



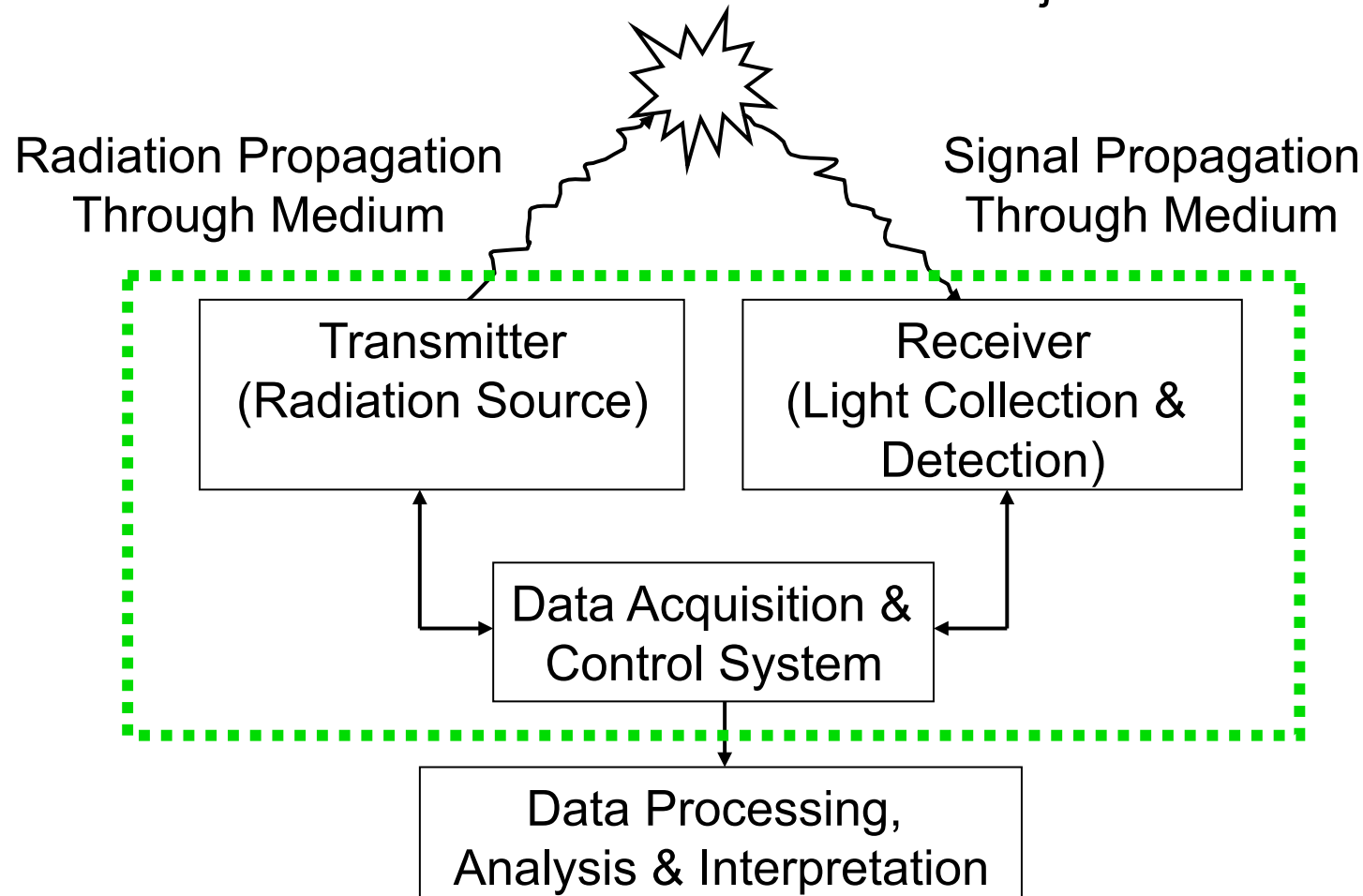
# Lecture 13. Temperature Lidar (3) Resonance Fluorescence Doppler Lidar Instrumentation

- ☐ Introduction
- ☐ Classic Na Doppler Lidar
- ☐ Solid-State Na Doppler Lidar
- ☐ Solid-State K Doppler Lidar
- ☐ Solid-State Fe Doppler Lidar
- ☐ Summary



