Optimization of a Prototype Atomic Clock

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REU Final Talk

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Acknowledgements

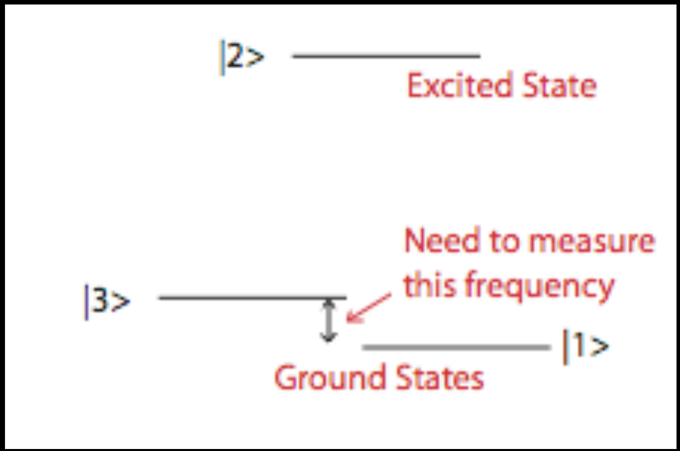
- Prof. Irina Novikova
- Prof. Eugeniy Mikhailov
- Chris Carlin

Outline

- Clocks
- Experimental Setup
- First Coherent Population Trapping (CPT) Results
- First Clock Results
- Second CPT Results
- Second Clock Results

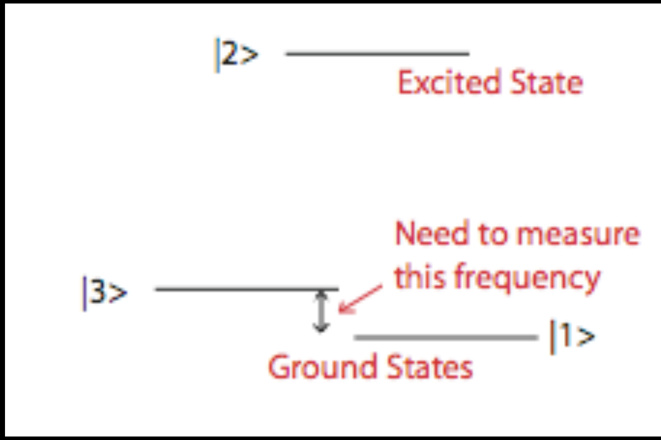
What is a second?

- *the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.*



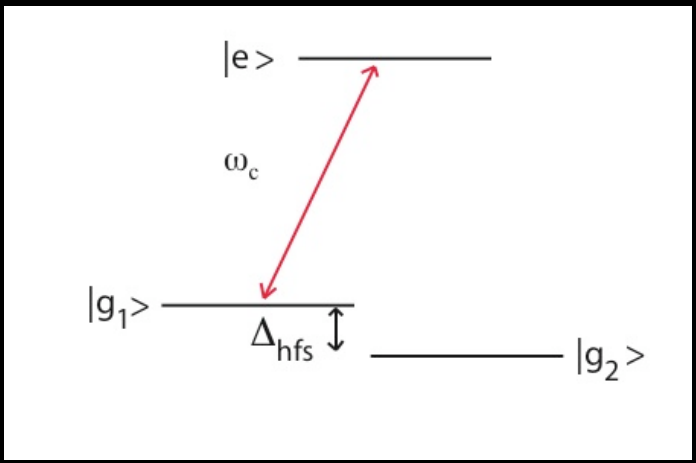
How are atomic clocks made?

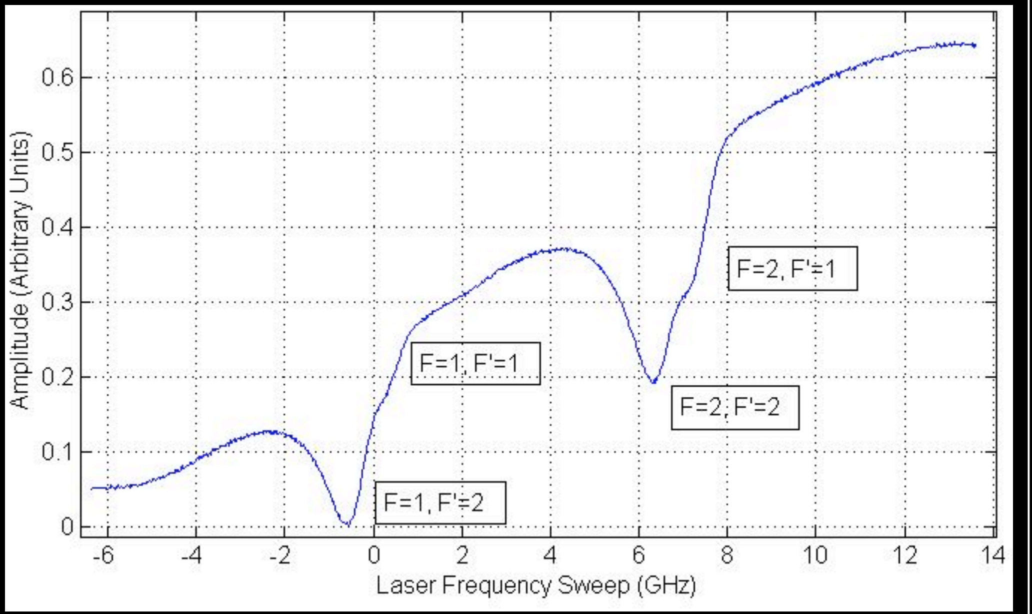
- Use atomic resonance as oscillator
- Counter fed by oscillator
- Have feedback loop to keep counter on atomic resonance



Review of Light Interaction

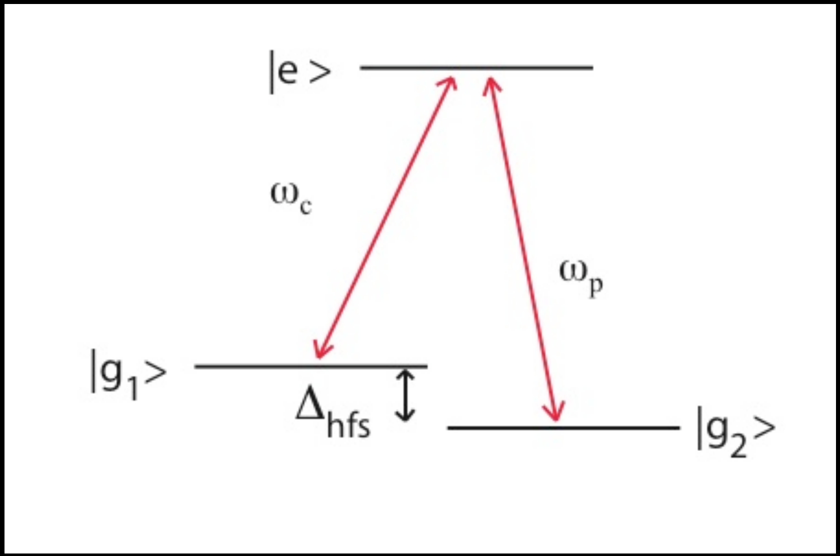
- When frequency near optical resonance, light gets absorbed

