Laser Control for Atom Trapping and Cooling

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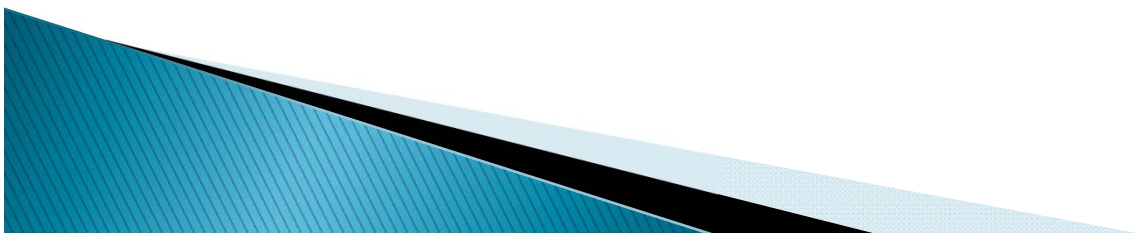
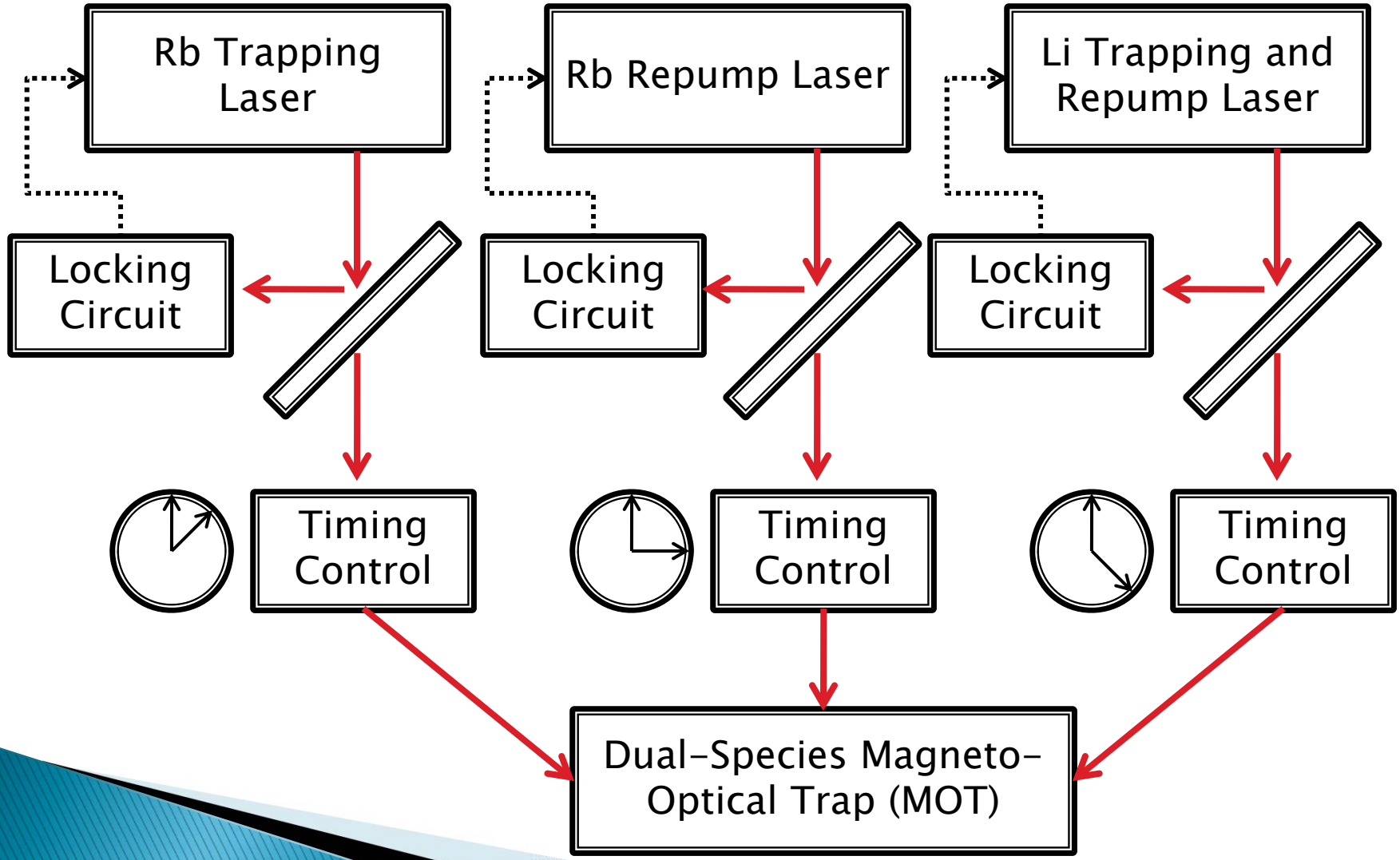
PURDUE
UNIVERSITY

Goals

- Overall Project Goal:
  - Photoassociation of Li and Rb
- My REU Goals:
  - Work on electronics to help control the dual-species magneto-optical trap (MOT)
    - Laser locking circuits
    - Timing Controls

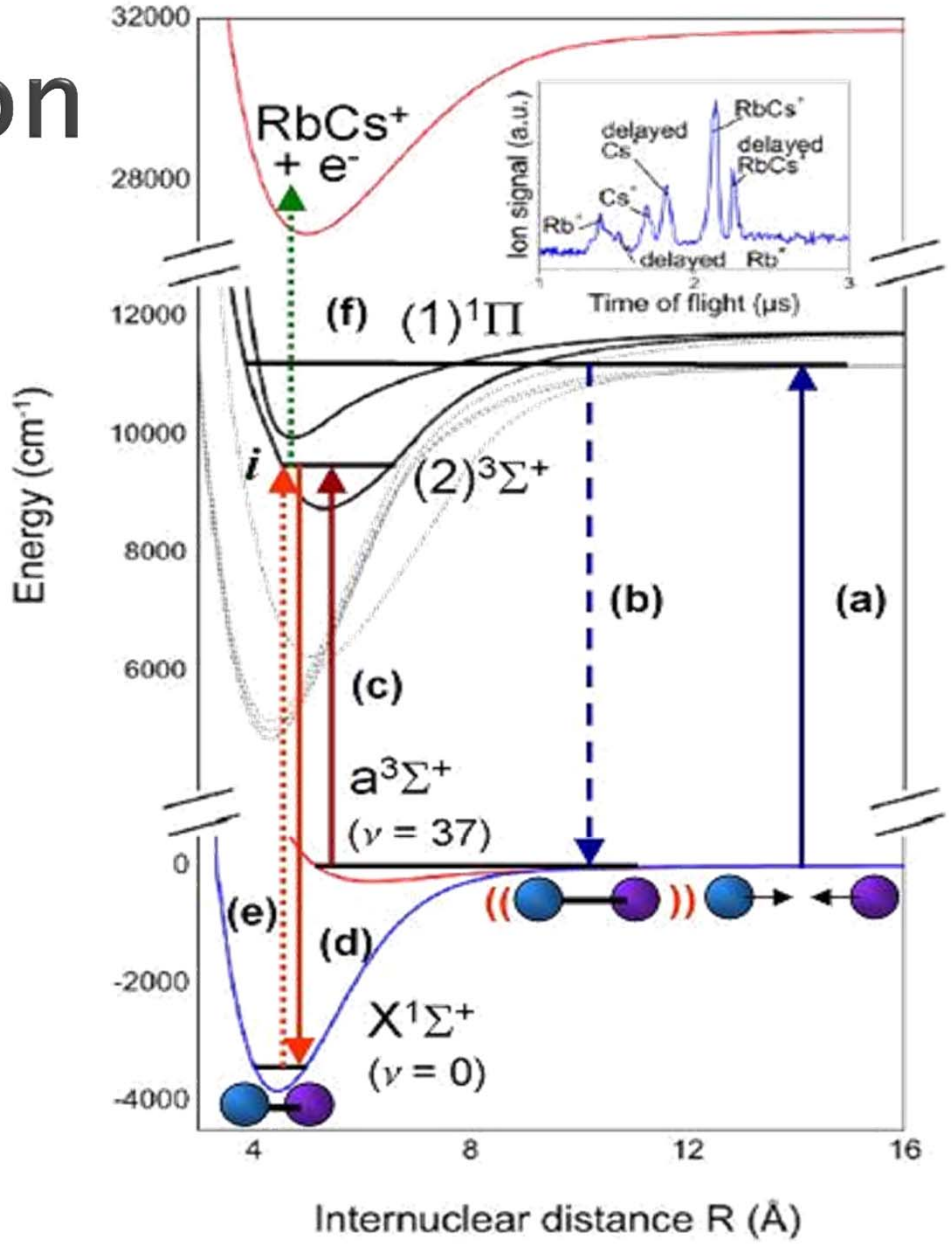


Where My Work Fits In



Photoassociation

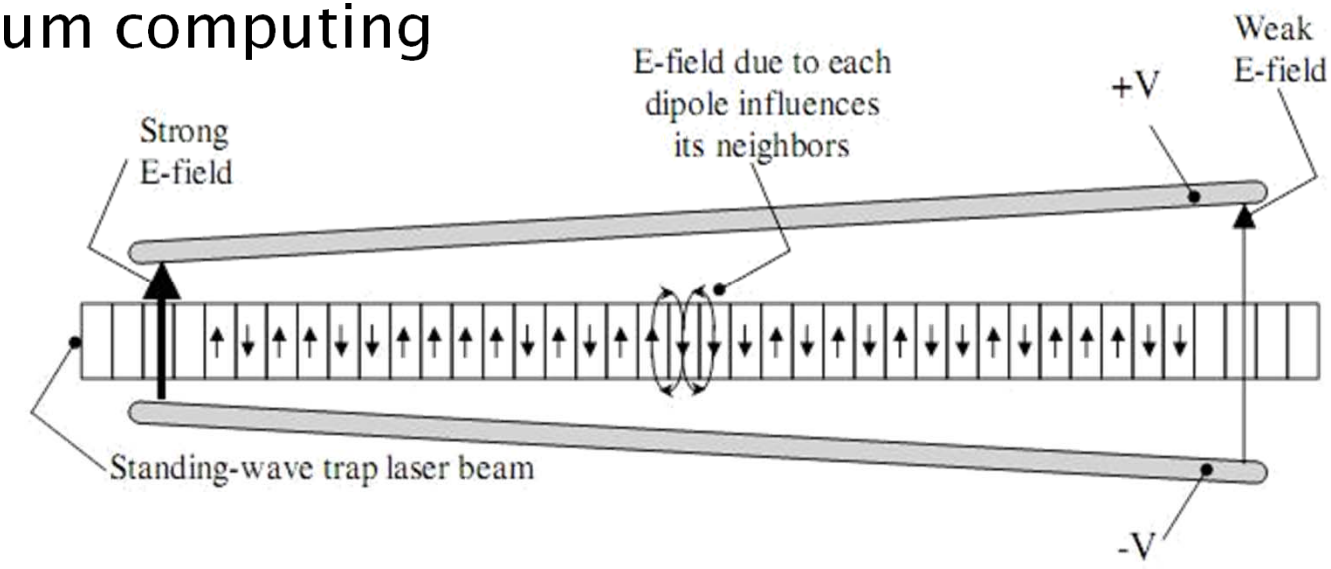
- Using light to form molecules from atoms



J. M. Sage et al. "Optical Production of Ultracold Polar Molecules"

Photoassociation

- Why LiRb?
  - Polar molecule
  - More complicated than atoms
- Potential applications:
  - Quantum computing

