# Towards fast-light gyroscope, modification of dispersion, and pulling sensitivity

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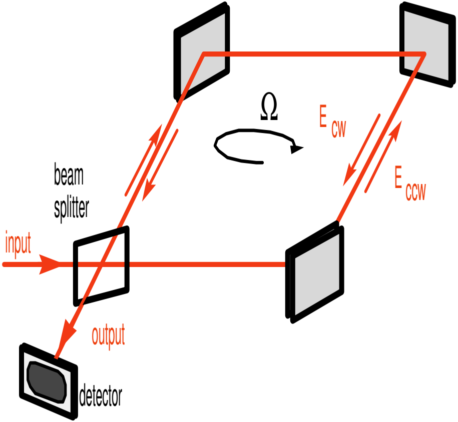
Rochester Scientific

SPIE, 09 Febraury 2015

# Sagnac effect in interferometer

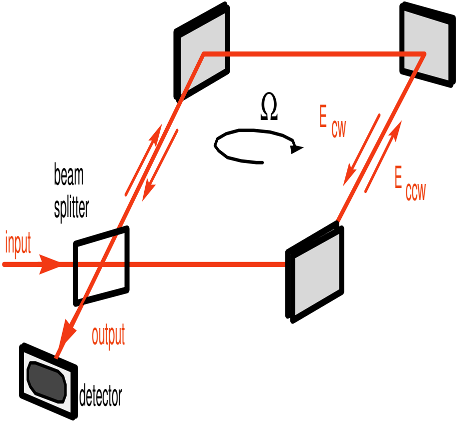



$$t_{\pm} = \frac{2\pi R}{c}\left(1 \pm \frac{R\Omega}{c}\right)$$

$$\Delta t = t_{+} - t_{-} = \frac{4\pi R^2\Omega}{c^2}$$

$$\Delta\phi = 2\pi\frac{c\Delta t}{\lambda} = \frac{8\pi A\Omega}{c\lambda}$$

# Sagnac effect and cavity response




$$\Delta p = c\Delta t = \frac{4A\Omega}{c}$$

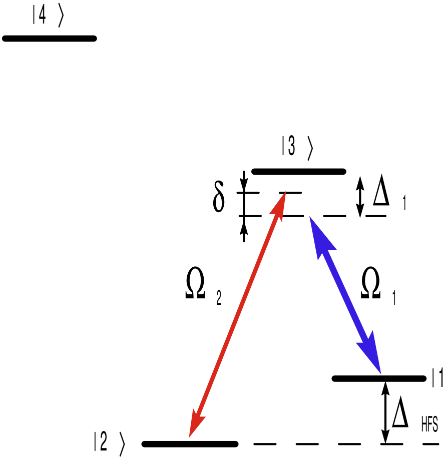
$$\Delta f = f_0 \frac{\Delta p}{p} \frac{1}{n_g} = \Delta f_{empty} \frac{1}{n_g}$$

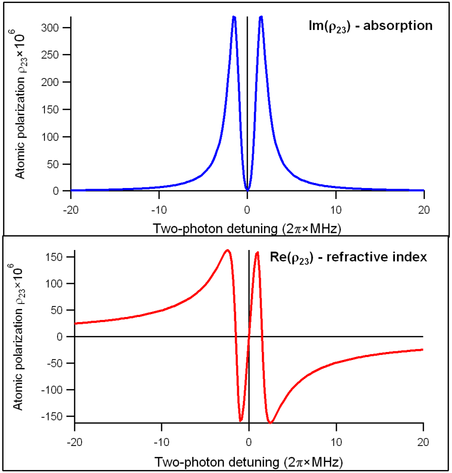
Group index

$$n_g(f) = n + f_0 \frac{\partial n}{\partial f}$$

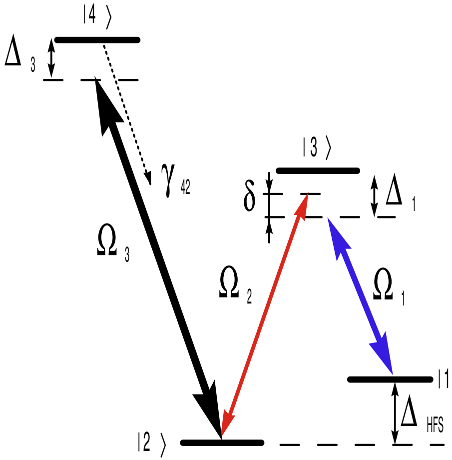
Cavity response enhanced if $n_g < 1$ i.e. under the fast light condition

