Ladder-type electromagnetically induced transparency with optical pumping effect

$$: National Science Council, Taiwan

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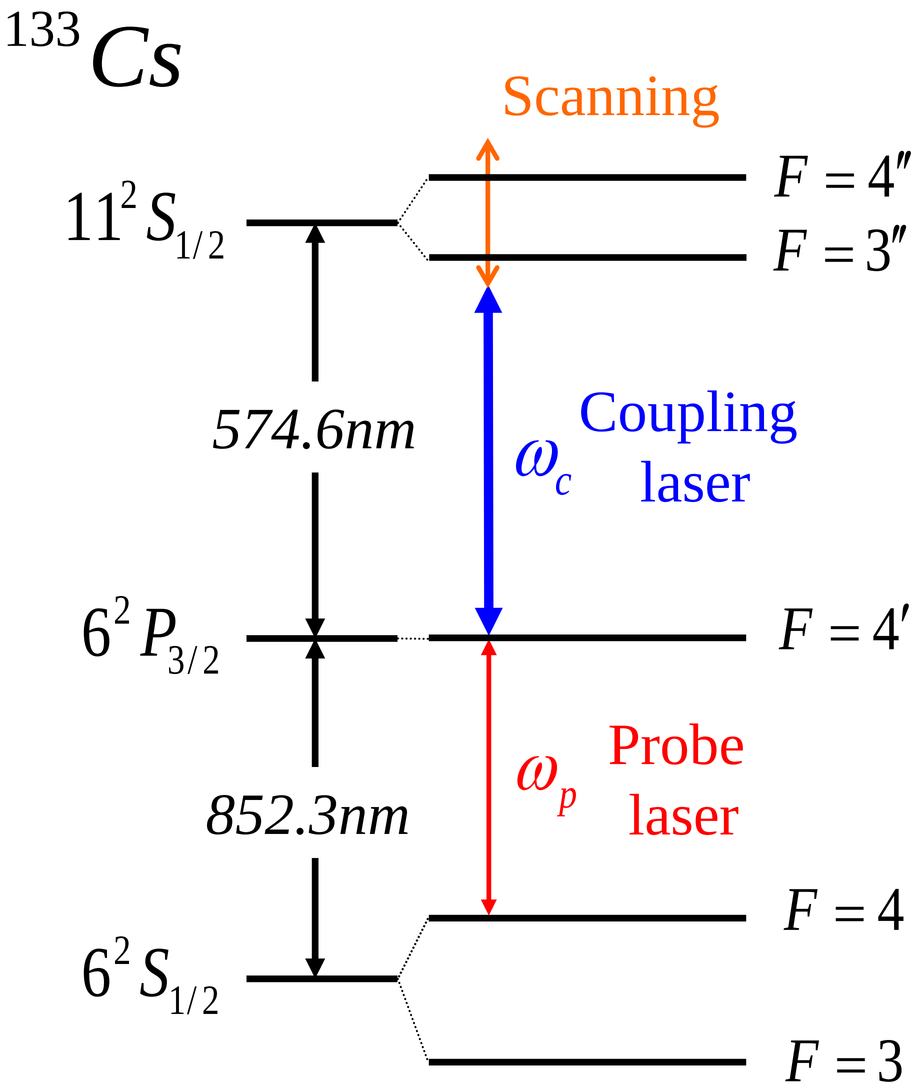
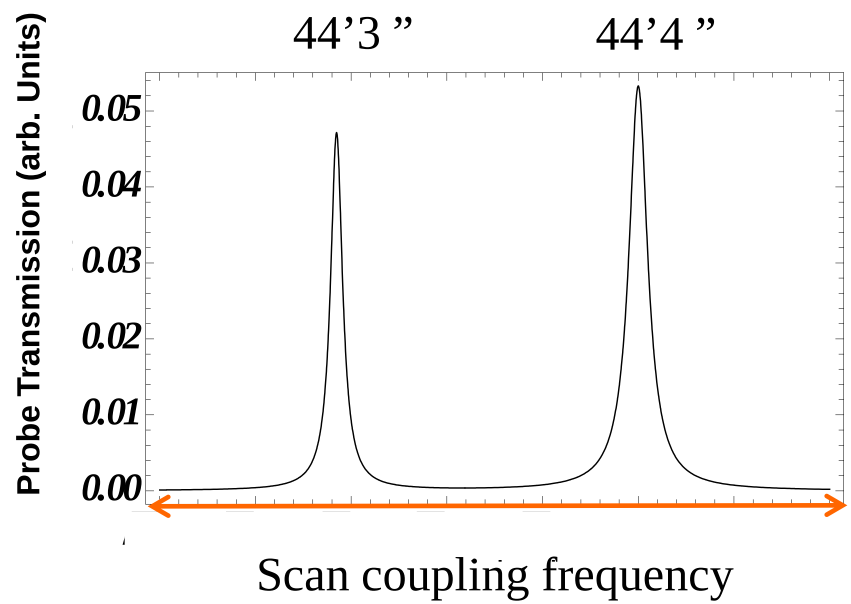
Outline

- Overview
- Introduction of EIT
- Hyperfine Structure
- Experimental Setup
- Result and Analysis
- Conclusion

Overview





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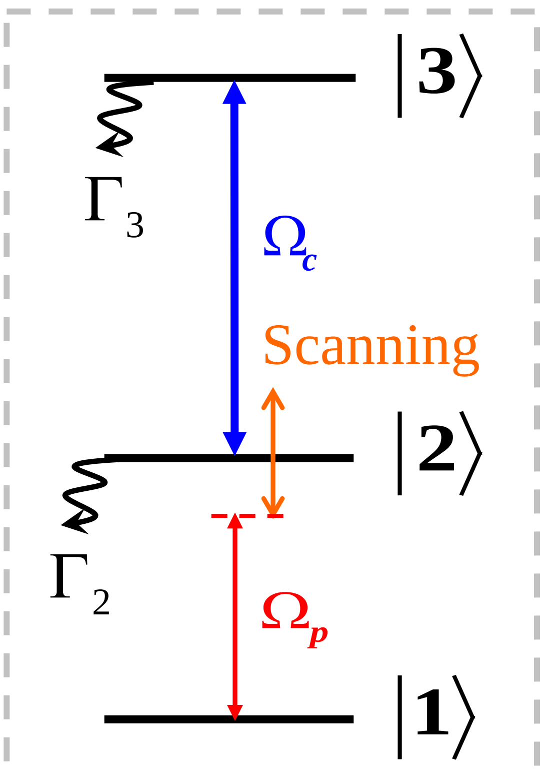
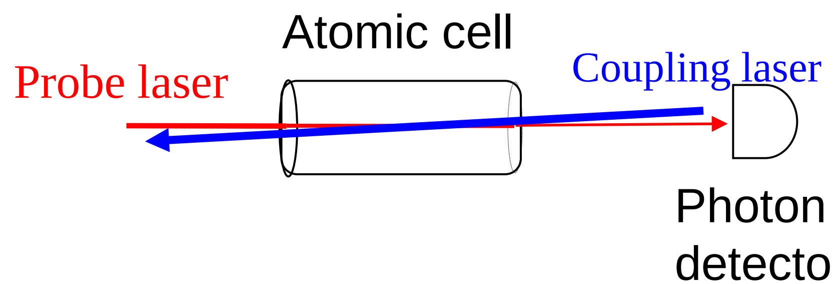
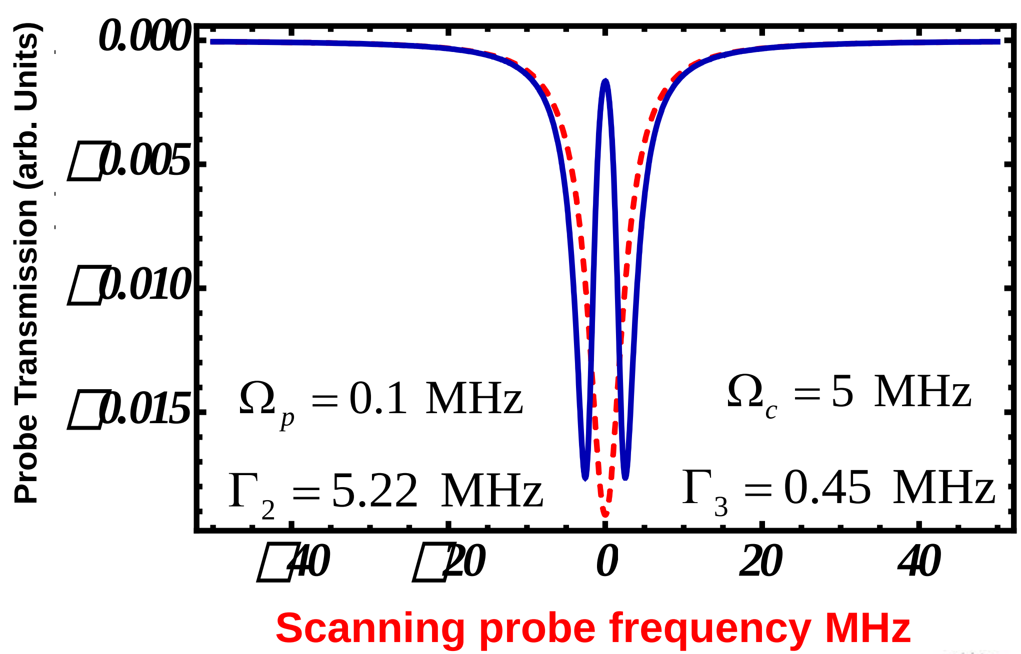
Introduction of EIT







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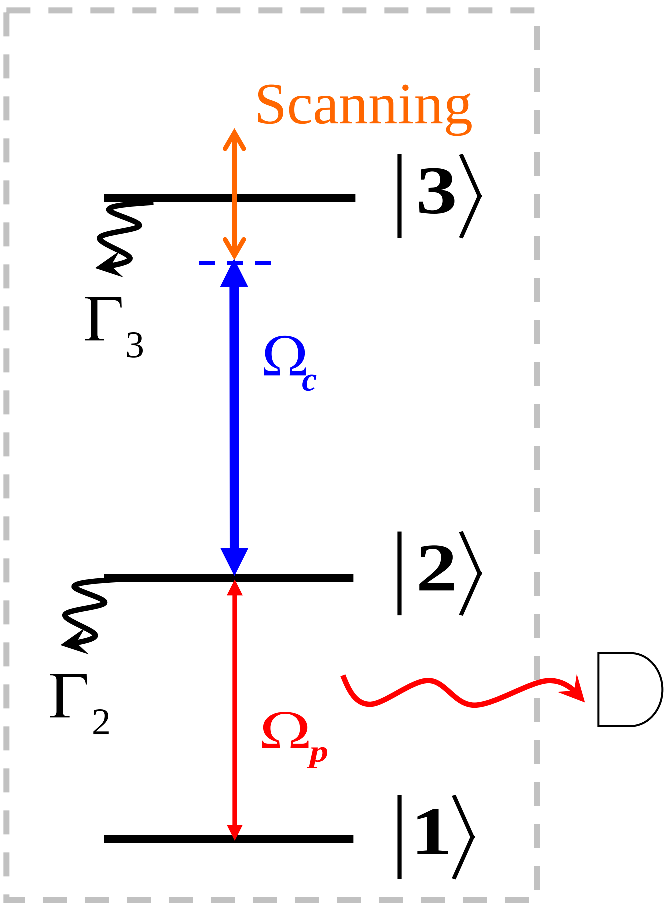
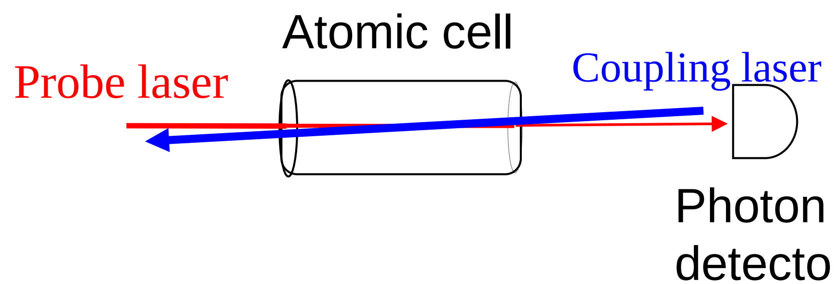
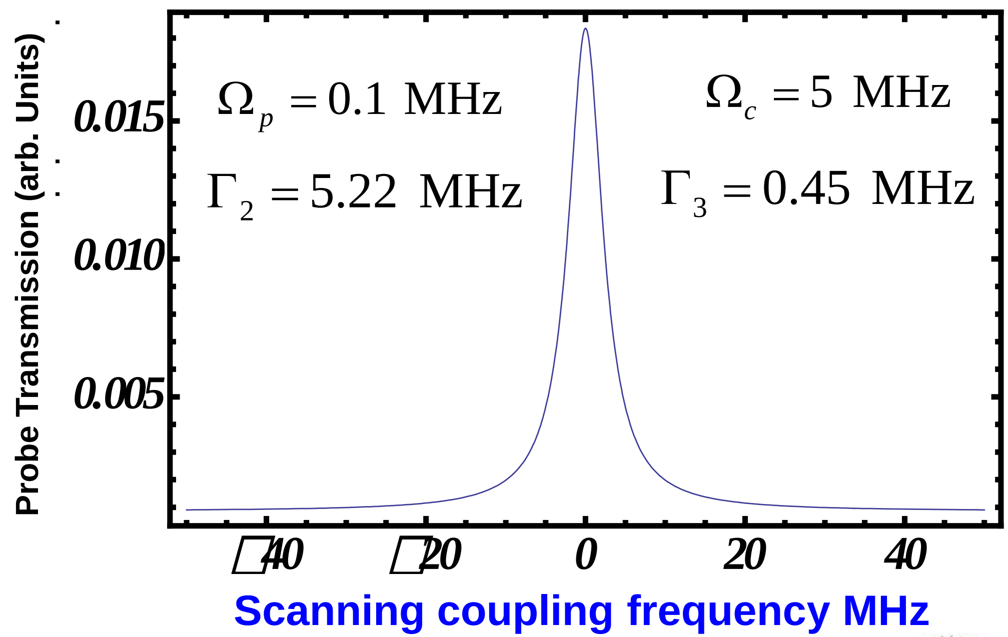
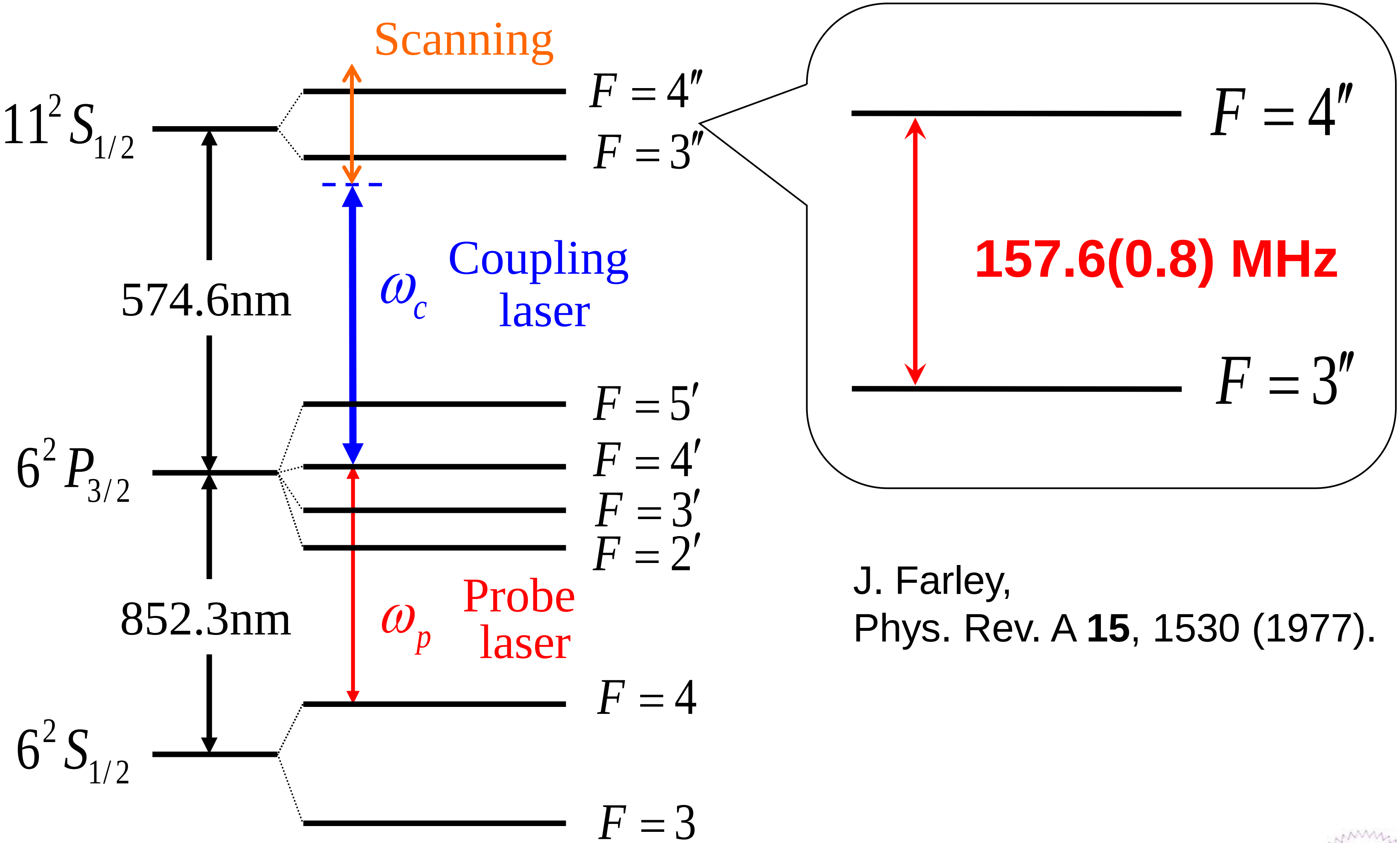
Introduction of EIT