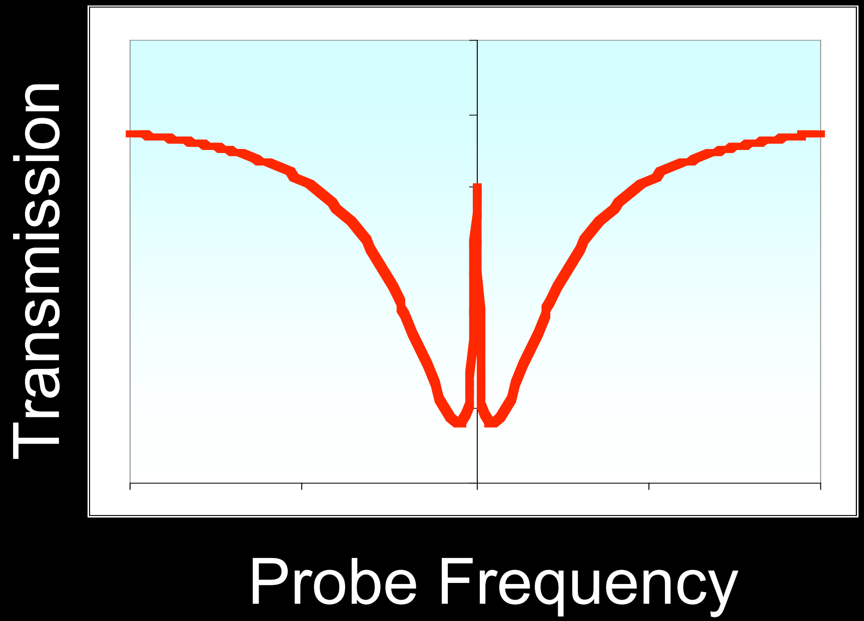




Review continued

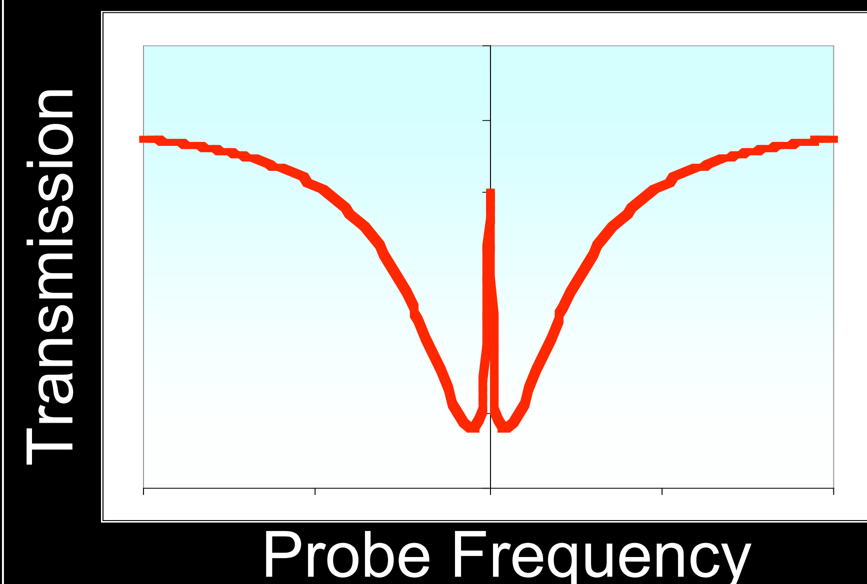
- 3-level absorption and transmission

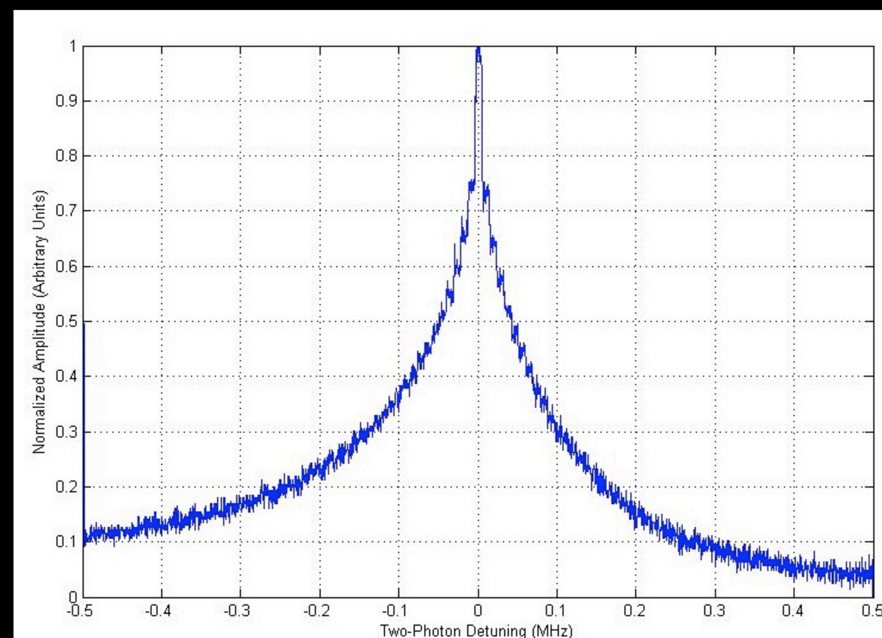




Our Goal

- Get lasers on optical and atomic resonance to achieve maximum transmission



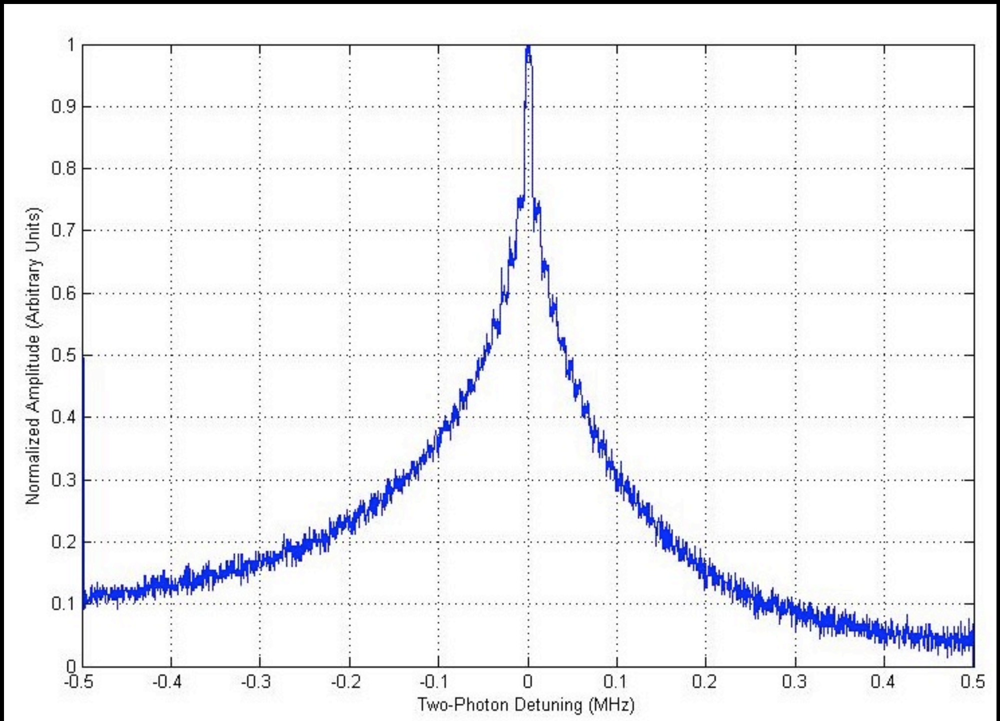


Our Goal's Mathematics

$$|dark\rangle = \frac{\Omega_1 |g_2\rangle - \Omega_2 |g_1\rangle}{\sqrt{|\Omega_1|^2 + |\Omega_2|^2}}$$

