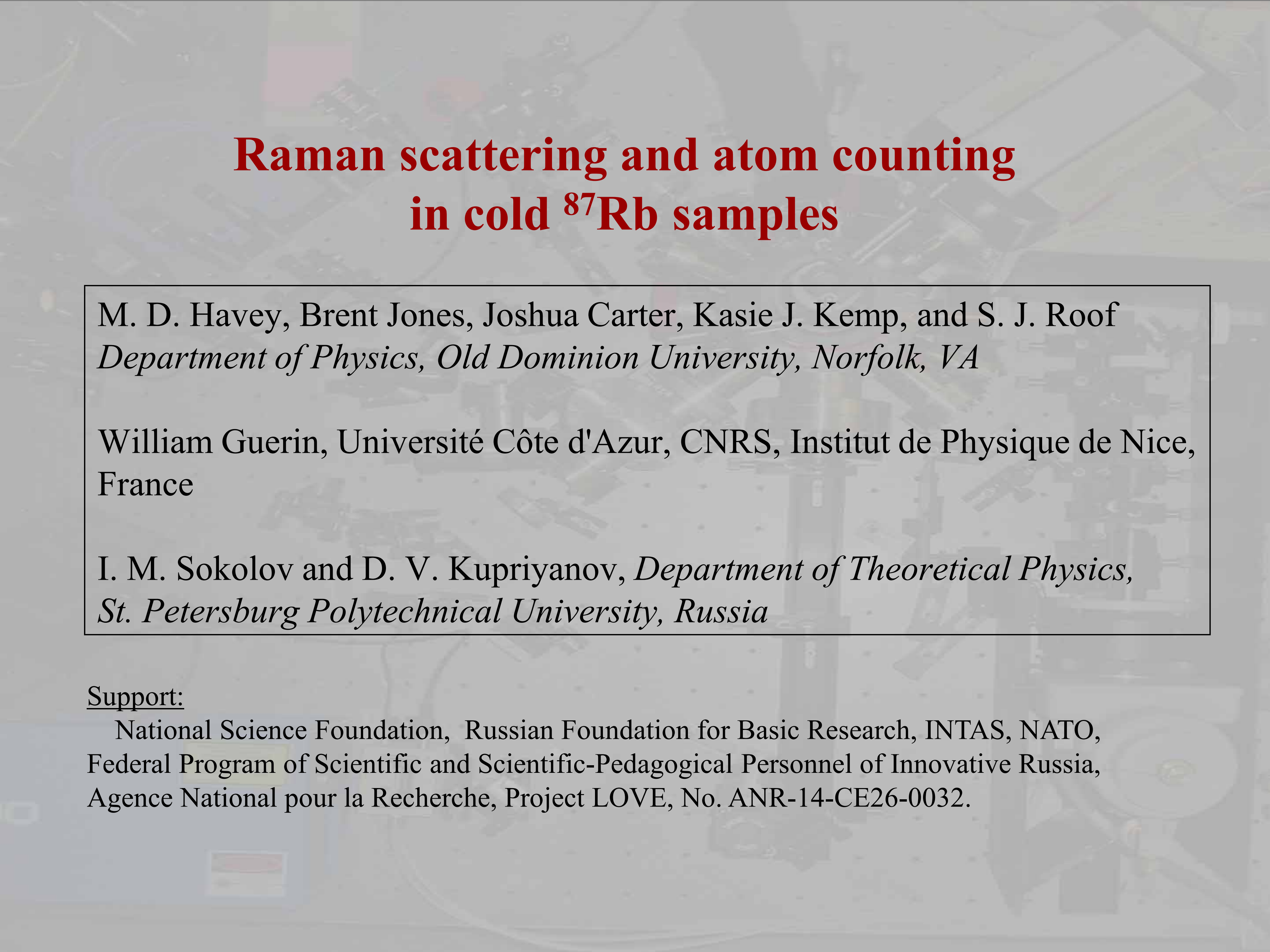


Raman scattering and atom counting in cold ^{87}Rb samples

M. D. Havey, Brent Jones, Joshua Carter, Kasie J. Kemp, and S. J. Roof
Department of Physics, Old Dominion University, Norfolk, VA

William Guerin, Université Côte d'Azur, CNRS, Institut de Physique de Nice, France

I. M. Sokolov and D. V. Kupriyanov, *Department of Theoretical Physics, St. Petersburg Polytechnical University, Russia*

Support:
National Science Foundation, Russian Foundation for Basic Research, INTAS, NATO, Federal Program of Scientific and Scientific-Pedagogical Personnel of Innovative Russia, Agence National pour la Recherche, Project LOVE, No. ANR-14-CE26-0032.

