

Trapped atom, EIT and laser cooling



JUN. 9TH, 2010 GROUP MEETING

CHAO ZHUANG

A sequel of Xingxing Xing's EIT talks... .. :P



Motivation?



I had a wried thought...

Inbox



Aephraim



Chao Zhuang to Aephraim, Xingxing, Ardavan, Amir, Rockson, Chris, Luciano, Yasaman, Greg, [show details](#) Feb 10

[Reply](#)



maybe there's a simple answer....

is it possible to use the vibrational levels in the optical lattice to do EIT.....

let's say we have two wells, a lambda system consists $|g_{\text{electron}}\rangle|_{\text{left well}}\rangle$, $|g_{\text{electron}}\rangle|_{\text{right well}}\rangle$, and $|e_{\text{electron}}\rangle|_{\text{the well between left and right}}\rangle$ (because internal excited state sees a optical potential 180degrees out of phase to the potential internal ground state...) XD



Aephraim M. Steinberg to Chao, Xingxing, Ardavan, Amir, Rockson, Chris, Luciano, Yasaman [show details](#) Feb 10

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Interesting, and in principle there's no reason not.

But if the wells aren't also differently-polarized (à la polarisation-gradient molasses, Jessen/Deutsch-style lattices, etc), then you need to address the different transitions. How? Energy shift? Very small.

But all possible in principle....

Most recent paper



PHYSICAL REVIEW A **81**, 033418 (2010)

Dissipative light scattering by a trapped atom approaching electromagnetically-induced-transparency conditions

Maryam Roghani,^{*} Heinz-Peter Breuer,[†] and Hanspeter Helm[‡]

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(Received 16 September 2009; revised manuscript received 15 January 2010; published 22 March 2010)

We study the time dependence of the spectrum of inelastically scattered radiation from a trapped atom. The atom is illuminated by two lasers tuned to the electromagnetically induced transparency (EIT) of the free atom. For counterpropagating laser beams, rapid removal of vibrational energy is observed as the atom approaches near-EIT conditions. We show that the imbalance in the sidebands of the scattered radiation spectrum explains quantitatively the cooling of the center-of-mass motion of the trapped atom. We also examine parameters critical for EIT cooling in situations far from the Lamb-Dicke limit.

PHYSICAL REVIEW A **77**, 043418 (2008)

Trapped-atom cooling beyond the Lamb-Dicke limit using electromagnetically induced transparency

Paper I'm talking about



Ground State Laser Cooling Using Electromagnetically Induced Transparency

Giovanna Morigi,¹ Jürgen Eschner,² and Christoph H. Keitel³

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(Received 5 May 2000)

Experimental Demonstration of Ground State Laser Cooling with Electromagnetically Induced Transparency

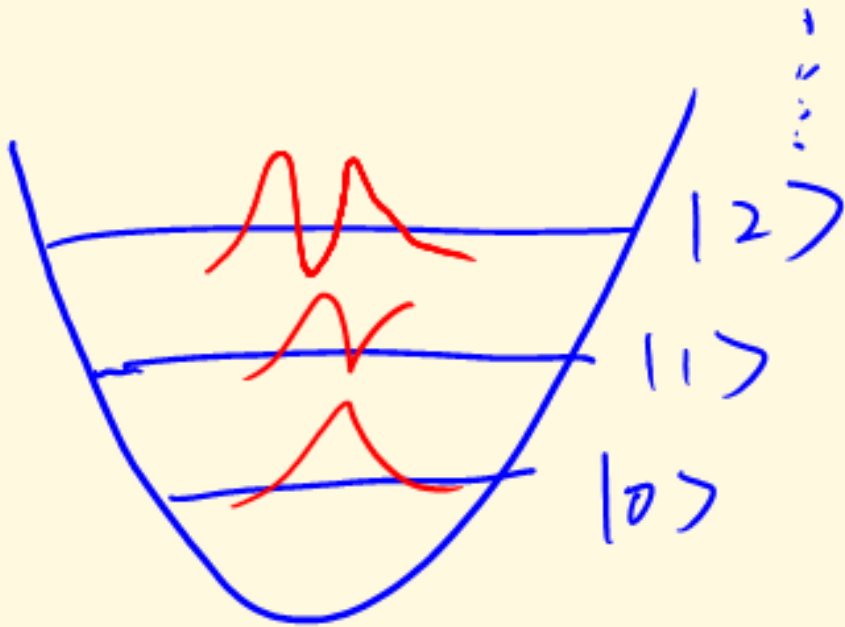
C. F. Roos,* D. Leibfried, A. Mundt, F. Schmidt-Kaler, J. Eschner, and R. Blatt

Institut für Experimentalphysik, University of Innsbruck, A-6020 Innsbruck, Austria

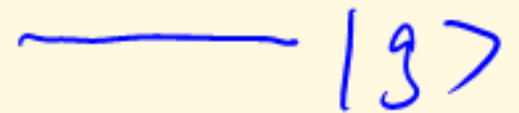
(Received 11 September 2000)

Ground state laser cooling of a single trapped Ca^+ ion is achieved with a technique which tailors the absorption profile for the cooling laser by exploiting electromagnetically induced transparency. Using the Zeeman structure of the $S_{1/2}$ to $P_{1/2}$ dipole transition we achieve up to 90% ground state probability. The new method is robust, easy to implement, and proves particularly useful for cooling several motional degrees of freedom simultaneously, which is of great practical importance for the implementation of quantum logic schemes with trapped ions.

