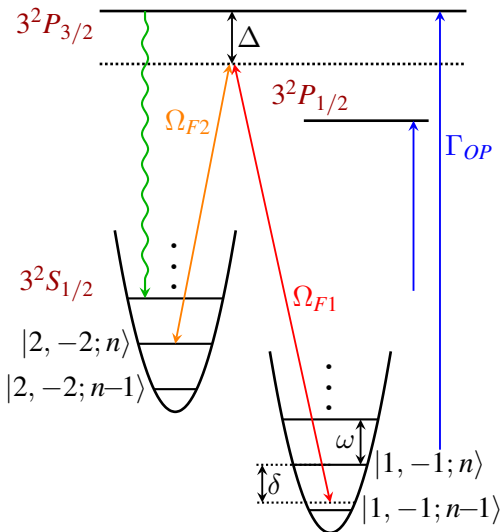
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Raman sideband cooling



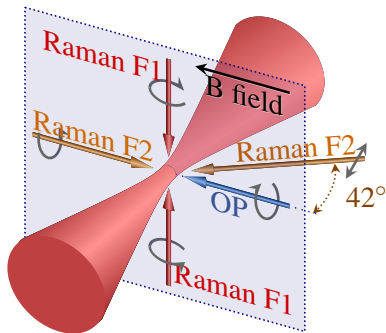
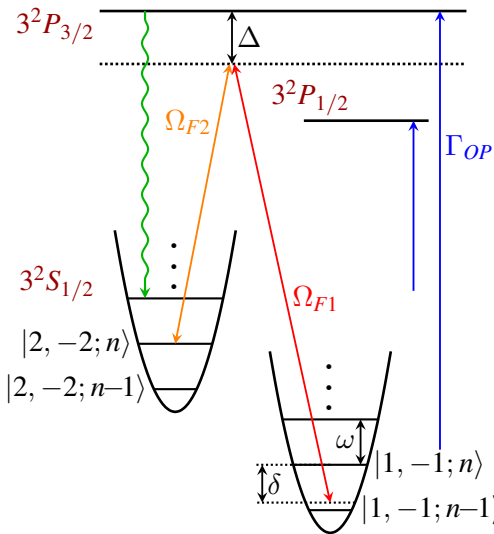
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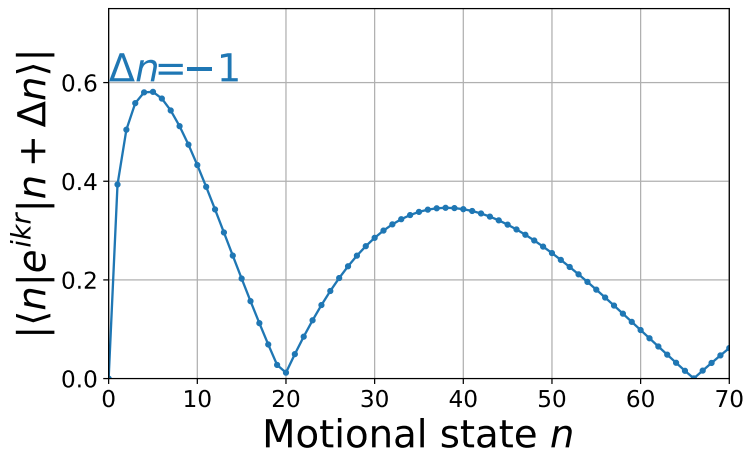
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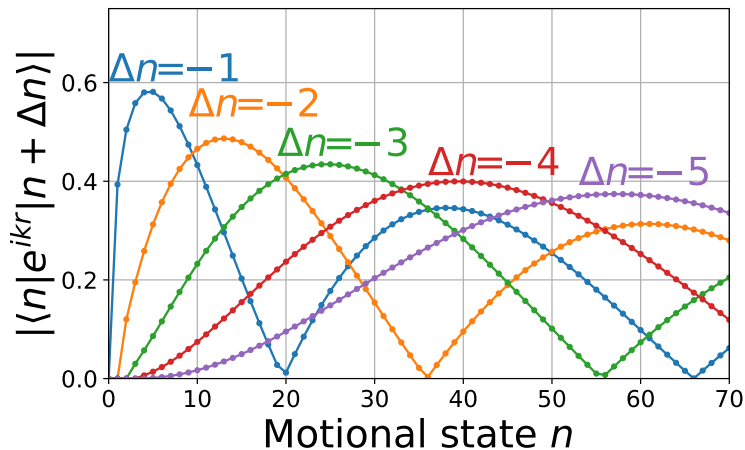


