Parametric four-wave mixing in atomic vapor induced by a frequency-comb and a cw laser

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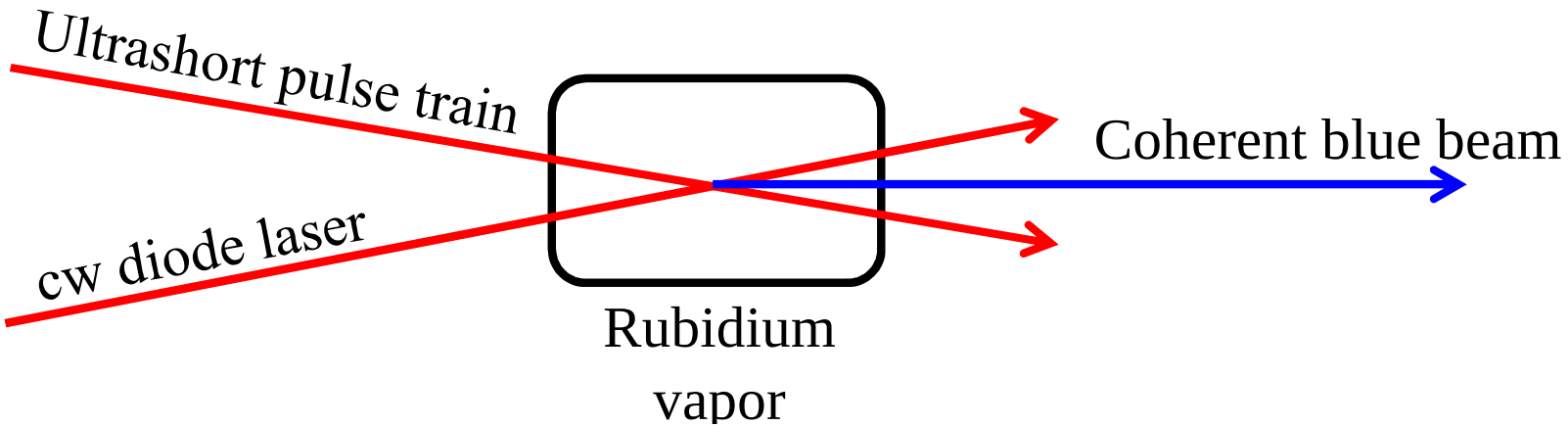
Introduction

- The objective is to study the coherent blue light generated in rubidium vapor due to the combined action of an ultrashort pulse train and a cw diode laser.



Four-wave mixing

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- In general, we have three incident beams and one generated beam.
- In the weak interaction limit, it is a third-order process. We are interested in the generated field that is the result from the polarization that can be expressed as

$$P_4 = \epsilon_0 \chi^{(3)} E_1 E_2 E_3$$

Correlated work

#118375 - $15.00 USD Received 9 Oct 2009; revised 20 Nov 2009; accepted 20 Nov 2009; published 30 Nov 2009

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Coherent and collimated blue light generated by four-wave mixing in Rb vapour

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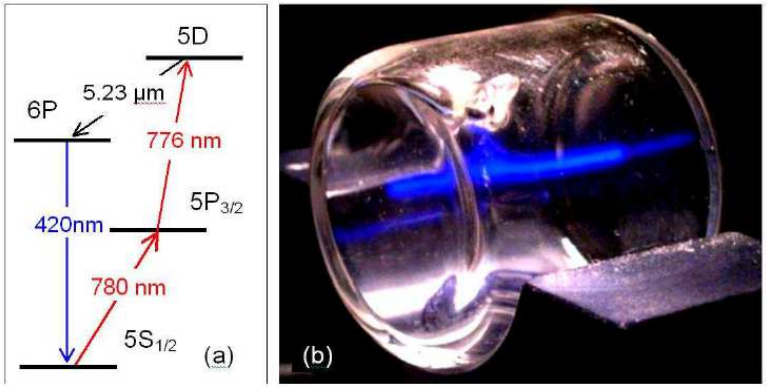

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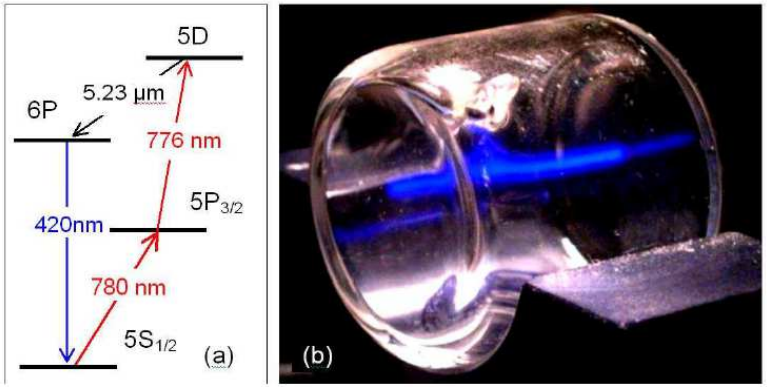
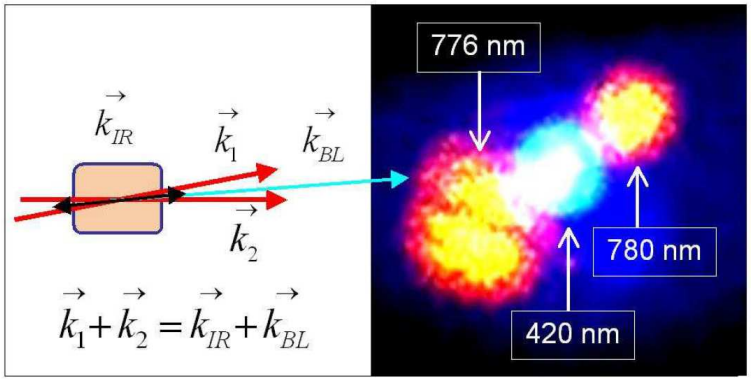
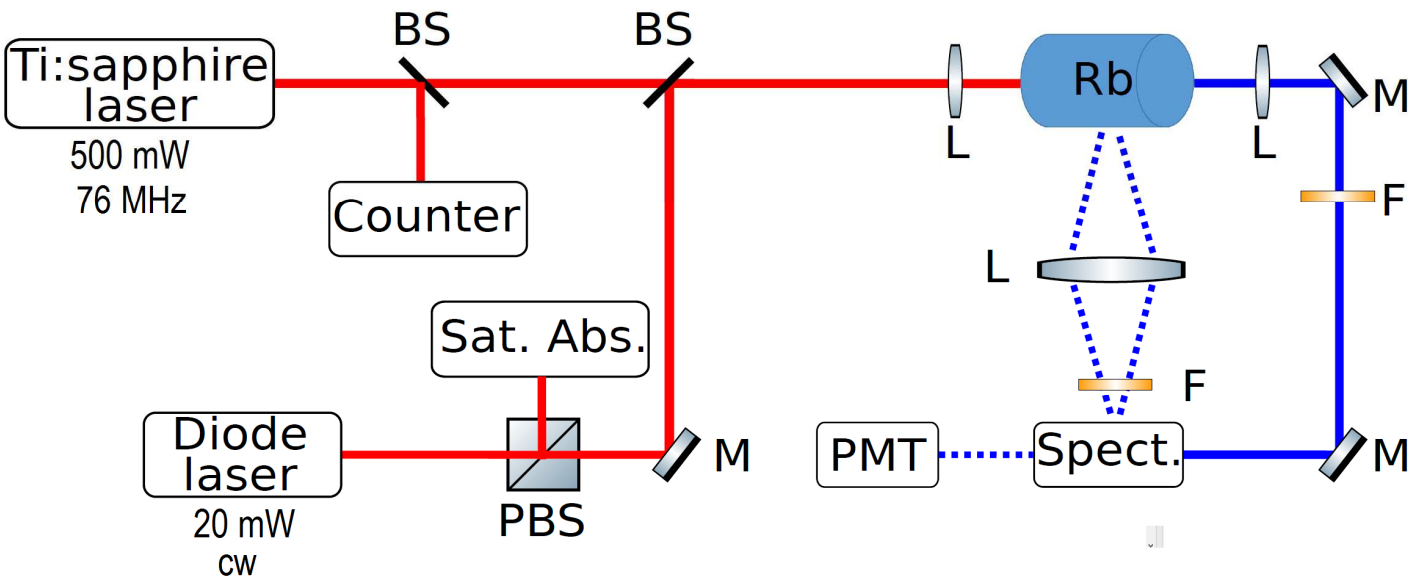
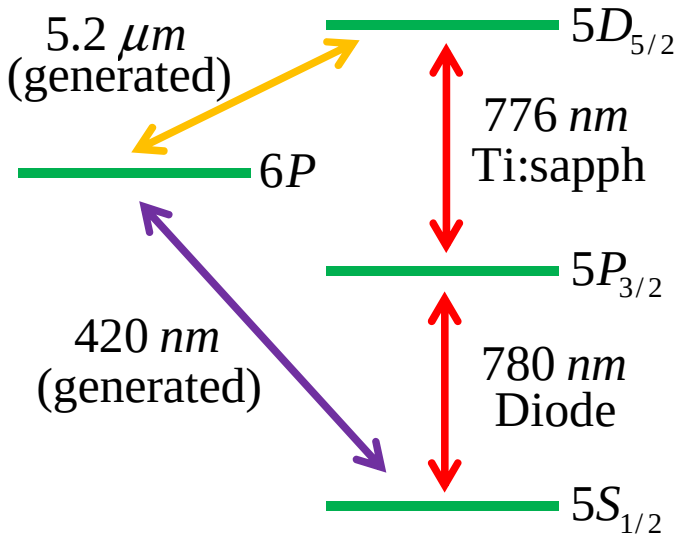




