Doppler-Free vs Doppler-Broadened Two Photon Absorption in Cesium Atoms

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ICFO-Unam-Uniandes Frontiers Research School, Mexico, October 12–17, 2025

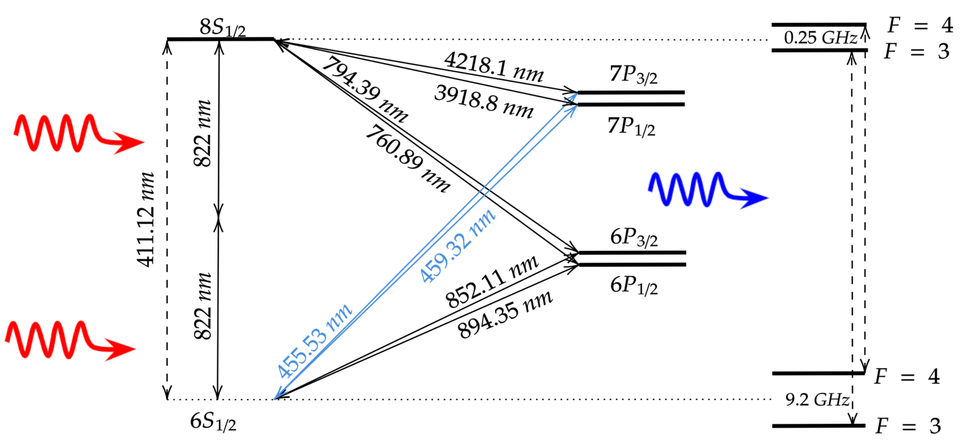
Abstract

Two-photon absorption (TPA) in atomic vapors plays an important role in areas such as frequency metrology, nonlinear optics, and quantum light–matter interactions. However, detecting the weak fluorescence signal associated with this process remains experimentally challenging, especially at low photon fluxes. We **studied the $6S_{1/2}\rightarrow 8S_{1/2}$ two-photon transition in cesium vapor using both Doppler-broadened (DB) and Doppler-free (DF) excitation schemes.** The fluorescence spectra were recorded for each case and fitted with Gaussian and Lorentzian profiles, respectively. The comparison reveals that the DF signal is stronger and narrower than the DB one, consistent with the expected Doppler and natural linewidths. Additional measurements at different cell temperatures show how the DF fluorescence amplitude scales with vapor density. These results establish a clear baseline for future two-photon and entangled two-photon absorption experiments in cesium, where precise fluorescence detection is essential.

Two-Photon Absorption (TPA)

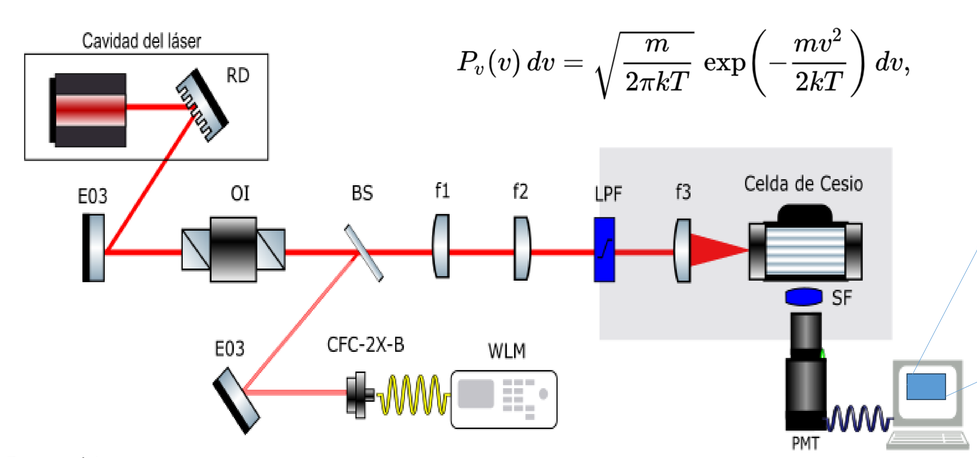
MOTIVATION

- **Characterization** of atoms, molecules, and organic materials.
- Starting point for studying **multiphoton processes** in **low-photon-flux** and quantum regimes.
- Basis for atomic clocks, four-wave mixing, and entangled two-photon absorption (**ETPA**).
- Comparing Doppler-free (DF) and Doppler-broadened (DB) configurations allows direct evaluation of **signal strength** and **spectral width**.