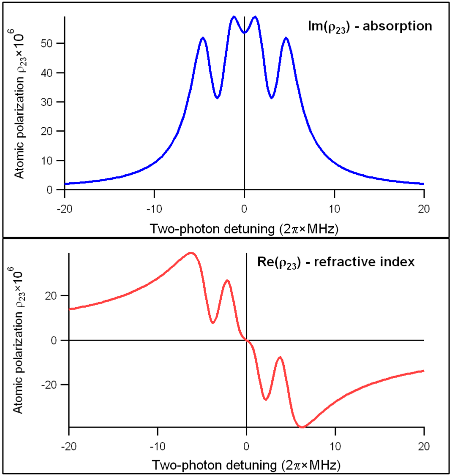
Shahriar et al., PRA **75**, 053807 (2007)


|4 ⟩
|3 ⟩
δ
Δ 1
Ω 2
Ω 1
|1
Δ HFS
|2 ⟩

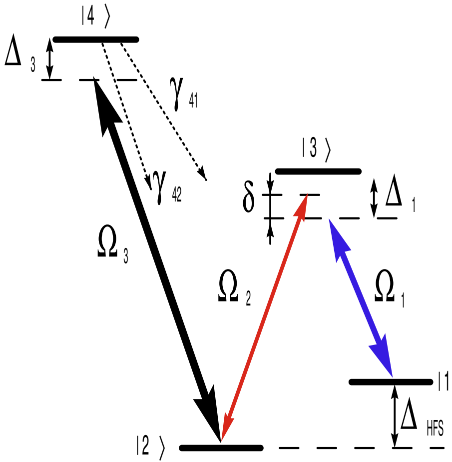

Im(ρ23) - absorption
Atomic polarization ρ23×10^6
Two-photon detuning (2π×MHz)
Re(ρ23) - refractive index
Atomic polarization ρ23×10^6
Two-photon detuning (2π×MHz)

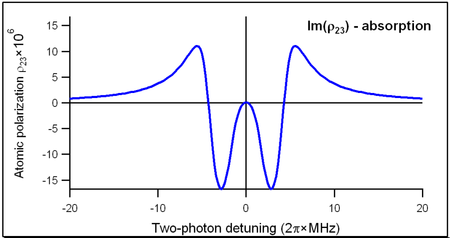
# N-scheme, with forbidden transition - fast but no gain

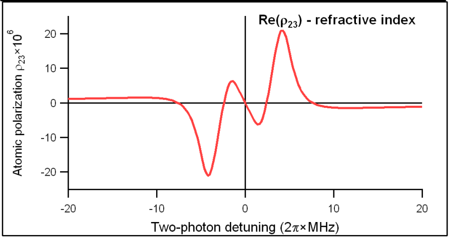


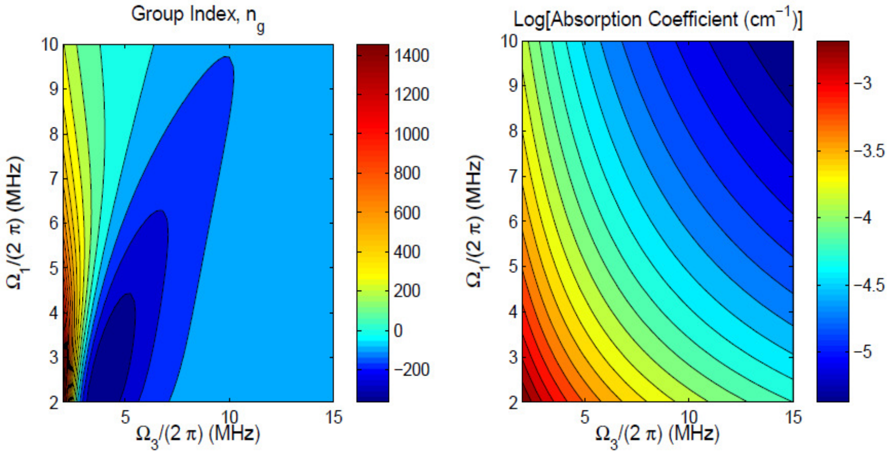
# N-bar with four-wave mixing - fast and with gain



