# Abstract

We have developed a comprehensive two semester laboratory course dedicated to laser cooling and trapping of neutral atoms. The course is accessible for undergraduate students in physics, applied physics, biophysics and engineering physics as well as incoming graduate students. In the first semester, students are introduced to eleven experiments dedicated to topics such as laser spectroscopy, laser frequency stabilization, optical detectors, electro-optic and acousto-optic devices, optical fibres, RF and digital electronics, vacuum systems and data acquisition and analysis. In the second semester, students carry out atom trapping and preliminary investigations of the properties of laser cooled atoms based on the expertise acquired in the first semester. We present an overview of experiments related to this course and give details related to the construction of home-built diode lasers and tapered amplifiers that can reduce the cost of course development. This work has been submitted to the Canadian Journal of Physics.

# Course Format

**4061: *Experimental Techniques in Laser Physics* - 3 credits**
- Cycle through 11 labs in groups of 2
- Two 3 hour lab sessions per week
- Two TA's and instructor present
- Enrollment restricted to 20 students per section
- Brief lab reports with extensive curve fitting and analysis
- Oral and written exams
- 12 lecture module covers theory of instrumentation
- **emphasis is on hands-on skills**

**4062: *Atom Trapping Lab* - 3 credits**
- Students work in groups of 4-5.
- Each group attempts to trap Rubidium atoms.
- Carry out simple tests on cold Rb atoms.
- Comprehensive lab report.
- Oral and written exams.
- 12 lecture module covers theory of radiation pressure force and optical dipole forces.

**Both courses are available to graduate students as 5061 and 5062.**

# 4061 Experiments

**Common Mathematica data analysis tutorial**

1. Doppler Free Spectroscopy and the Zeeman Shift
2. Emission/Absorption Spectroscopy & Electro-optic Modulator
3. Lock-in Amplifier: Laser Frequency Stabilization
4. Optical Detectors
5. Gaussian Beam Propagation & Fiber Coupling
6. Reflection & Transmission of EM Waves
7. Fabry-Perot/Laser Linewidth/Index of Refraction & Faraday Isolator
8. RF Circuits & Heterodyne Detection
9. Vacuum Systems
10. Data Acquisition - Labview

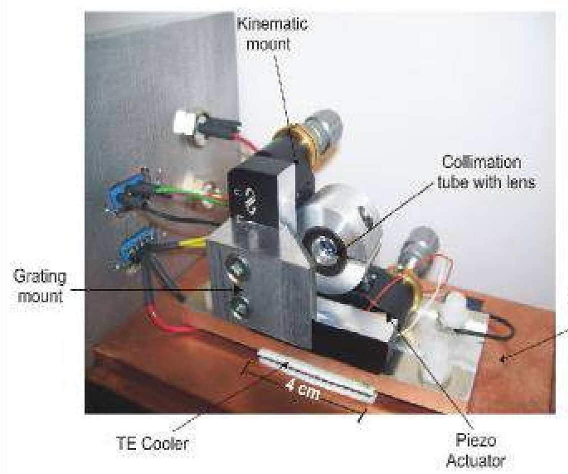
**4062 Outline**
- Trapping Rb atoms
- Open ended experiments with cold atoms measuring:

i. Temperature
ii. Optical Pumping
iii. Atom number
iv. Absorption

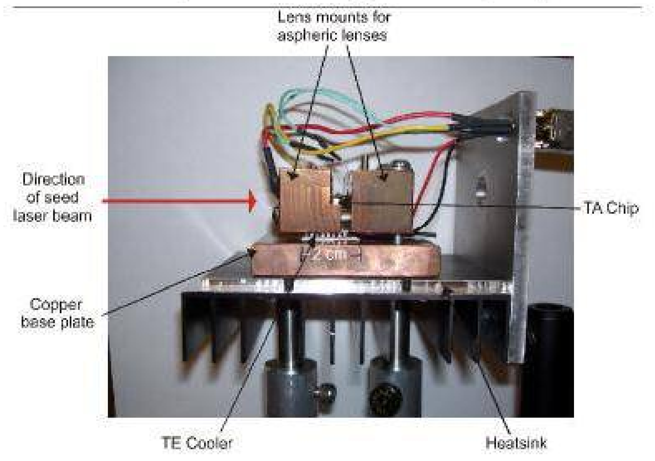
# Home Built Laser Systems

External cavity diode laser (ECDL)