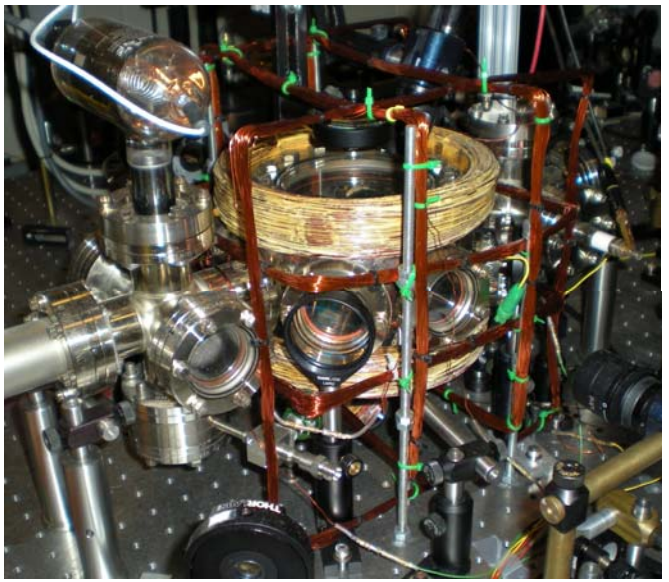


D. DeMille. "Quantum Computation with Trapped Polar Molecules"

MOT Basics

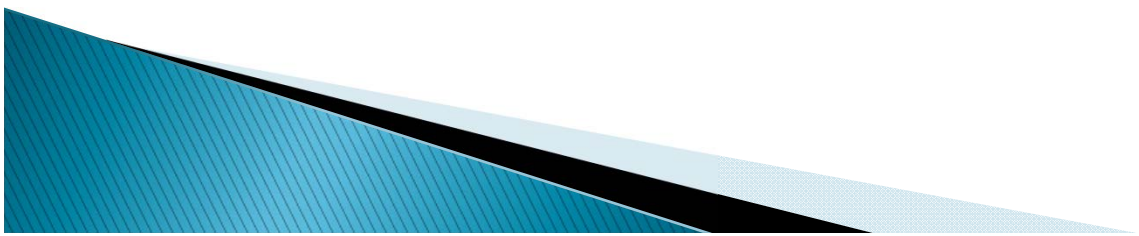
- Magneto-Optical Trap
  - Used to trap and cool atoms
- Requirements to trap atoms:

1. Velocity-dependent force
2. Position-dependent force

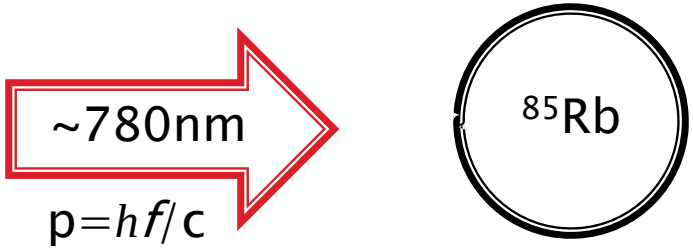


Velocity-Dependent Force

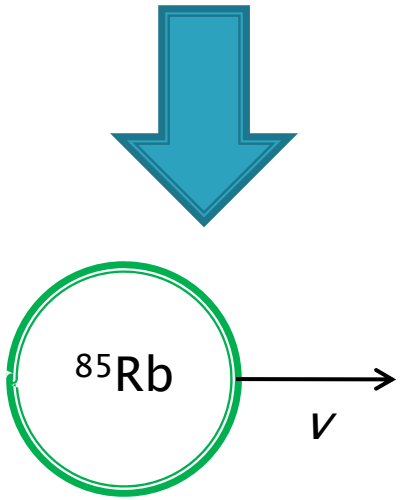
- Principle ideas:
  - Photons carry momentum
  - Atoms can absorb photons
  - Conservation of momentum
  - Doppler shift

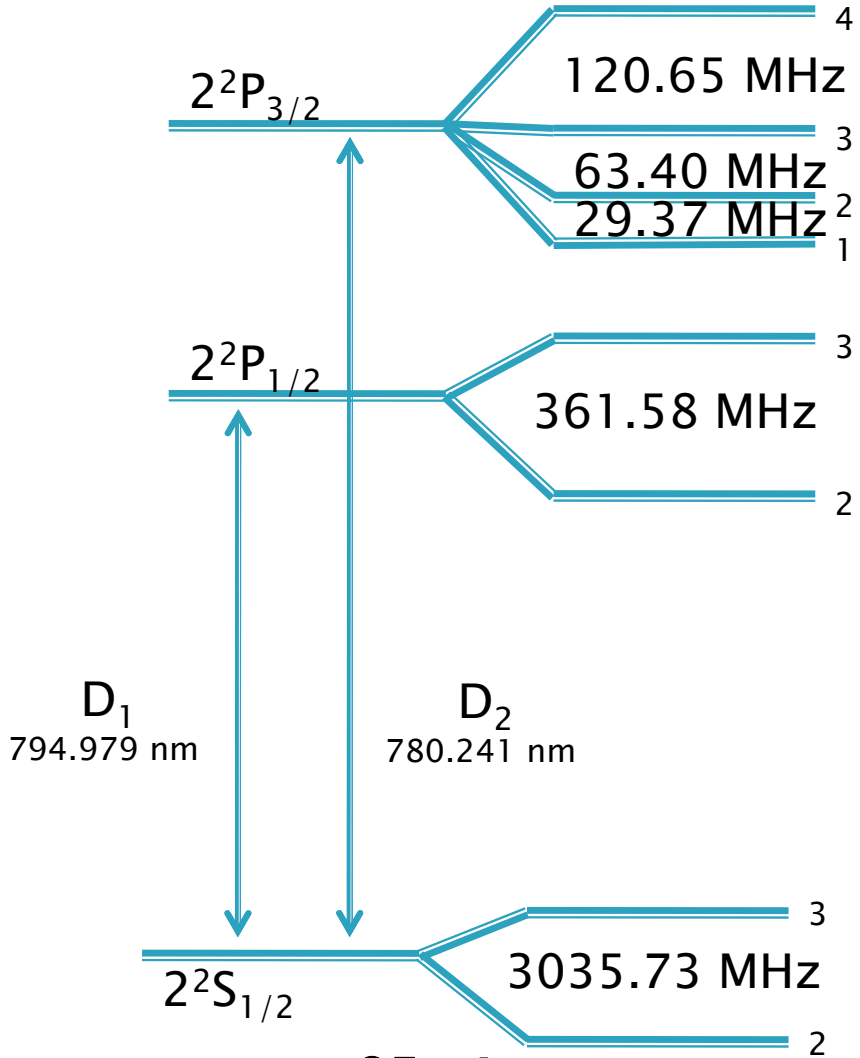


Photons Transfer Momentum to Atoms



Conservation of Momentum



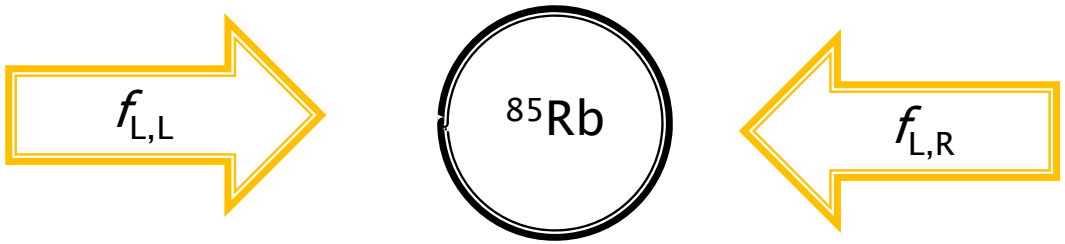


85Rb

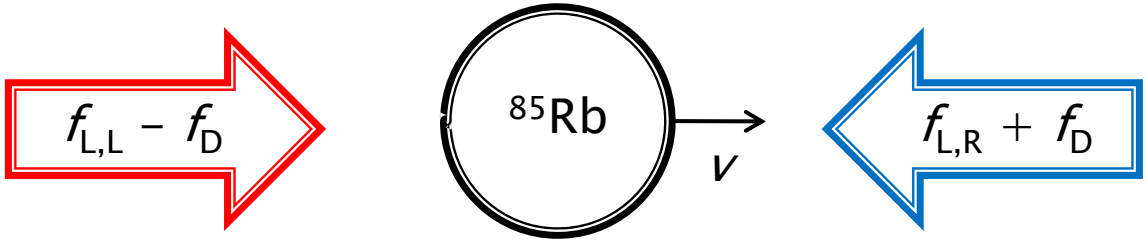
J. Lorenz

Using the Doppler Shift

- Atom at rest:

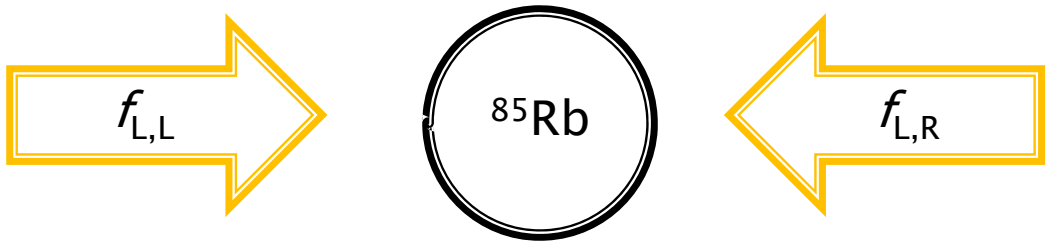


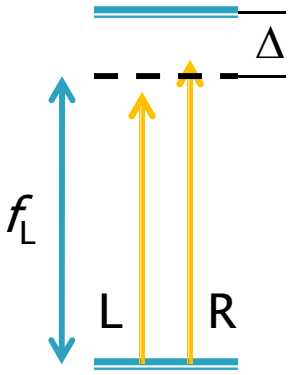
- Atom moving towards the right:



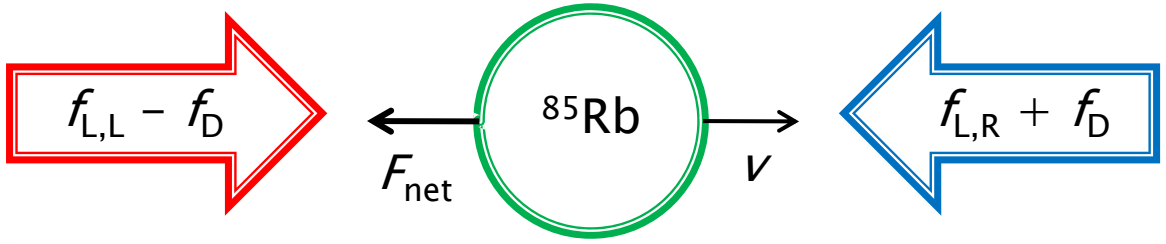
Doppler Cooling

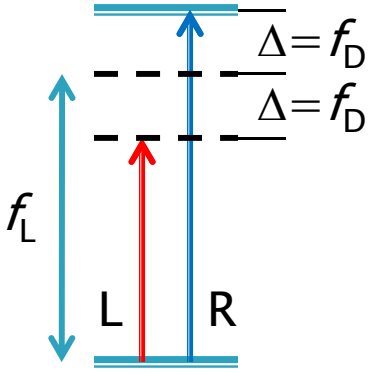
- Red-detune the laser from the transition frequency by Δ
- Slow moving atoms