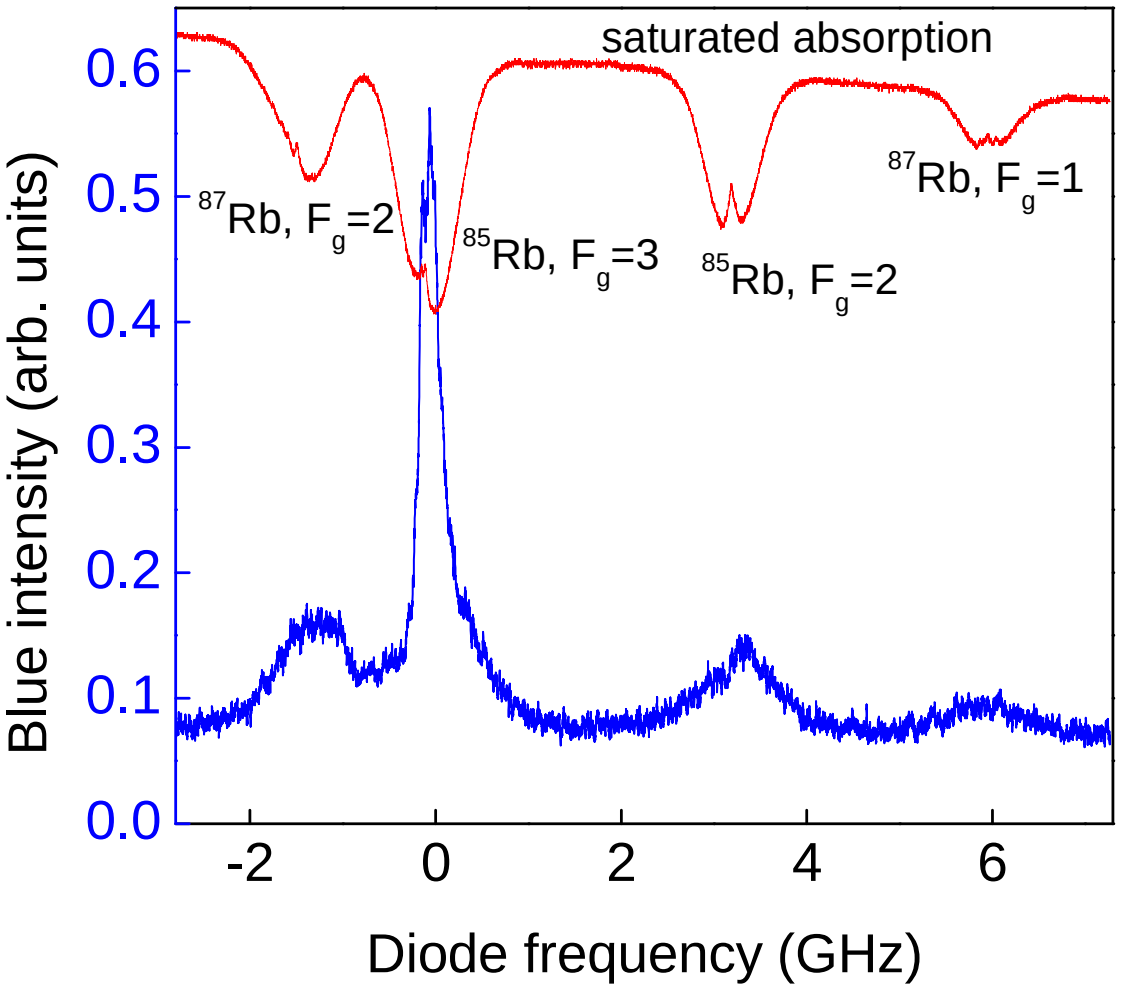
Setup


Ti:sapphire laser
500 mW
76 MHz
BS
BS
Counter
Sat. Abs.
Diode laser
20 mW
cw
PBS
M
L
Rb
L
M
F
L
F
PMT
Spect.
M


5.2 μm
(generated)
$5D_{5/2}$
776 nm
Ti:sapph
$6P$
$5P_{3/2}$
420 nm
(generated)
780 nm
Diode
$5S_{1/2}$

Experimental Results

- $I_{cw} = 1.9\ \mathrm{W/cm^2}$
- $I_{fs} = 1.0\ \mathrm{mW/cm^2}$ (each mode)
- $T = 85^o\mathrm{C}$



