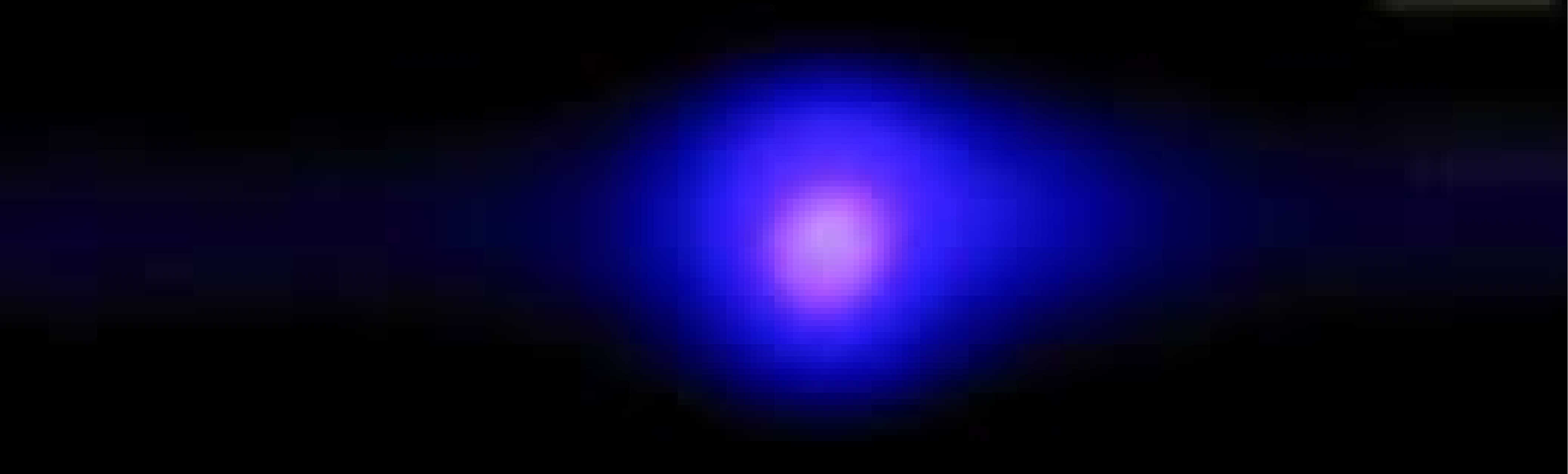
Passive Reference Cavities for Frequency Stabilization of Yb^+ Cooling Lasers



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Yb atom cloud (Barber, NIST)