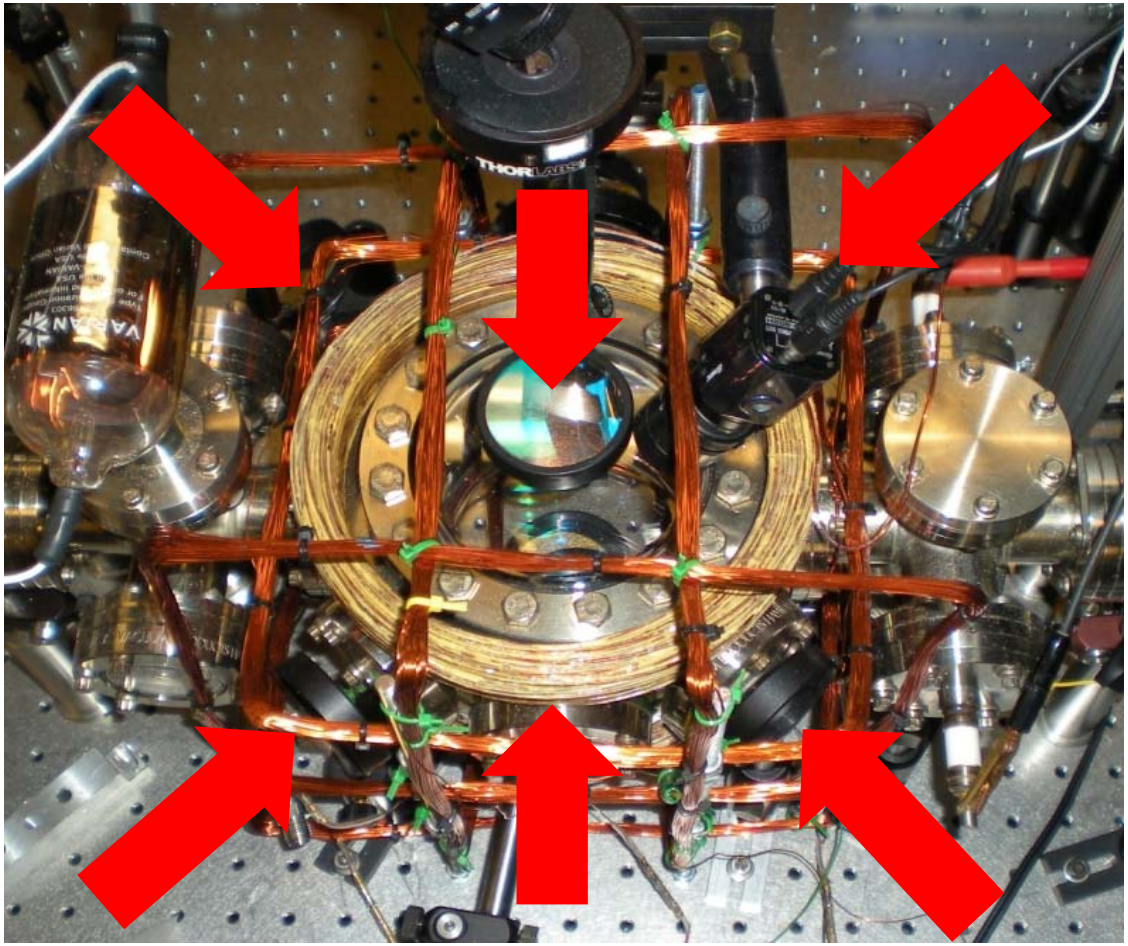


- Fast moving atoms



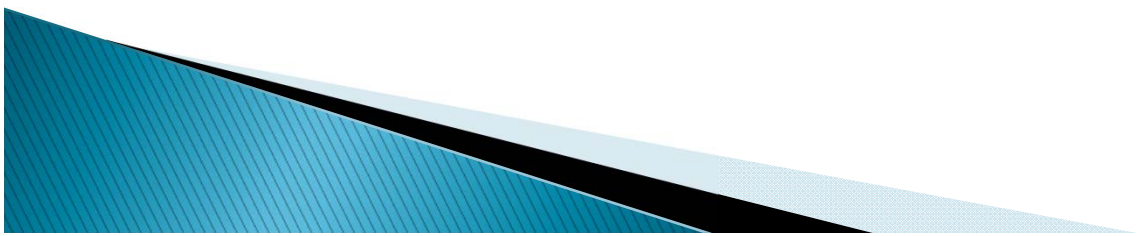


3D Velocity-Dependent Atom Trapping



Position-Dependent Force

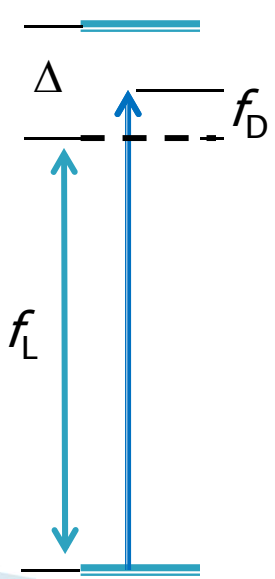
- Principle Ideas:
  - Slow moving atoms
  - Zeeman effect
  - Selection rules



Slow Moving Atoms and the Zeeman Effect

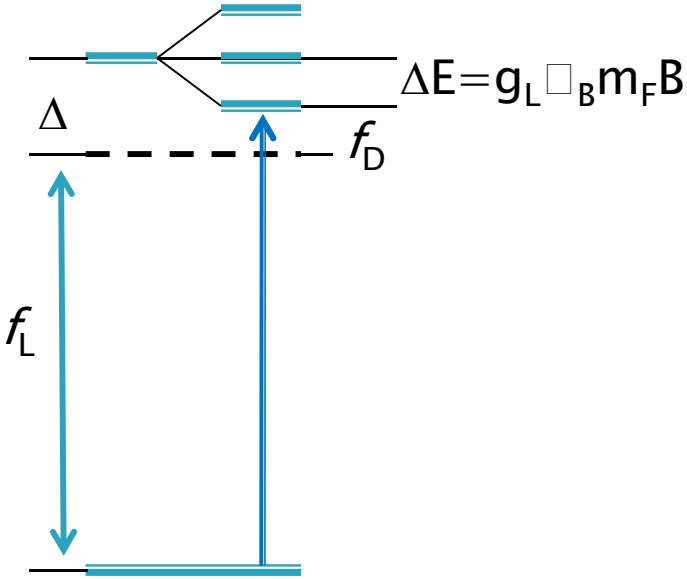
Slow Moving Atoms

- Too slow to Doppler shift laser onto resonance



Zeeman Effect

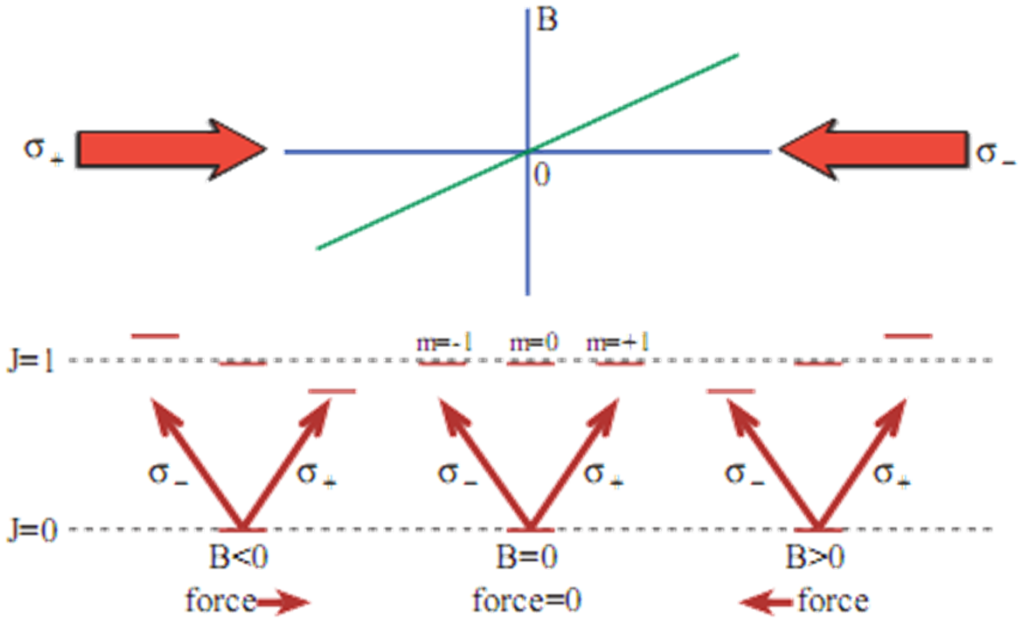
- Used to shift atomic energy levels onto resonance



Applying Selection Rules

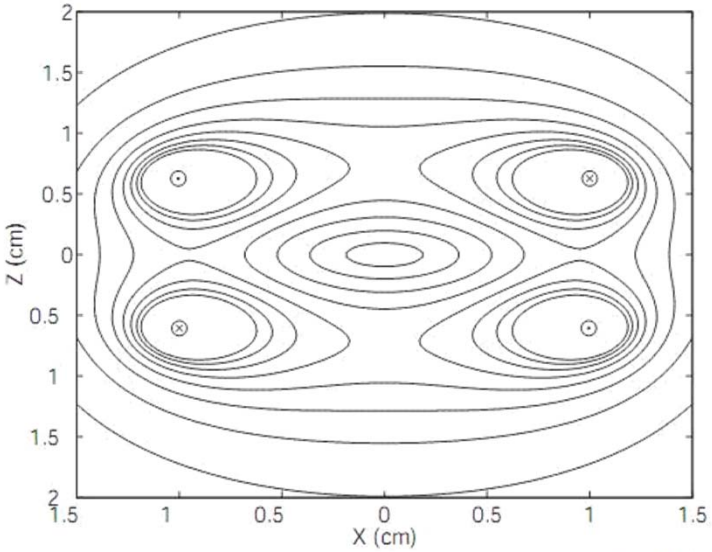
Selection Rules

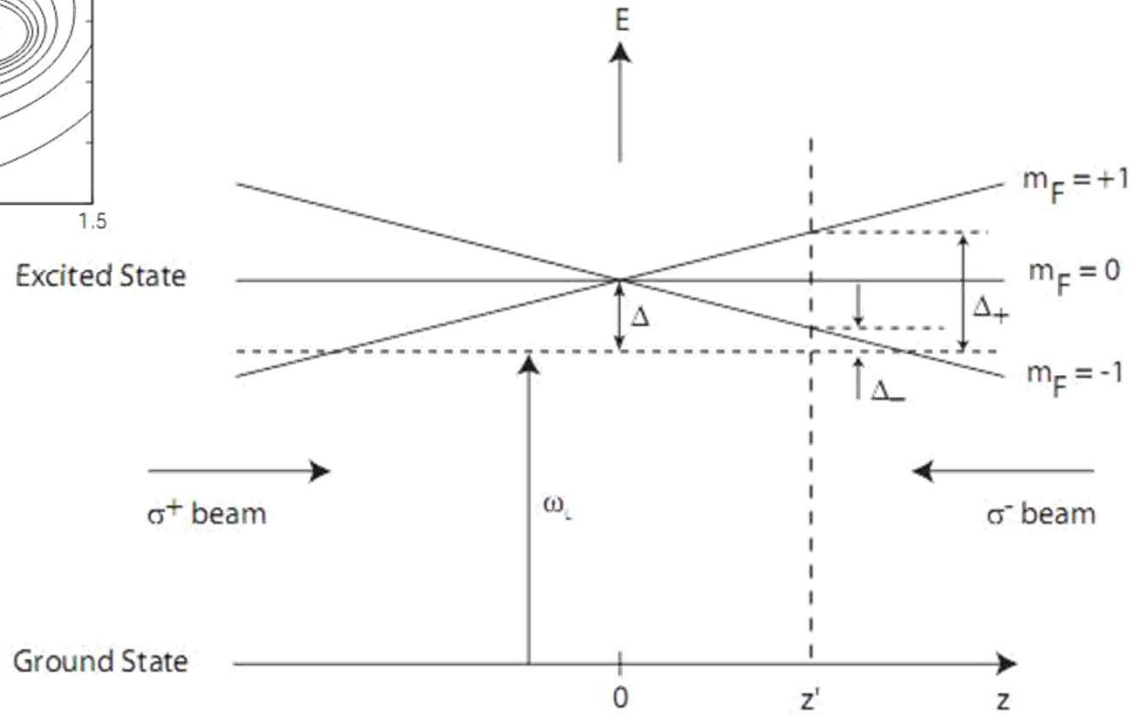
- In a magnetic field, atoms preferentially absorb light depending on its polarization