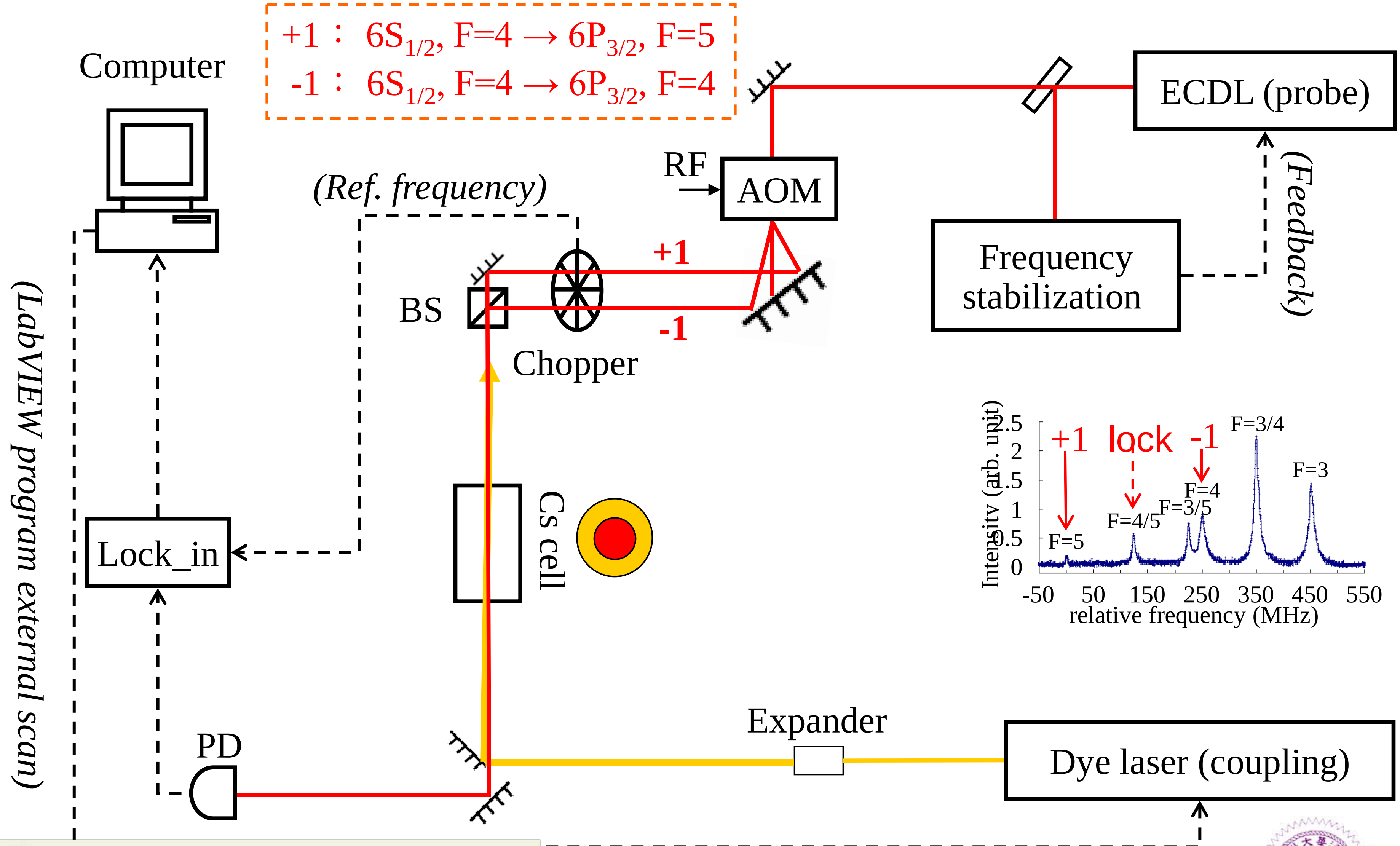


Energy Level Diagram of ^{133}Cs

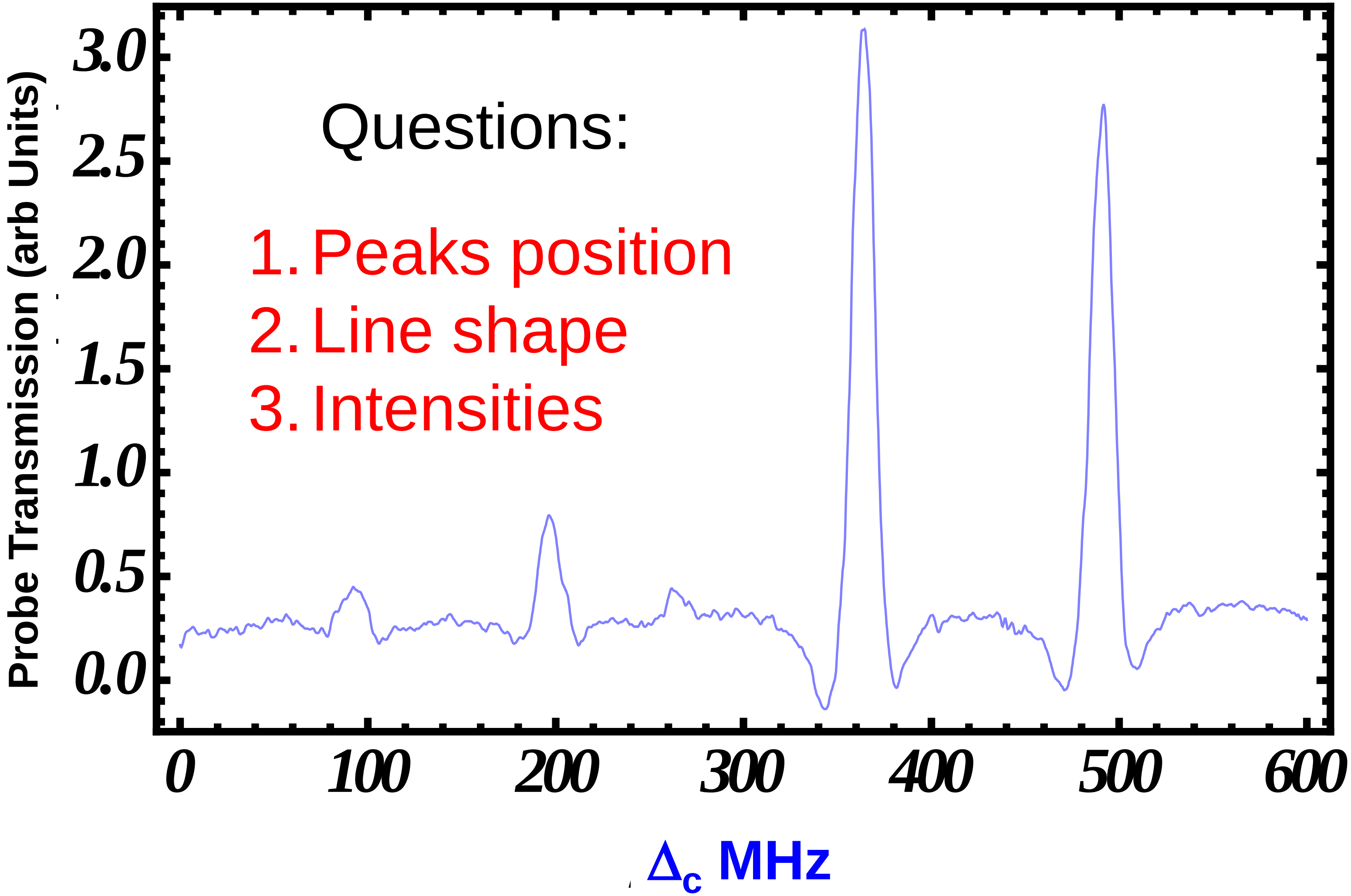


J. Farley,
Phys. Rev. A **15**, 1530 (1977).

Experimental Setup



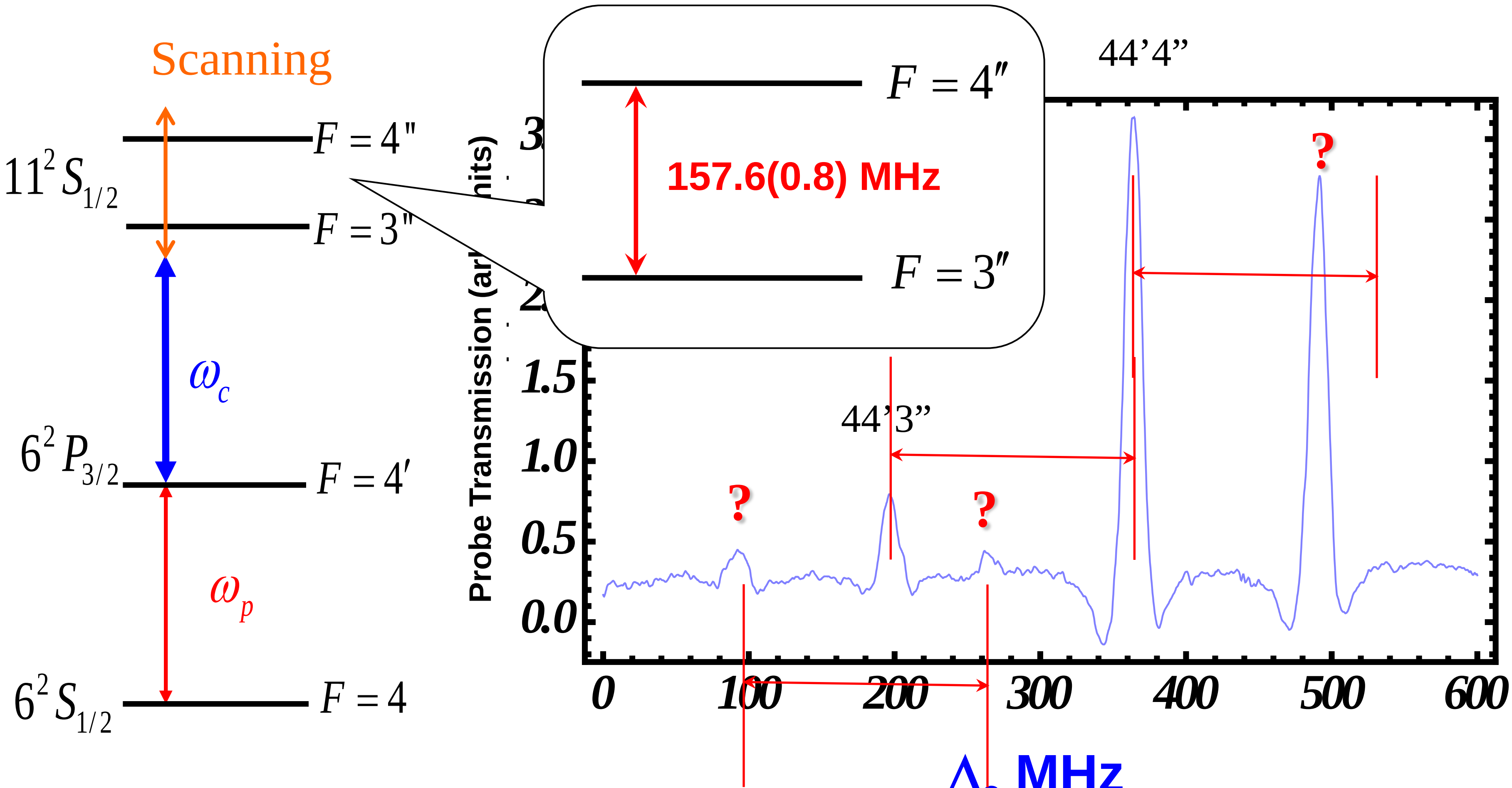
Experimental Result



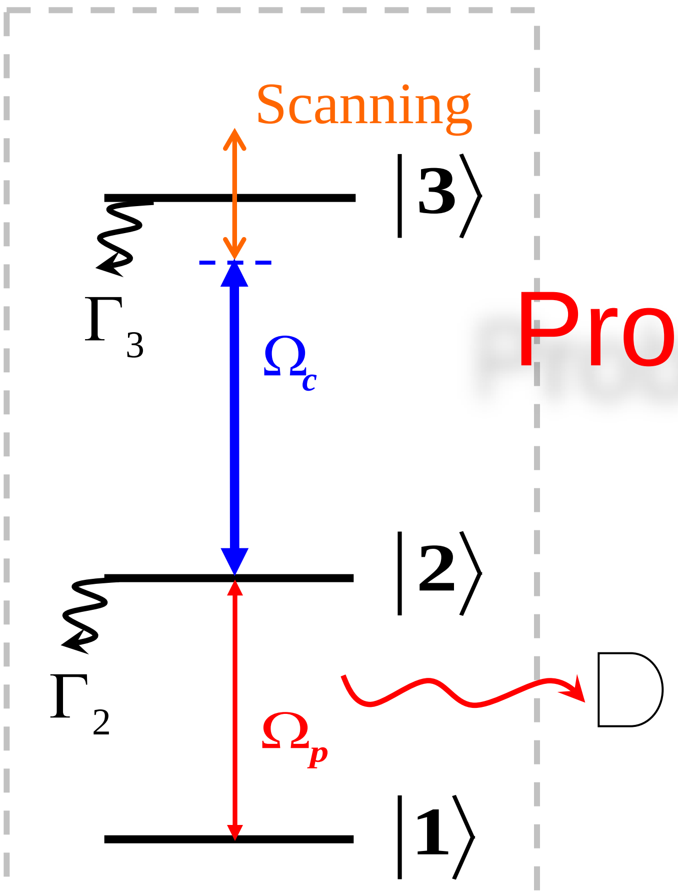
Questions:

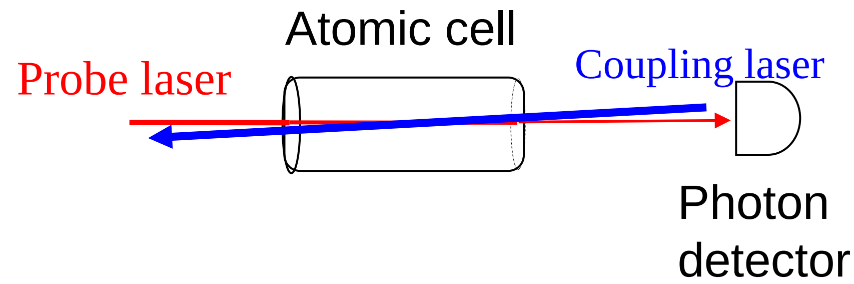
1. Peaks position
2. Line shape
3. Intensities

Experimental Result

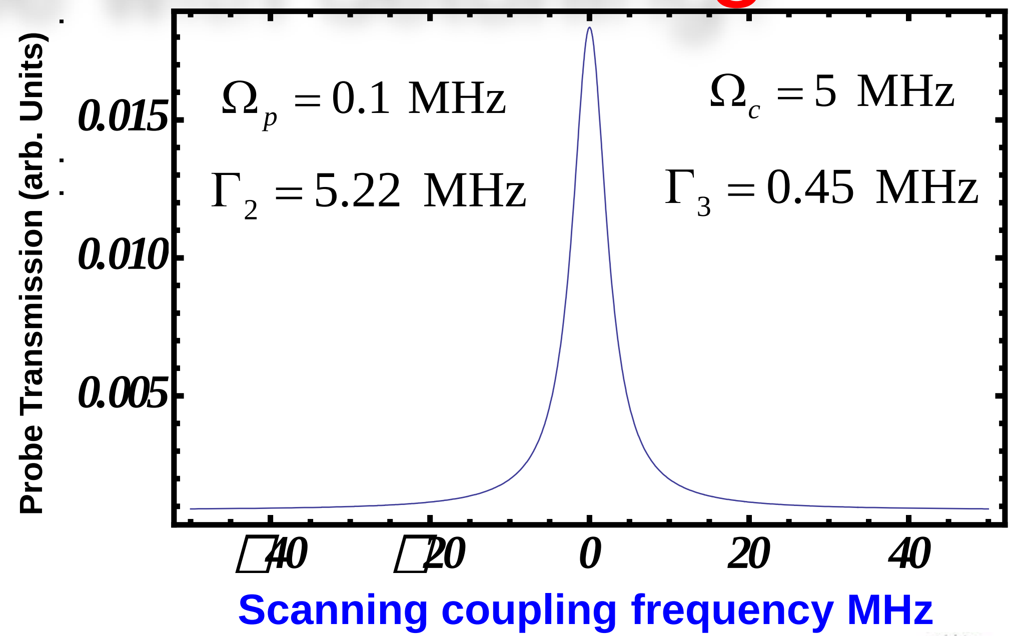


Introduction of EIT

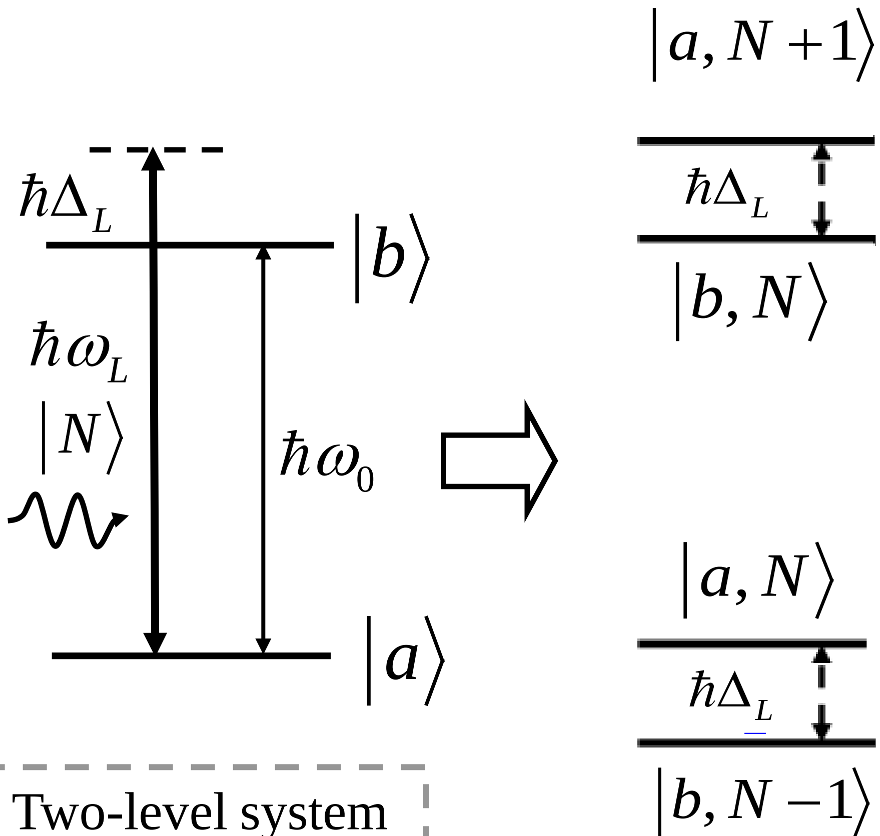




Probe with detuning?



