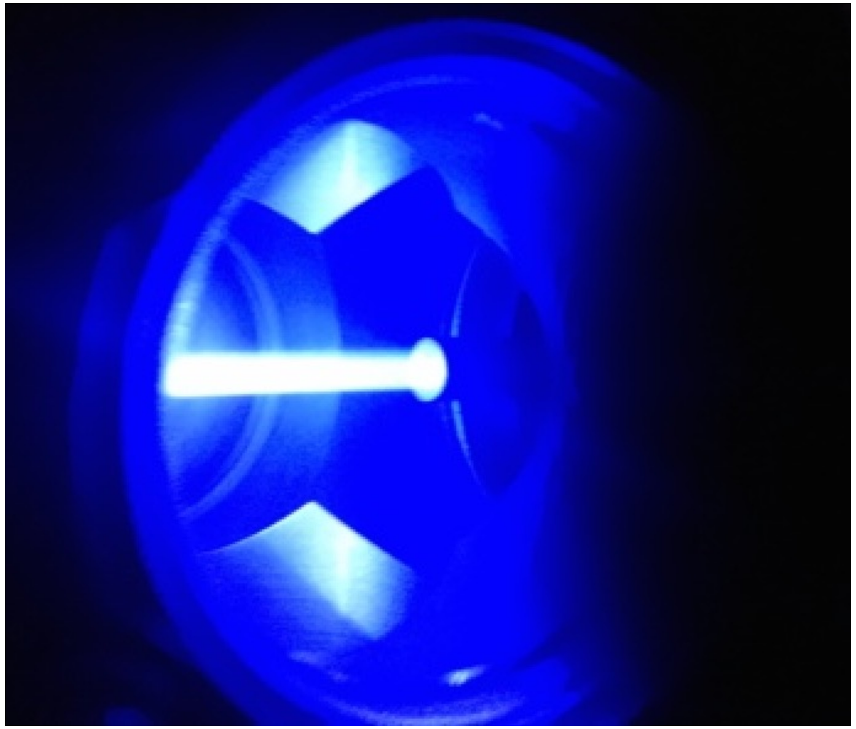
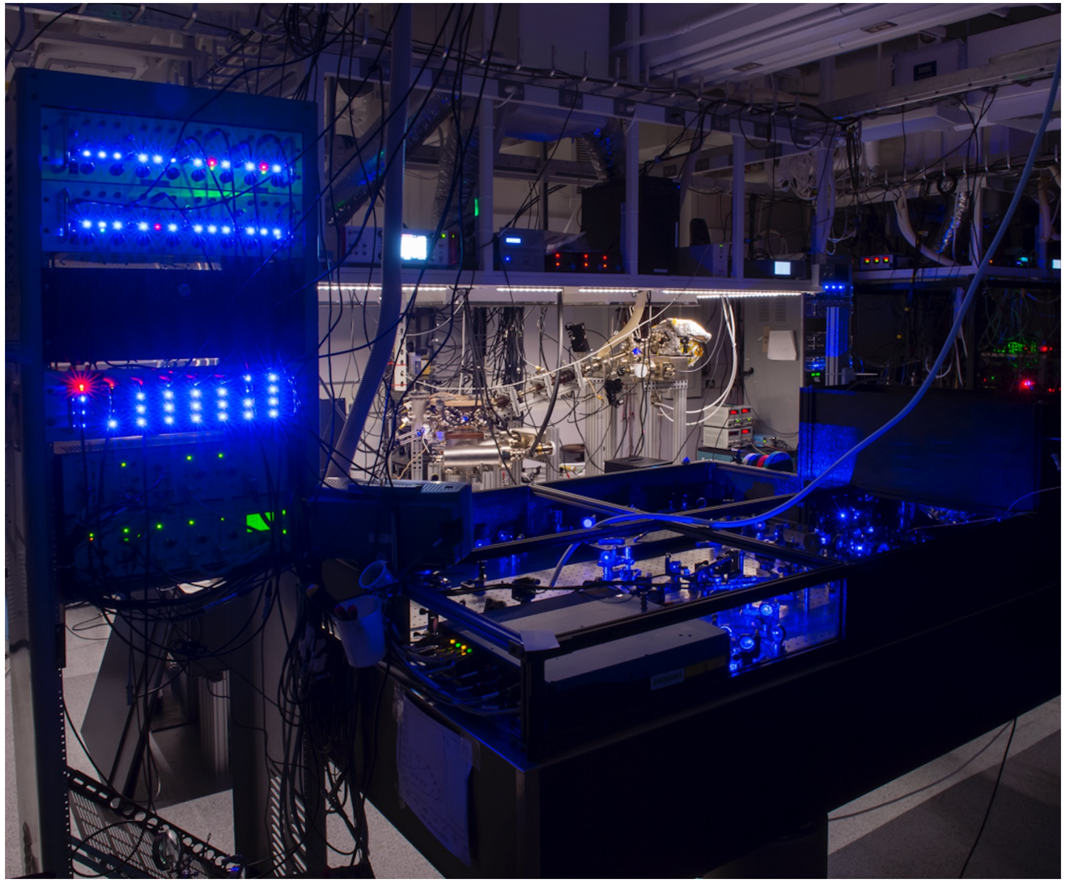
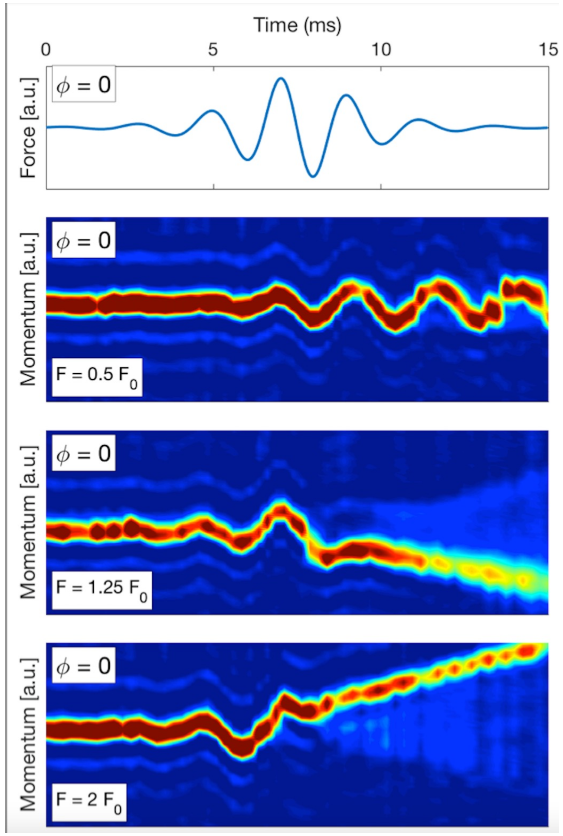






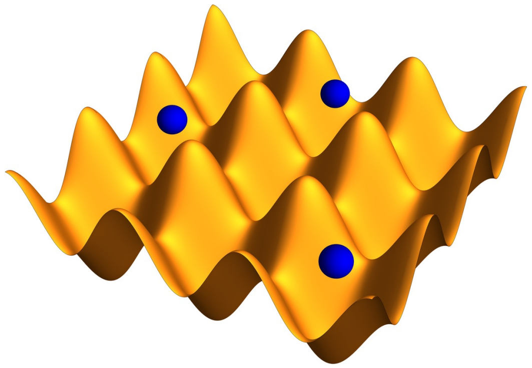

# A narrow-line diode laser system for strontium laser cooling

UC SANTA BARBARA PHYSICS

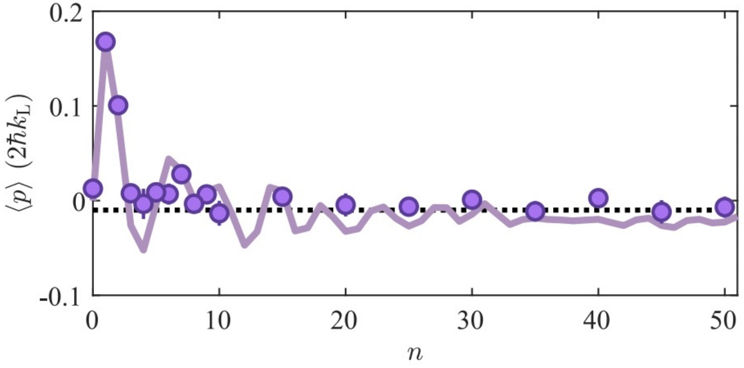
Jacob VanArsdale, Dr. Toshihiko Shimasaki, and Dr. David Weld

NSF

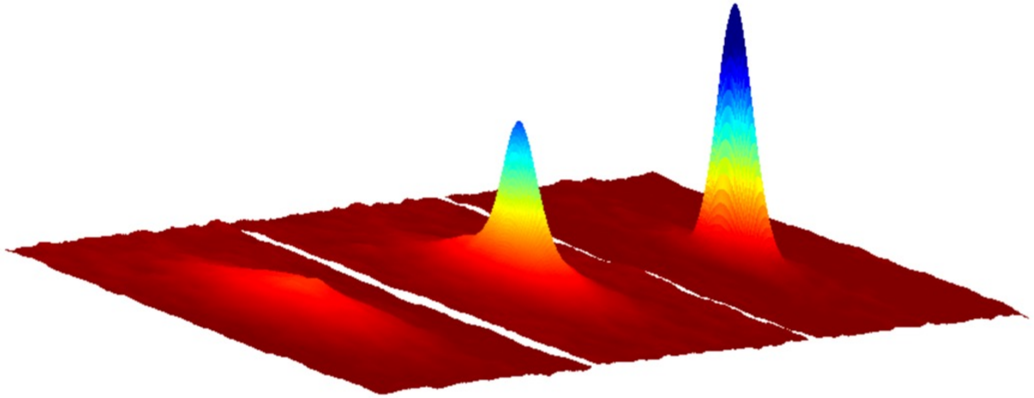
# Why do we cool atoms?



- Confining atoms in optical lattices gives us great control
- Can create Bose-Einstein Condensates (BECs), reach temperatures on the order of ~100 nK
- Opens door to a quantum playground in experimental physics:
  - Quantum boomerangs
  - Time-reversal of quantum systems
  - Atom interferometry



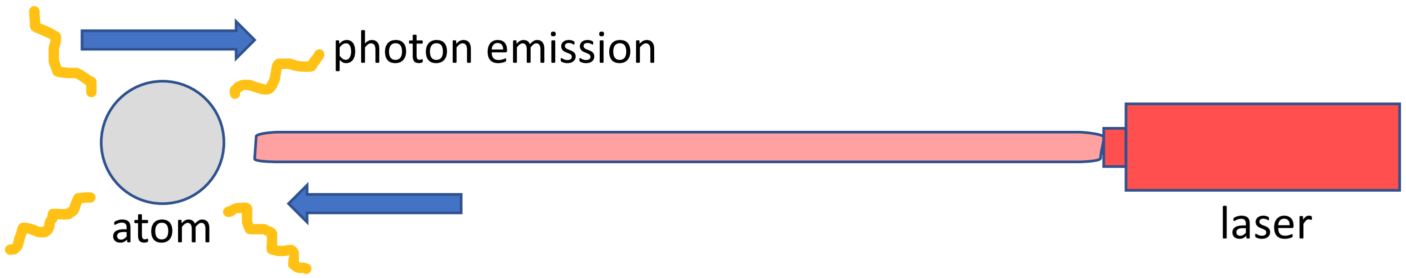

Observation of the quantum boomerang effect



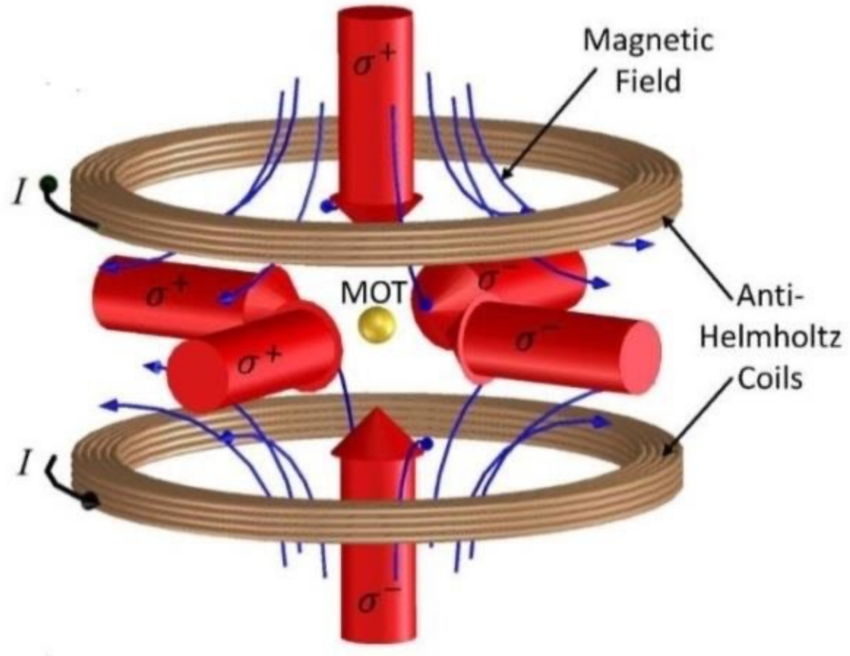
Strontium BEC in Weld Lab

# Using Lasers to Cool and Trap Atoms

- Doppler shifts allow for momentum transfer from photons
- Spontaneous emission is spherically symmetric