Talk organization

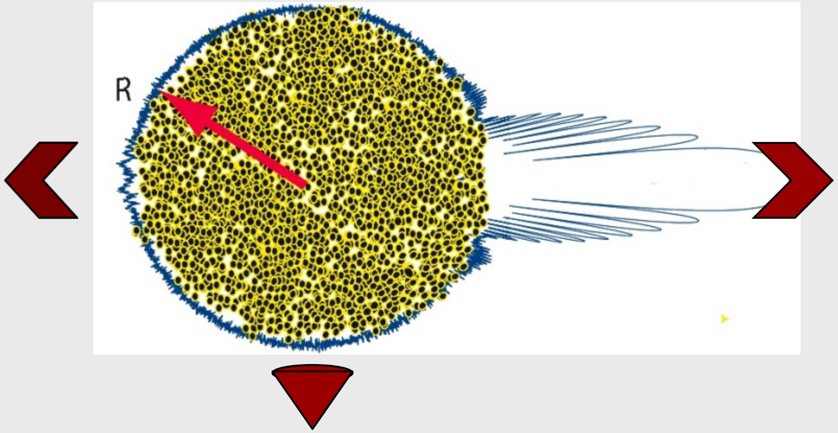
- Introductory remarks

- Current focus
  - Light scattering on open transitions: counting atoms
  - Cooperative/collective interactions, open transitions and optical depth scaling in denser samples

- Recent efforts
  - Steady-state coherent beam transmission measurements
  - Optical lensing in a FORT
  - Large sample linear optics super-radiance

- Earlier studies
  - Scattering and afterglow in high-density and cold ^{87}Rb
  - F = 2 - F' = 3 and F = 1 - F' = 0 light scattering experiments
  - Scaling and comparison with calculations
  - Time evolution of action spectra

Some cold atom light scattering processes



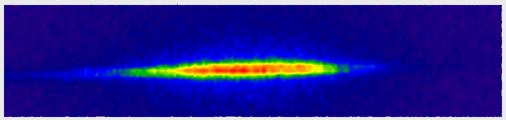
Coherent backscattering

Super-radiance
Super-flash, FID

Sub-radiance
Super-radiance
Diffuse scattering

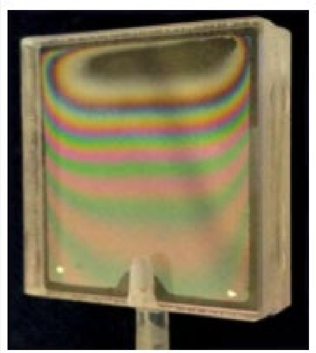
Diffusely scattered light intensity:

- Sample is anatomically granular - homogenization
- Speckled in each realization – not self averaging
- Polarization, residual thermal motion, detuning are important

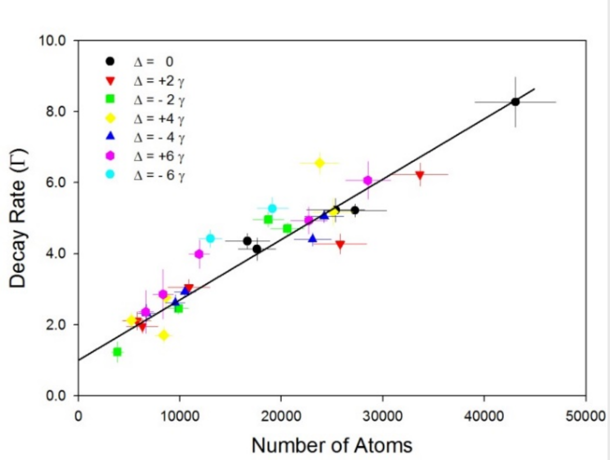


Modified image borrowed from Svidzinsky, *et al.*
Phys. Rev. Lett. 100, 16054 (2008).