**Specifications**:
- 150 mW output power
- 1 MHz laser linewidth
- 10 GHz scan range

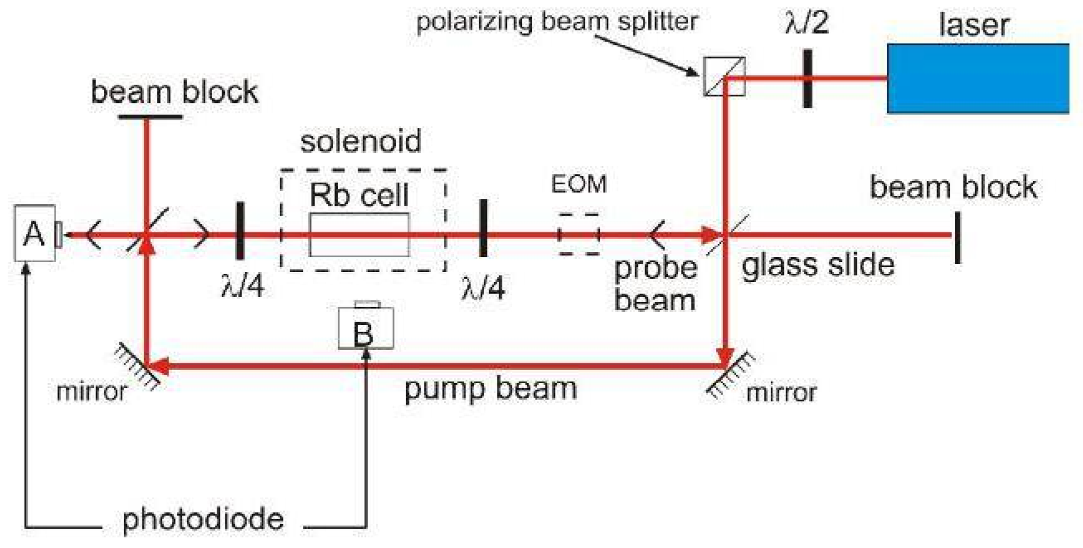



Tapered amplifier (TA)