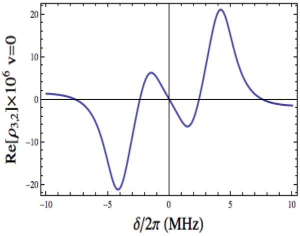
# N-bar with four-wave mixing - optimal parameters

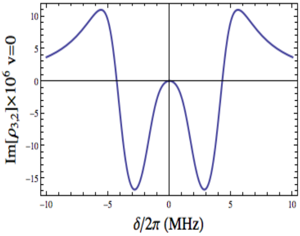



N. B. Phillips, *et al.* Journal of Modern Optics, Issues 1, 60, 64-72, (2013).

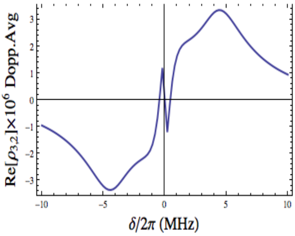
# N-bar with Doppler averaging

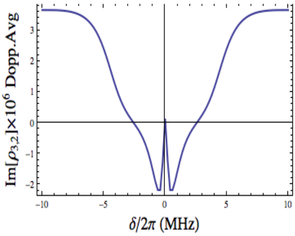
Refractive index | Absorption




Stationary atoms

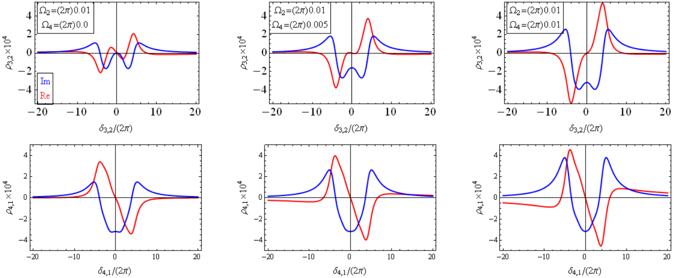


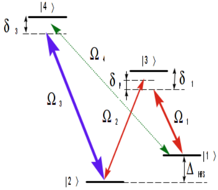




Room temperature
Doppler averaged

# N-bar field competition

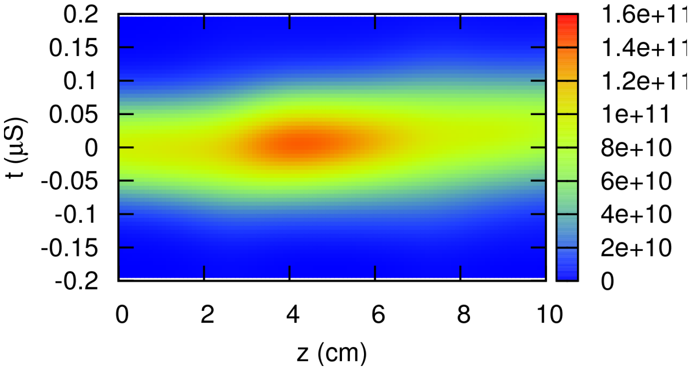
$\Omega_4 = 0$ $\quad$ $\Omega_4 = \Omega_2/2$ $\quad$ $\Omega_4 = \Omega_2$