Some recent and connected experimental research

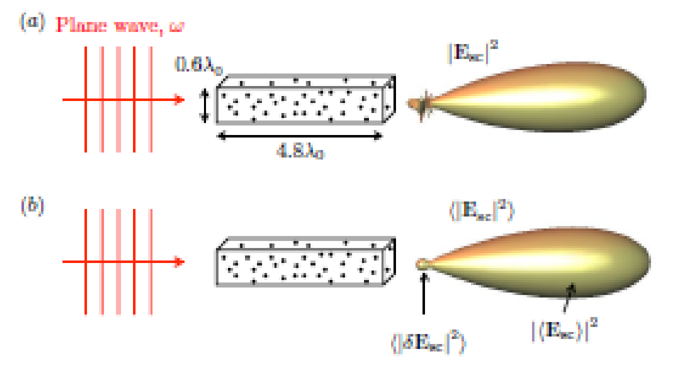


Collective Lamb shift of a nanoscale atomic vapor layer….T. Peyrot, (PRL, 2018)

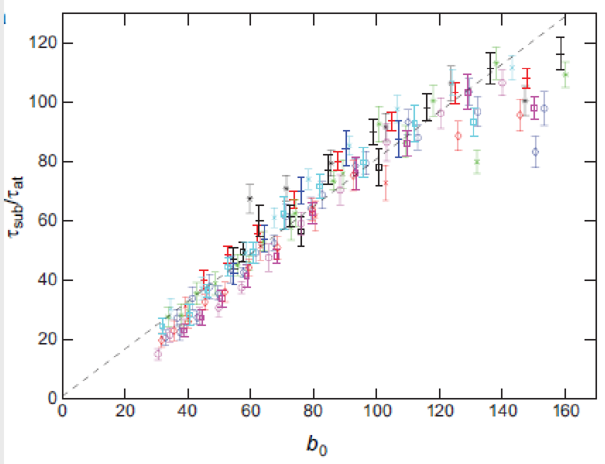


Super radiance in an extended ensemble of cold atoms, S.J. Roof, *et al*. (PRL, 2016)

Super radiance in a large cloud of cold atoms…M. O. Araujo, *et al.* (PRL, 2016)



Homogenization of an ensemble of interacting…, N.J Schilder*, et al*., (PRA, 2017)



Dicke subradiance in a large cloud of cold atoms, W. Guerin, *et al*., (PRL, 2016)

Focus of the current project

Motivations:

- *Direct measurement of the atom number in a Bose condensate*, Hung-Wen Cho, *et al.*, (Optics Express 15, 12114 (2007).
- *Collective suppression of optical hyperfine pumping in dense clouds of atoms in microtraps*, Shimon Machluf, *et al.*, (ArXive:1804,09759v1, 2018).
- Baseline for experiments at higher density / optical depth when cooperative effects should appear.

The experimental questions we ask:

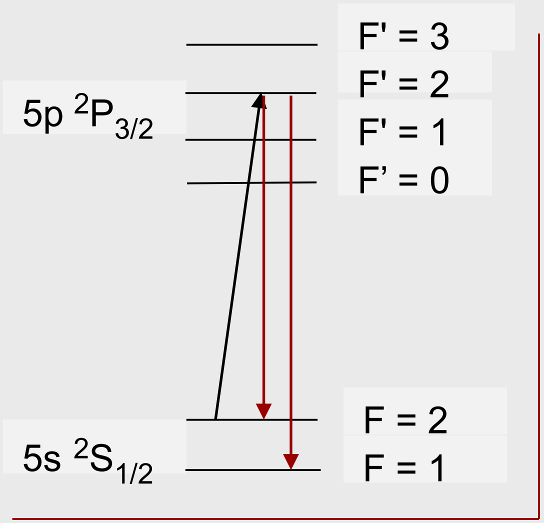
How do optical transients and time-integrated scattered light intensity scale

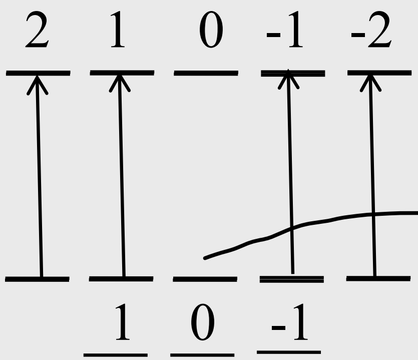
- with probe intensity and detuning from resonance?
- With peak atomic density or optical depth?