**Specifications**:
- 20 mW seed power
- 850 mW output
- injection current of 1.7 A
- no water cooling required

# Experimental Setup for Three ECDL-Based Labs

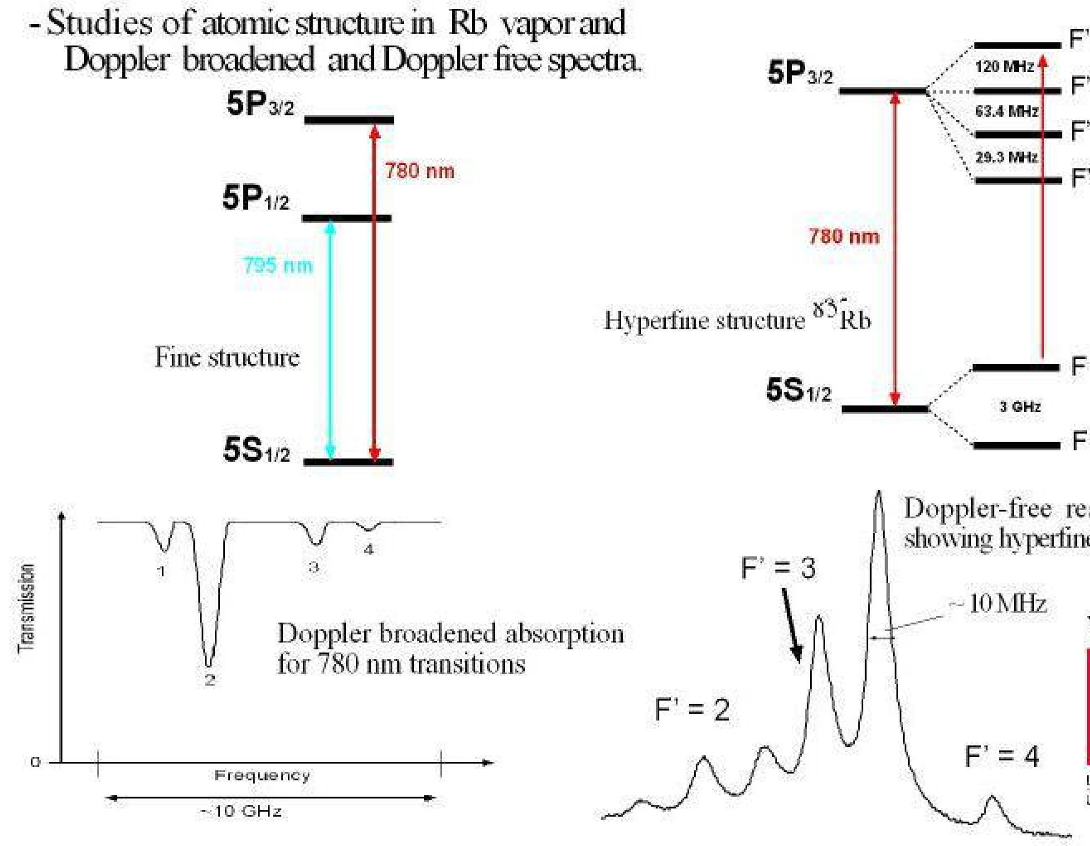



This setup allows the study of:

i. Fluorescence and absorption spectroscopy frequency sidebands due to EOM
ii. Zeeman shift of spectral lines
iii. Laser frequency stabilization using lock-in detector.

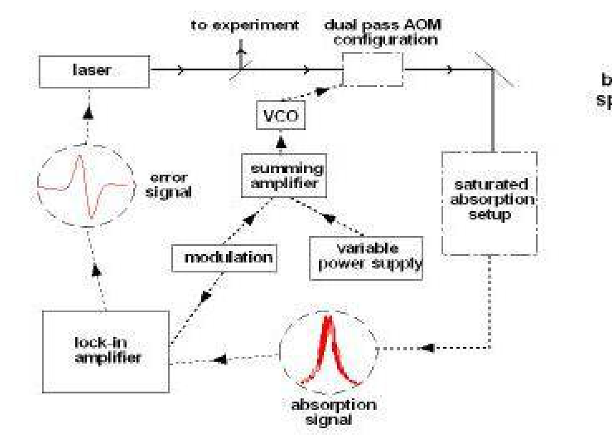
# Absorption and Fluorescence Spectra

- Studies of atomic structure in Rb vapor and Doppler broadened and Doppler free spectra.

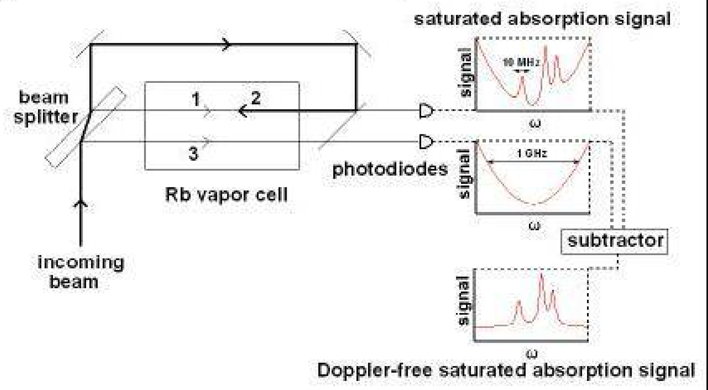



# Laser Frequency Locking to Atomic Transition

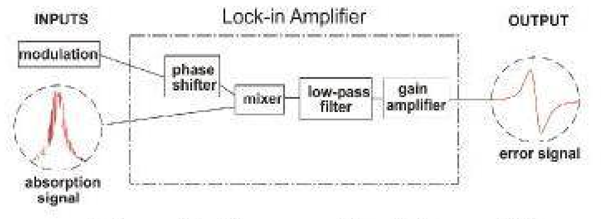
Setup for obtaining the first derivative error signal



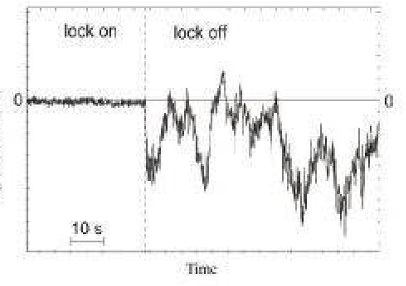

Saturated absorption setup




Students assemble lock-in detector and stabilize laser frequency to atomic transition