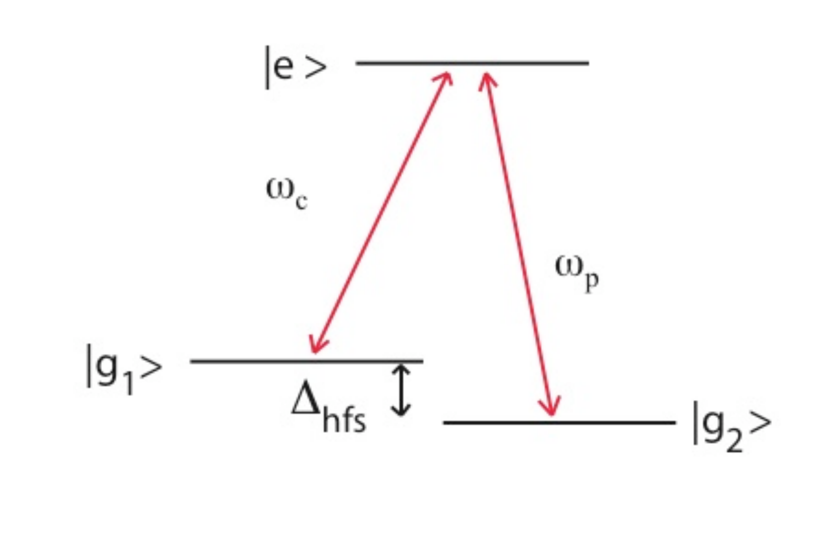
$$\Omega_1 = \frac{\wp_{eg_1} \mathcal{E}_1}{\hbar}$$

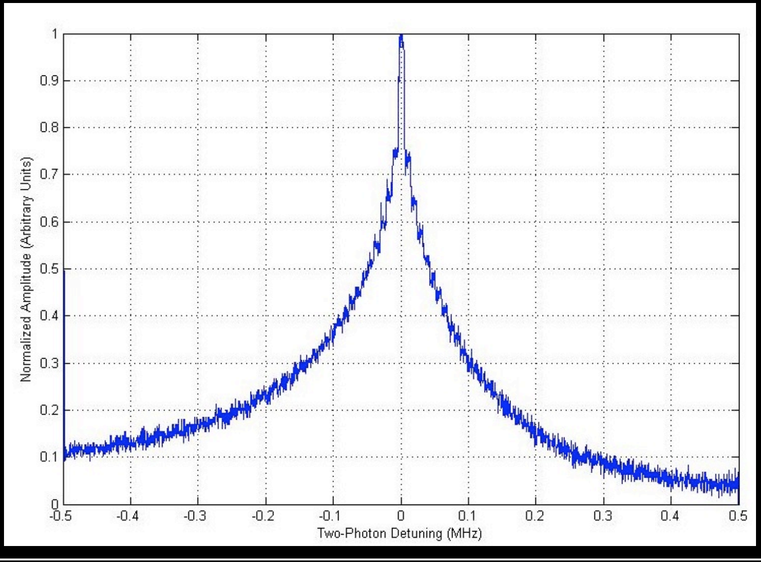
$$\Omega_2 = \frac{\wp_{eg_2} \mathcal{E}_2}{\hbar}$$



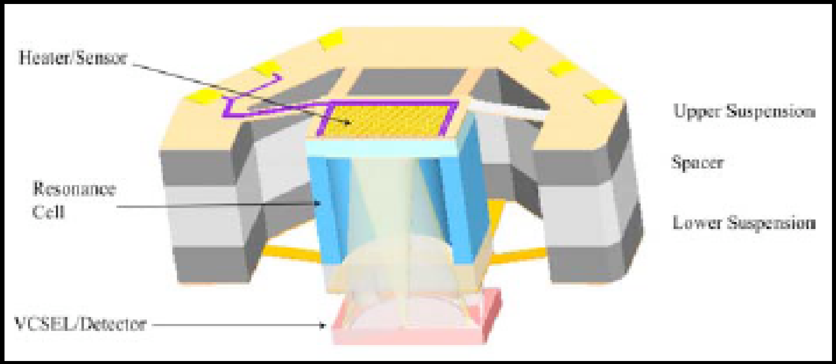
How is our clock made?

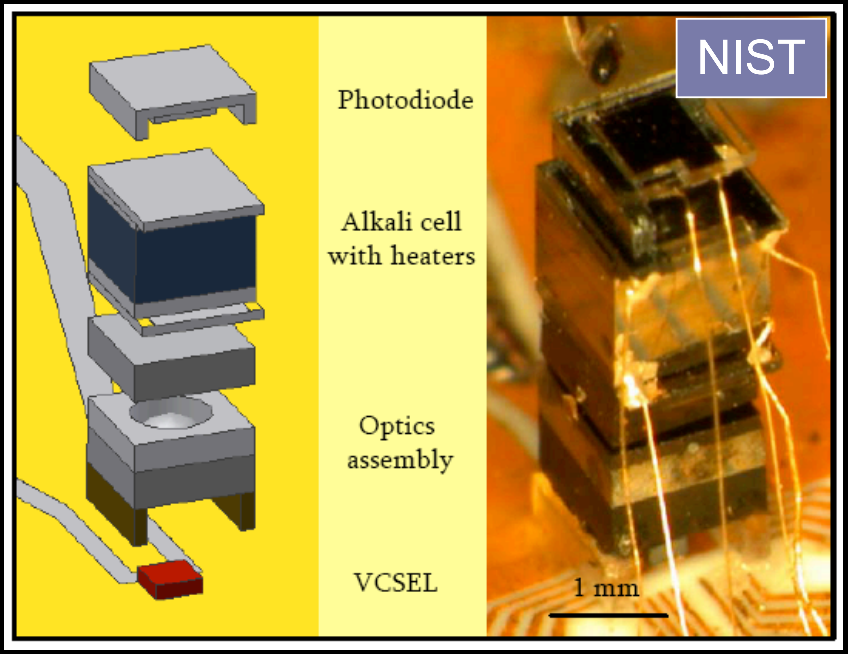
- Use lasers to drive transition between hyperfine levels of ground state
- Use feedback to match lasers to 6.834 GHz