Dressed-State Approach

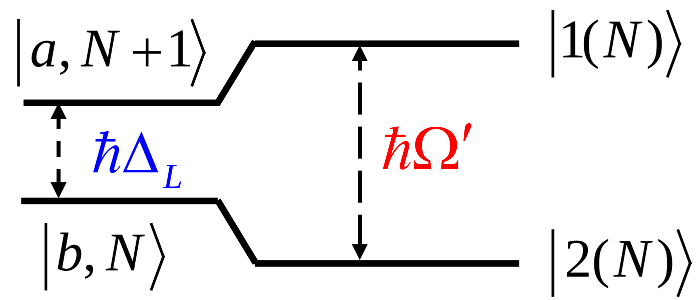


Two-level system
+
Quantized field

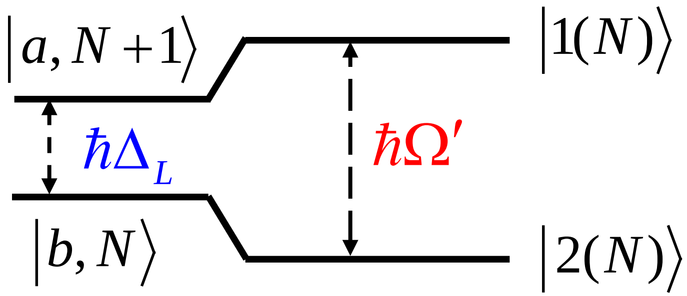
Uncoupled states

$$\upsilon_N = \langle b, N | V_{AL} | a, N+1 \rangle = \frac{\hbar\Omega_L}{2}$$

$$\boxed{\hbar\Omega' = \hbar\sqrt{\Delta_L^2 + \Omega_L^2}}$$



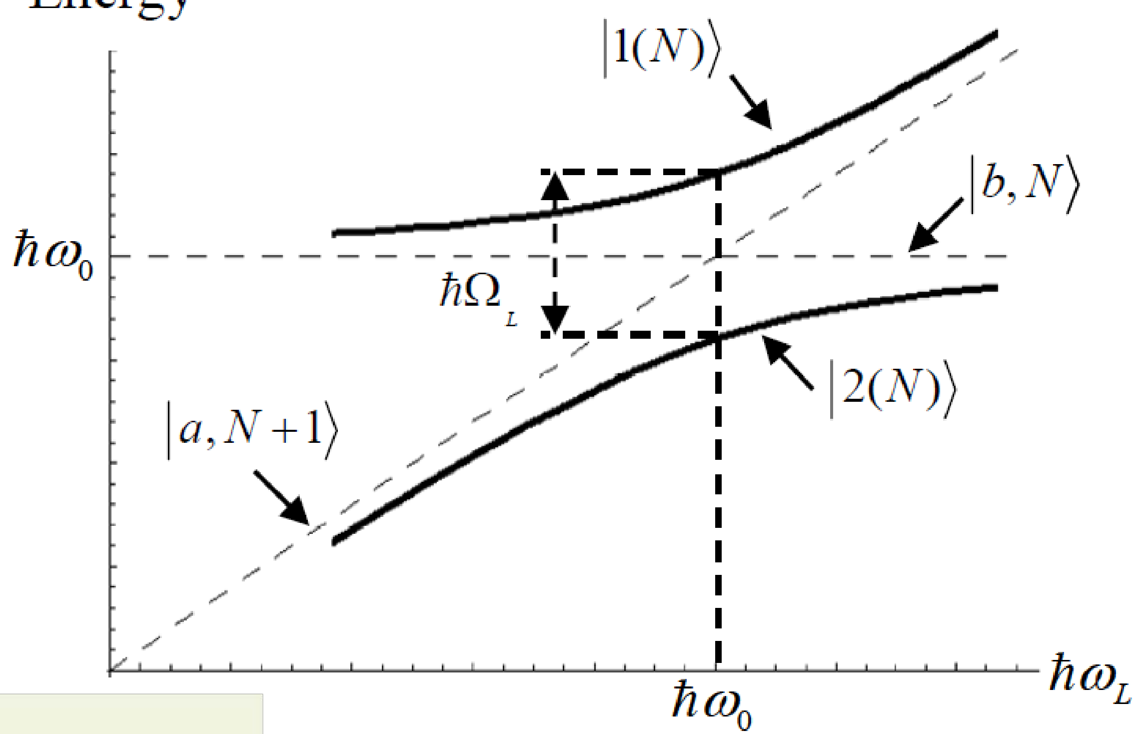
Dressed-State Approach



$|1(N)\rangle = \sin\theta\,|a, N+1\rangle + \cos\theta\,|b, N\rangle$

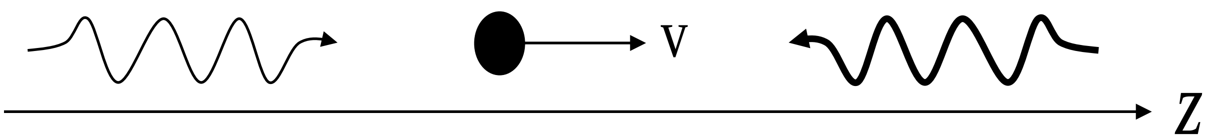
$|2(N)\rangle = \cos\theta\,|a, N+1\rangle + \sin\theta\,|b, N\rangle$

$\theta = 1/2 \tan^{-1}(\Omega_L/\Delta_L)$



Wavelength Mismatching Factor

$$\omega_p' = \omega_p(1 - \frac{v}{c}) \qquad \qquad \omega_c' = \omega_c(1 + \frac{v}{c})$$



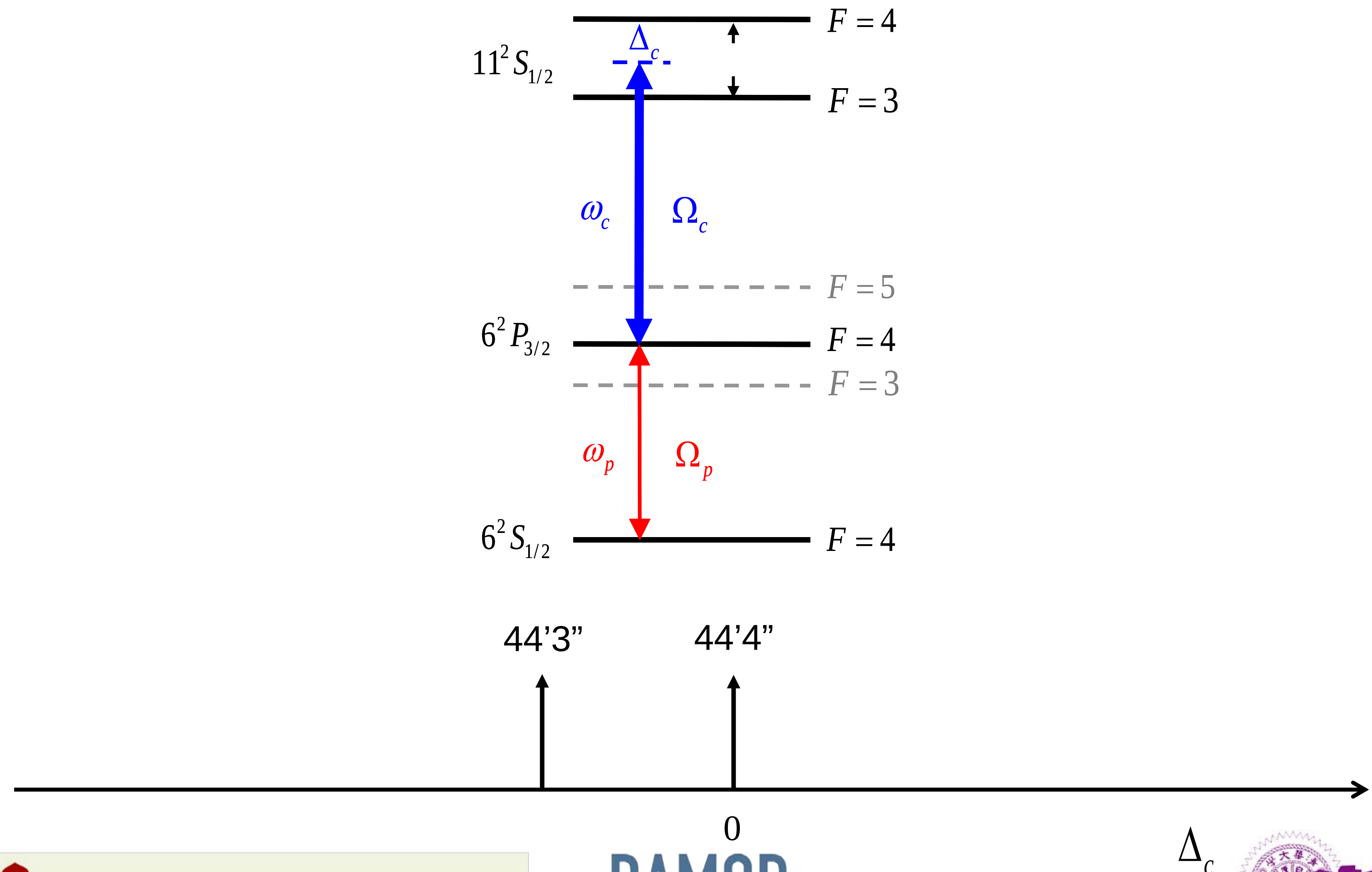
$$\Delta_p = \omega_p - \omega_p' = \omega_p \frac{v}{c}$$

$$\Delta_c = \omega_c - \omega_c' = -\omega_c \frac{v}{c}$$

$$v = \frac{\Delta_p}{\omega_p} c = -\frac{\Delta_c}{\omega_c} c$$

$$\Delta_c = -\frac{\omega_c}{\omega_p} \Delta_p = -\frac{\lambda_p}{\lambda_c} \Delta_p = \kappa \Delta_p \Rightarrow \boxed{\hbar\Omega' = \hbar\sqrt{\left(\kappa \Delta_p\right)^2 + \Omega_p^2}}$$

On Resonance EIT (44’3”& 44’4”)



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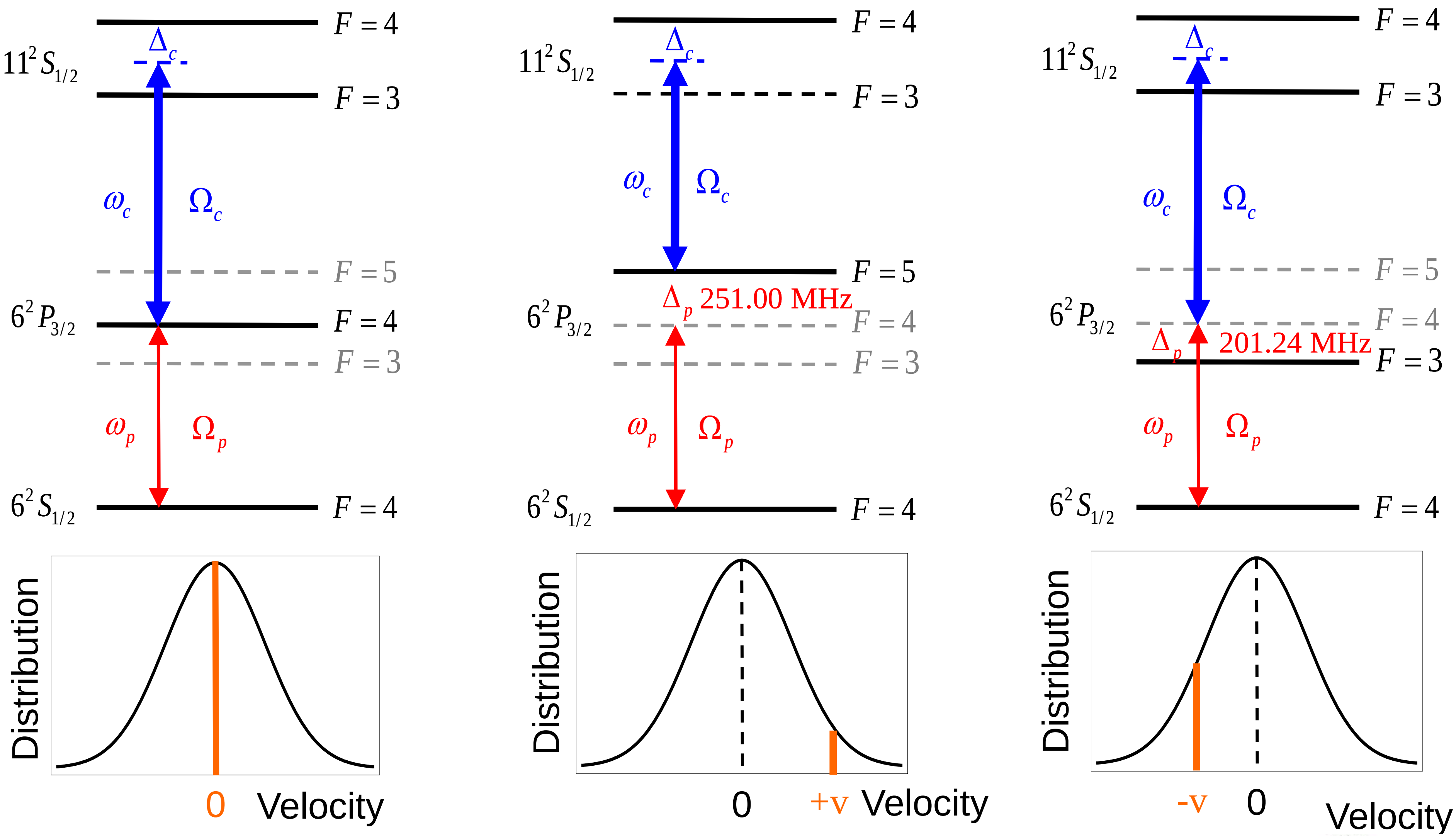
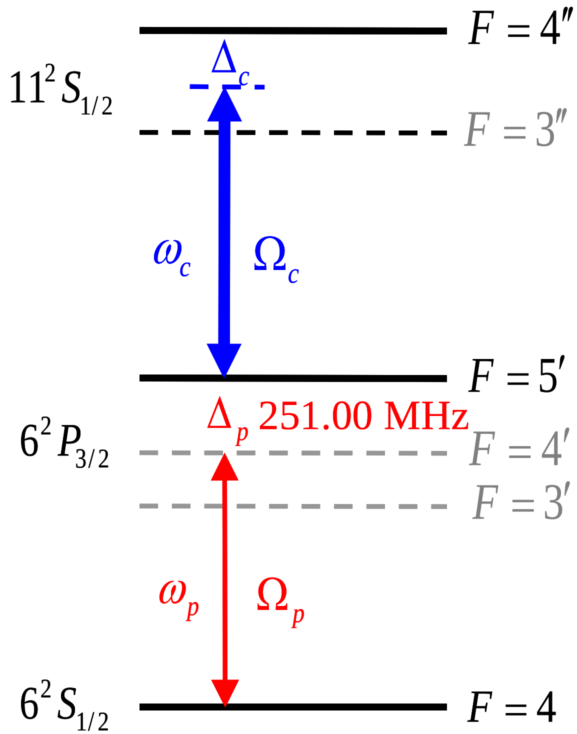
EIT in Multi-level system



Off Resonance EIT (45’4”)