Doppler cooling fundamentals




Magneto-Optical Trap

https://www.researchgate.net/figure/conceptual-scheme-of-a-magneto-optical-trap-MOT-and-typical-expansion-of-a-cloud-of_fig4_348383229

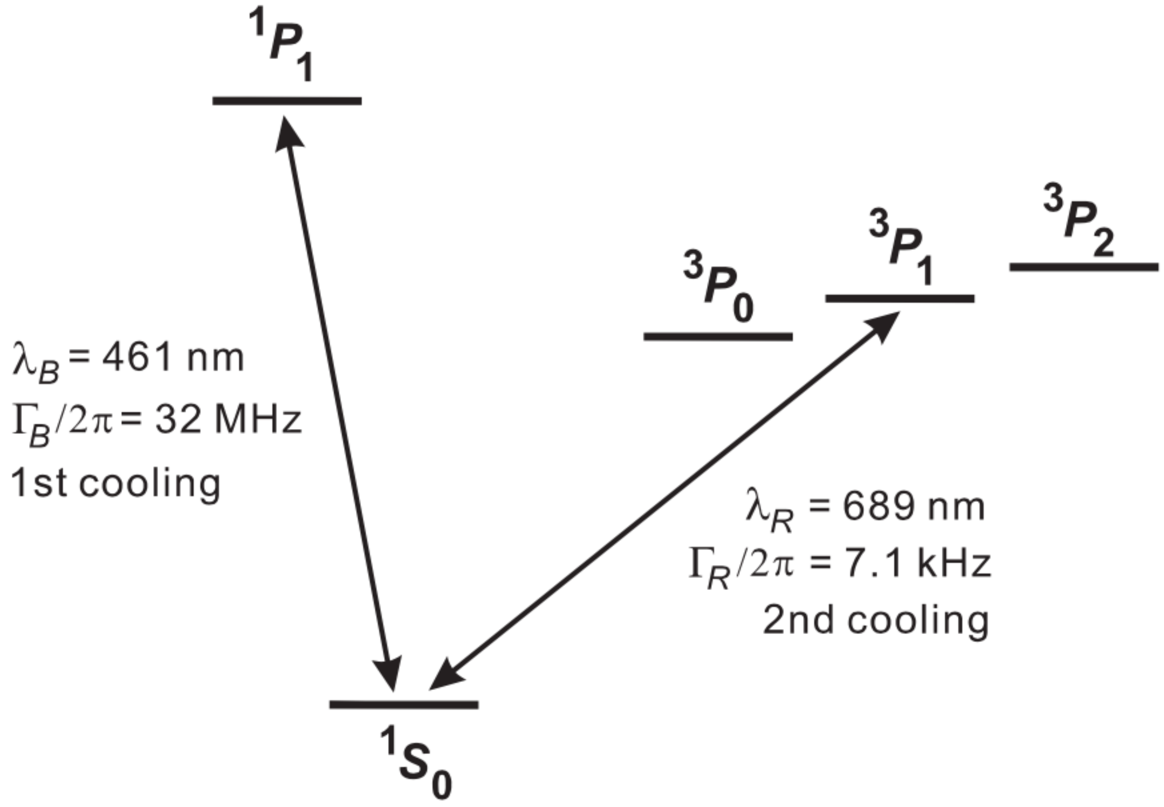
# 689nm Strontium Cooling Transition

- Doppler cooling limit:

$$T_{\text{Doppler}} \propto \text{linewidth}$$

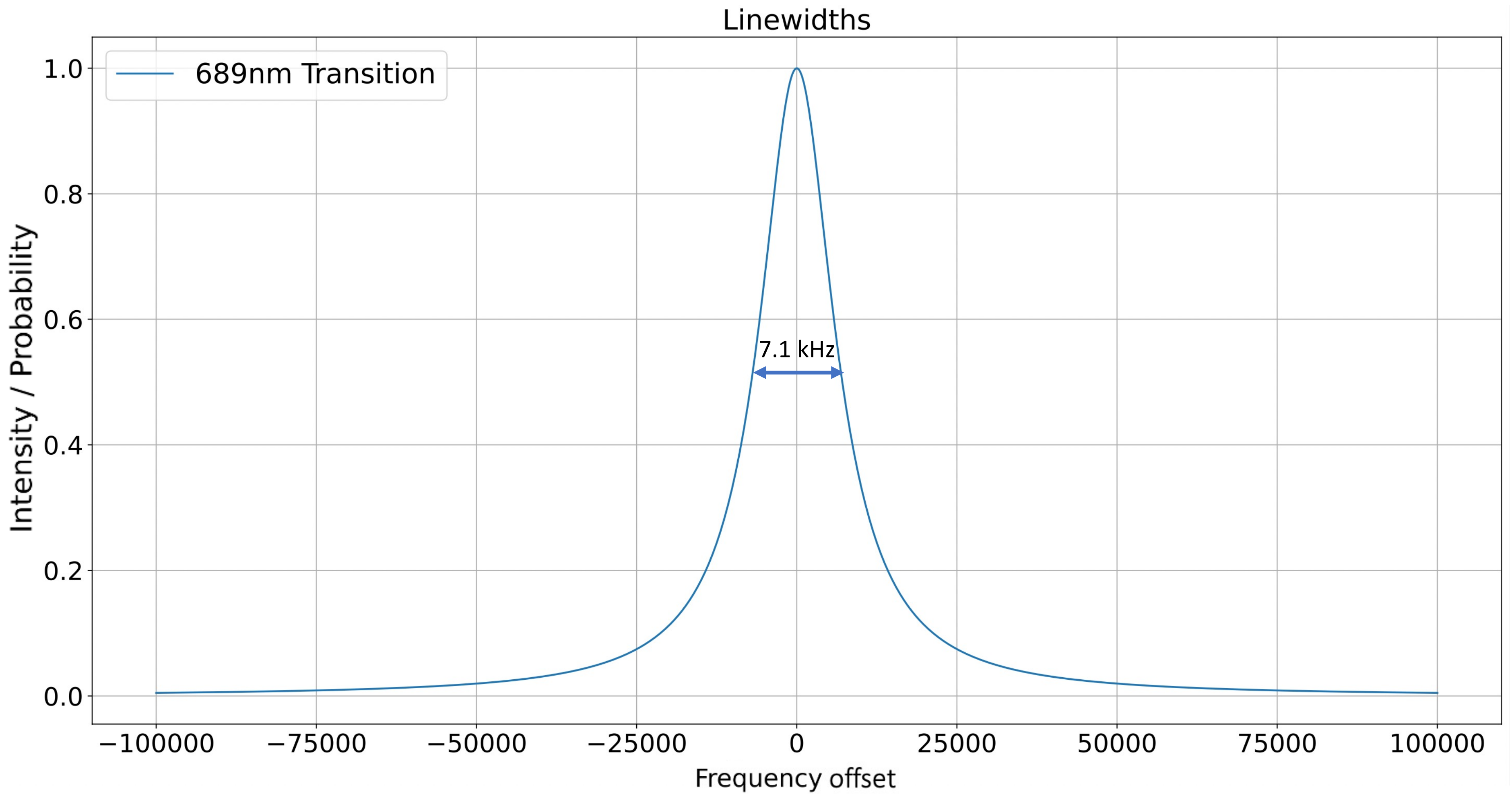
- Spin-forbidden transition ($\Delta S \neq 0$) yields very narrow 7.1 kHz linewidth