# Introduction

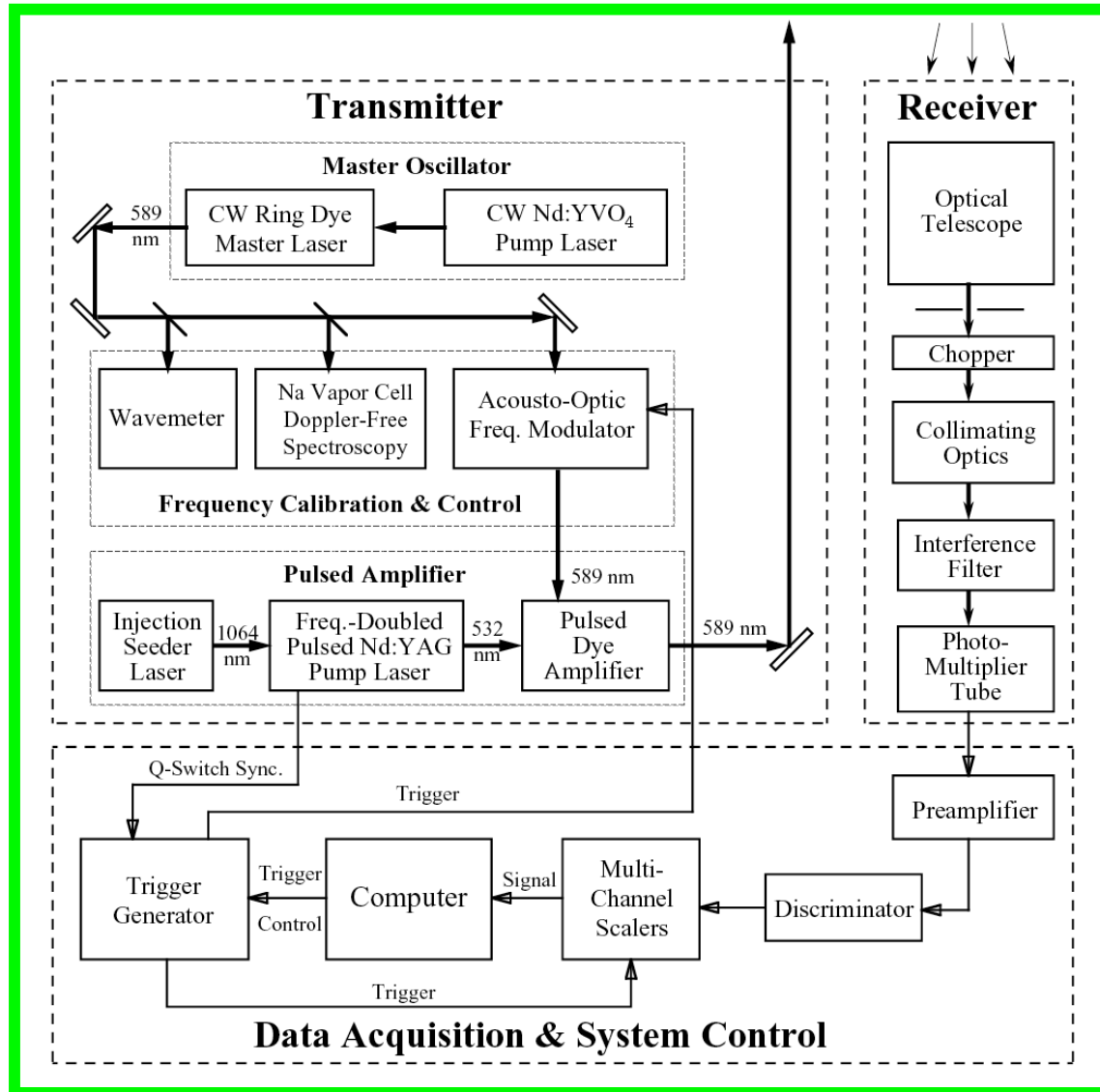
Interaction between radiation and objects



❑ Resonance Doppler lidar has the frequency discriminator in atmosphere - atomic absorption lines!  $\Rightarrow$  Narrowband transmitter, broadband receiver.  $\Rightarrow$  High signal levels and accurate knowledge on the frequency discriminator!<sup>2</sup>

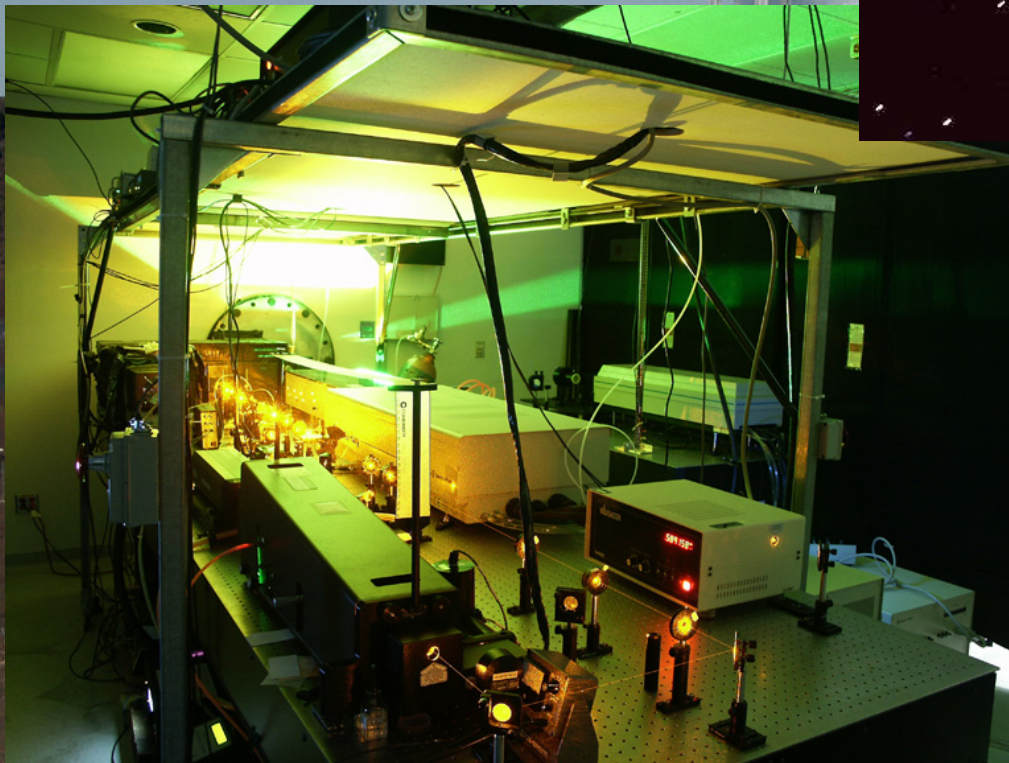


# Classic Na Doppler Lidar



Dye-laser-based Na wind and temperature Lidar  
(See textbook Chapter 5 by Chu and Papen, 2005)

