Constructing a Saturated Absorption Spectroscopy System for Laser Locking

Camden Kasik

Motivation
Fine-Structure constant

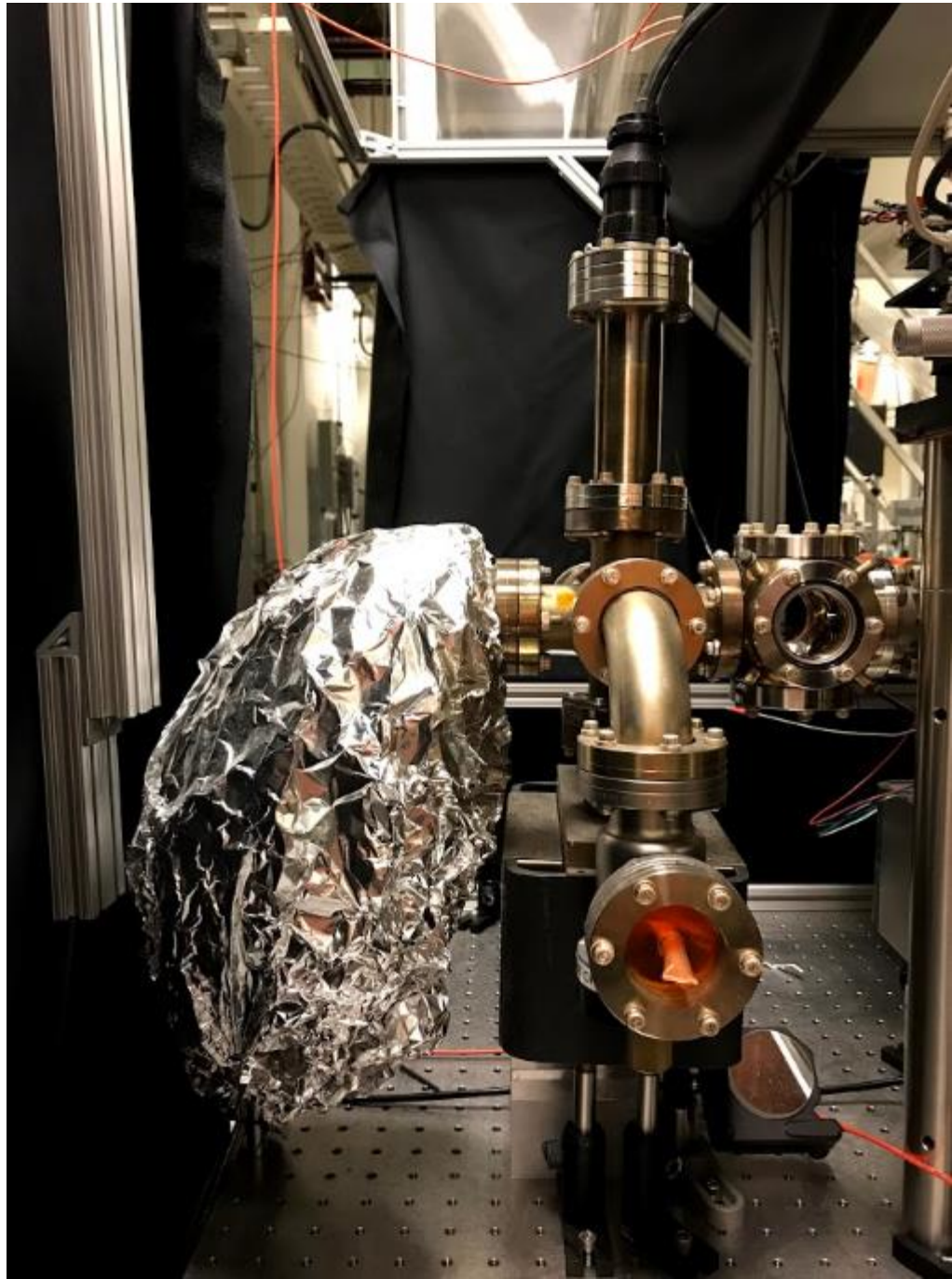
- Fine-Structure constant
  - Fundamentally characterizes electromagnetic interactions of charged particles
- Advance interferometry measurements
  - Gravity gradients
  - Equivalence principle tests
- Test of Quantum Electrodynamics (QED) theory

- Best measurements
  - 0.25ppb Electron $g_e - 2$ [1]
  - 0.2ppb from cesium recoil [2]
- Our goals
  - 0.1ppb from recoil

[1] Tatsumi Aoyama, Masashi Hayakawa, Toichiro Kinoshita, and Makiko Nio Phys. Rev. Lett. **109**, 111807 – (2012)
[2] Parker, R.H., et al., Science 360, 191-195 (2018).

Laser cooling

- Atomic beam
  - Oven with two holes
- Zeeman Slower
  - Doppler effect
- Magneto Optical Trap
  - In an ultrahigh vacuum
- Optical Dipole trap
  - Evaporative cooling



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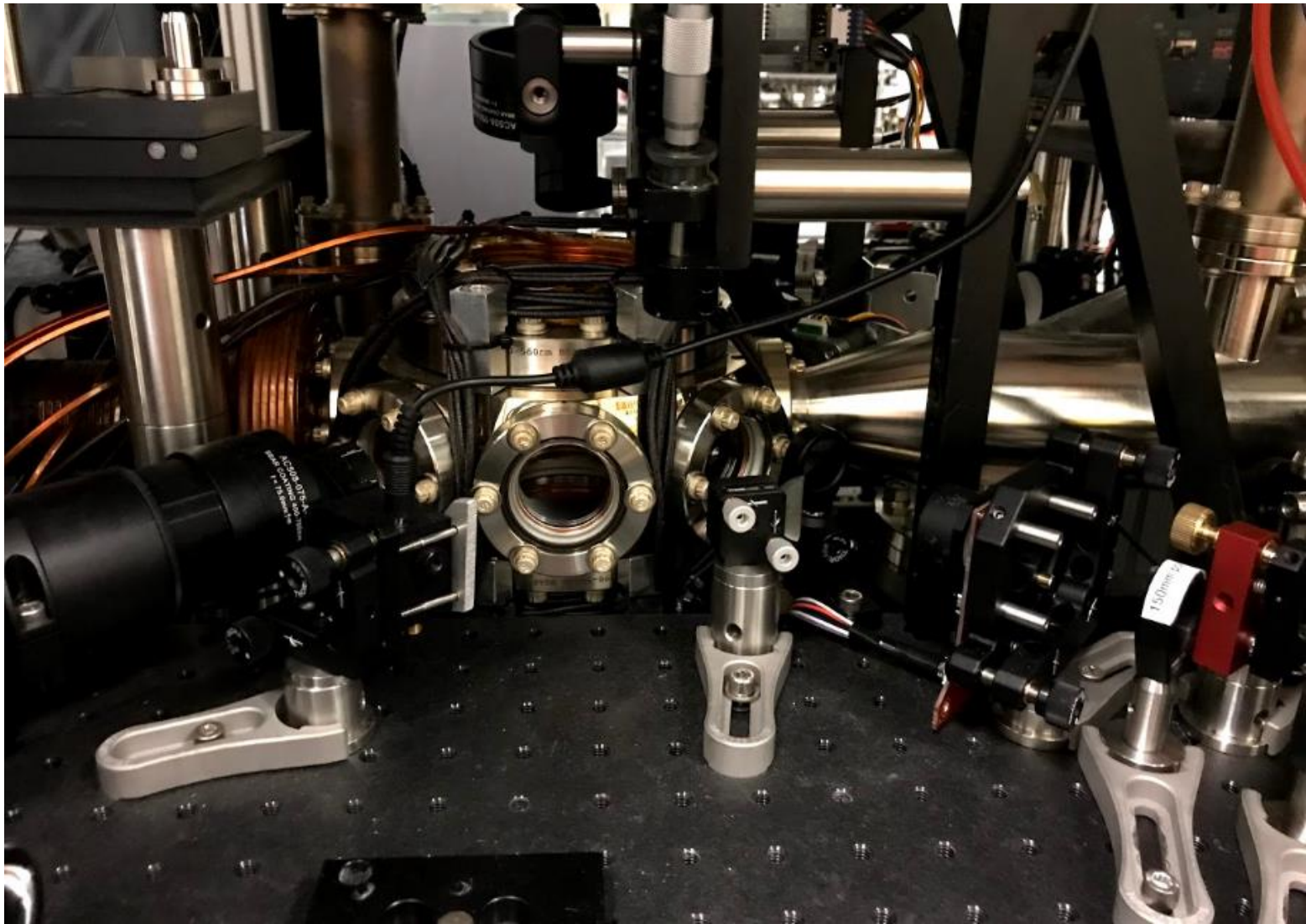