- Currently can cool to 20 μK, but Doppler limit is 200 nK

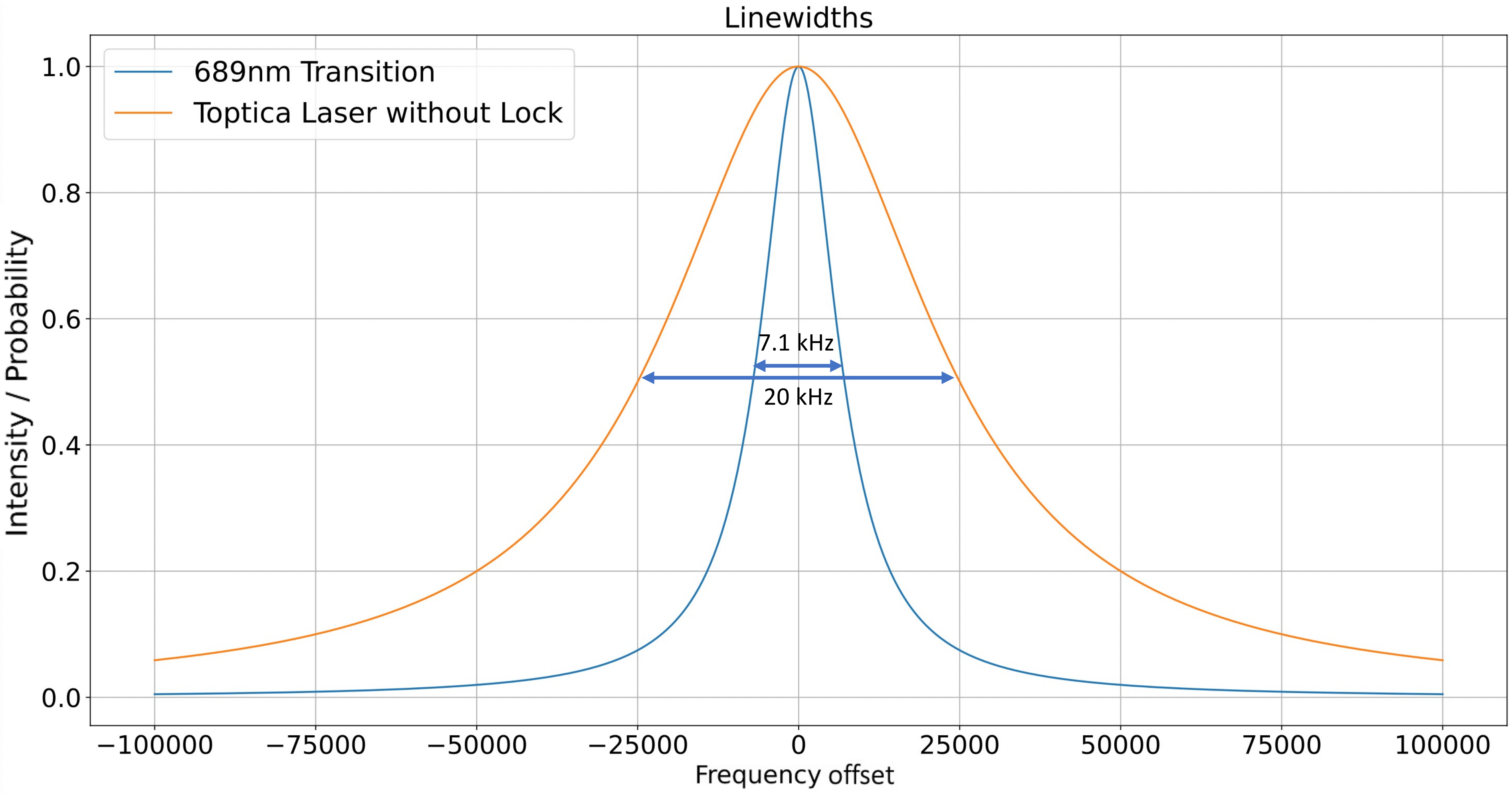



Strontium energy levels used for cooling

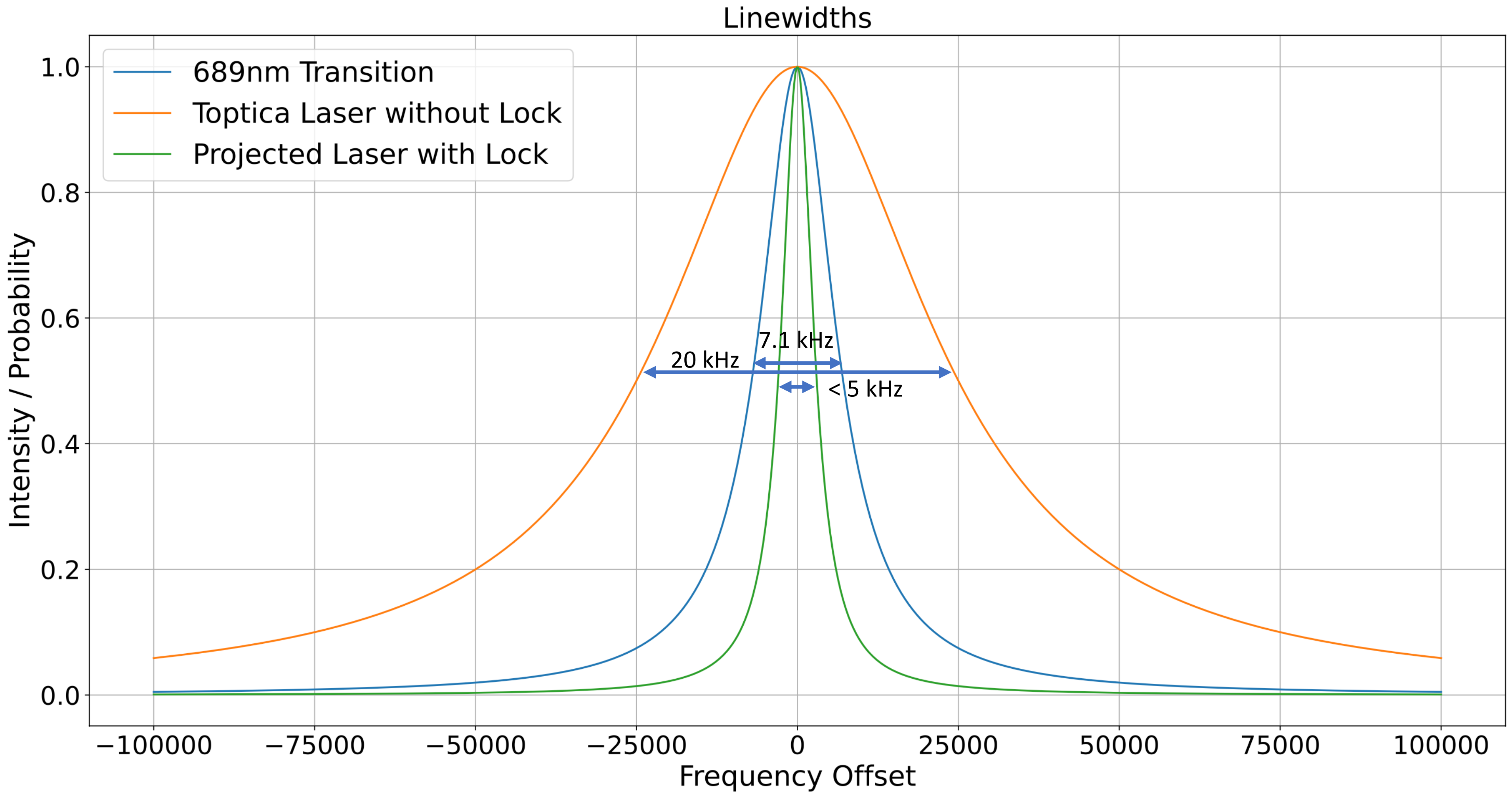
# Linewidth Comparisons



# Linewidth Comparisons

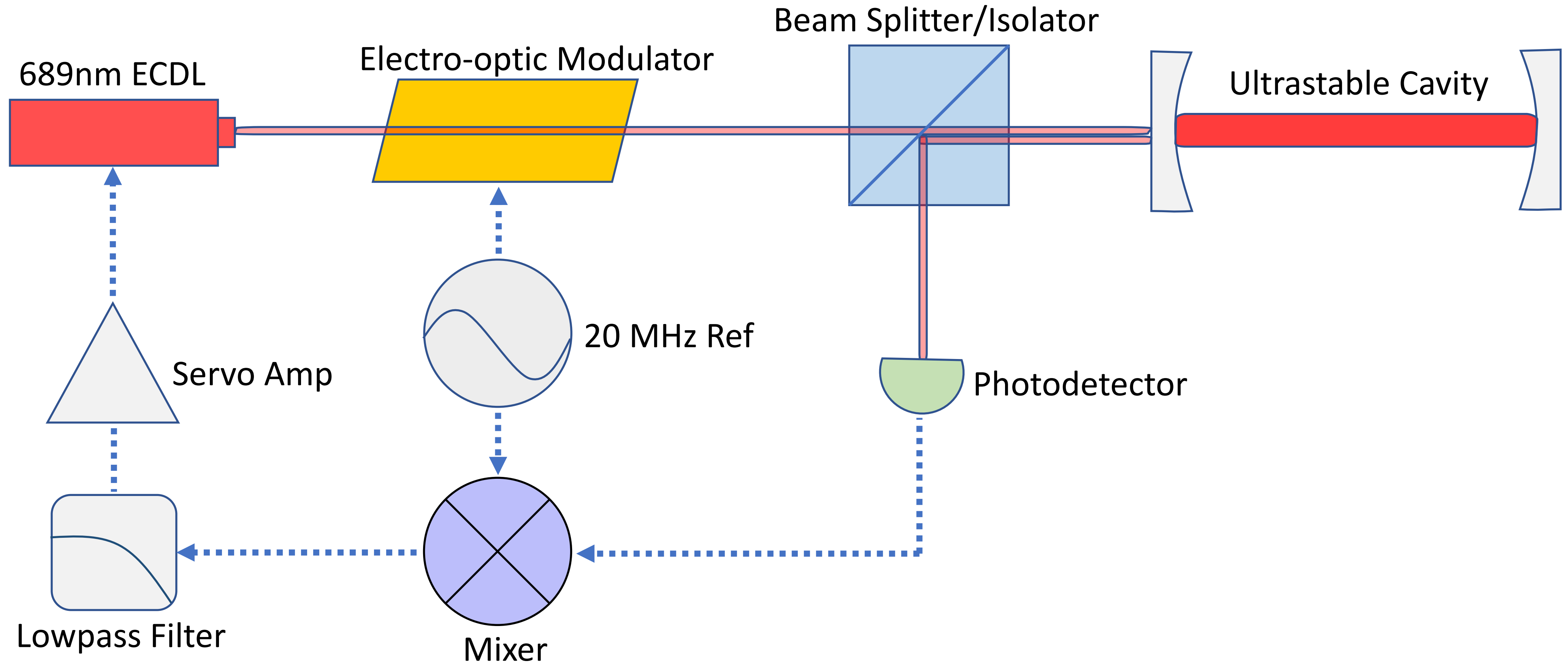


# Linewidth Comparisons



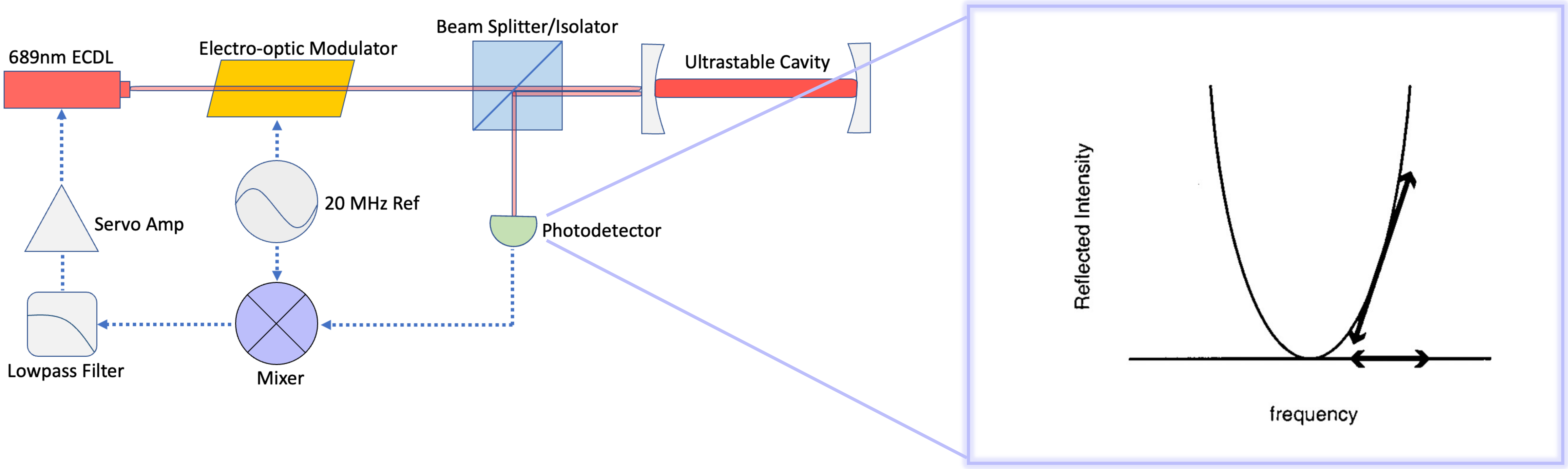
# The Pound-Drever-Hall (PDH) Technique

Diode lasers can be tunable!



