

Ultracold molecule assembly

The background features a 3D visualization of an ultracold molecule assembly trap. A large, dark, cylindrical structure with a ribbed texture is shown in perspective. A bright green, cone-shaped beam of light originates from the left and focuses into a circular region on the right. Within this focused area, numerous small, colorful molecular models (blue, orange, and yellow spheres) are depicted, representing the assembly of ultracold molecules.

Yichao Yu

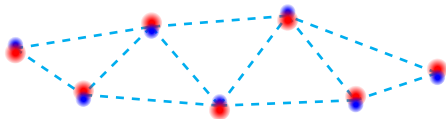
Ni Group/Harvard

Aug 11, 2017

Molecules in optical tweezer

Features

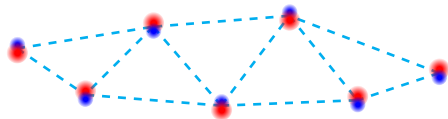
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Molecules in optical tweezer

Features

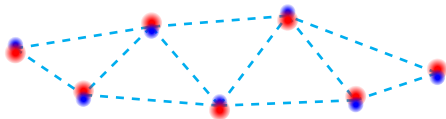
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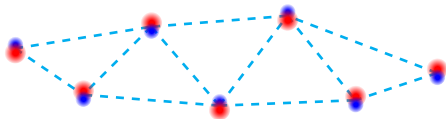
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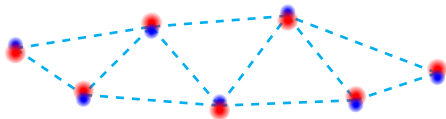
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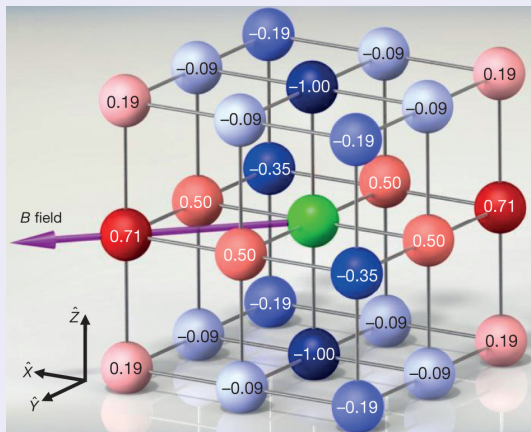
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- Rich internal energy levels
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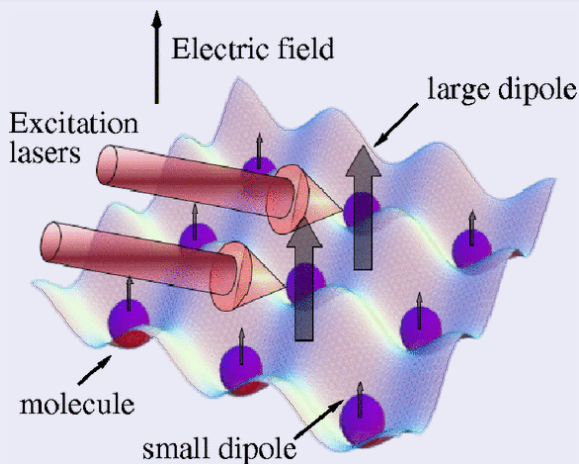
Simulation of many-body system^[1]



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

[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).

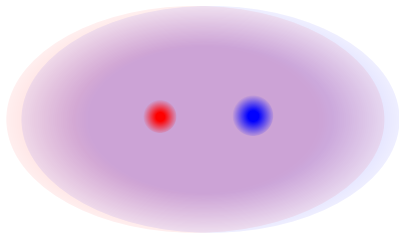
Making molecules from atoms

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



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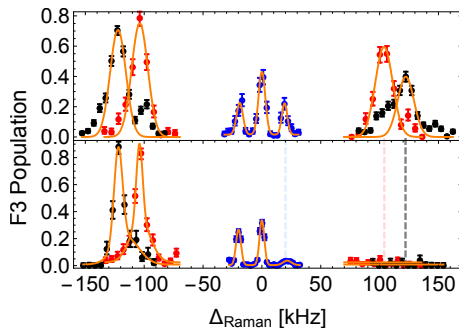
Atom loading and cooling

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

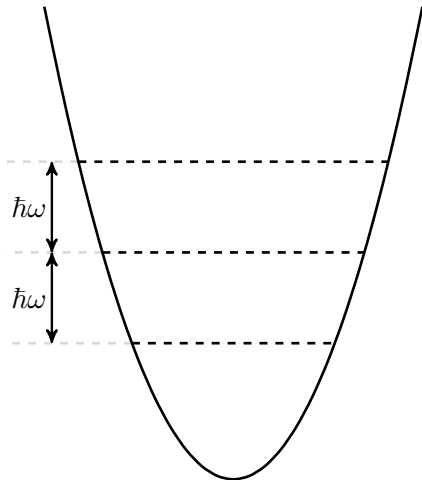


Atom loading and cooling

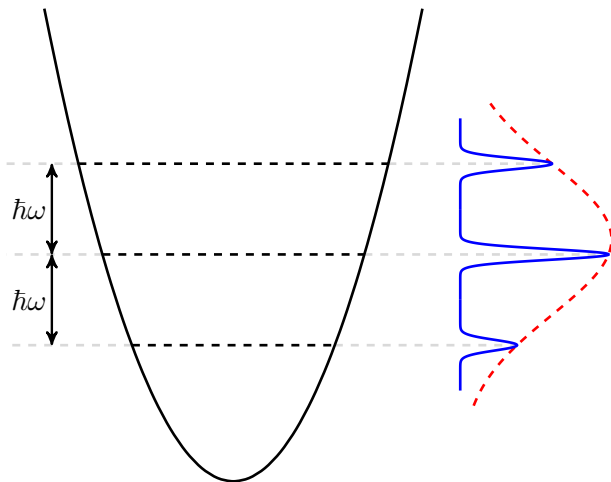
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Raman sideband cooling