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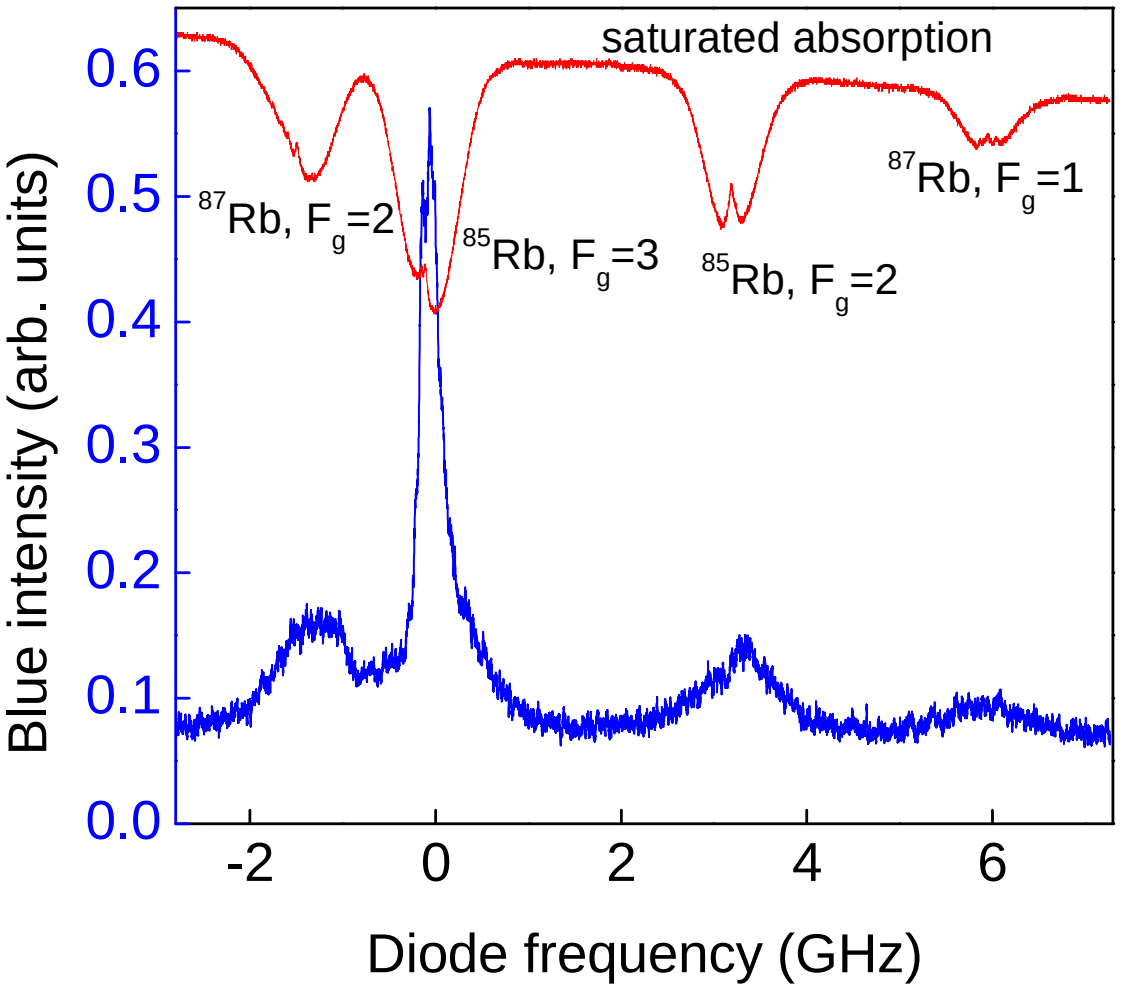
- Broad peaks: fluorescence induced by both lasers



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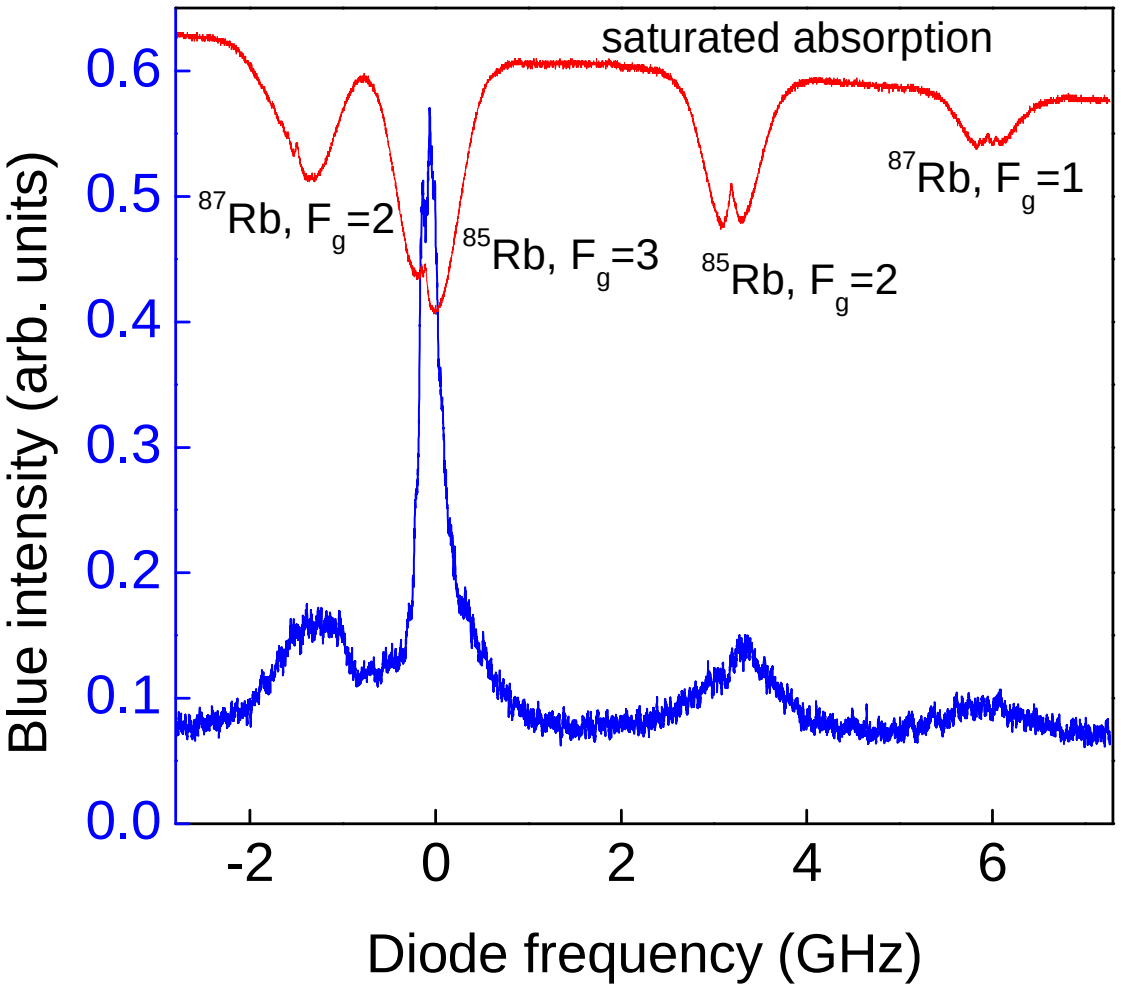
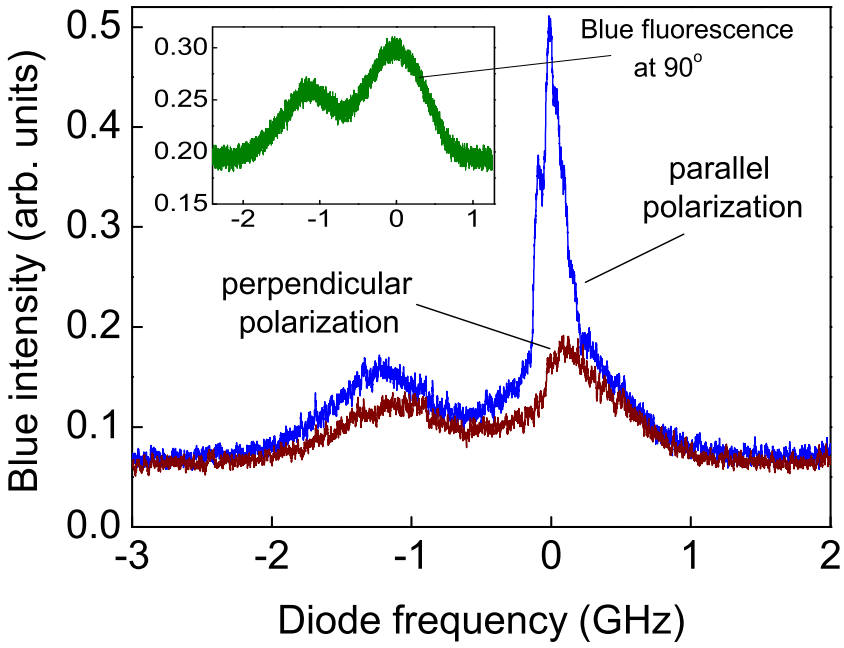
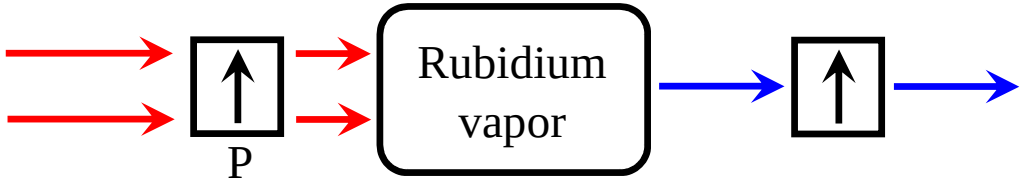
- Broad peaks: fluorescence induced by both lasers
- Flat Background: fluorescence induced by femtosecond laser