Trapped atom



atom in a trap



electronic state

Combined picture



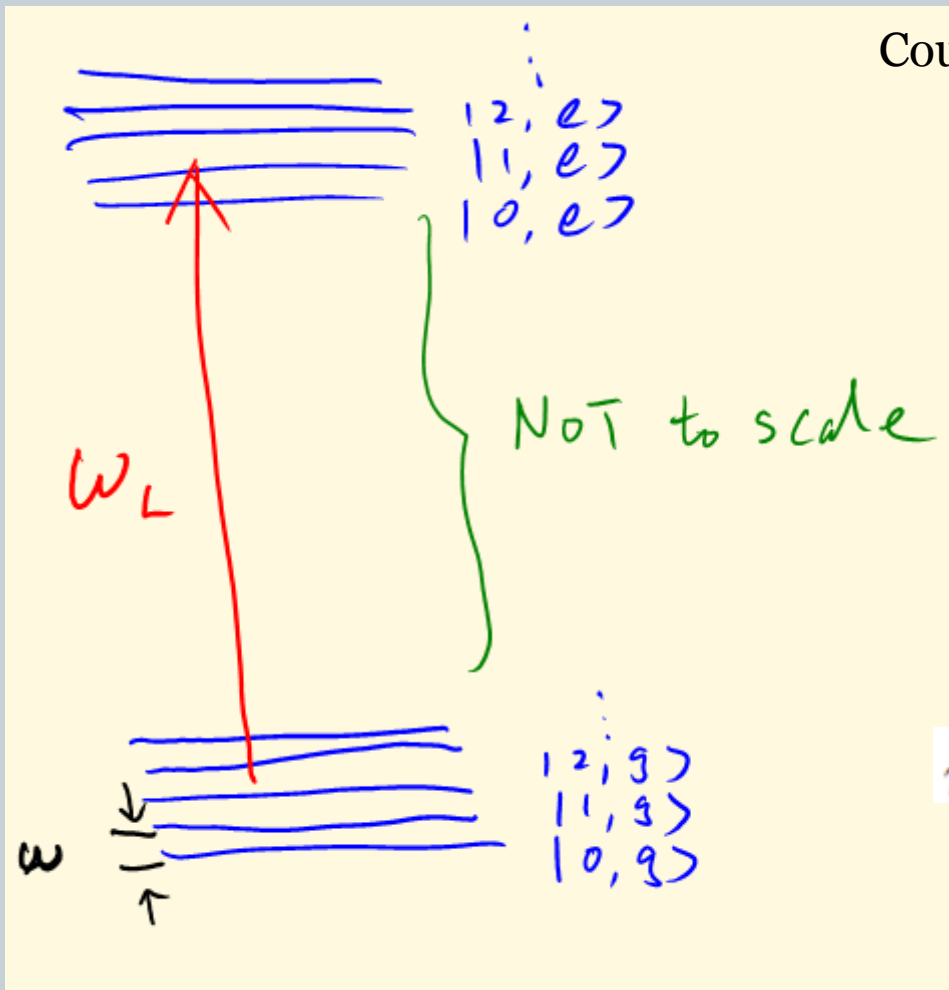
Coupling strength between vibrational states

Franck-Condon factors

$$\langle n | e^{\pm i \vec{k}_q \cdot \vec{x}} | m \rangle = F_{nm}^{(\pm \eta)}$$

determines

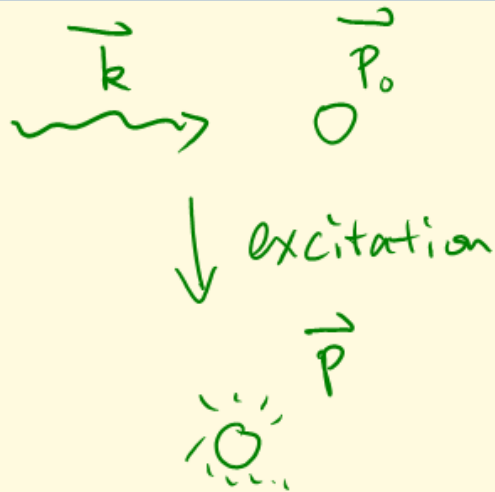
η is the Lamb-Dicke parameter,



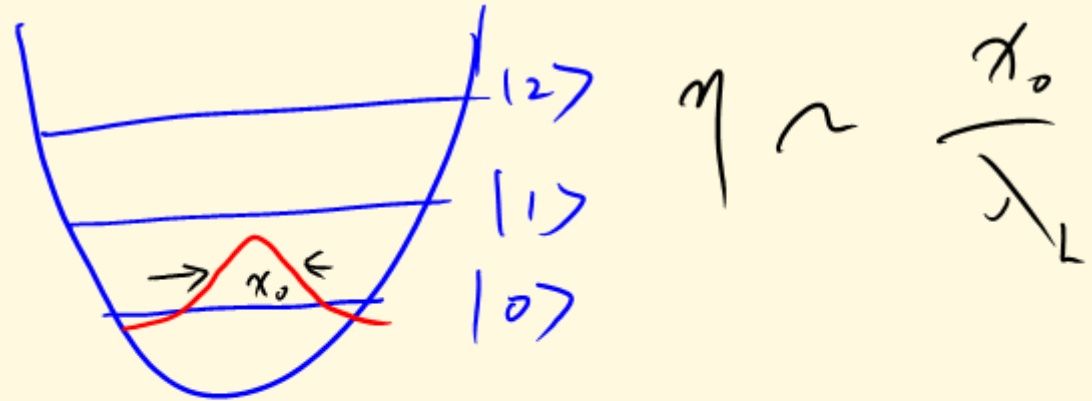
Lamb-Dicke parameter



$$\eta^2 = \frac{E_r}{\hbar\omega}$$



photon energy
 = electron energy + \bar{E}_r



$$x_0 \leftrightarrow \omega \leftrightarrow \hbar\omega$$

$$\lambda_L \leftrightarrow k_L \leftrightarrow \bar{E}_r$$

When consider coupling strength:
 Conservation of energy
 Conservation of momentum