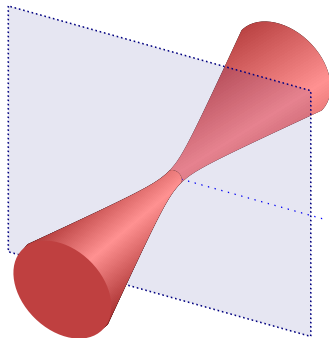
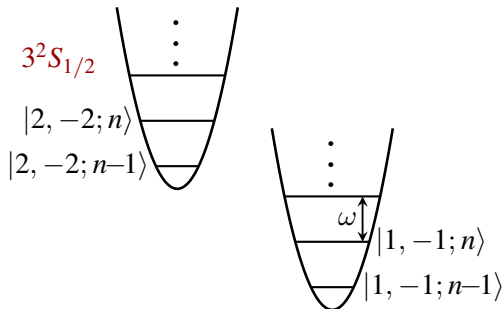


Raman sideband cooling

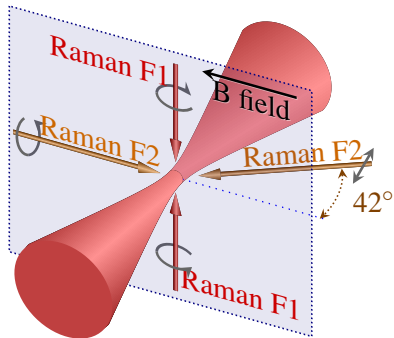
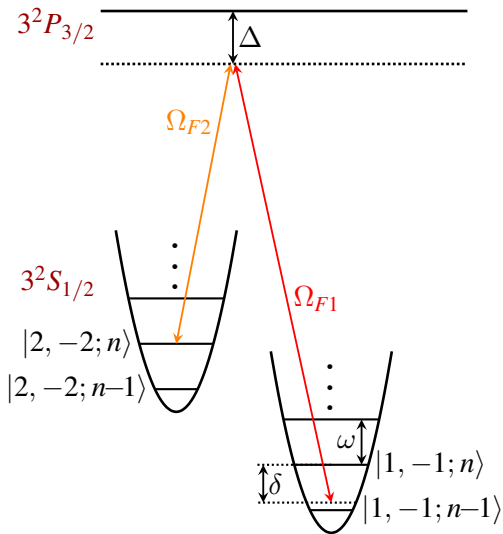


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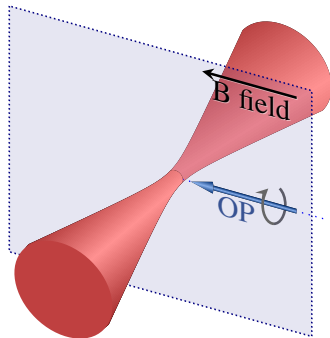
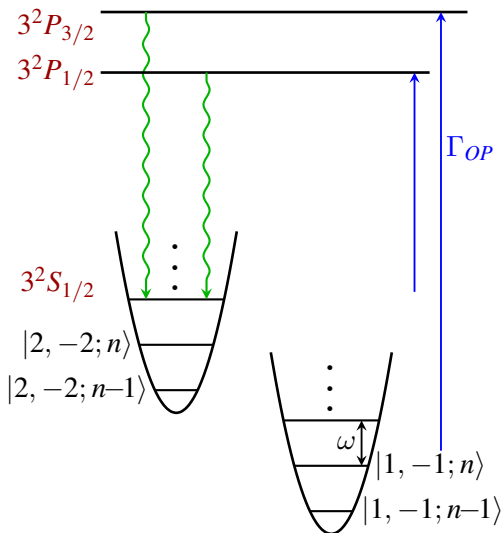
$3^2P_{3/2}$



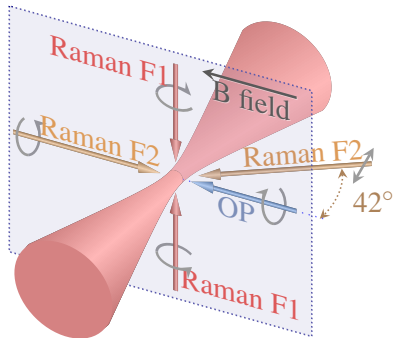
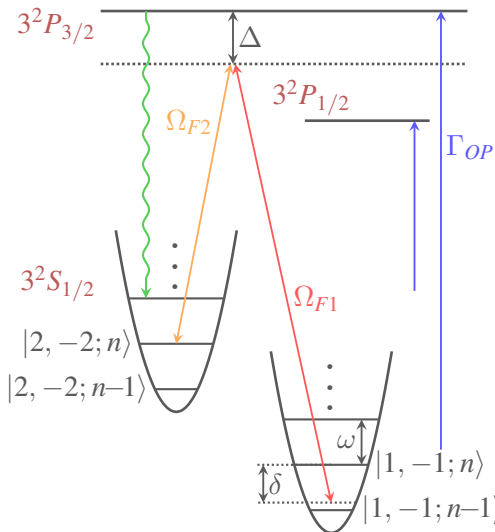
Raman sideband cooling



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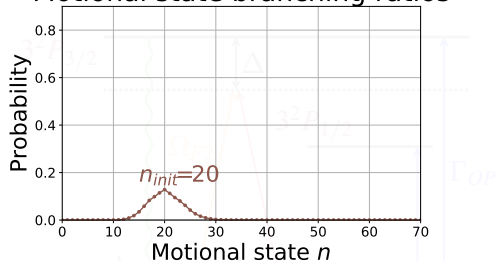


