QUANTUM COMPUTING WITH TRAPPED IONS AND LASER COOLING

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UW Physics REU Summer 2009
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OUTLINE

- Overview of Quantum Computing and Laser Cooling
- Discussion of Fabry-Perot Cavities and their relevance to laser stabilization
- Our setup - optical cavities, high voltage drivers, computer control loops

WHY QUANTUM COMPUTING?

- Applications in NP problems (non-deterministic polynomial) ?

- Main motivation: Break RSA Encryption

  - RSA relies on the “hardness” of factoring big numbers, but a quantum computer could do it efficiently [Shor]

WHAT MAKES A QUANTUM COMPUTER DIFFERENT?

- It uses quantum states as bits instead of transistors

- This means that not only can your “qubit” be a zero or a one, it can be a superposition of zero and one:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

HOW DOES ONE MAKE A QUANTUM COMPUTER?

- There are a number of proposals for the physical construction of a quantum computer
- Popular choices include energy levels and photon polarization; any two state system works

OPTIONS

Table 4.0-1
The Mid-Level Quantum Computation Roadmap: Promise Criteria

QC Approach	The DiVincenzo Criteria: Quantum Computation					The DiVincenzo Criteria: QC Networkability	
	#1	#2	#3	#4	#5	#6	#7
NMR	🔴	🟡	🟡	🟢	🟡	🔴	🔴
Trapped Ion	🟡	🟢	🟡	🟢	🟢	🟡	🟡
Neutral Atom	🟡	🟢	🟡	🟡	🟡	🟡	🟡
Cavity QED	🟡	🟢	🟡	🟡	🟢	🟡	🟡
Optical	🟡	🟡	🟢	🟡	🟡	🟡	🟢
Solid State	🟡	🟡	🟡	🟡	🟡	🔴	🔴
Superconducting	🟡	🟢	🟡	🟡	🟡	🔴	🔴
Unique Qubits	This field is so diverse that it is not feasible to label the criteria with "Promise" symbols.						

Legend: 🟢 = a potentially viable approach has achieved sufficient proof of principle

🟡 = a potentially viable approach has been proposed, but there has not been sufficient proof of principle

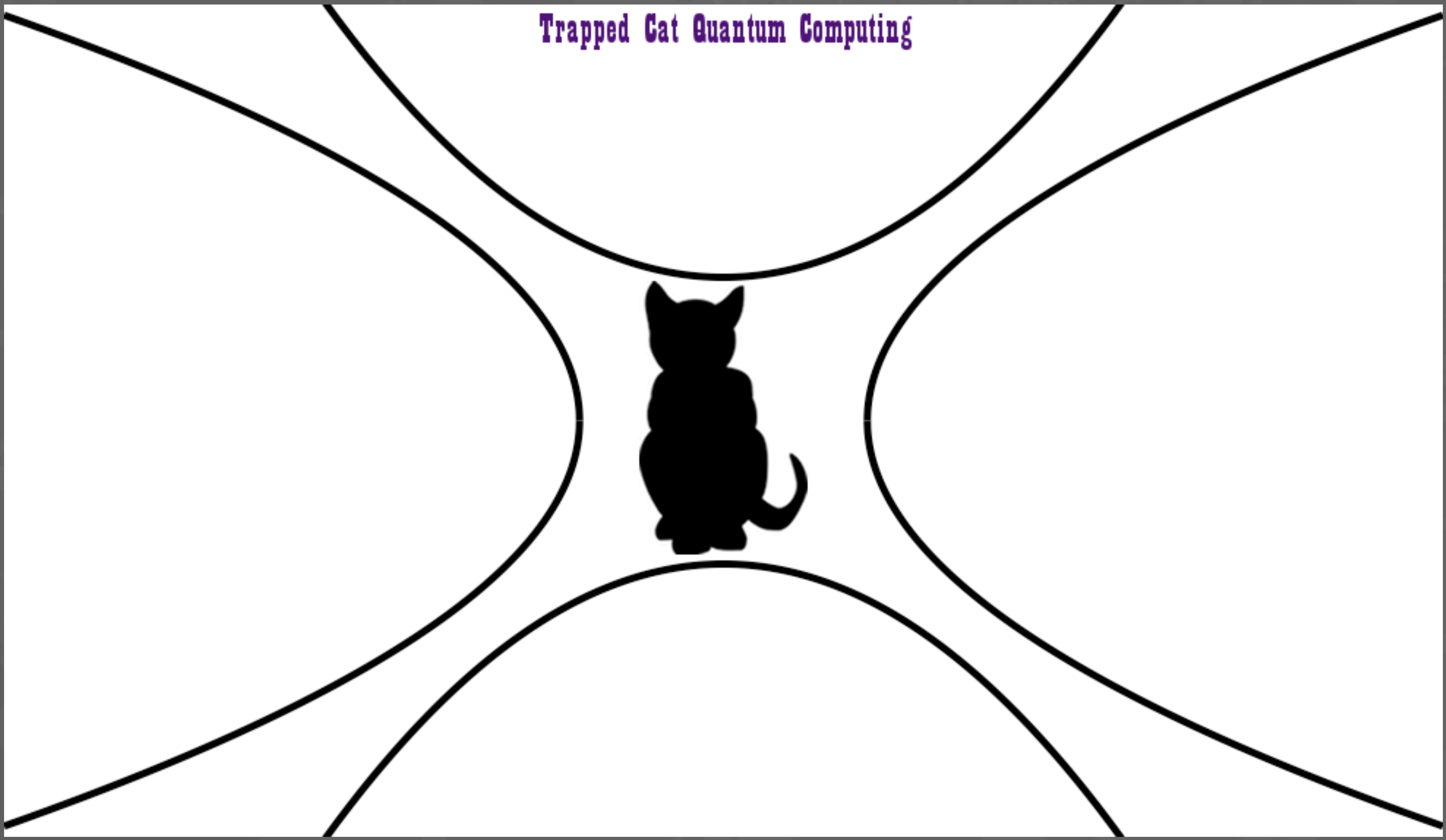
🔴 = no viable approach is known

The column numbers correspond to the following QC criteria:

#1. A scalable physical system with well-characterized qubits.
#2. The ability to initialize the state of the qubits to a simple fiducial state.
#3. Long (relative) decoherence times, much longer than the gate-operation time.
#4. A universal set of quantum gates.
#5. A qubit-specific measurement capability.
#6. The ability to interconvert stationary and flying qubits.
#7. The ability to faithfully transmit flying qubits between specified locations.

http://qist.lanl.gov/qcomp_map.shtml

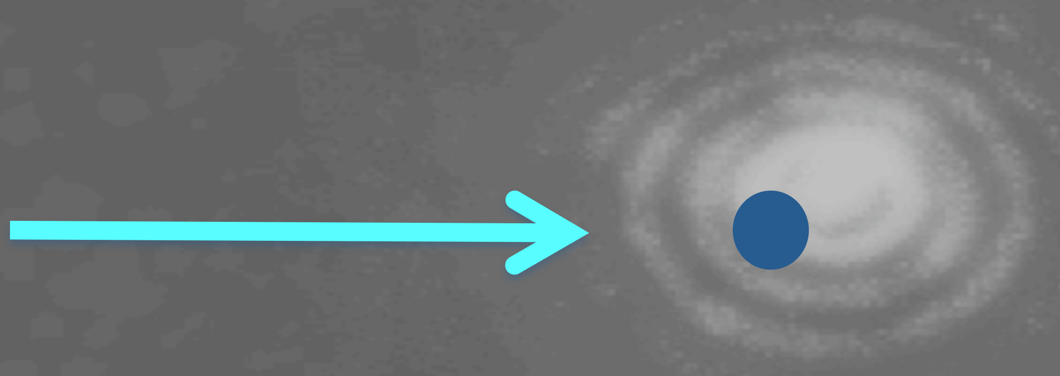
QUCAT? CATBIT? QUAT?