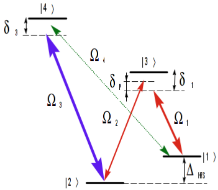


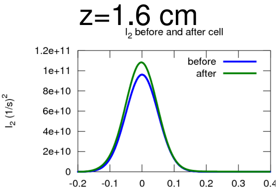



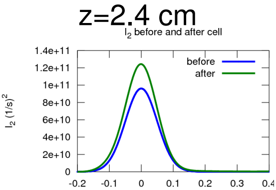

$\Omega_1 = 2\pi 3$ MHz, $\Omega_3 = 2\pi 6$ MHz, $N = 10^9$ cm$^{-3}$

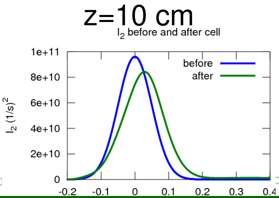
# N-bar beam propagation



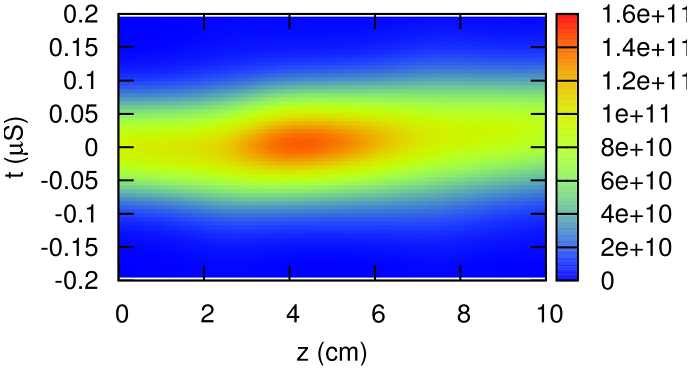



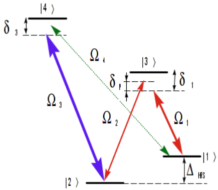



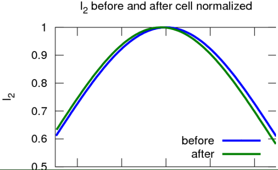



# N-bar beam propagation

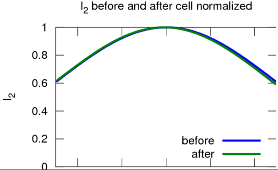


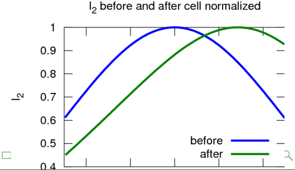
z=1.6 cm




z=2.4 cm

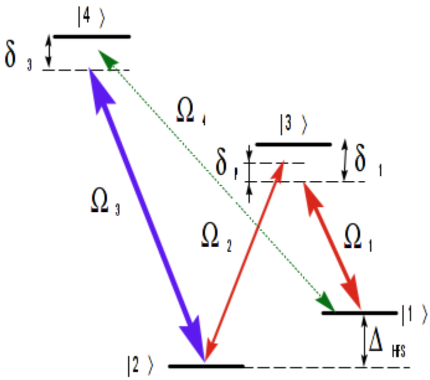



z=10 cm

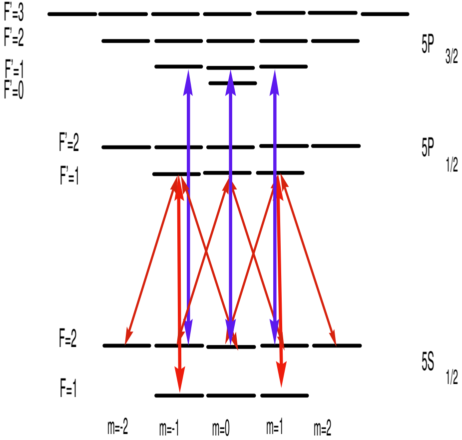


# N-bar levels and fields diagram

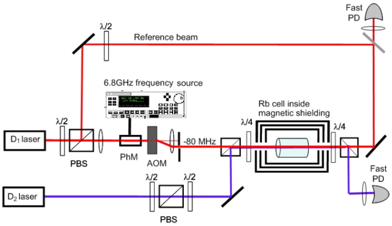
Artificial atom



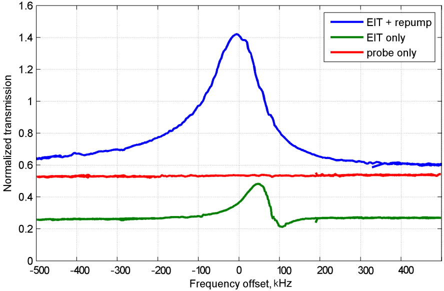

$^{87}$Rb atom



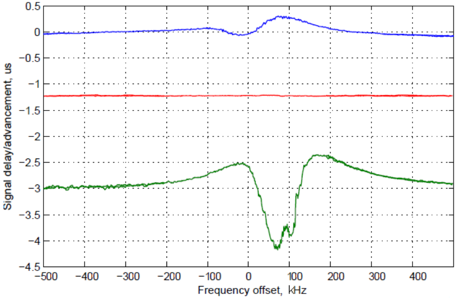
# N-bar scheme linearly polarized pumps - single pass