University of Colorado. "Advanced Optics Lab: Laser Cooling and Trapping"

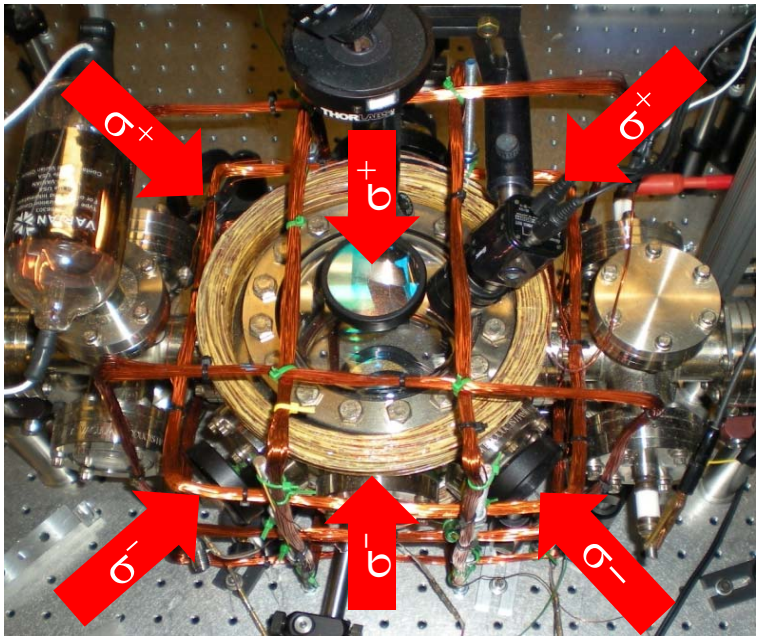
1D MOT

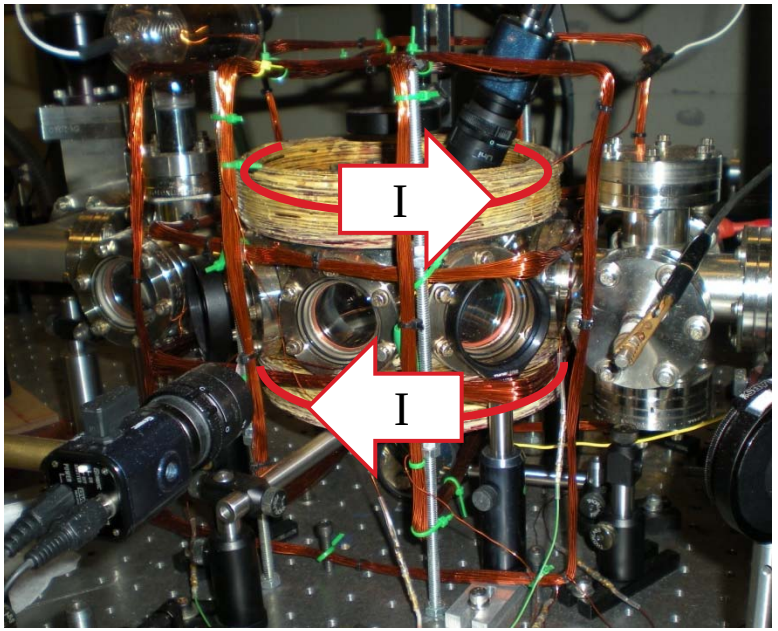




A. Mills. "Nonlinear Ground-state Pump-probe Spectroscopy in Ultracold Rubidium: Raman-coupled Dressed State Spectroscopy"

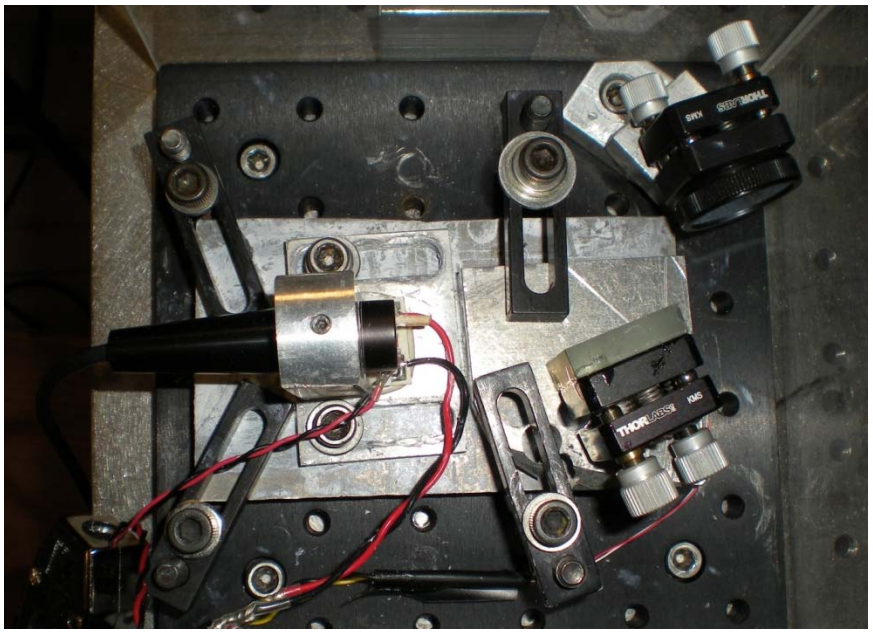
3D MOT





Laser Locking Circuits

- Lasers must be tuned and kept at specific frequencies
- Stabilizing lasers:
  - Temperature control
  - Current control
  - Electronic feedback



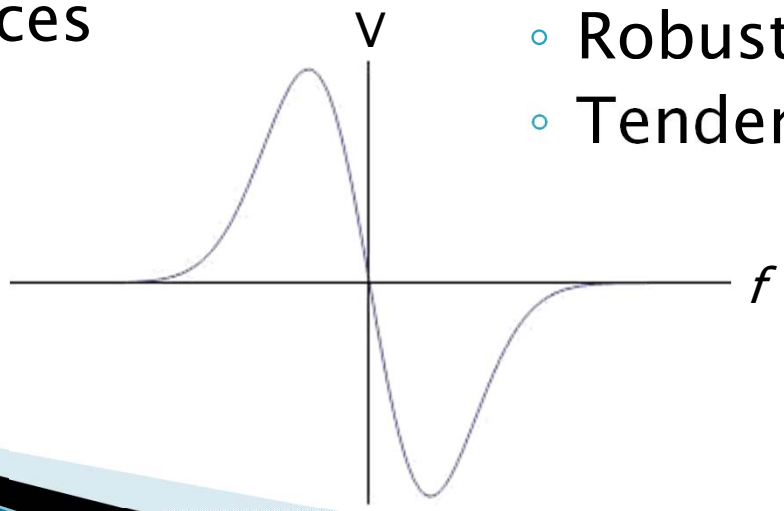
Common Locking Schemes

Peak Locking

- Small capture range:
  - Accurate
  - Sensitive to disturbances

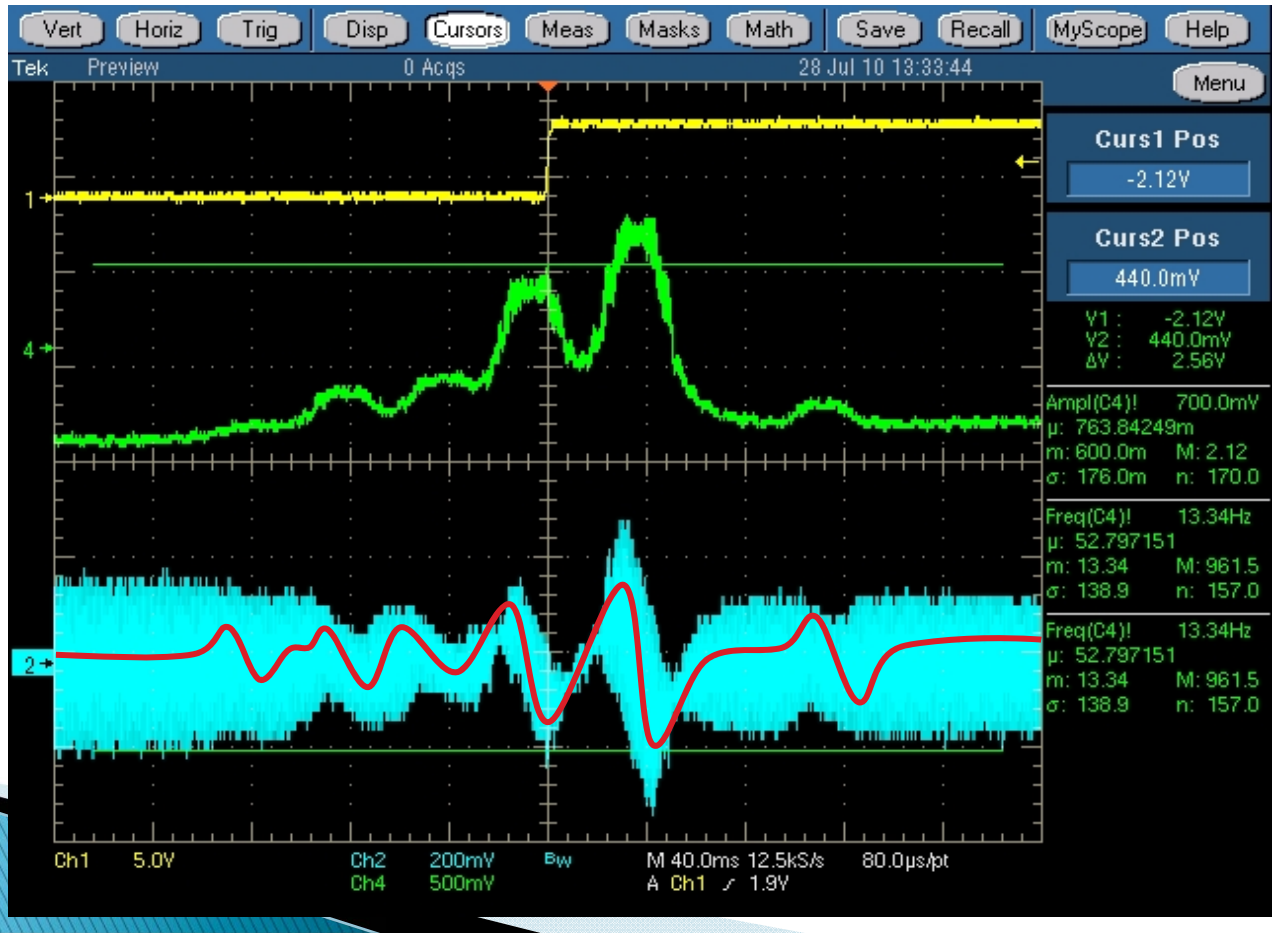
Dichroic Atomic Vapor Laser Lock (DAVLL)