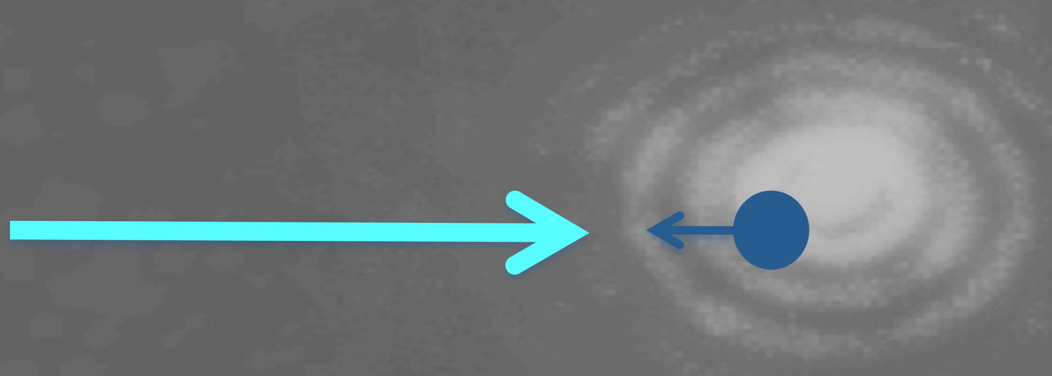
TRAPPED BA+ IONS

- Trapped Ba+ ions have a hyperfine splitting of the ground state in the S orbital - our qubit here at UW.
- Trapping ions requires laser cooling, which needs very stable lasers
- Our job was to stabilize the cooling lasers to high accuracy