Raman sideband cooling



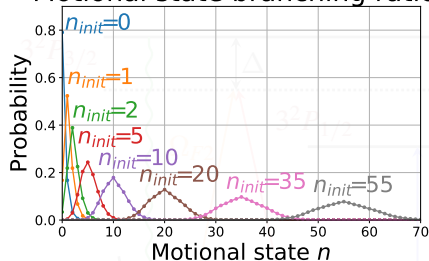
- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter
 $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering
 $\approx 3 \sim 15\text{kHz}$

Motional state branching ratios



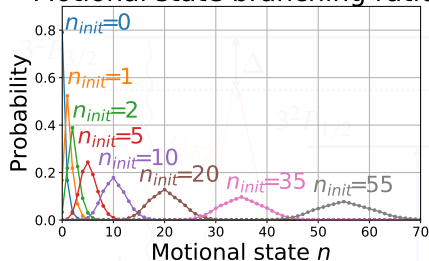
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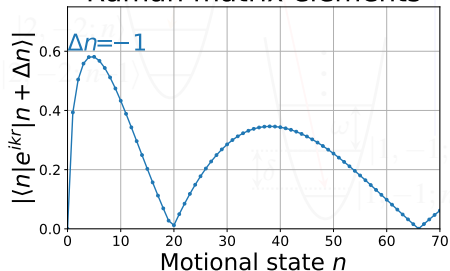


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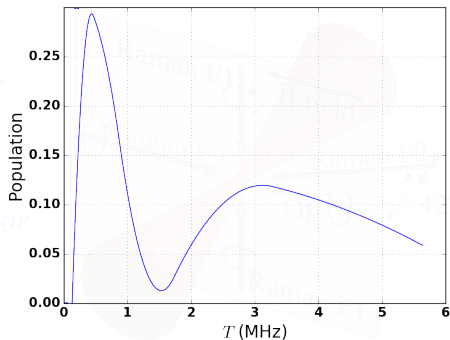
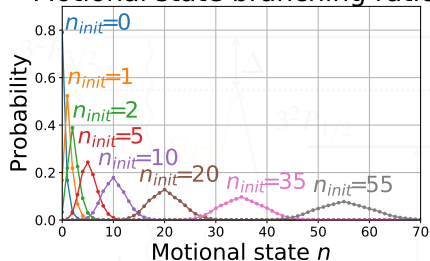
Raman matrix elements



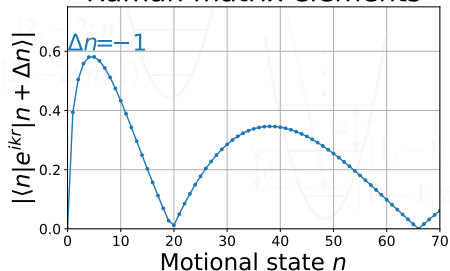
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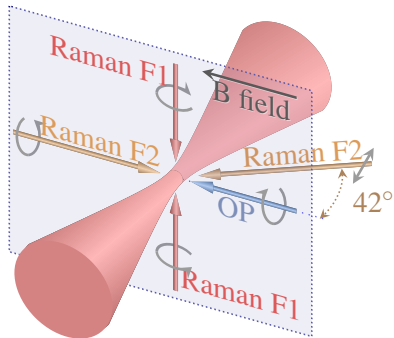
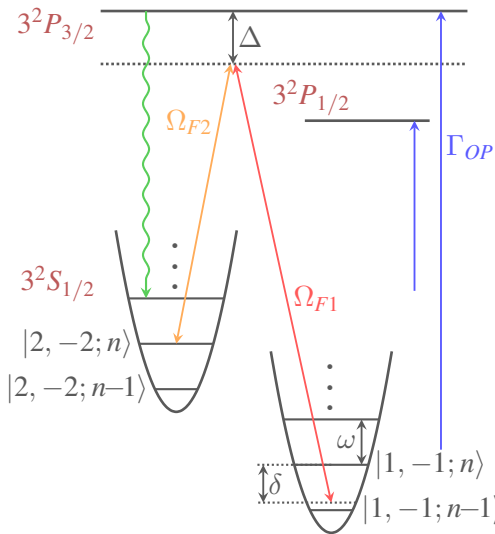