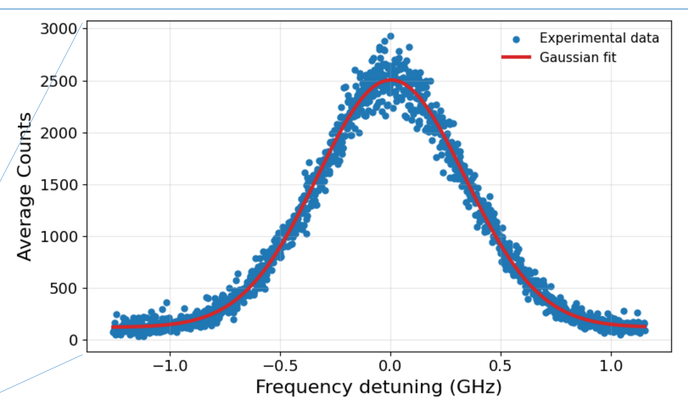
$$E = \frac{1}{2}h\nu_{res} + \frac{1}{2}h\nu_{res}$$

Doppler-Broadened TPA – Linear Polarization



$$P_v(v)\,dv = \sqrt{\frac{m}{2\pi kT}}\,\exp\left(-\frac{mv^2}{2kT}\right)dv,$$

Beam waist:
X: w0 = 15.6 +/- 0.4 μm
Y: w0 = 12.7 +/- 0.4 μm



Quantity	Value
R^2 (Gaussian fit)	0.98
FWHM (MHz)	808 ± 1
Natural linewidth (MHz)	1.53
Experimental temperature (K)	318.3 ± 0,8

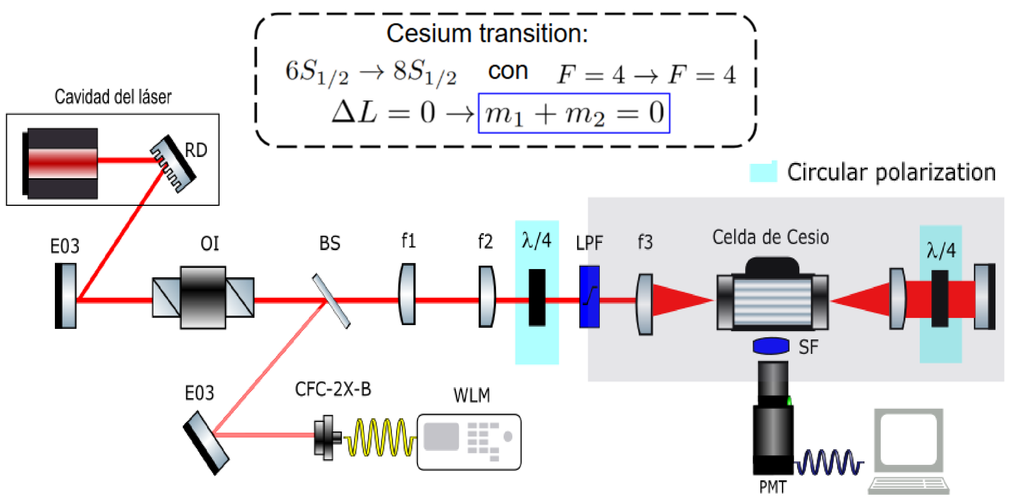
$T_{teo} = 45°C$ = 318.15 K

1. $\frac{\nu_{inc}}{2} < \frac{\nu_{res}}{2}$
2. $\frac{\nu_{inc}}{2} > \frac{\nu_{res}}{2}$
3. $\frac{\nu_{inc}}{2} = \frac{\nu_{res}}{2}$

Atomic reference frame: (Doppler-effect) $\nu'_{inc} = \nu_{inc}\left(1 \pm \frac{v_z}{c}\right)$