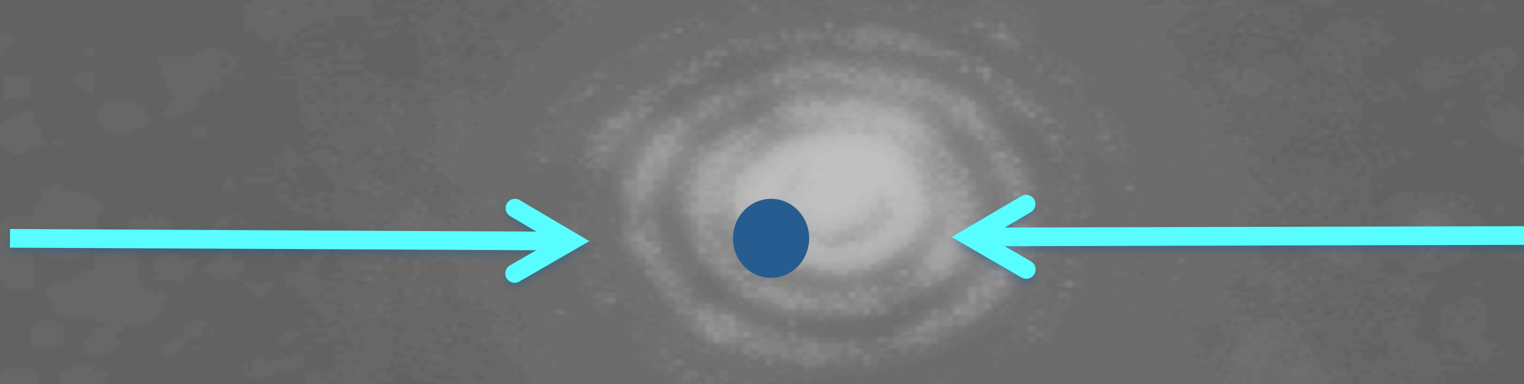
LASER COOLING



LASER COOLING



LASER COOLING



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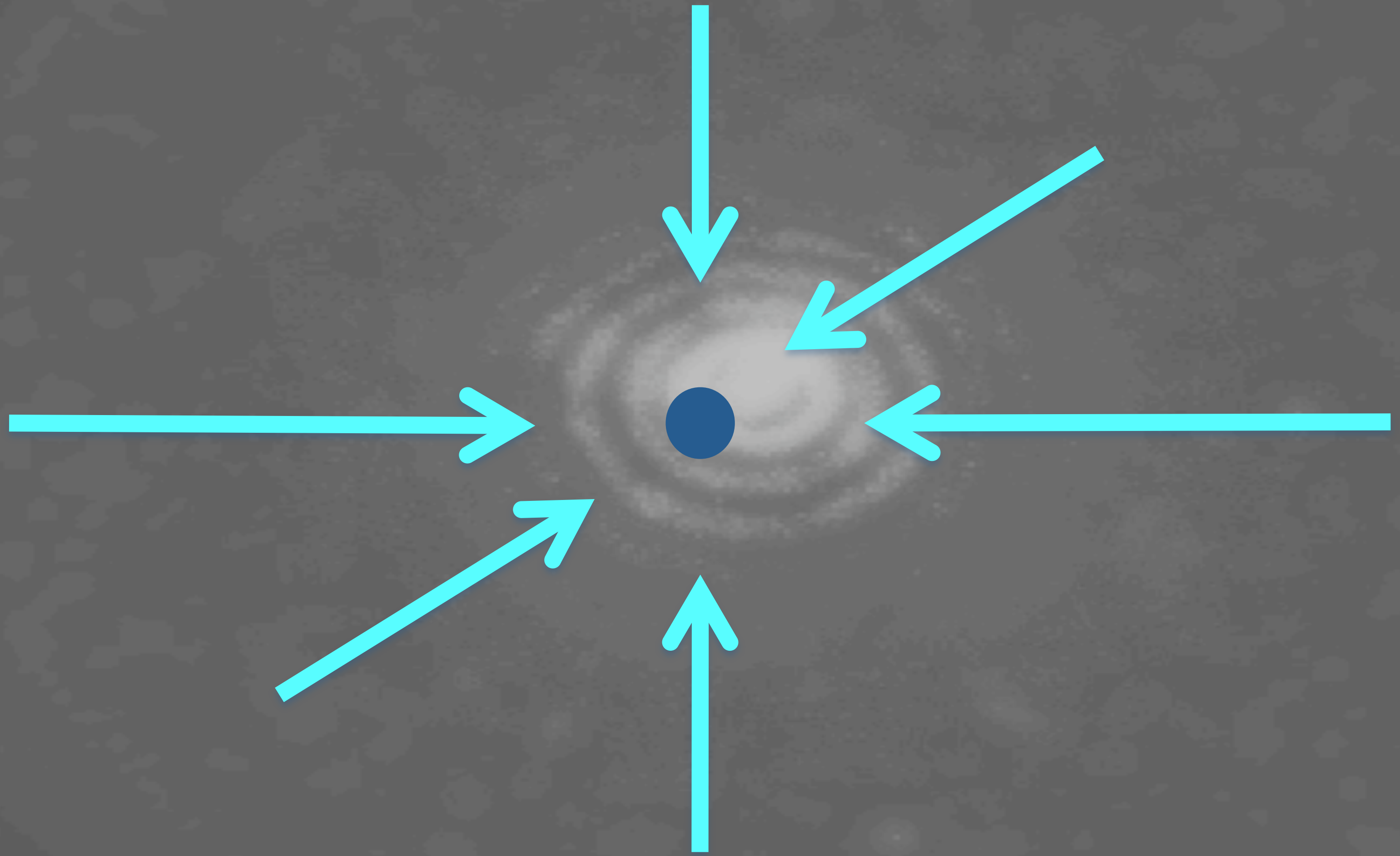
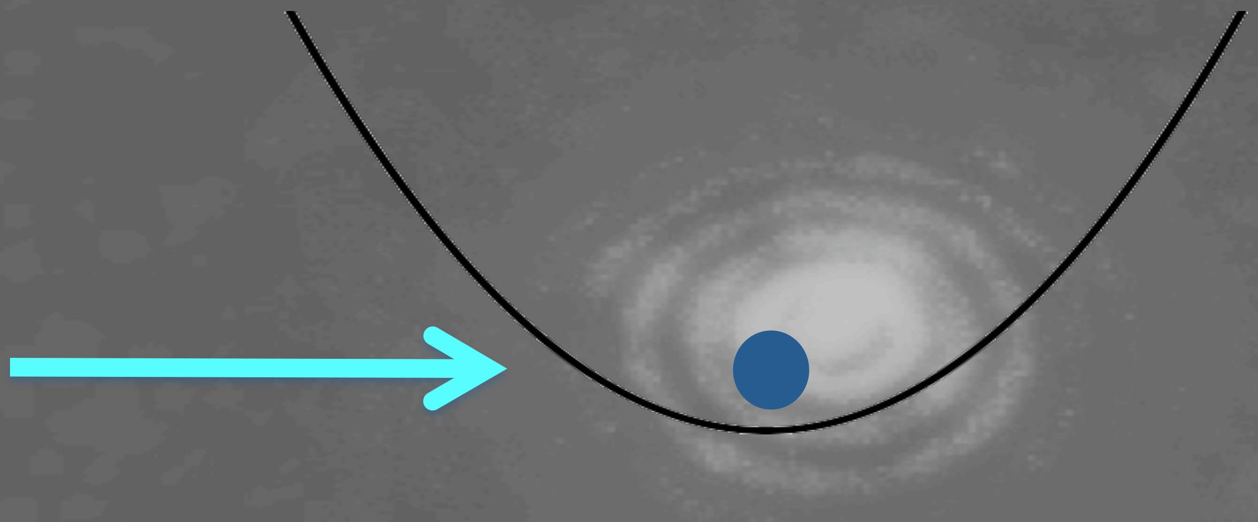
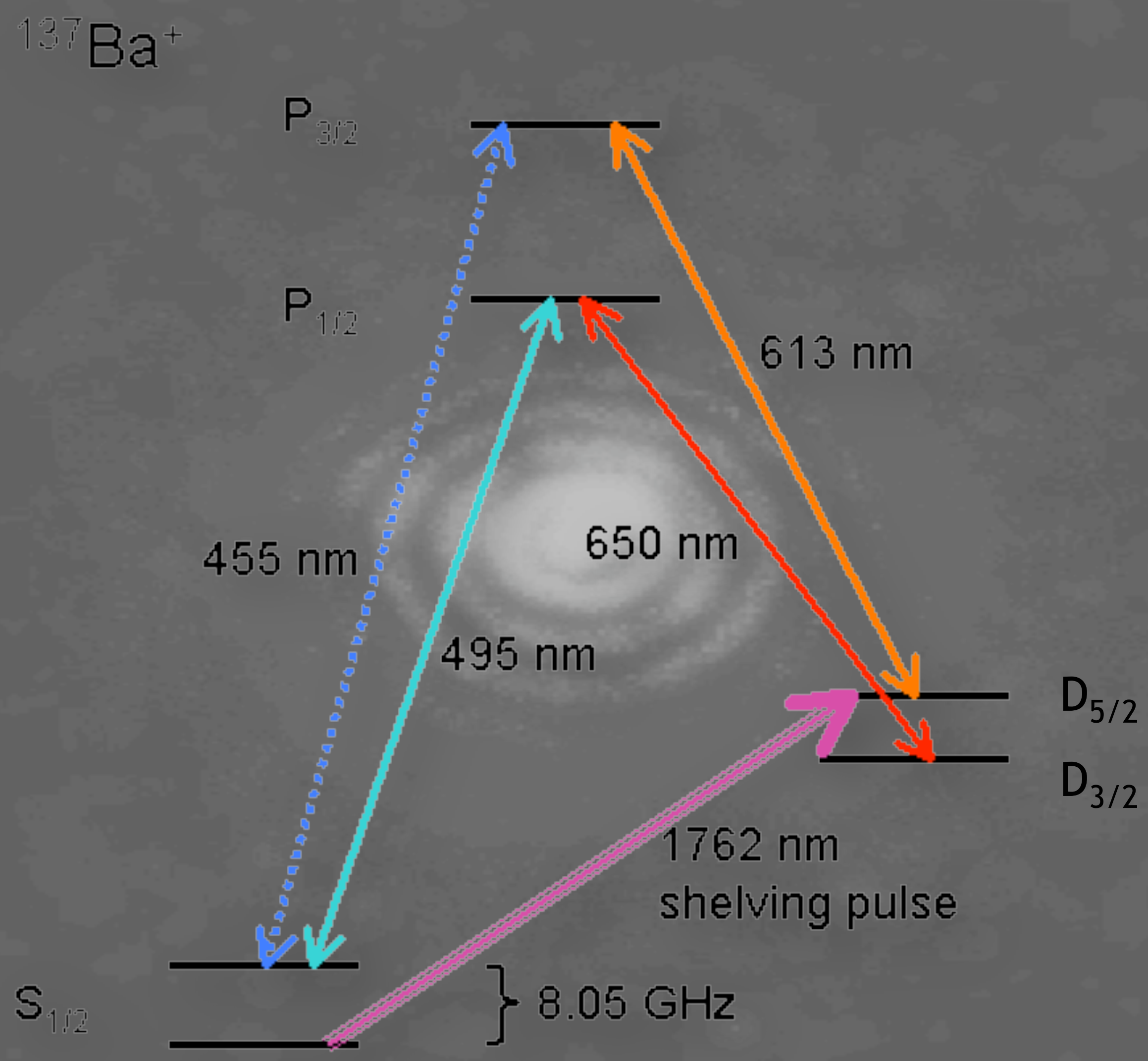