Raman matrix elements



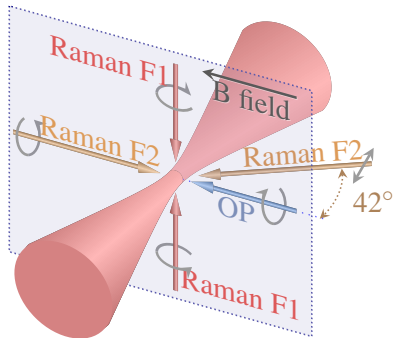
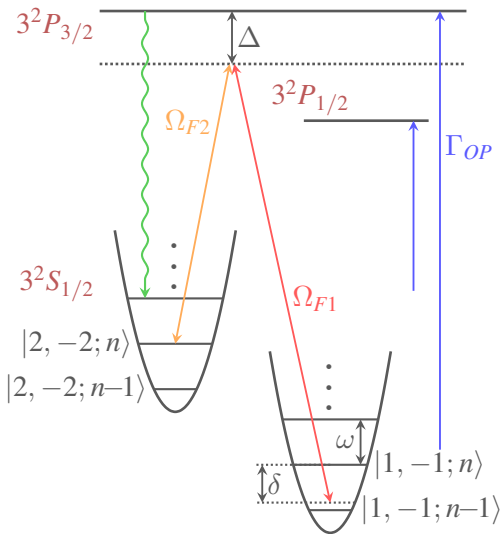
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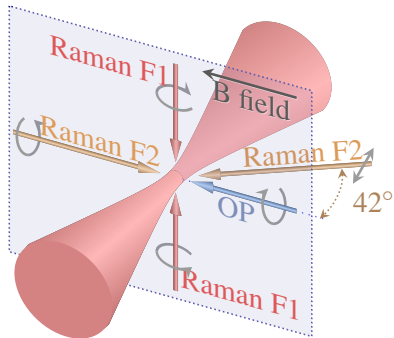
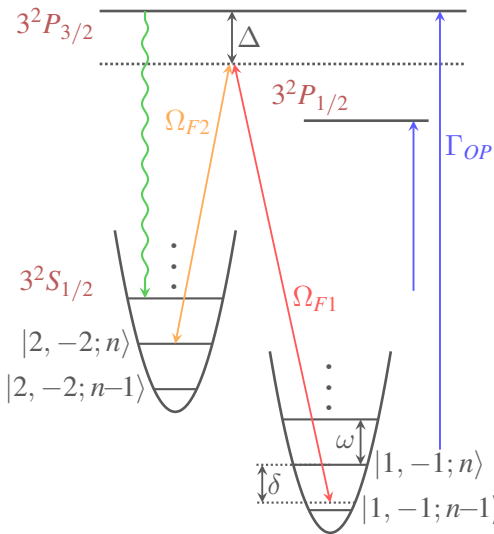
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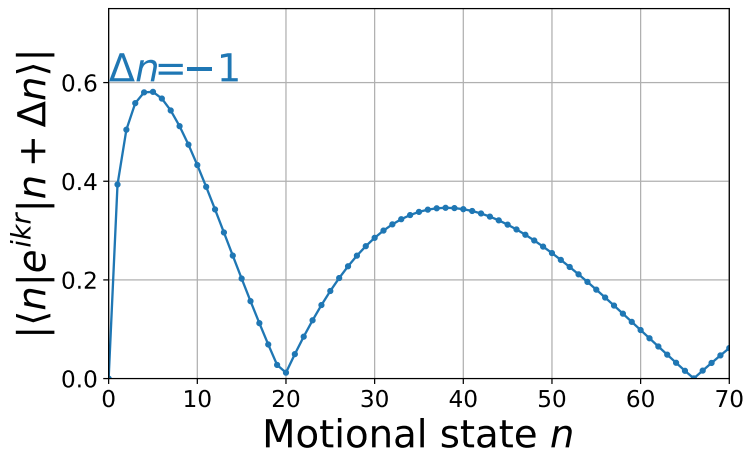
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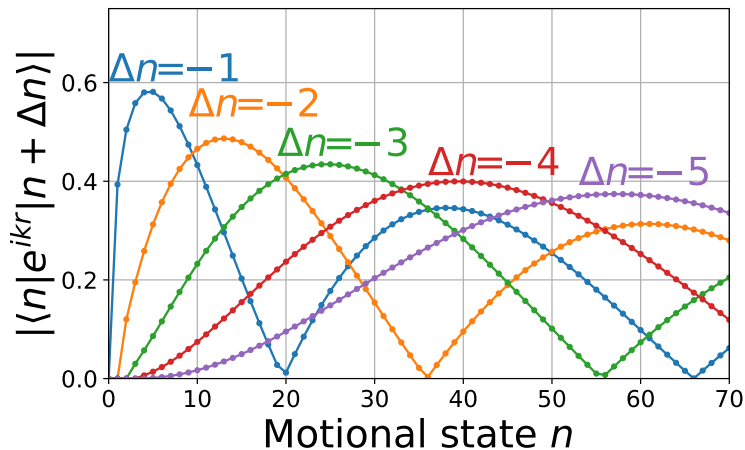


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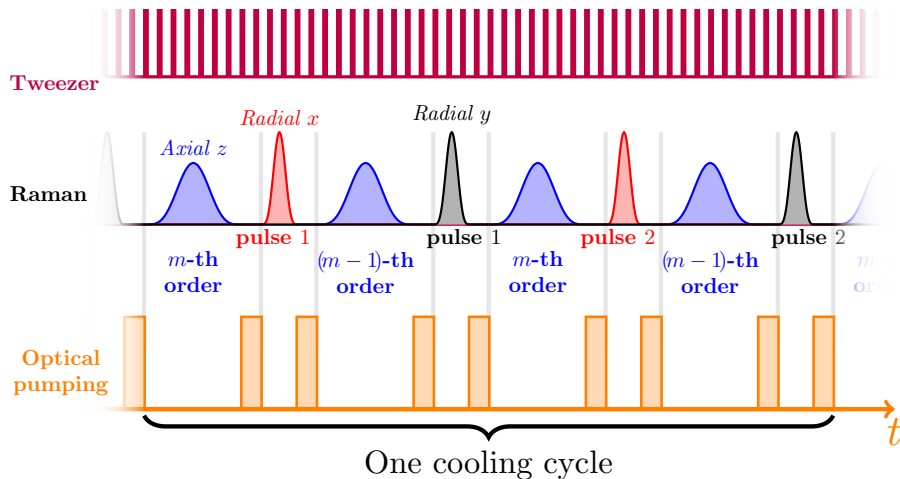
Raman matrix elements