# Large-Aperture Na Doppler Lidar



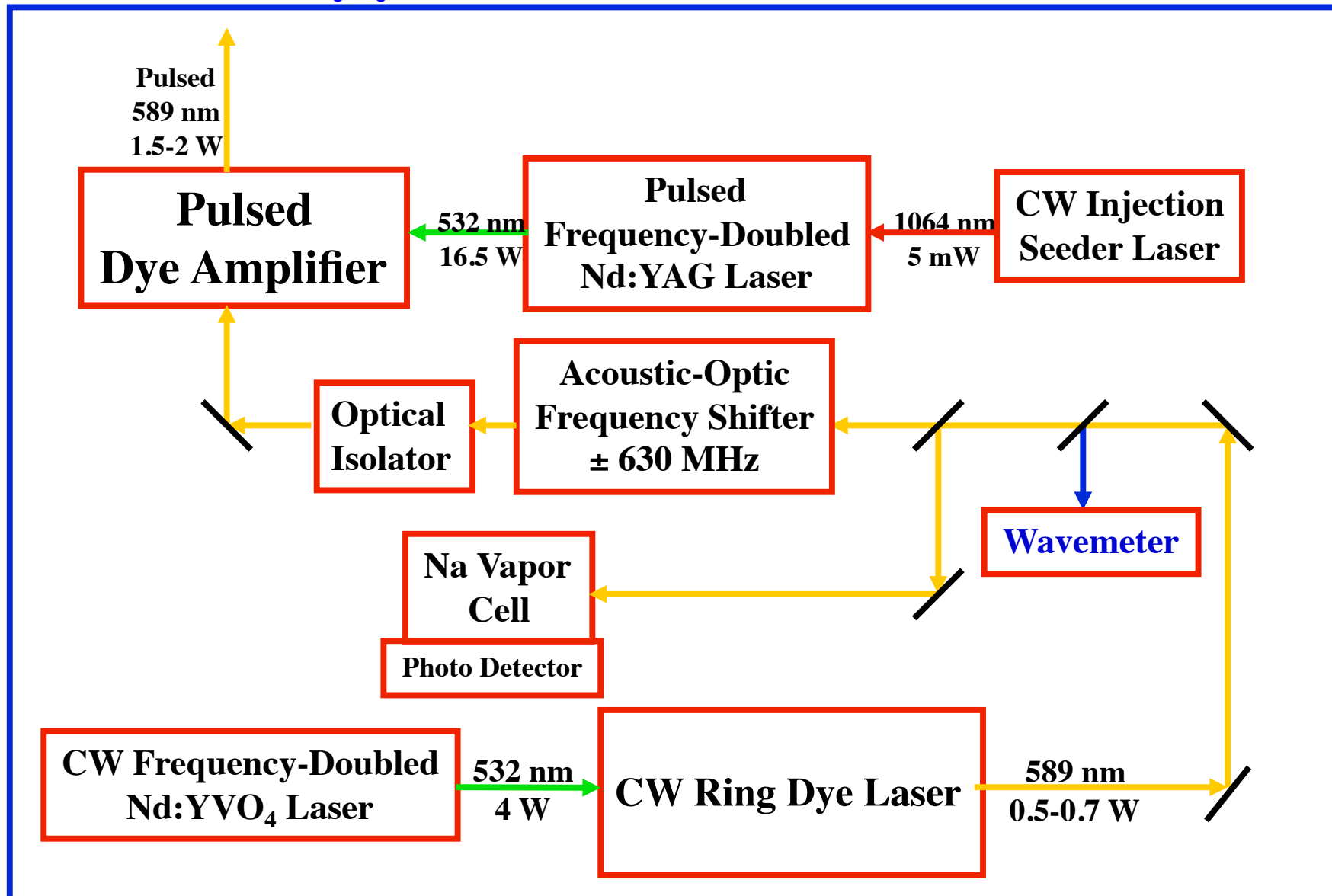
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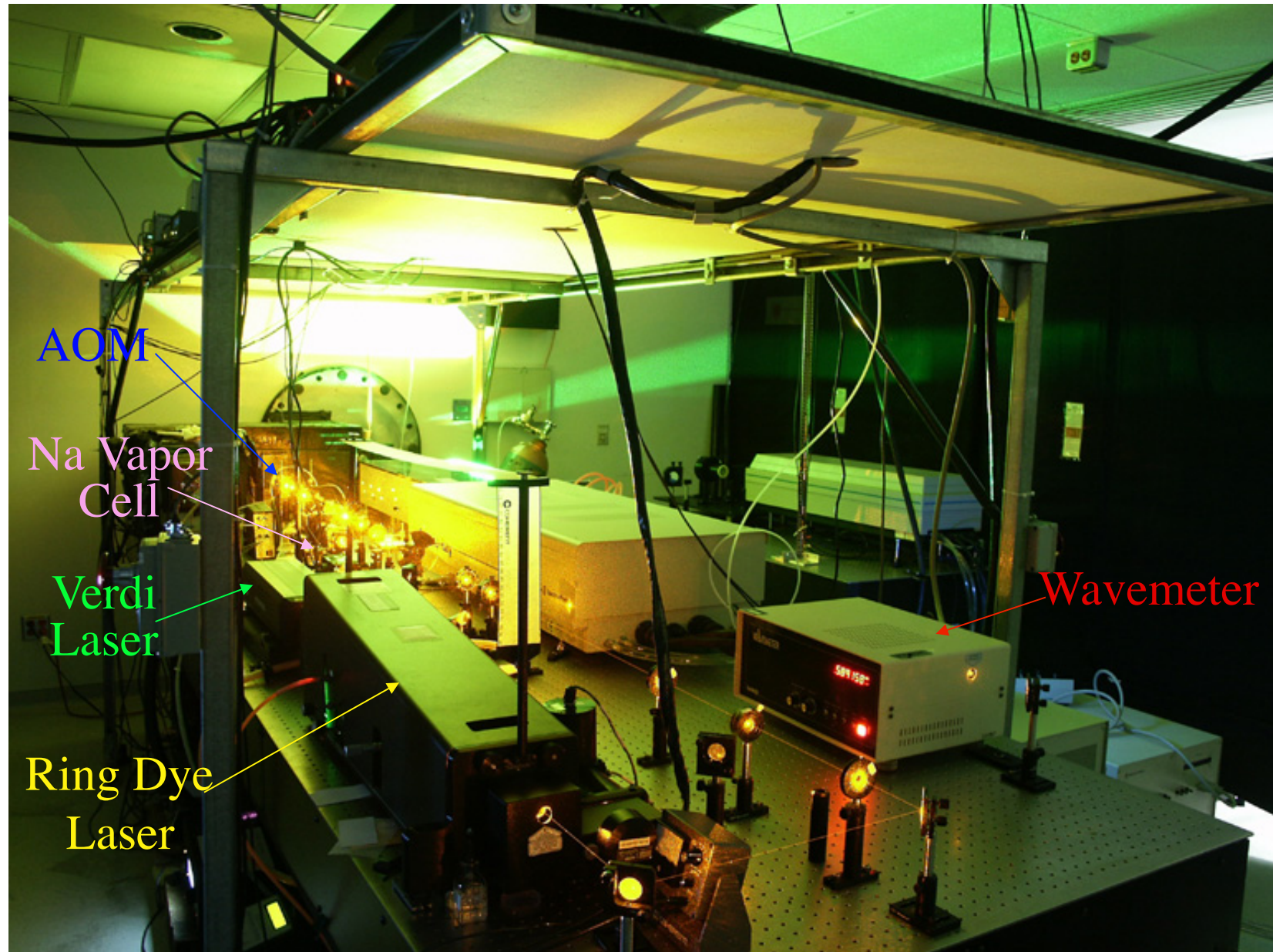