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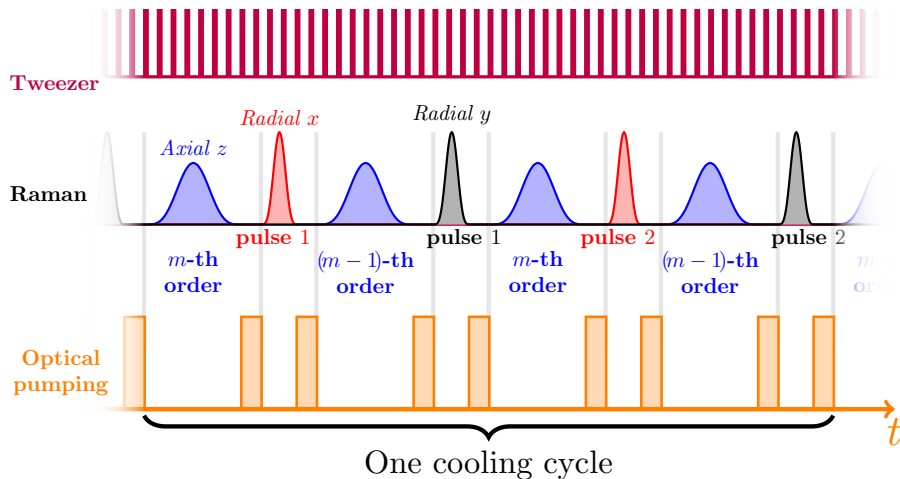
Raman matrix elements



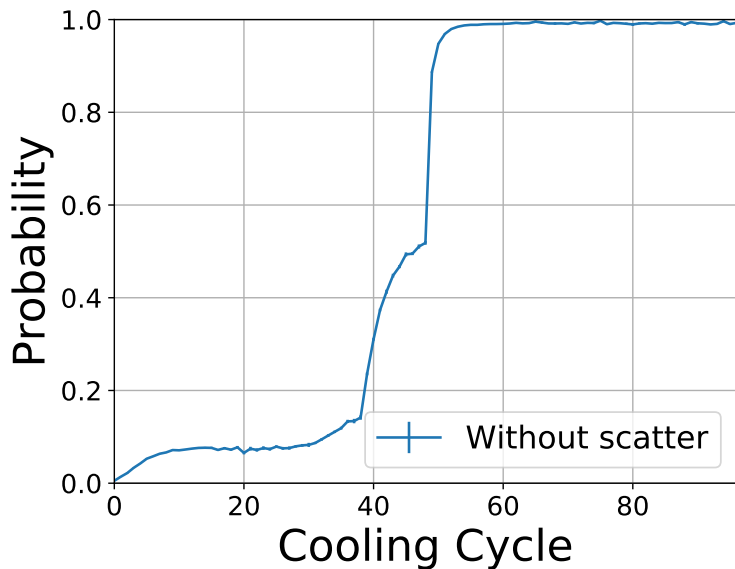
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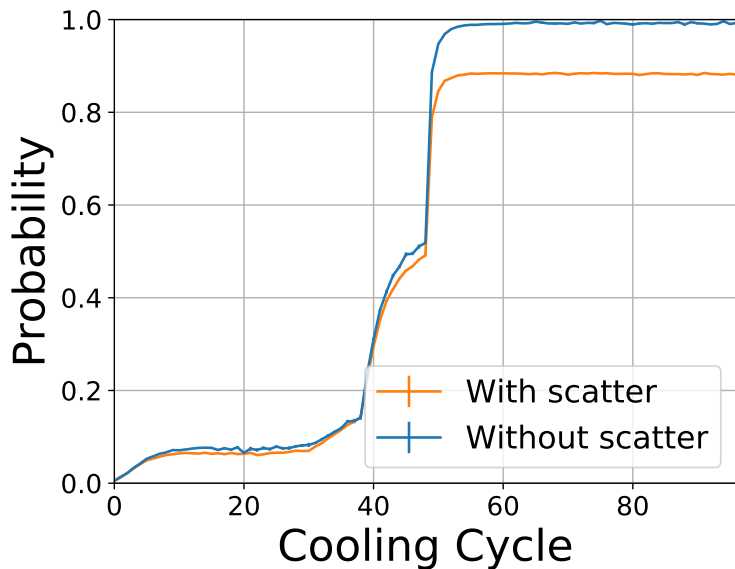
Sequence and simulation