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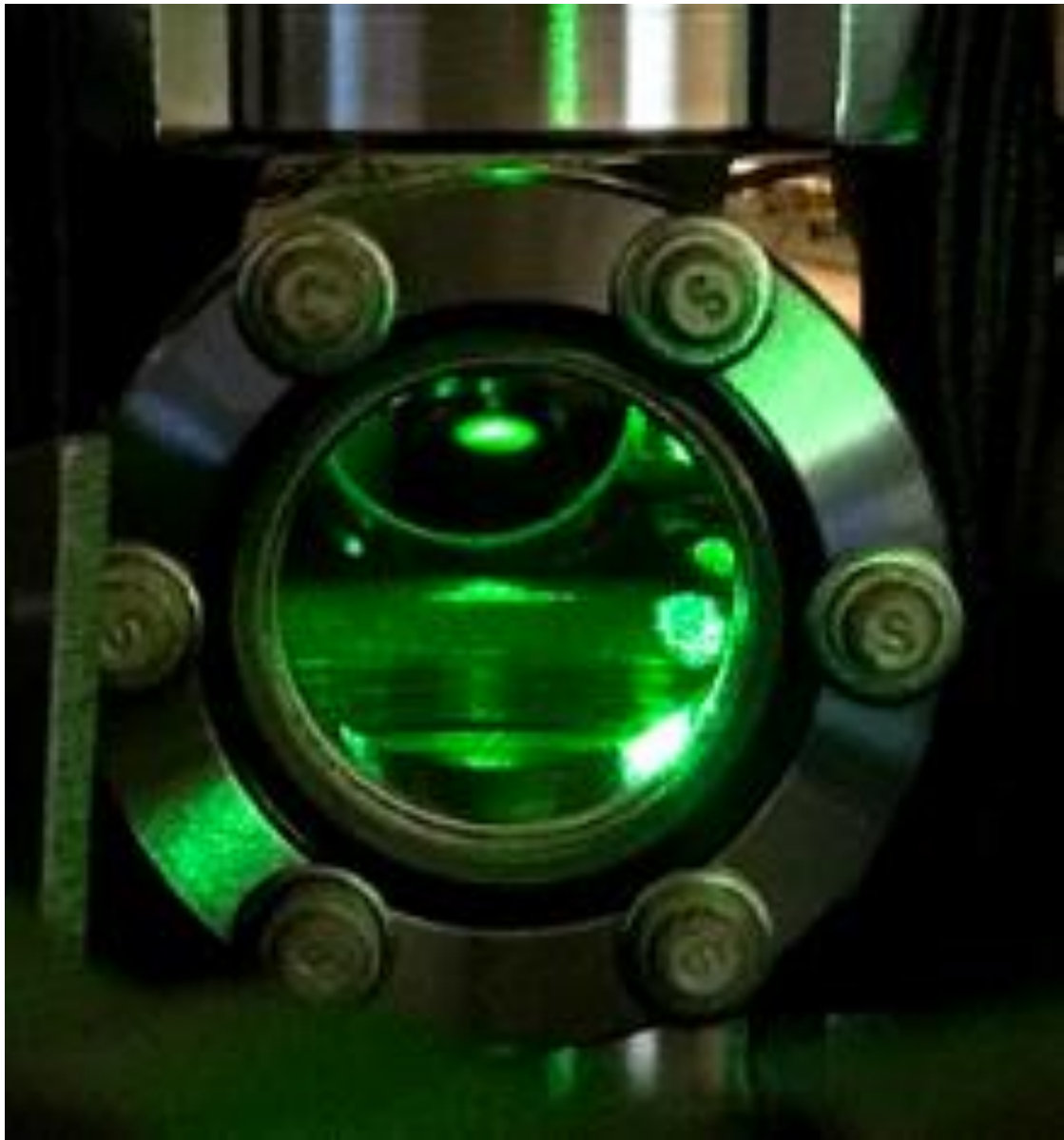

Our way of measuring it

$$\alpha^2 = \frac{4\pi R_\infty}{c}\frac{m}{m_e}\frac{\hbar}{m}$$

- Recoil frequency method- Rate of phase evolution
- Bose Einstein Condensate (BEC) for low velocity distribution
  - Coherence
- Contrast Interferometer (CI)
- Bragg pulses for acceleration
  - Standing waves
  - Make diffraction grating

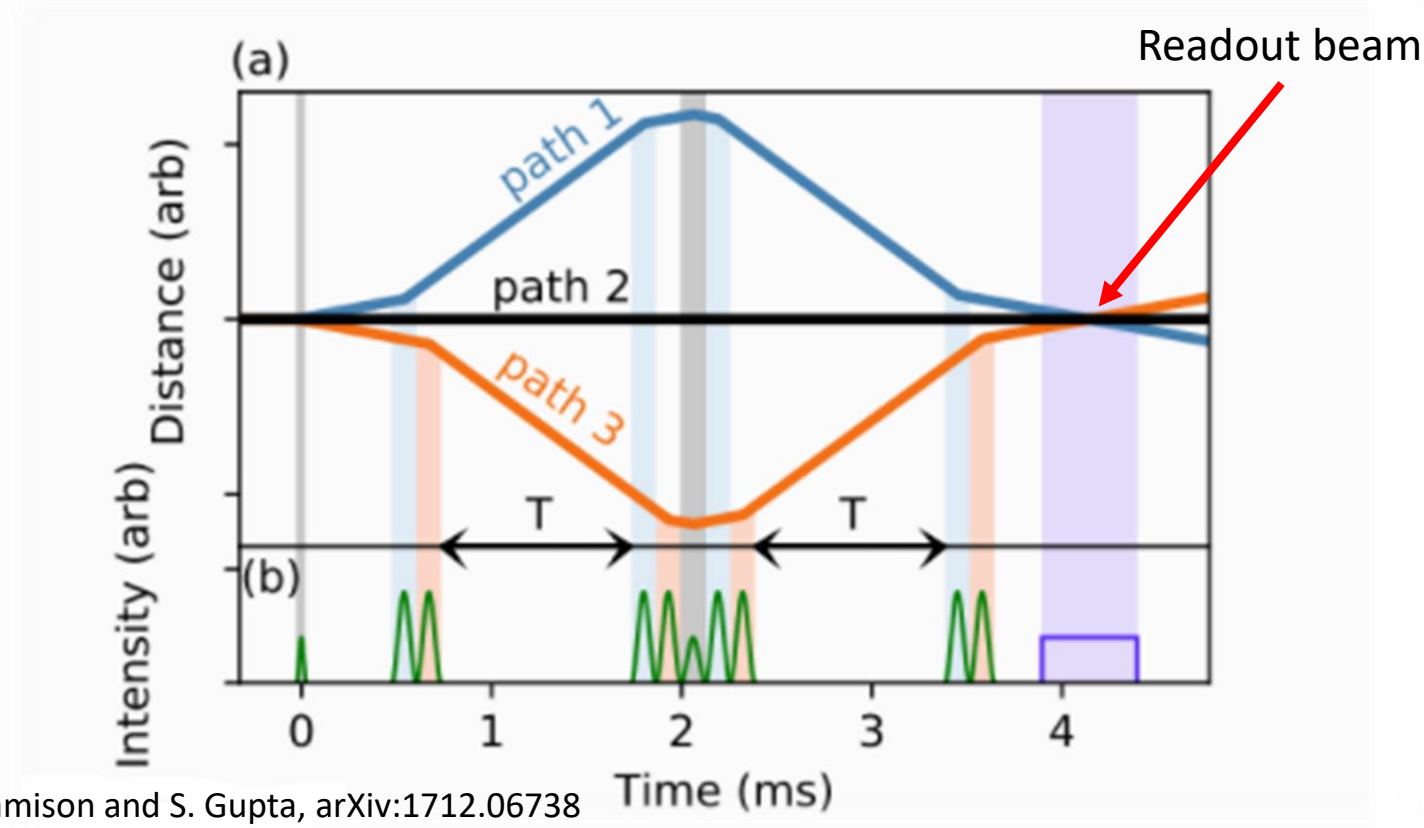

Image from: B. Plotkin-Swing, D. Gochnauer, . McAlpine, A. O. Jamison and S. Gupta, arXiv:1712.06738