- Large capture range:
  - Robust
  - Tendency to drift

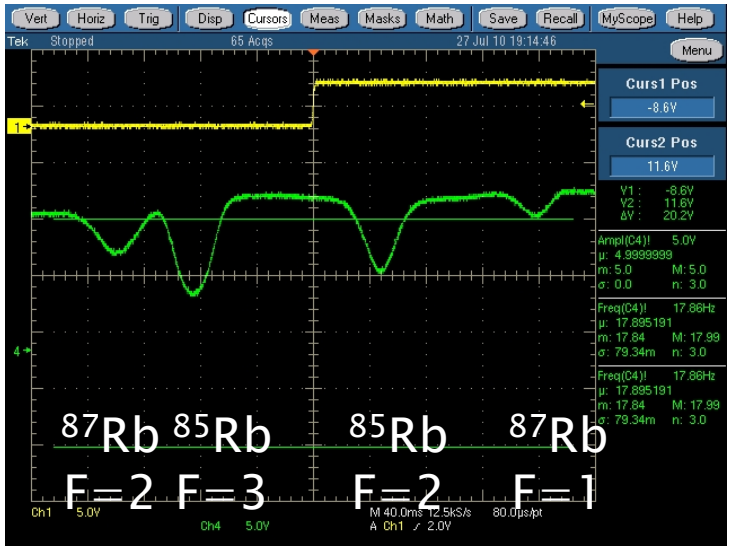


Peak Locking Scheme

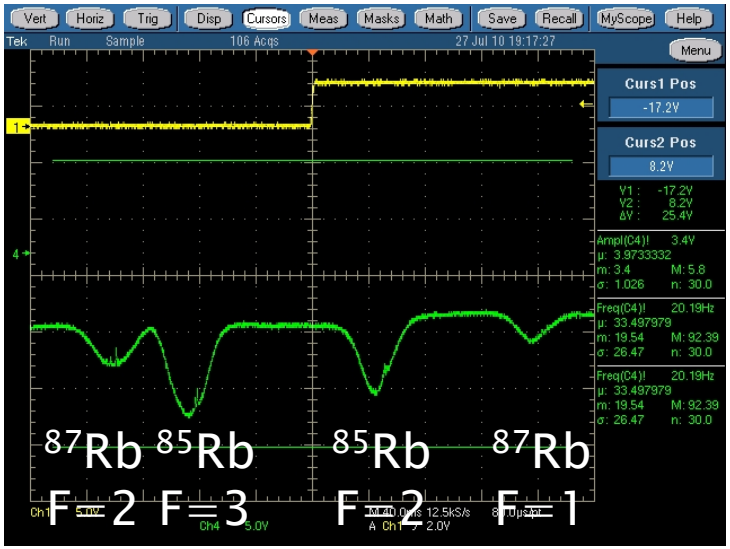
- Idea: take the “derivative” of the Doppler-free saturated absorption signal



Saturated Absorption Spectroscopy

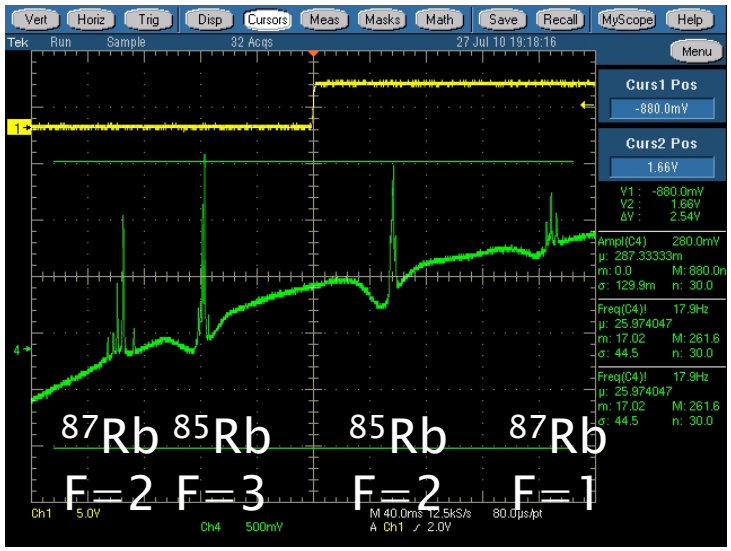


Doppler broadening

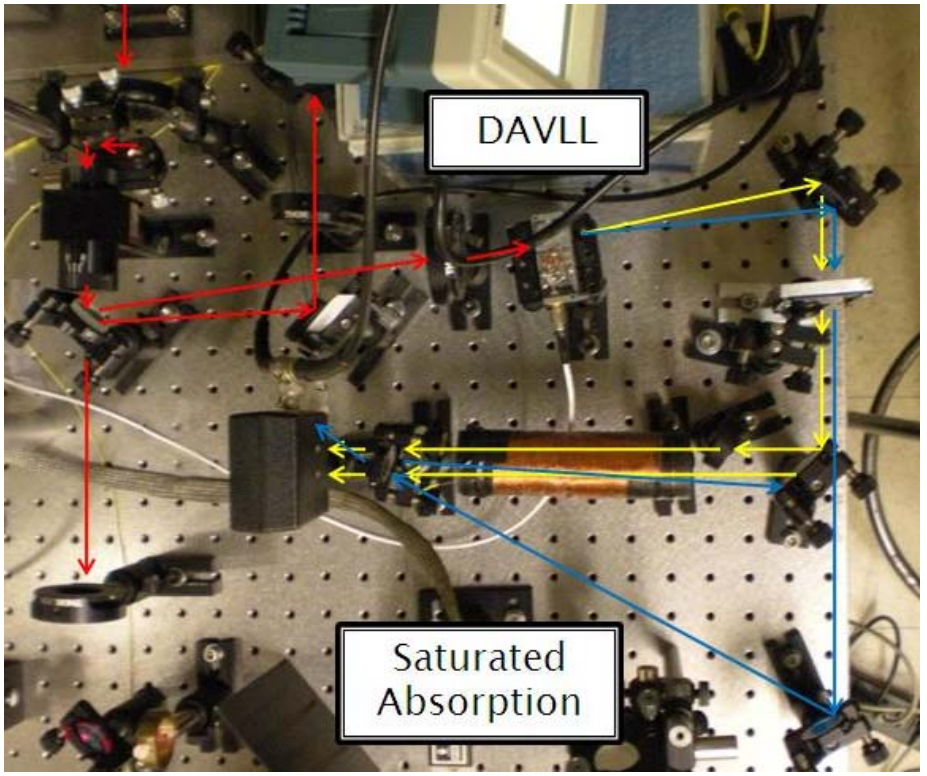


“Hole burning”