What do we observe?

- Nearly constant time-integrated intensity with detuning variations
- Lorentzian variation of optical pumping rate
- ***Suggestion of scaling of quantities with optical depth***

Experimental scheme: atom counting on open transitions in cold gases



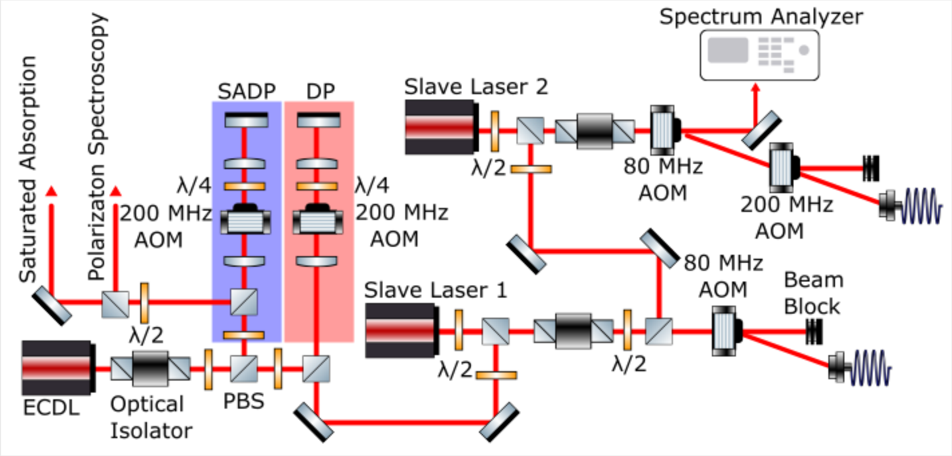


F'-F	3-2	2-2	2-1	1-2
P_L	9/28	21/47	1/67	-7/11

Dark state

Solve by:

1. External B
2. Polarization switching
3. Multiple scattering



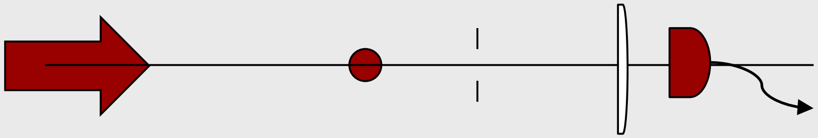
To sample chamber

Simple technique for directly and accurately counting the number of atoms in a magneto-optical trap, Y.-C. Chen, *et al*., (PRA 64, 031401, 2001)

Direct measurement of the atom number in a Bose condensate, Hung-Wen Cho, *et al*., (Optics Express 15, 12114 (2007)