Polarization and density dependence





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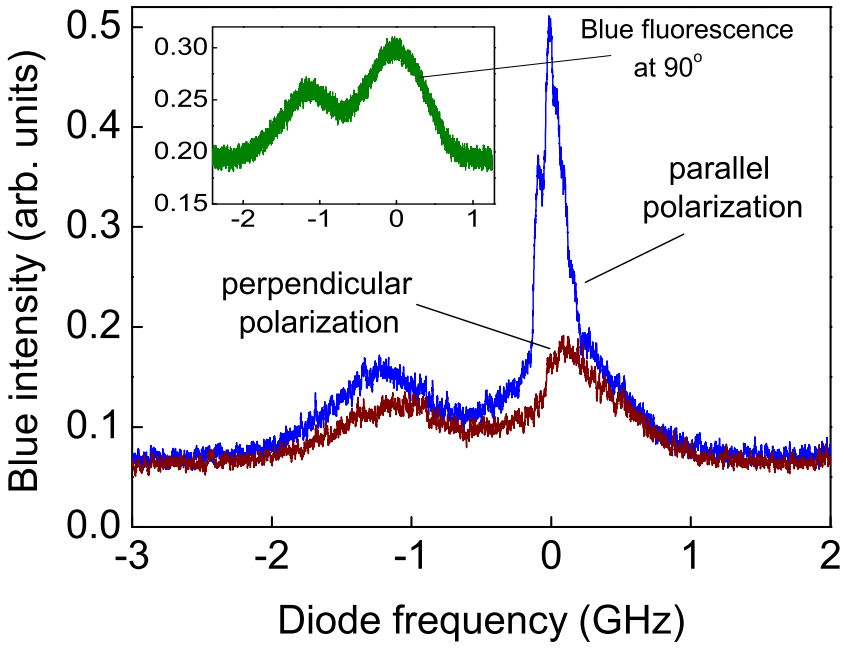

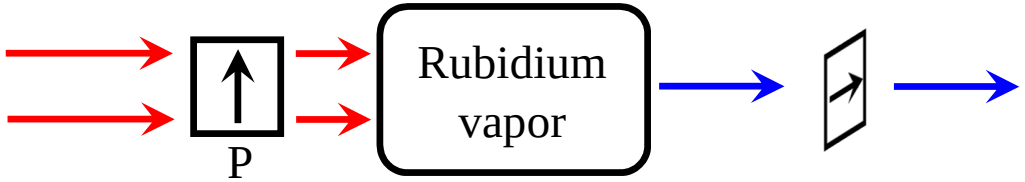

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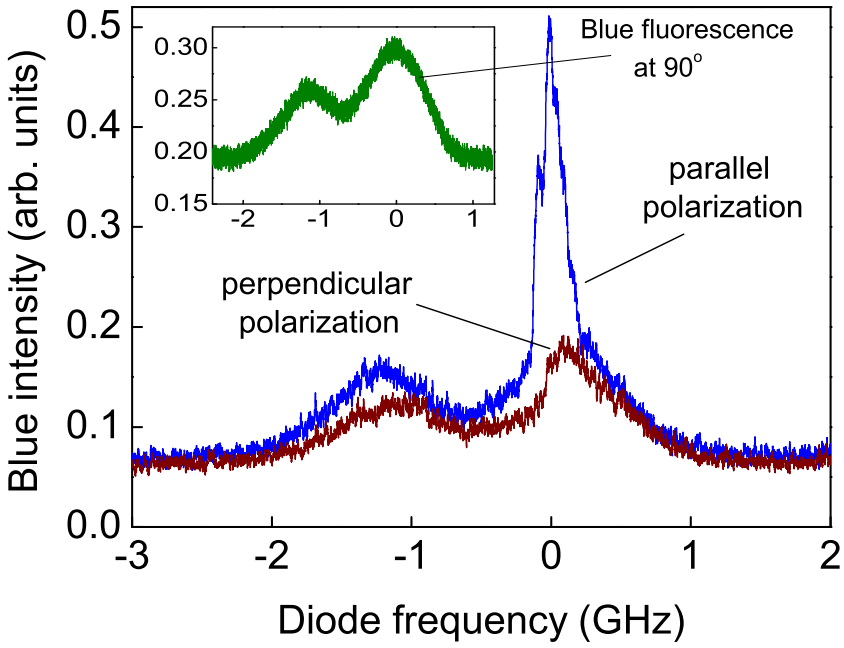
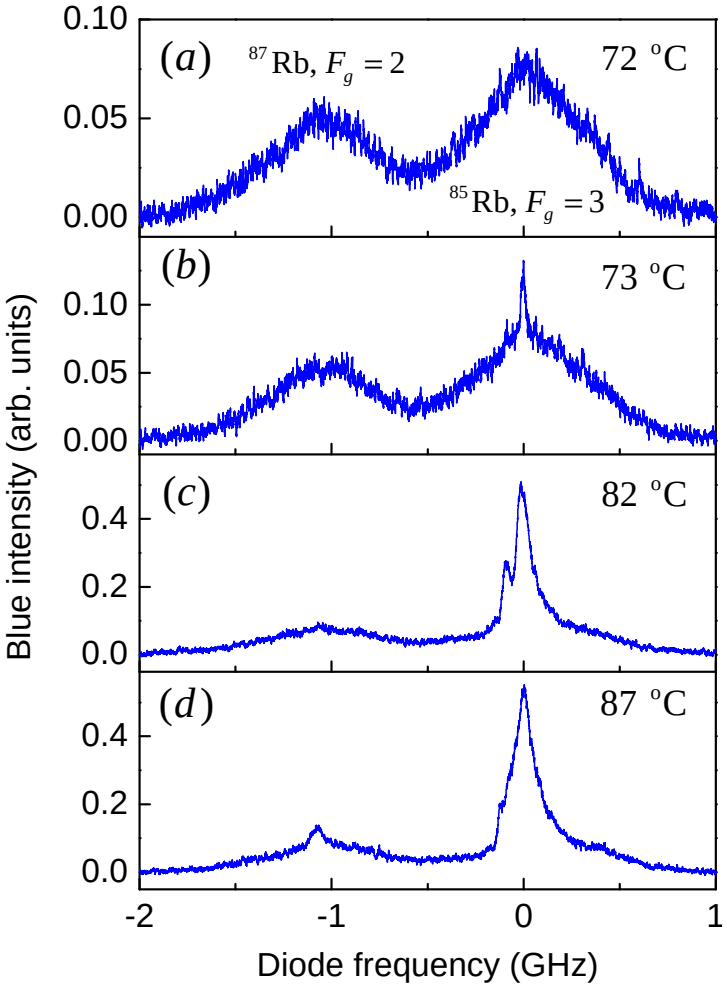
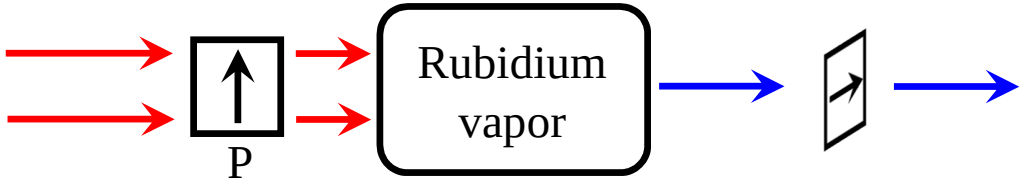
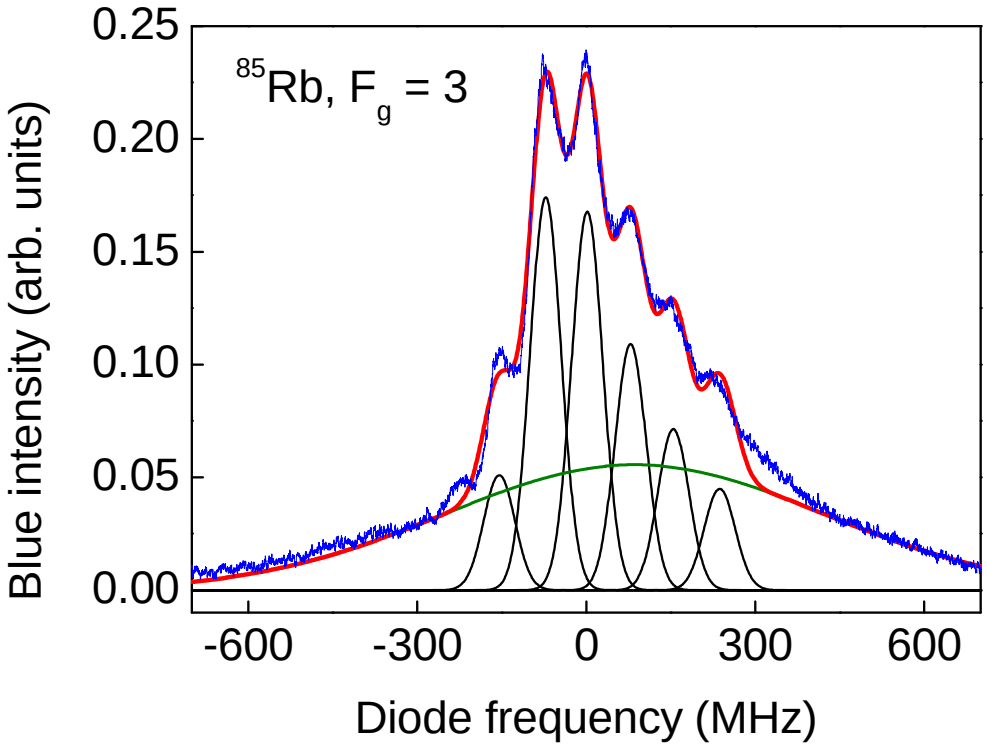