Lamb-Dicke limit

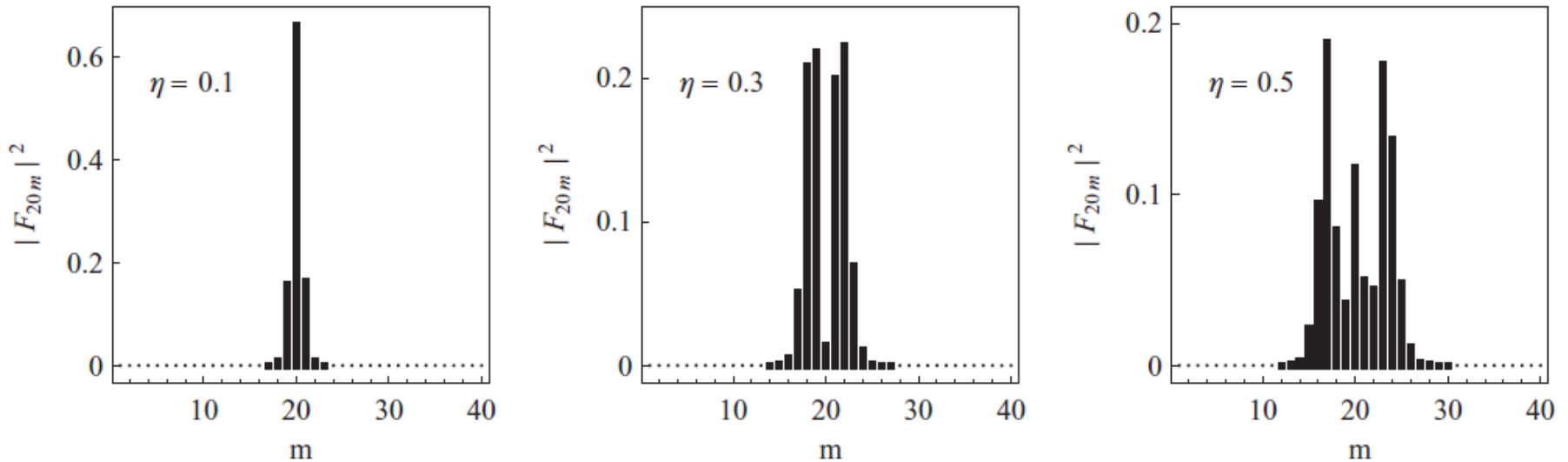


FIG. 2. Strength of sideband transitions from $n = 20$ for three values of η .

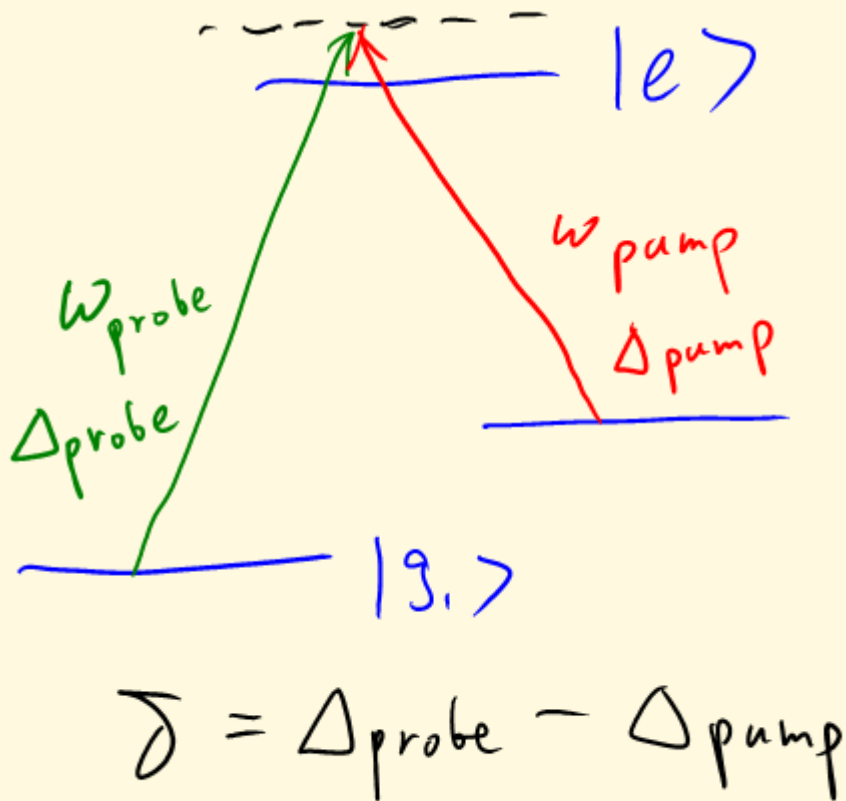
PHYSICAL REVIEW A 81, 033418 (2010)

$$\eta^2 = \frac{E_r}{\hbar\omega} \rightarrow \text{O}$$

Laser has some linewidth: satisfy conservation of energy
Conservation of momentum is not easy to satisfy,
unless the vibrational states are not changed