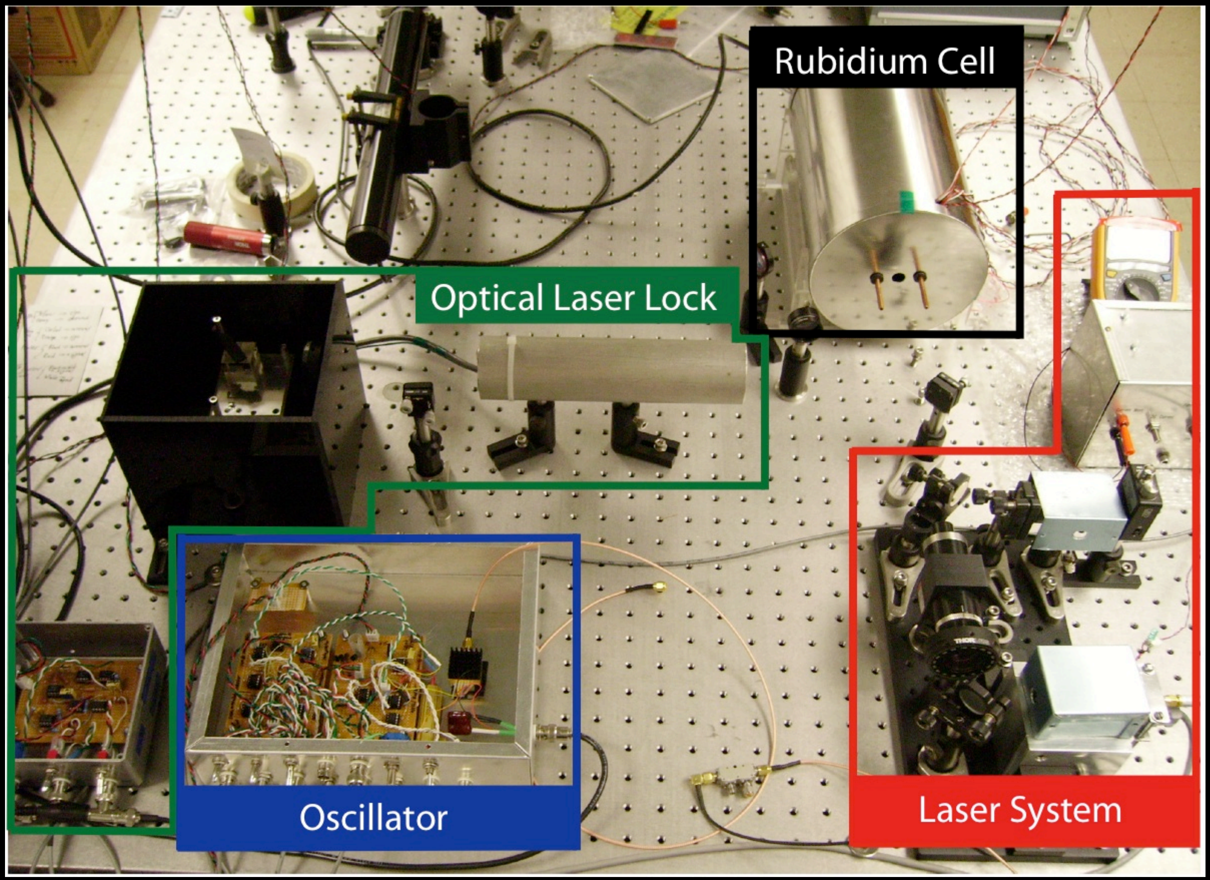


Miniature Atomic Clocks





The Experiment



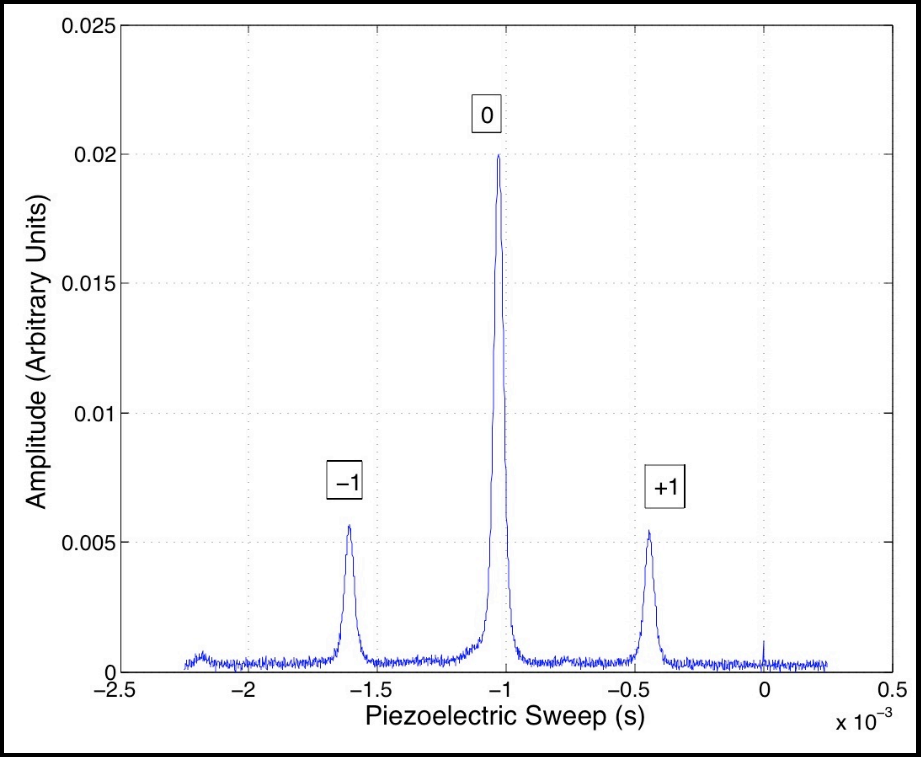
Phase Modulation

- Apply rf field to laser, create carrier and sideband comb

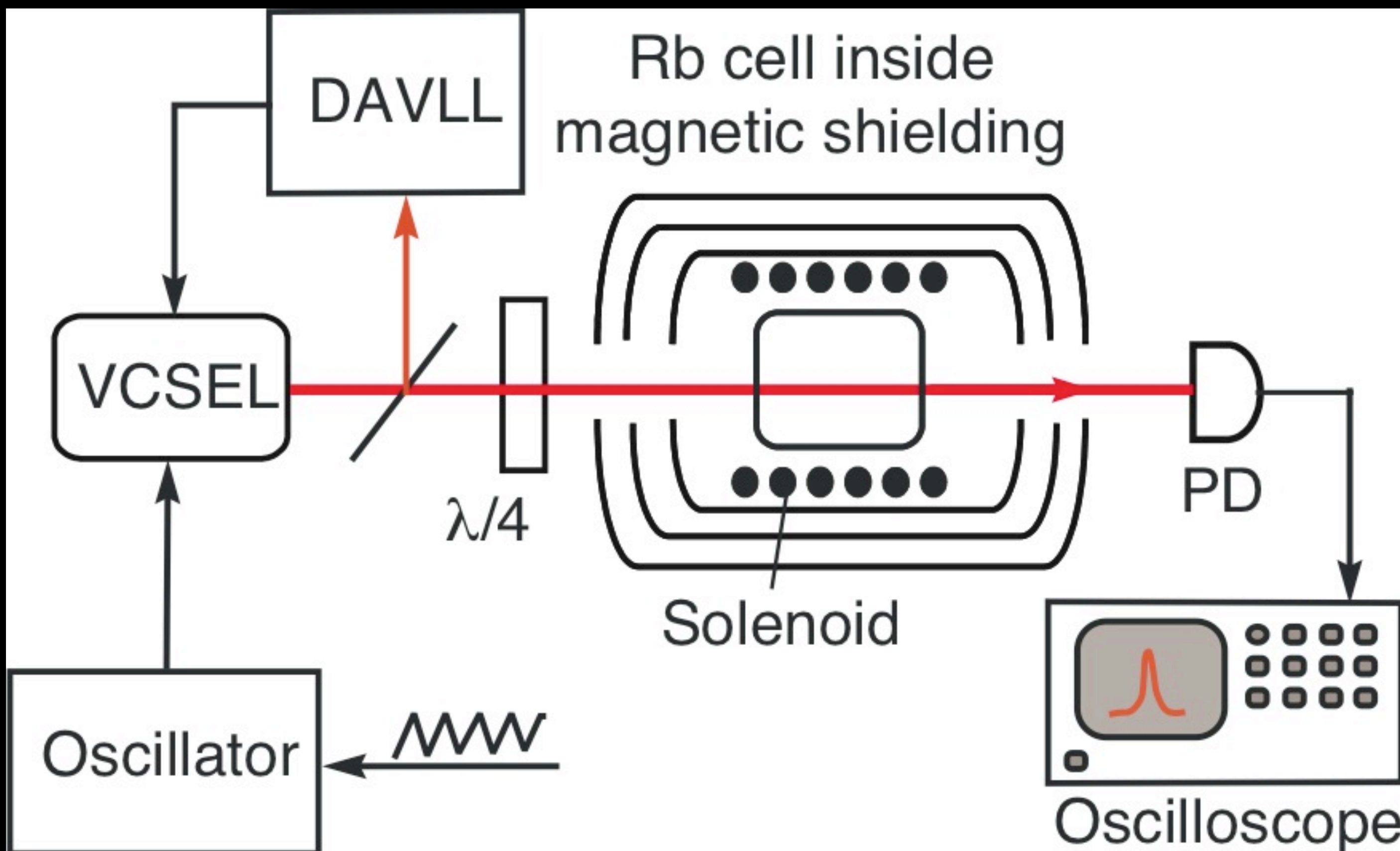
$$E = E_0 e^{ikx - i\omega t + i\varphi(t)}$$

$$\varphi(t) = \varepsilon sin(\omega_m t)$$

$$E = \sum_{n=0}^{\infty} E_0 J_n(\varepsilon) e^{ikx - i(\omega - n\omega_m)t}$$