Experimental Results

- $T = 85^o$C
- Slow scanning
- Average of 10 measurements



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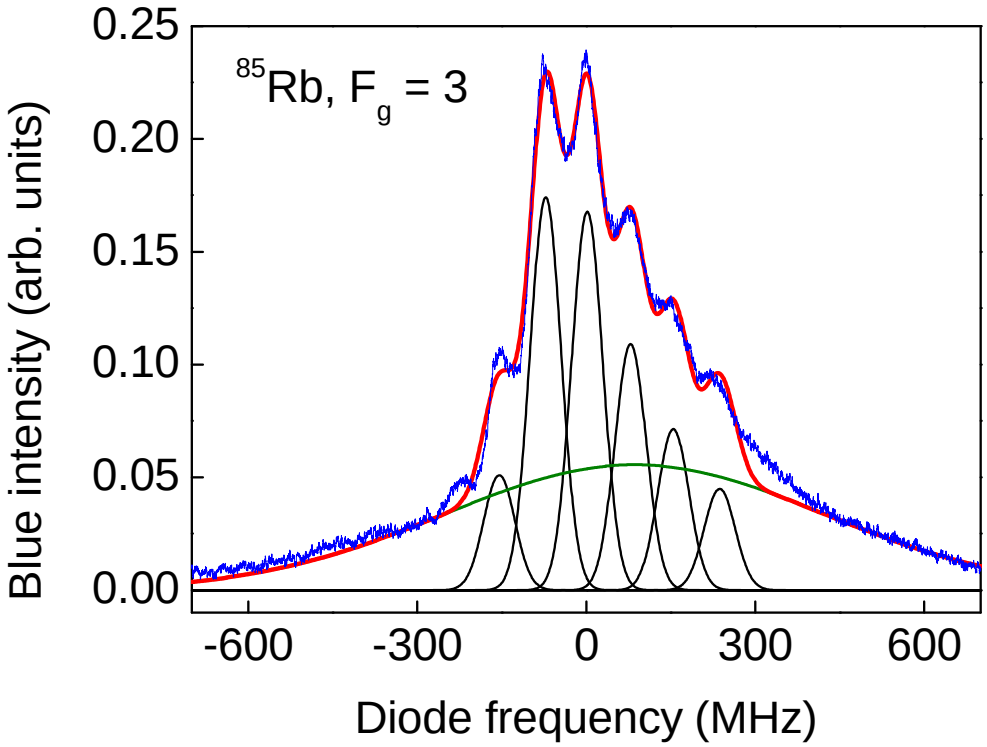