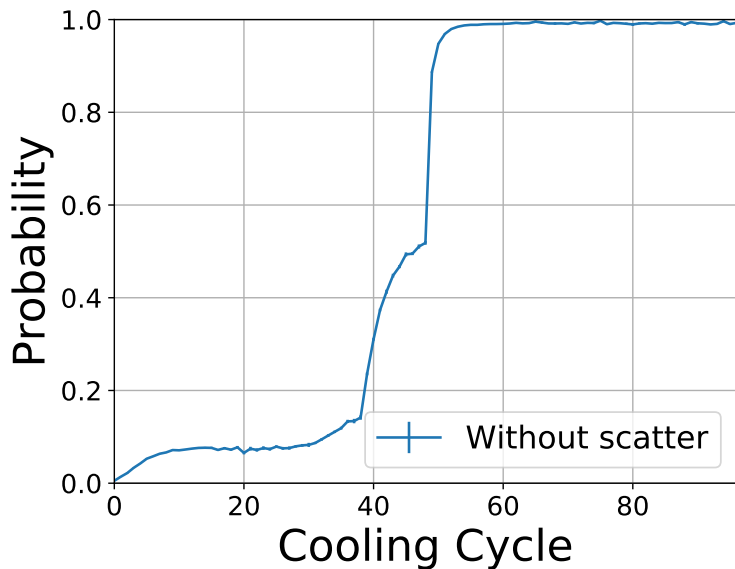
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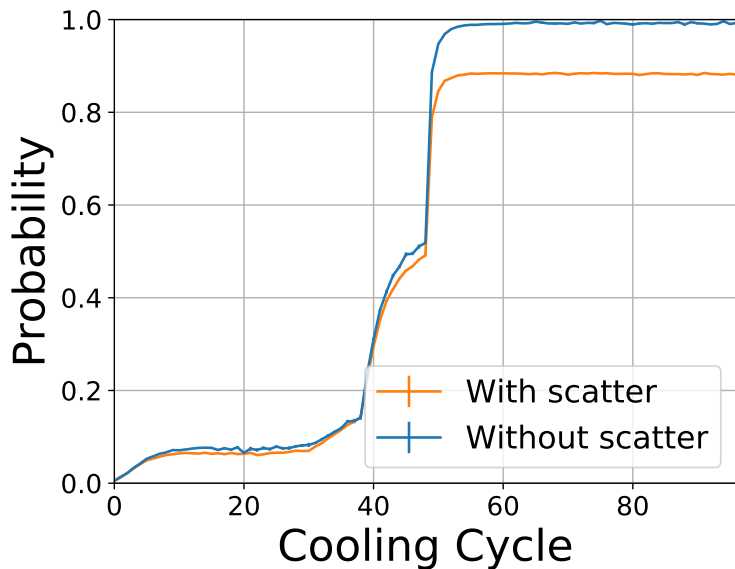
Sequence and simulation