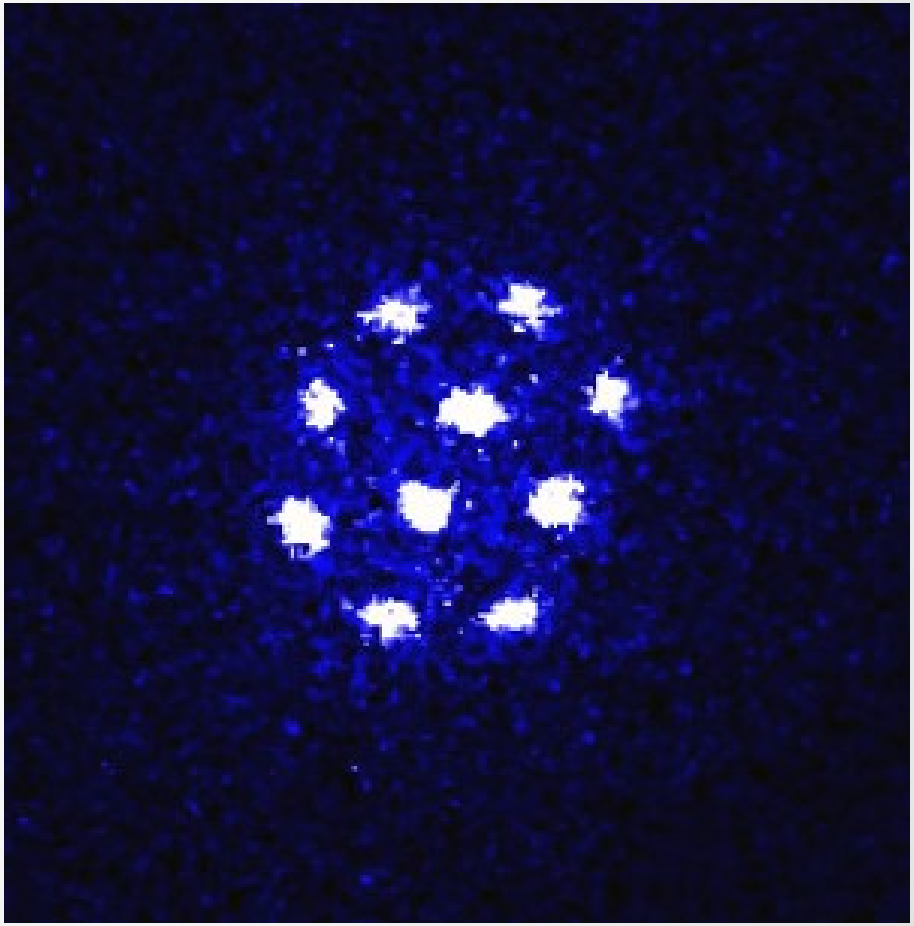
Quantum Computing

- Qubits – store information in a superposition of two states
- Quantum algorithms – number factorization, many body models, database search
- Requires qubits that interact strongly with each other but that are decoupled from the environment until measurement

- Question – What kind of system would make a good candidate for a quantum computer?

Trapped Ions!

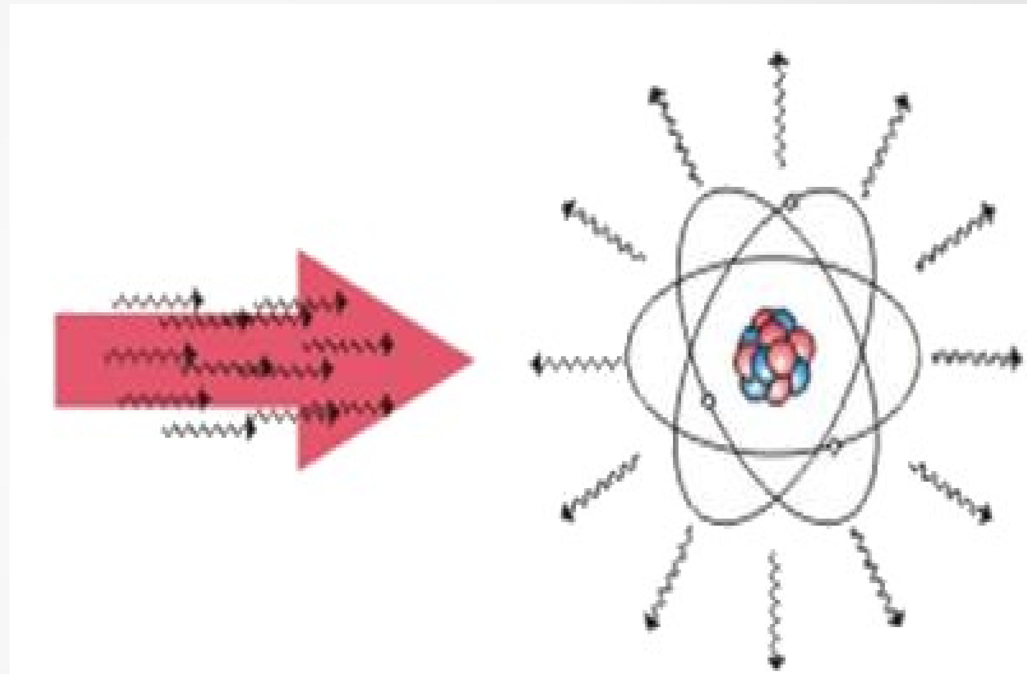
- Store quantum information in the ion's hyperfine states - Ba^{+}
- Can be isolated in various traps at low pressure and temperature
- Strong interactions between ions
- Lasers allow cooling and controlled manipulations of ions
- Problem: Scalability
- Challenge: Ions interact with their environment, leading to heating and decoherence



Aps.org

Doppler Cooling

- Redshift laser light from the electronic transition
- Atoms moving towards the laser see the light on resonance, scattering light
- The incoming laser light is then providing radiation pressure opposite the ion's movement, decreasing temperature
- Driving this scattering requires longterm stability in the laser frequency



http://www-users.york.ac.uk/~phys24/Pages/Techniques/MDS/index2.shtml

- Problem: Qubits and doppler cooling use the internal states, meaning we cannot do both simultaneously!