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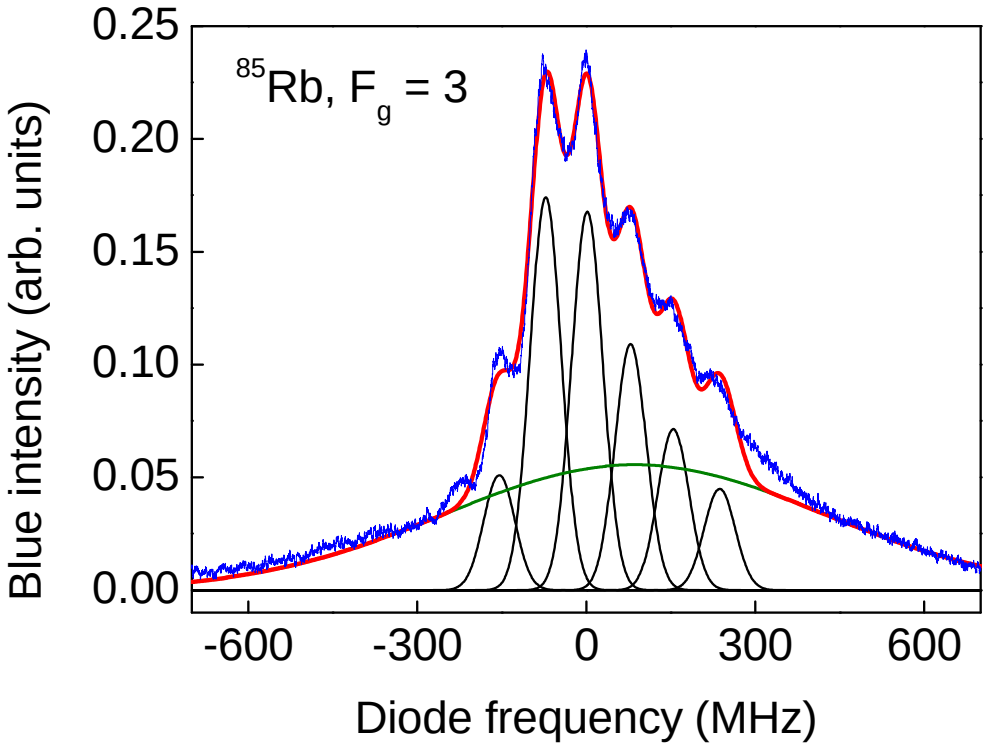
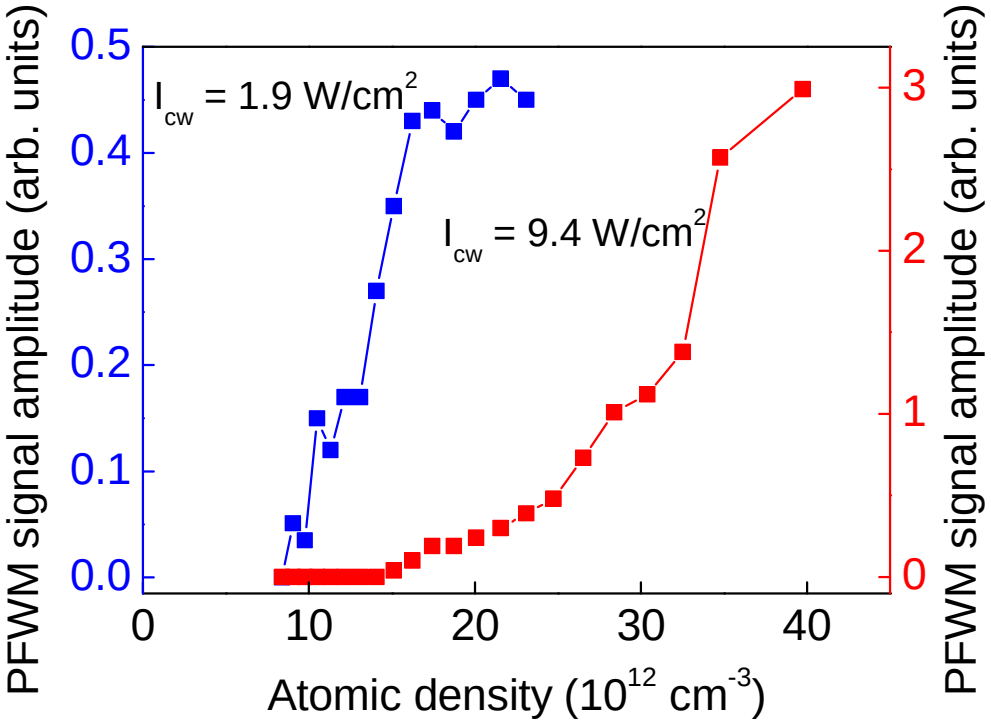
- Peak linewidths: ≈ 55 MHz
- Frequency difference between two adjacent peaks: 78 ± 4 MHz



Density dependence

- Femtosecond and diode lasers in resonance with your transitions



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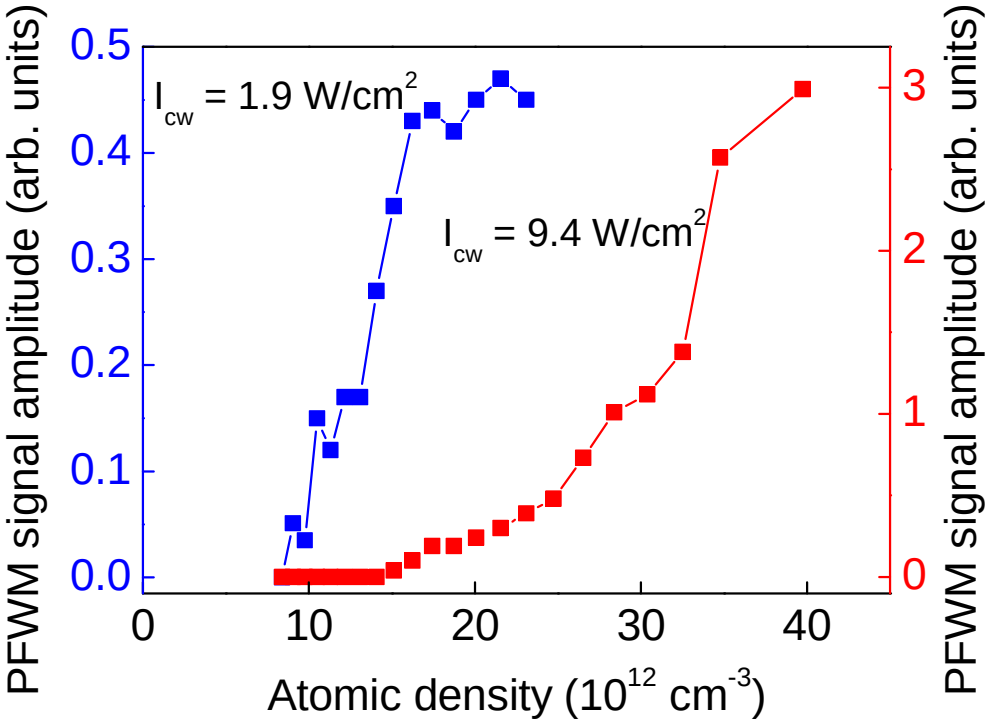

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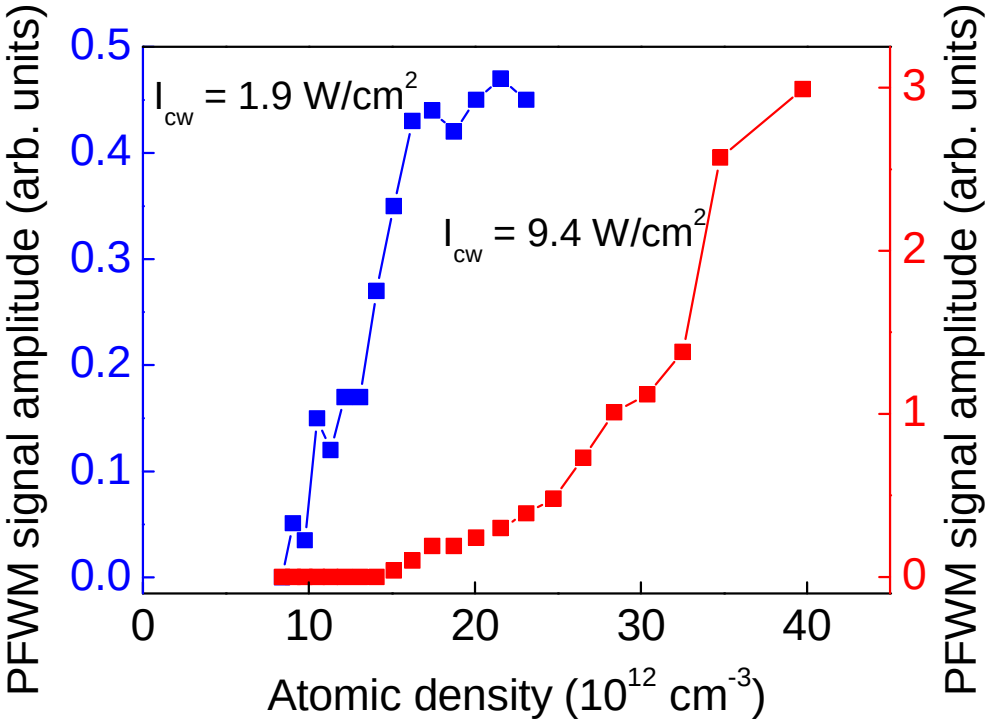
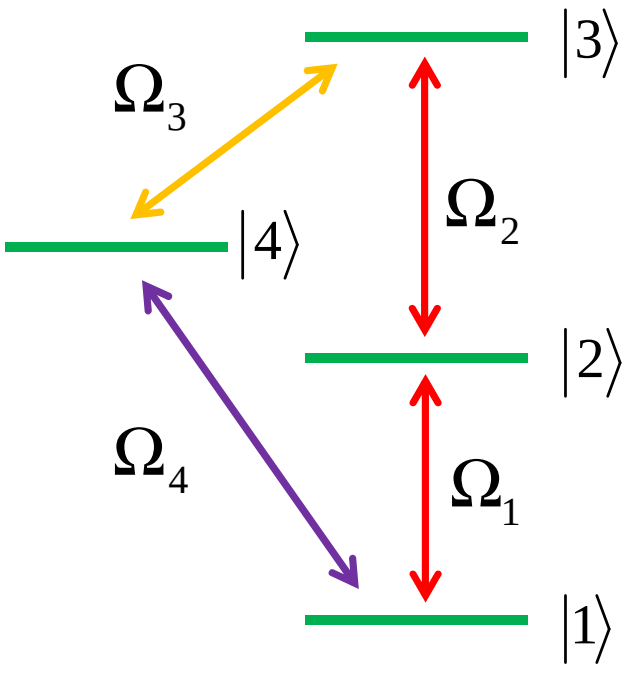
- Exponential growth
- "Threshold" shift as a function of the diode intensity