Saturated Absorption Spectroscopy

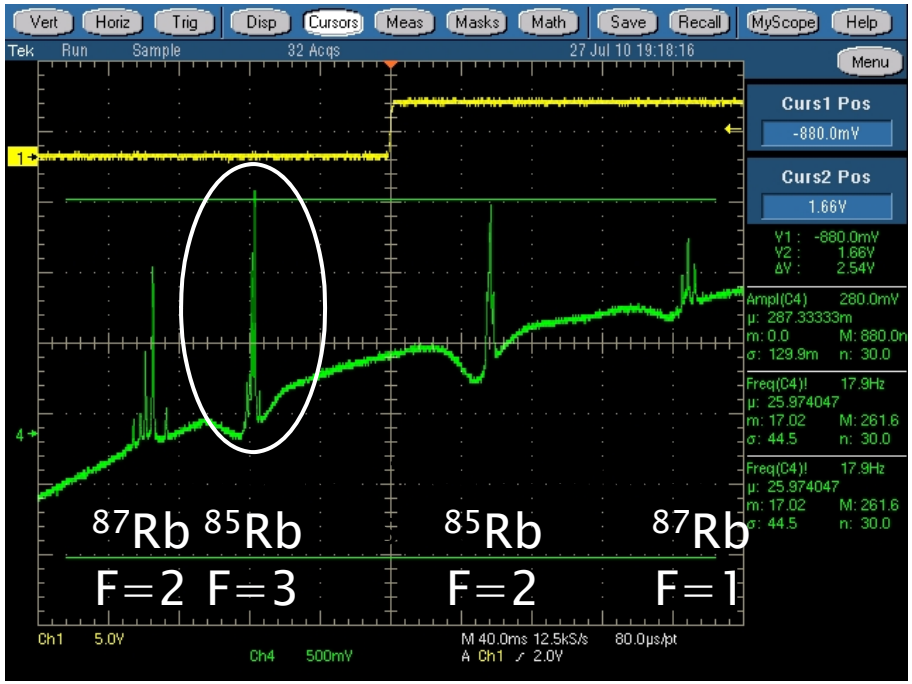


Doppler-free saturated absorption

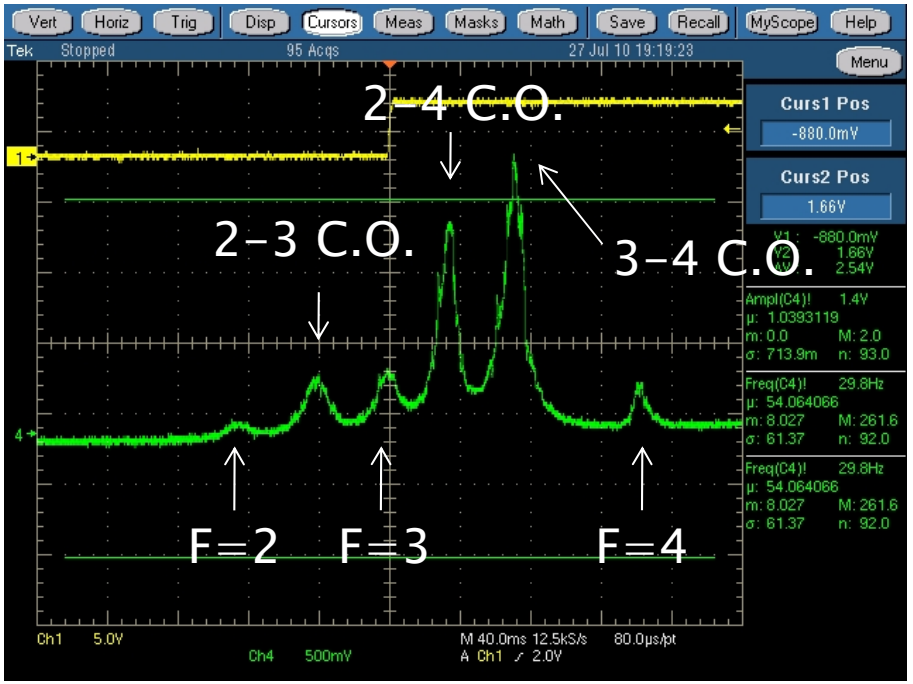


Physical implementation of Doppler-free saturated absorption

Close-up of ^{85}Rb D_2 line



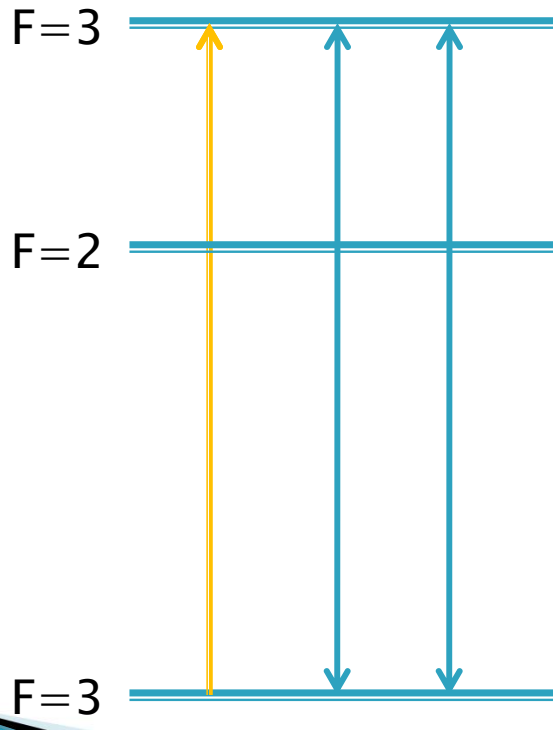
Look at ^{85}Rb F=3 ground state



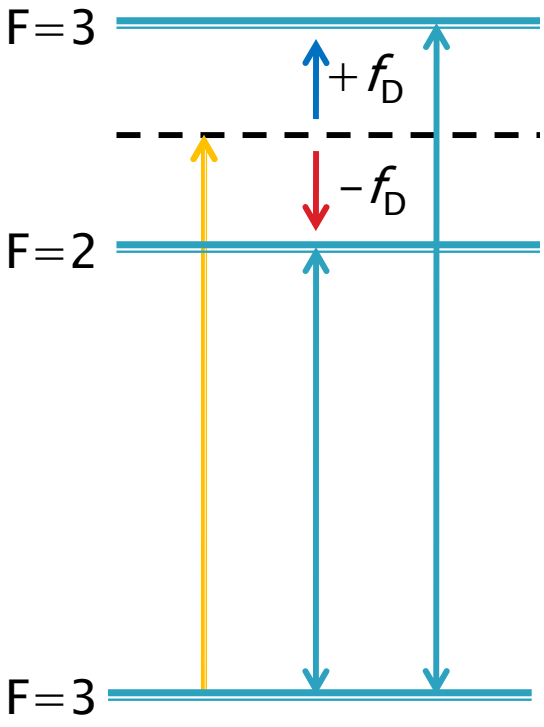
Close-up of ^{85}Rb hyperfine peaks

Hyperfine and Crossover Peaks

- Hyperfine Peaks



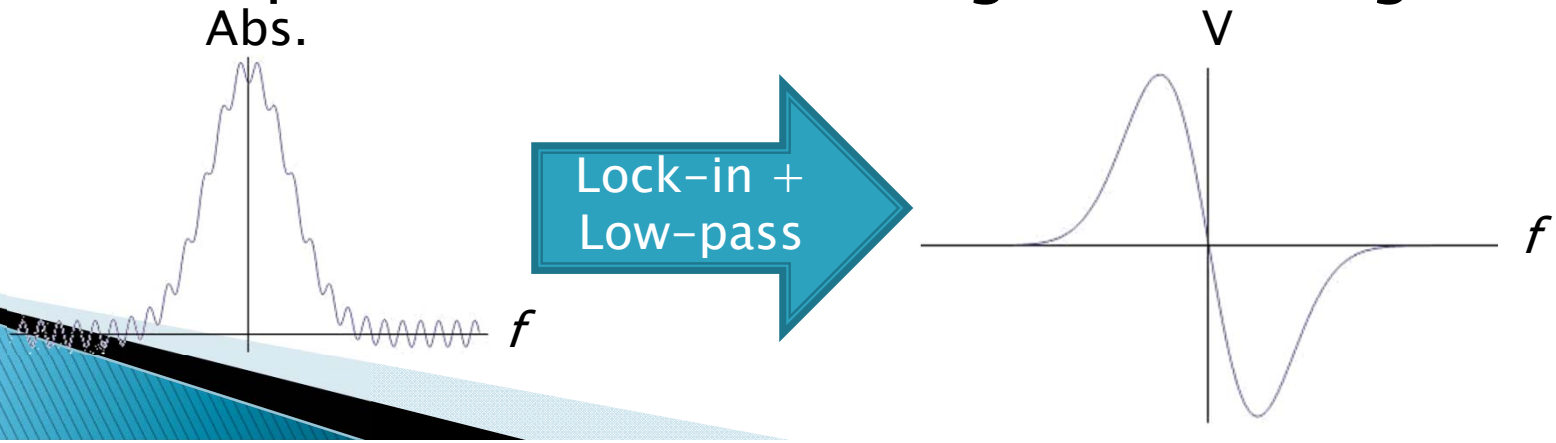
- Crossover Resonances



Obtaining the "Derivative"

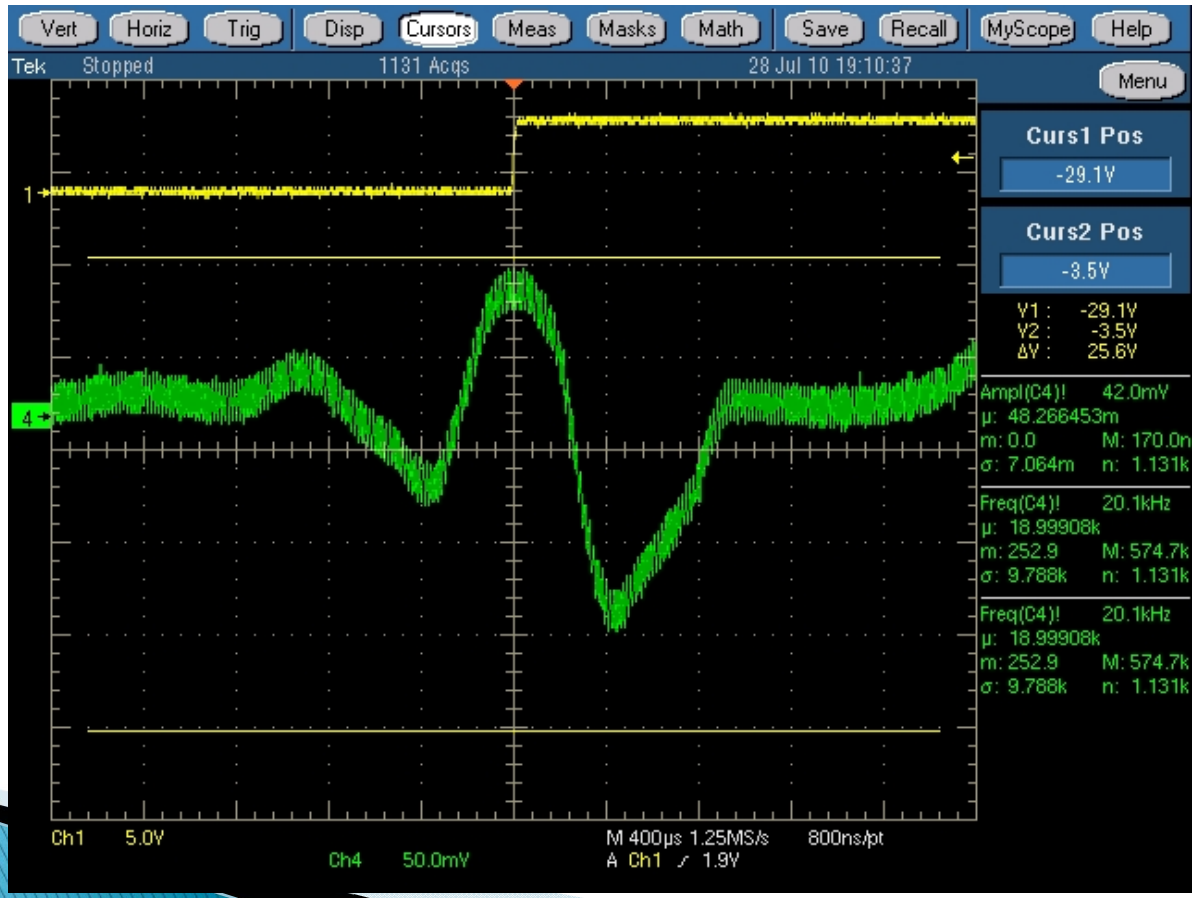
1. Apply a dither to the Doppler-free saturated absorption signal