Sympathetic Cooling

- We can introduce a second species of ion to cool Ba^+
- Strong interactions between the ions ensures that cooling the second species leads to cooling of Ba^+
- Most efficient with a species of similar mass

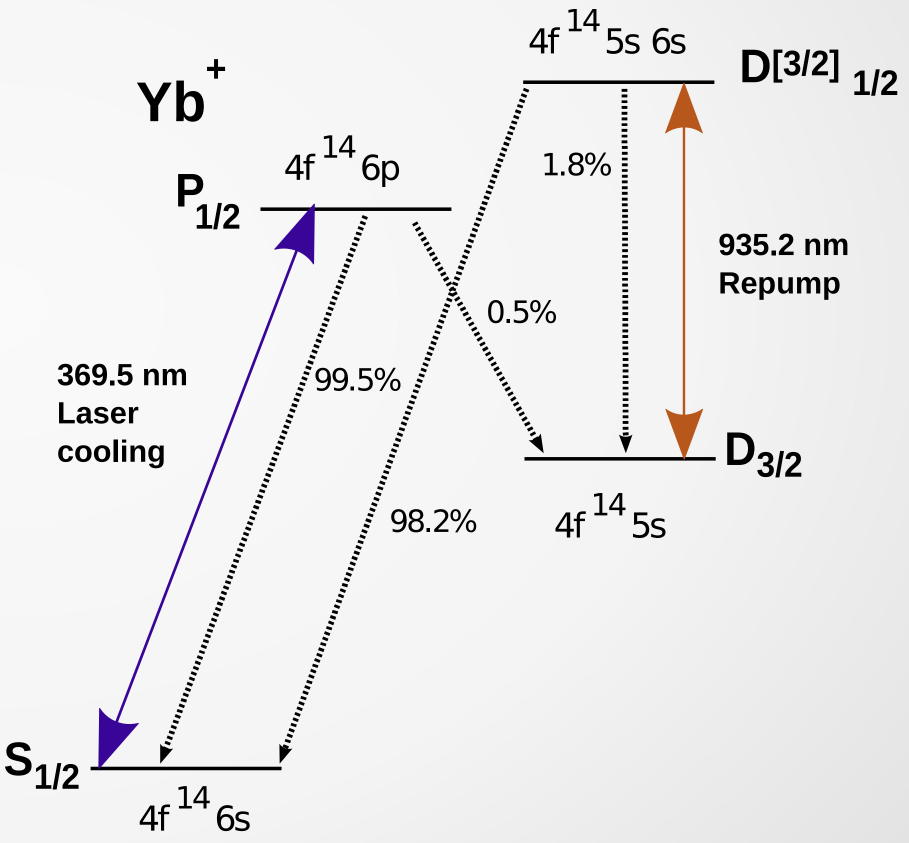
- Goal: Use a commonly trapped ion that has a similar mass to Ba^+

Ytterbium Ions

- Similar mass to Ba^+

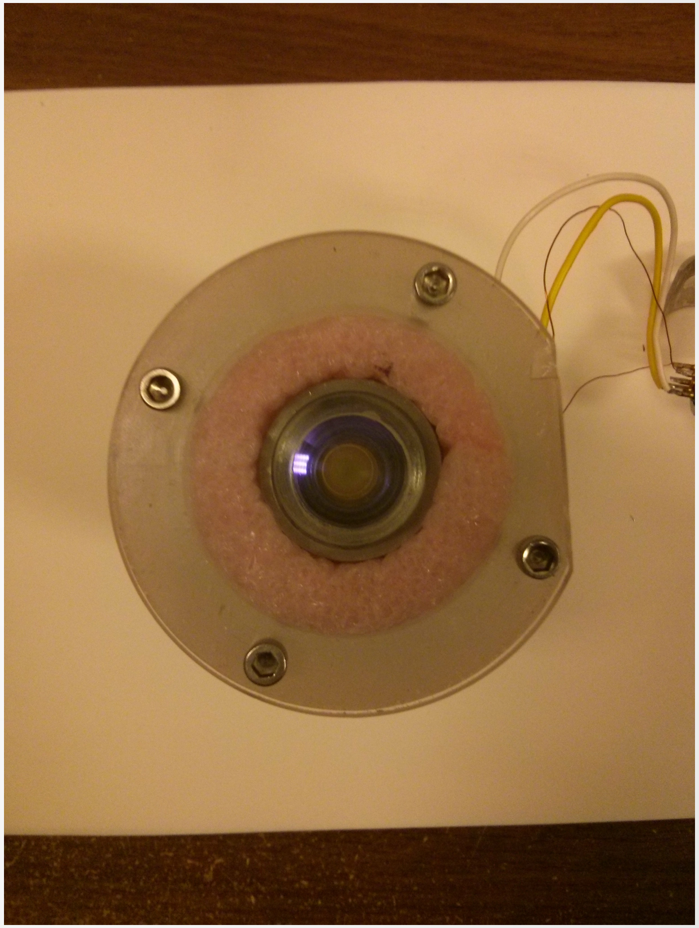
$$\frac{m_{Yb^+}}{m_{Ba^+}} = 1.26$$

- 370 nm laser used for cooling
- 935 nm repump laser to remove ion from $D_{3/2}$ state



Laser Drift

- Frequency drifts with ambient conditions
- To keep lasers stable they can be locked to an optical cavity.