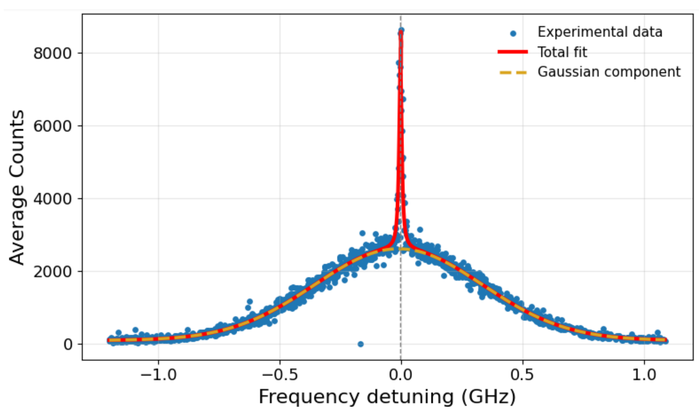
Doppler-Free TPA – Linear and Circular Polarization

Cesium transition:
$6S_{1/2} \rightarrow 8S_{1/2}$ con $F = 4 \rightarrow F = 4$
$\Delta L = 0 \rightarrow m_1 + m_2 = 0$



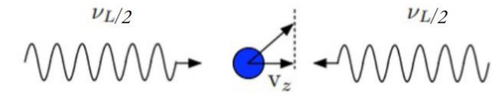
Linear polarization

$\pi : m = 0$

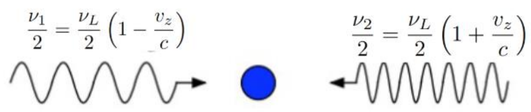


$T_{teo} = 45°C$ = 318.15 K

Laboratory reference frame:



Atomic reference frame:

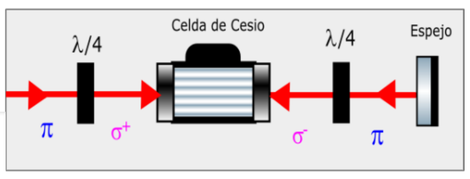


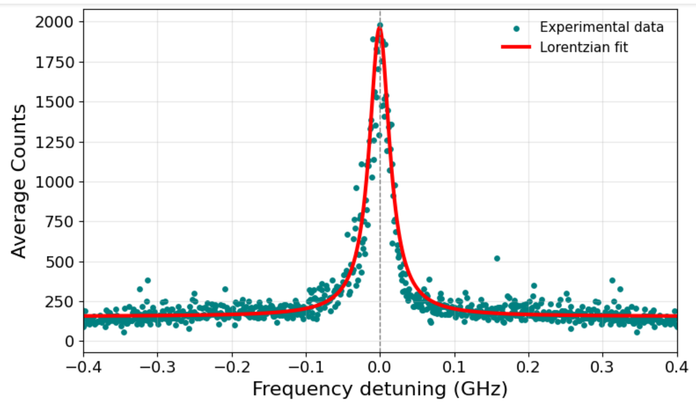
$E = h\nu_L$ → No Doppler broadening!

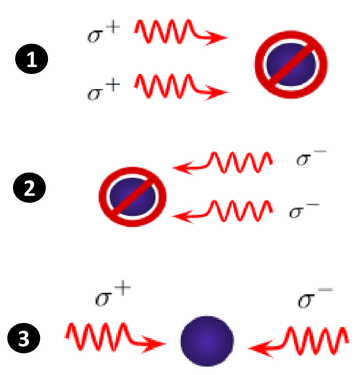
Quantity	Value
R^2 (Gaussian + Lorentzian fit)	0.96
FWHM Lorentzian (MHz)	5.96 ± 0.01
Natural linewidth (MHz)	1.53

Circular polarization

$\sigma^+ : m = +1$
$\sigma^- : m = -1$







Quantity	Value
R^2 (Lorentzian fit)	0.88
FWHM Lorentzian (MHz)	10.14 ± 0.01
Natural linewidth (MHz)	1.53

$T_{teo} = 45°C$ = 318.15 K

Temperature-dependent Doppler-Free Study

Conclusions and Future Work

- **DF fluorescence signal is 3:1 higher than the DB signal** in linear polarization scheme.
- Temperature from DB width agrees with expected Doppler broadening.
- Next steps include **improving temperature measurements** to **estimate atomic density**.
- **Reducing laser feedback** from the final mirror will enhance frequency scan stability.
- Future work will focus on extending DF measurements to **low-photon-flux regimes.**

References

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