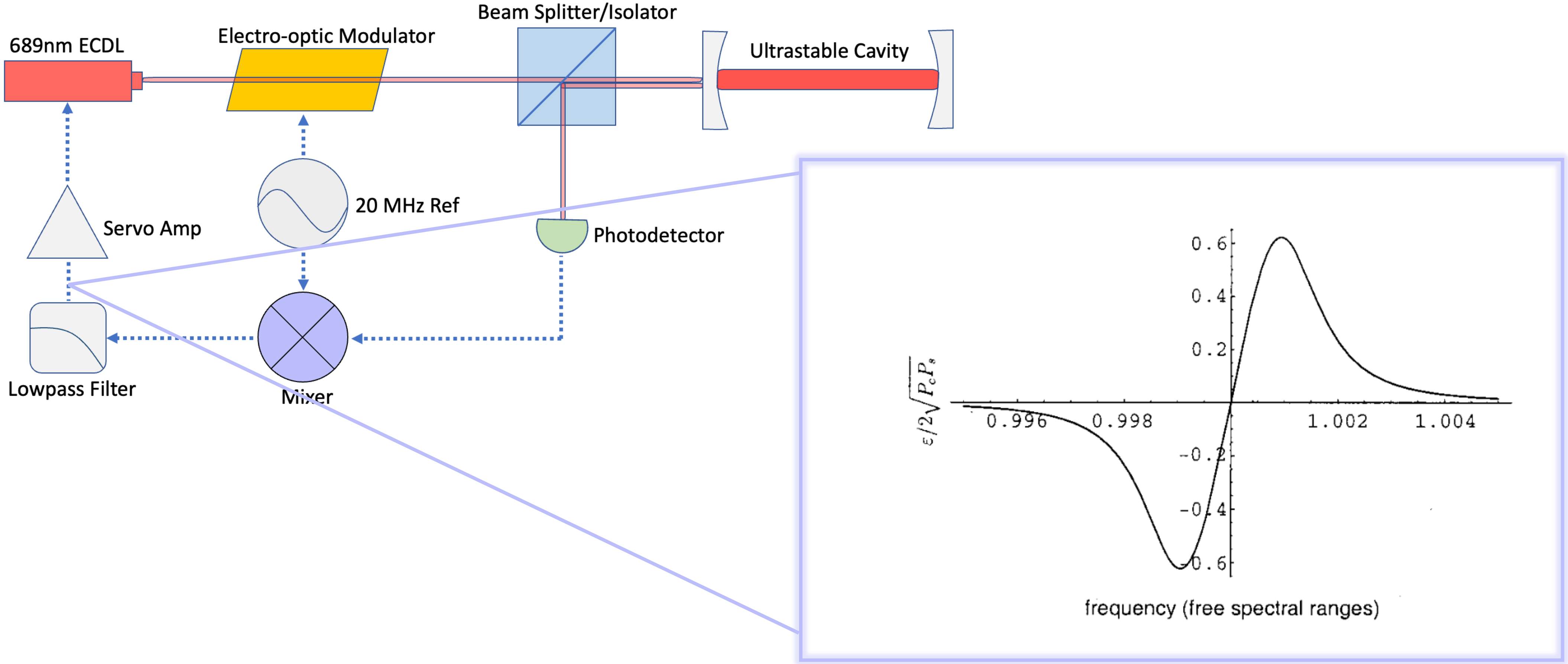
# PDH Technique in Detail

Goal: to see drifts in laser frequency and correct them with feedback

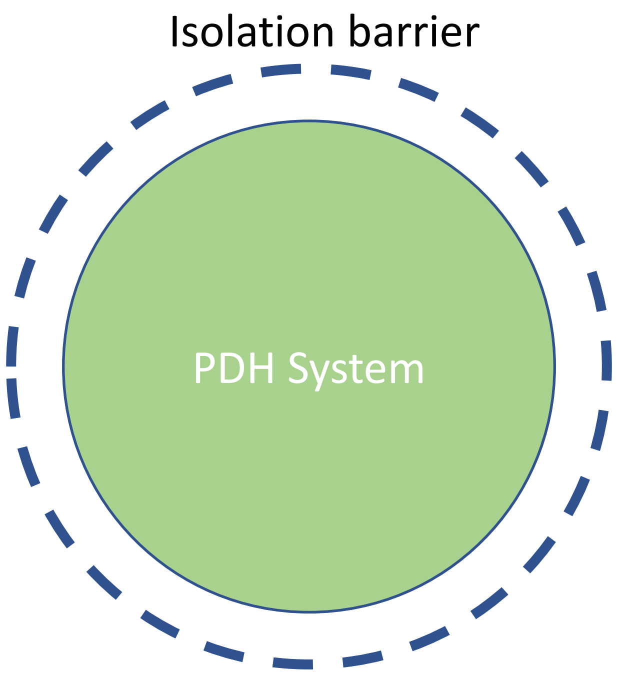


# PDH Technique in Detail

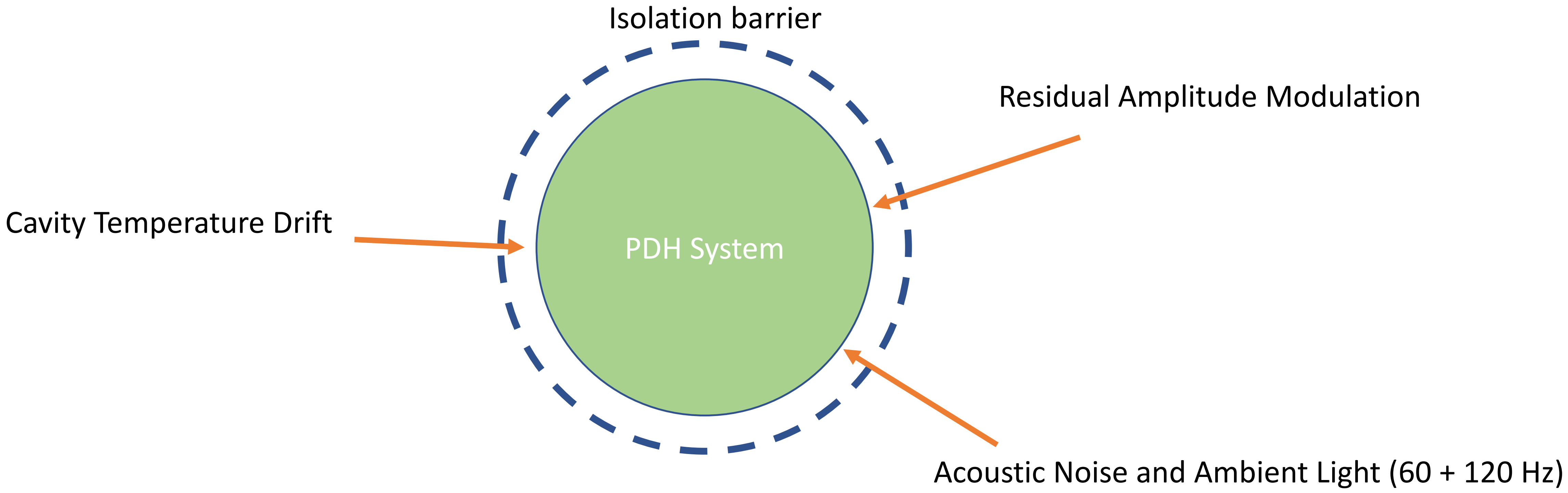
Phase is asymmetric about the cavity resonance!



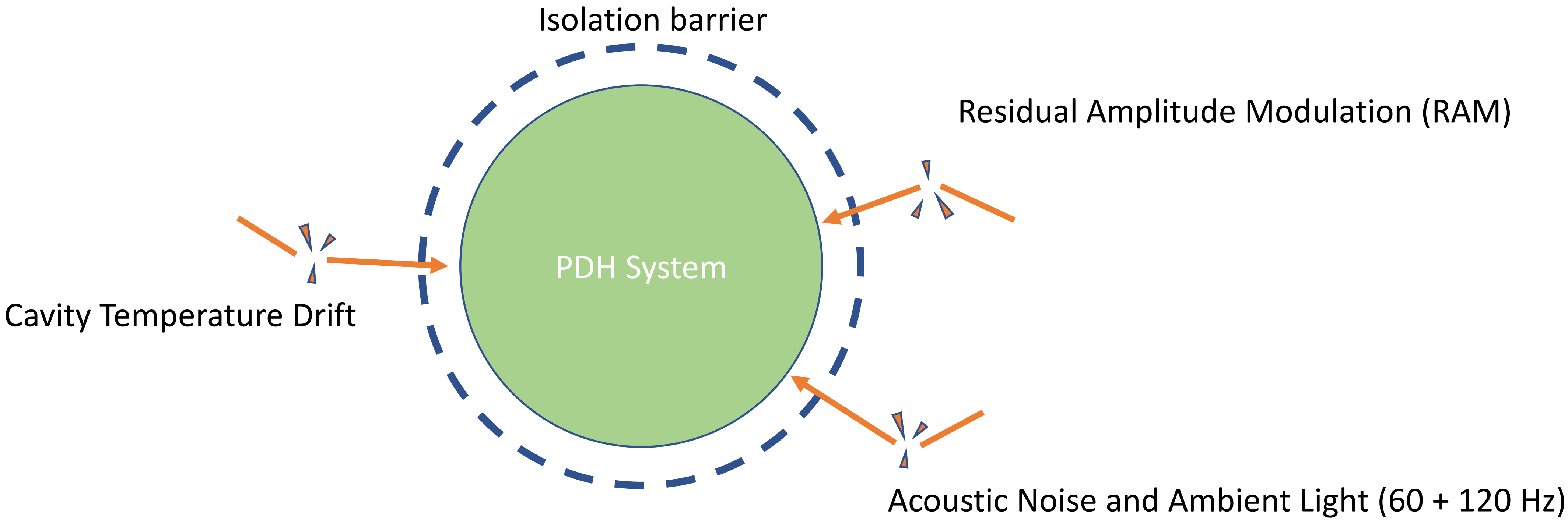
# Technical Challenges for Stability



# Technical Challenges for Stability

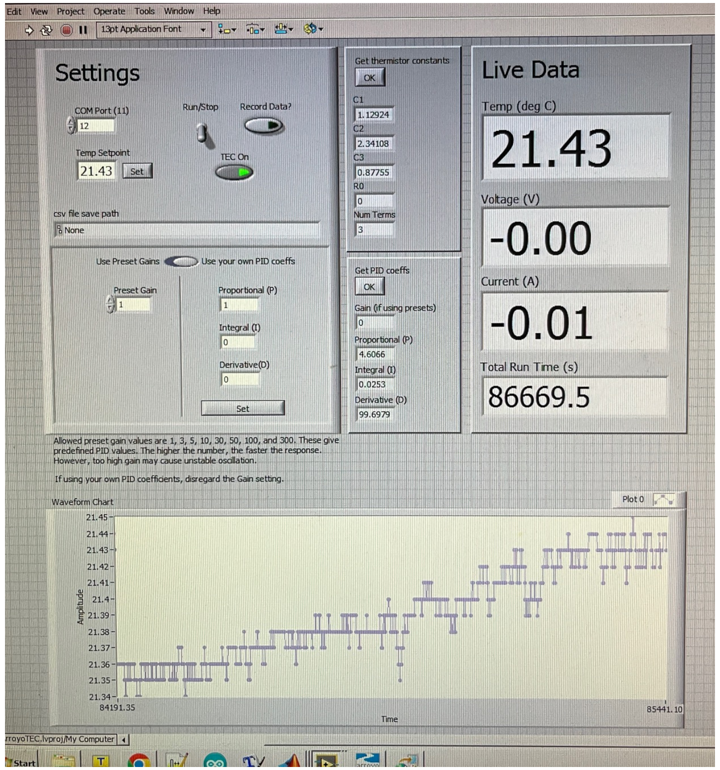


# The Challenge: remove unwanted perturbations to system

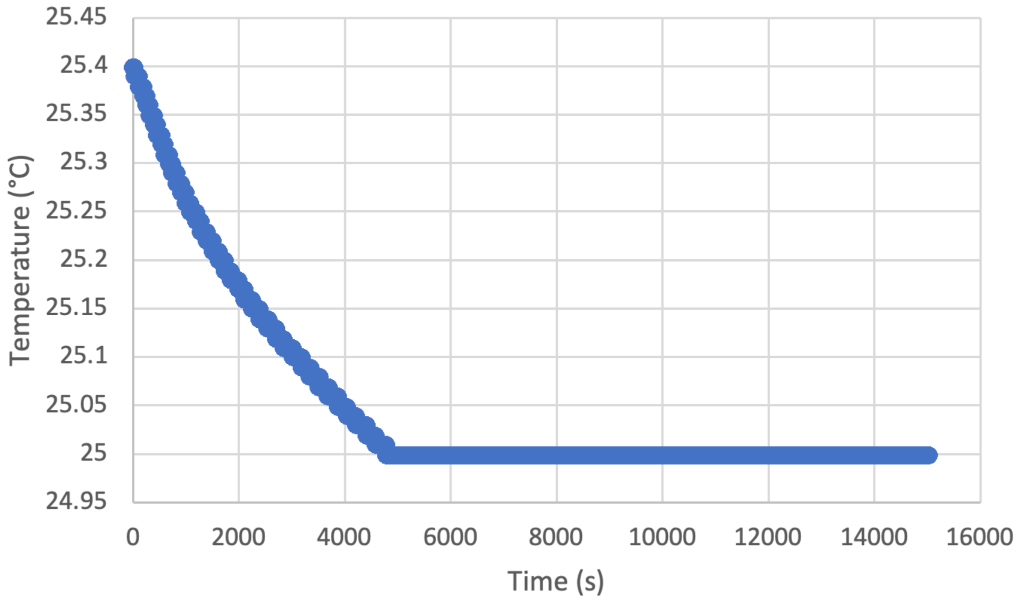


# Cavity Length Stabilization

- 1°C change → 825 kHz difference in the lowest order cavity mode
- Temperature control with LabView PID program
- Stable to within 0.005 °C → 4 kHz difference!