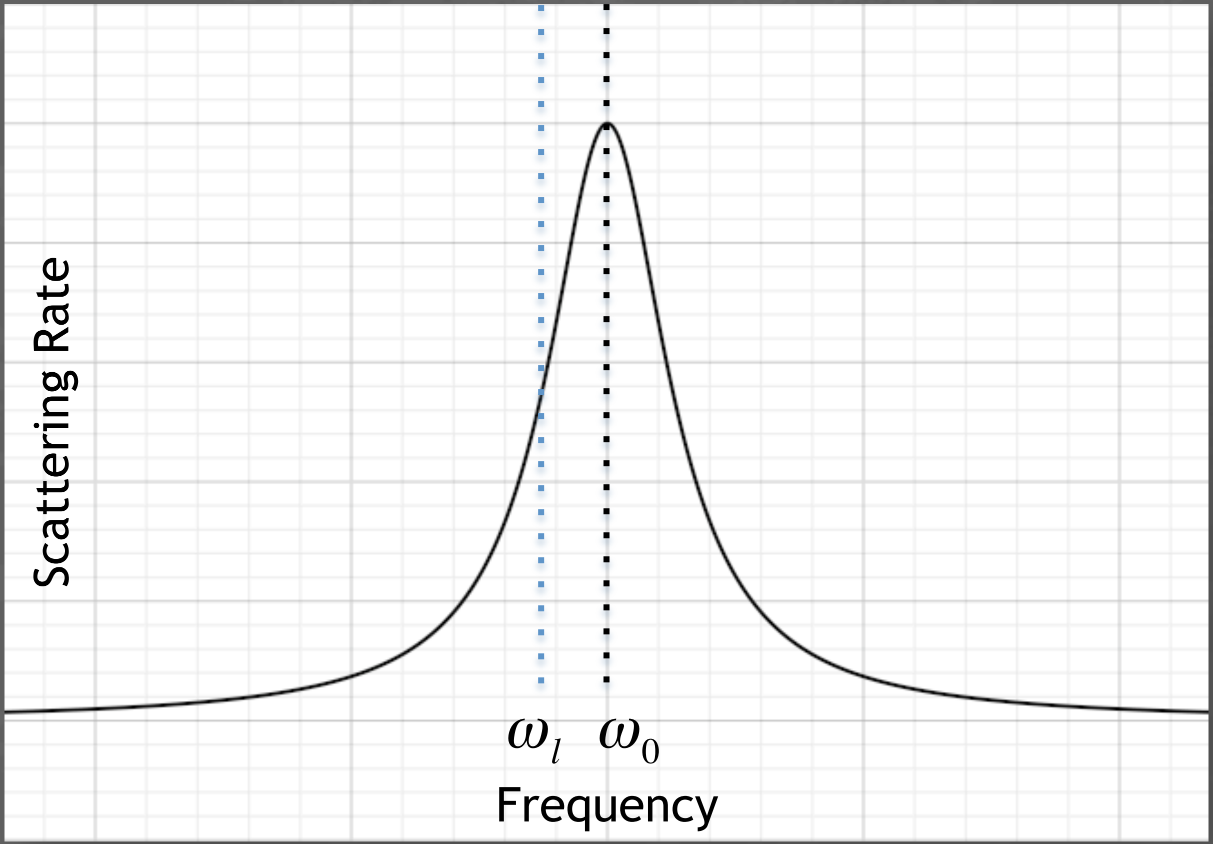
LASER COOLING





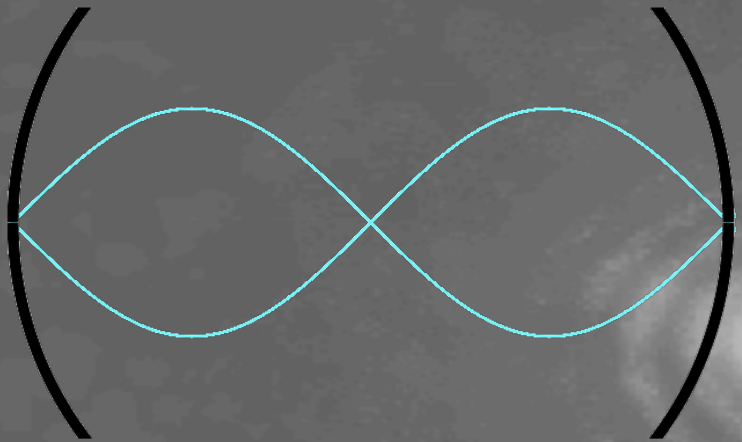
http://depts.washington.edu/qcomp/research.html

DETUNING



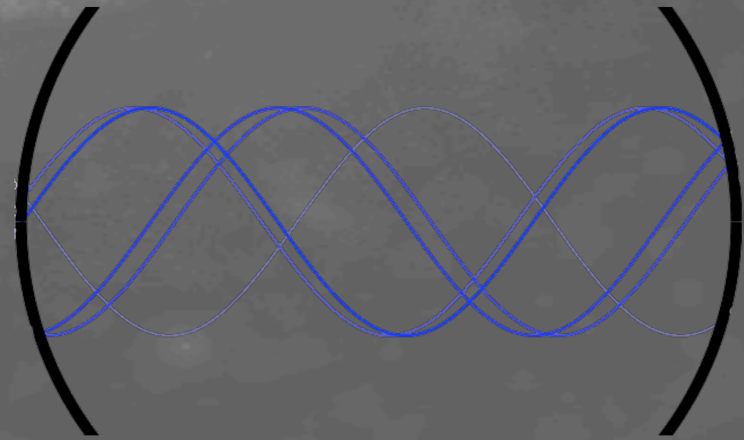
Metcalf and Straten, “Laser Cooling and Trapping”