Project: Create two optical cavities that can be used to stabilize the lasers needed for Yb^{+} cooling

Cavity Theory and Design

- In designing a cavity there are a few considerations
  - Free spectral range (FSR) – spacing between longitudinal modes of the cavity

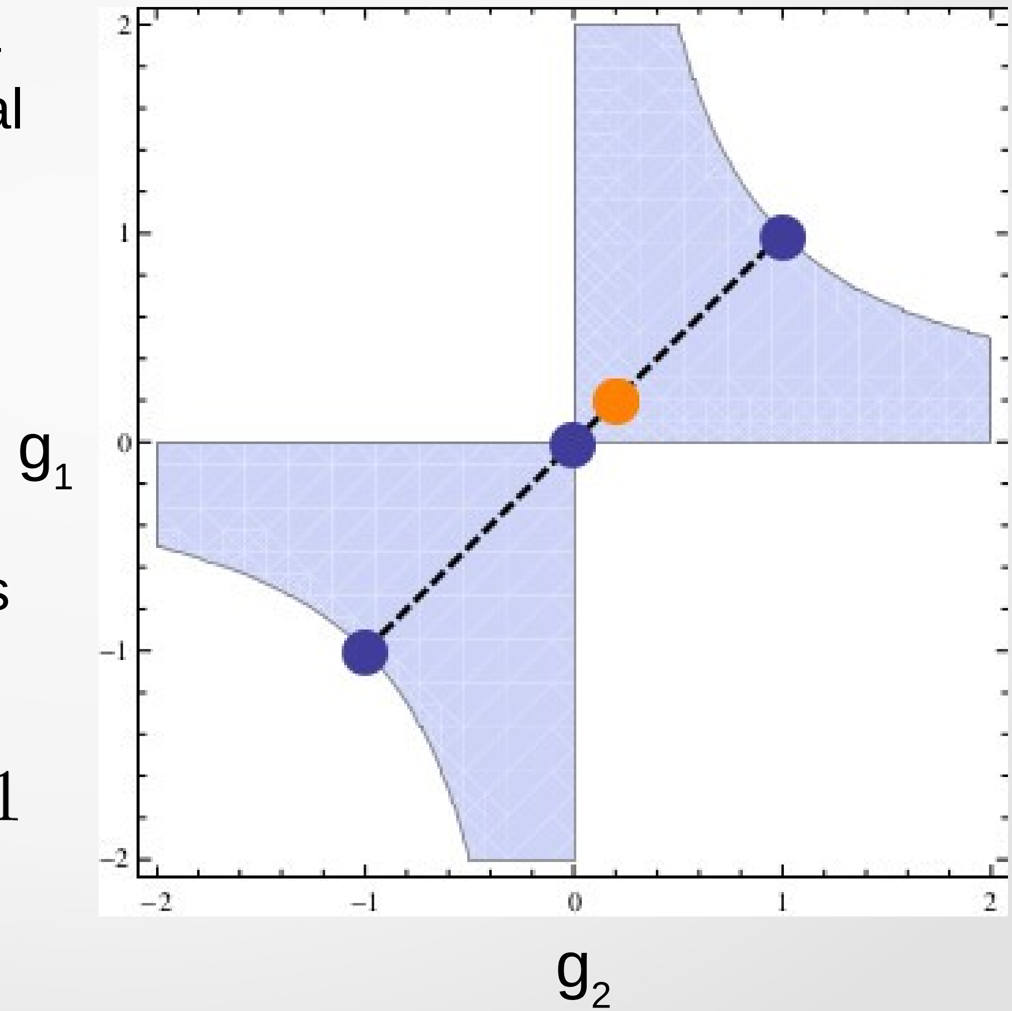
$$FSR = \frac{c}{2l}$$

$$l = 75 - 80 \text{ mm}$$

  - Cavity stability – a stable cavity has periodic ray paths