NOTE: one photon excitation

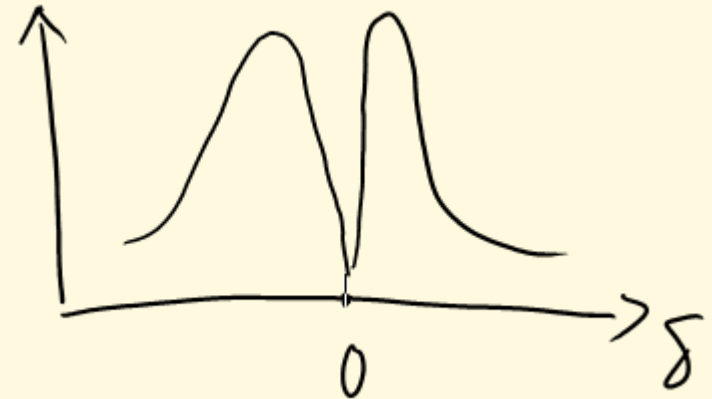
Λ -shaped atomic levels



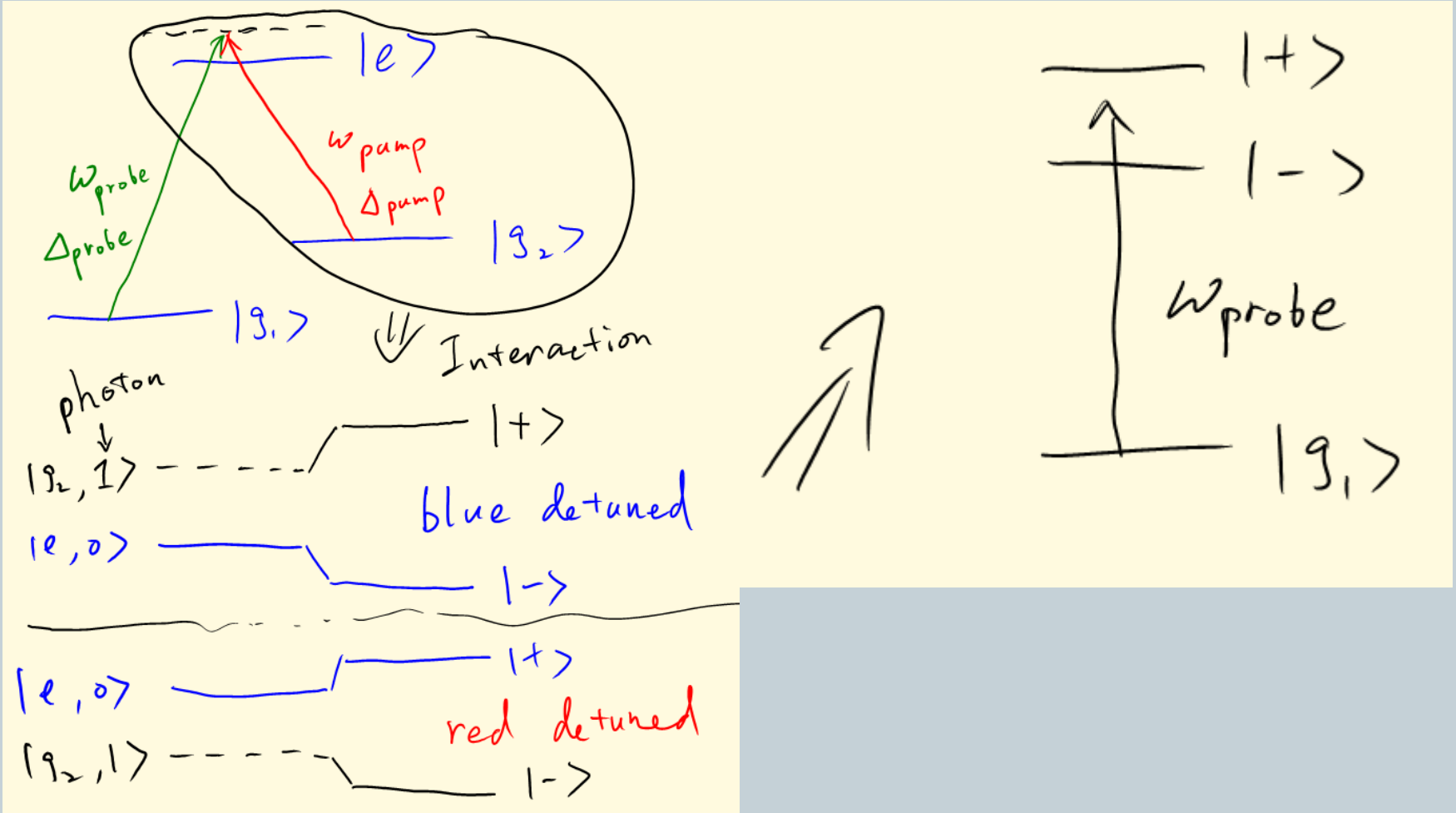
Interference

Dark-state

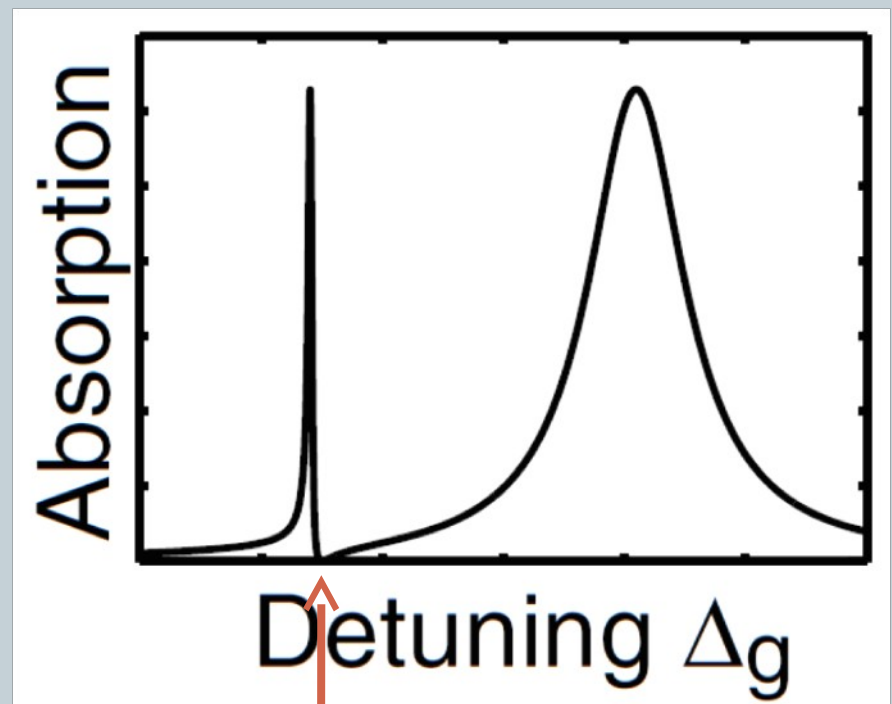
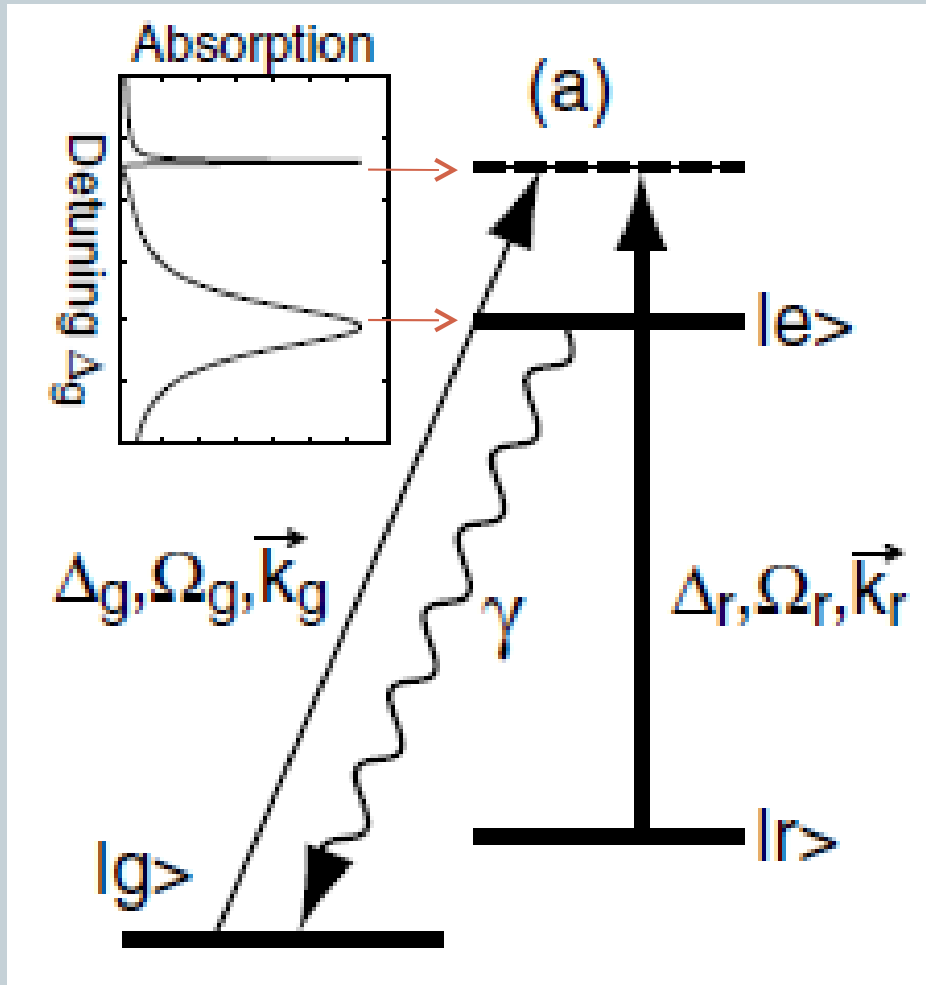
Absorption of Probe