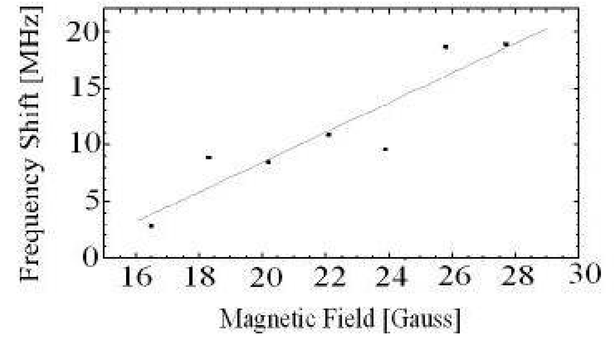



Schematic diagram of lock-in amplifier



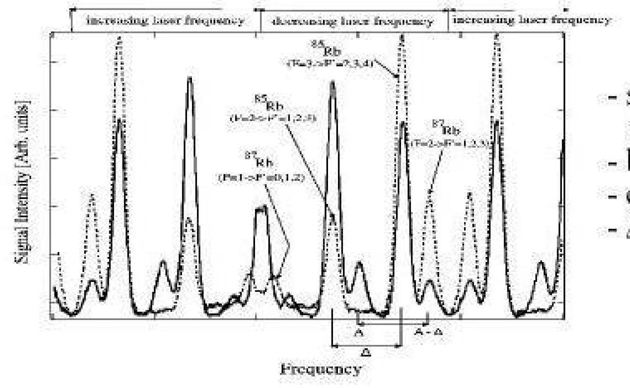

# Zeeman Shift and Electro-Optic Modulation

The frequency shift of the F = 3 to F' = 4 transition as a function of magnetic field




- slope gives (1.31 ± 0.25) MHz/Gauss for the Zeeman shift; expected value for the F = 3, $m_F$ = 3 to F' = 4, $m_F$ = 4 transition is 1.4 MHz/Gauss.

Oscilloscope traces of the fluorescence signal observed as the laser frequency is scanned

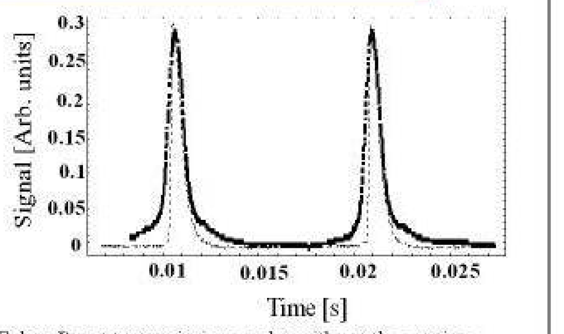



- spectra are Doppler broadened transitions
- broken line: EOM off.
- continuous line: EOM on
- Δ= 2.915 GHz.

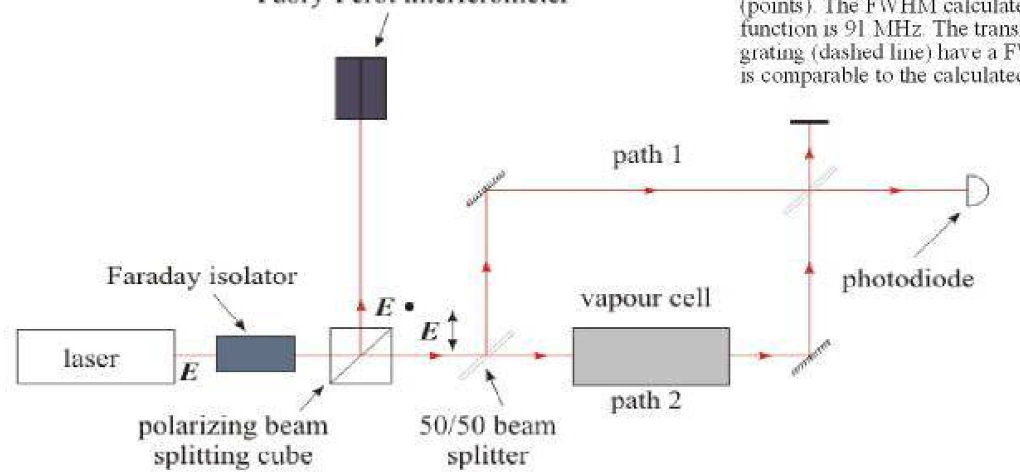
# Laser Linewidth/ Faraday Isolator/ Refractive Index