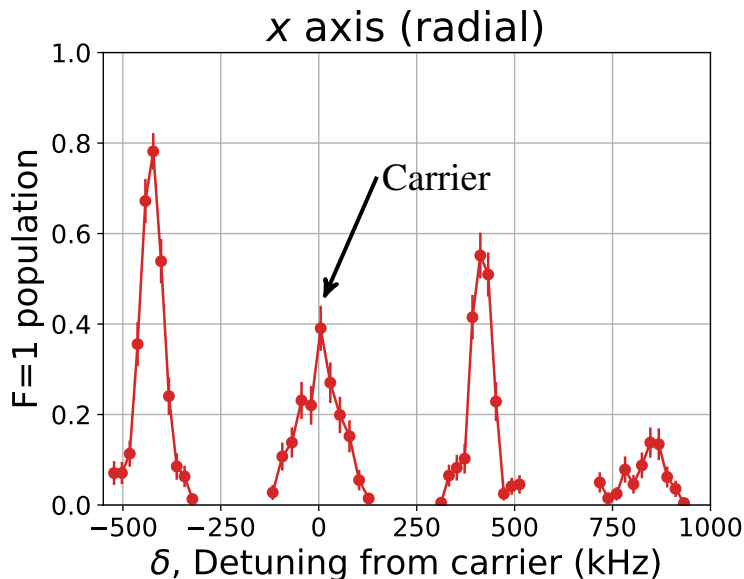


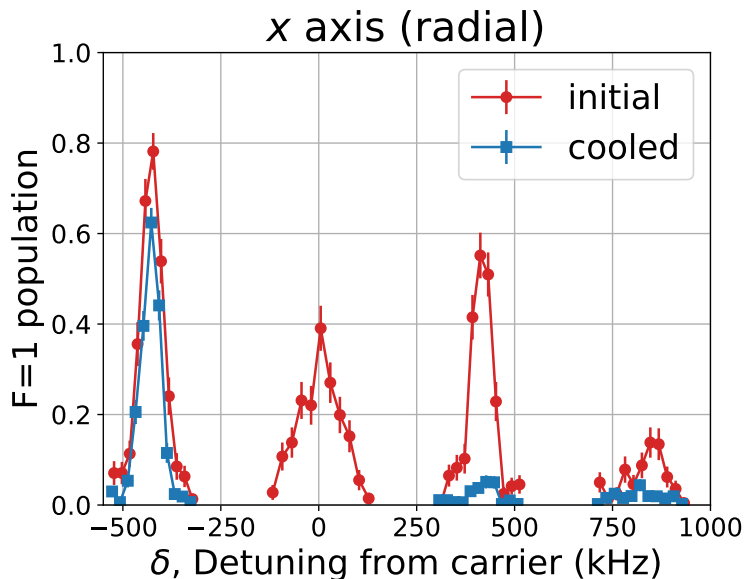
Sequence and simulation

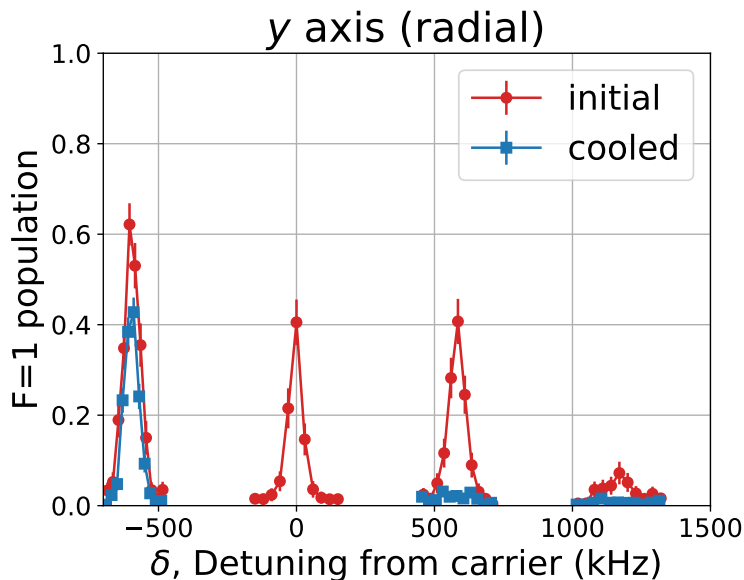


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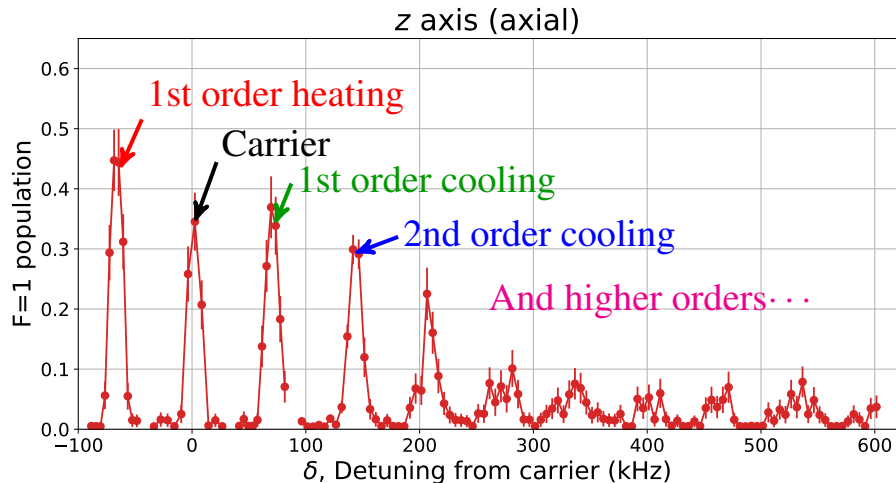