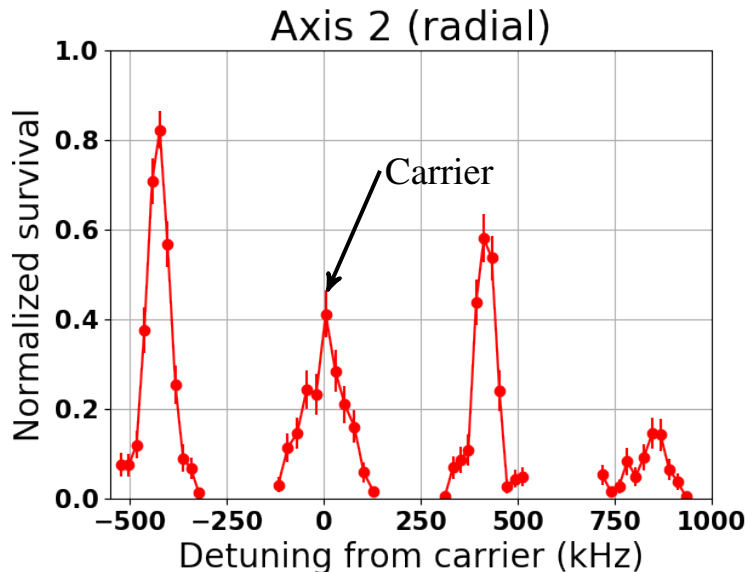


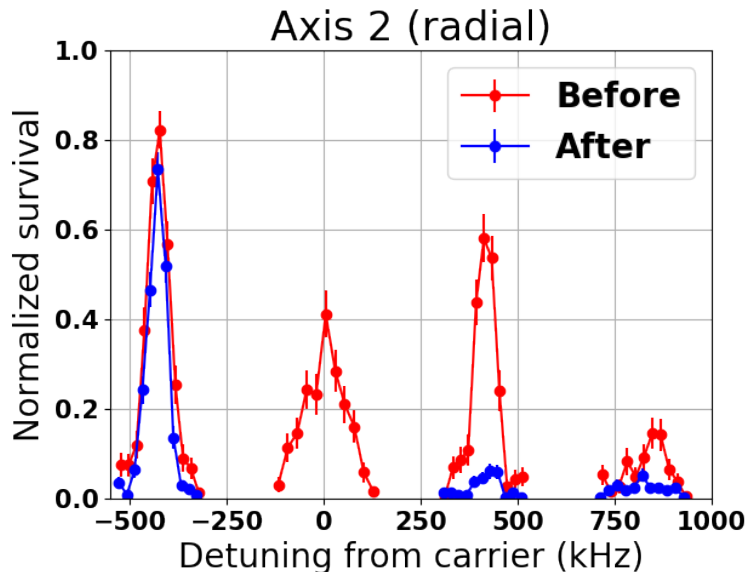
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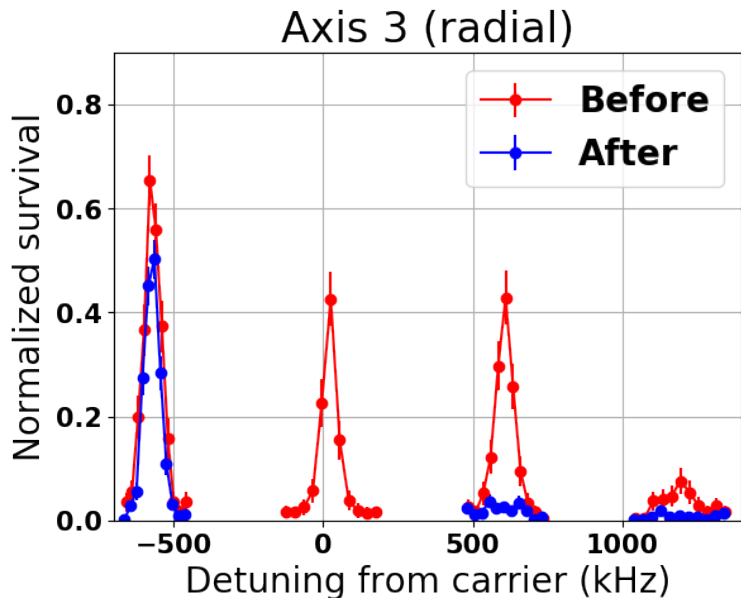