Theory

- Diamond-type four-level system interacting with four cw lasers.
  - Ω_1: diode laser
  - Ω_2: one mode of the femtosecond laser
  - Ω_3: seed field
  - Ω_4: blue beam generated



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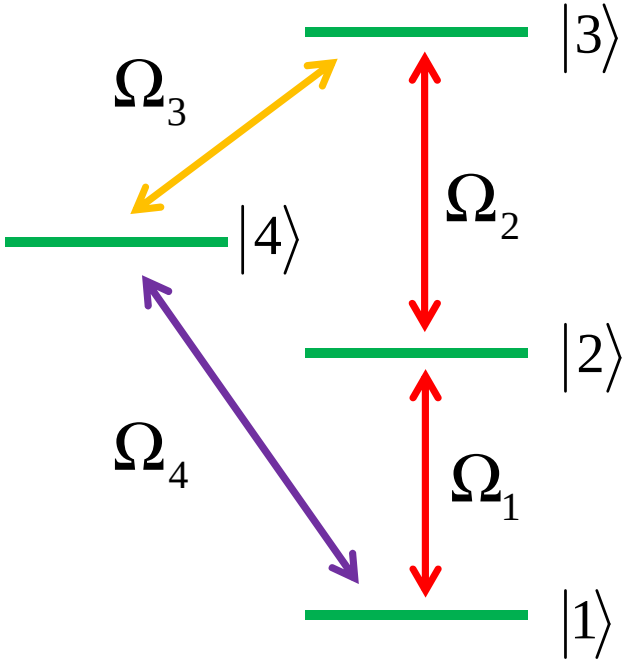
$$\hat{H}_{int} = -\hat{\mu} \cdot E$$

(Dipole electric approximation)



Maxwell-Bloch equations

$$\frac{\partial \hat{\rho}}{\partial t} = -\frac{i}{\hbar}\left[\hat{H}, \hat{\rho}\right] \qquad \text{(Liouville-Neumann)}$$

$$\frac{\partial^2 E}{\partial z^2} - \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = \mu_0 \frac{\partial^2 P}{\partial t^2} \qquad \text{(Wave equation)}$$

$$P = N\left\langle \hat{\mu} \right\rangle \qquad \text{(Polarization)}$$

Maxwell-Bloch equations

$$\frac{\partial \rho_{jk}(z,t)}{\partial t} = -(i\omega_{jk} + \gamma_{jk})\rho_{jk}(z,t) - \frac{i}{\hbar}\langle j|\,[\hat{H}_{int}, \hat{\rho}]\,|k\rangle$$

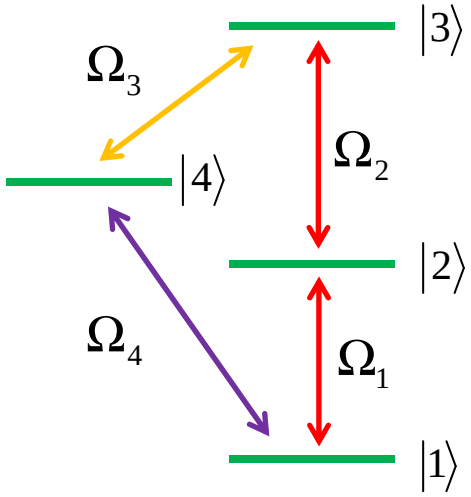
$$\frac{\partial \Omega_j(z,t)}{\partial z} = -i\alpha_{jk}\gamma_{jk}\sigma_{jk}(z,t)$$

where

$$\Omega_j = \frac{\mu_{jk}E_j^0}{\hbar} \quad \text{(Rabi frequency)}$$

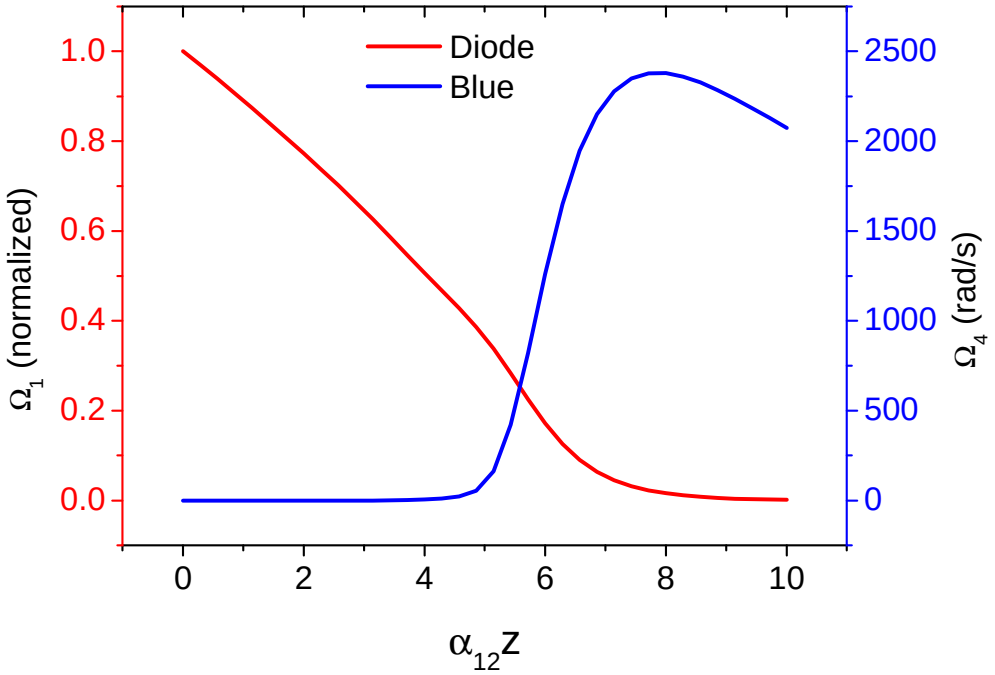
$$\alpha_{jk} = \frac{\mu_{jk}^2\omega_j}{2\hbar c\epsilon_0\gamma_{jk}}N$$

$$\sigma_{jk} = \rho_{jk}e^{-i\omega_j t}$$



Theoretical result

- Numerical solution of the equations
- All fields at resonance
- Initial conditions:
  $\Omega_1 = 0.7\gamma_{22}$, $\Omega_2 = 2.4\gamma_{33}$, $\Omega_3 = 2.4 \times 10^{-7}\gamma_{33}$ and $\Omega_4 = 0$
  $\rho_{11} = 1$, $\rho_{ij} = 0$ for $(i, j) \neq (1, 1)$