# Na Doppler Lidar Transmitter





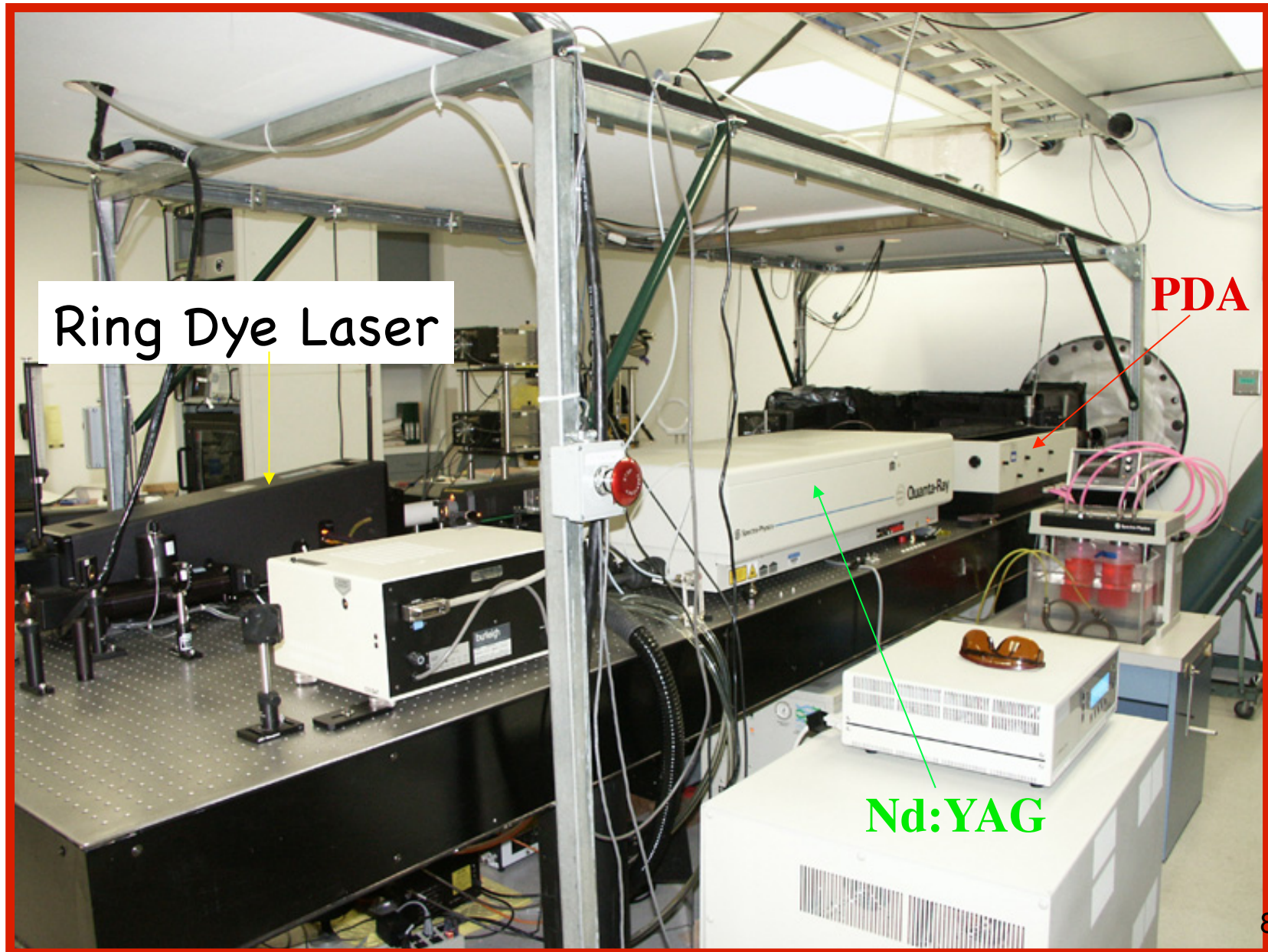
# Na Lidar Transmitter Photo 1