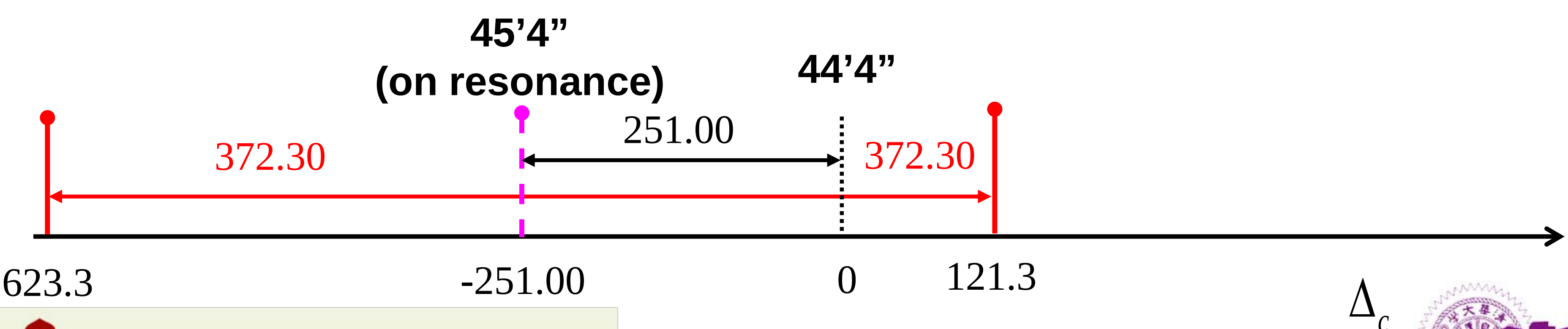


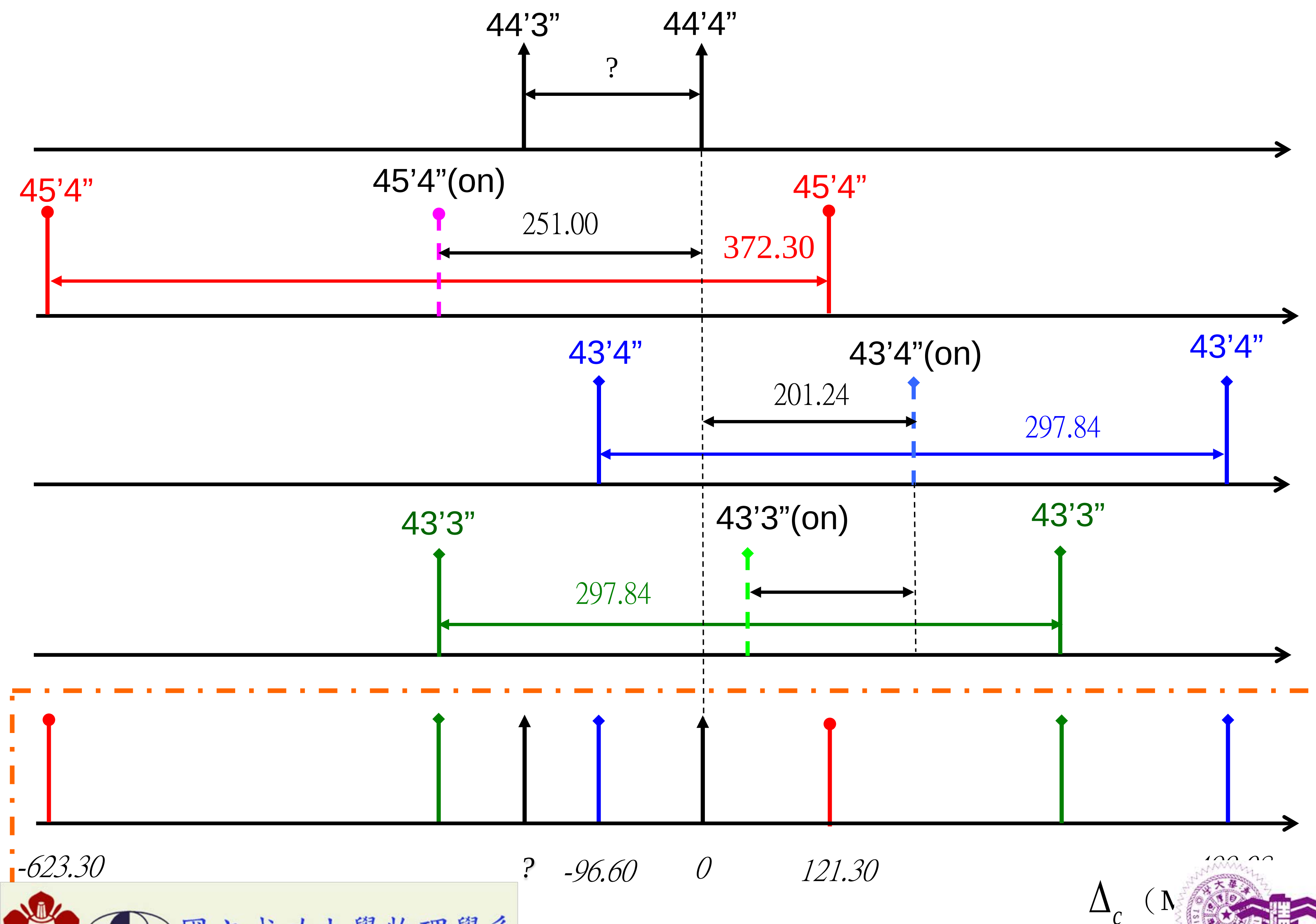
$$\Omega' = \sqrt{\left(\kappa\,\Delta_p\right)^2 + \Omega_p^2}$$

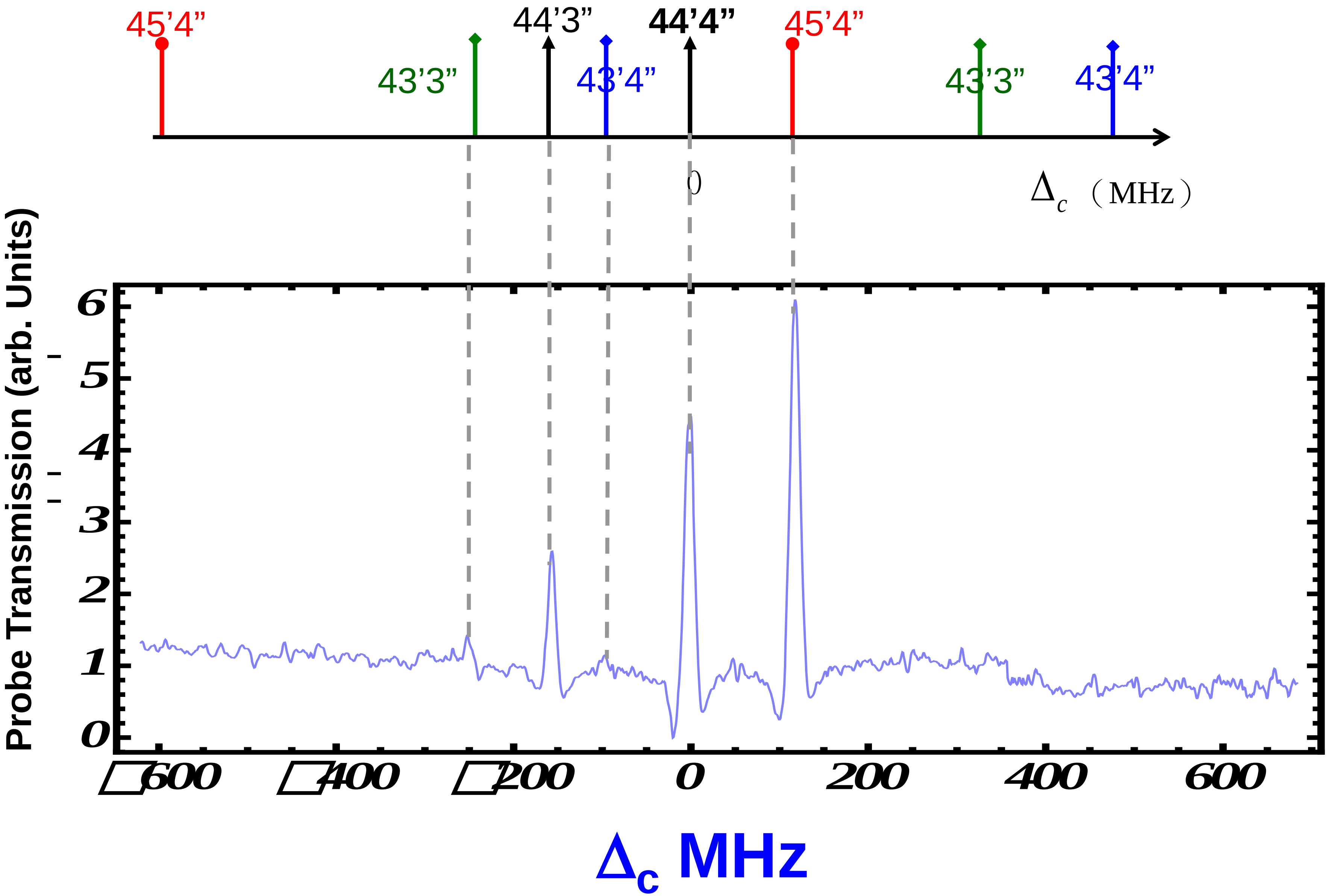
$$\kappa = \frac{\lambda_p}{\lambda_c} = \frac{17399.416}{11732.307} \approx 1.48$$

$$\Omega_5' = \sqrt{(1.48\times 251.00)^2 + 0.34^2}$$

$$\Omega_5' = 372.30\ \ MHz$$




44'3"
44'4"
?
45'4"
45'4"(on)
251.00
45'4"
372.30
43'4"
43'4"(on)
201.24
43'4"
297.84
43'3"
43'3"(on)
43'3"
297.84
-623.30
?
-96.60
0
121.30
Δ_c (M



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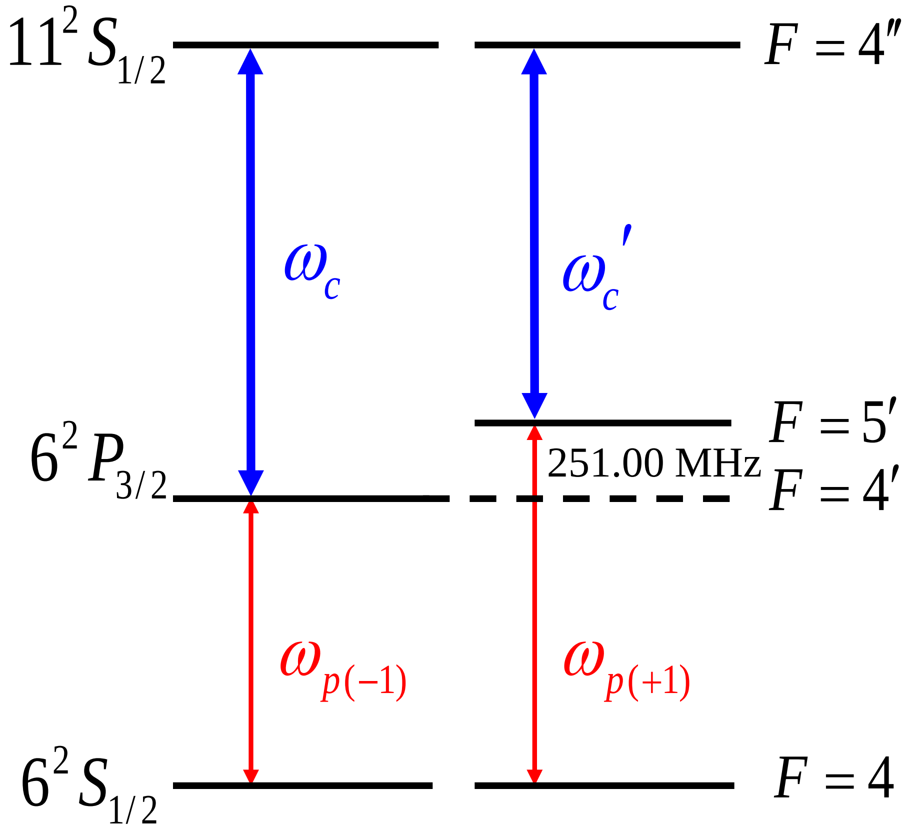
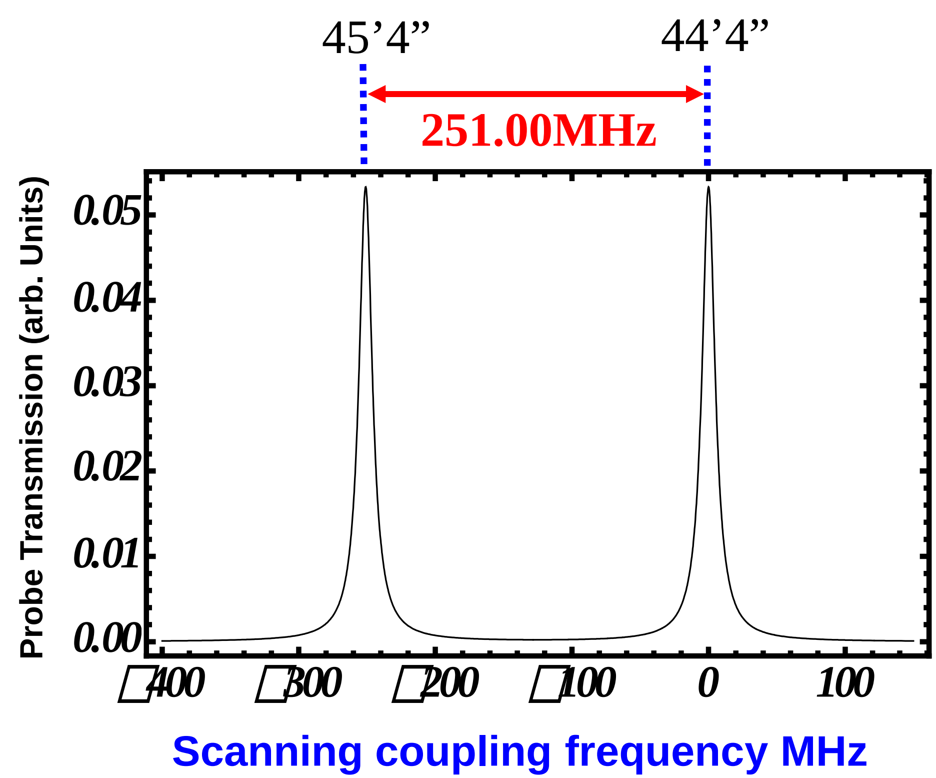
Frequency Calibration





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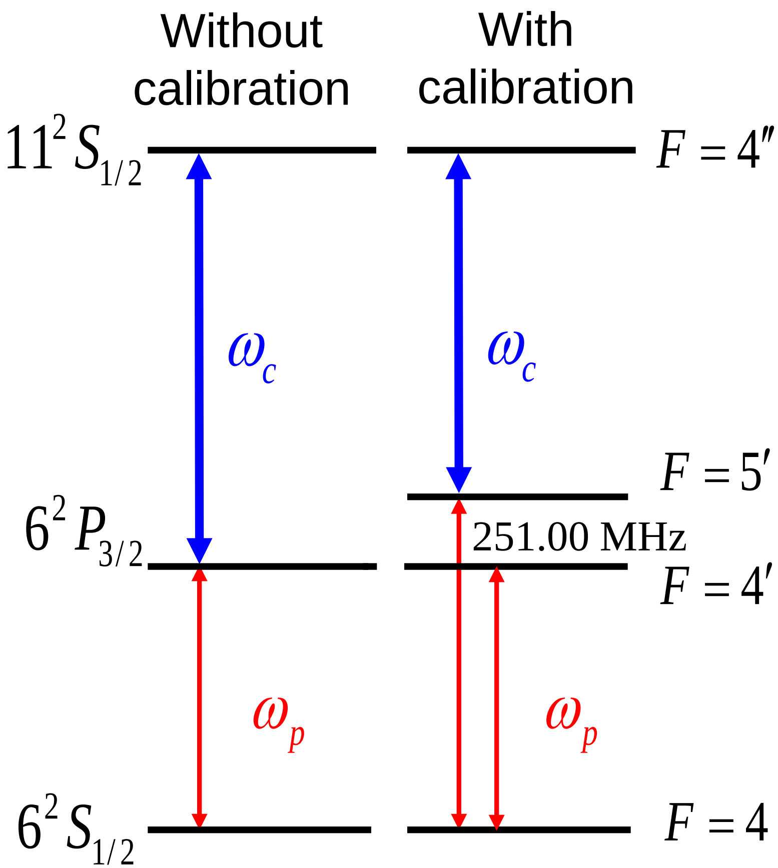
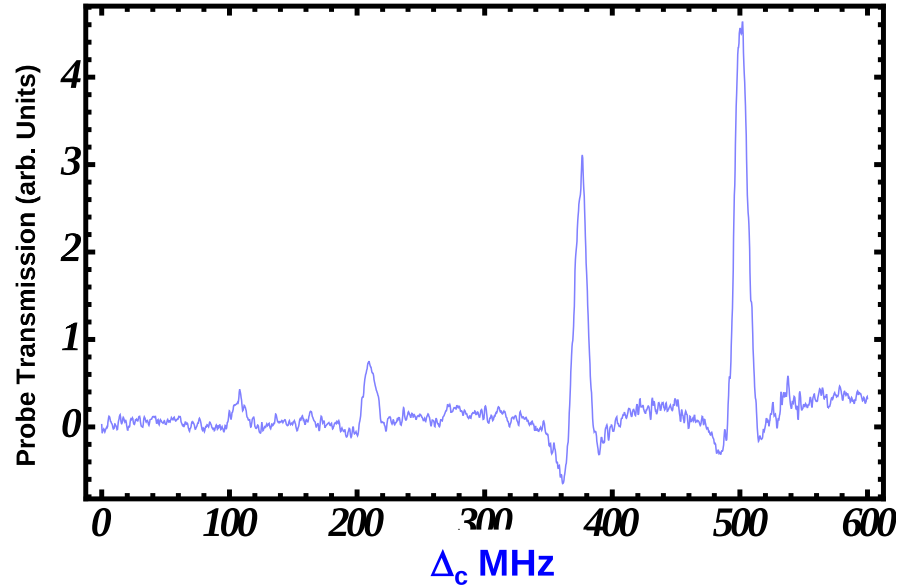
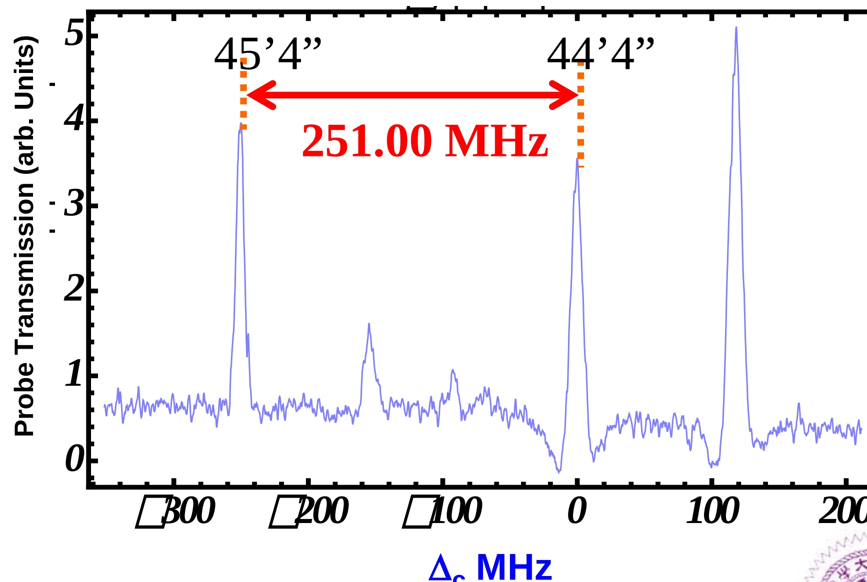
EIT Spectra with Calibration