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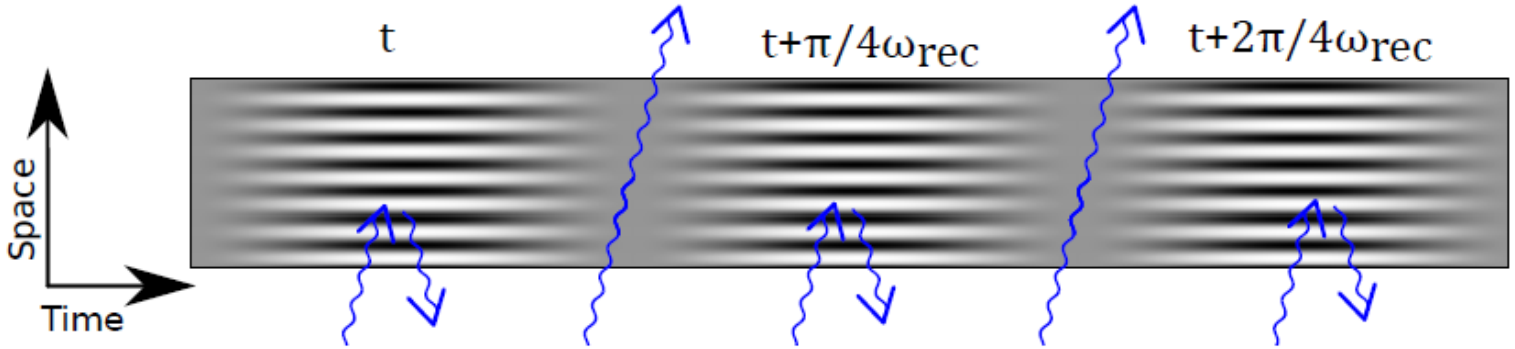

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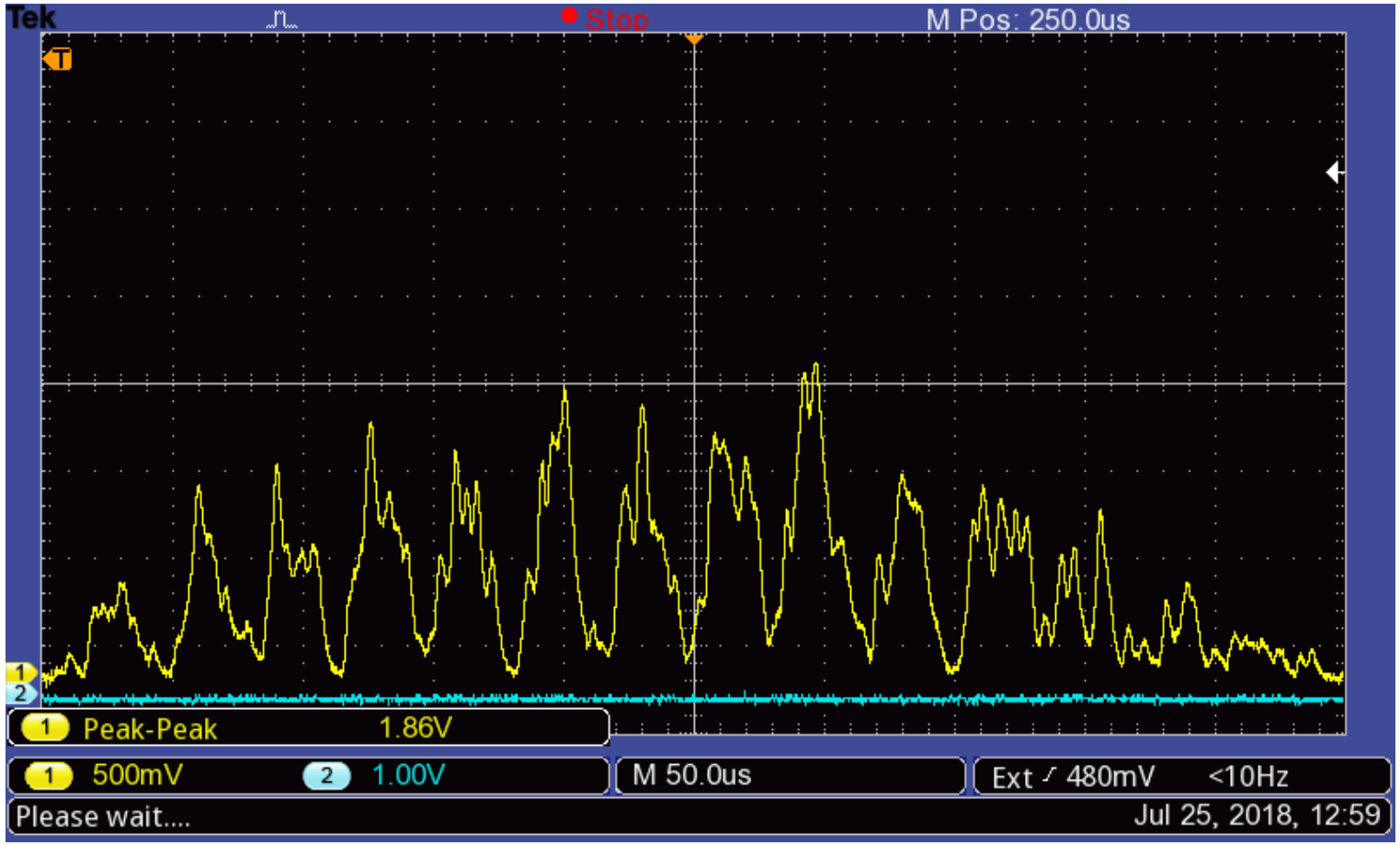
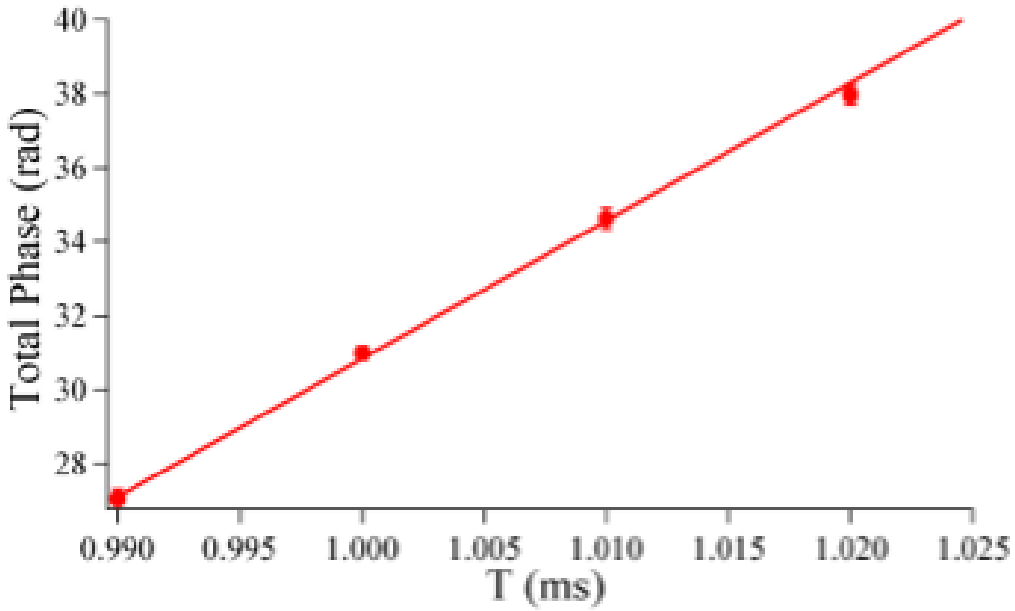
Contrast Interferometer



Measuring the recoil frequency from phase

- Acceleration increases precision
- Recoil Frequency
  - What is this



- $\Phi(2T) = \frac{1}{2}n^2\omega_{recoil}T + \Phi_{offset}$

$$\frac{\delta\omega_{recoil}}{\omega_{recoil}} = \frac{\delta\phi}{\frac{1}{2}n^2\omega_{recoil}T\sqrt{M}}$$