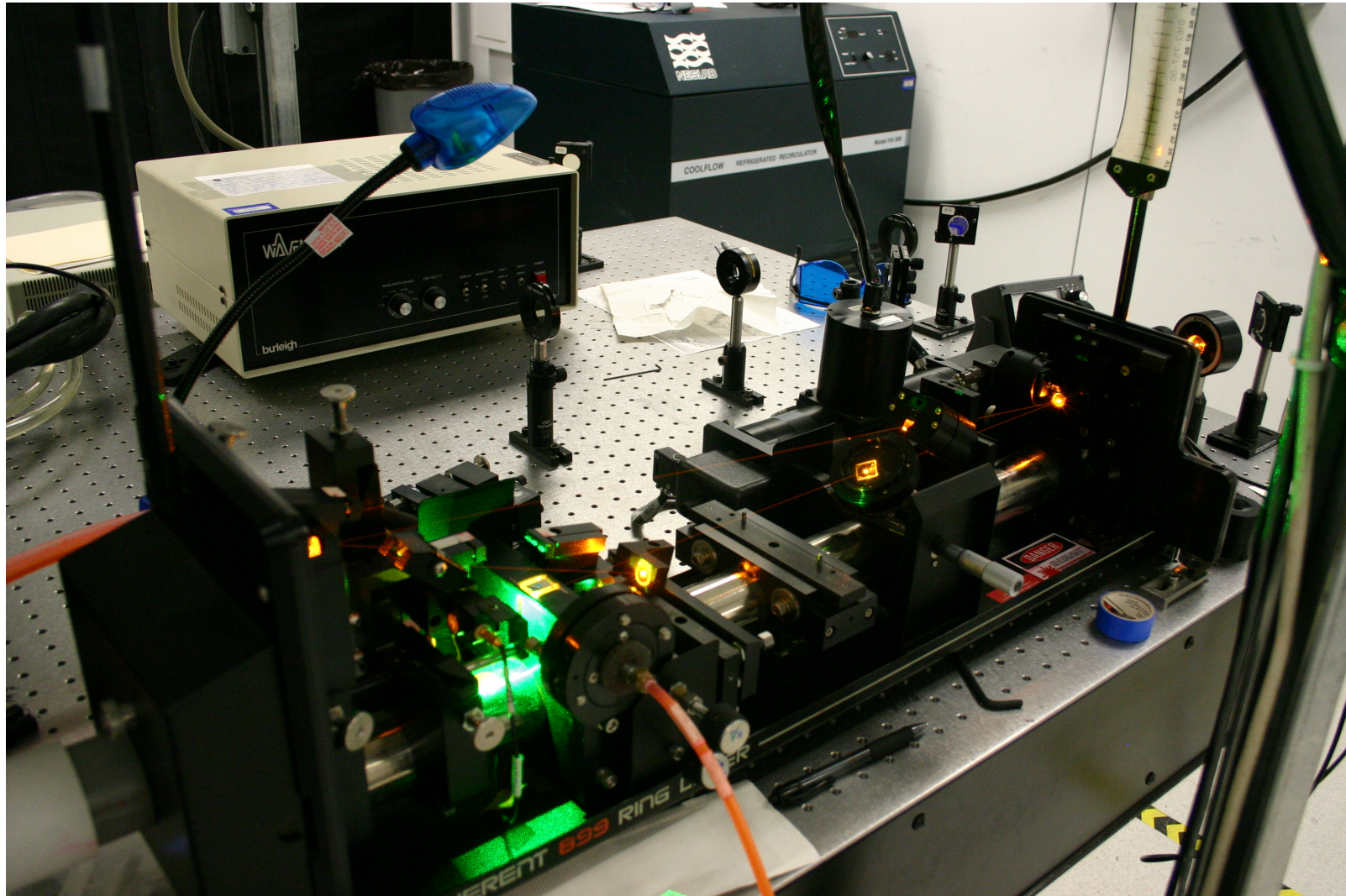
# Na Lidar Transmitter Photo 2





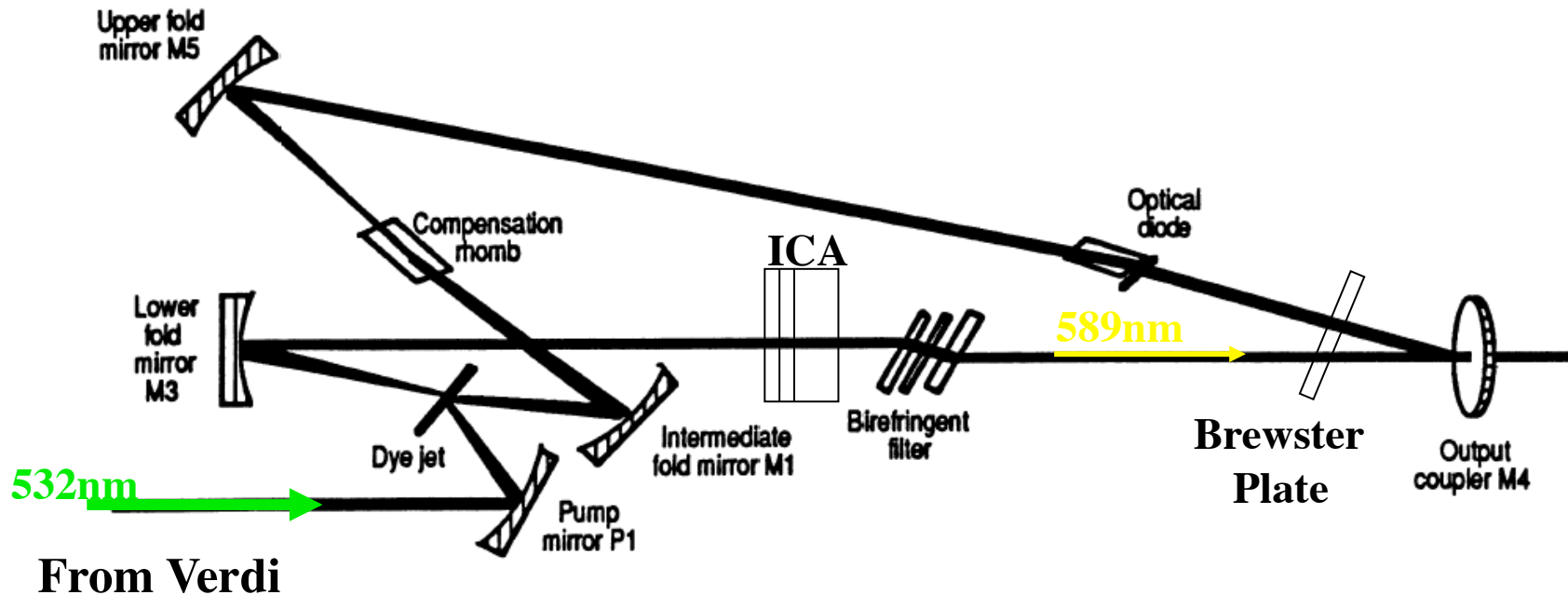