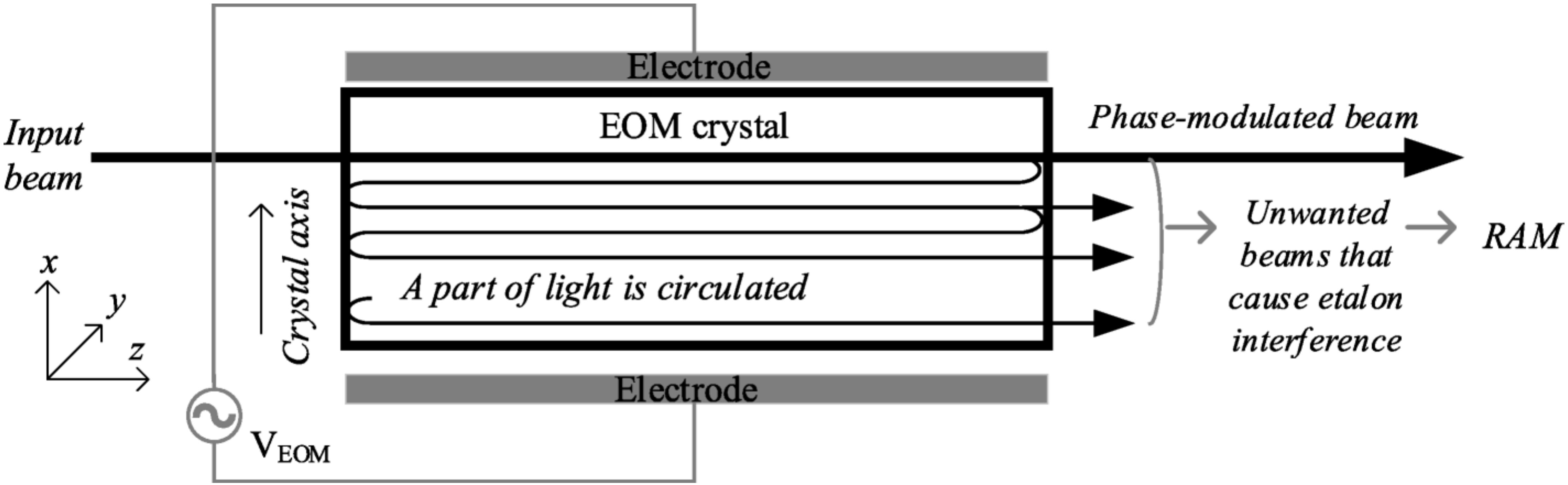



P = proportional
I = integral
D = derivative



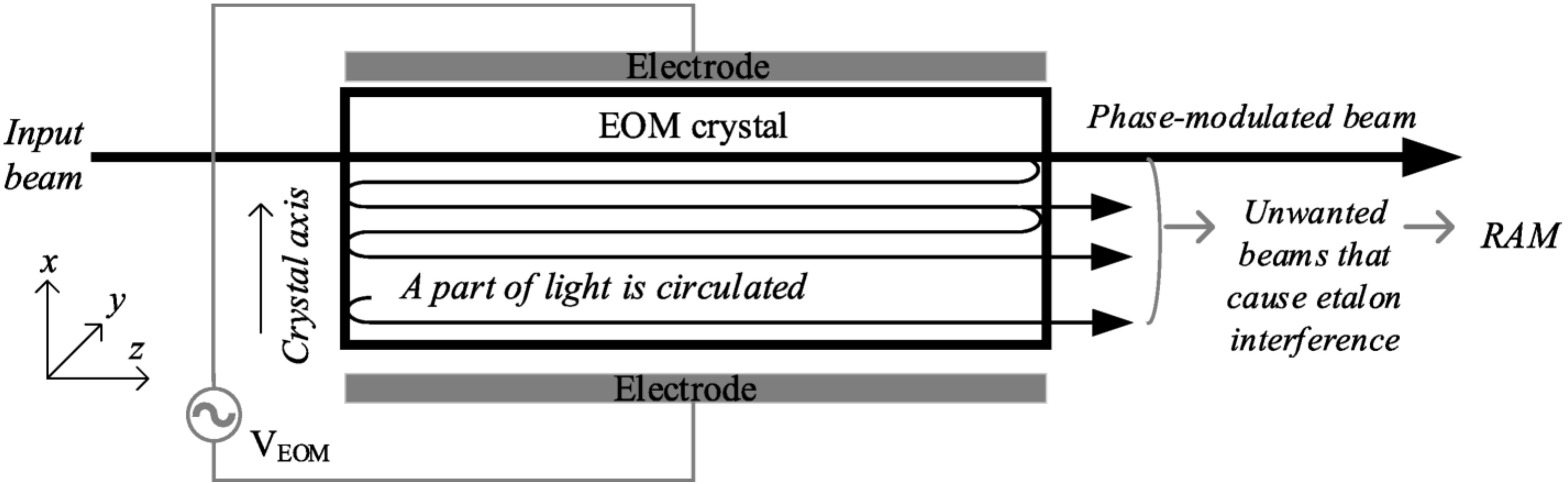
# Electro-optic Modulators and RAM

- Alignment of laser with crystal axis
- DC feedback to rotate crystal axis
- Temperature stabilization with TEC



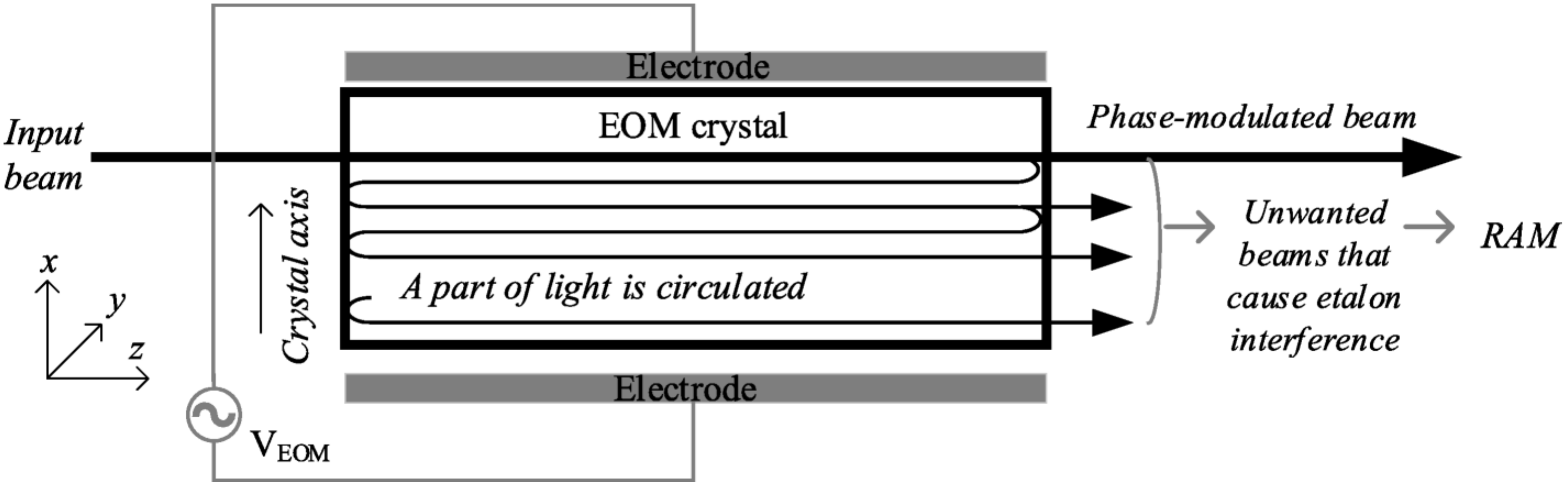
# Residual Amplitude Modulation in EOMs

- Alignment of laser with crystal axis ✓
- DC feedback to rotate crystal axis
- Temperature stabilization with TEC



# Residual Amplitude Modulation in EOMs

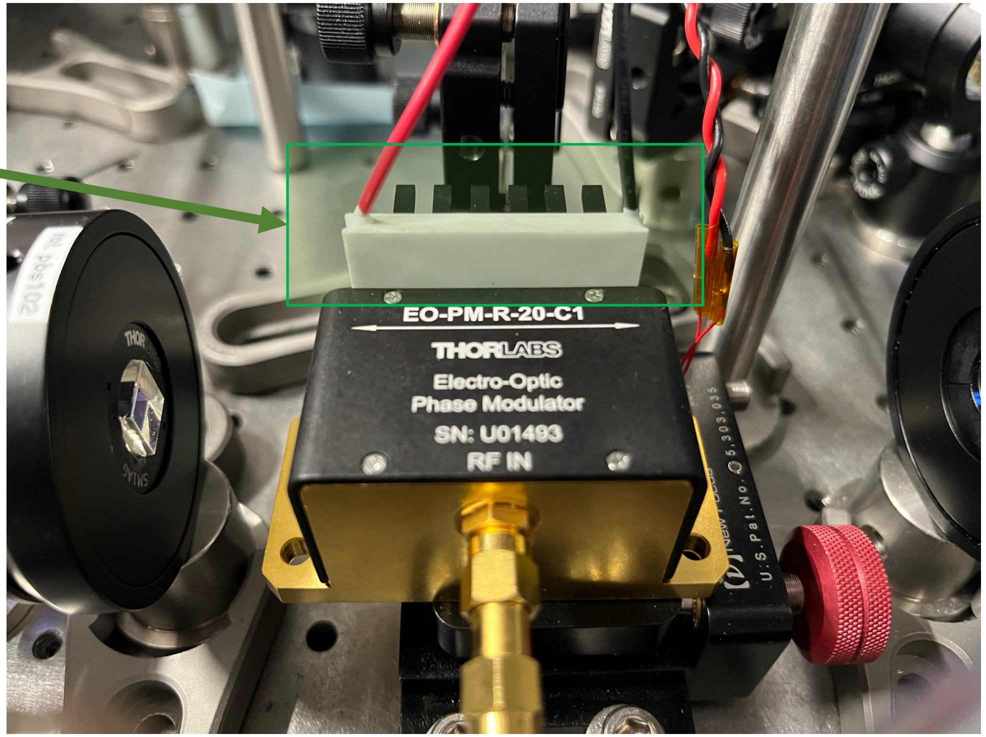
- Alignment of laser with crystal axis ✓
- DC feedback to rotate crystal axis ✗ Not possible with resonant EOM
- Temperature stabilization with TEC



# Residual Amplitude Modulation in EOMs

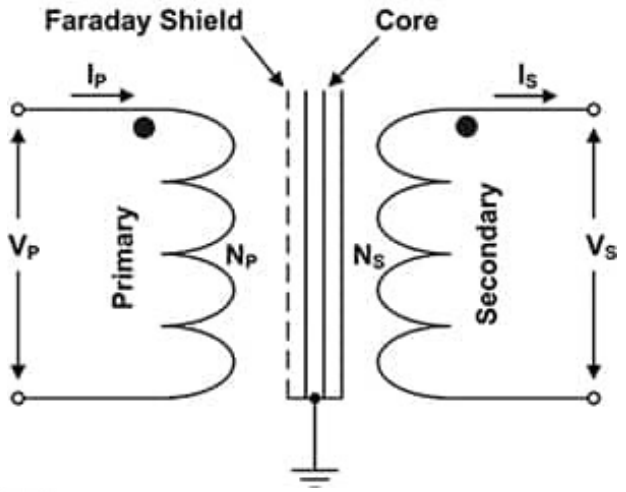
- Alignment of laser with crystal axis ✓
- DC feedback to rotate crystal axis ✗
- Temperature stabilization with TEC ✓

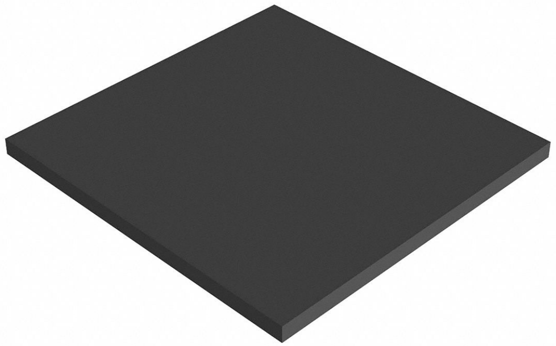
Thermo-electric Cooler (TEC)



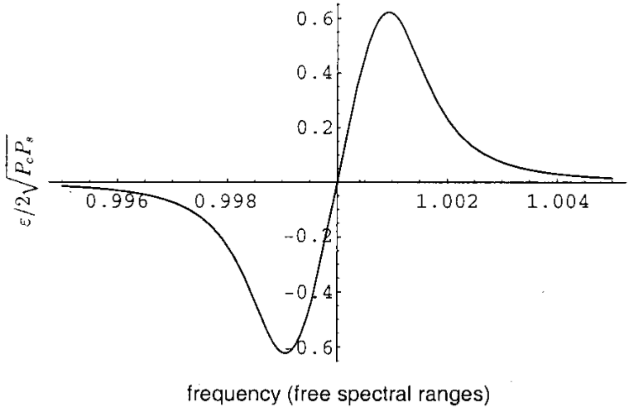
# Electric, Acoustic, and Mechanical Isolation

- 60 Hz noise from high current sources, potential ground loops
  - Isolation transformer removes this issue
- Acoustic noise and mechanical vibrations
  - Polyurethane sheet, high-density foam
  - Use as much mass as possible for damping