This setup allows the measurment of:

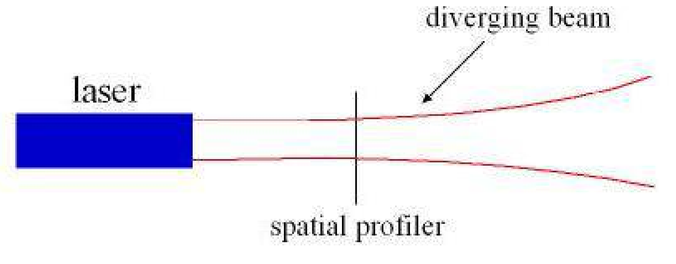
i. Linewidth of the laser using Fabry-Perot interferometer with and without grating feedback
ii. Index of refraction of Rb vapour using interferometer
iii. Properties of a Faraday isolator




Fabry-Perot transmission peaks without the grating (points). The FWHM calculated by using an interpolation function is 91 MHz. The transmission peaks with the grating (dashed line) have a FWHM of 58 MHz which is comparable to the calculated resolution of the FPI.

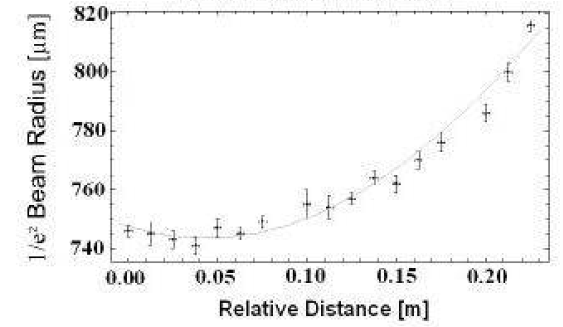



# Gaussian Beam Propagation / Reflectivity

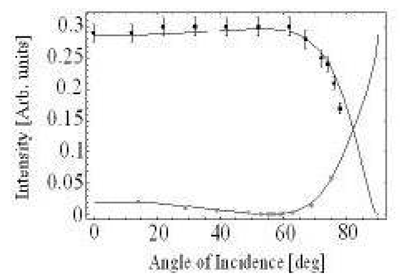



- Fiber coupling
- Pinhole filtering

Beam radius as a function of distance from the laser aperture

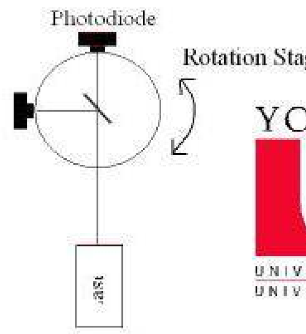



Reflection & Transmission of EM Waves




The reflectance and transmittance plotted for the case of an air-glass interface ($n_1$ = 1 and $n_2$ = 1.5) with P-polarized light.

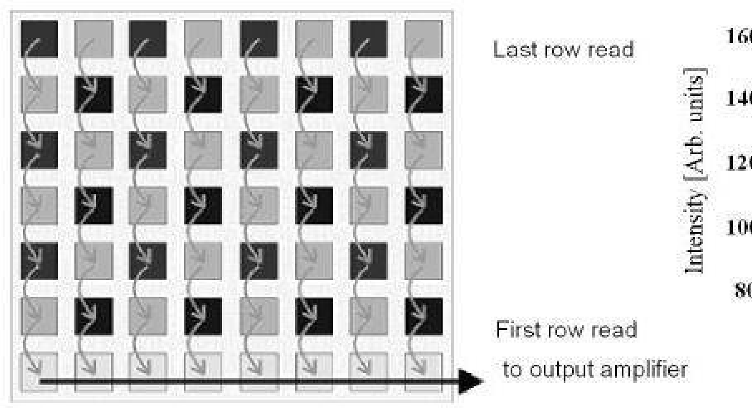
-Compare reflectivities of glass slides and dielectric mirrors