Dressed states picture



EIT



$$\Delta_g = \Delta_r$$

When EIT meets vibrational levels

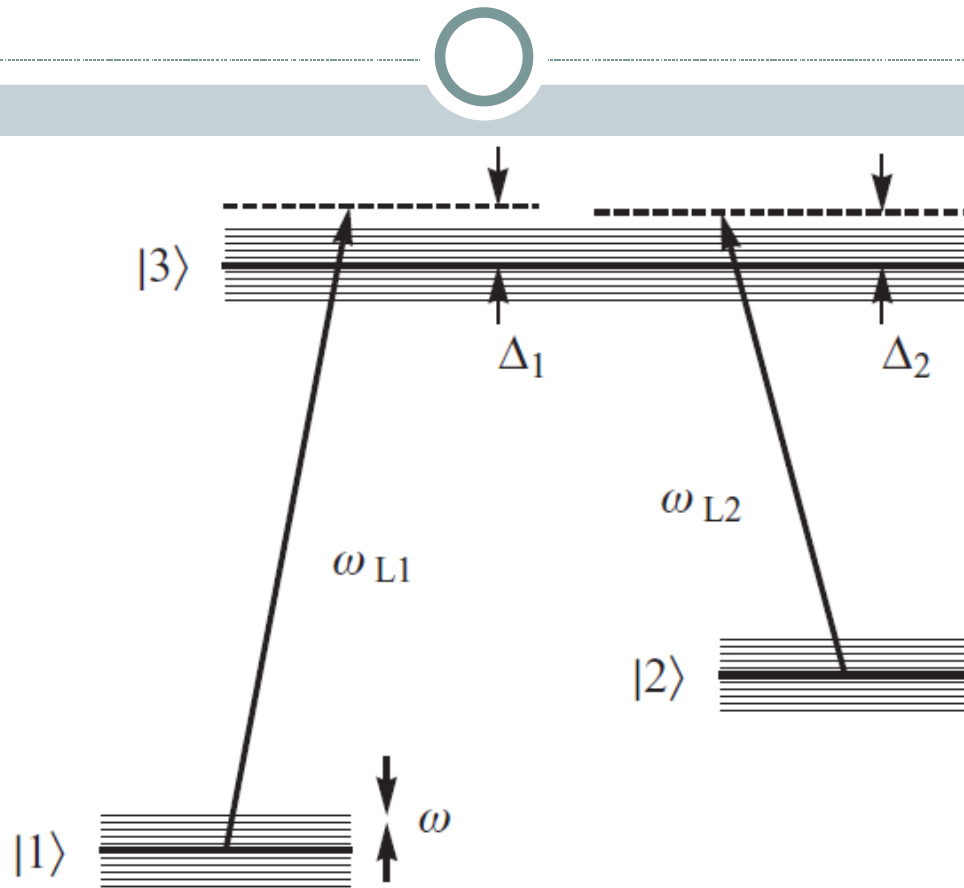


FIG. 1. Trapped three-level atom in the presence of two counter-propagating lasers at the frequencies ω_{L1} and ω_{L2} . The trap frequency is ω .