Analysis and results: data channels

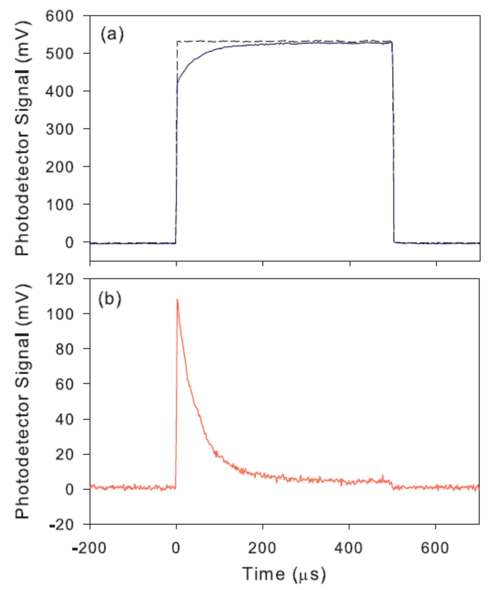
Forward Scattering

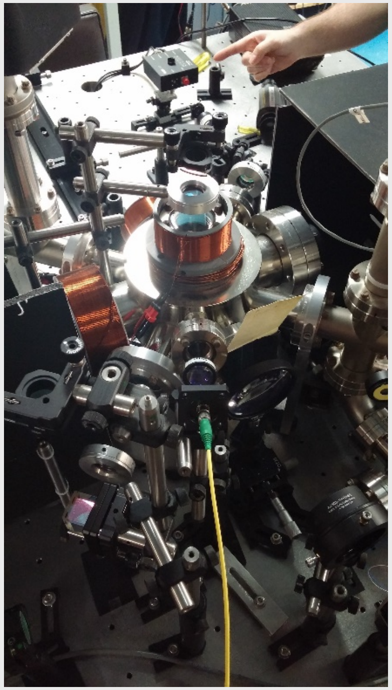


Probe beam MOT/FORT Detector/Scope

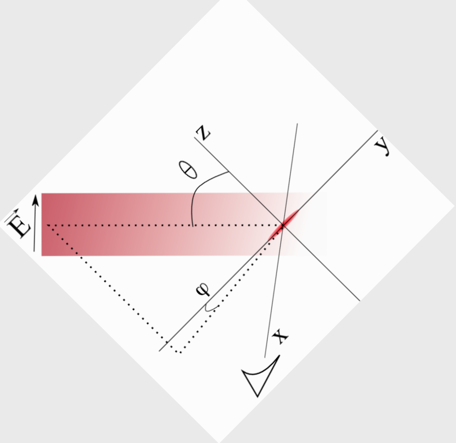
$$N_A = \frac{\lambda}{2hc}\chi \int dt V(t)$$