← Number of shots

- ΔP= n$\hbar k$

Measuring the recoil frequency from phase

- $\omega_{recoil} = \frac{\hbar k_{laser}^2}{2m}$
- $\alpha^2 = \frac{4\pi R_\infty}{c} \frac{m}{m_e} \frac{\hbar}{m}$

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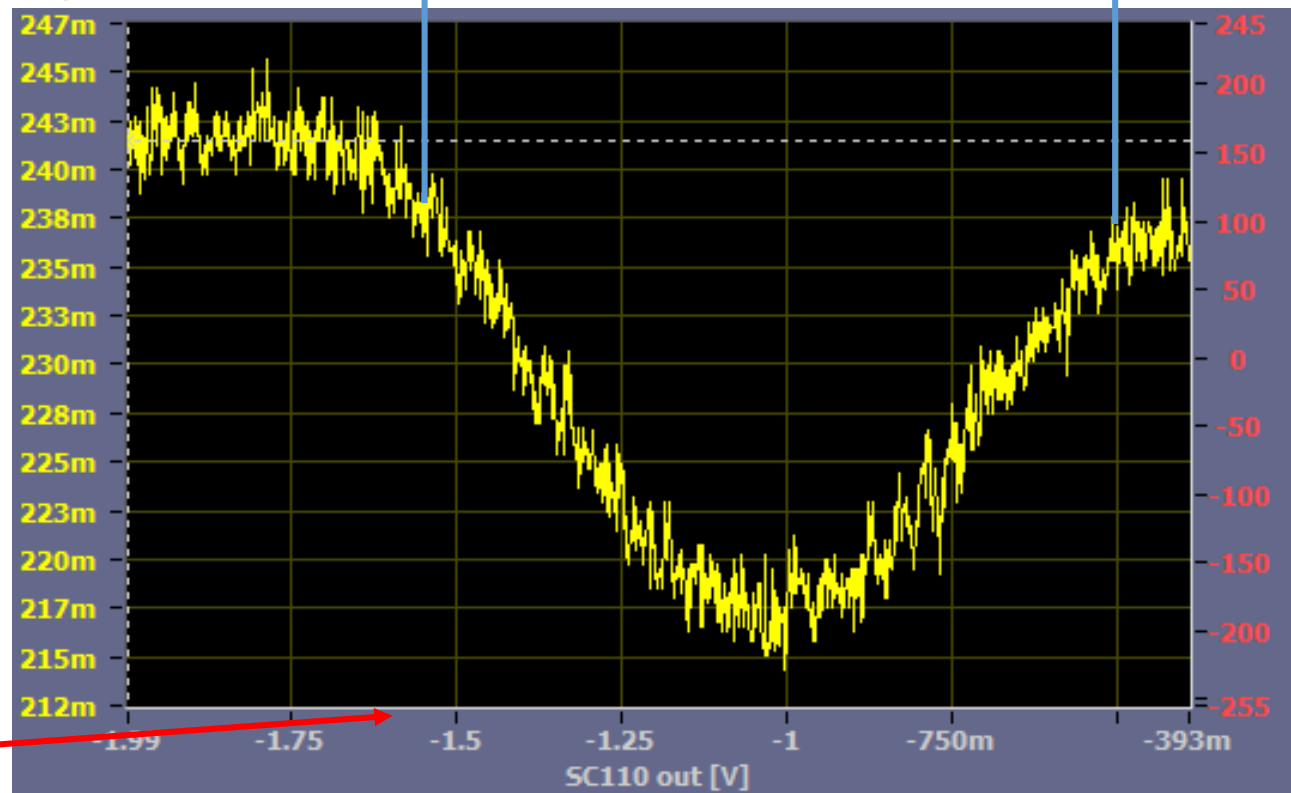
What I did

- Laser frequency stabilization
  - Laser for cooling and diffraction beams
  - Doppler effect
  - $\omega_{recoil} = \frac{\hbar k_{laser}^2}{2m}$

Need on the order of a MHz

About 500MHz



Frequency axis

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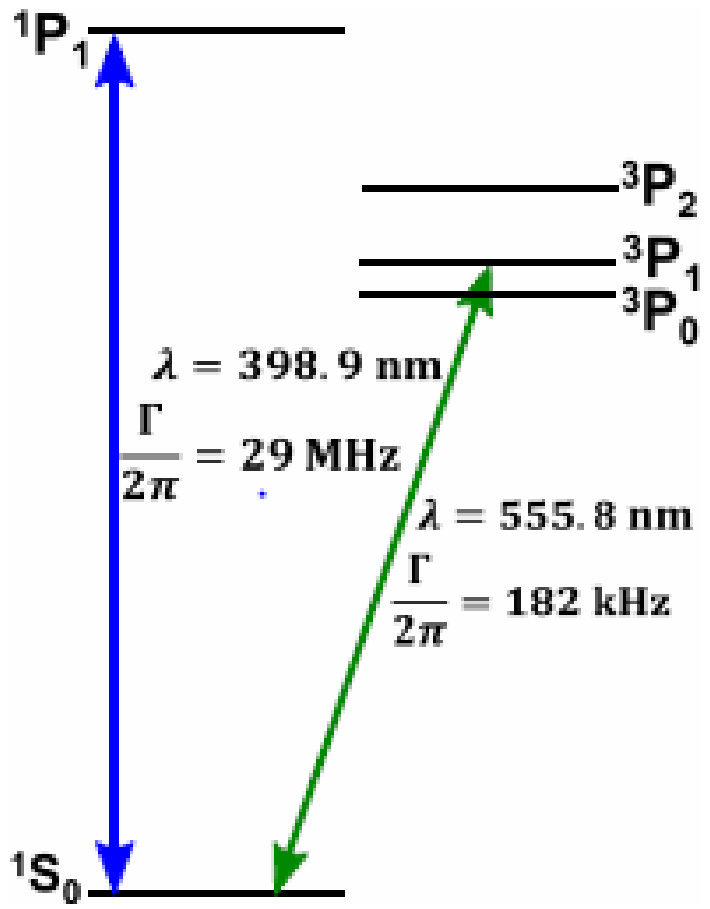
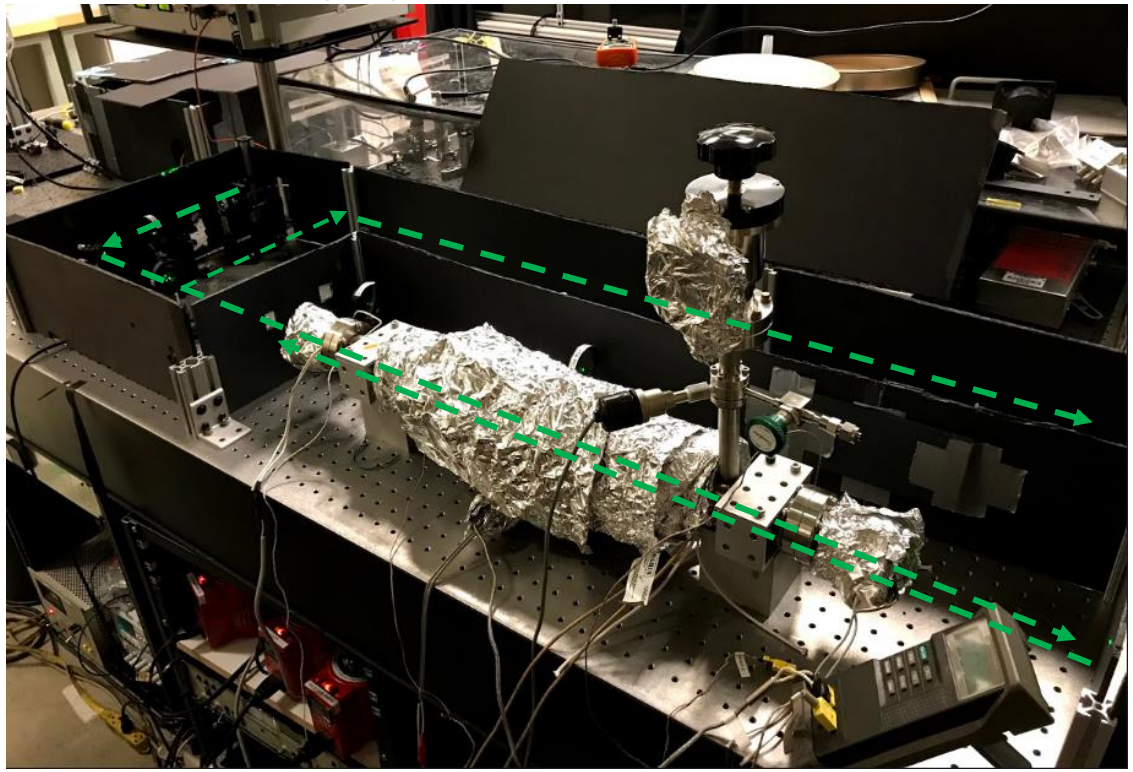
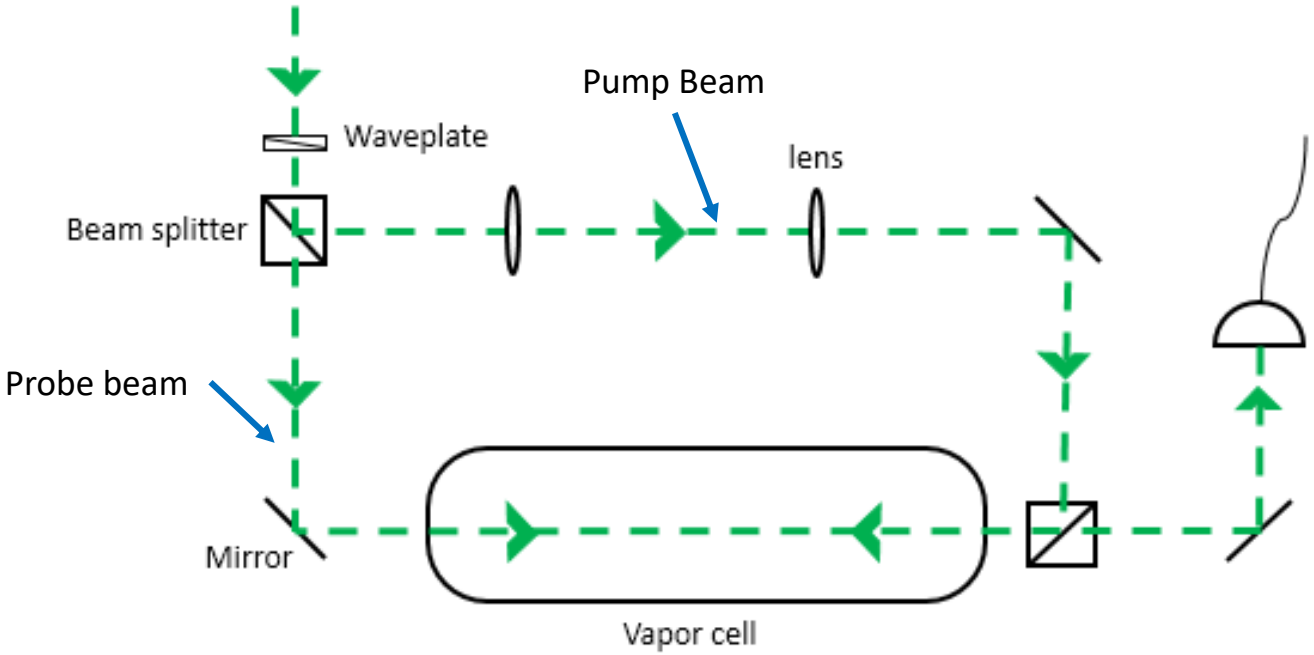