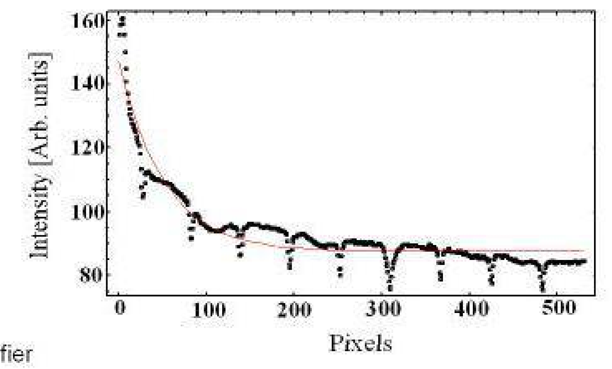



# Optical Detectors

- Study properties of photodiode, photo multiplier tube (PMT) and charge coupled device (CCD)

CCD readout diagram:



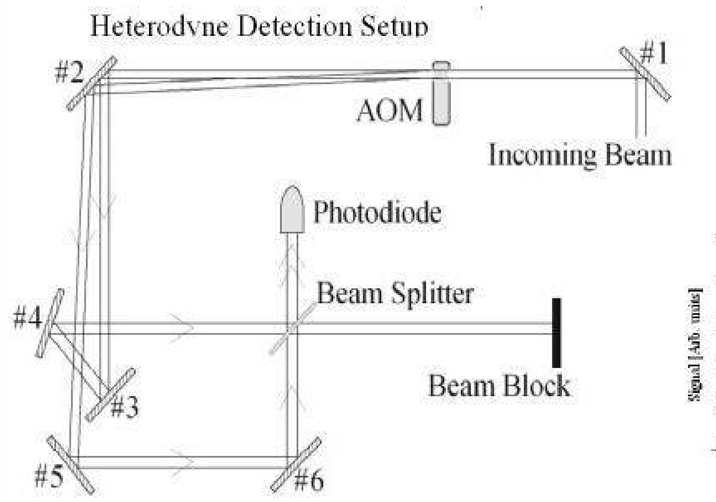



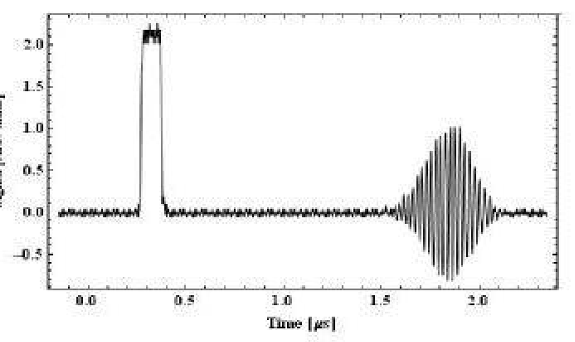

A CCD camera is used to measure the decay time of the photo-active coating on the screen of an analogue oscilloscope because this modelsthe typical trap expansion time. The fit gives a decay time of (86 ± 3) μs.