$\chi = 0.3774$ mW/V

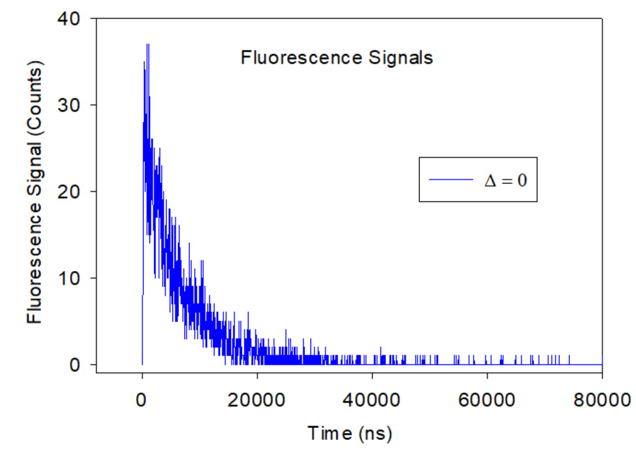




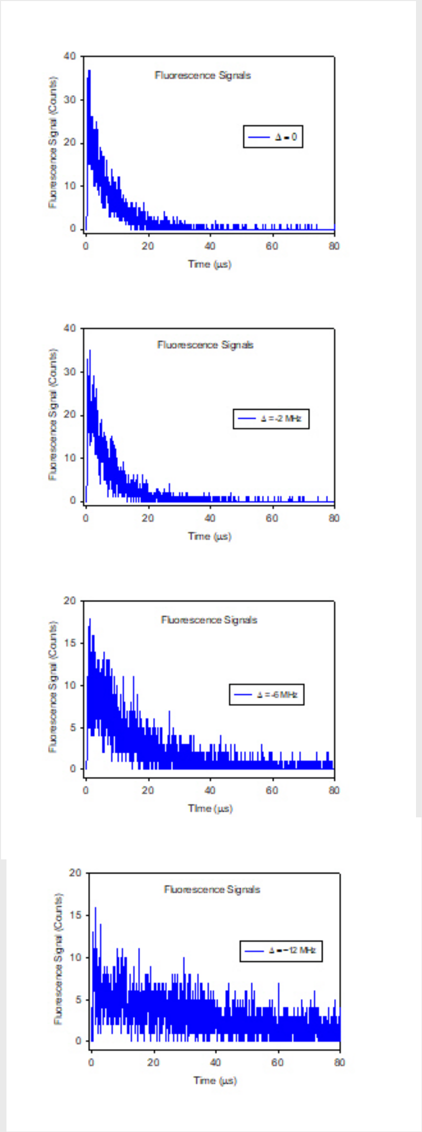
Fluorescence



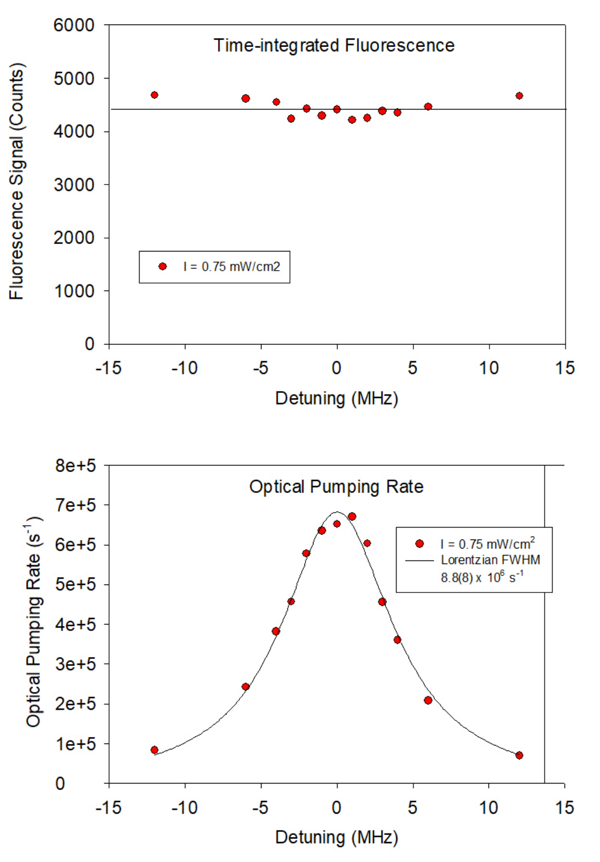
PMT → MCS



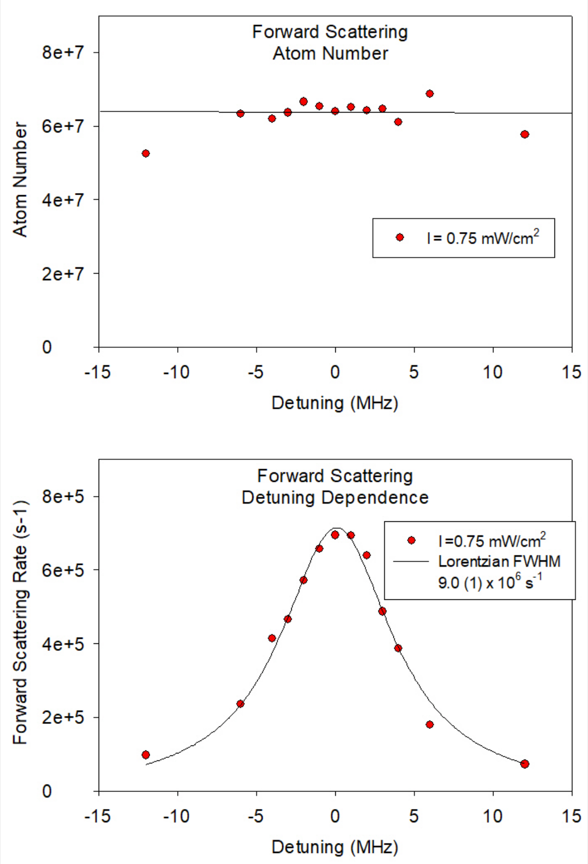
Observation of constant (with detuning) time-integrated signals