Saturated absorption spectroscopy

- Fixing Doppler broadening
- Probe beam is the one detected





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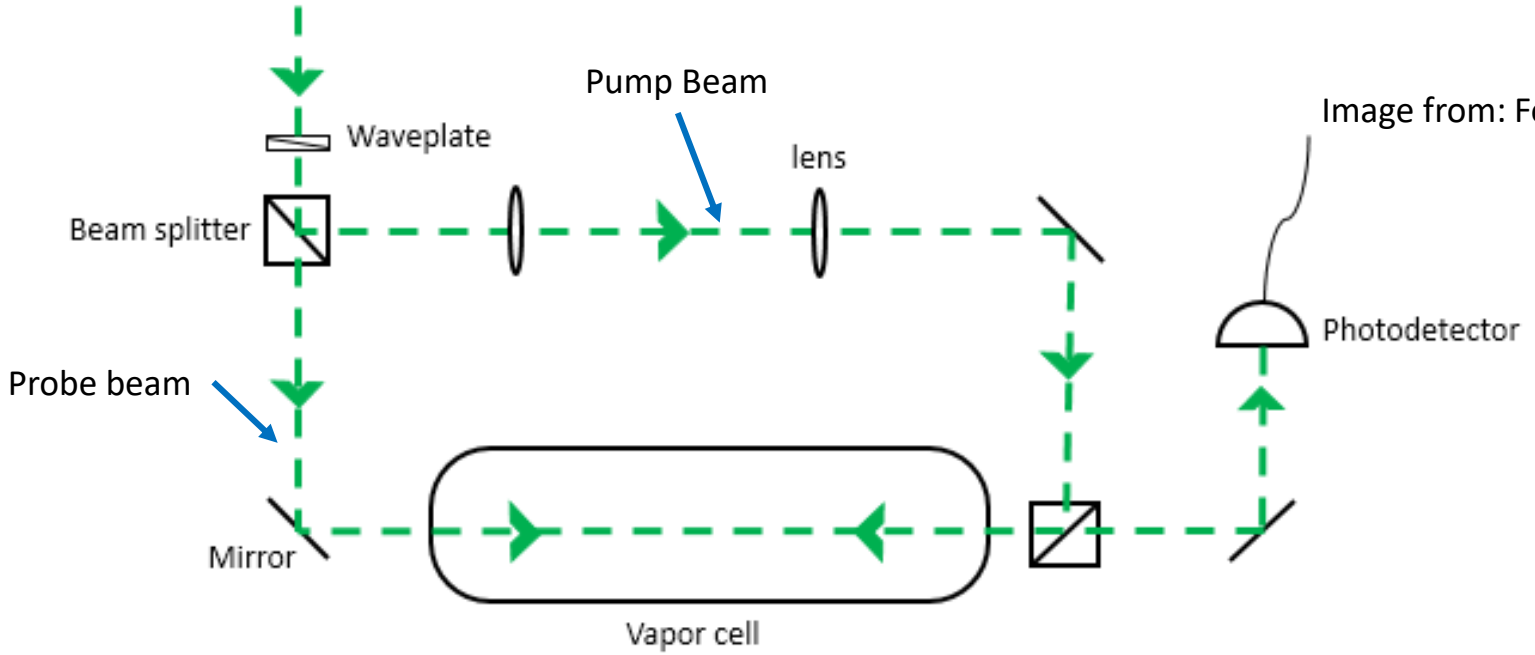