2. Use a lock-in amplifier and low-pass filter to convert amplitude of dither on signal to voltage

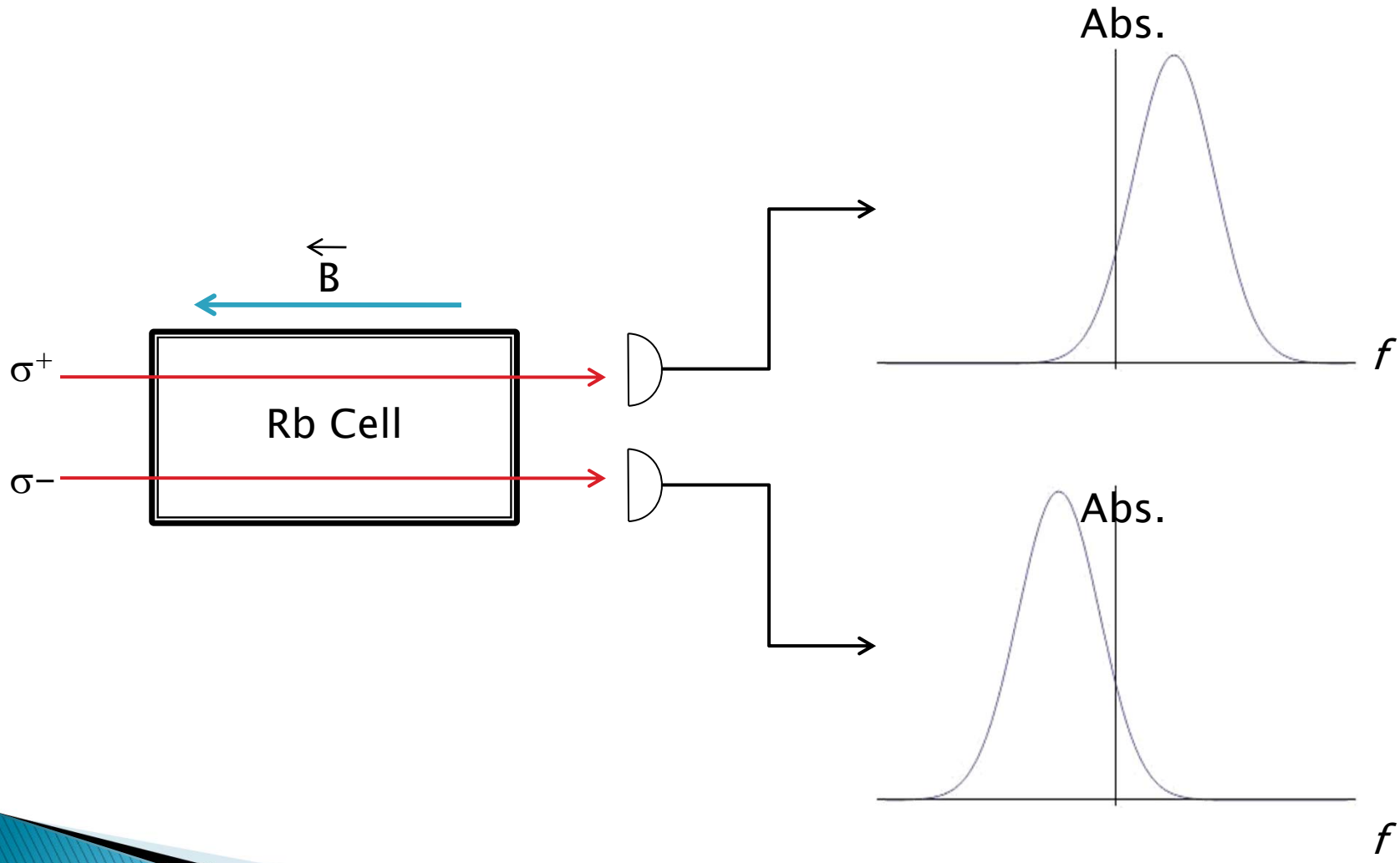


DAVLL Scheme

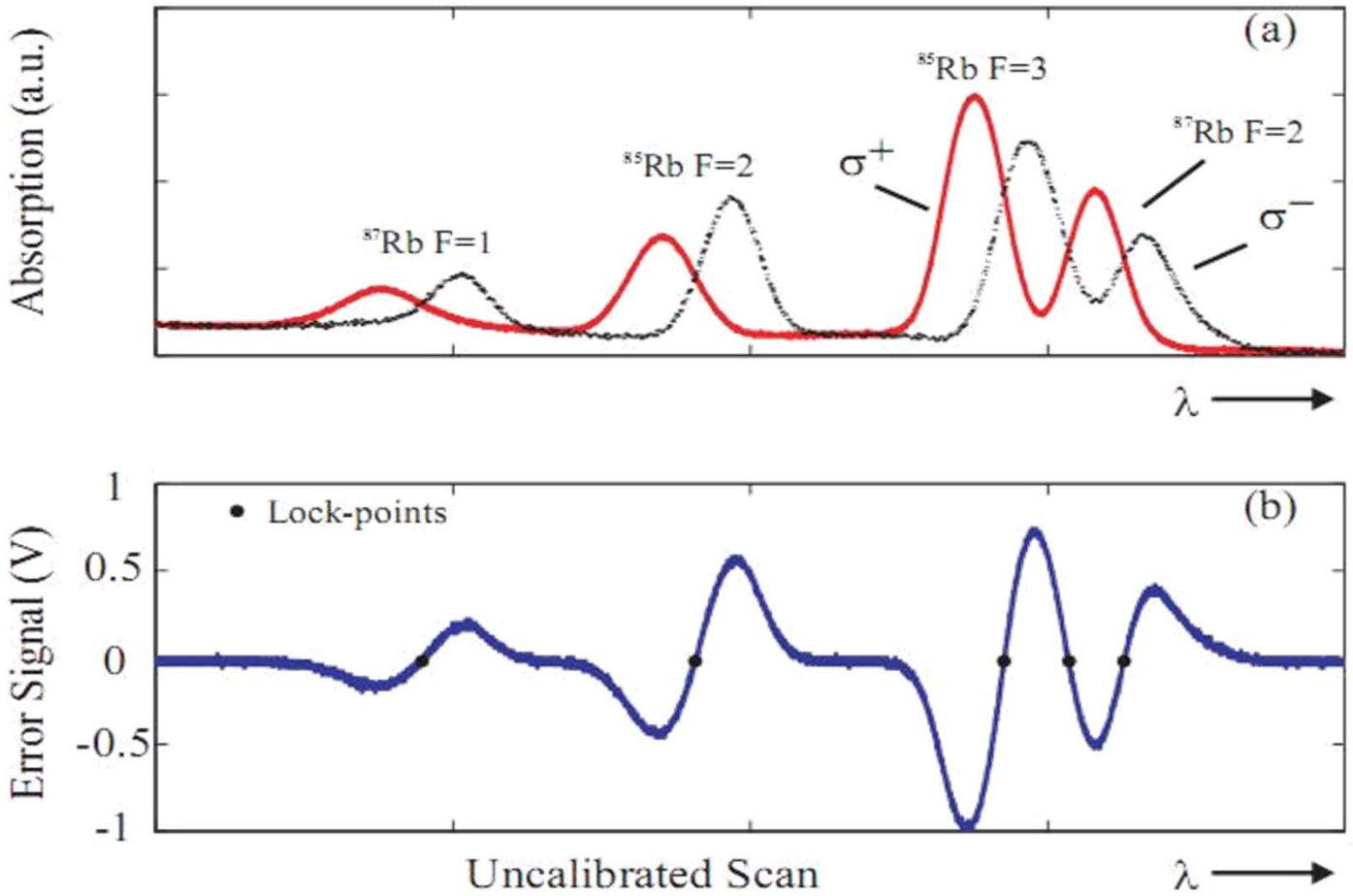
- Idea: in a magnetic field, atoms absorb light differently depending on its polarization



DAVLL Setup



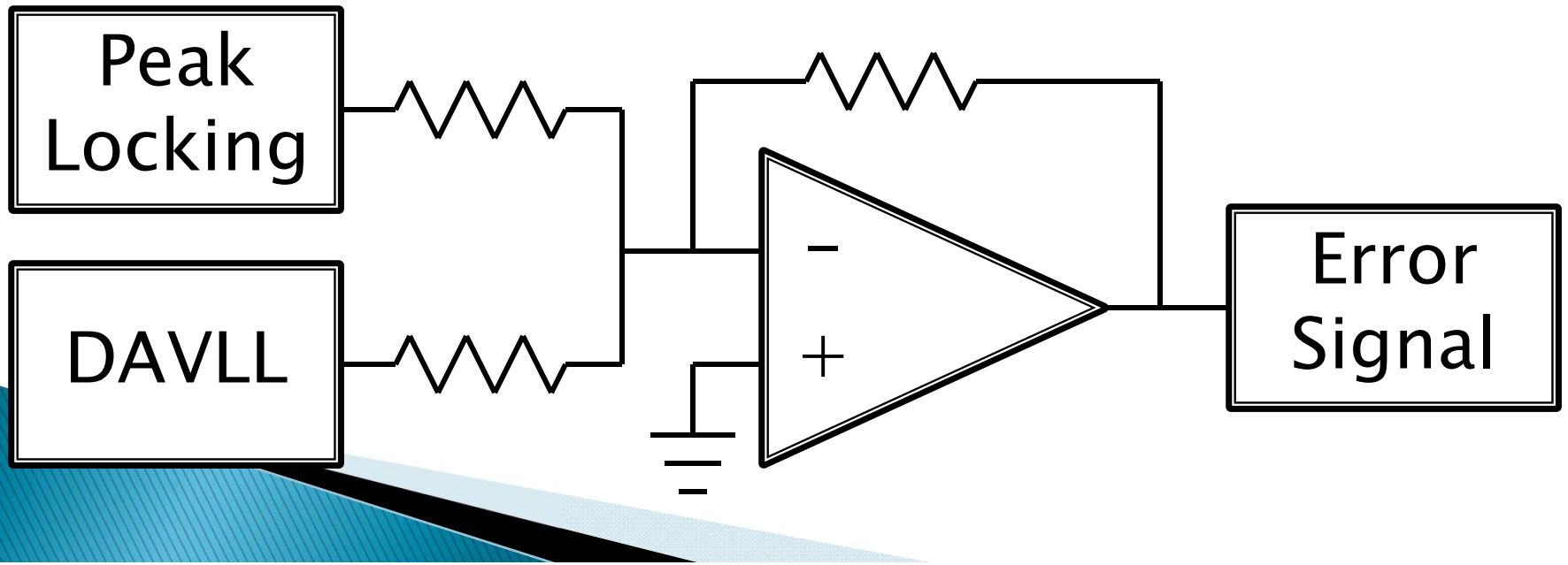
DAVLL Signal



A. Mills. "Nonlinear Ground-state Pump-probe Spectroscopy in Ultracold Rubidium: Raman-coupled Dressed State Spectroscopy"

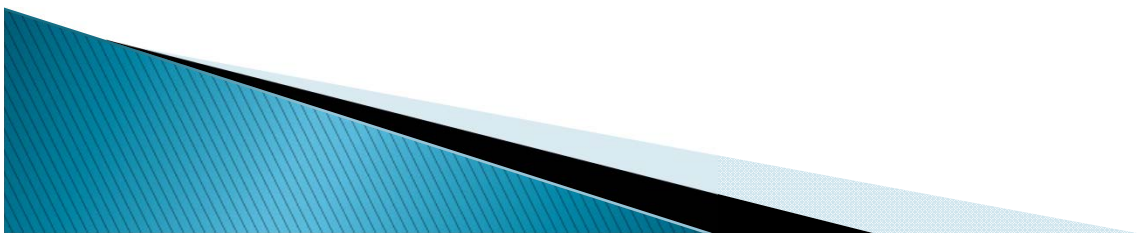
Combined Locking Scheme

- Want benefits of both peak locking and DAVLL schemes
  - Accurate
  - Robust
- Brute force approach



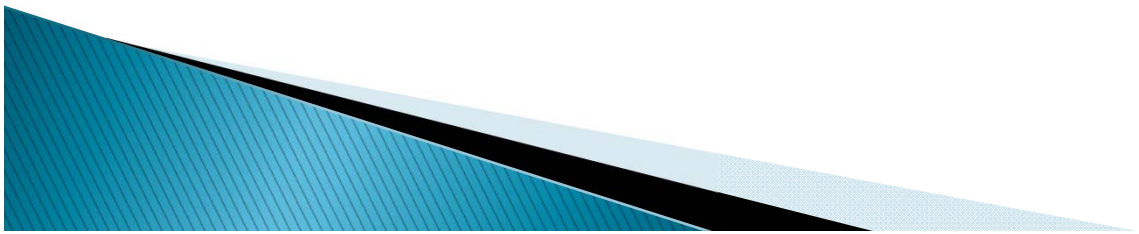
Results

- Have not yet had the chance to do extensive testing
- Appears to be somewhat quirky:
  - Does not yet lock as well as we had hoped
- Improvements:
  - Tweak component values
  - Adjust error signals
  - Better method of combining signals



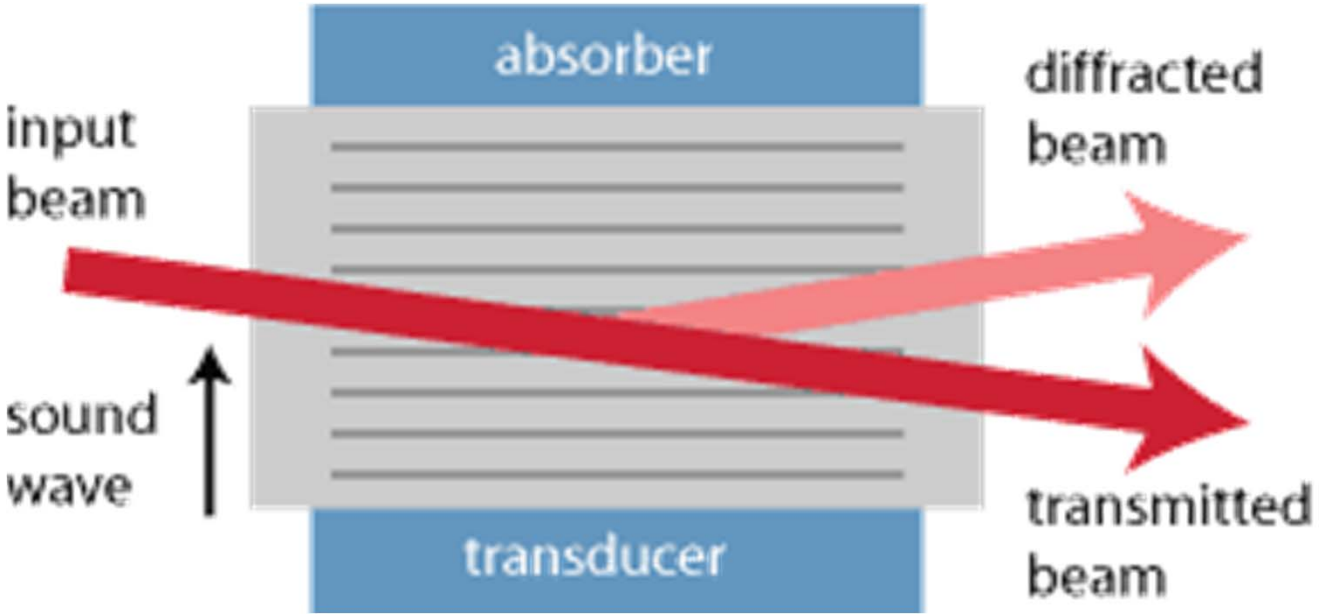
Timing Control

- Need method of controlling multiple acousto-optic modulators for the dual-species MOT
- Interface with National Instruments data acquisition card