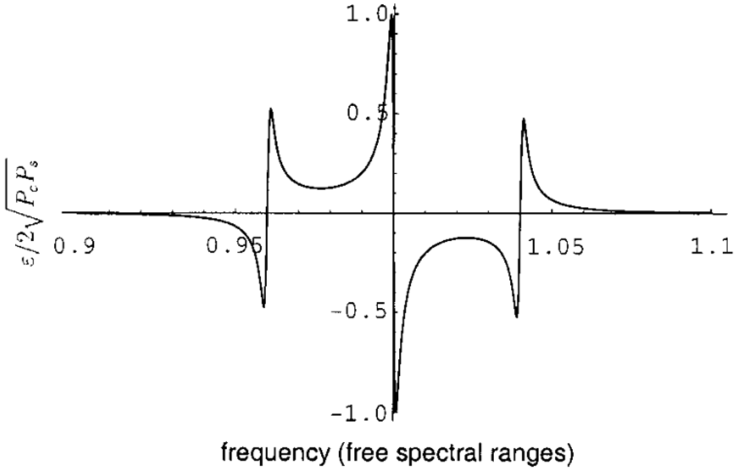


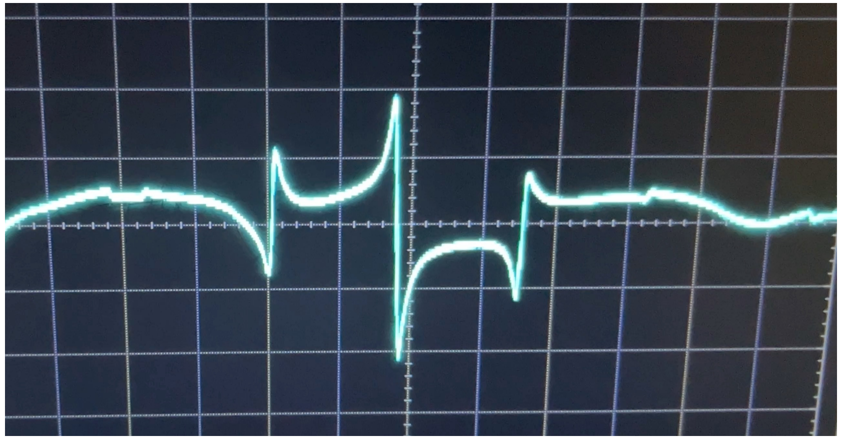
# The Error Signal




Low frequency regime




High frequency regime

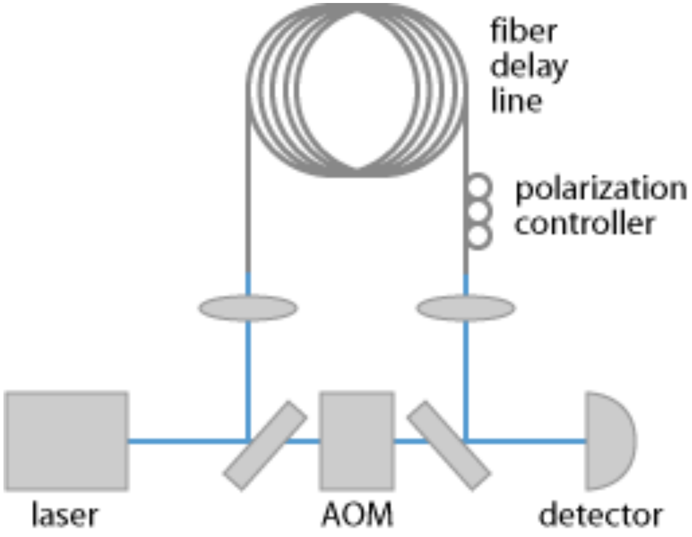


Before noise correction

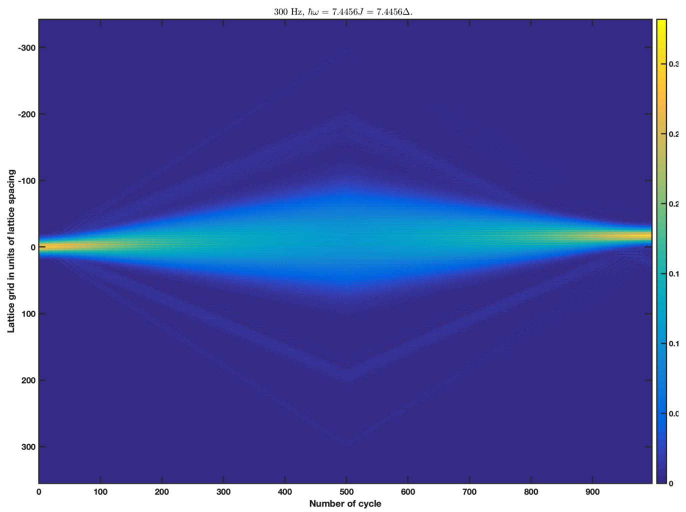
After noise correction

# Future Research

- Testing the lock this week
  - Measure laser linewidth with self-heterodyne technique
  - Increase maximum atom number in BECs
  - Reach lower temperatures in Doppler cooling stage
- Much more quantum many-body physics research from the Weld lab!



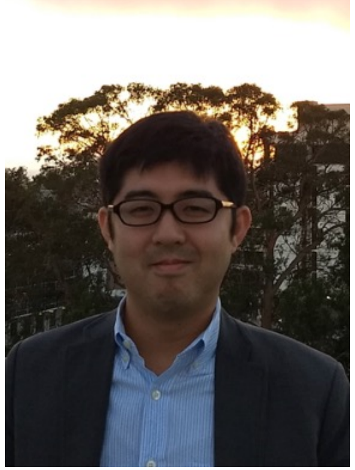
Self-heterodyne technique



Time-reversal protocol with lattice shaking! (from Yifei Bai)

# Acknowledgements

David Weld, Advisor



Toshi Shimasaki, Mentor

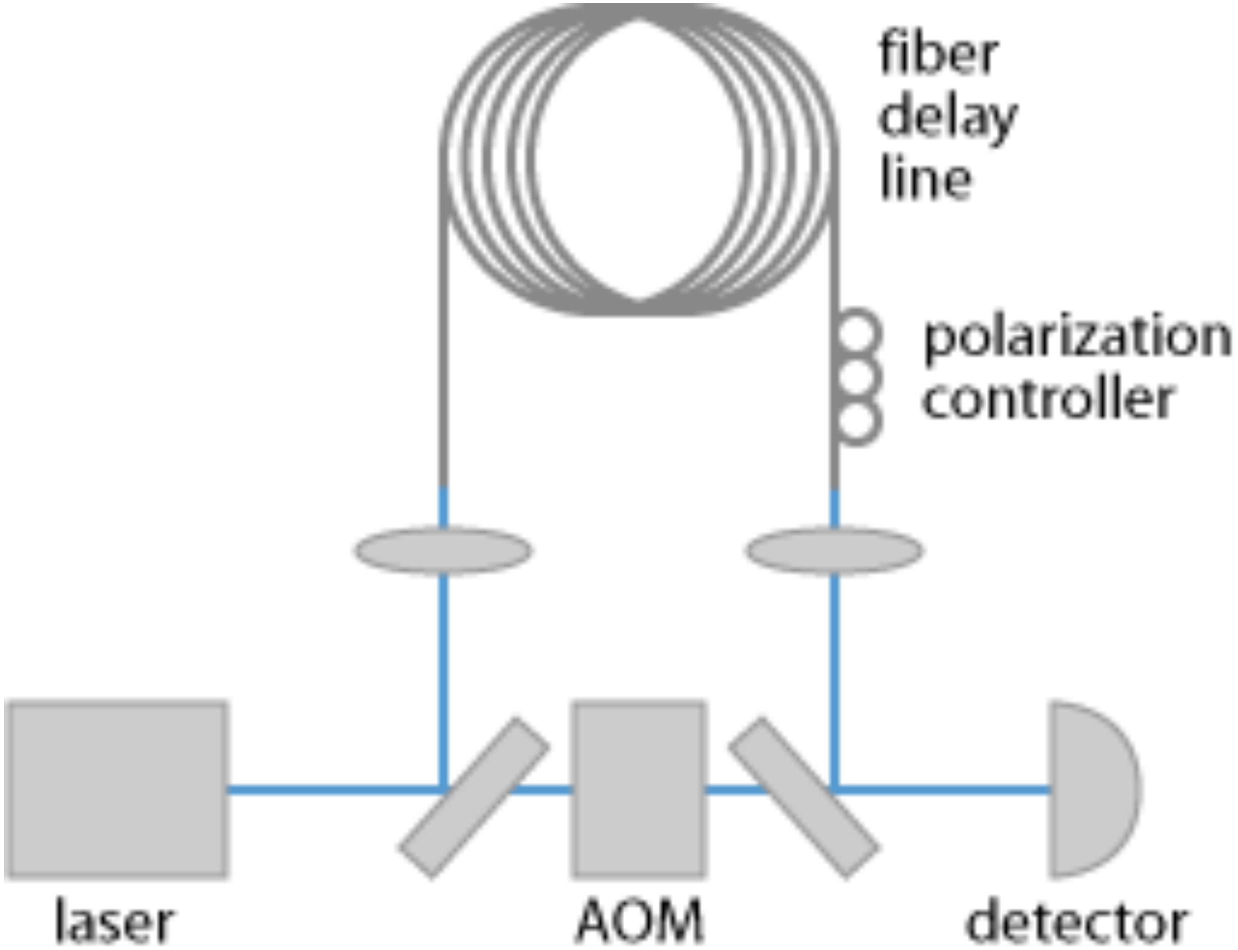

The Weld Lab!