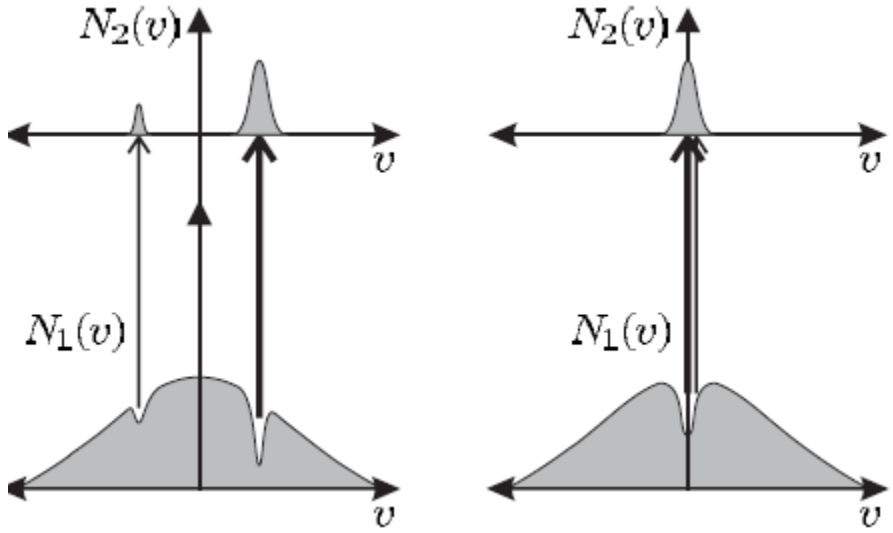
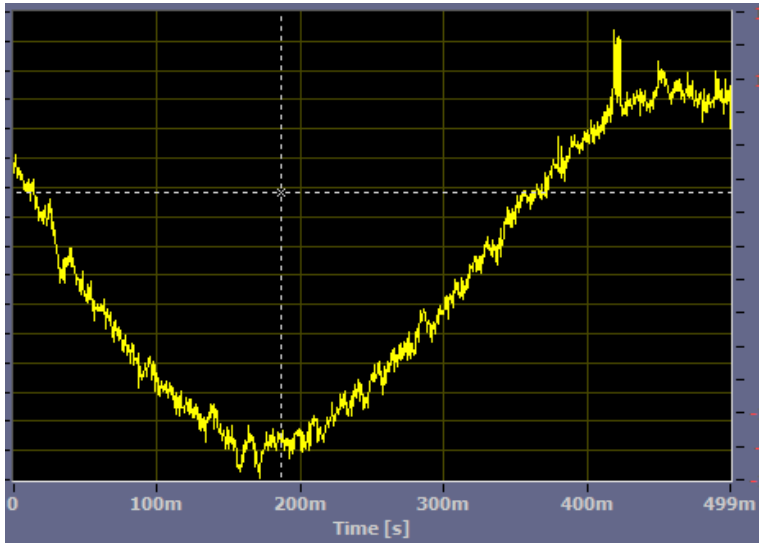
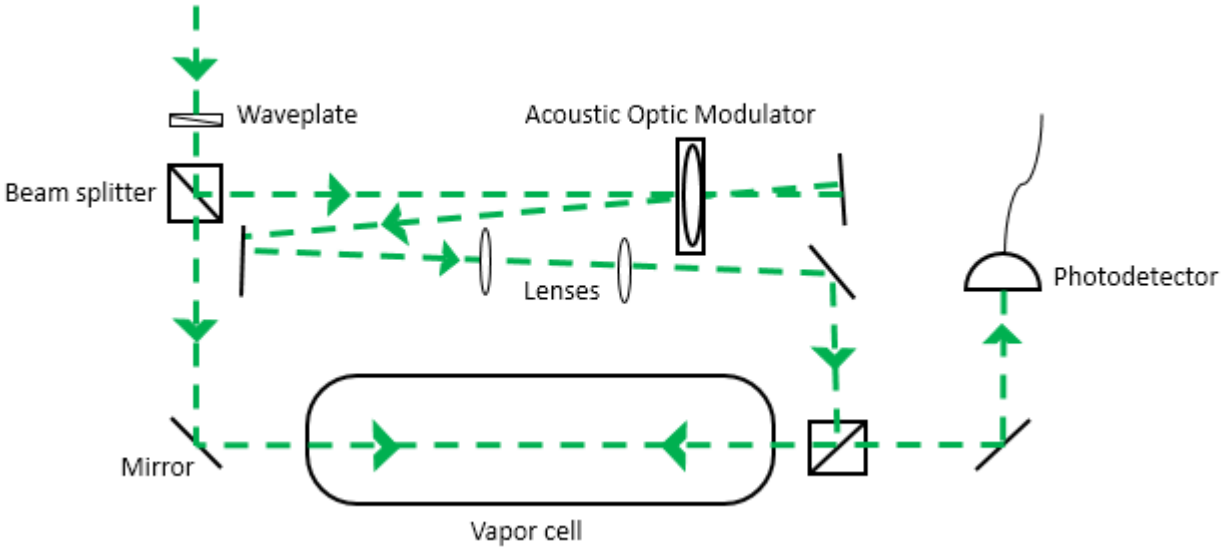


Image from: Foot, C. J. (2005). Atomic physics (Vol. 7). Oxford University Press.

Saturated absorption spectroscopy

- Acousto Optical Modulator (AOM)
  - Shift frequency
  - Modulates frequency
  - RF to sound waves
- Mix modulation signal with transmission
- Error signal
  - Lock to negative slope at 0