OPTICAL CAVITIES

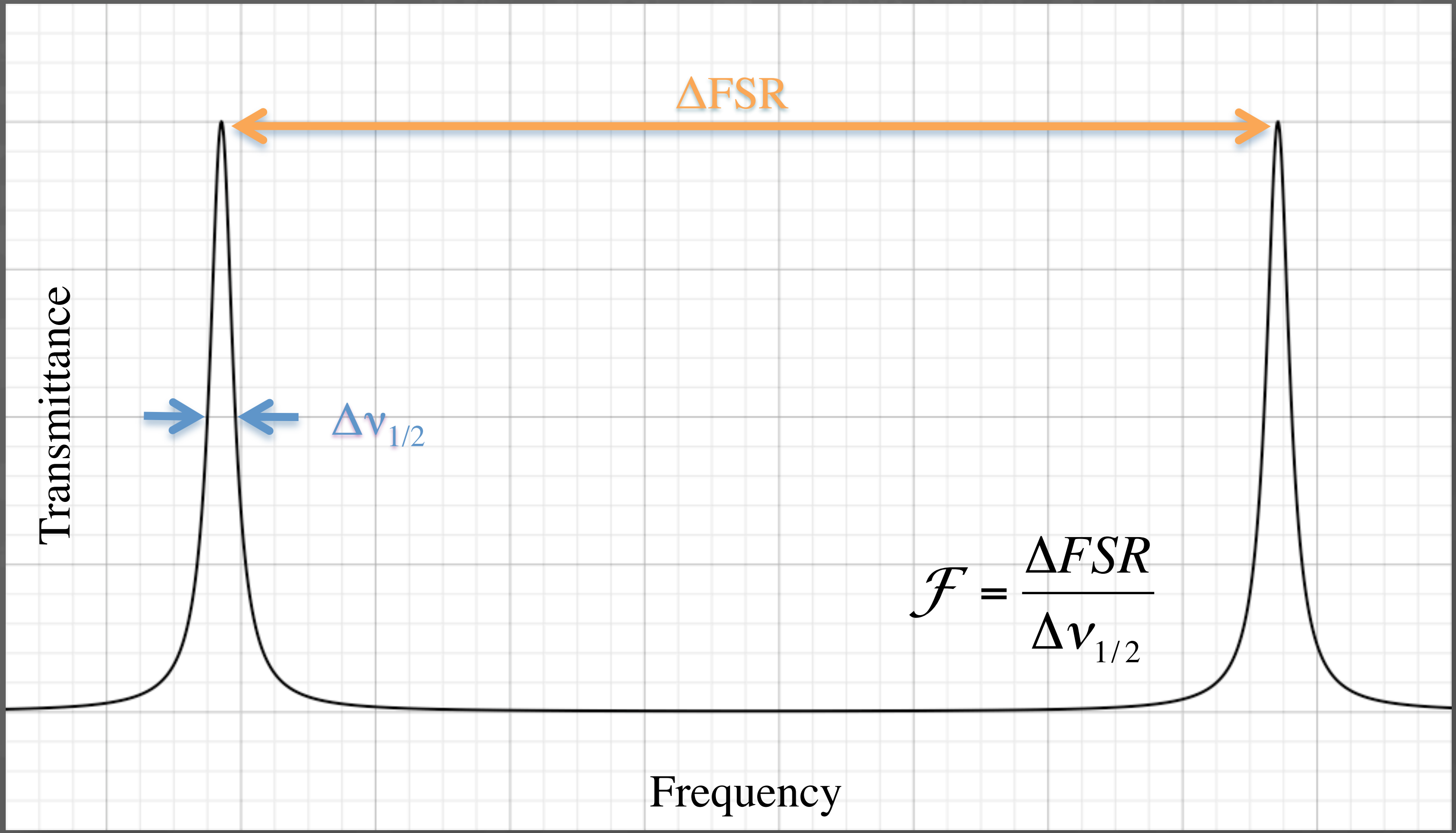


Resonant

Non-resonant

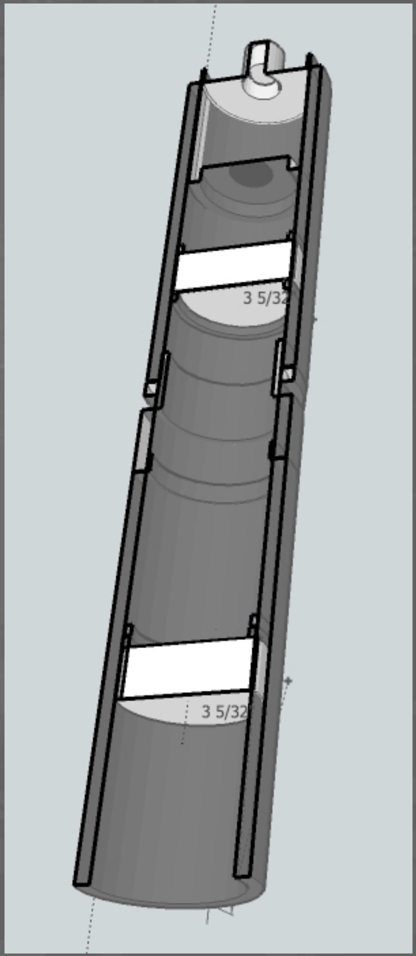


FINESSE

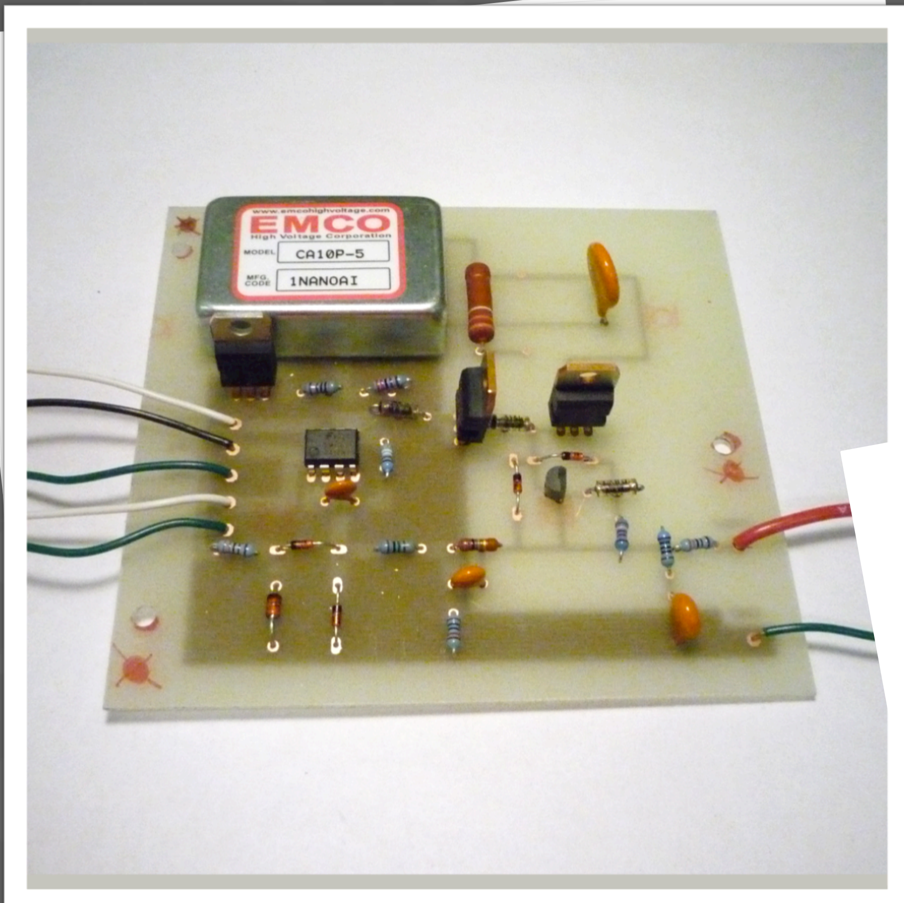


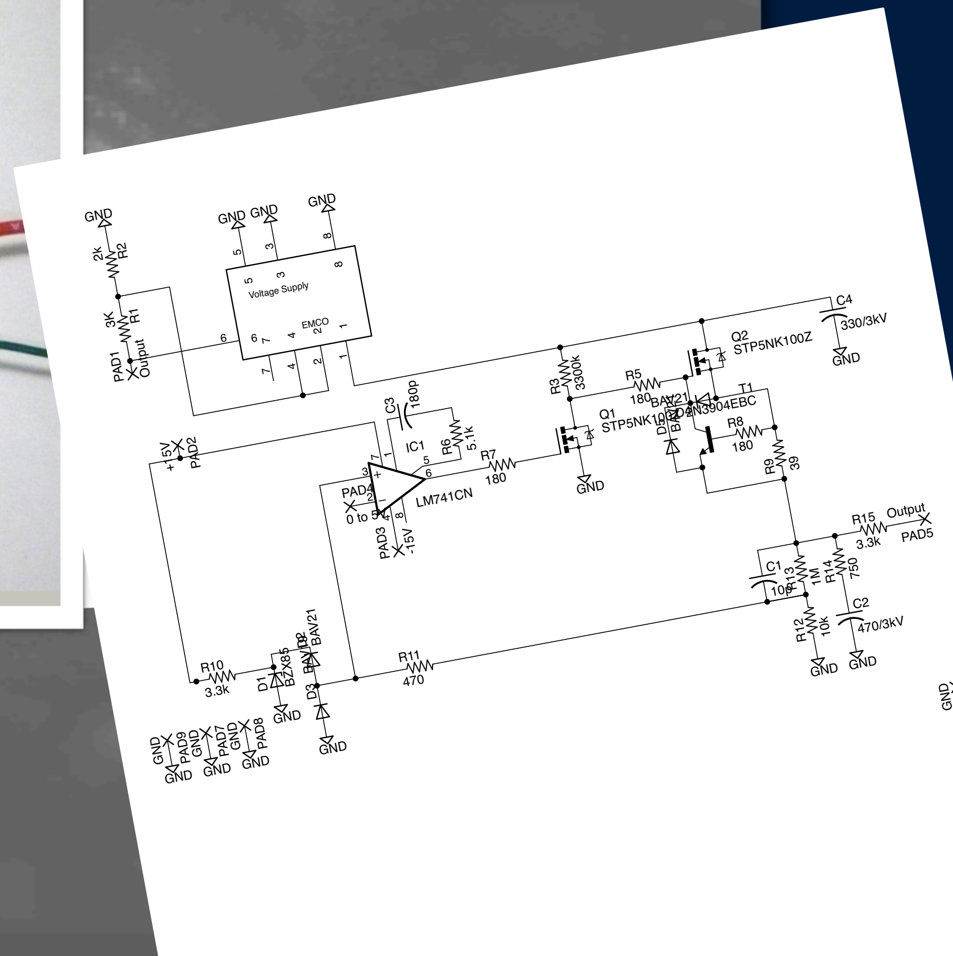
Meshede, "Optics, Light and Lasers"