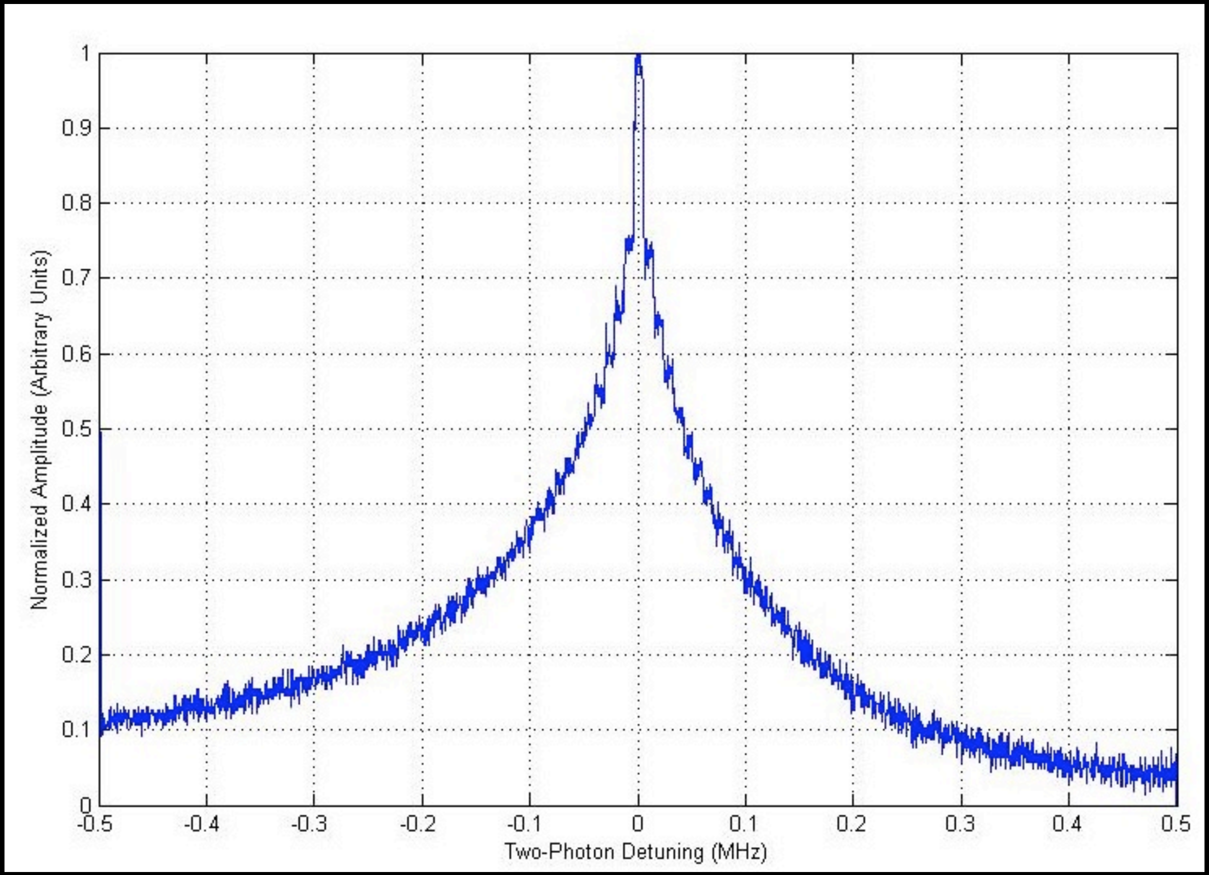


CPT Experiment



CPT Experiment continued

$$|dark\rangle = \frac{\Omega_1 |g_2\rangle - \Omega_2 |g_1\rangle}{\sqrt{|\Omega_1|^2 + |\Omega_2|^2}}$$

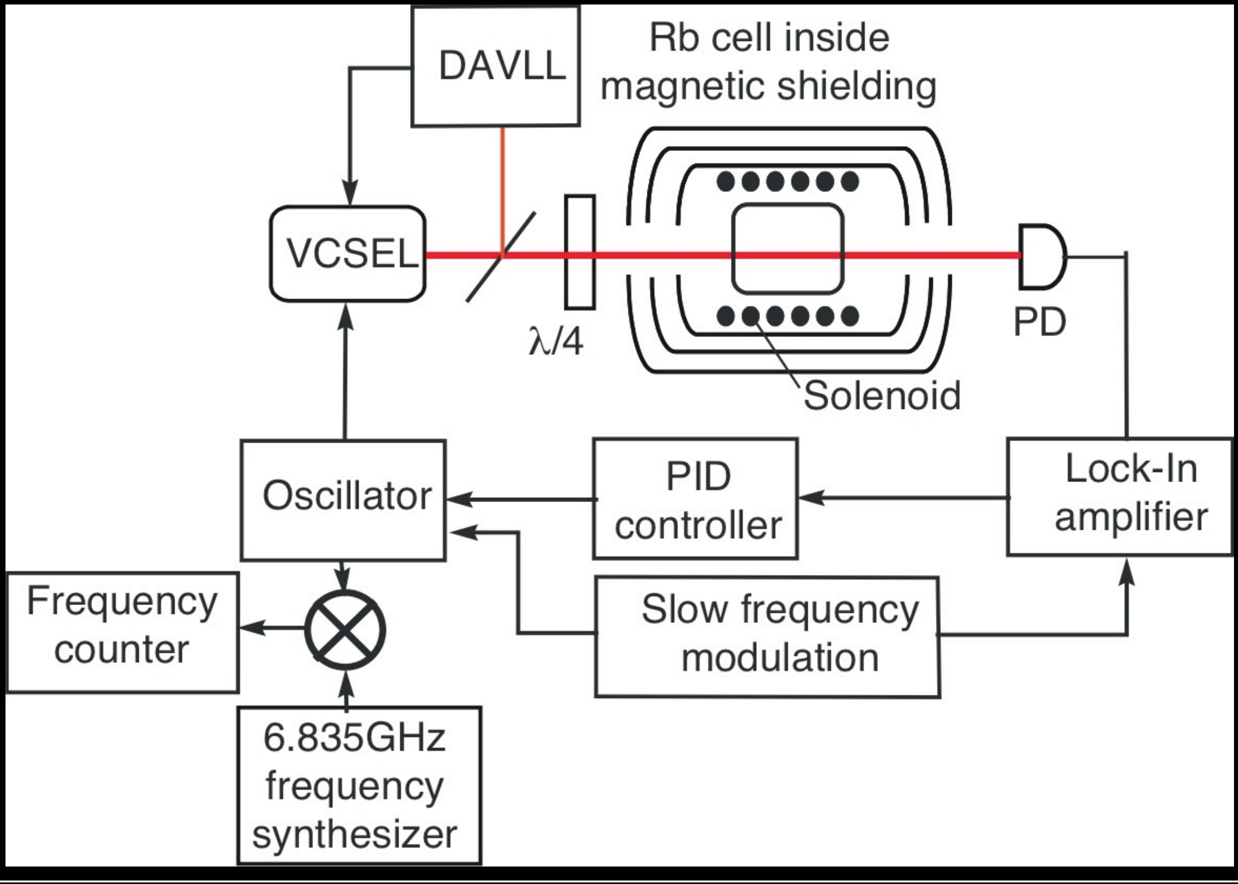