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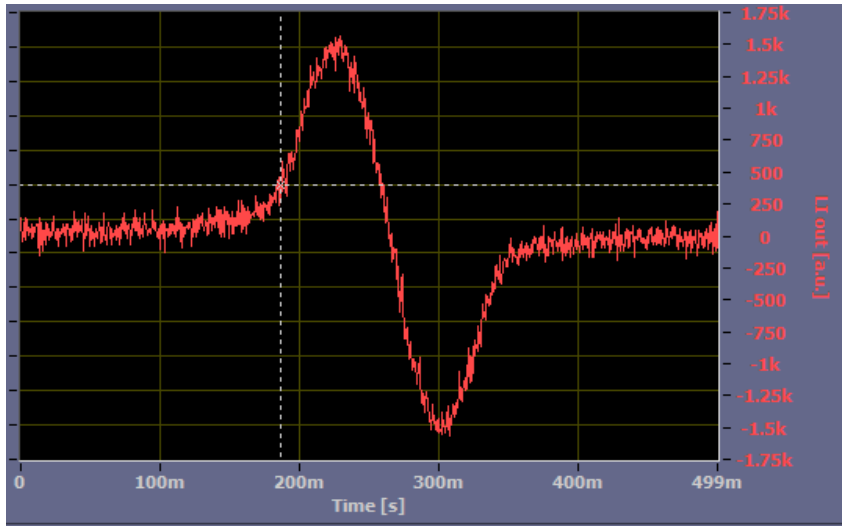
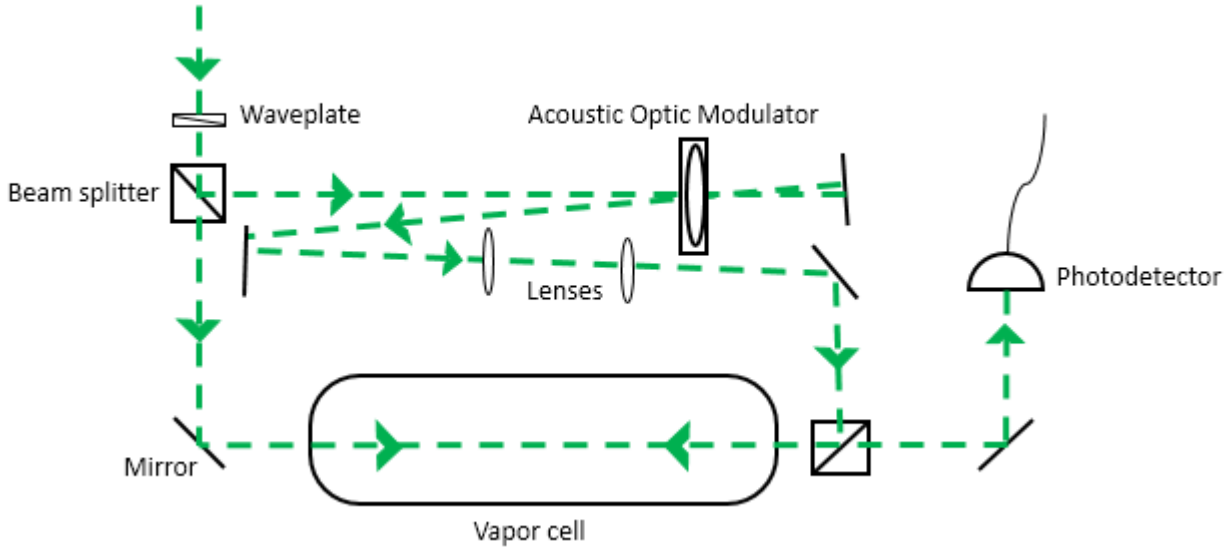
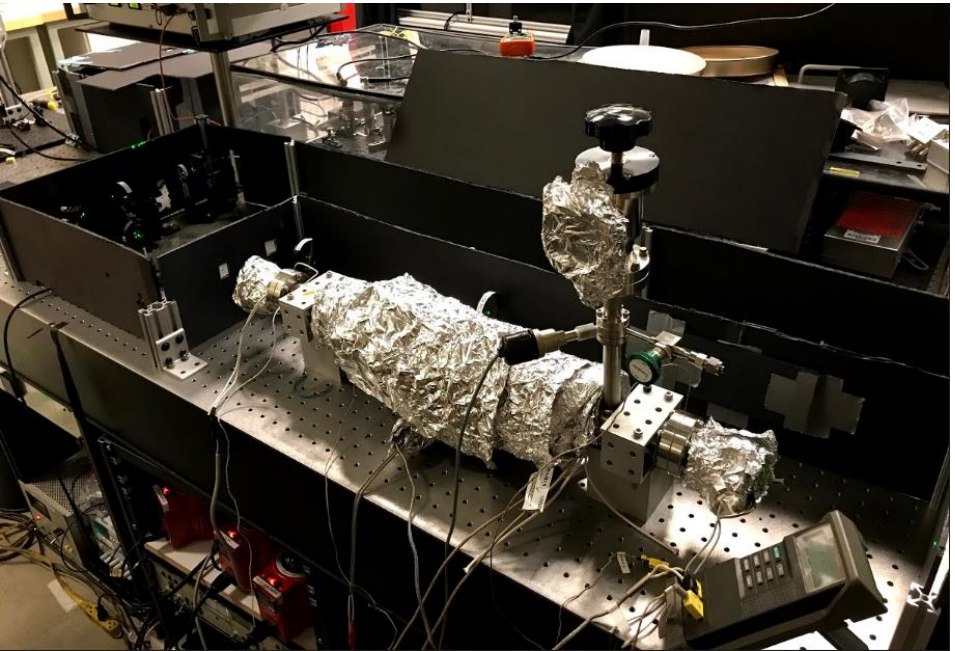
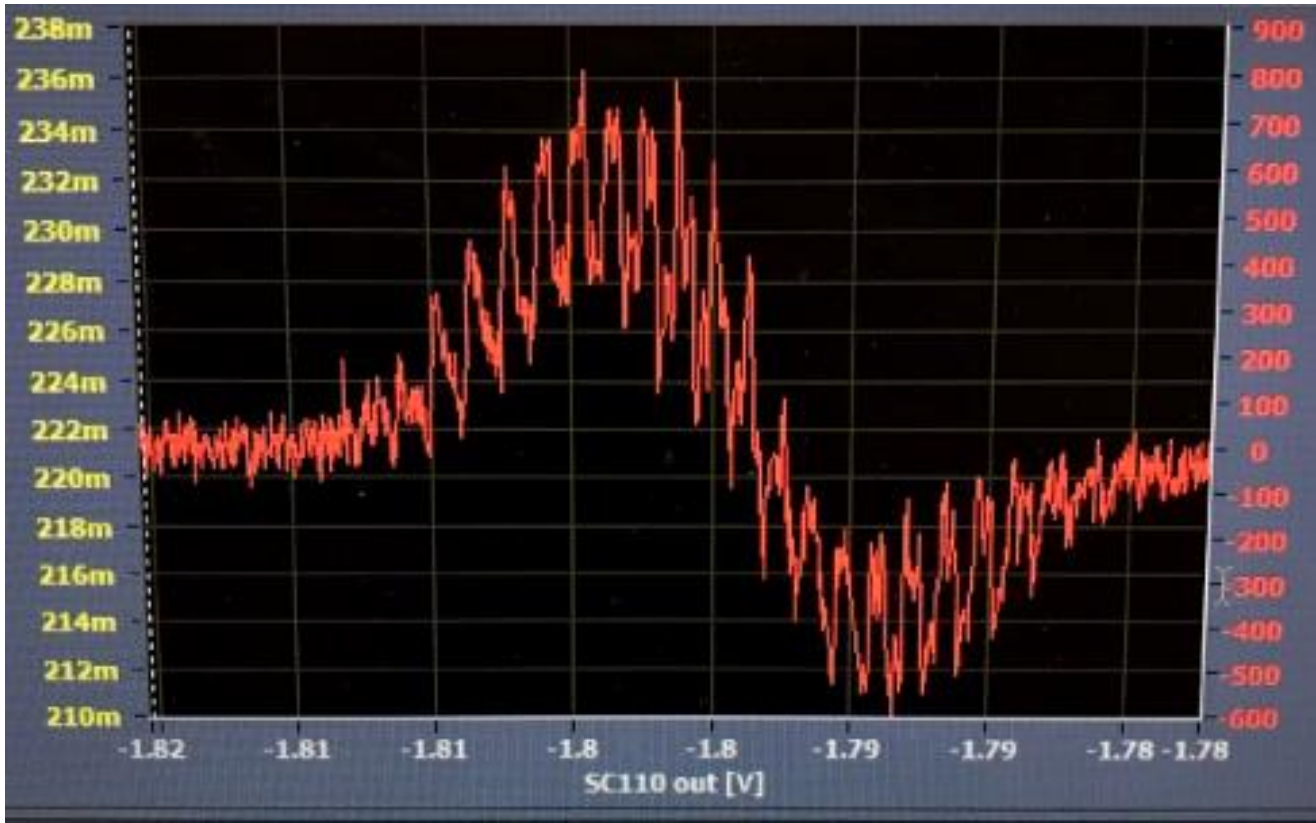




Problems

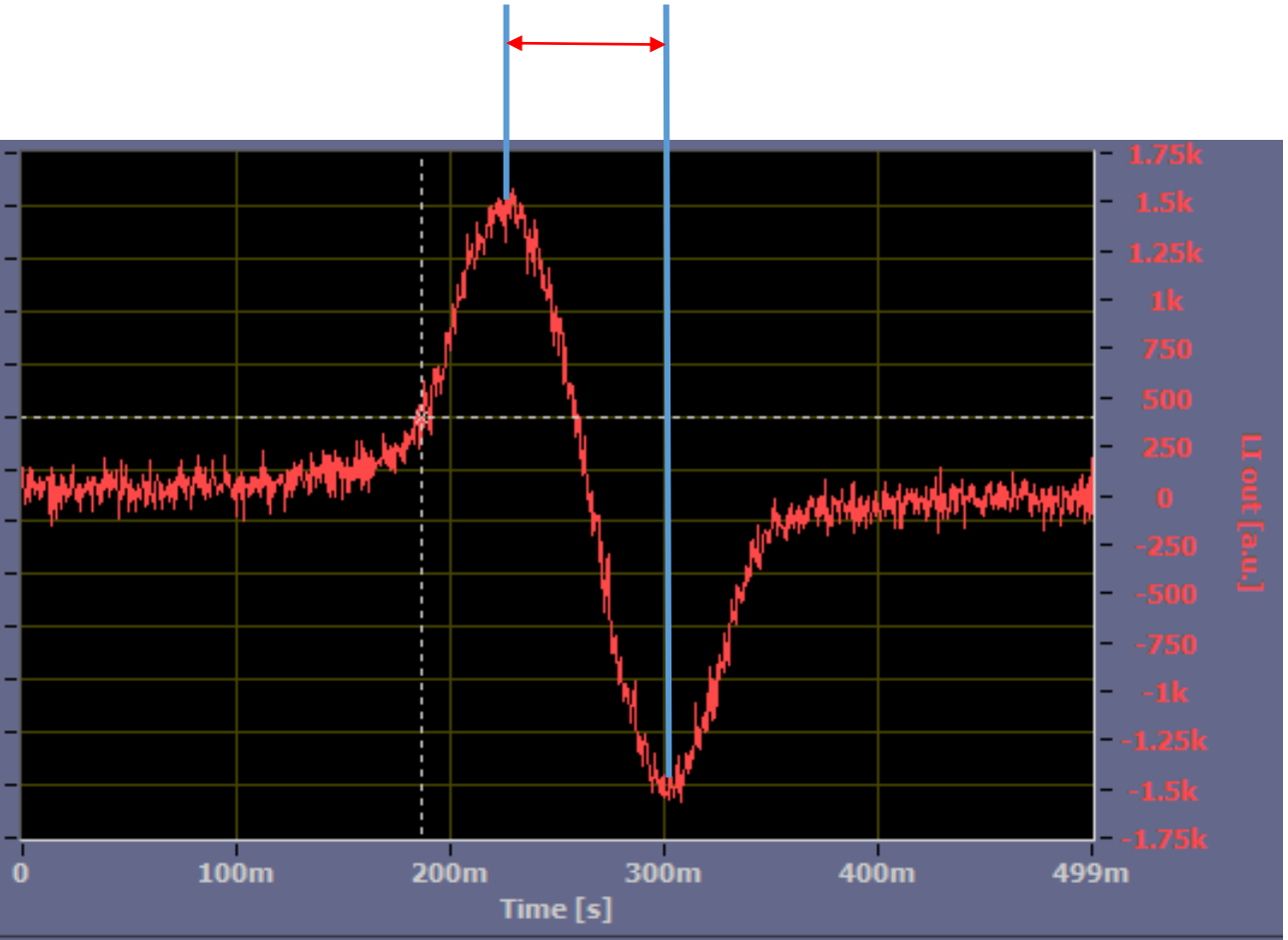
- 60Hz noise
  - Heater tape
  - Correct grounding