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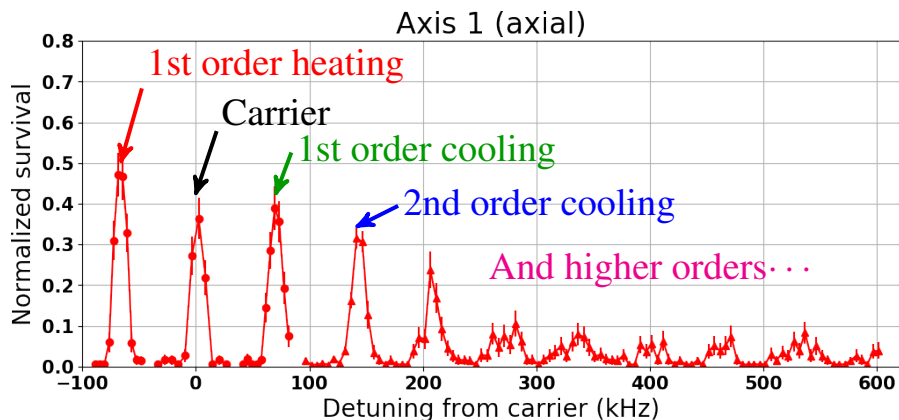




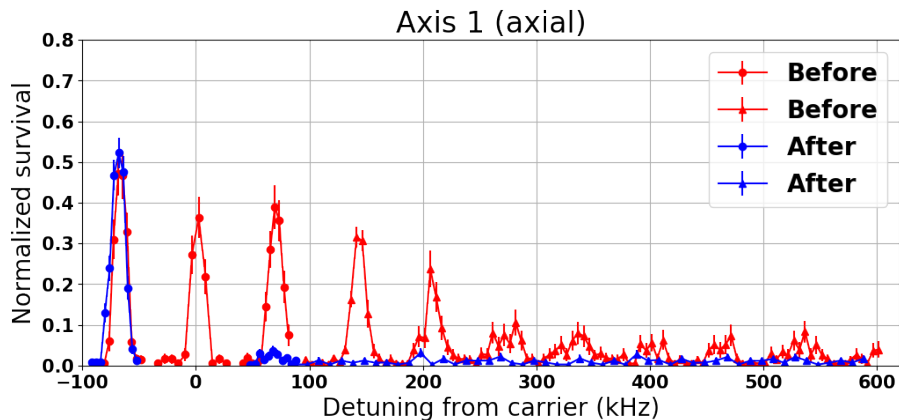




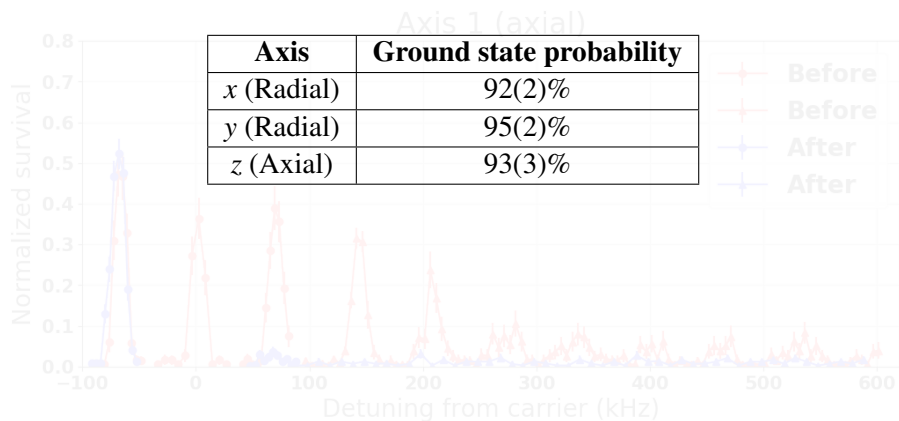
Raman sidebands



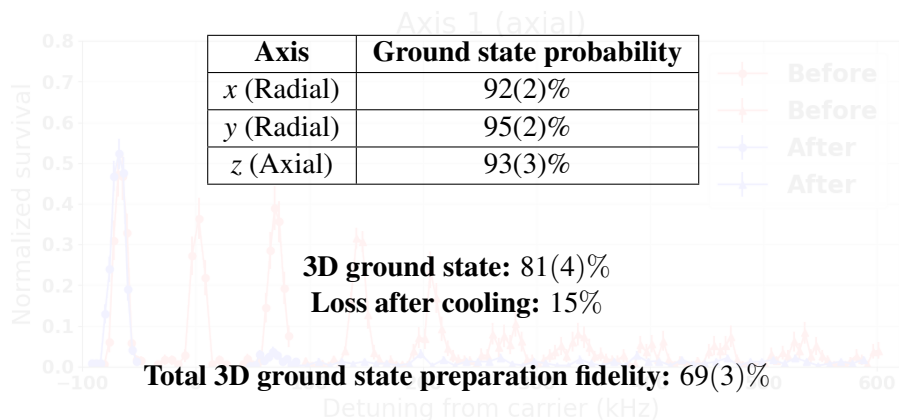