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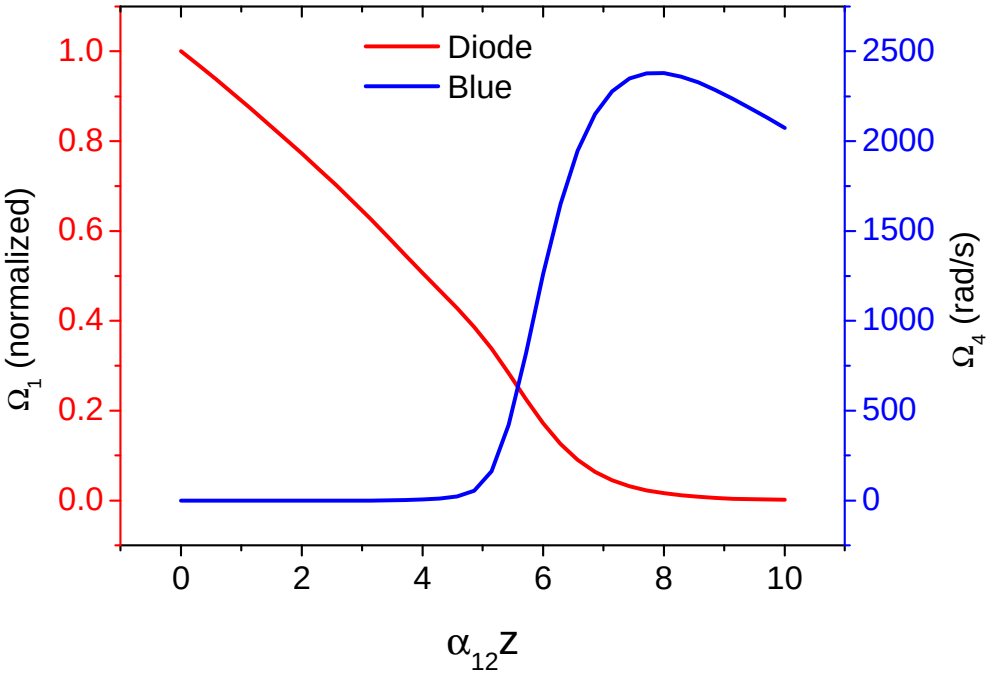

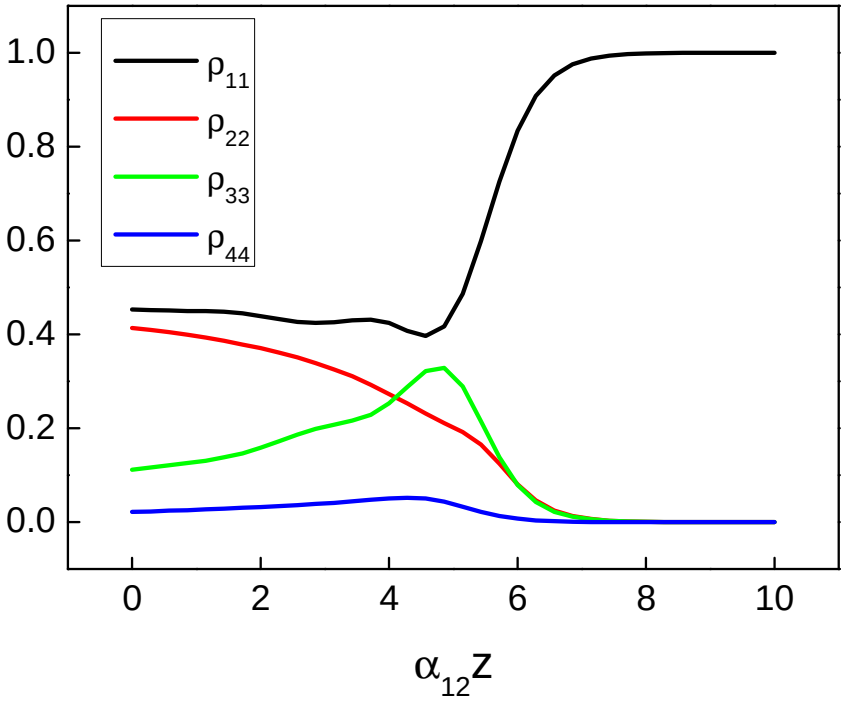

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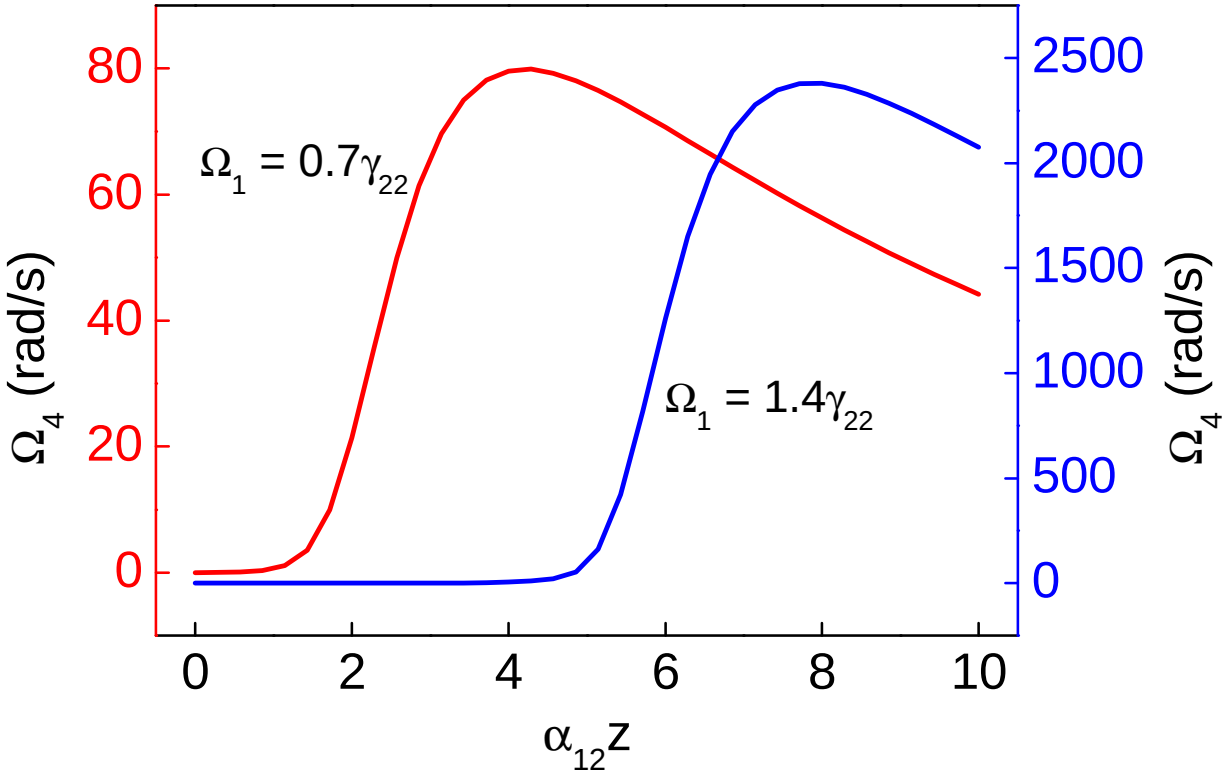

Conclusions

- We have investigated the coherent blue light generated in atomic vapor using a parametric four-wave mixing process due to the combined action of a cw laser and a train of ultrashort pulses.
- Many modes can be responsible for inducing the nonlinear process.
- Blue signal characterization: exponential growth with saturation.
- The density dependence was theoretically modeled.
- Next step: frequency diode dependence modeling with CUDA parallel programming (See poster P116 this afternoon).

C A P E S

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

FACEPE
Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco

Thank you very much!