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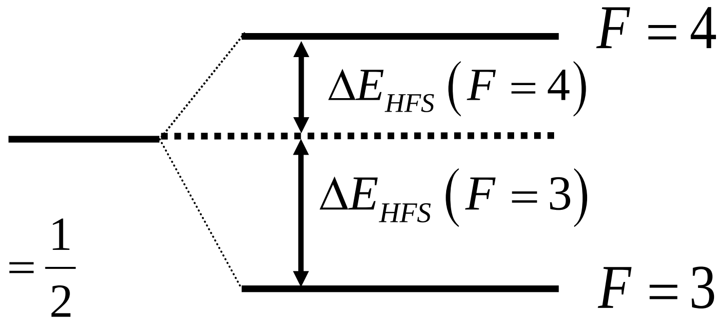
Hyperfine Structure

I、J couple $\Rightarrow$ $ns\ ^2S_{1/2}$

$I=\frac{7}{2}$, $J=\frac{1}{2}$



I ： Nucleus spin angular momentum quantum number

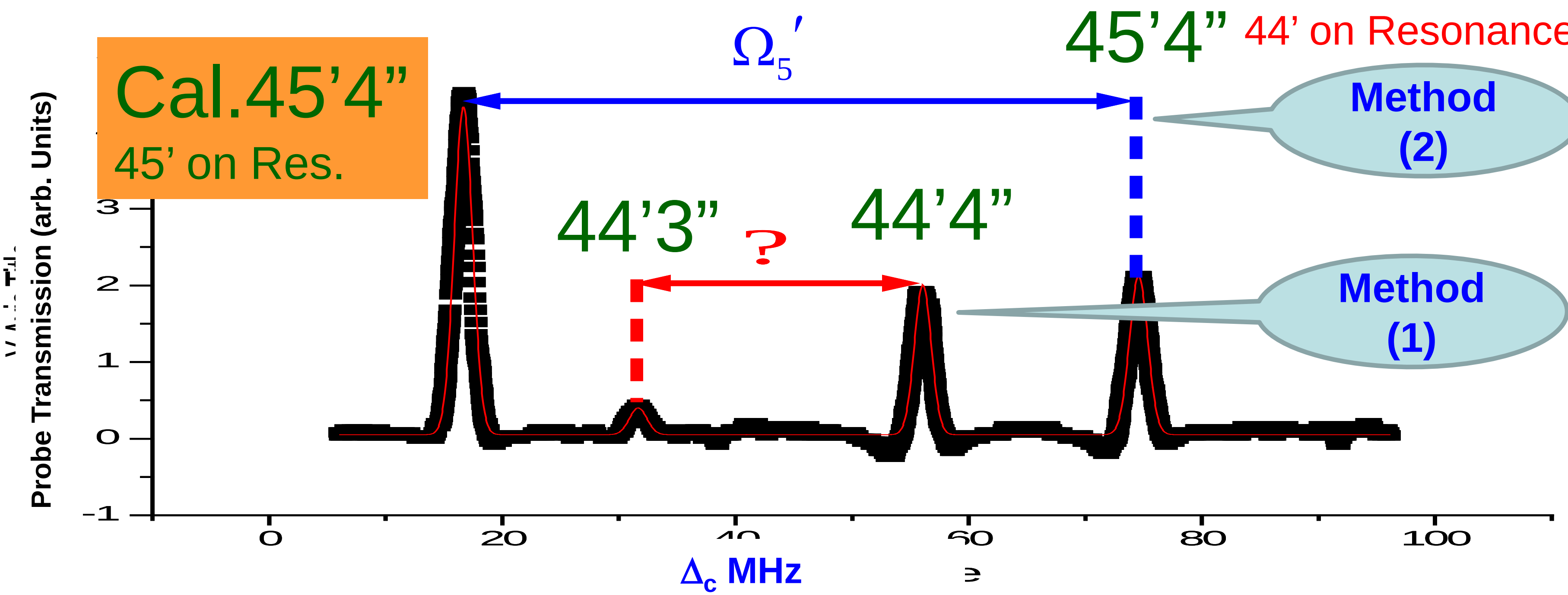
J ： Total angular momentum of electron

$F=I+J$ ： Total angular momentum of atom

No B for s State

$$\boxed{\Delta E_{HFS}=\frac{A}{2}\left[F(F+1)-I(I+1)-J(J+1)\right]+B\cdot K}$$

Hyperfine Splitting & **A** Coefficient



$$\Omega_5' = \sqrt{(1.48 \times 251.00)^2 + 0.34^2}$$

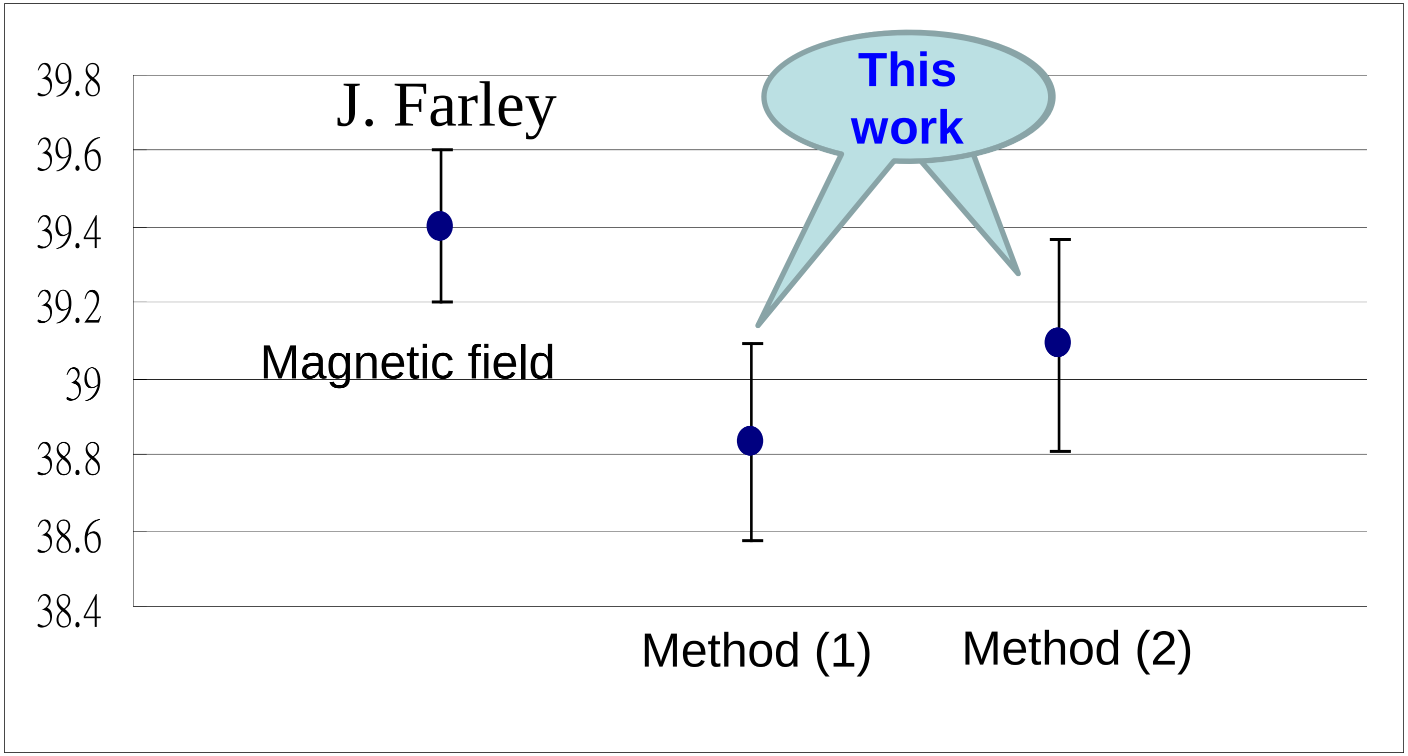
$$\Omega_5' = 372.30 \ \ MHz$$

$$\boxed{\begin{aligned} \Delta_{34} &= 156.34 \pm 1.10 MHz \\ A &= 39.09 \pm 0.28 MHz \end{aligned}}$$

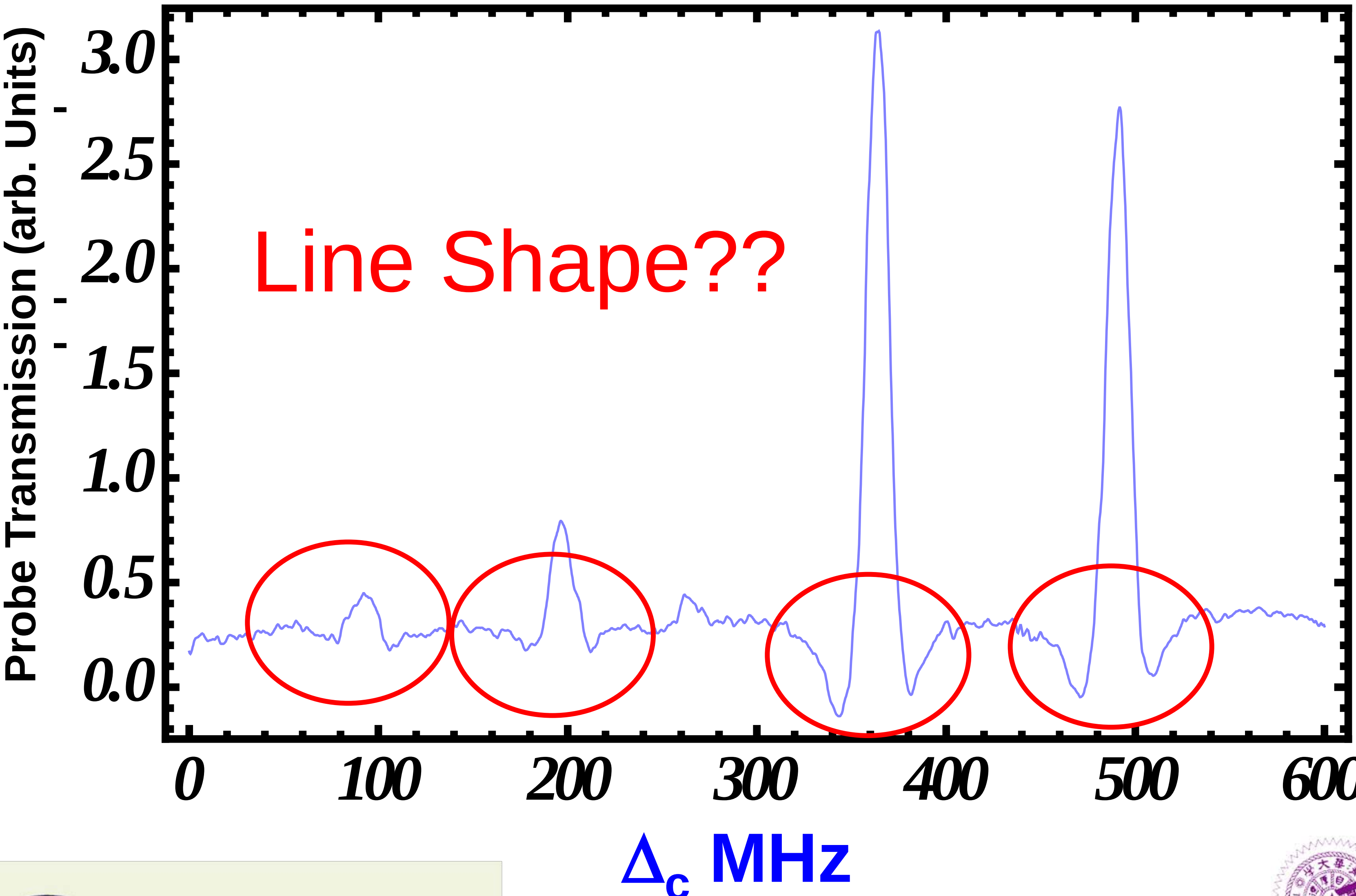
$$\Delta E_{HFS} = \frac{A}{2}\left[F(F+1) - I(I+1) - j(j+1)\right]$$

Hyperfine Splitting & **A** Coefficient

A: the magnetic dipole coupling constant



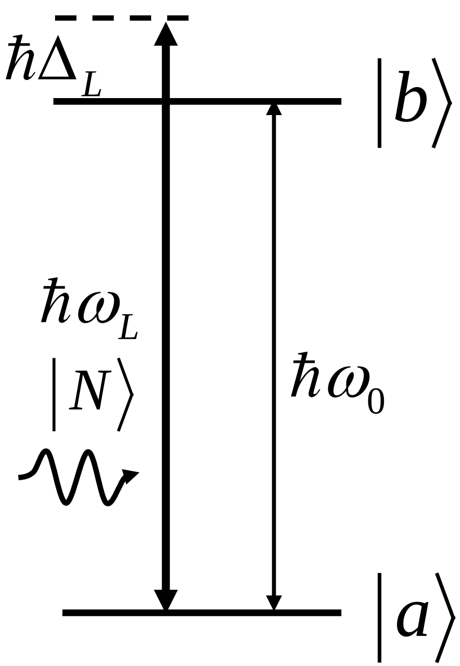
Experimental Result



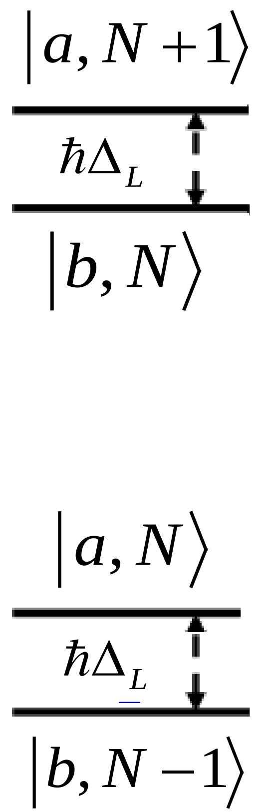
Dressed-State Approach

For a fixed probe laser frequency,
atom with different velocity “sees” different detuning.

$$\upsilon_N = \langle b, N | V_{AL} | a, N+1 \rangle = \frac{\hbar\Omega_L}{2}$$

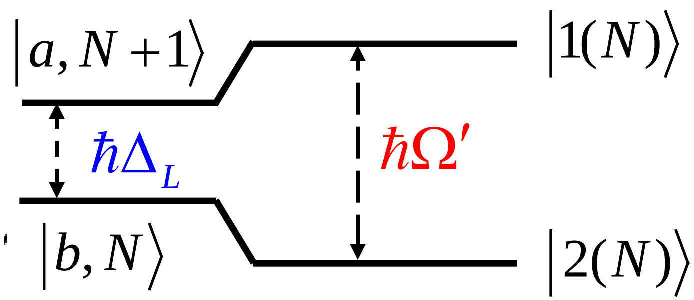


Two-level system
+
Quantized field

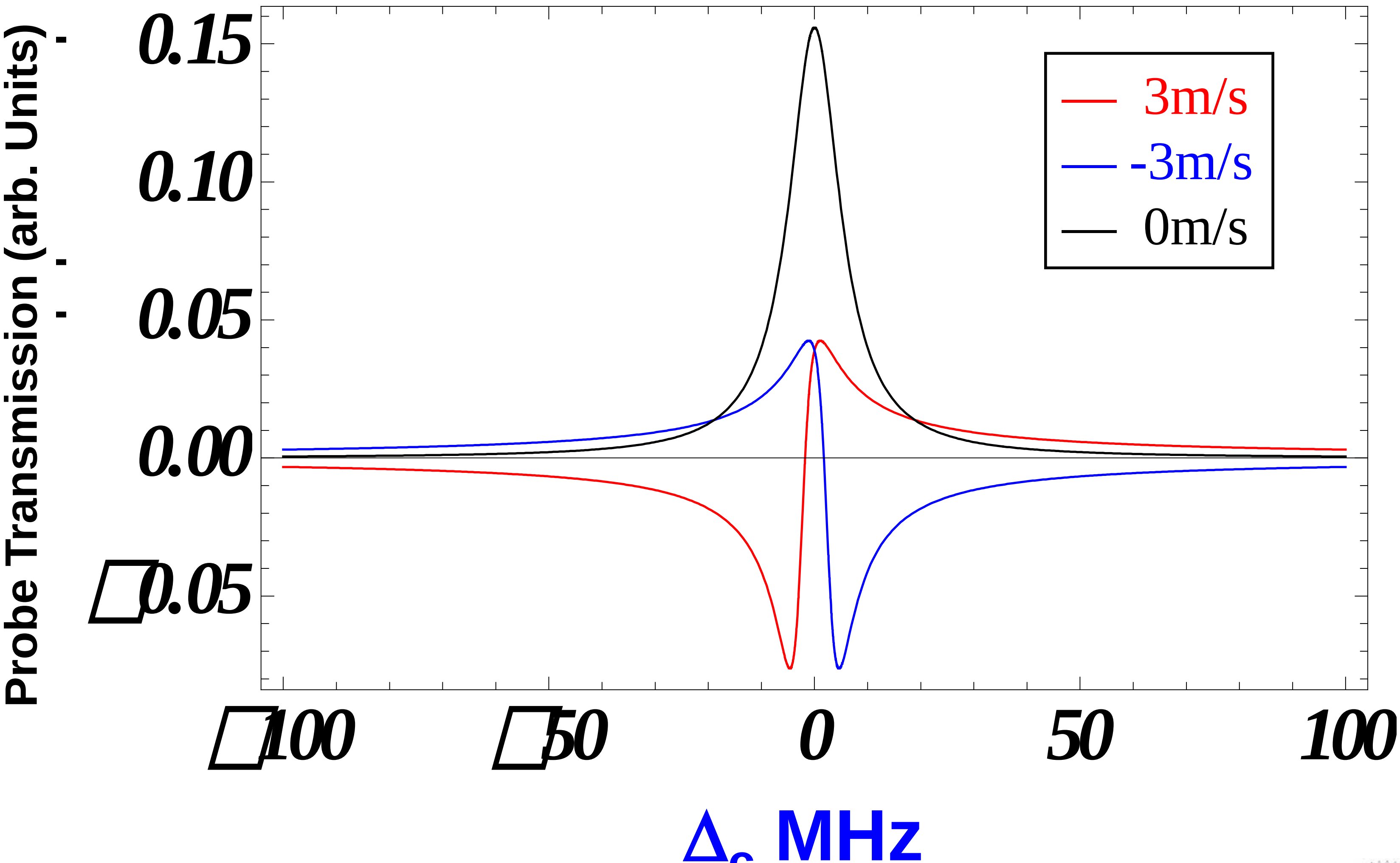


Uncoupled states

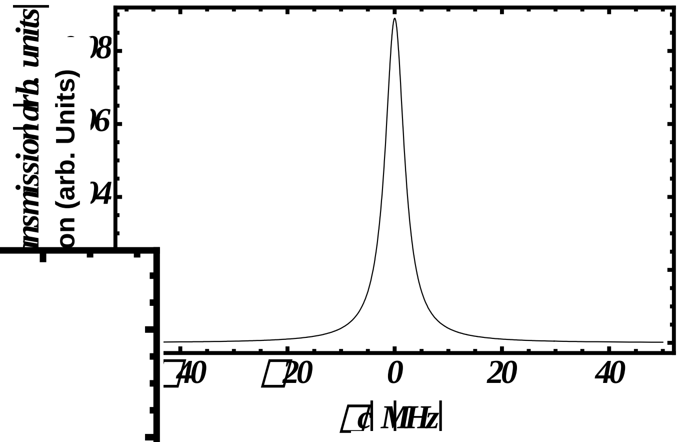
$$\boxed{\hbar\Omega' = \hbar\sqrt{\Delta_L^2 + \Omega_L^2}}$$