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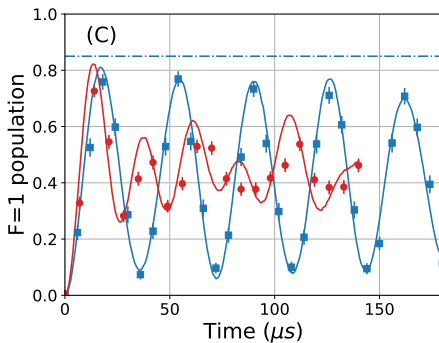
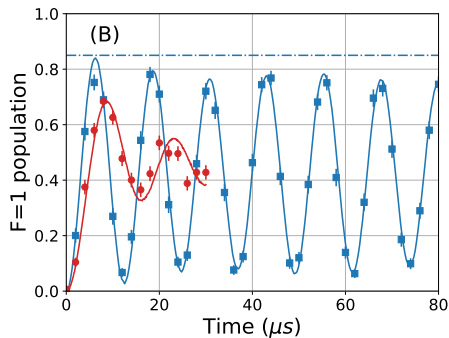
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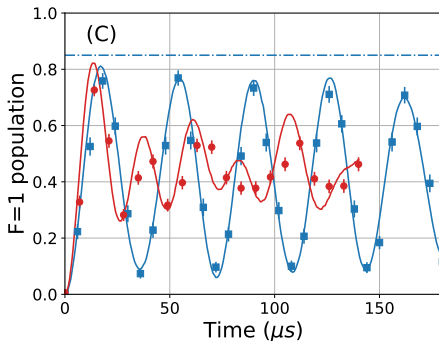
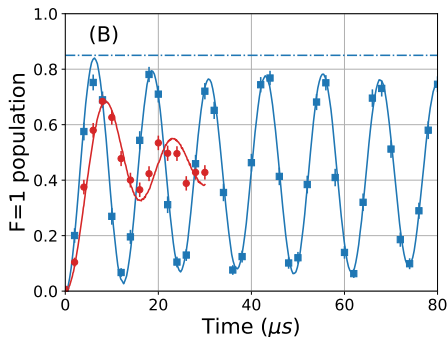
Raman sidebands