CAVITY DESIGN



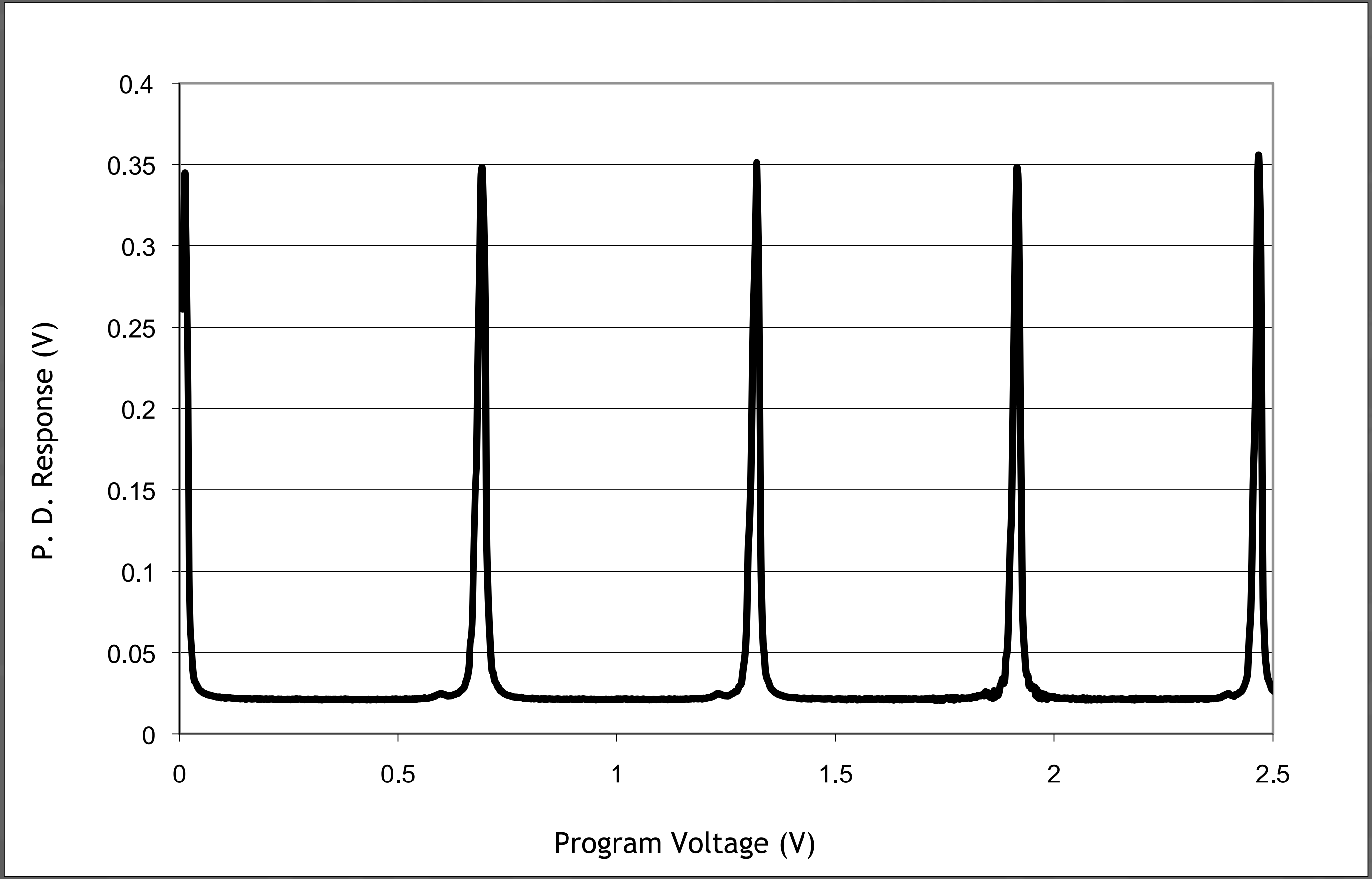
PIEZO DRIVER





Harowitz and Hill, “The Art of Electronics”