Sathya Guruswamy, REU Director

Supported by NSF PHY-1852574

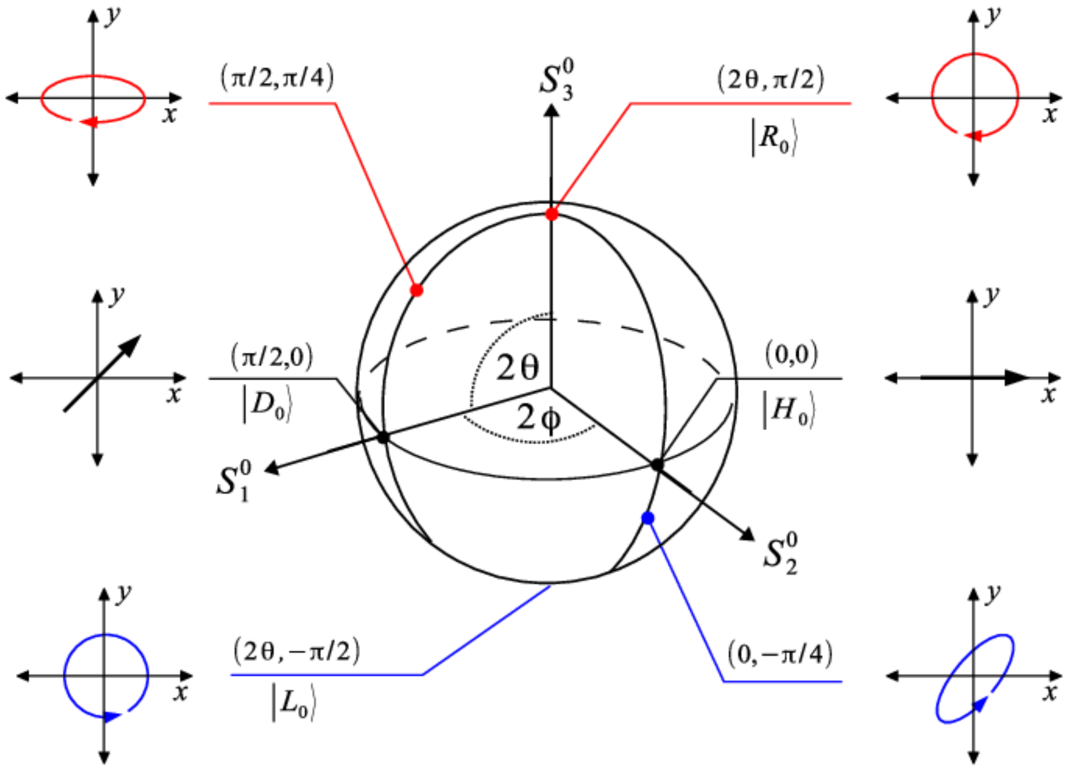
# Backup Slides

# How to measure linewidth: self-heterodyne technique

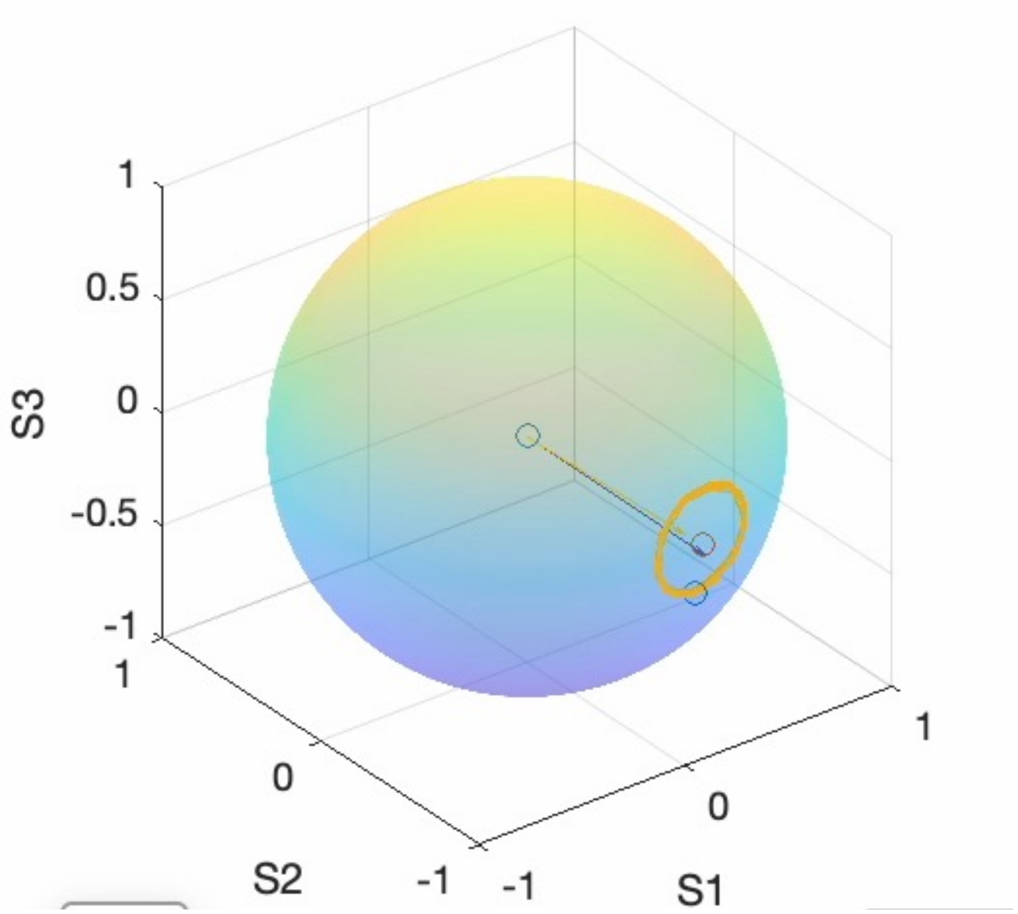



https://www.rp-photonics.com/self_heterodyne_linewidth_measurement.html

# Polarization Considerations



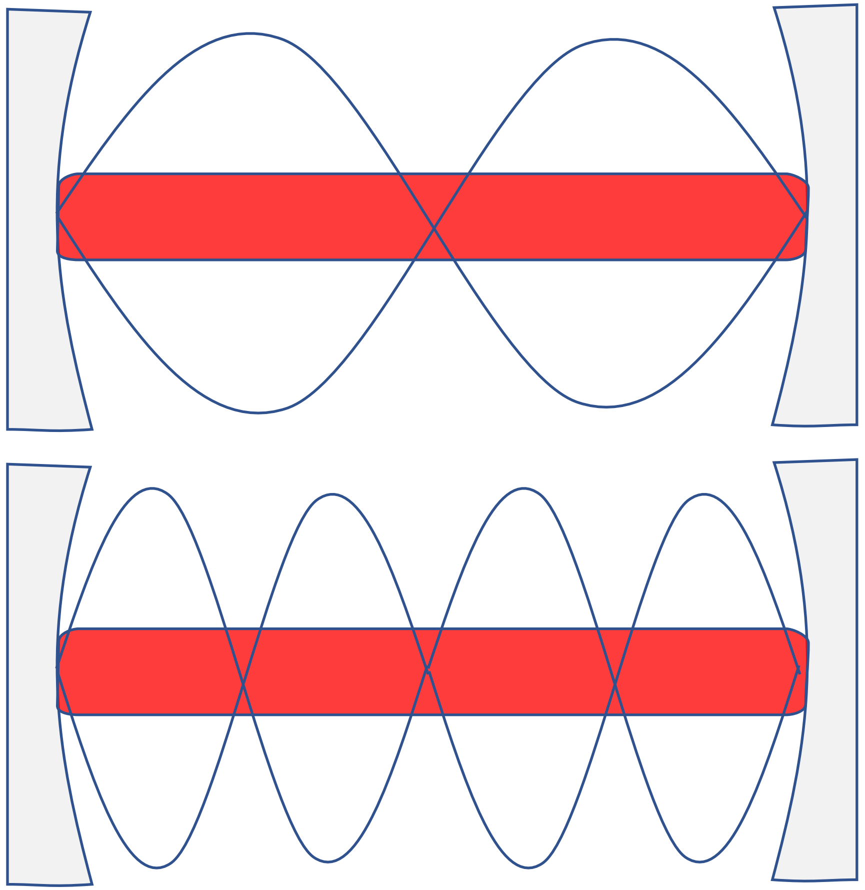

The Poincaré Sphere

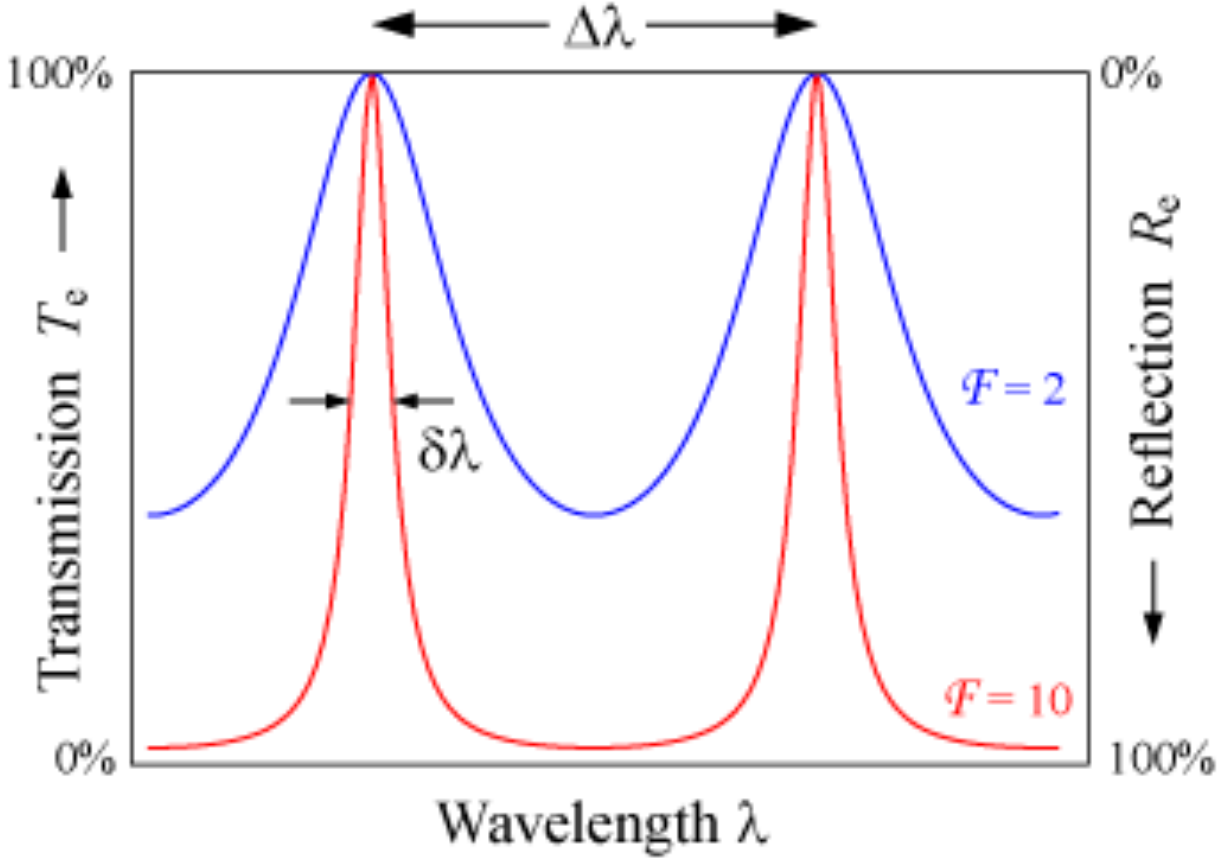



Effect of Temperature Variation

# Characterizing a Fabry-Perot Cavity

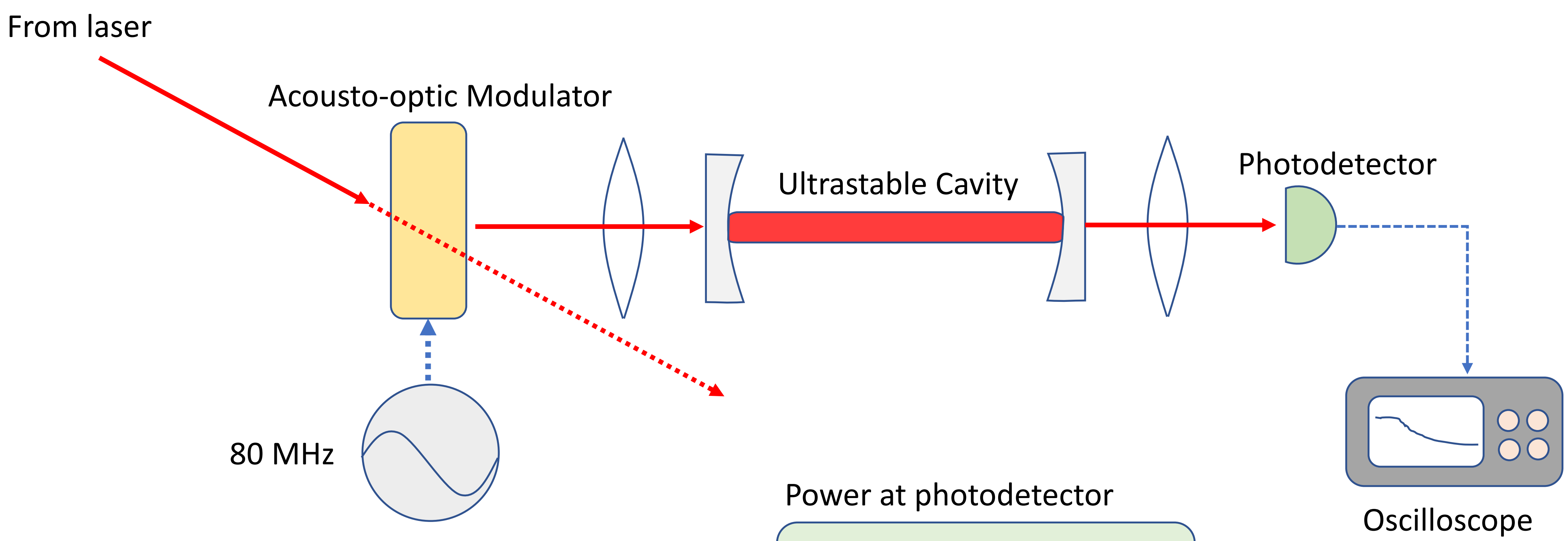
Fabry-Perot cavities






$$Finesse = \frac{Free\ spectral\ range}{Cavity\ linewidth}$$

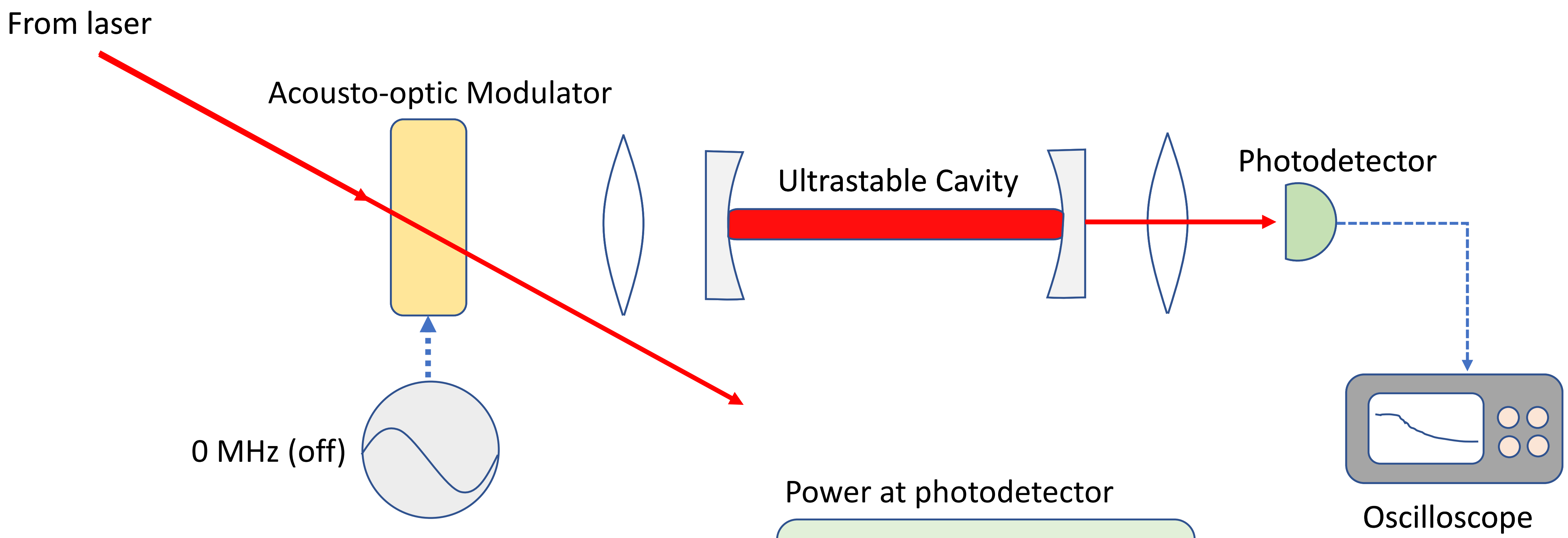