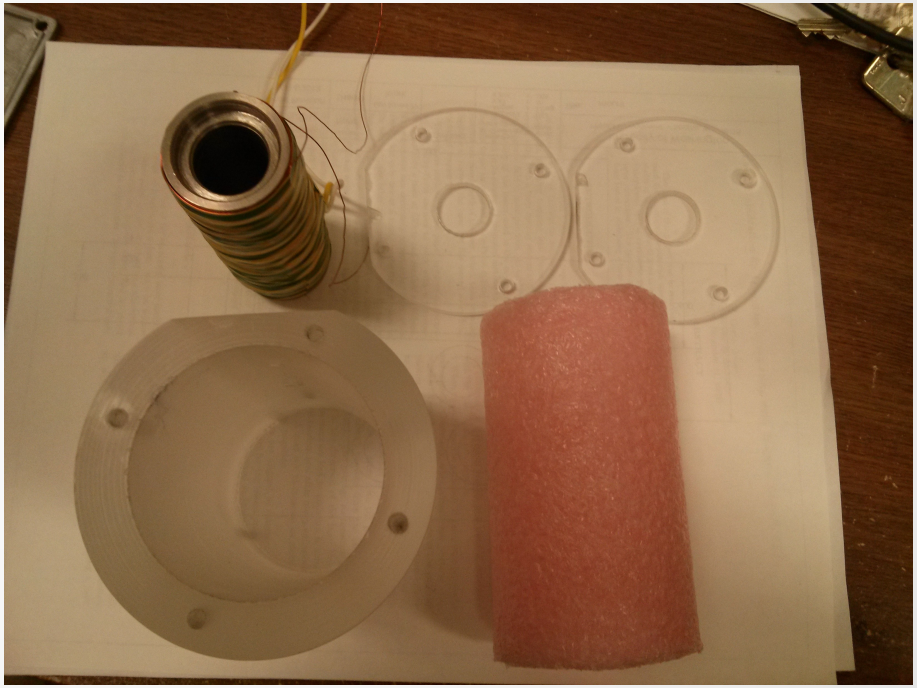
$$g \equiv 1 - \frac{l}{R} \qquad 0 \leq |g| \leq 1$$

Regions of Stability for g_1 vs g_2



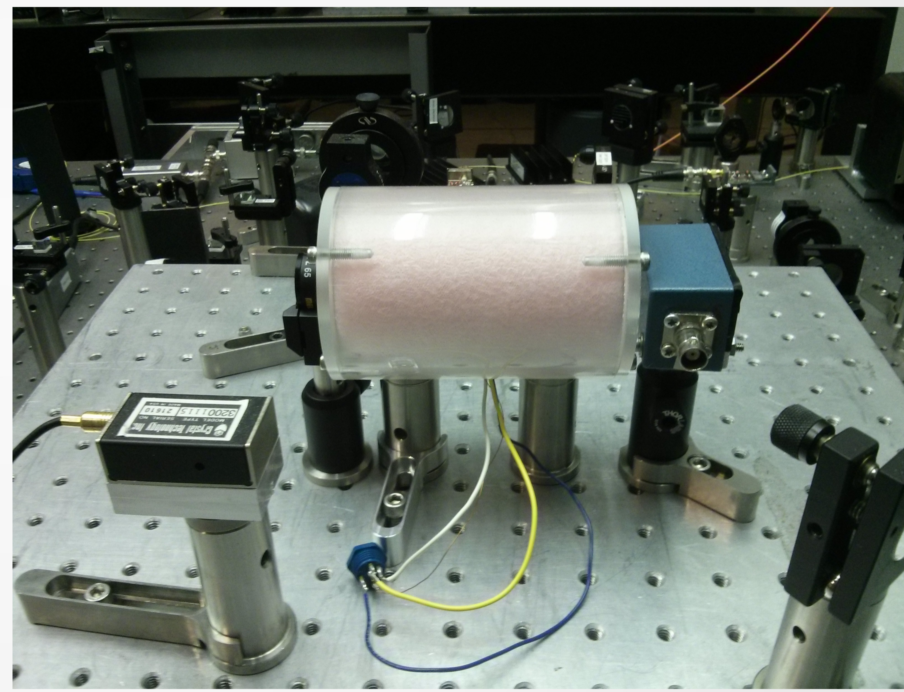
Cavity Construction

- 1.25 in diameter rod of Invar cut to 3.5 in
- Concentricity!
- Bore out inner diameter and end recessions
- Wrap in ≈ 8 Ω of wire
- Construct cases for each cavity