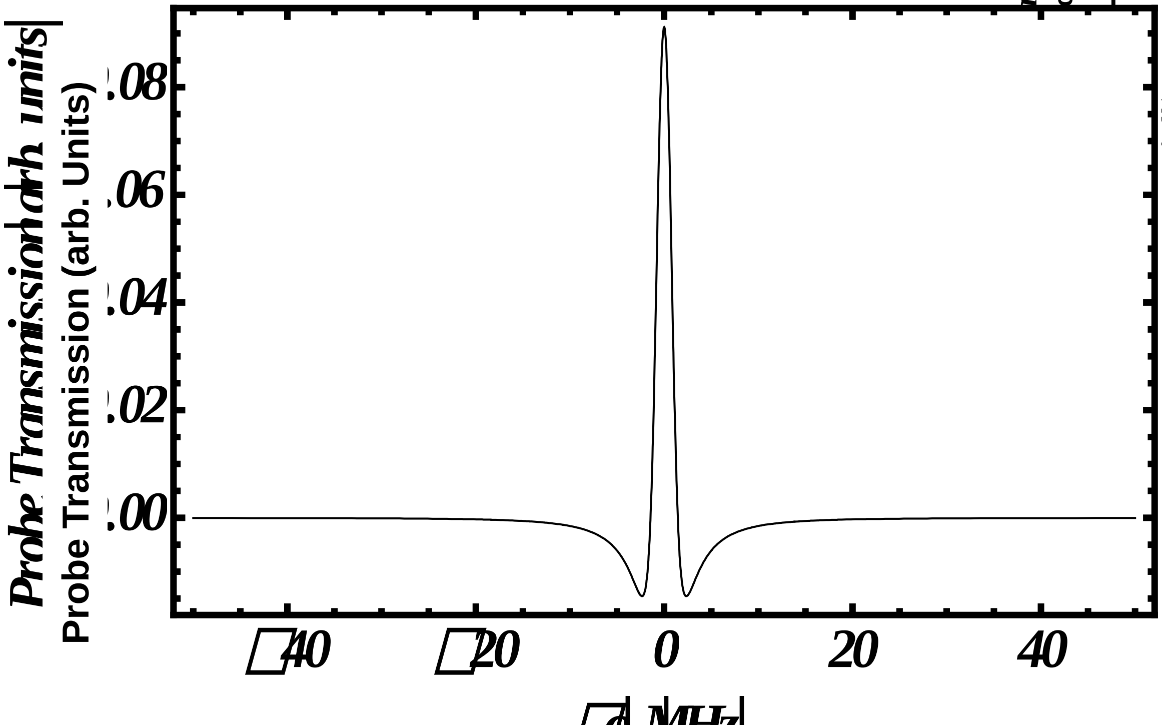


Integrate Over the Doppler Velocity Group



Integrate Over the Doppler Velocity Group



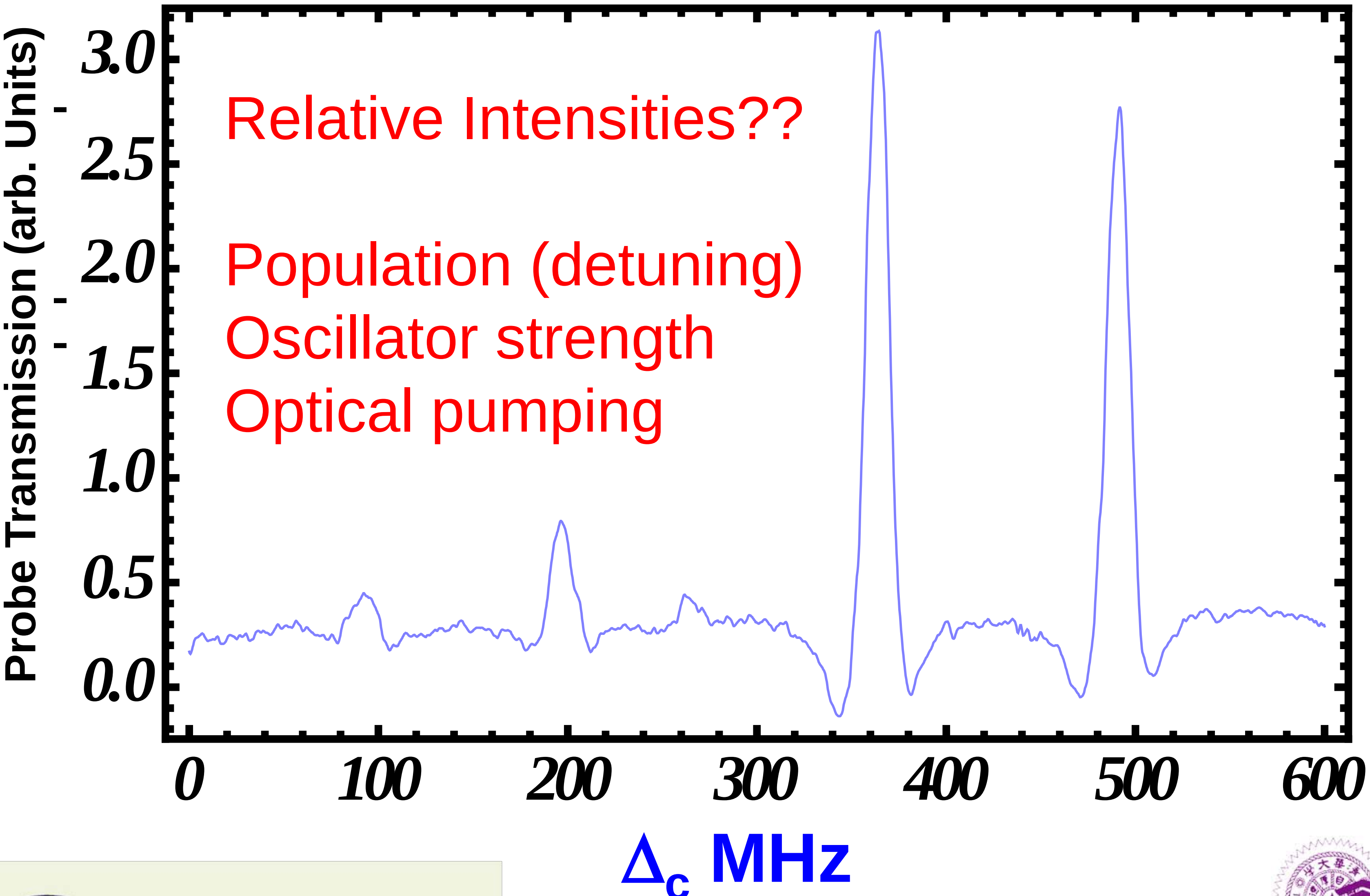


Velocities:

-1000→+1000 m/s

Step: 1 m/s

Experimental Result



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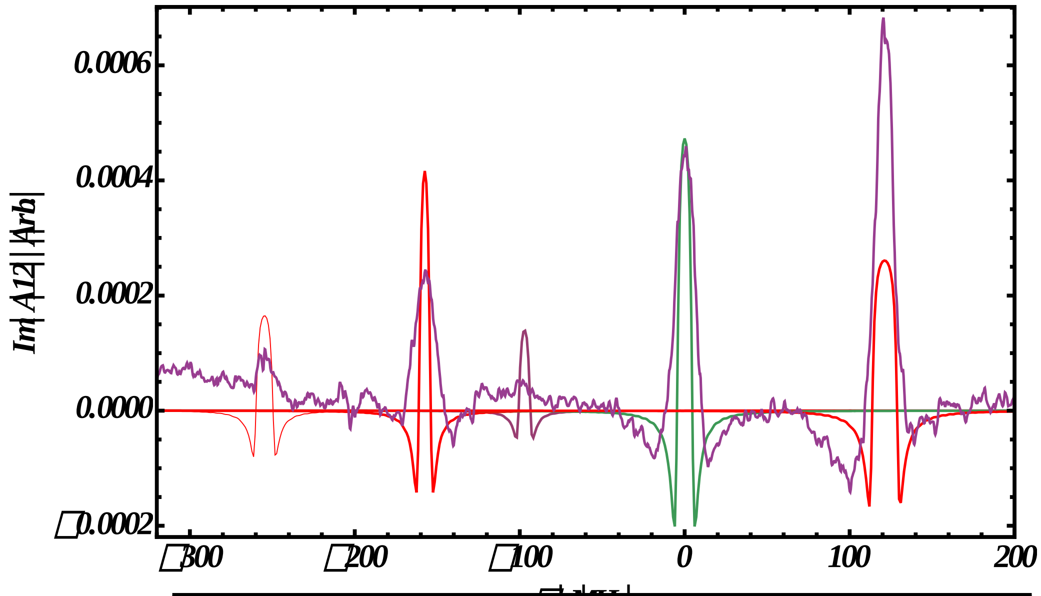
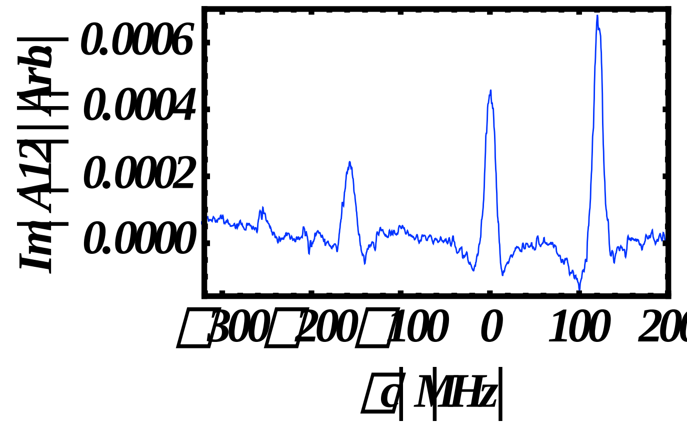
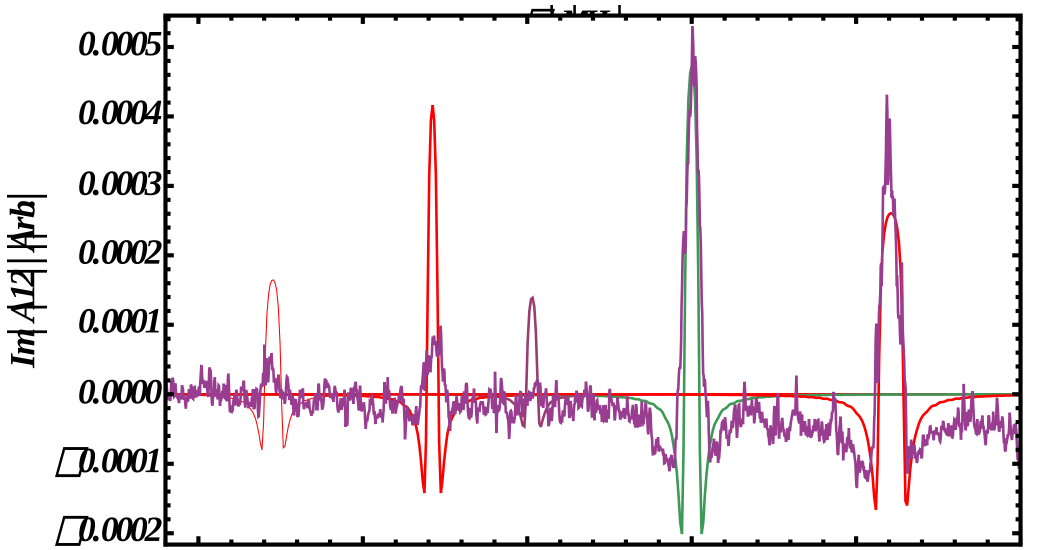
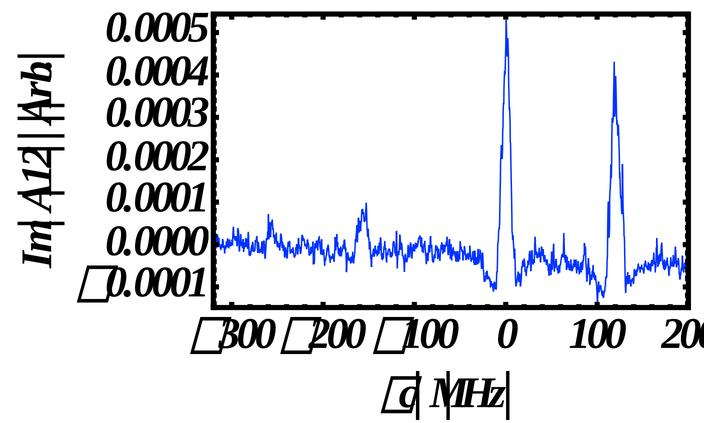
Experimental Result with simulations