First CPT Lineshape Results

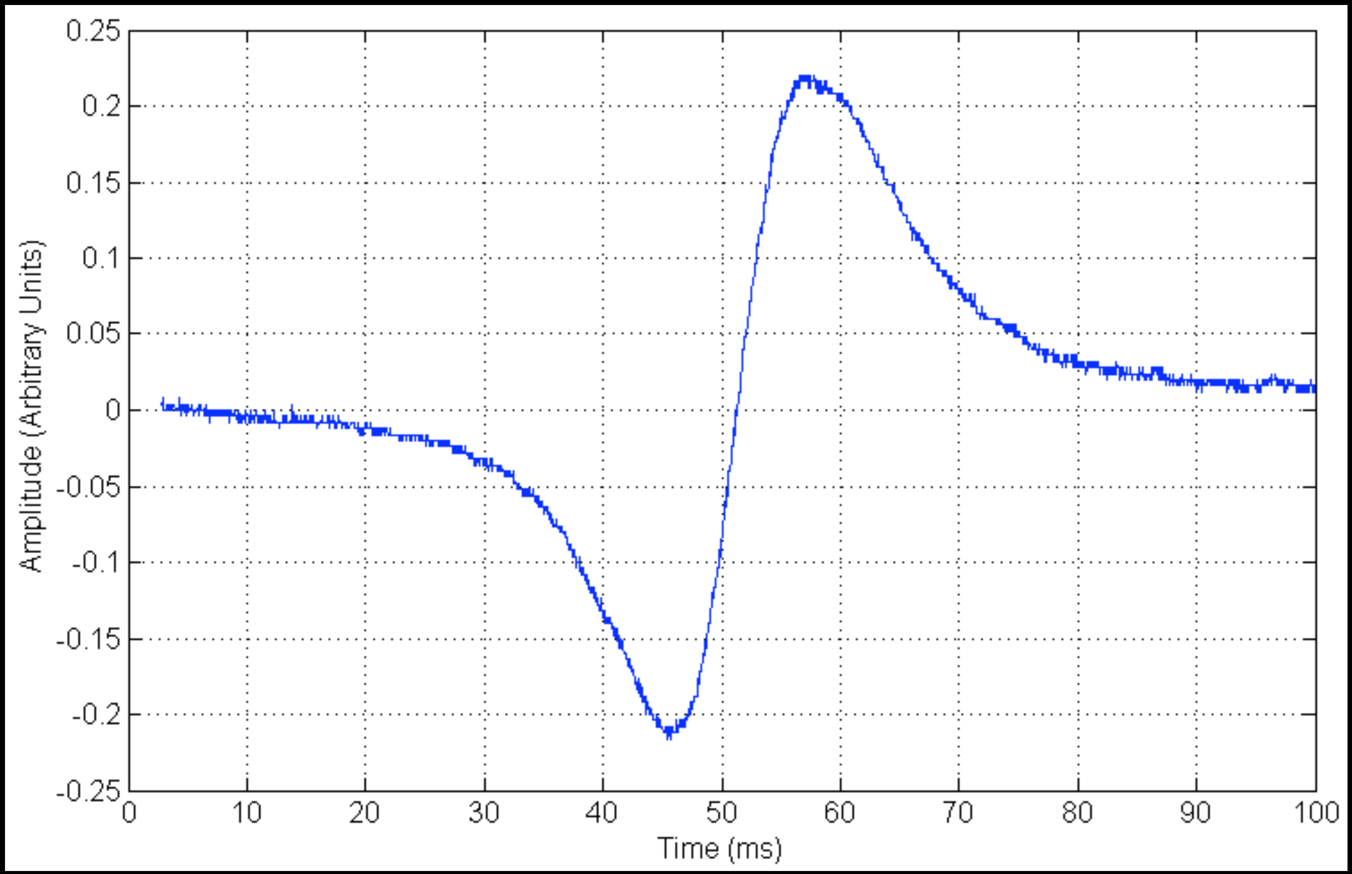
- Four rubidium cell temperatures
- Three input rf powers
- 45 degrees Celsius best temperature
- Retake data with four input rf powers
- 90% sidebands best