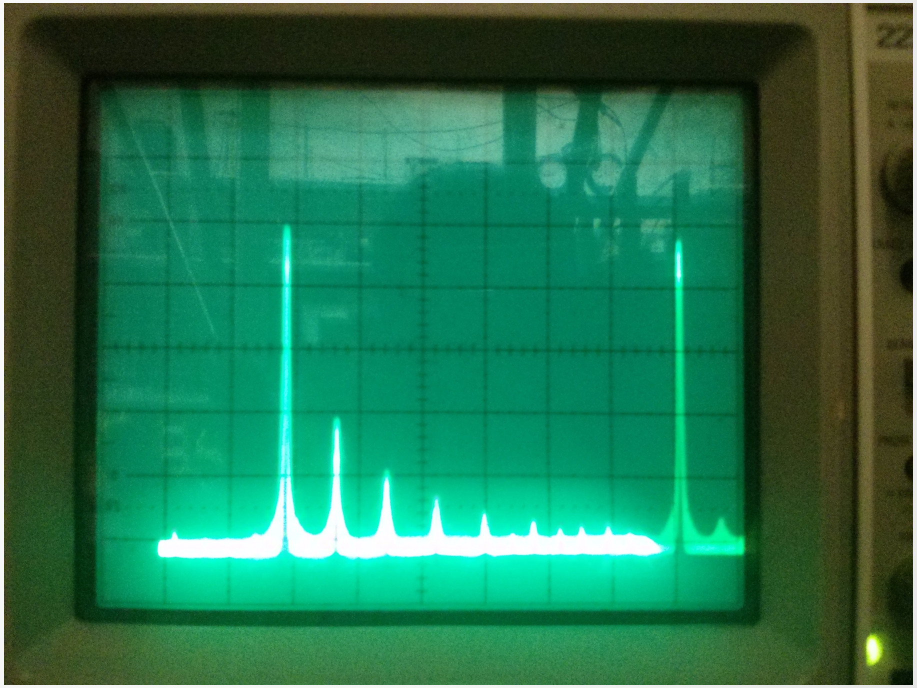
Testing for Cavitation

- Use 399 nm and 986 nm light
- Test reflection R at these wavelengths
  - 399 nm ≈ 99 %
  - 986 nm ≈ 98 %
- Couple lasers into cavities
- Sweep laser frequency and maximize transmission peaks



Seeing a Transmission Spectrum

- Cavitation seen in both cavities, but what does the spectrum look like?
- Mode match laser to cavity using a lens
- Further refine coupling
- Well defined peaks with good spacing!



Finesse – 986 nm

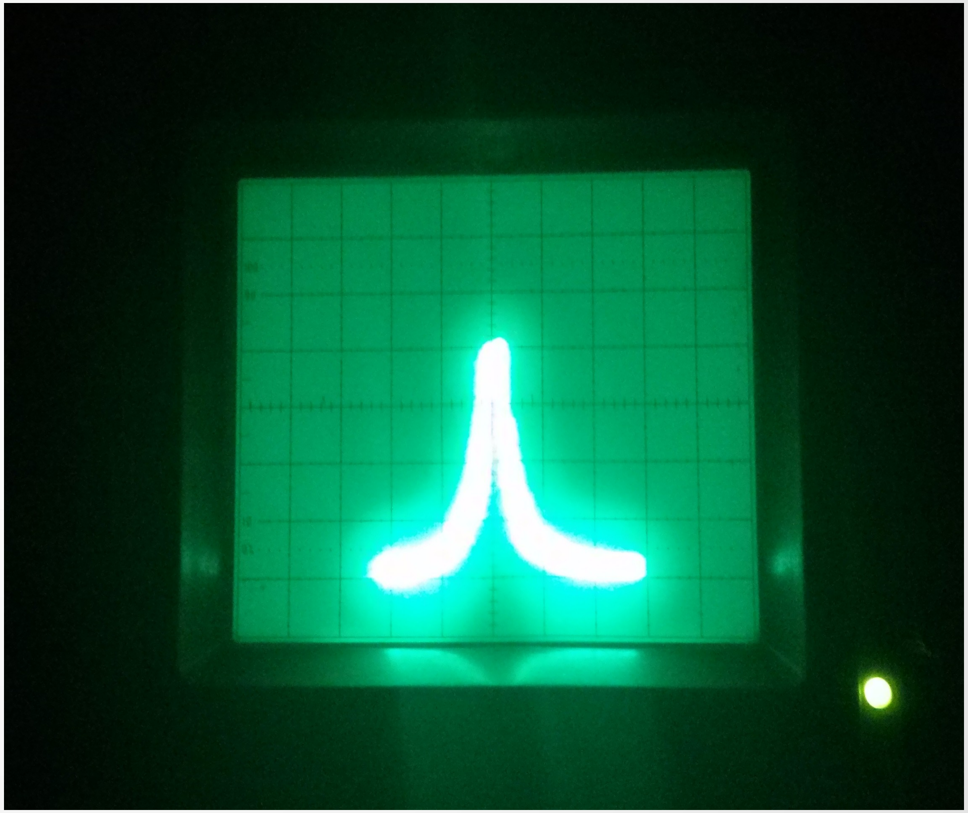
- Full width at half maximum

$$\Delta v_{1/2} = 18MHz$$

- Finesse (F)