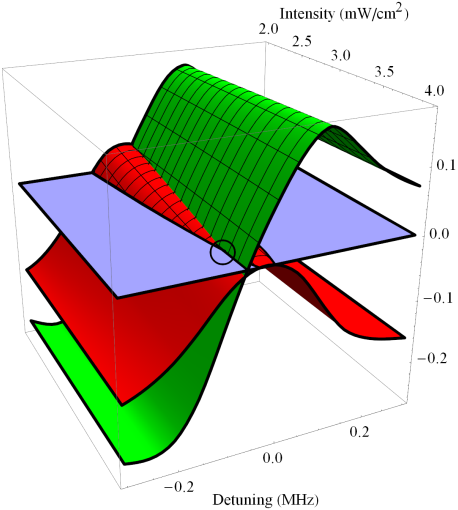

## Transmission




## Delay



# Gyro lasing - no fast light condition



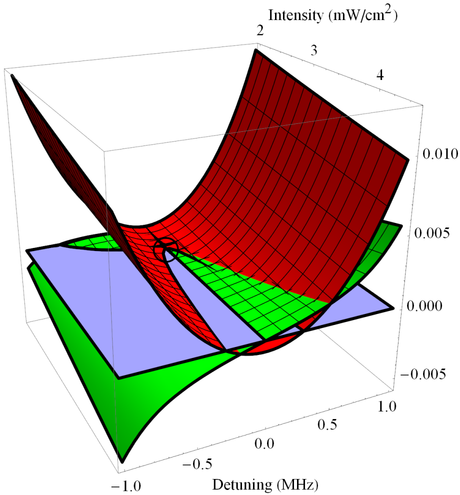

Lasing conditions

- round trip gain is 1
- round trip phase shift is 0

Simulation parameters

- N = $9.6 \times 10^{10}$ 1/cm$^3$
- $\delta_1 = -2\pi \times 800$ MHz
- $\delta_3 = 0$ MHz
- $\Omega_1 = 6$ mW/cm$^2$
- $\Omega_3 = 10$ mW/cm$^2$
- Finesse = 18

# Gyro lasing - fast light condition, single frequency




Lasing conditions

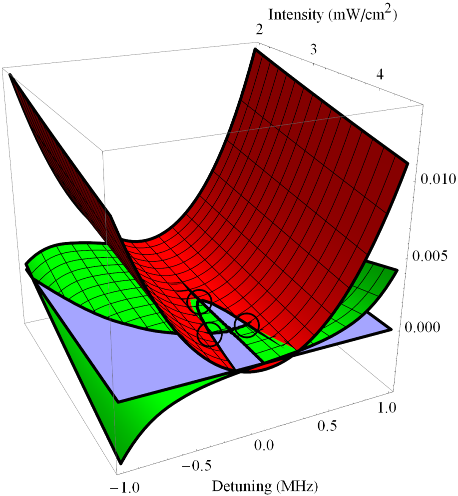
- round trip gain is 1
- round trip phase shift is 0

Simulation parameters

- N = 4.8 × 10$^{10}$ 1/cm$^3$
- $\delta_1 = 0$ MHz
- $\delta_3 = 0$ MHz
- $\Omega_1 = 48.2$ mW/cm$^2$
- $\Omega_3 = 192.9$ mW/cm$^2$
- Finesse = 60

$$\Delta f = 150 \Delta f_{empty.cavity}$$

# Gyro lasing - fast light condition, multiple frequencies




Lasing conditions

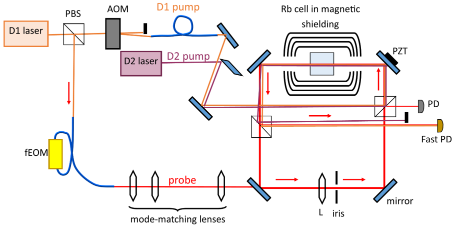
- round trip gain is 1
- round trip phase shift is 0