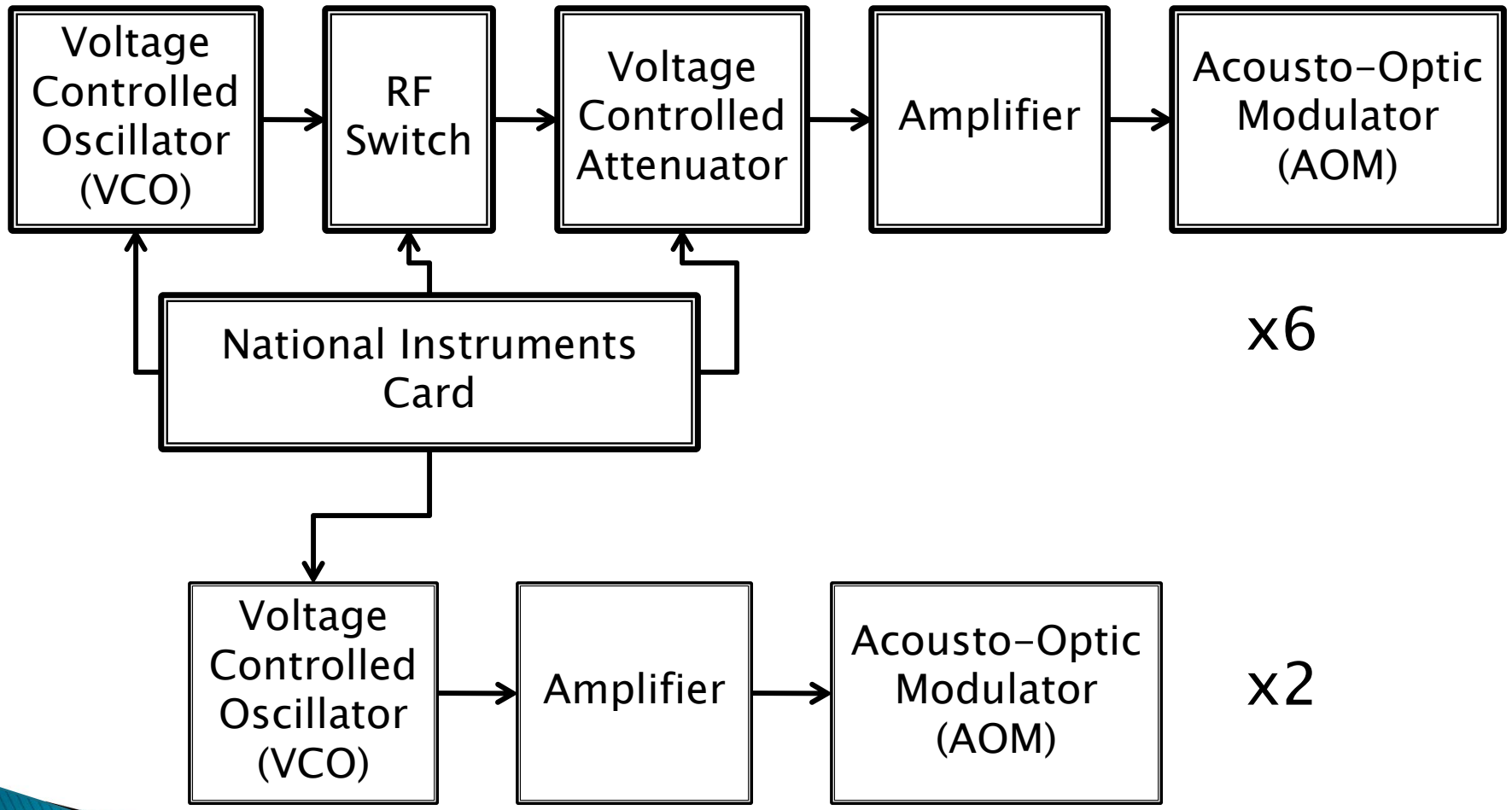
Acousto-Optic Modulator (AOM)

- AOMs are used for:
  - Frequency shifting
  - Fast shutters

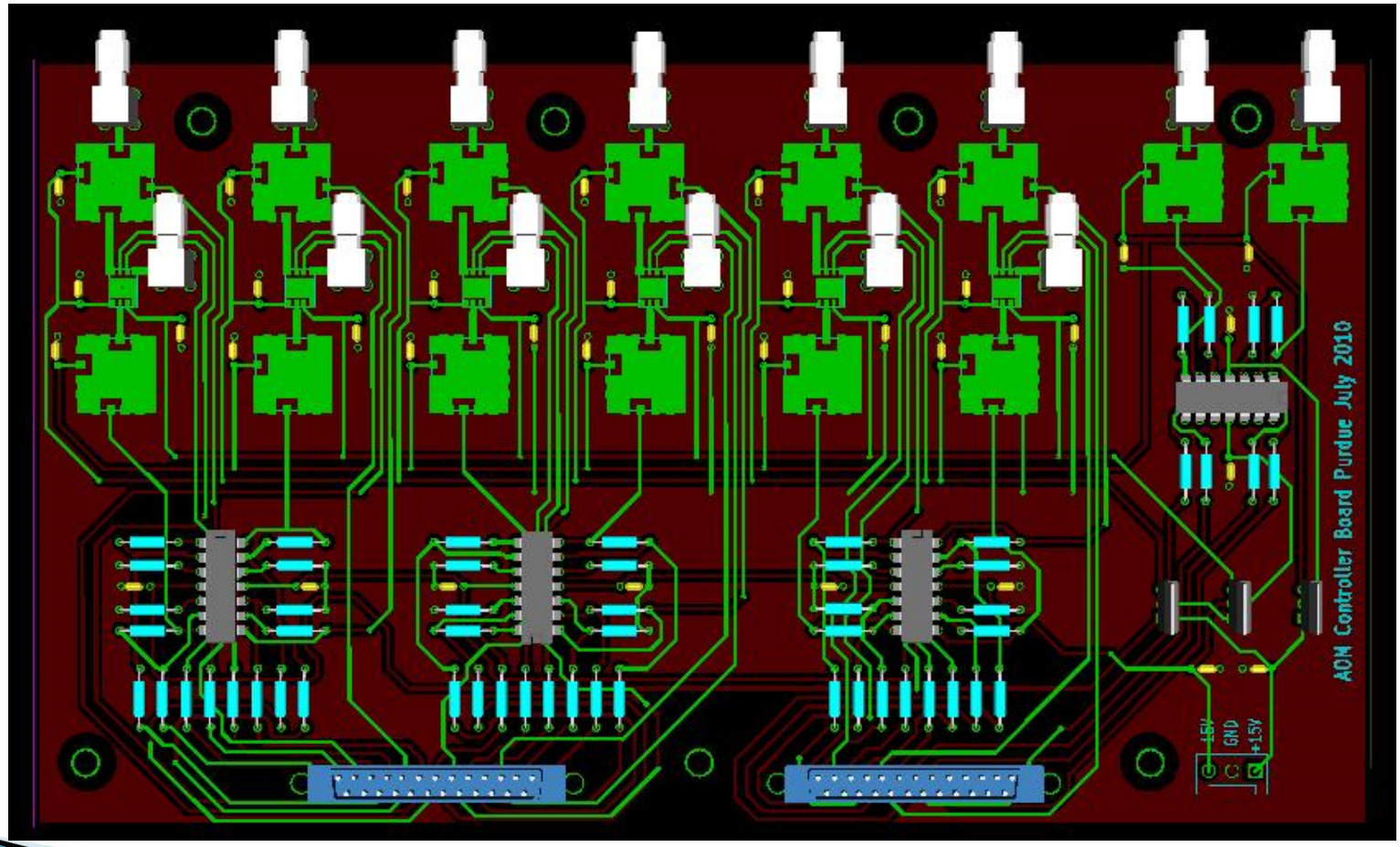


RP Photonics “Acousto-optic Modulators”

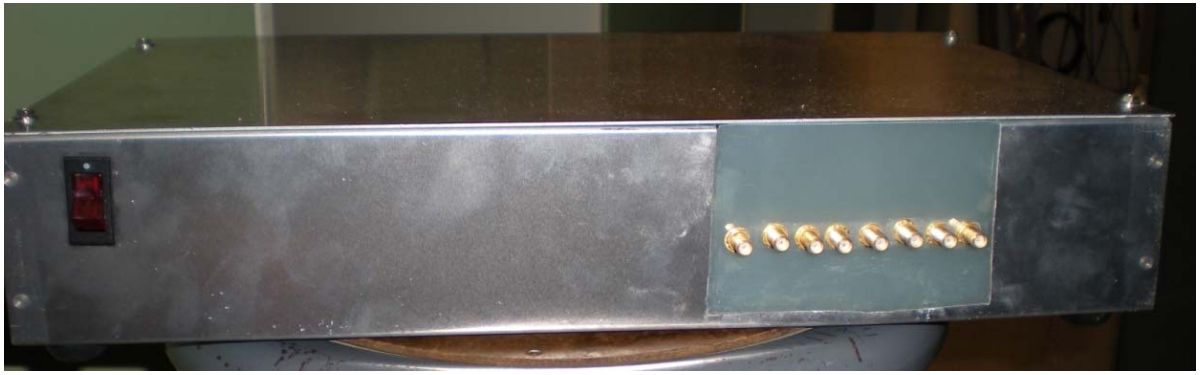
Electronics Setup



AOM Controller Board Layout

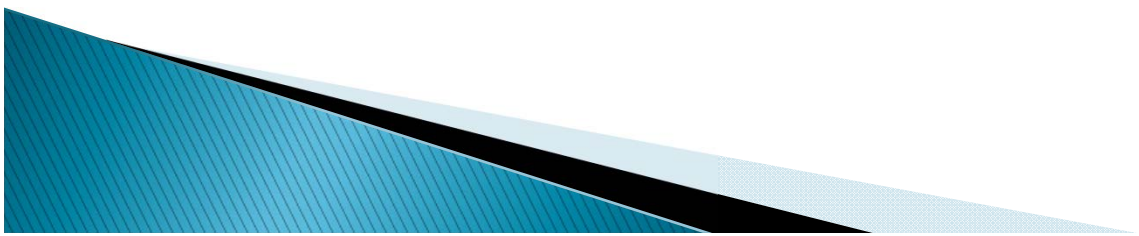


AOM Controller Board Housing



Summary and Conclusion

- My projects involved working on control mechanisms for the dual-species MOT
  - Laser locking circuits
  - AOM controller board



Thank You

- Dr. Daniel S. Elliott
- Dr. Sergei Savikhin
- John Lorenz
- Adeel Altaf
- Dionysios Antypas

¿Questions?