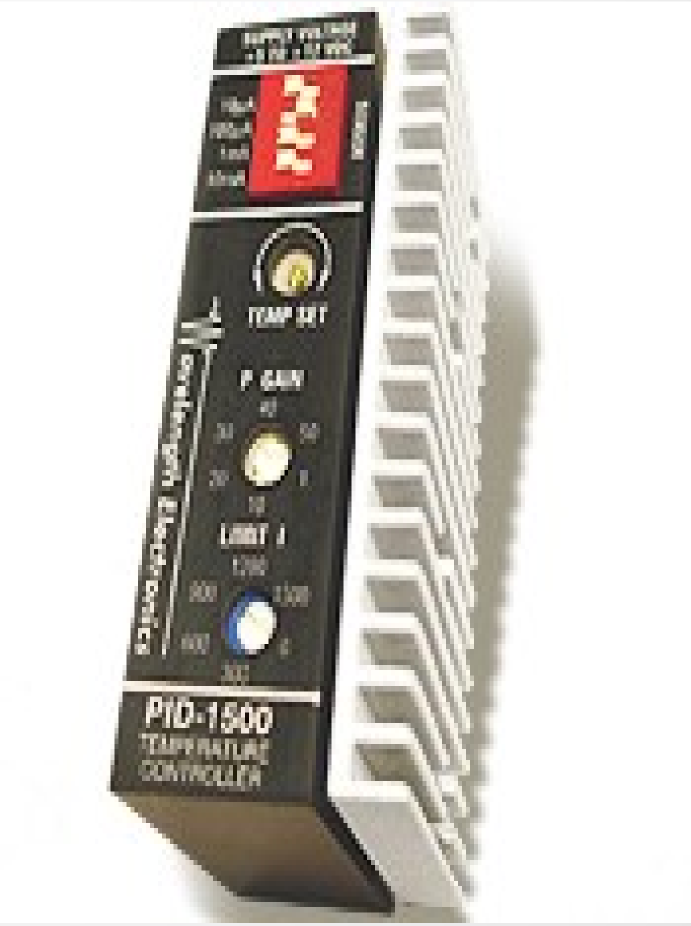
$$F = \frac{FSR}{\Delta v_{1/2}}$$

$$F = 104$$

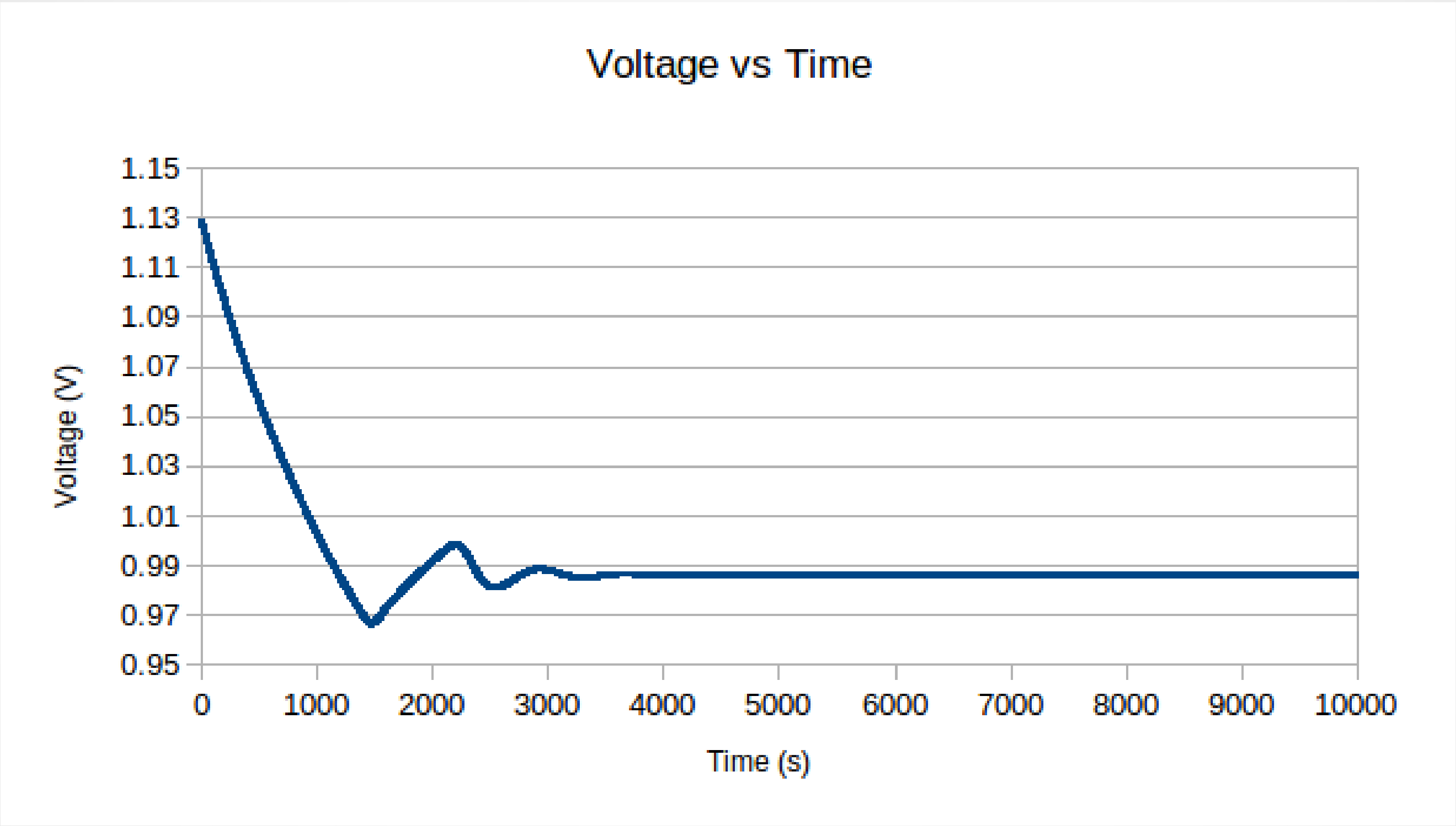


Temperature Stability

- Use a PID Controller to stabilize the cavities temperature
- Use a thermistor to monitor temperature as voltage
- Monitor stabilization using Lab View



Temperature Stability



Temperature Stability in Frequency Space

- Use propagation of uncertainty to relate voltage fluctuations to frequency fluctuations in the cavity.
- To get an idea of how stable the cavity is, use the fluctuation in voltage from the long term stabilization run.