First CPT Lineshape Results

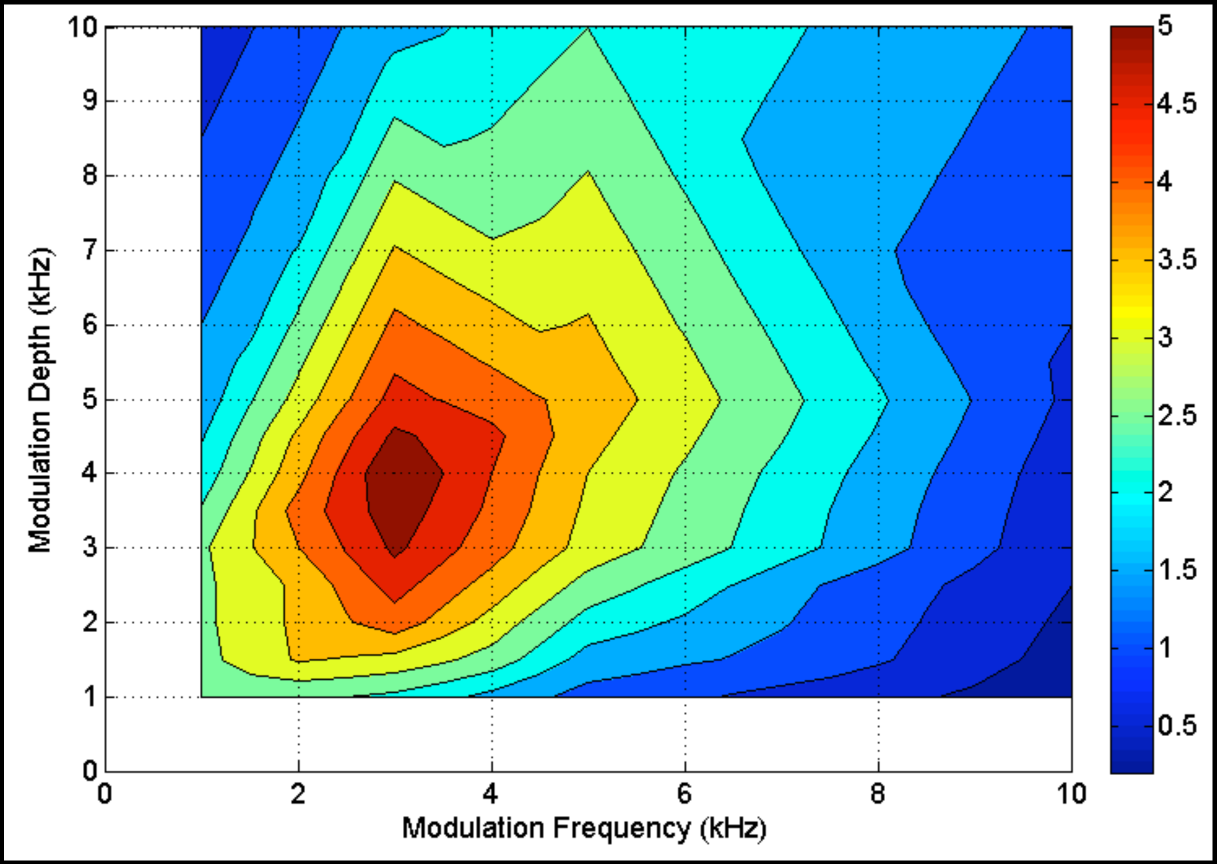
Clock Experiment



Lock-in Amplifier Error Slope



Lock-in Amplifier Plot

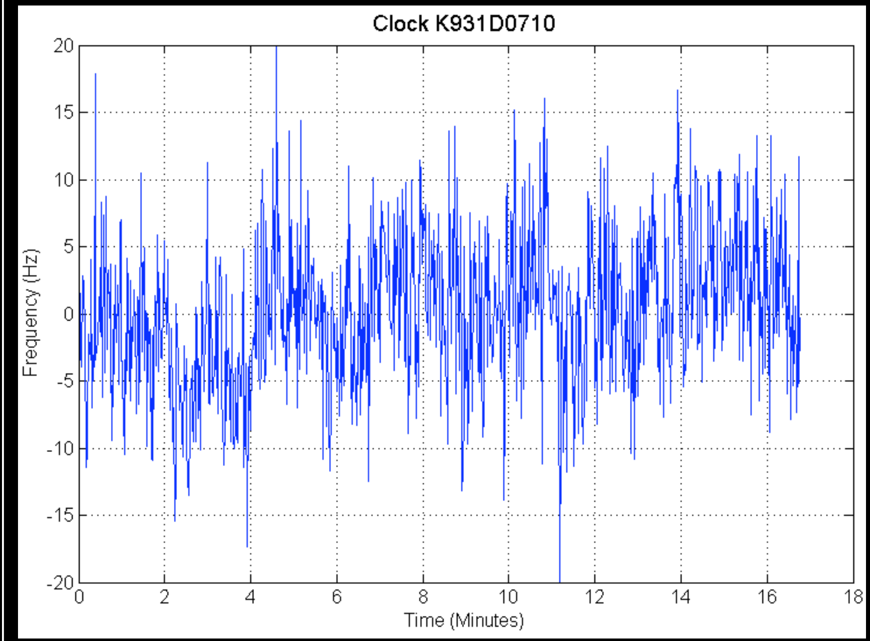


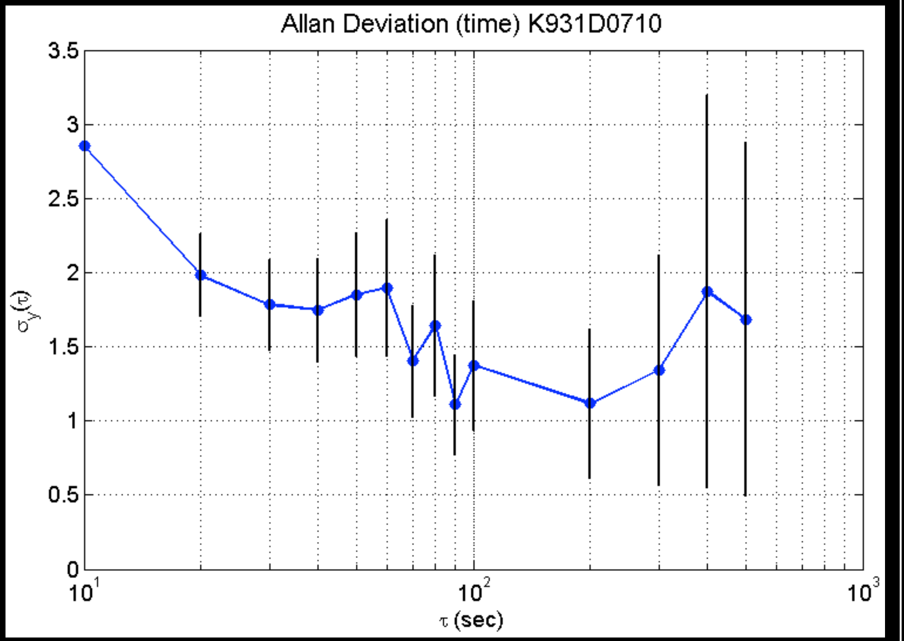
First Clock Results

- Locking point F=2 to F'=1 transition instead of F=1 to F'=2
- Measure with Allan variance
- Only get 4e-10 Allan variance (not good)

$$\sigma_\nu^2(\tau) = \frac{1}{2}\left\langle \nu^2 \right\rangle$$