# Ring Dye Laser





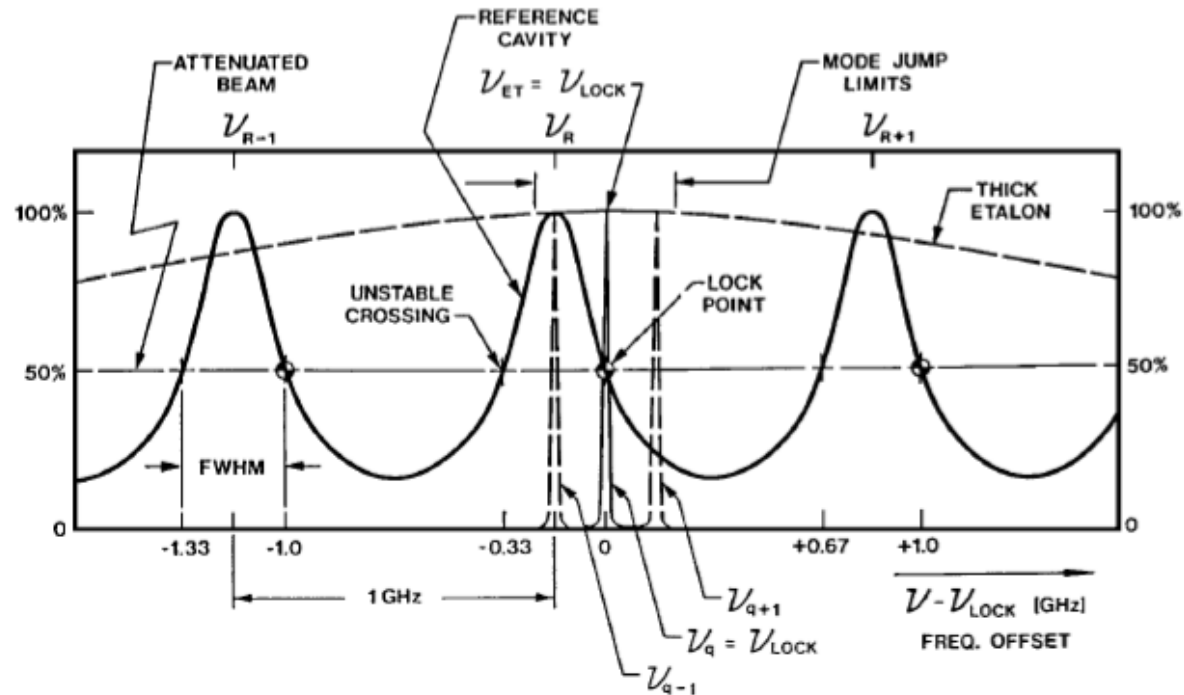
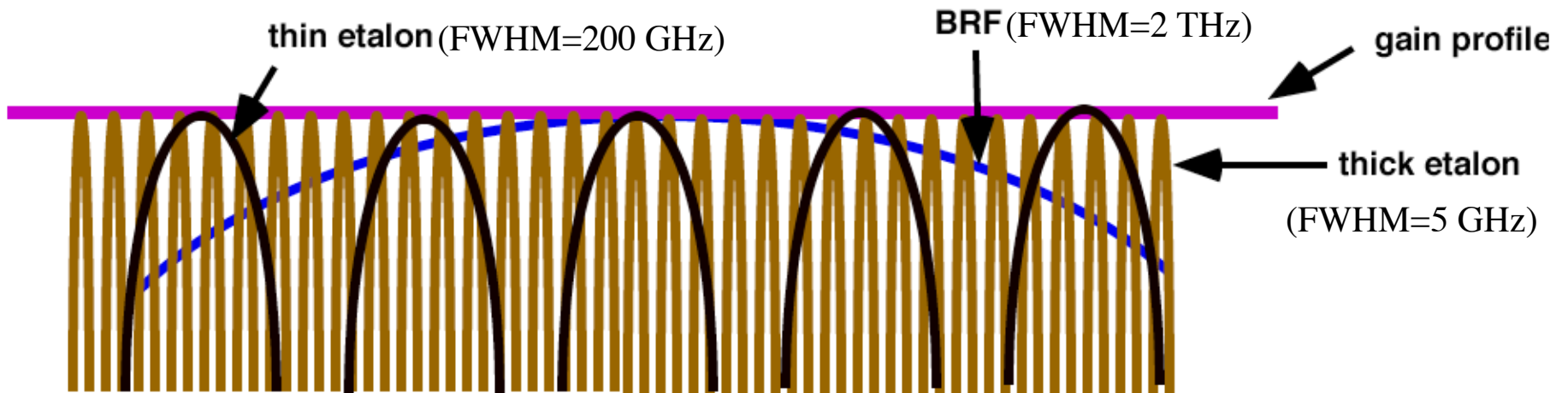
# Ring Dye Laser