$$\Delta V \approx 150\mu\mathrm{V}$$

$$T(v) = \frac{B}{\ln\left(\frac{V}{V_0}\mathrm{e}^{\frac{B}{T_0}}\right)}$$

$$\triangle f = \frac{c\alpha_L T_0^2 \Delta V}{2\lambda B V_0}$$

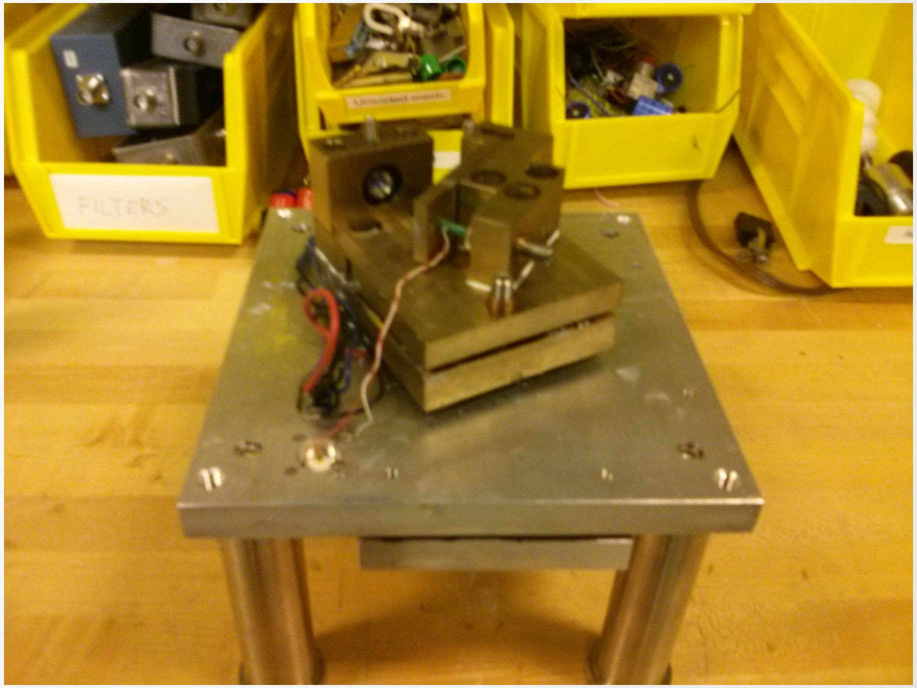
$$\Downarrow$$

$$\Delta f \approx 1.4\ \mathrm{MHz}$$

$$\Delta f_{Al} \approx 26\ \mathrm{MHz}$$

Conclusions

- 2 Cavities for Yb+ Cooling were made
  - Cavitation verified
  - Temperature stabilized
- Ongoing work – construction of 370 nm and 935 nm



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References

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Questions?