Rabi flopping (radial)

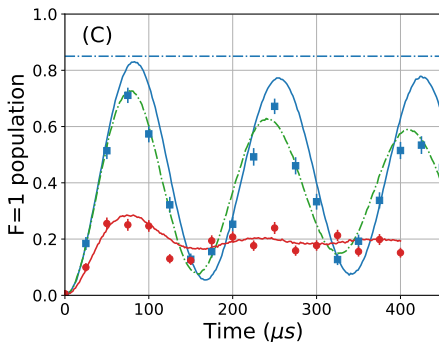
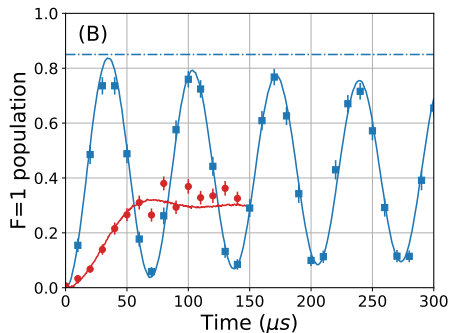


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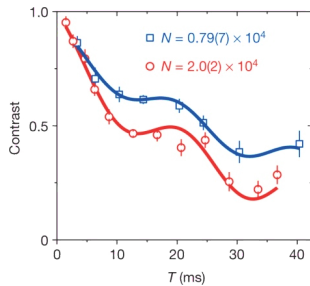
Good agreement in ground state probability
between spectrum and Rabi flopping data.

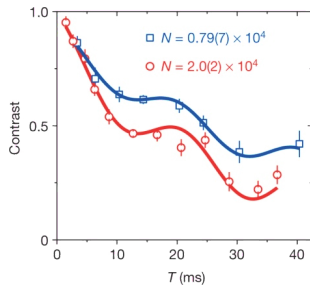
Rabi flopping (axial)

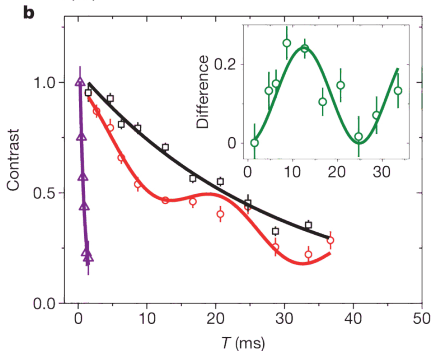
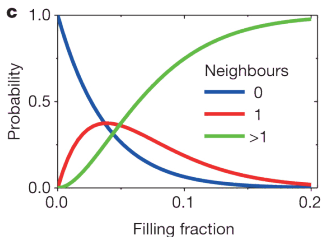
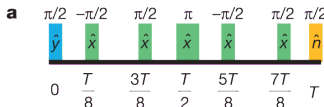
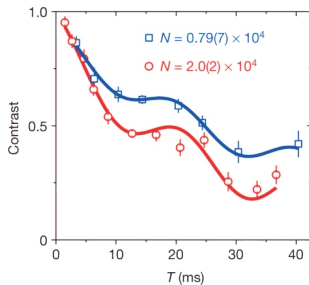


Decoherence caused by technical noise.
E.g. 1.5 mG of magnetic field noise.

In progress





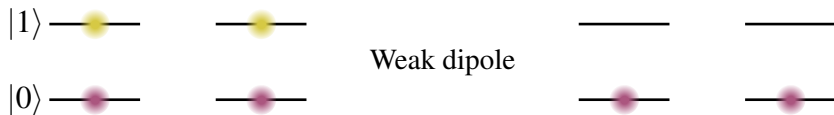
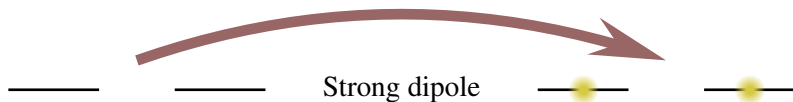