1. “Four mirror + Dye jet” form the laser resonance cavity.
2. Unidirectional lasing prevents spatial hole-burning.
3. Rhomb compensates the astigmatism effect.
4. Optical diode forces the unidirectional lasing.
5. BRF + ICA (etalons) select frequency and narrow bandwidth.
6. “Brewster plate + RCA + M3 PZT” actively control frequency.

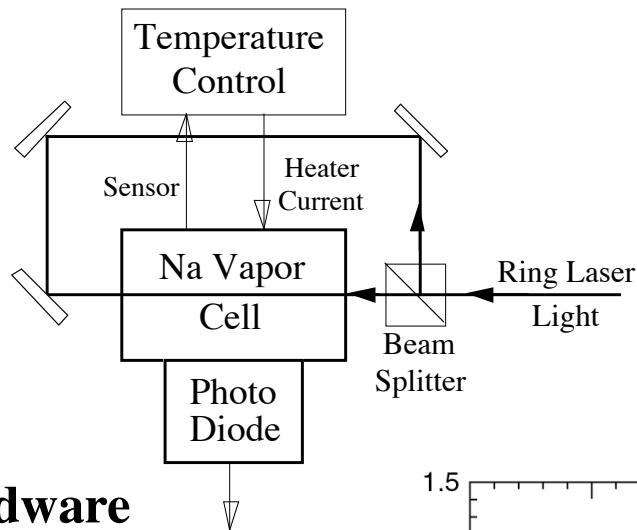


# Frequency Selection in Ring Laser

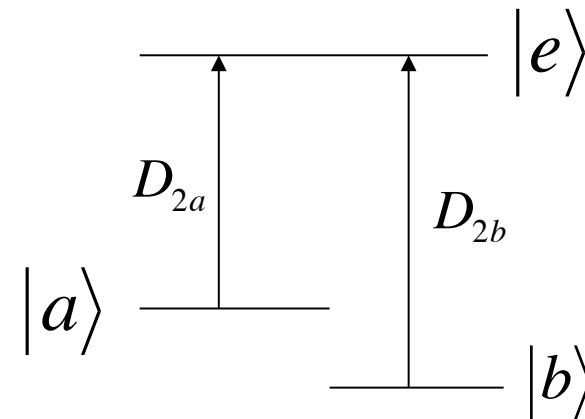




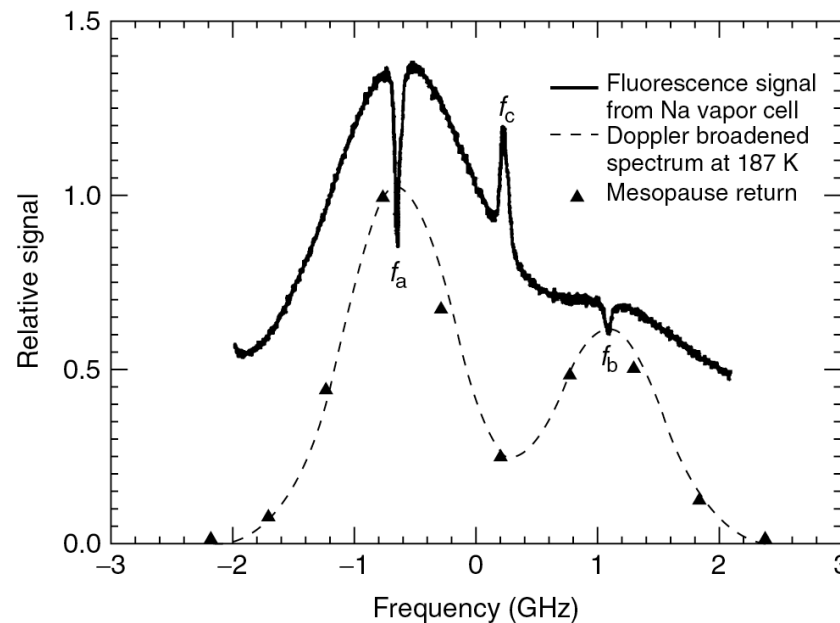
# Na Doppler-Free Spectroscopy & Laser Frequency Lock