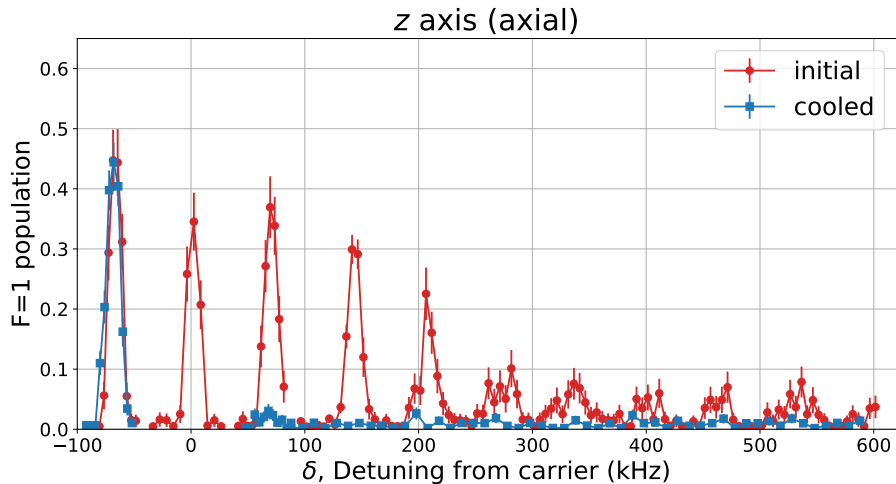




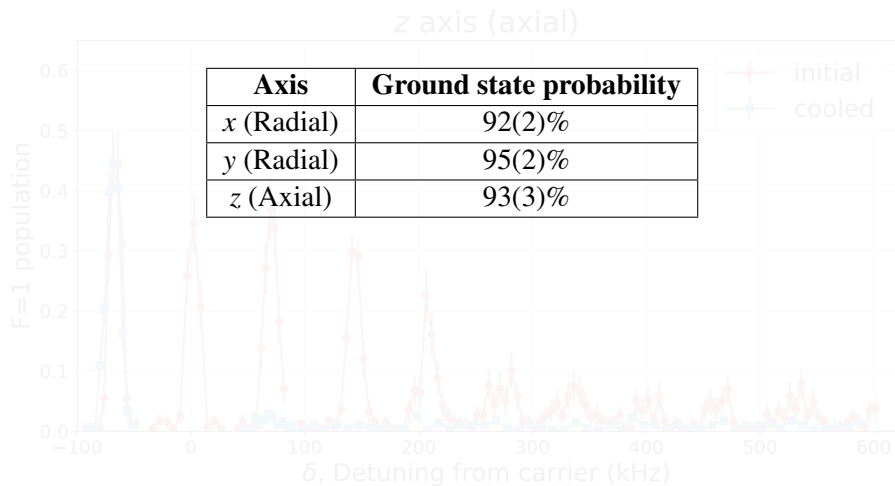
Raman sidebands



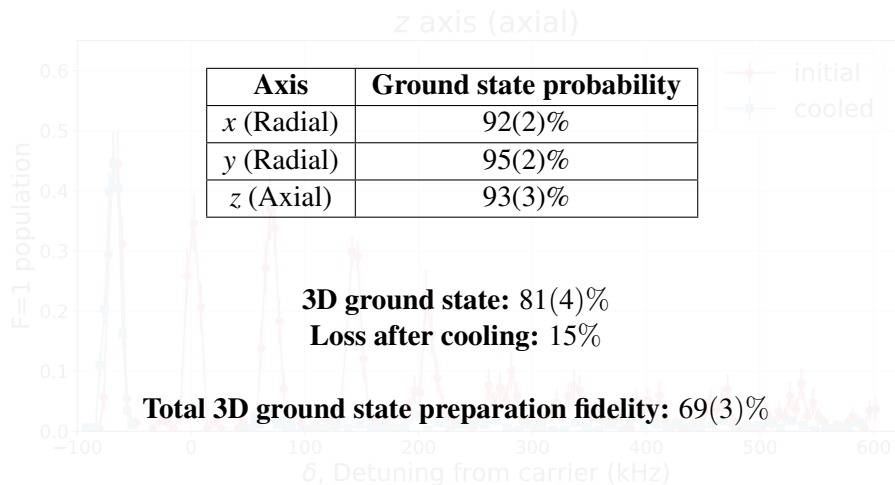
Raman sidebands



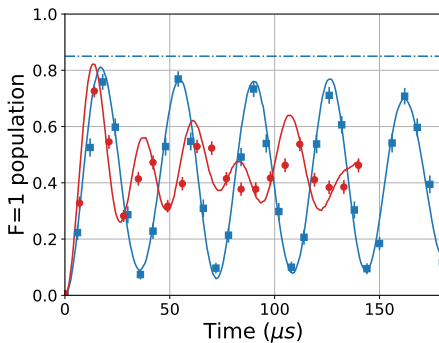
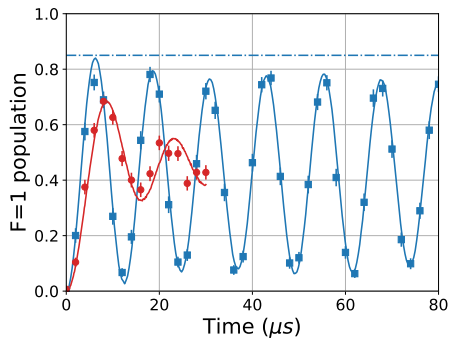
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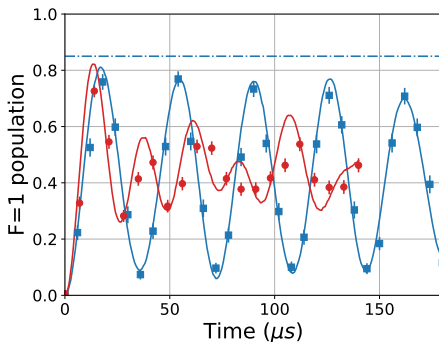
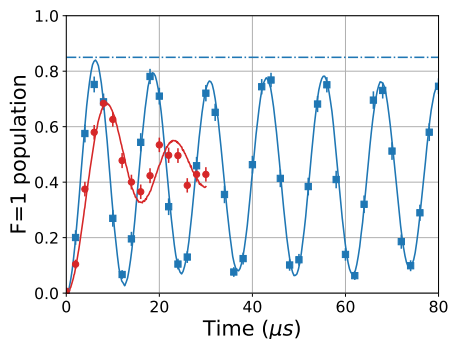
Raman sidebands



Rabi flopping (radial)

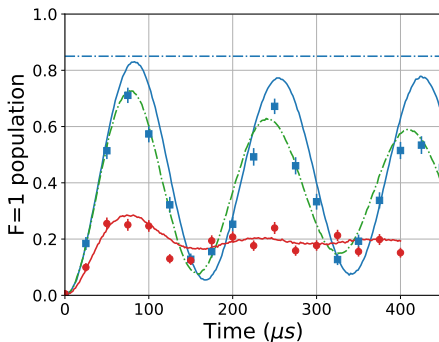
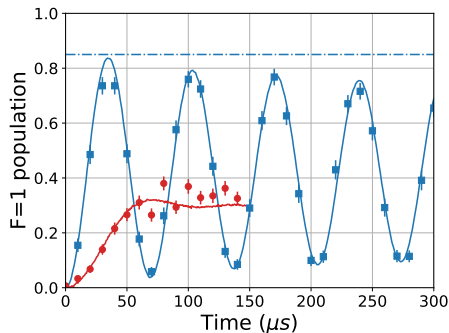


Rabi flopping (radial)



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.

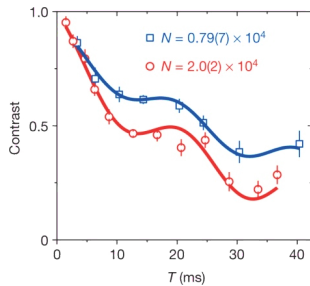
Conclusion

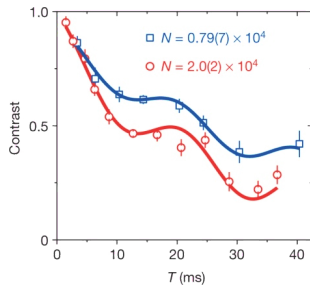
- Trapping of Na and Cs atoms
- Ground state cooling of Na^[3] and Cs

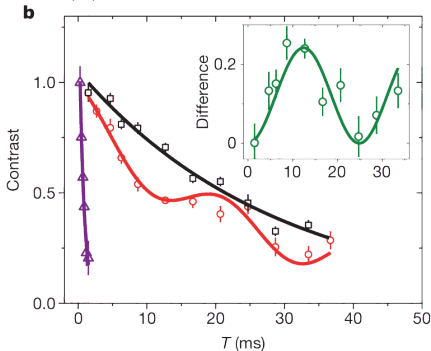
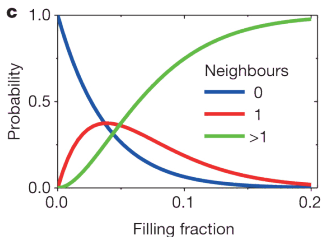
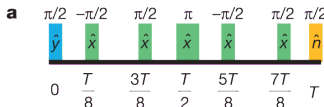
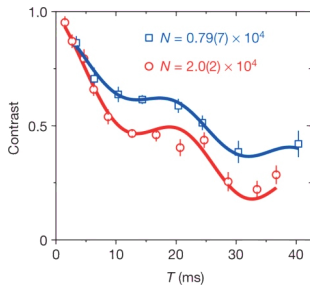
In progress