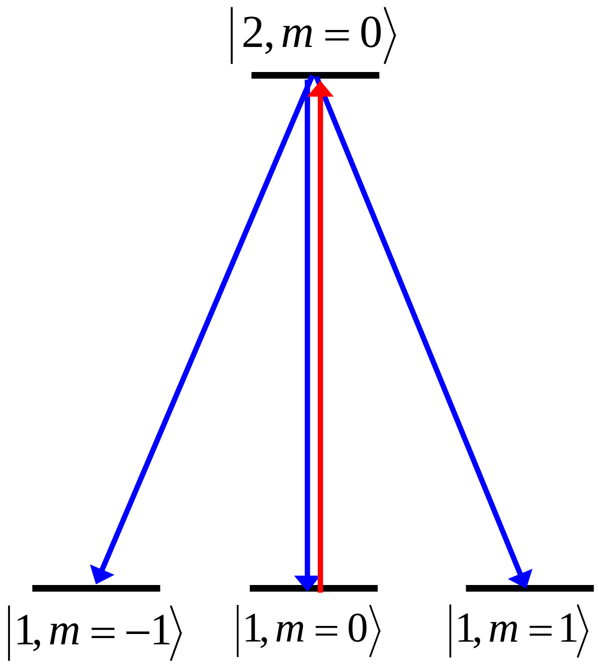


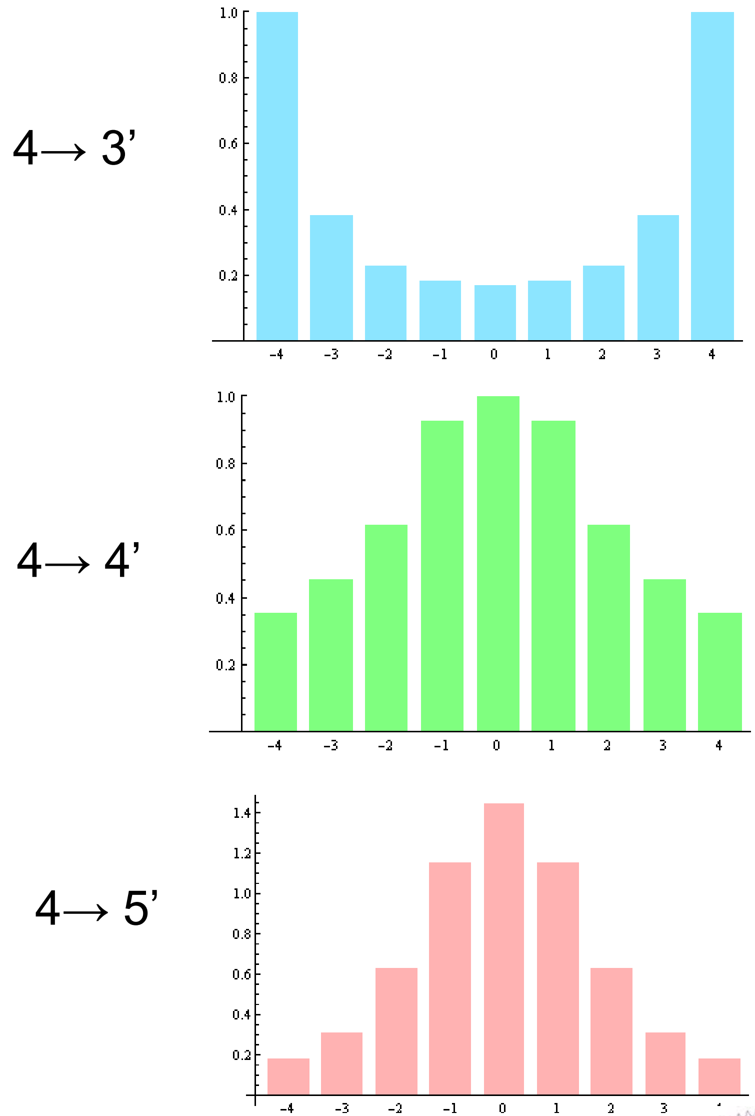






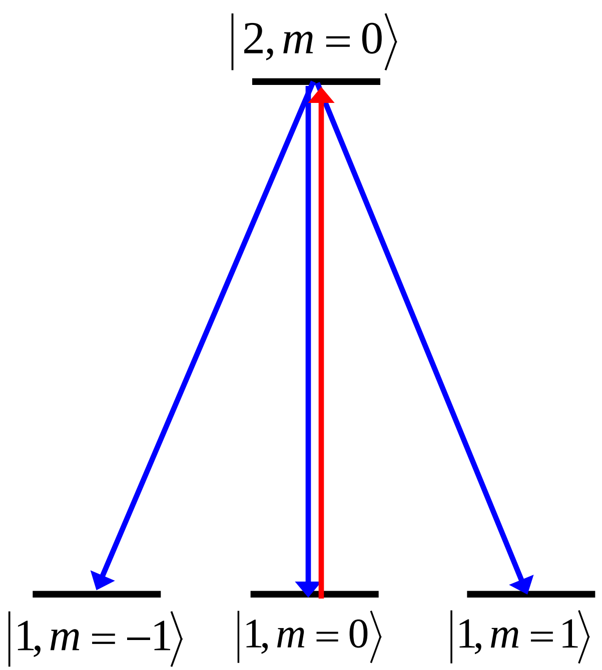
Optical Pumping of the Ground State

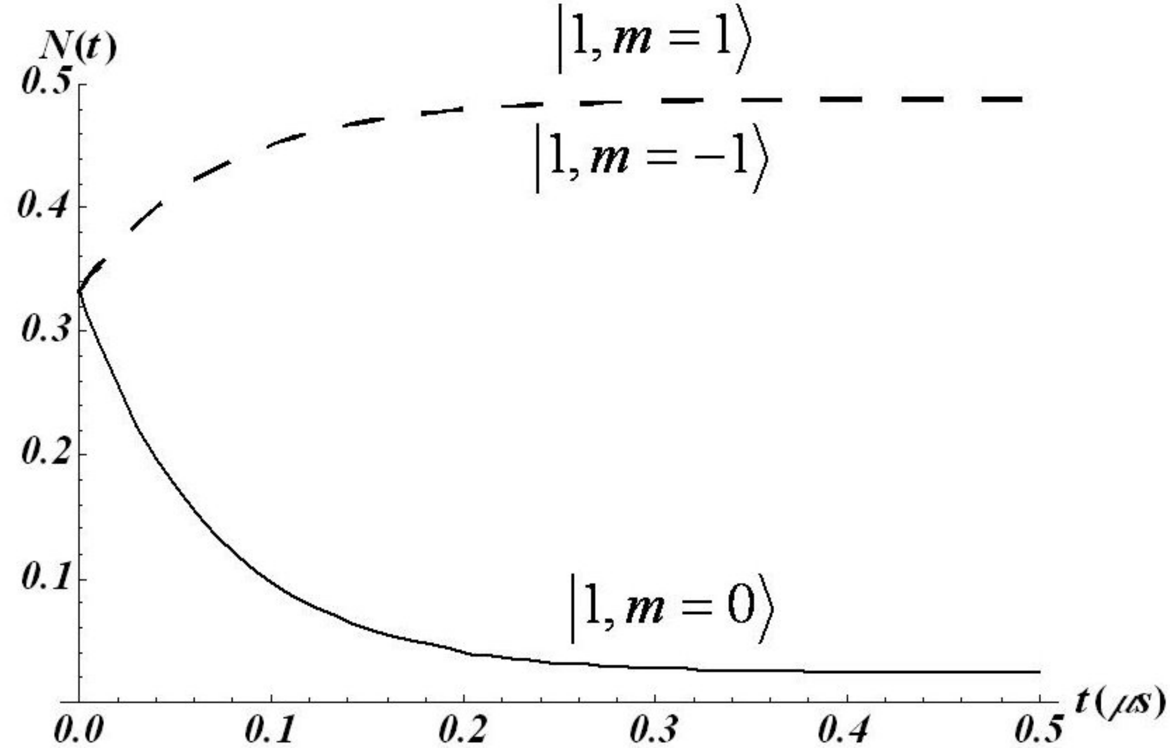




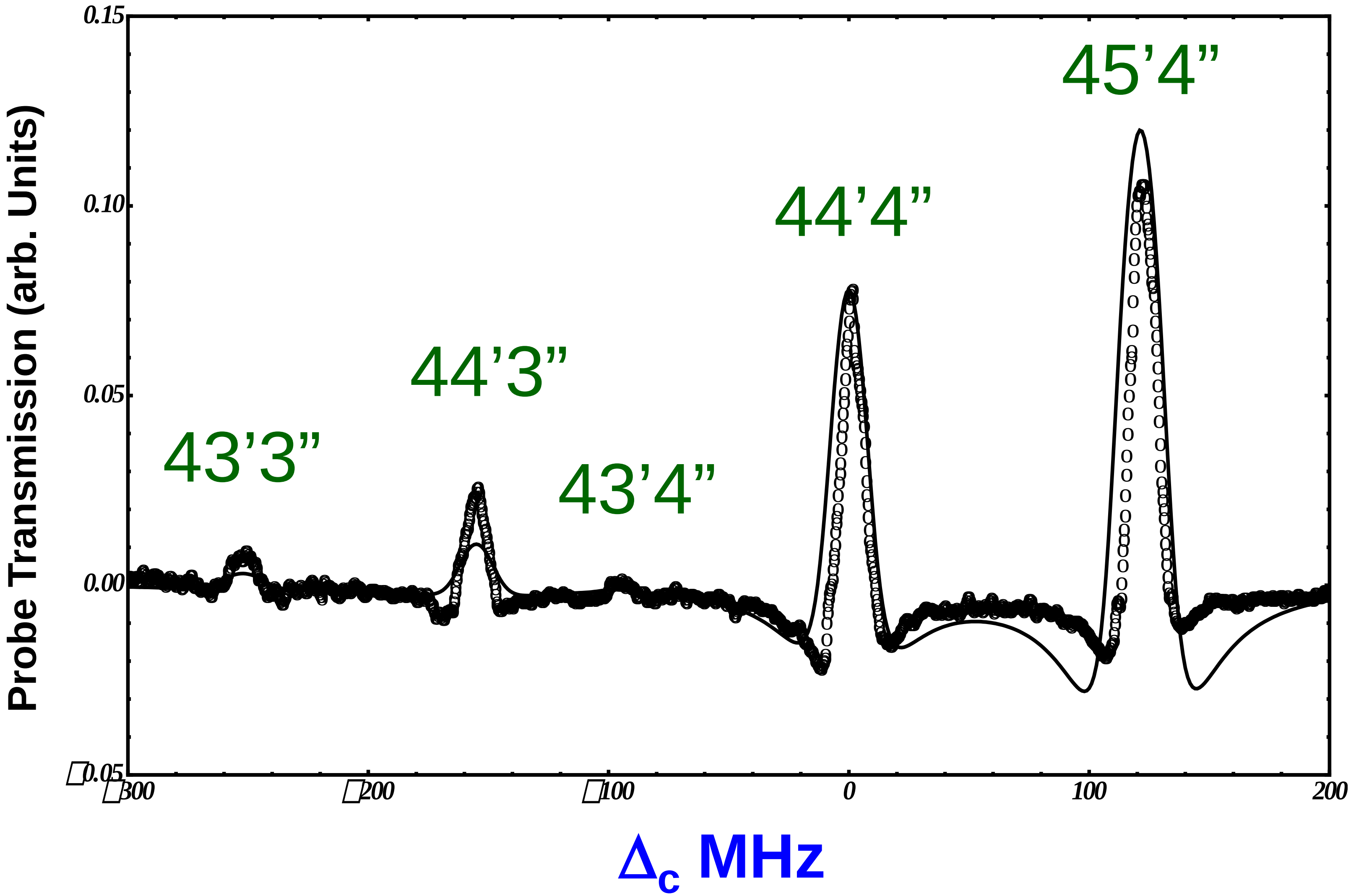
Optical Pumping of the Ground State

Optical Pumping Time





EIT Spectrum with Simulation



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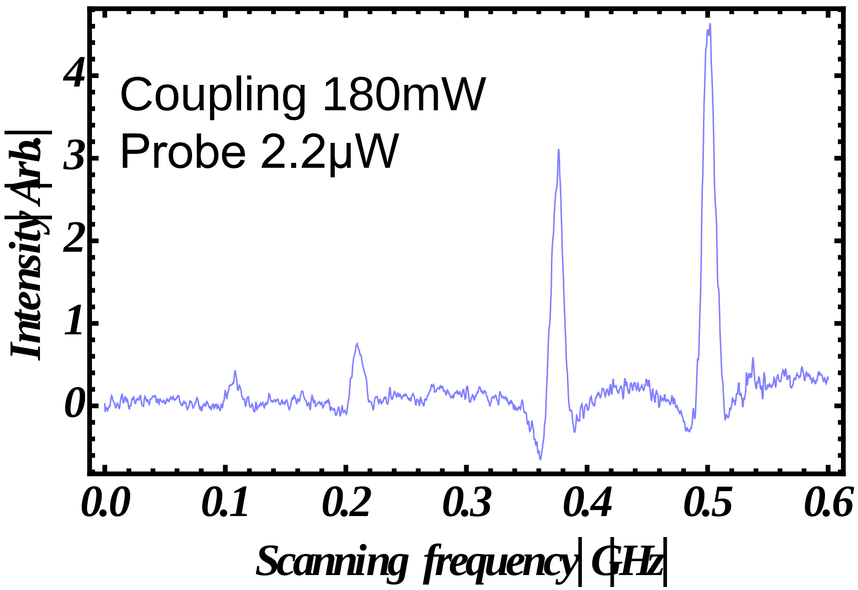
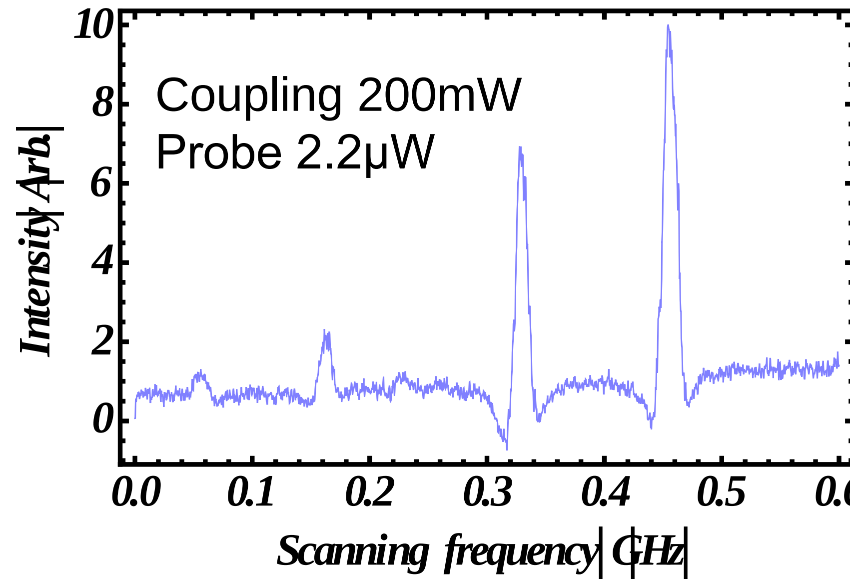
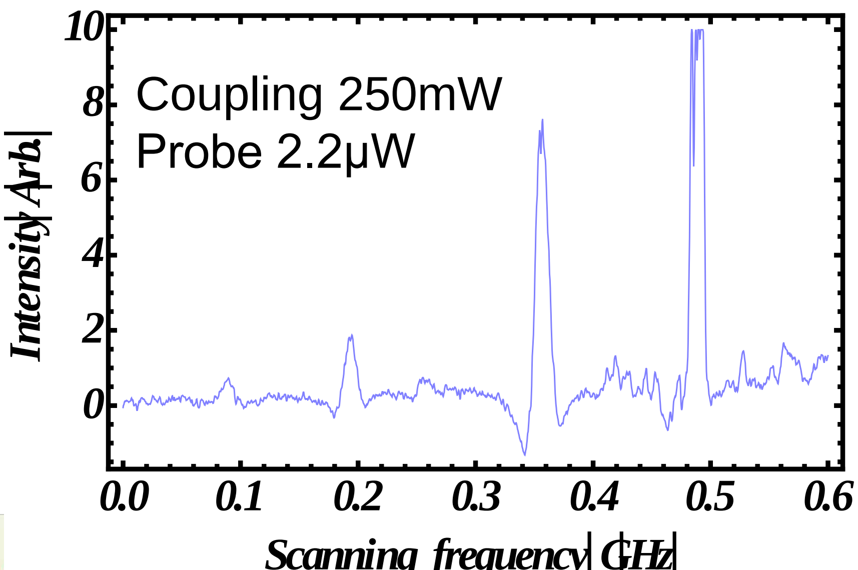
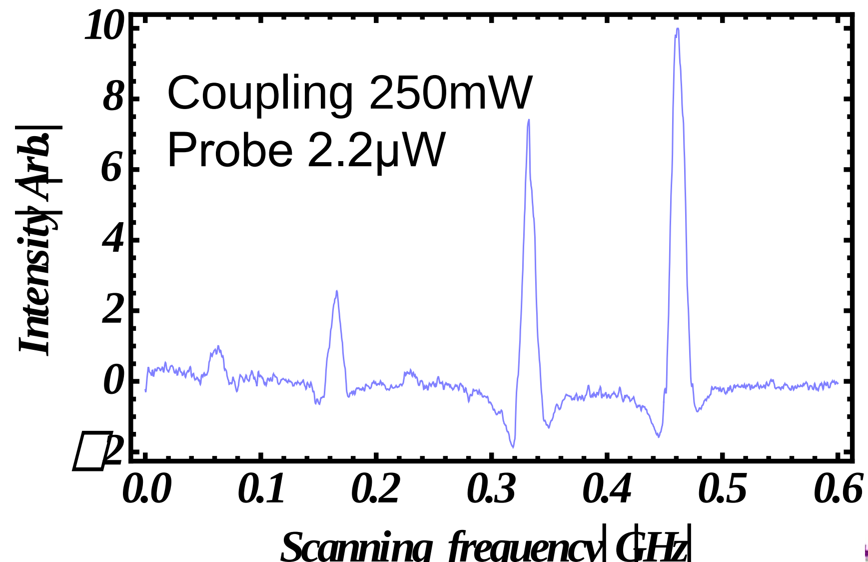
EIT Spectrum of Power Dependence