Fluorescence Signals



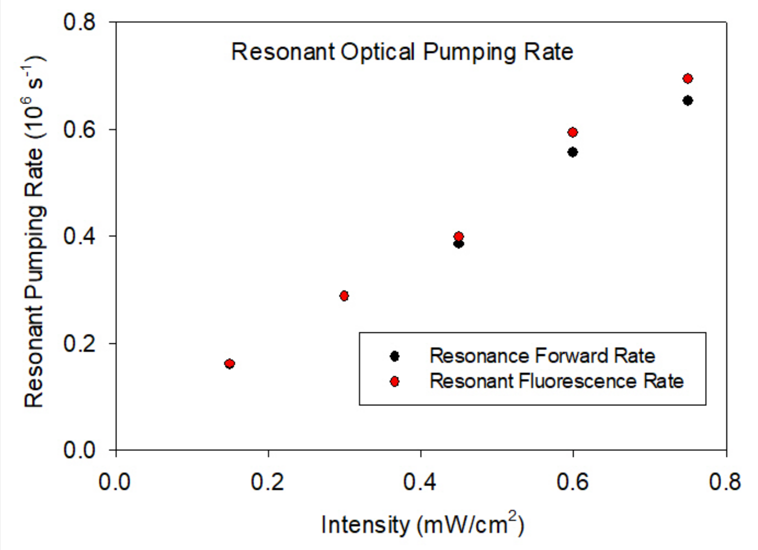
Forward Scattering

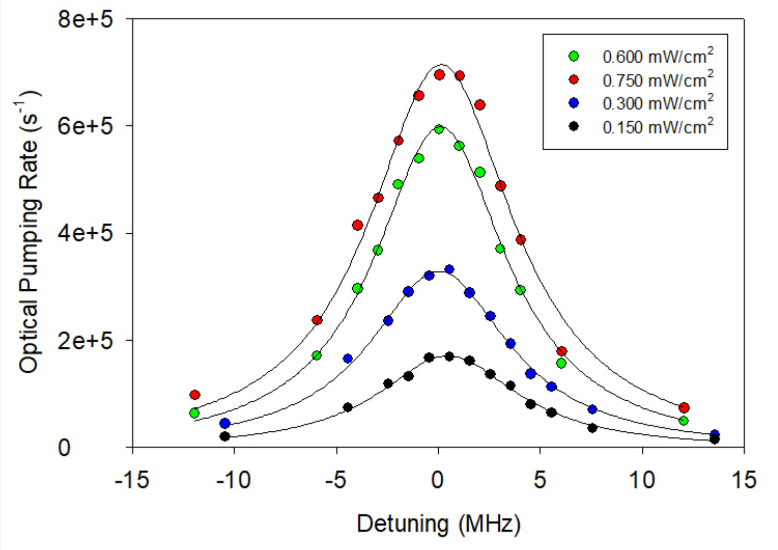


Notes:

1. Approximately constant time integrated signals with detuning
2. Similar detuning curves – final state interactions?

Probe intensity dependent features in the measurements

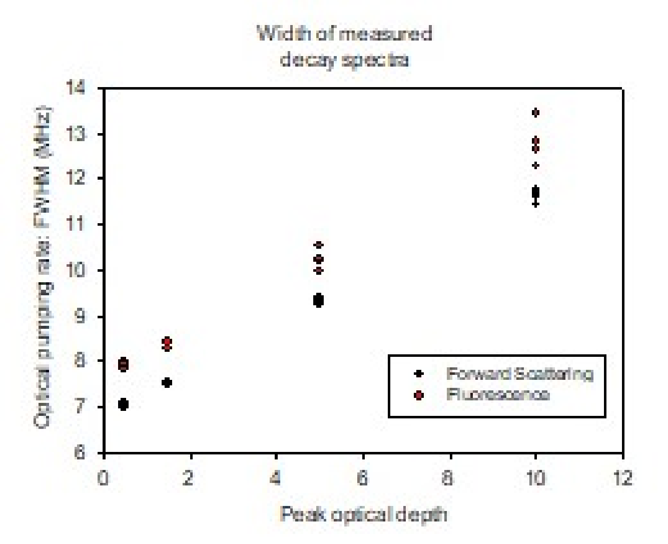


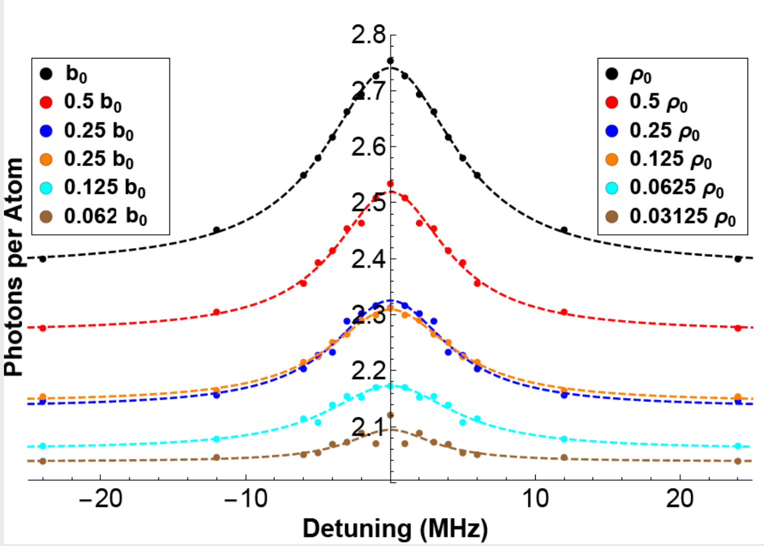


Resonant optical pumping rate is linear with probe intensity. Fluorescence and forward scattereing show essentially the same behavior.