Simulation parameters

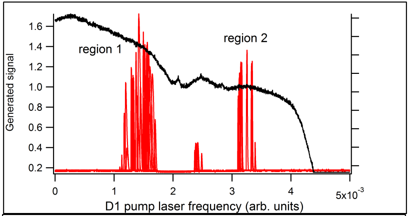
- N = $4.8 \times 10^{10}$ 1/cm$^3$
- $\delta_1 = 0$ MHz
- $\delta_3 = 0$ MHz
- $\Omega_1 = 50.6$ mW/cm$^2$, 5% higher
- $\Omega_3 = 192.9$ mW/cm$^2$
- Finesse = 60

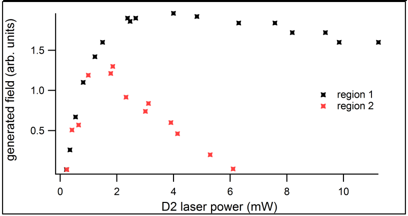
Multiple lazing points might be problematic in the experiment

# First gyro setup and its performance

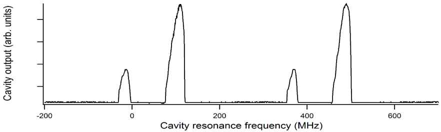



$\Omega_2$ tuned around $F = 1 \rightarrow F' = 1, 2$



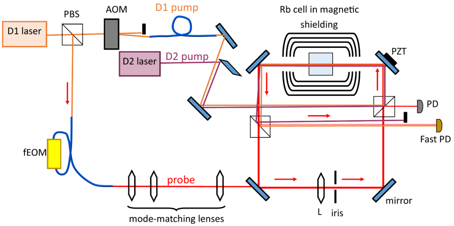




Finesse = 20

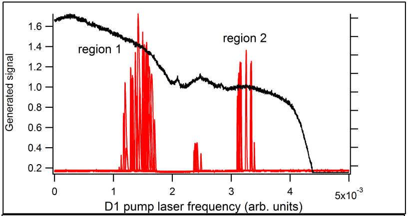



E. Mikhailov, *et al.* Optical Engineering, Issue 10, 53, 102709, (2014)

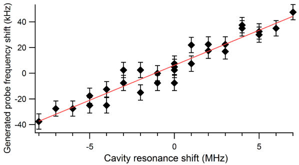
# First gyro setup and its performance

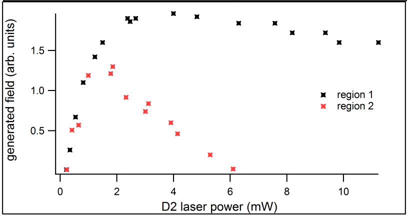



$\Omega_2$ tuned around $F = 1 \rightarrow F' = 1, 2$



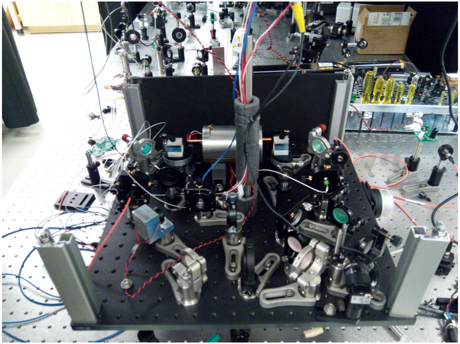

Finesse = 20 $\rightarrow$ Pulling $1/200$

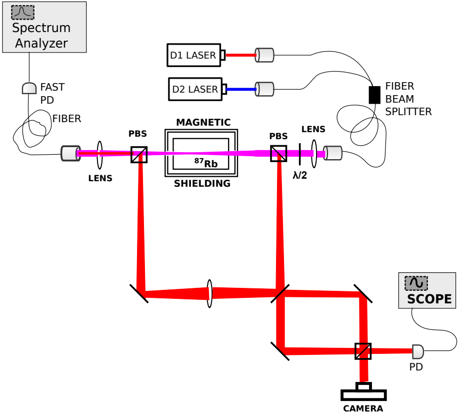


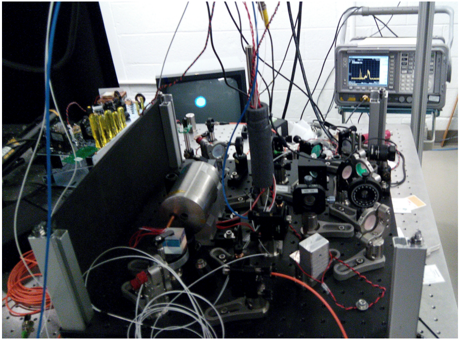

E. Mikhailov, *et al.* Optical Engineering, Issue 10, 53, 102709, (2014)