Dressed states



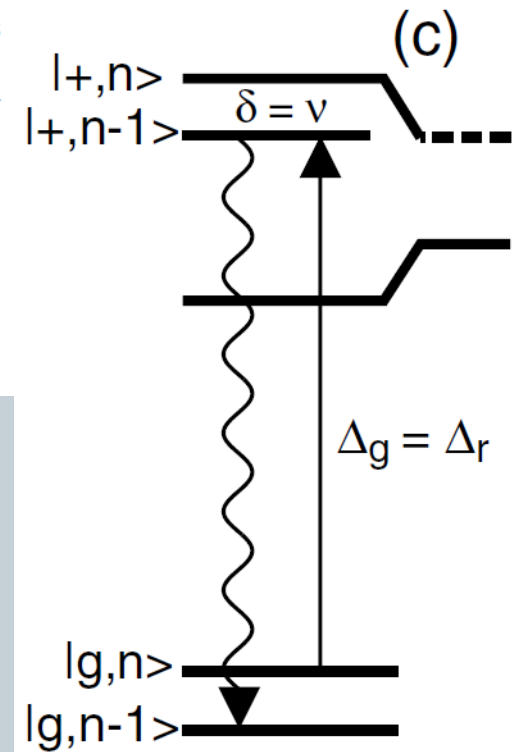
laser [22]; see Fig. 1c. These dressed states, and hence the maxima of the narrow and the broad curves, are shifted from Δ_r by $+\delta$ and $-\Delta_r - \delta$, respectively, with

$$\delta = (\sqrt{\Delta_r^2 + \Omega_r^2} - |\Delta_r|)/2 \quad (1)$$

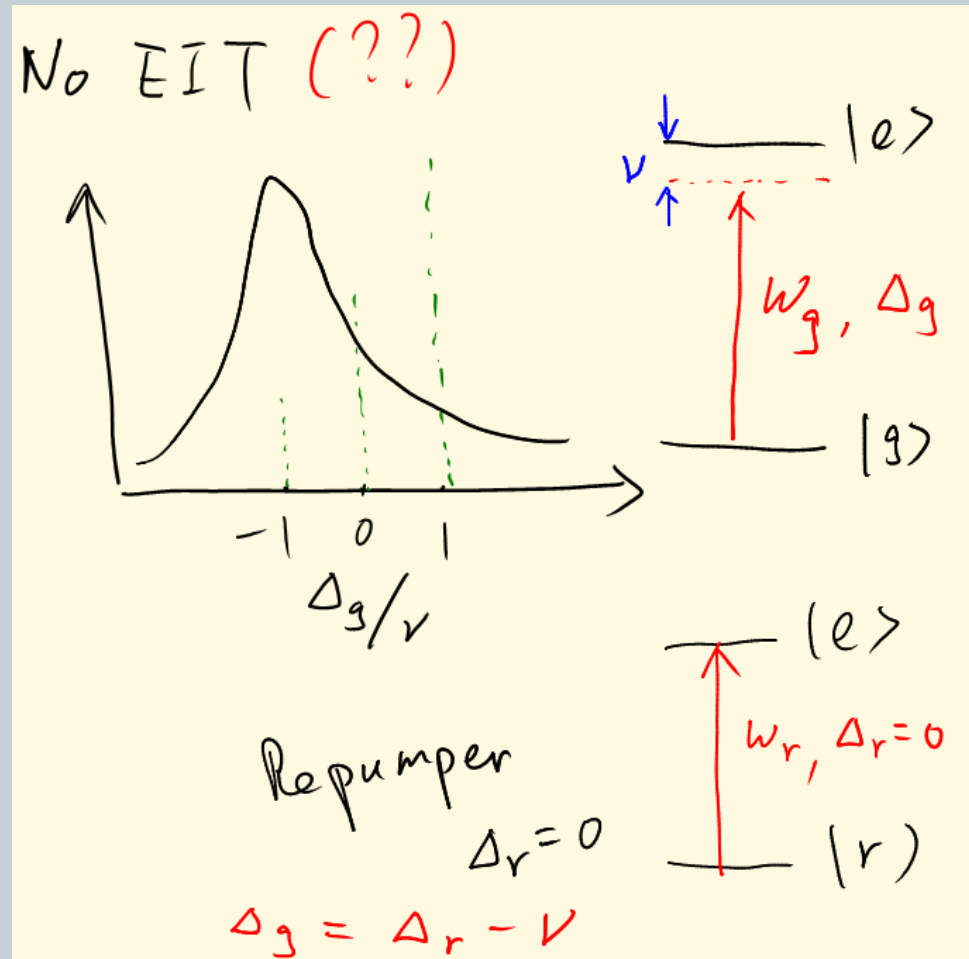
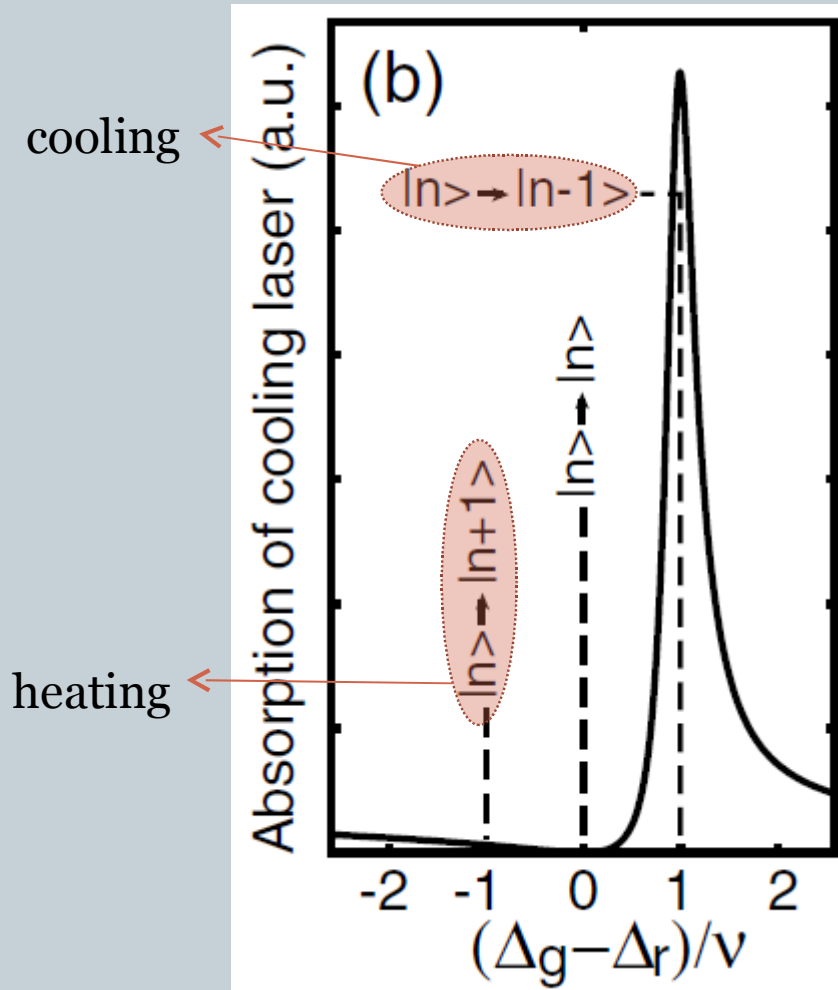
being the ac Stark shift induced by the coupling laser.