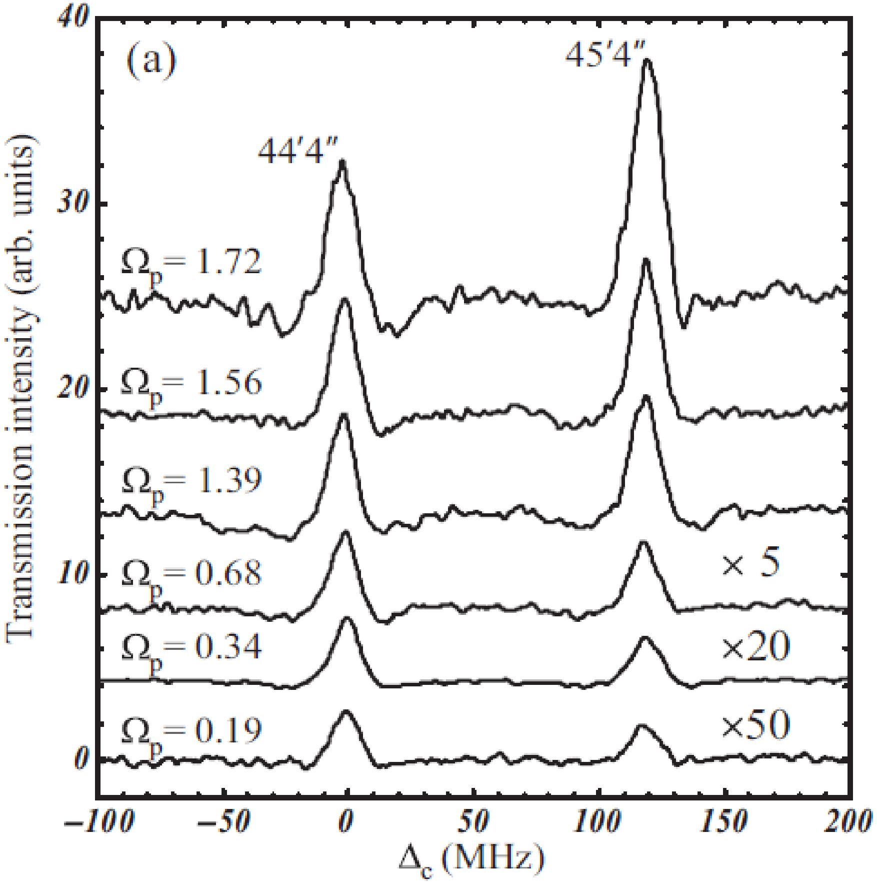




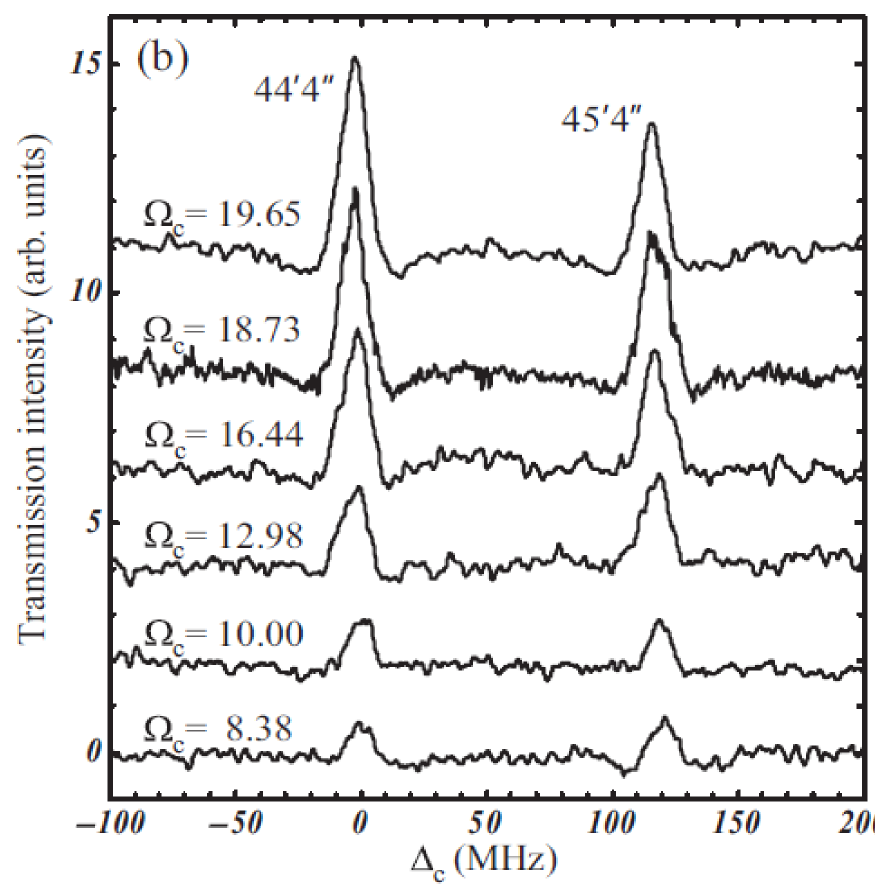




EIT Spectrum of Power Dependence

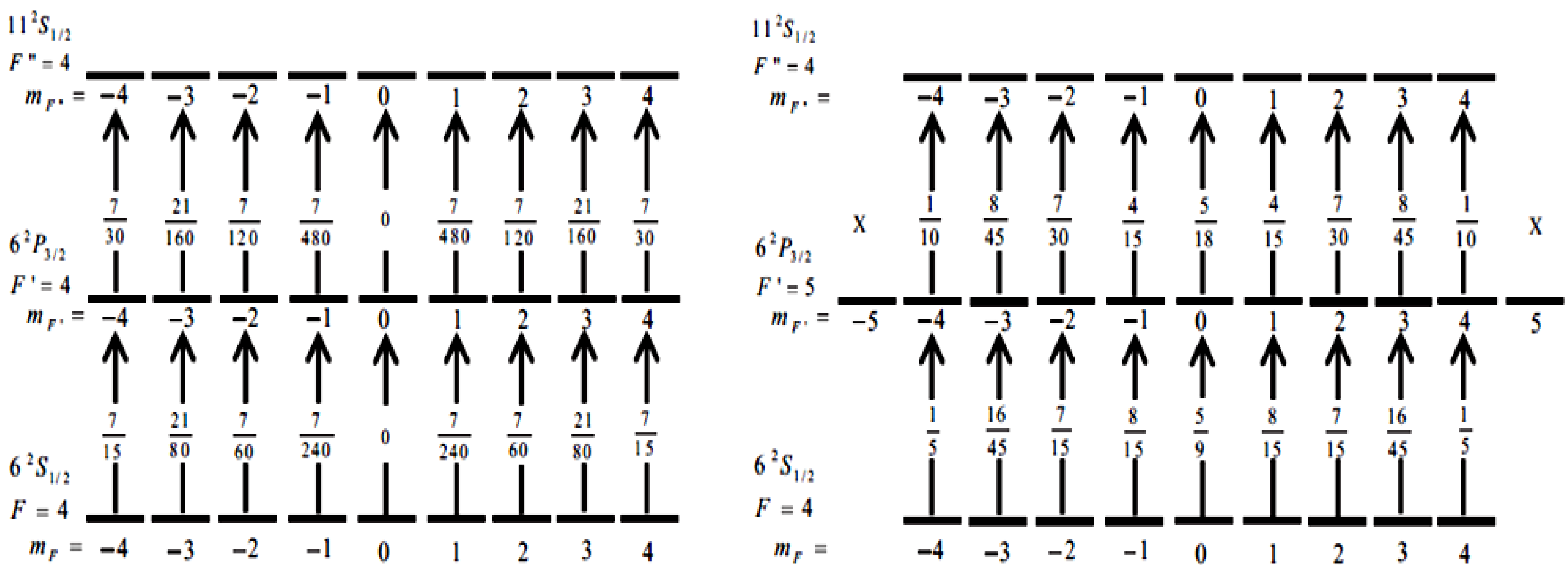


Coupling Power Dependence



Probe Power Dependence

Oscillator Strength for the Zeeman Sublevels

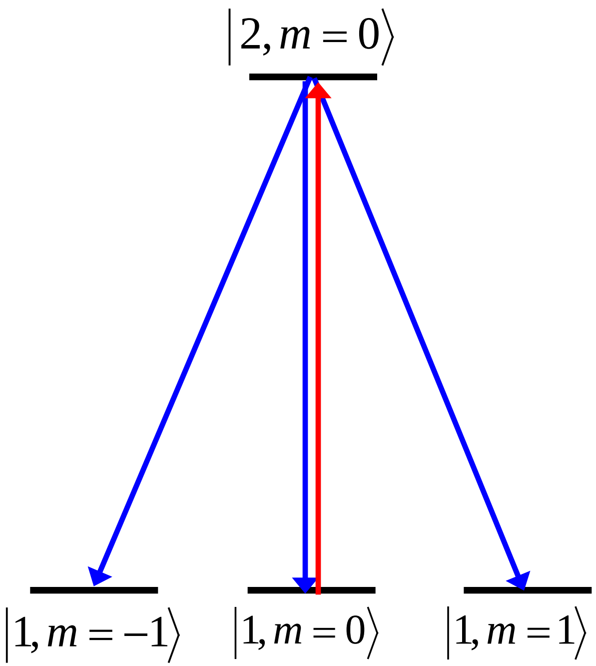


(a) (b)

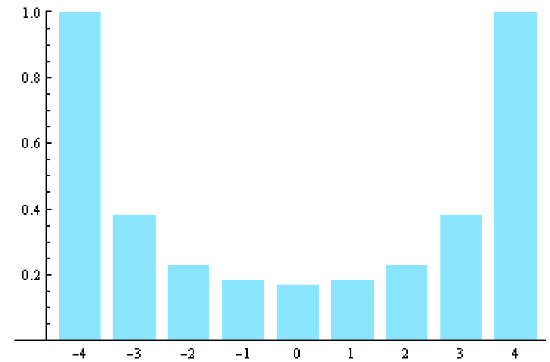
For 44'4"
0-0-0 is 0

For 45'4"
+/-5 is out of transition path

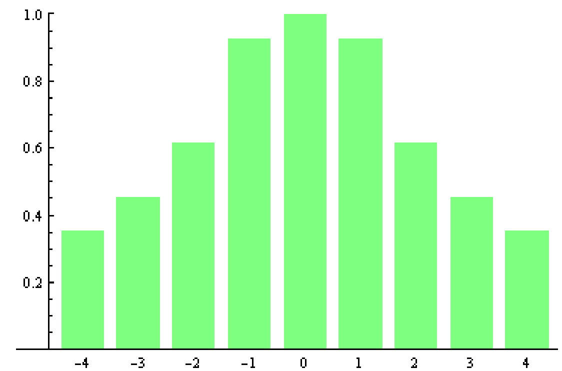
Optical Pumping



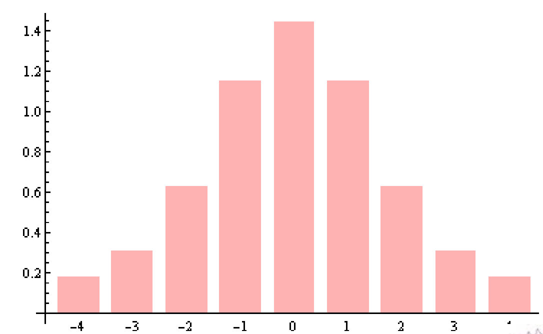
4→ 3’



4→ 4’



4→ 5’



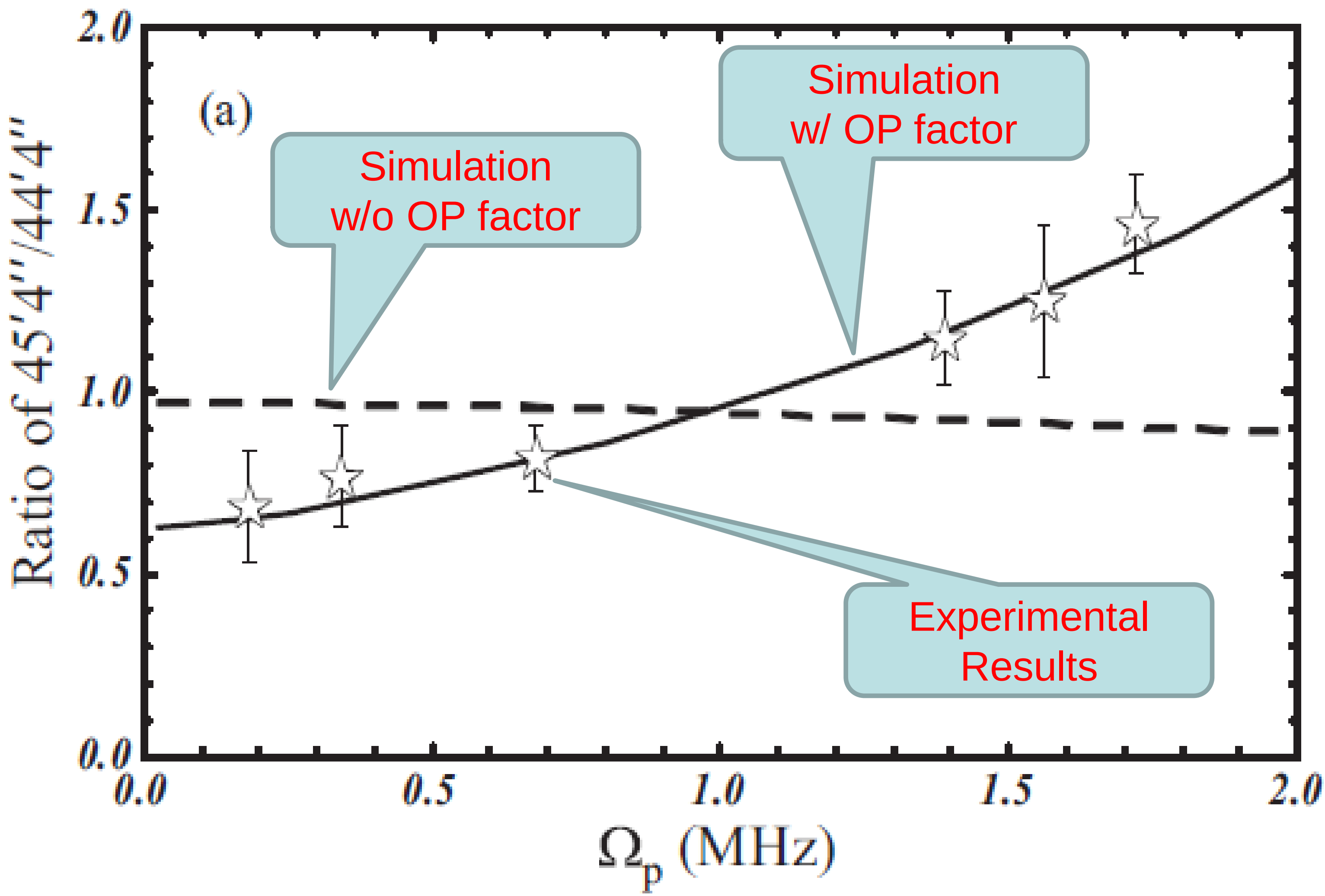
Probe Optical pumping, 0-0-0 is 0

Coupling Optical Pumping, +/-5 is X

Optical Pumping Factors for Upper and Lower Transitions

Transition	Ω_p (MHz)	Lower ratio (%)	Upper ratio (%)	O.P. (%)
44′4″	0.056	88.81	94.49	83.91
	0.176	88.02	94.27	82.98
	0.557	78.22	92.98	72.73
	1.243	47.82	91.85	43.92
45′4″	0.080	100	54.68	54.68
	0.254	100	57.19	57.19
	0.804	100	65.73	65.73
	1.799	100	69.47	69.47
Transition	Ω_c (MHz)	Lower ratio (%)	Upper ratio (%)	O.P. (%)
44′4″	3.91	78.22	99.31	77.68
	8.76	78.22	96.47	75.46
	12.39	78.22	92.83	72.62
	17.52	78.22	85.84	67.15
45′4″	5.13	100	98.02	98.02
	11.47	100	82.70	82.70
	16.22	100	65.15	65.15
	22.94	100	44.51	44.51

EIT Peaks Ratio for Probe Rabi Frequency



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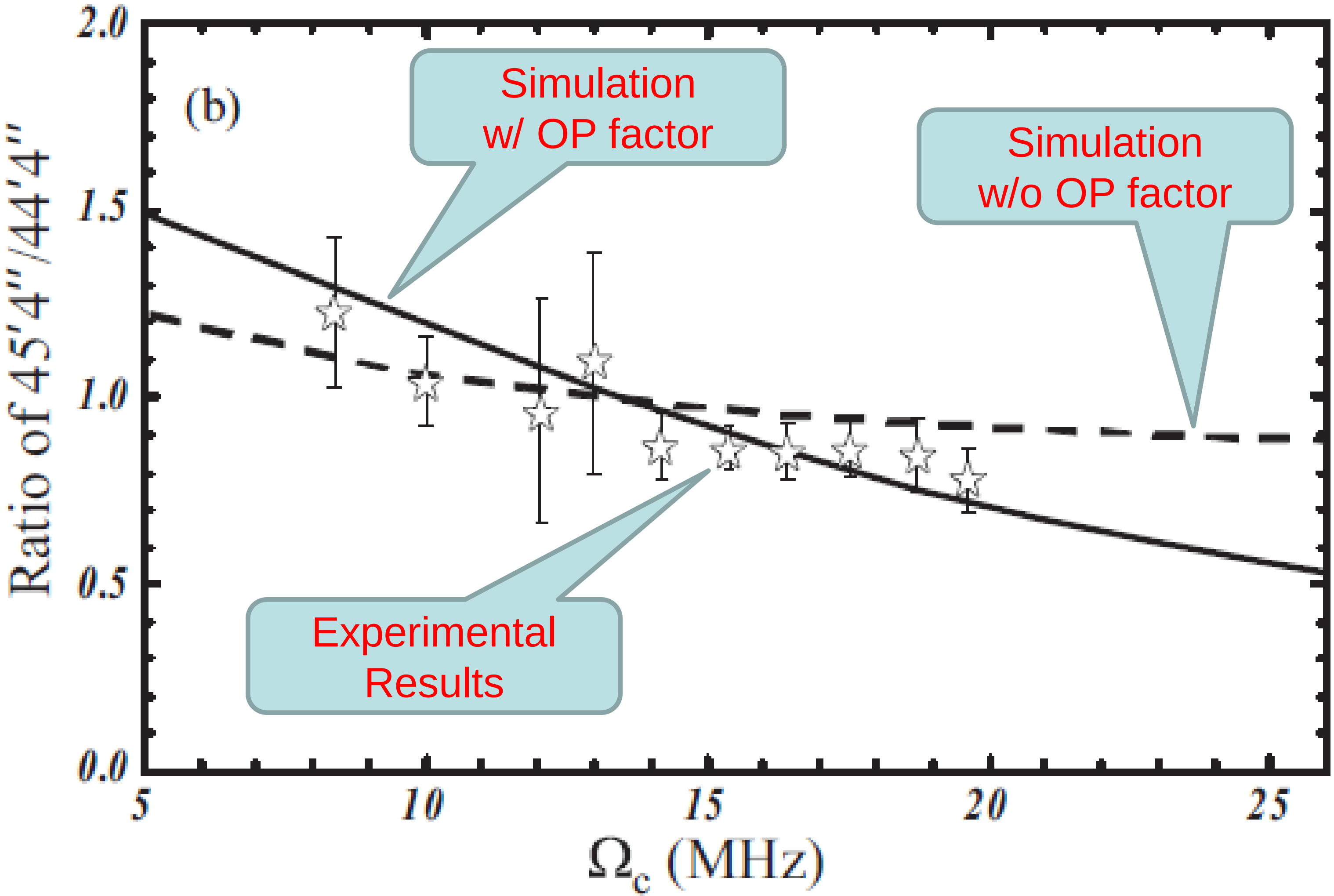
EIT Peaks Ratio for Coupling Rabi Frequency



Conclusion

- We had measured the hyperfine structure of Cs 11S by using the transmission of cascade-type EIT in room-temperature cell
- The multi-level EITs are successfully labeled by adding κ factor into detuning term of **Ω**'
- Line shape and intensities are simulated by integrating over Doppler velocities and considering the optical pumping effects for both probe and coupling fields

張詠詠/ Optical Pumping

蔡志宏/ HF11s

李明宗/ DS picture

何宗勳/ All works

Thanks for your attention!

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