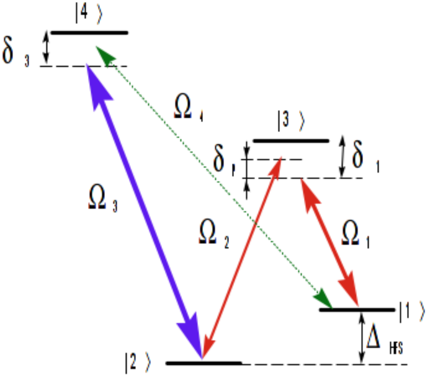
# Gyro setup




Spectrum Analyzer
FAST PD
FIBER
D1 LASER
D2 LASER
FIBER BEAM SPLITTER
MAGNETIC
SHIELDING
$^{87}$Rb
PBS
PBS
LENS
LENS
λ/2
SCOPE
PD
CAMERA

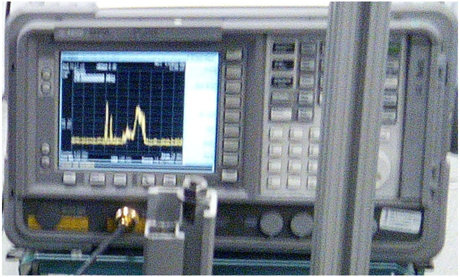
# Gyro setup and lasing beat-note

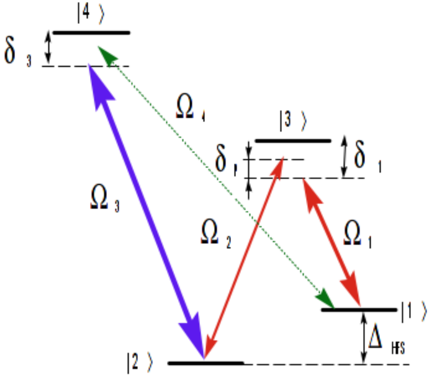




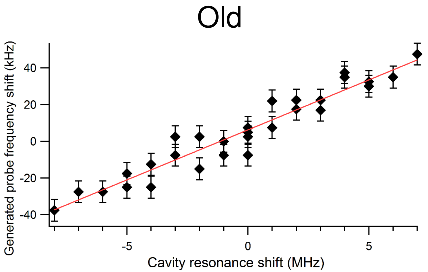
# Gyro setup and lasing beat-note

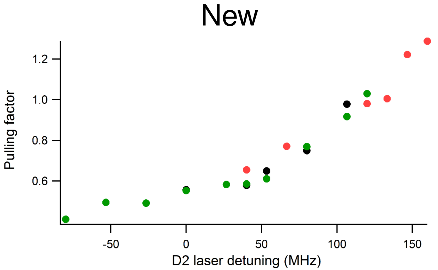
Spectrum analyzer 20 MHz span





# Gyro pulling - response to cavity length change




Pulling drastically improved by mainly two factors

- Higher finesse 20 $\rightarrow$ 70
- Higher pumping powers

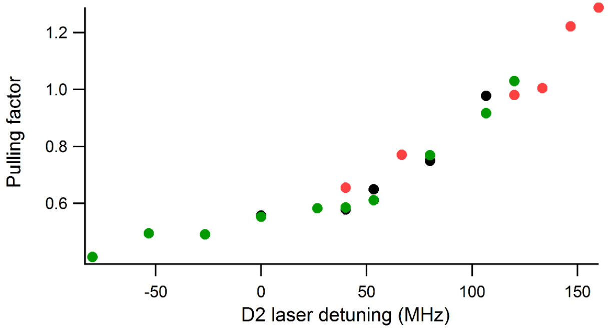
Higher pulling happens at $D_2$ detuning where lasing tends to stop

# People


Irina Novikova, Matt T. Simons, Joshua Hill, Hunter Rew (WM), Dmitry Budker, Simon Rochester (Rochester Scientific).

# Summary

- We demonstrated feasibility of fast laser
- Our laser has pulling factor exceeding 1
- We are working on the laser stabilization to demonstrate rotation sensitivity




Financial support NAVAIR