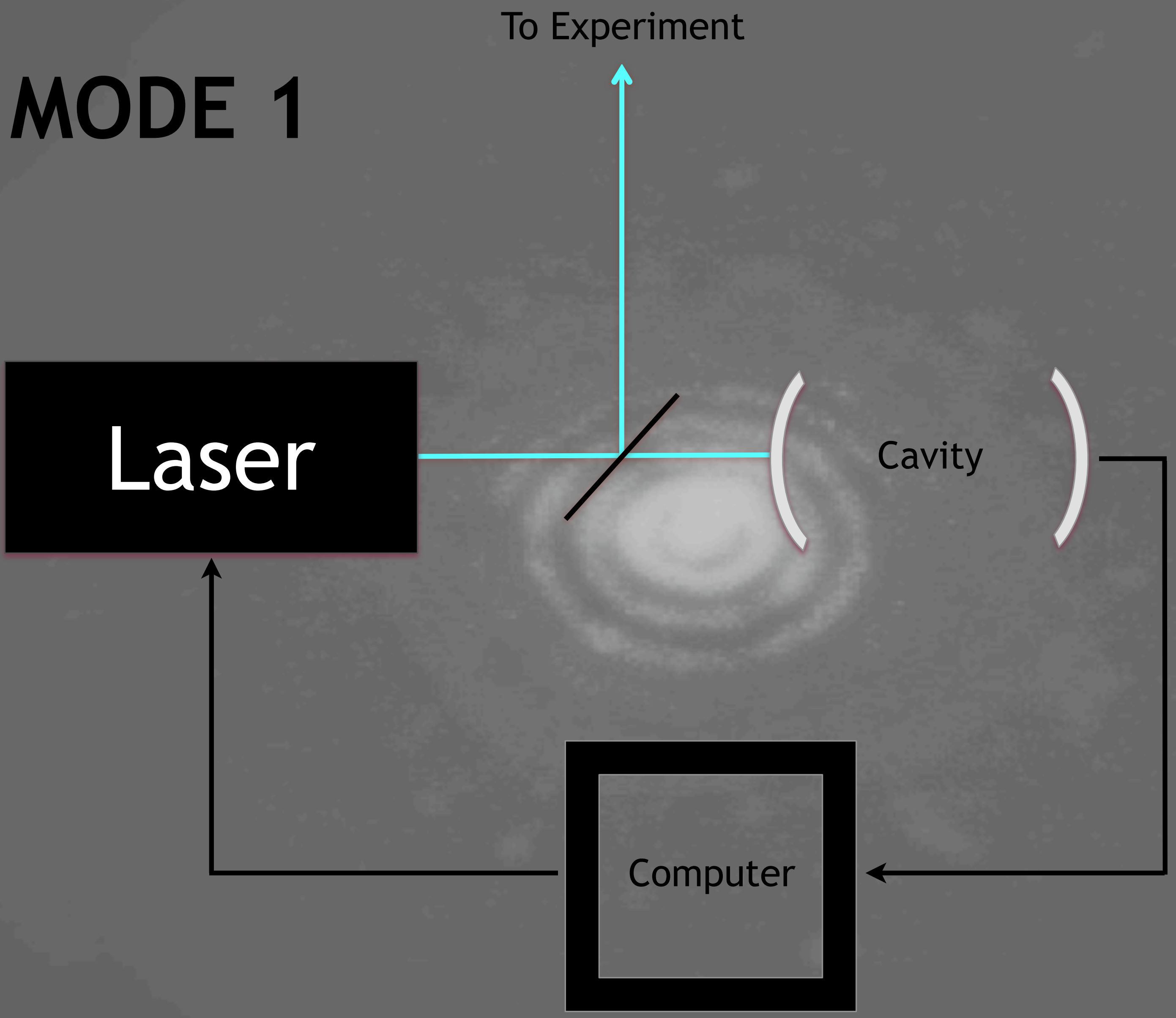
OUR CAVITY'S RESPONSE



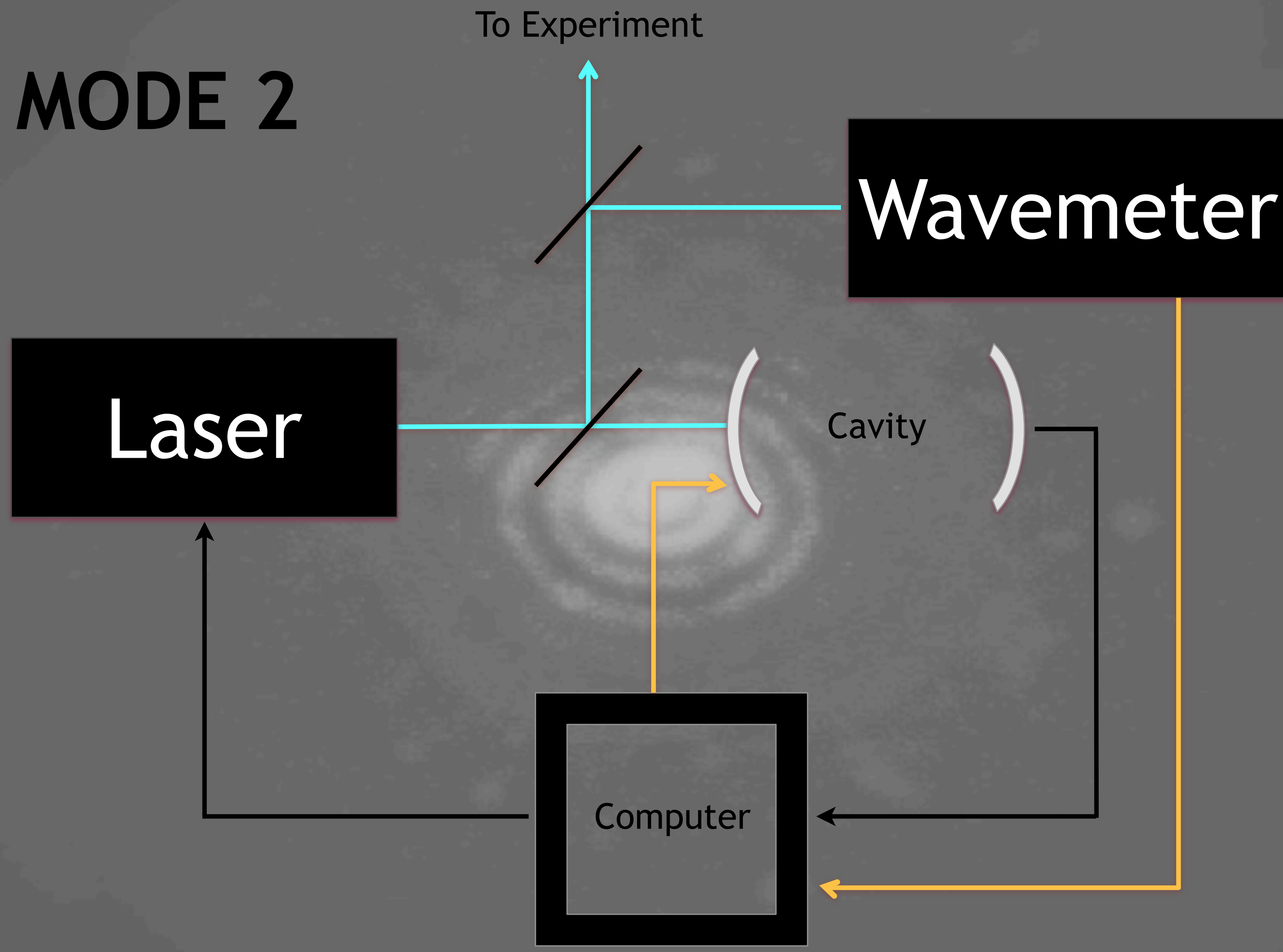
CONTROLLING OUR CAVITY

- Integrating our cavity into a monitoring system
- PI control loops, noise reduction, and possible improvements to be made

MODE 1



MODE 2

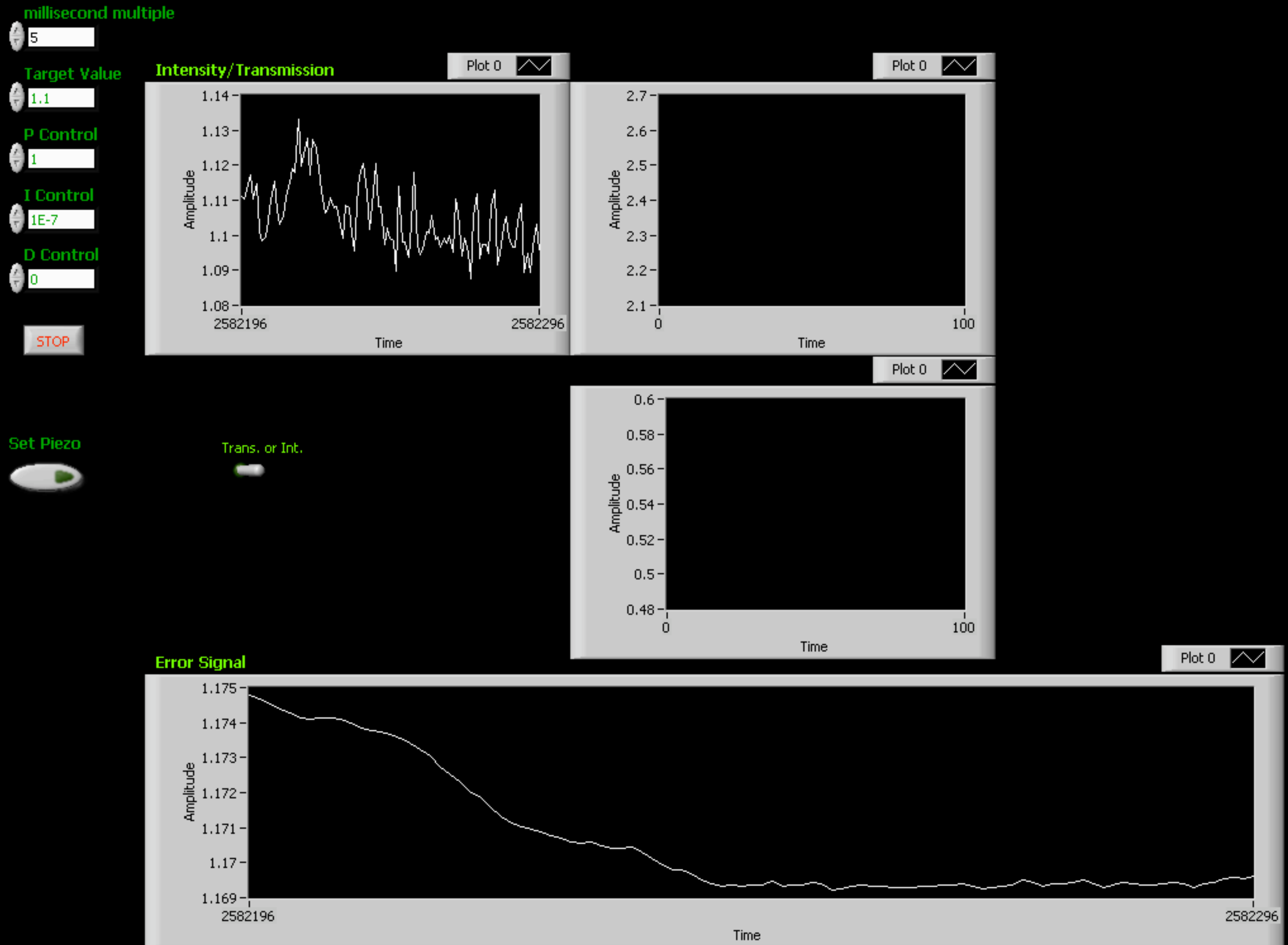


HOW DO WE ADJUST OUR LASER/ CAVITY SYSTEM?

- PI control loop: $\mathrm{Er} = P \cdot \varepsilon + I \cdot \int \varepsilon \, dt + D \cdot \frac{d}{dt} \varepsilon$

- The computer monitors the signal from the photodiode, computes the error signal, and outputs a correcting voltage