First Clock Results

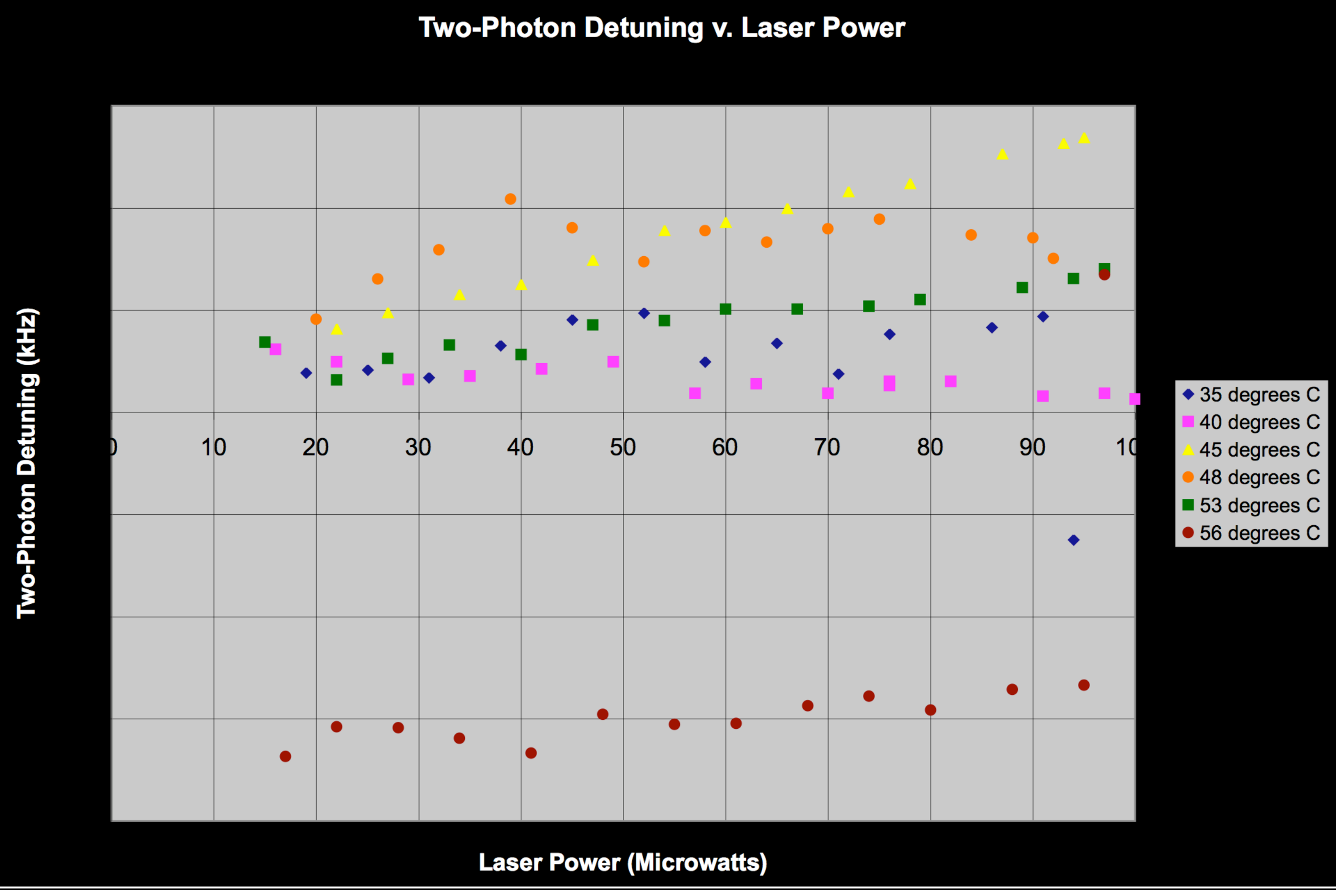




Second CPT Lineshape Results

- Lightshift cancellation at 75% sidebands
- Five different rubidium cell temperatures
- 40 degrees Celsius best temperature

Second CPT Lineshape Results



Second Clock Results

- Initial Allan variance of 2e-10
- Work out some noise issues and optimize lock-in parameters

Future Work

- Continue to optimize clock parameters to get best Allan variance possible