Quantum computation

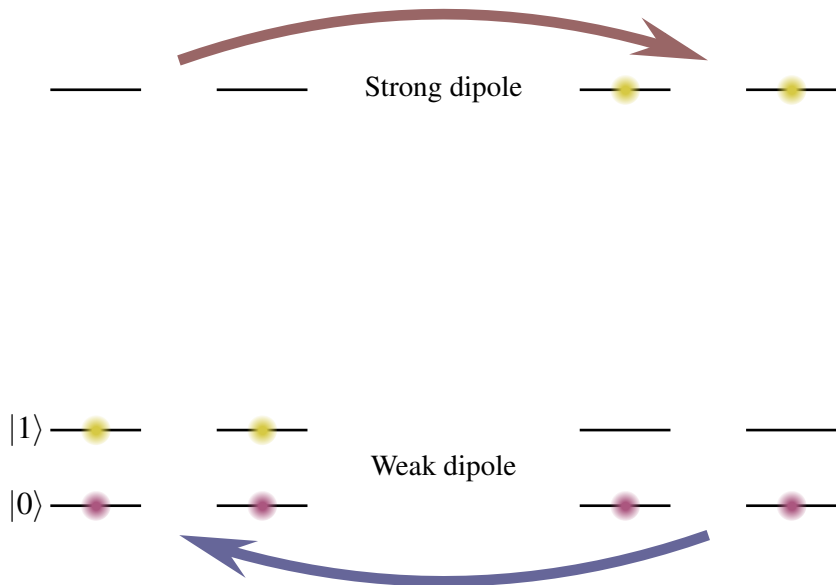
—— ——— Strong dipole

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

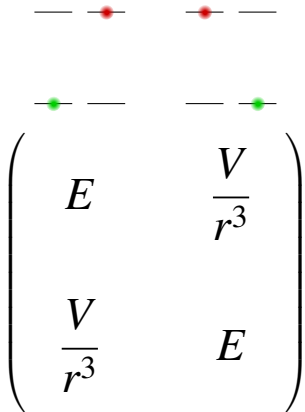
Quantum computation



Quantum computation



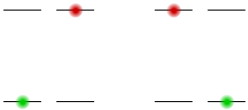
Quantum computation



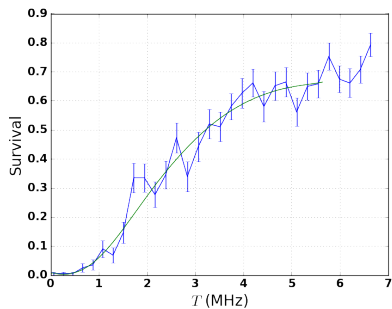
The diagram shows two horizontal lines representing energy levels. The top line has two red dots, and the bottom line has two green dots. The dots are positioned such that they appear to be coupled or interacting, with the first red dot aligned with the first green dot and the second red dot aligned with the second green dot.

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

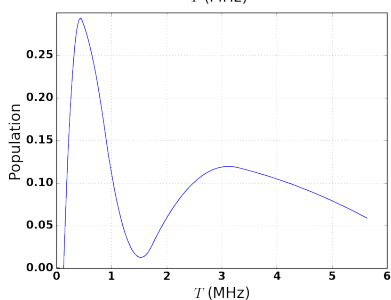
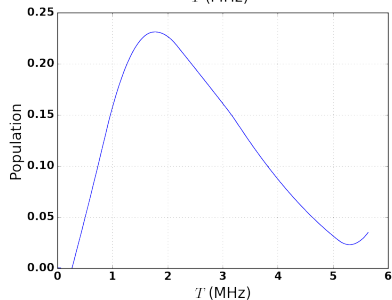
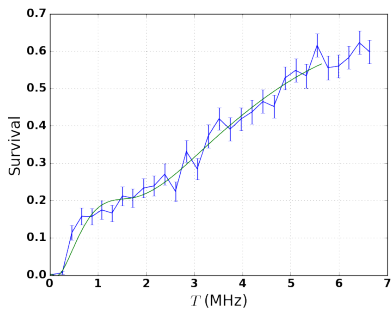
Quantum computation


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

Before cooling



After cooling



Merge trap