Then, by choosing $\Delta_r > 0$ and a suitable Rabi frequency Ω_r , the spectrum can be designed such that the $|g, n\rangle \rightarrow |e, n-1\rangle$ (red) sideband corresponds to the maximum of the narrow resonance, whereas the blue sideband falls into the region of the spectrum of small excitation probability, as shown in Fig. 1b. The condition on the laser parameters for enhancing the red-sideband absorption while eliminating the carrier is therefore

$$\Delta_g = \Delta_r; \quad \delta \simeq \nu. \quad (2)$$



Imbalance between cooling and heating



Dashed lines: coupling strength

Experiment: Ion trap

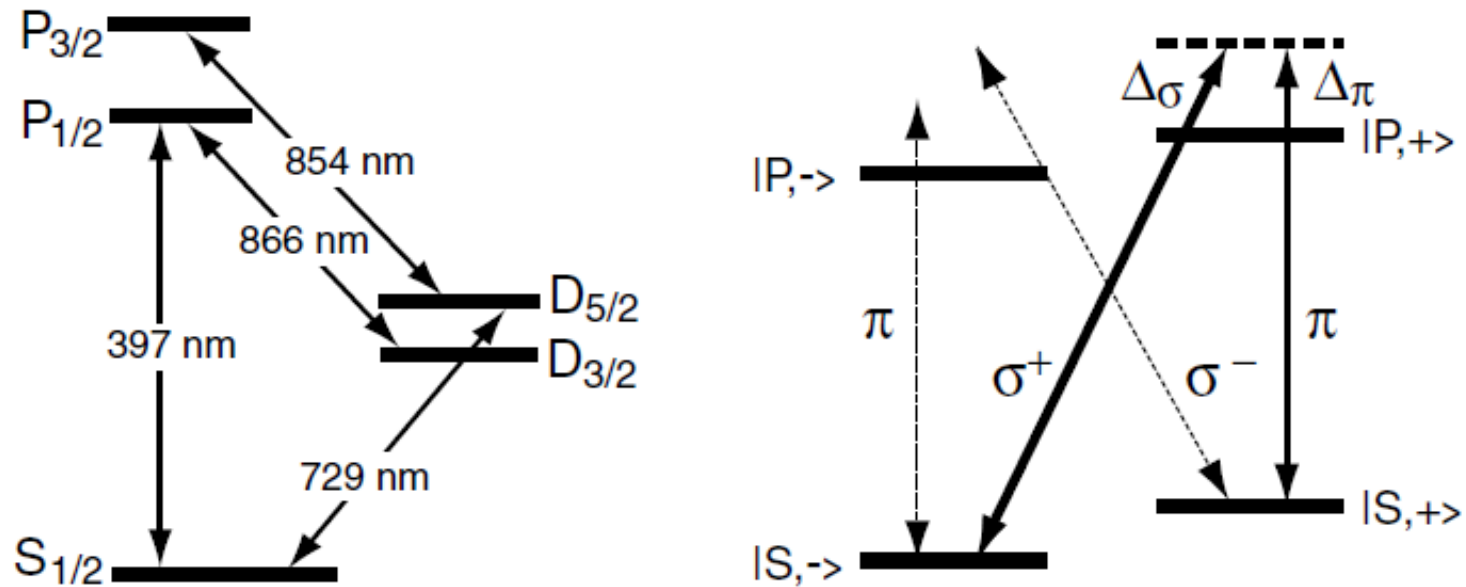


FIG. 1. Levels and transitions in $^{40}\text{Ca}^+$ used in the experiment (left). Zeeman sublevels of the $S_{1/2}$ and $P_{1/2}$ states and lasers relevant for the cooling (right). The σ^- light arises from the π laser beam not being orthogonal to the quantization axis. For EIT cooling, $\Delta\pi = \Delta\sigma$.