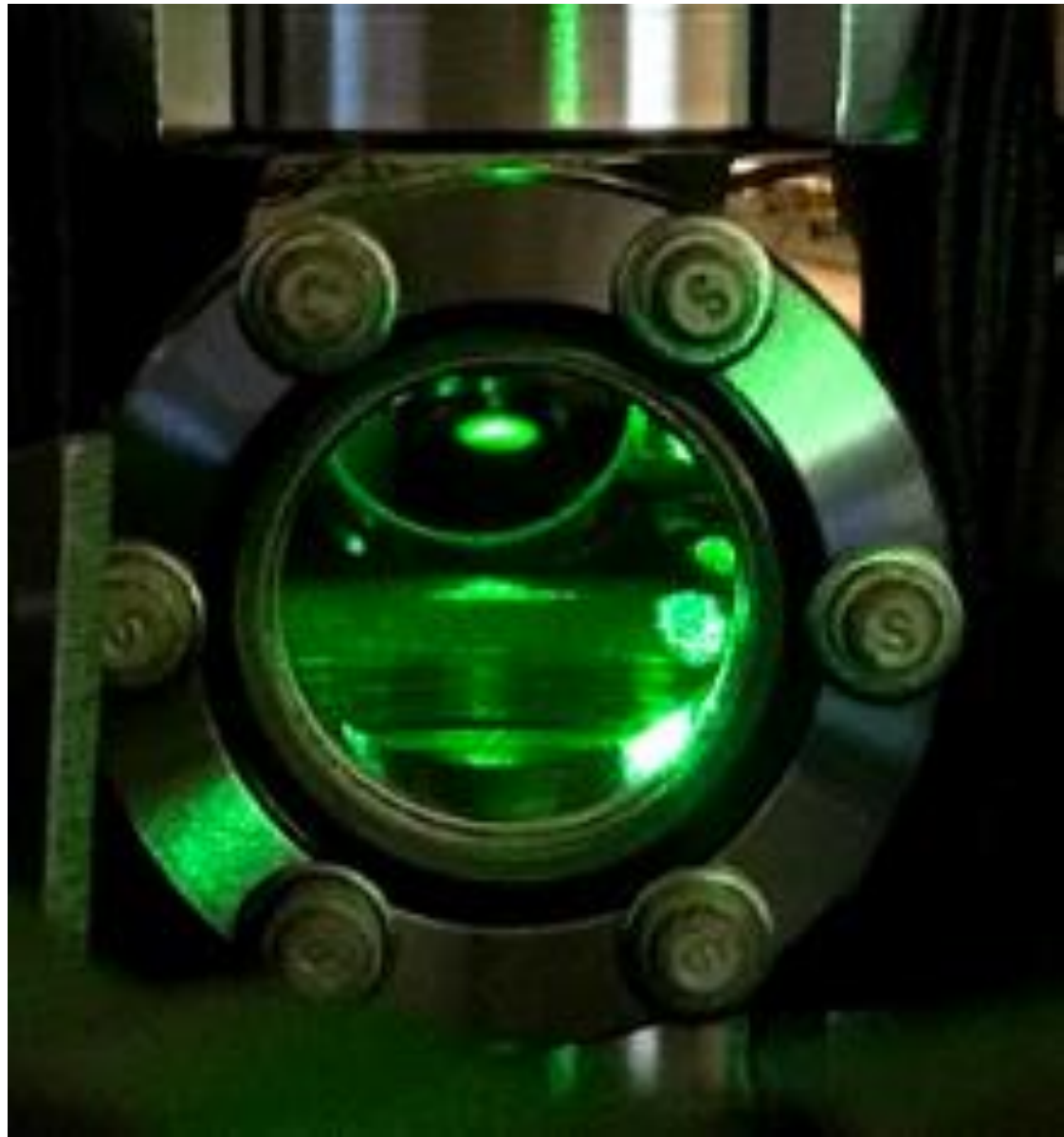




It Works!

About 6.3MHZ with 10:1 signal to noise





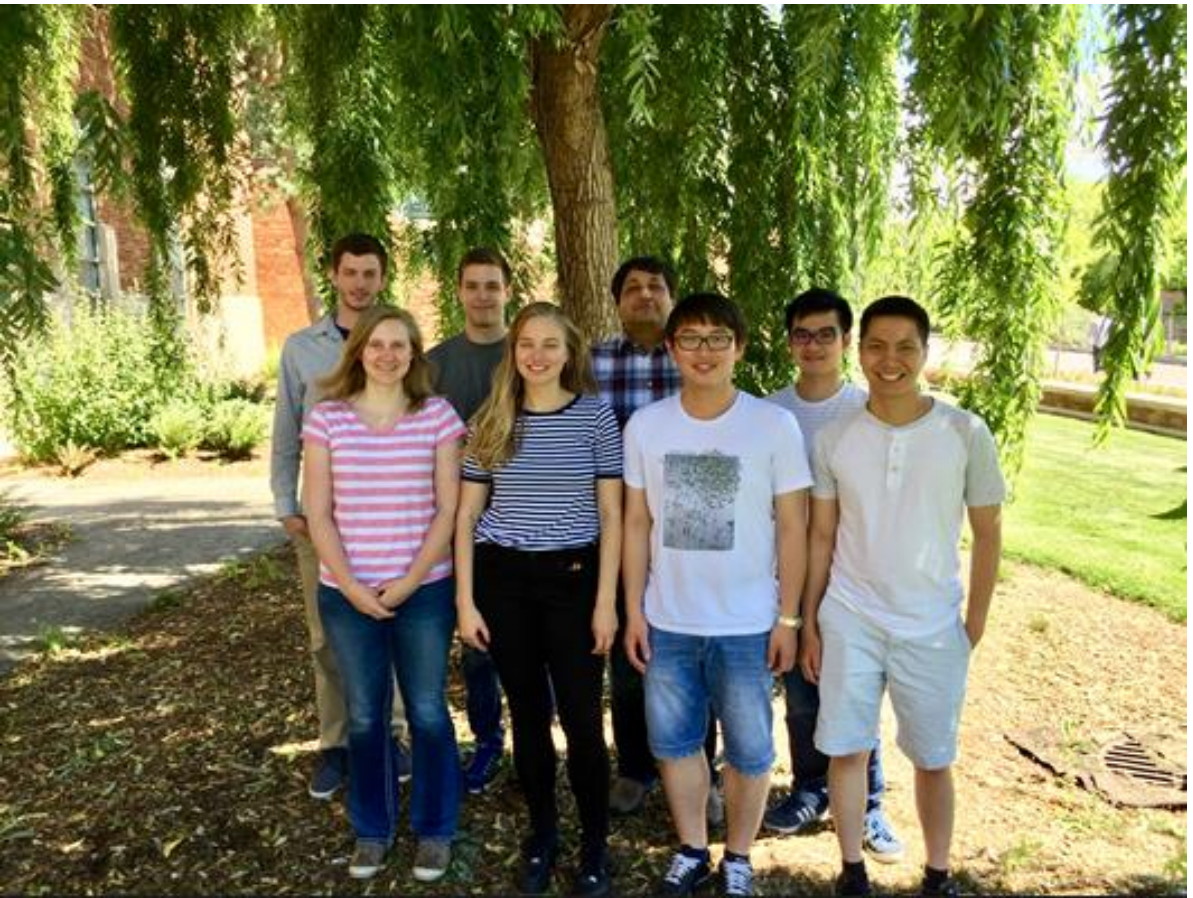
What is next

- Use this instead of the old beat node system to continue main experiment

- Mount spectroscopy in 3x1 foot breadboard

Thanks

Linda Vilett
Cheryl McDaniel
Gray Rybka



Other contributions

- Polarization optimization