Width remains constant at about 9 MHz while the peak of the Lorentzian grows linearly with probe intensity.

Random walk simulations – breakdown of the approach





Random walk simulations done, including Raman scattering. Applied at greater optical depth. Multiple scattering can occur on the 2 – 2 Rayleigh transition and the 2-1 Raman transition. This can lead to (a) redirection of the polarization of the fields inside the medium, or (b) lead to over counting the number of atoms in a sample.

Summary & Conclusions

Counting atoms by Raman scattering appears to work, so long as b << 1. In this regime, the number of atoms counted is constant with detuning, probe intensity, and atom density over a quite large range.

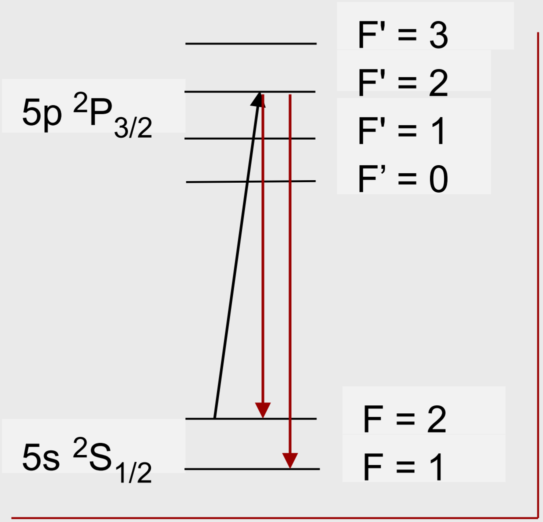
When b > 1 multiple scattering emerges and leads to a breakdown of uniform atom counting. In this case, simulations show that the number of atoms is overcounted when the probe is tuned near resonance.

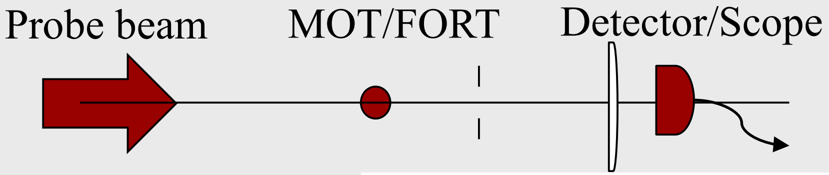
Multiple scattering may lead to mitigation of the dark state in the F = 2 level. This is because redirection of the initial probe polarization can lead to optical pumping of the F = 2, M = 0 state.

Other projects:

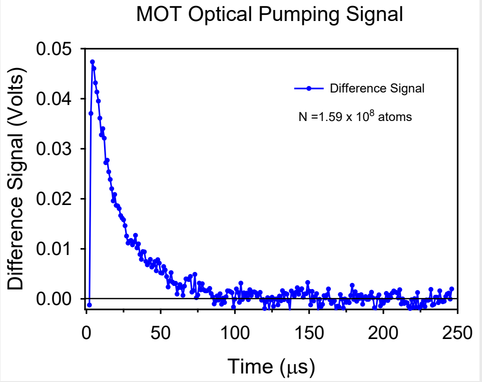
- Counting atom flux – 2D MOT (Narducci)
- Counting hot atoms/molecules, vapor pressure (Bayram)
- Enhanced multiple scattering
- Limits of the 3D method

Light scattering in cold gases on open transitions: counting atoms





$$N_A = \frac{\lambda}{2hc}\chi \int dt V(t)$$



$$\Gamma = \frac{w_a^3}{3\pi\epsilon_0\hbar c^3}\frac{2J+1}{2J'+1}|\langle J||d||J'\rangle|^2 \sum_F S_{FF'},$$

$$S_{FF'} = (2J'+1)(2F+1)\begin{Bmatrix} J & F & I \\ F' & J' & 1 \end{Bmatrix}^2$$

$$N_{photon} = 1 + \frac{1}{2} + \left(\frac{1}{2}\right)^2 + \cdots = 2$$

Other Projects

- Count atom flux – 2D MOT (Narducci)
- Count hot atoms/molecules, vapor pressure (Bayram)
- Suppress multiple scattering
- Limits of the method

Simple technique for directly and accurately counting the number of atoms in a magneto-optical trap, Y.-C. Chen, *et al.*, (PRA 64, 031401, 2001)