- Merge trap
- Photoassociation spectroscopy
- Make molecules

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







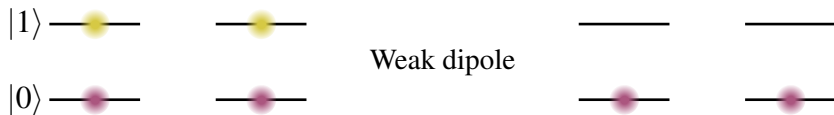
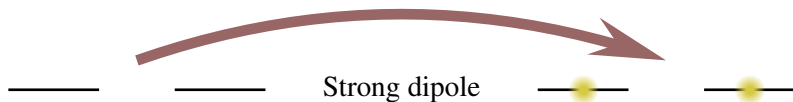
Quantum computation

———— Strong dipole

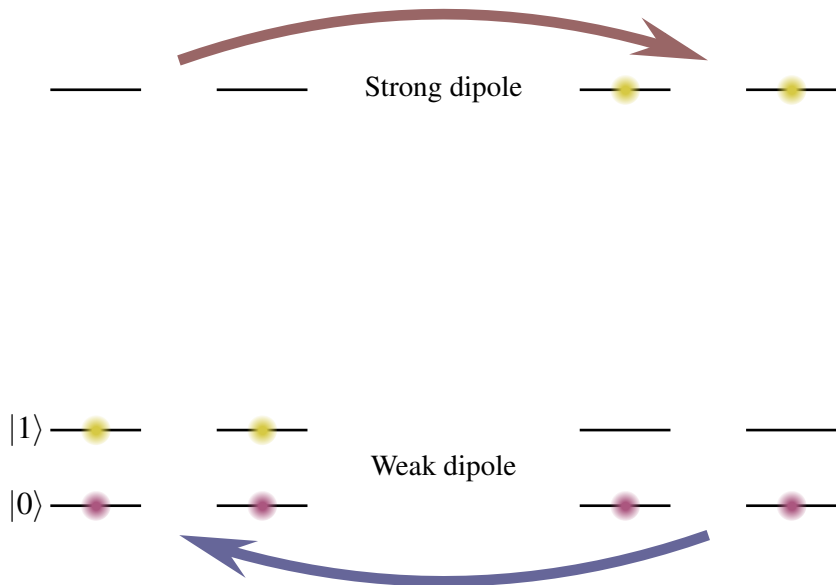
$|1\rangle$ ——— $|1\rangle$
 $|0\rangle$ ——— $|0\rangle$

Weak dipole

Quantum computation



Quantum computation

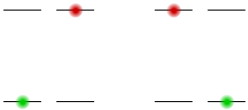


Quantum computation



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

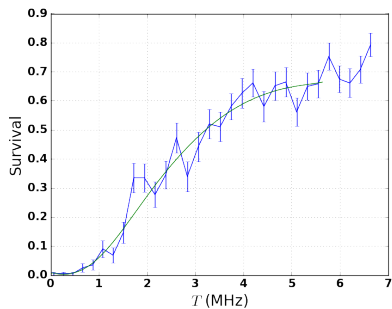
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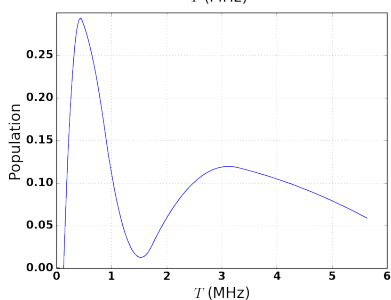
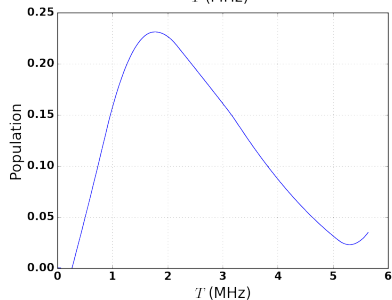
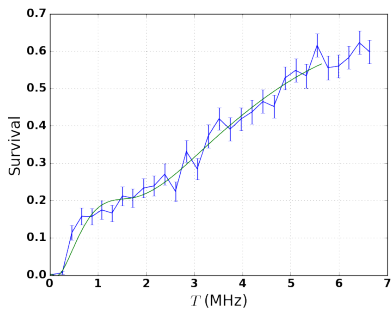
The diagram illustrates a quantum computation process. At the top, two horizontal lines represent energy levels. The upper line has two red dots, and the lower line has two green dots. Below this, a large blue arrow points from a matrix on the left to a matrix on the right.

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

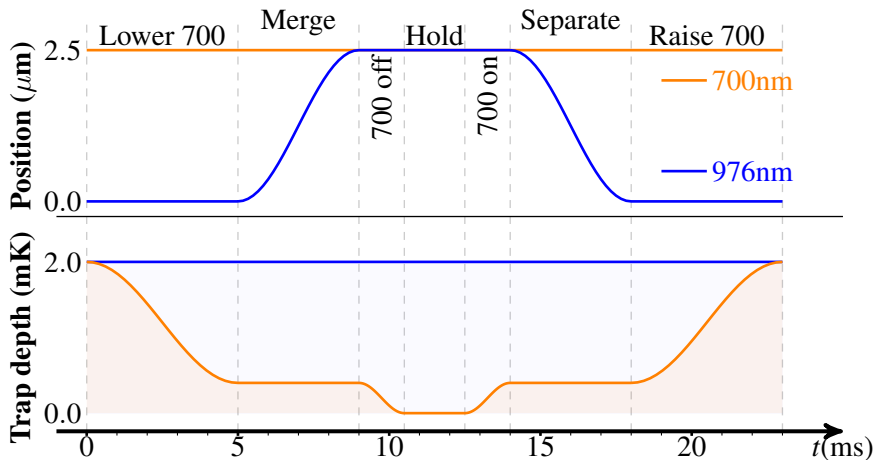
Before cooling



After cooling



Merge trap



Making molecule