# Cavity Ring-Down Spectroscopy




Power at photodetector

$$P(t) = P_0 e^{-\left(\frac{2\pi c}{lF}\right)t}$$

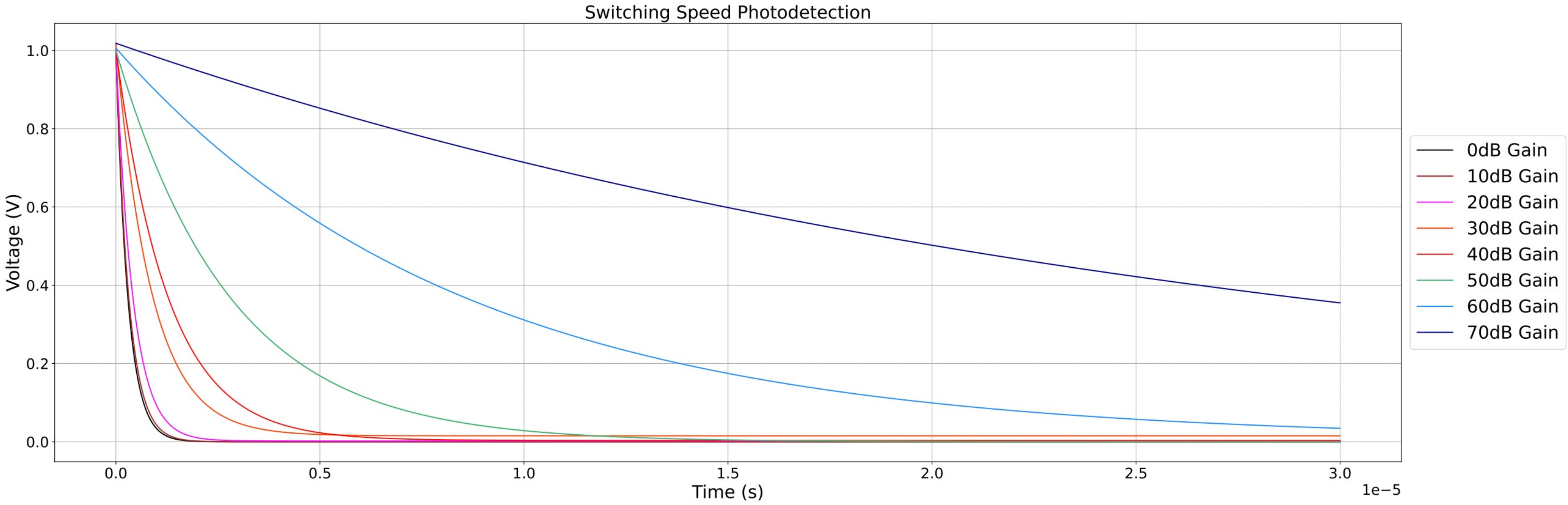
# Cavity Ring-Down Spectroscopy



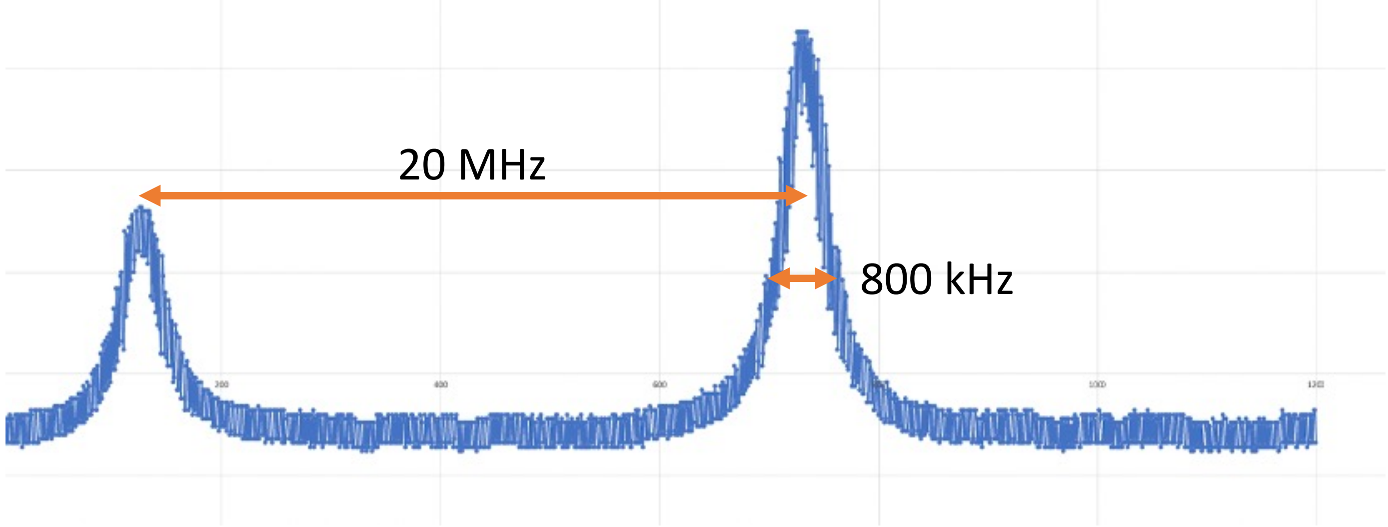

Power at photodetector

$$P(t) = P_0 e^{-\left(\frac{2\pi c}{lF}\right)t}$$

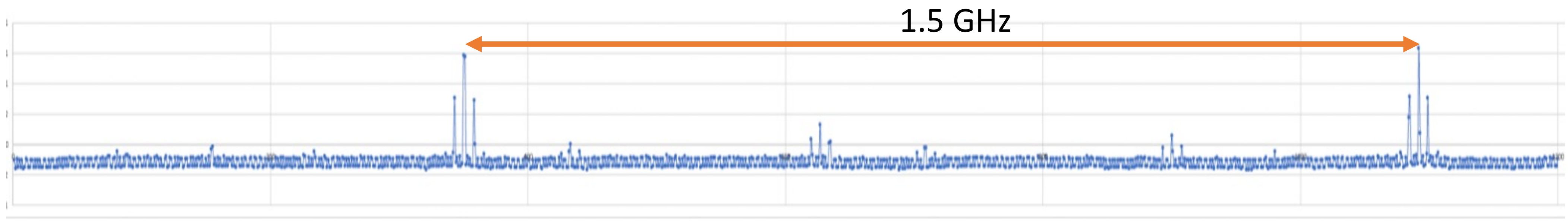
# The Photodetector Problem



# Another method: Cavity Scanning

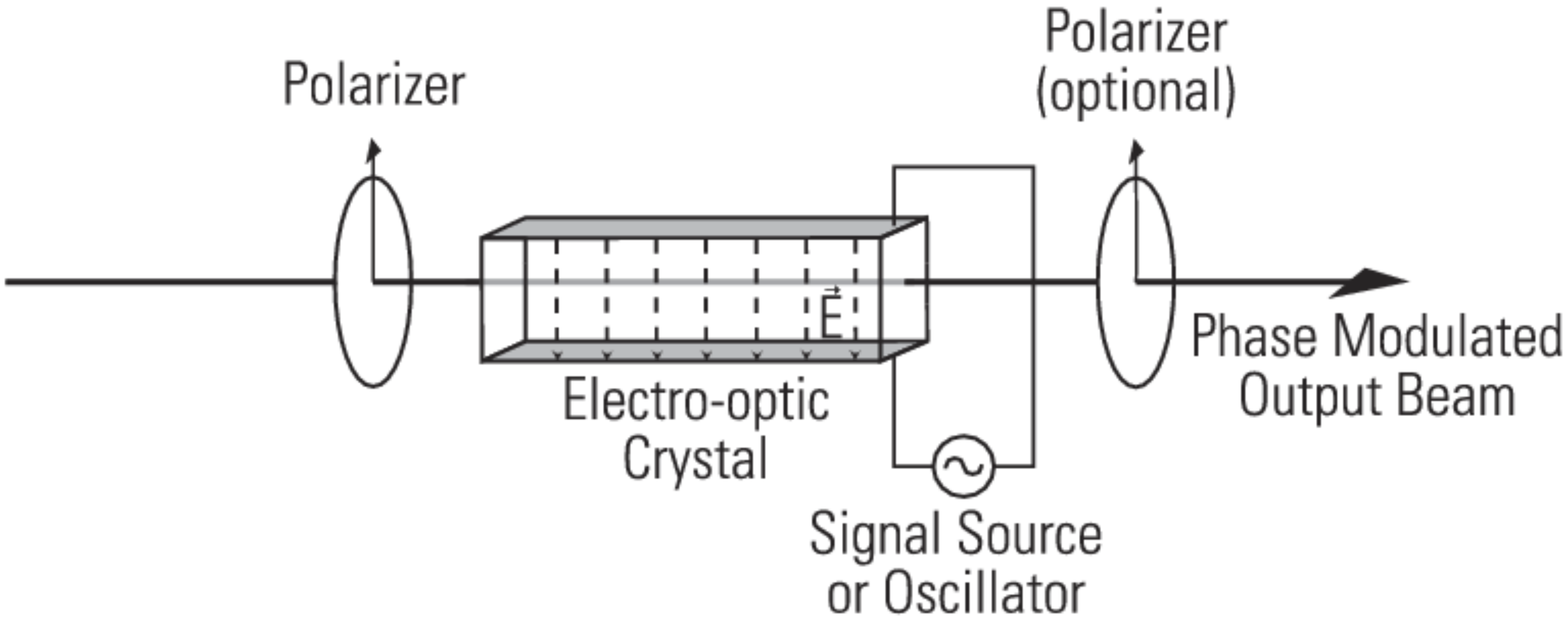



Linewidth Measurement

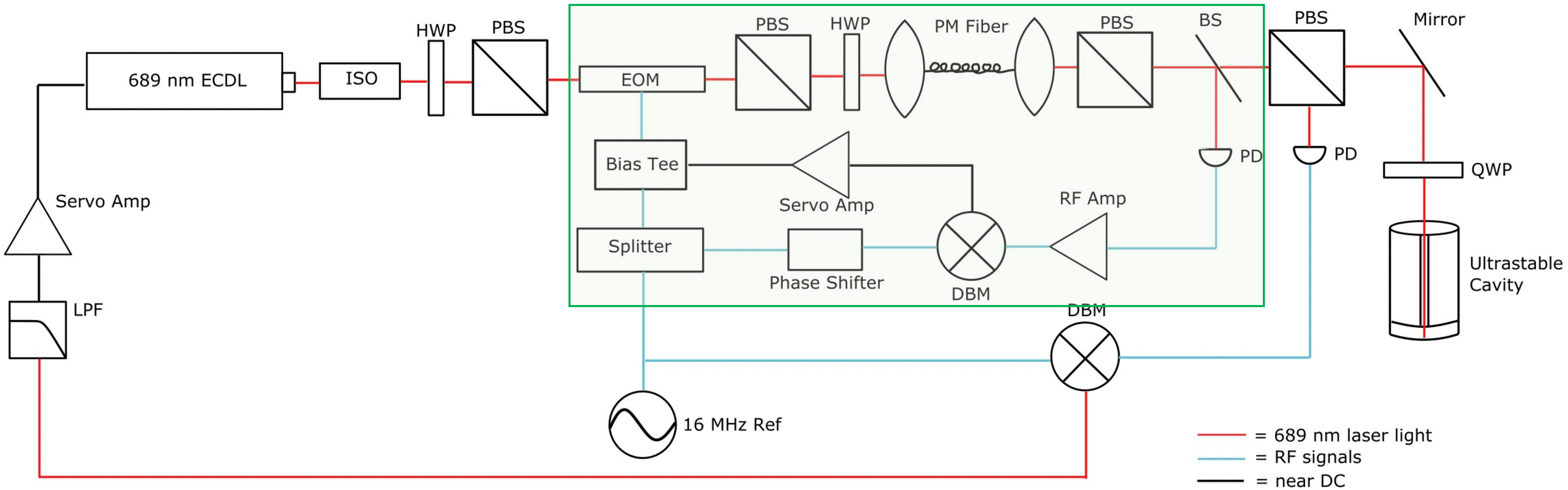



Free Spectral Range Measurement

# Electro-Optic Modulators: Theory of Operation



# Electro-optic Modulators: DC feedback



# Feedback to Eliminate RAM