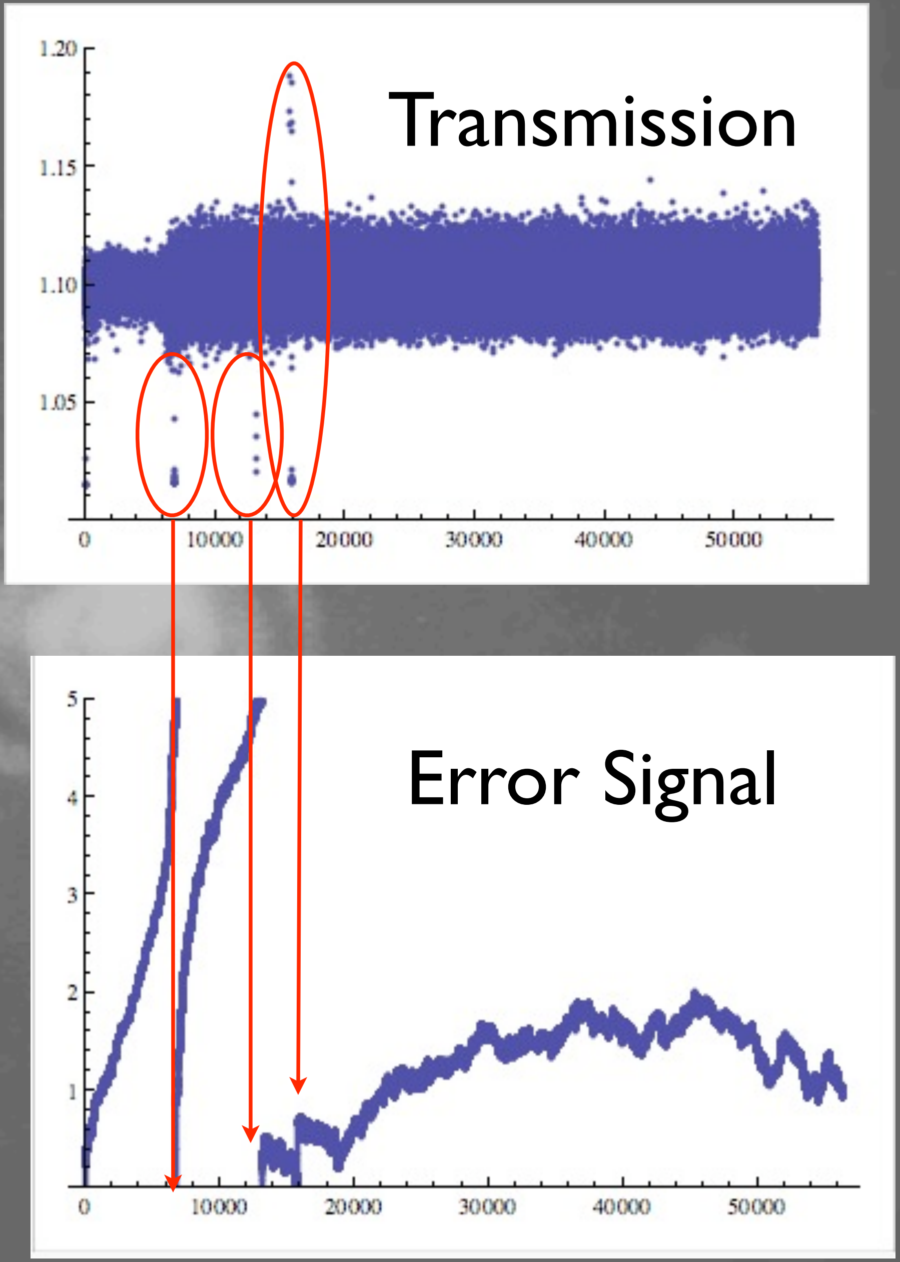
- Tuning the constants P and I can increase response time and narrow the range of error


millisecond multiple
5
Target Value
1.1
P Control
1
I Control
1E-7
D Control
0
STOP
Set Piezo
Trans. or Int.
Intensity/Transmission
Plot 0
Amplitude
Time
2582196
2582296
1.14
1.13
1.12
1.11
1.1
1.09
1.08
Plot 0
2.7
2.6
2.5
2.4
2.3
2.2
2.1
0
100
Amplitude
Time
Plot 0
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0
100
Amplitude
Time
Error Signal
Plot 0
1.175
1.174
1.173
1.172
1.171
1.17
1.169
2582196
2582296
Amplitude
Time

Recent Data

The light emitted from the cavity stays constant

The error signal never stops changing

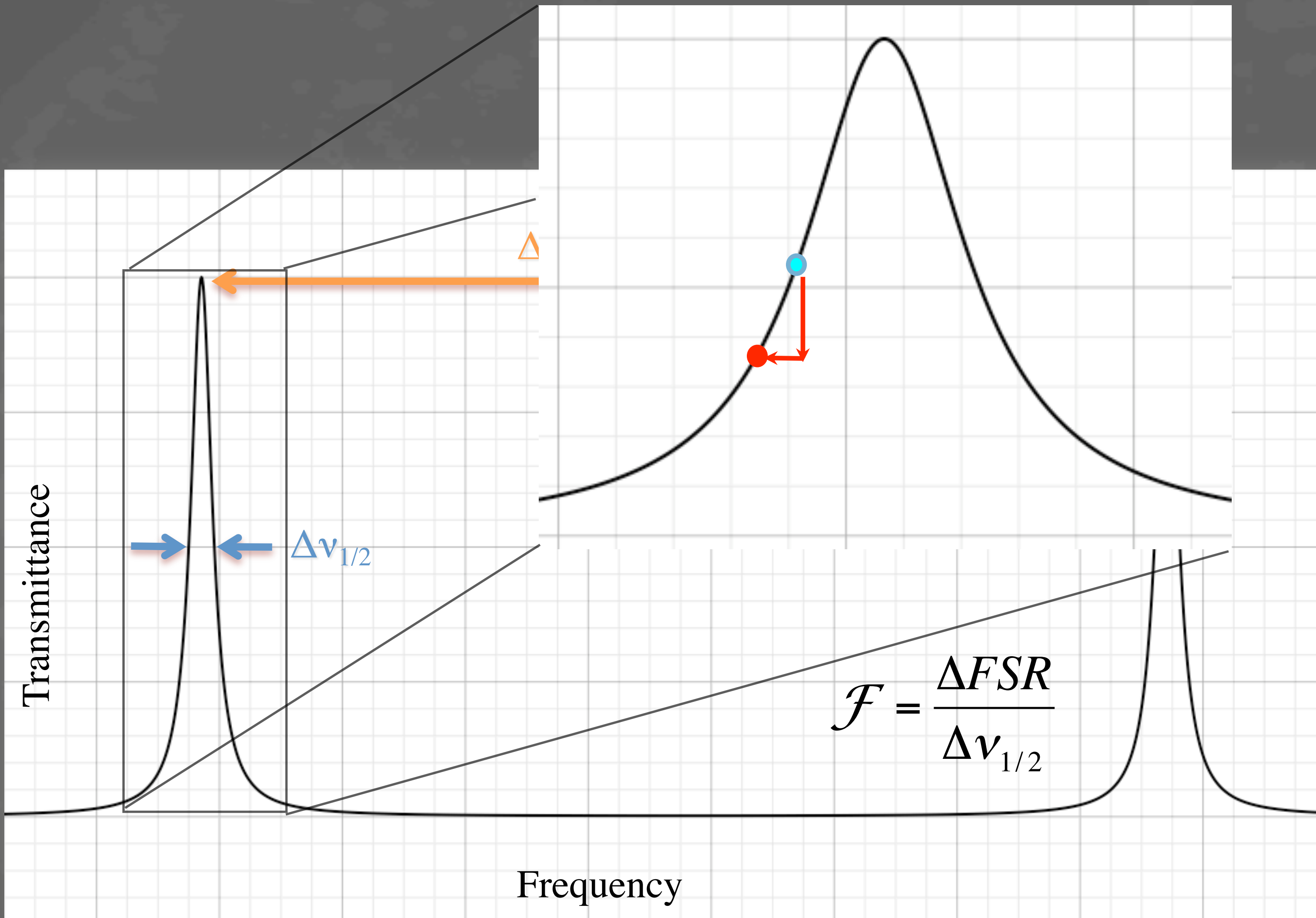


POSSIBLE REASONS FOR CURRENT UNSTABILITY

- The piezo electric doesn’t stabilize in length when the voltage across it changes frequently.

- The intensity of the laser fluctuates, causing noise in our signal that is interpreted at frequency fluctuations

The intensity changes, but it looks like the frequency changed



WHAT'S NEXT?

- Reduce noise in intensity to have greater resolution and tighter locking
- Stabilize the piezo electric (could stabilize on the time scale of weeks)

THE END!

- References:
  - http://depts.washington.edu/qcomp/research.htm
  - Metcalf and Straten, “Laser Cooling and Trapping
  - Meshede, “Optics, Light and Lasers”
  - Harowitz and Hill, “The Art of Electronics”
  - http://qist.lanl.gov/qcomp_map.shtml