Experiment results

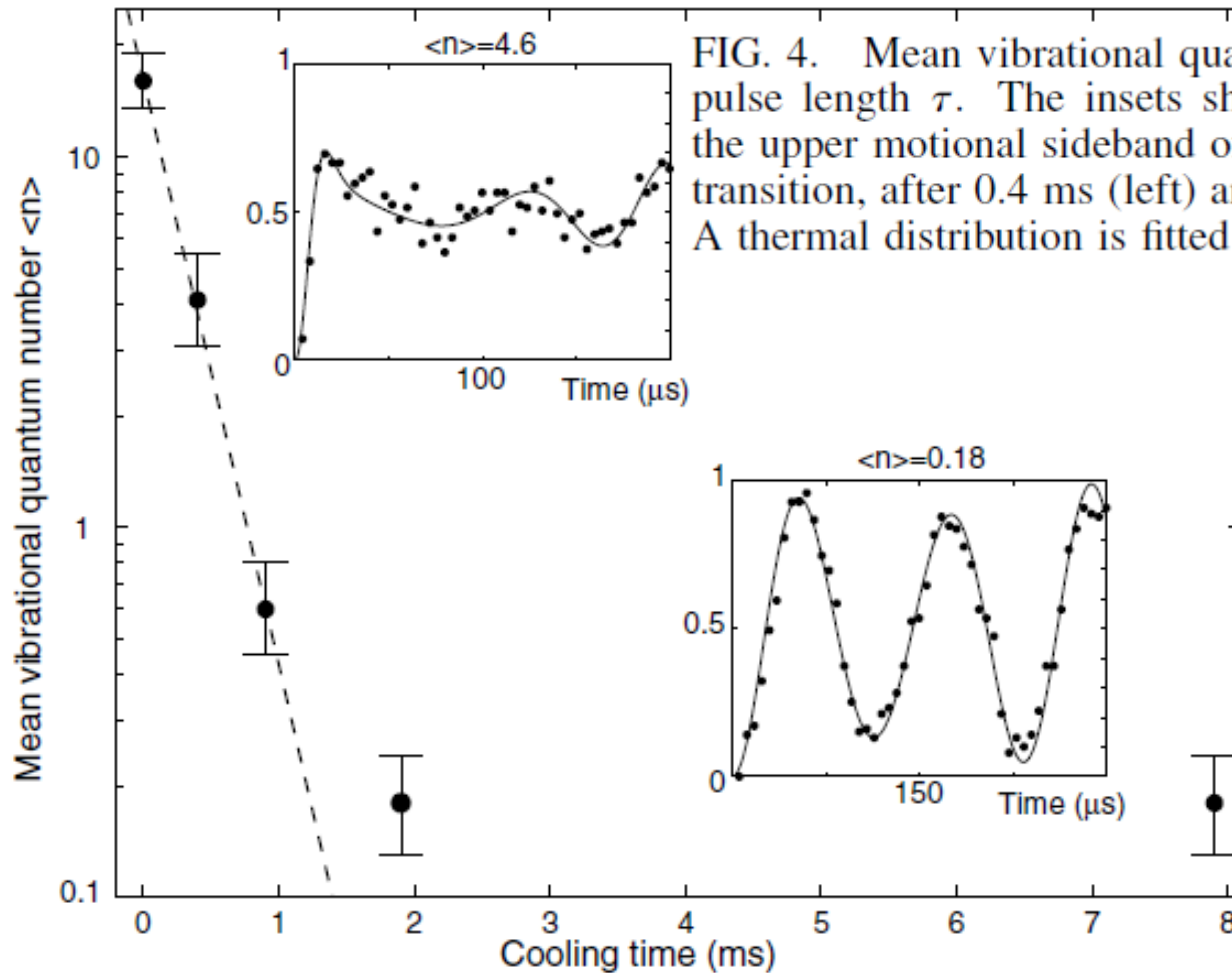
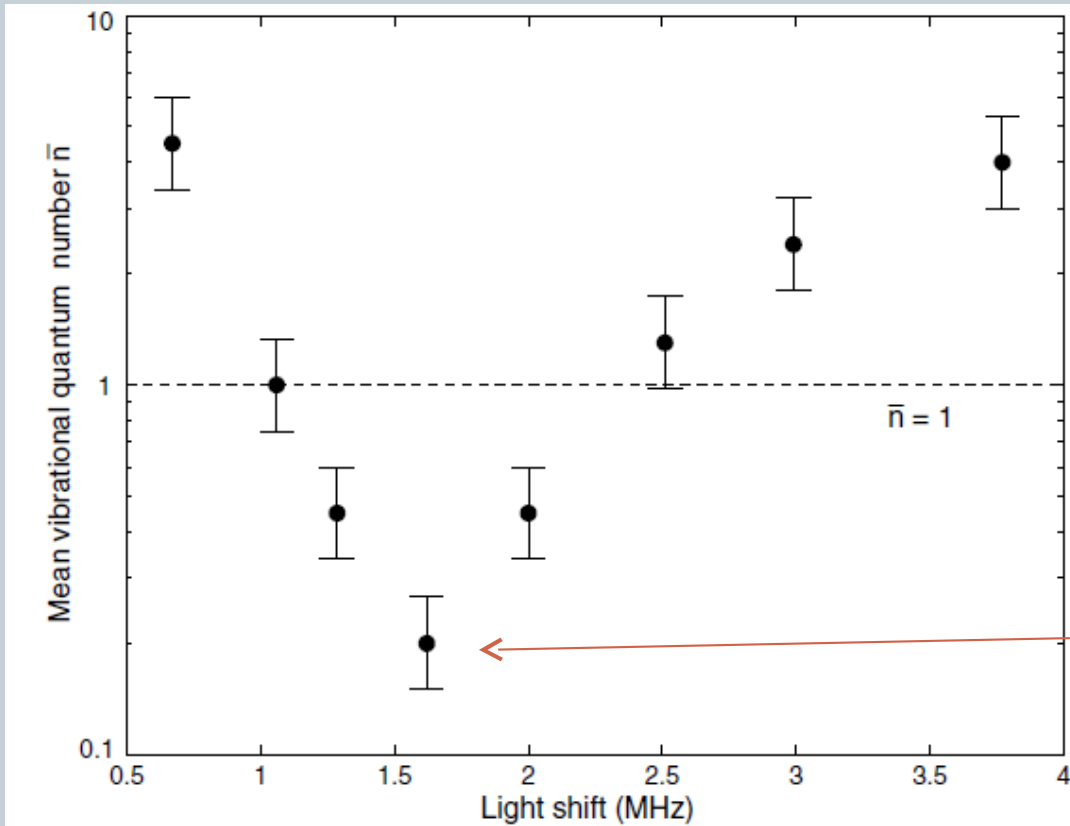


FIG. 4. Mean vibrational quantum number \bar{n}_y vs EIT cooling pulse length τ . The insets show Rabi oscillations excited on the upper motional sideband of the $|S, +\rangle \rightarrow D_{5/2}(m = +5/2)$ transition, after 0.4 ms (left) and 7.9 ms (right) of EIT cooling. A thermal distribution is fitted to the data to determine \bar{n}_y .

Experiment results



$$\delta = \nu$$

FIG. 3. Mean vibrational quantum number \bar{n}_y vs ac Stark shift $\delta/2\pi$, after 7.9 ms of EIT cooling (starting from a thermal distribution with $\bar{n}_y = 16$).

To sum up



- Better than Raman sideband cooling, two level sideband cooling....
- Must be **blue** detuned! And $\Delta_g = \Delta_r; \quad \delta = \nu$
- while Raman sideband can be either blue or red detuned and requires $\Delta_g = \Delta_r - \nu$
- Recent paper also say it's possible in far from the Lamb-Dicke limit, while sideband cooling requires the Lamb-Dicke limit

Thank you!