# RF Components / Acoustic-Optic Devices

- Study RF circuits, AOM and heterodyne detection

Heterodyne Detection Setup

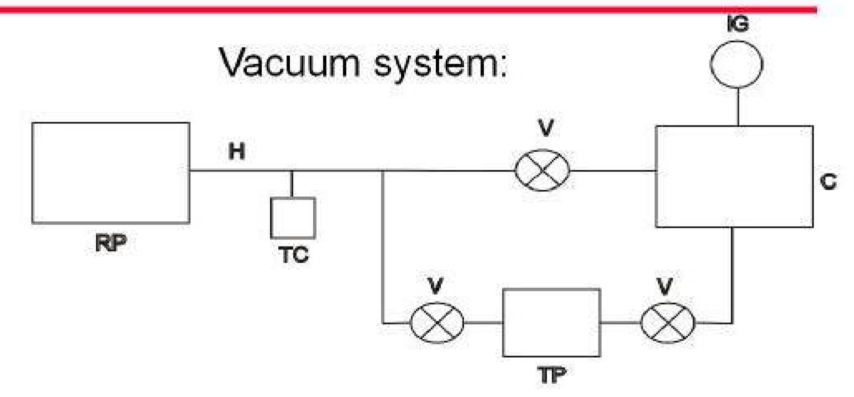


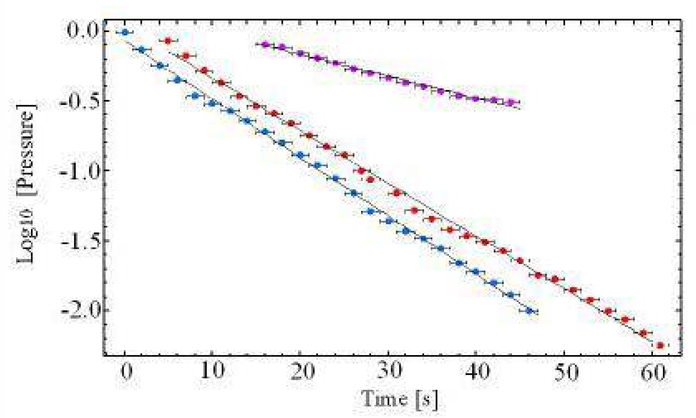

Pulsed heterodyne detection.
First trace is the pulsed driving signal and second trace is the pulsed RF signal for the AOM.

# Vacuum Components and Pumping Techniques

Legend:
- TC - Pirani Gauge
- RP - Roughing Pump
- IG - Ion Gauge
- TP - Turbo Pump
- C - Chamber
- V - Valve



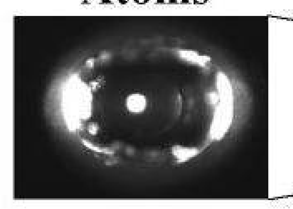

Logarithm of the foreline pressure (in Torr) as a function of time for various configurations




- Blue points: 4 ft bellows hose with a diameter of 2.4 cm. Slope = (-0.0417 ± 0.0005) s⁻¹.
- Red points: 8 ft bellows hose Slope = (-0.0376 ± 0.0004) s⁻¹.
- Purple points: 4.9 mm diameter aperture placed in line with 8 ft of hose Slope = (-0.0156 ± 0.0005) s⁻¹.

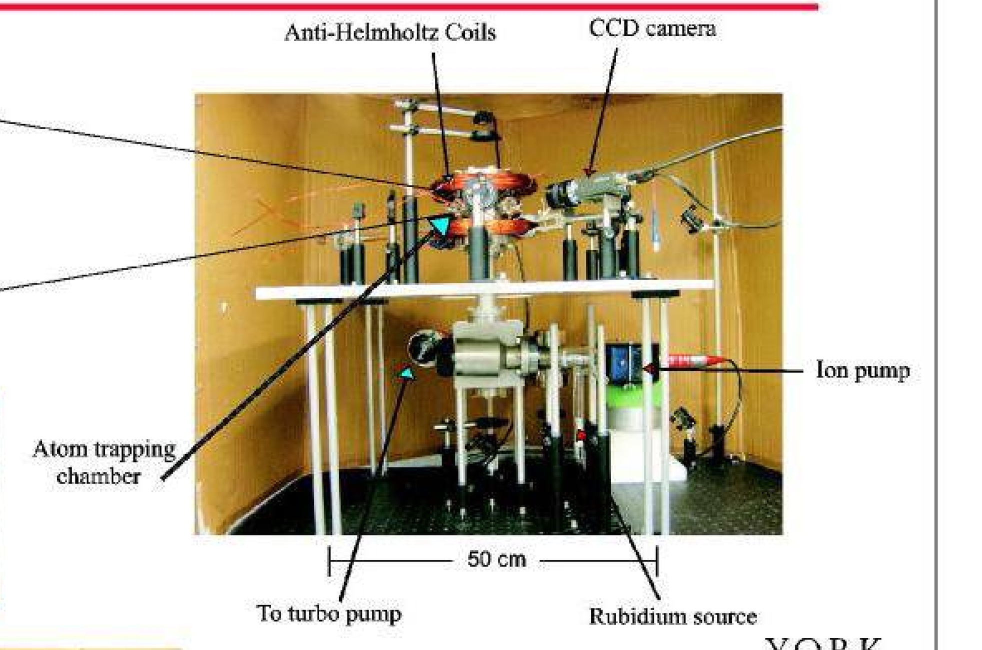
# Pictures of Experimental Setups

Trapped Rb Atoms



Laser Lock-in Lab

Zeeman Shift Lab




Atom Trapping Setup

# Final Remarks

- Course development completed during Jan - Aug 2005.
- Course was developed with contributions from graduate student support and involvement of undergraduates.
- Course development was completed under the supervision of Dr. A. Kumarakrishnan.

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