**Hardware**



**3-Level  
Explanation**

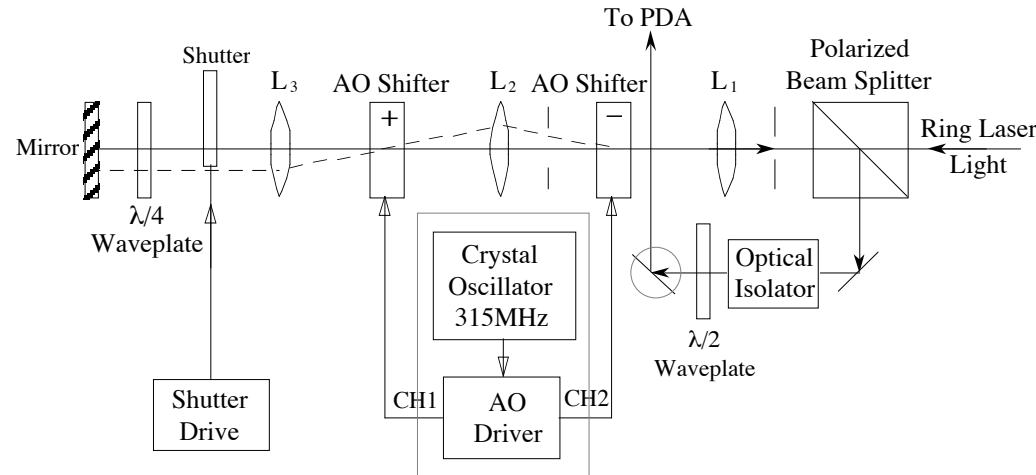




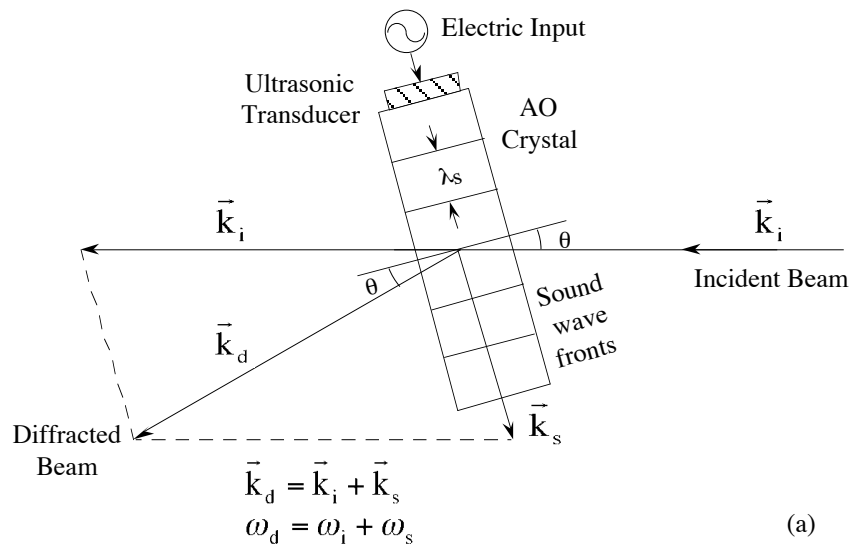


# Acousto-Optical Modulator

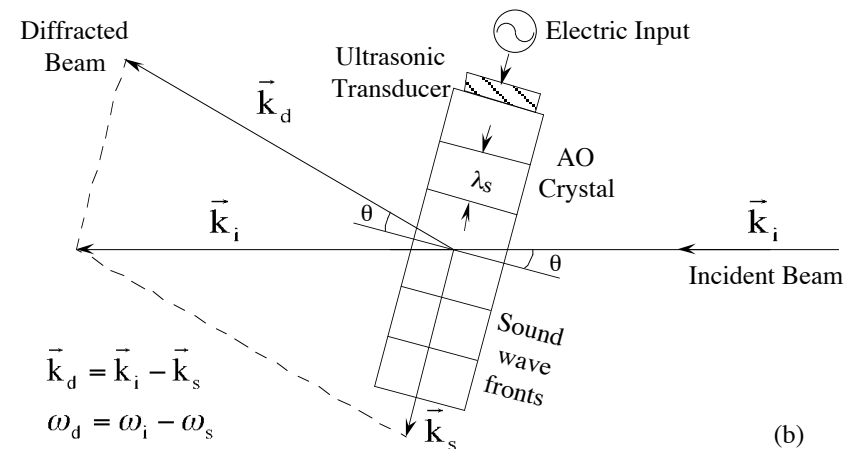
## Hardware



## Explanation: Doppler shift or Photon/Phonon Annihilation



(a)

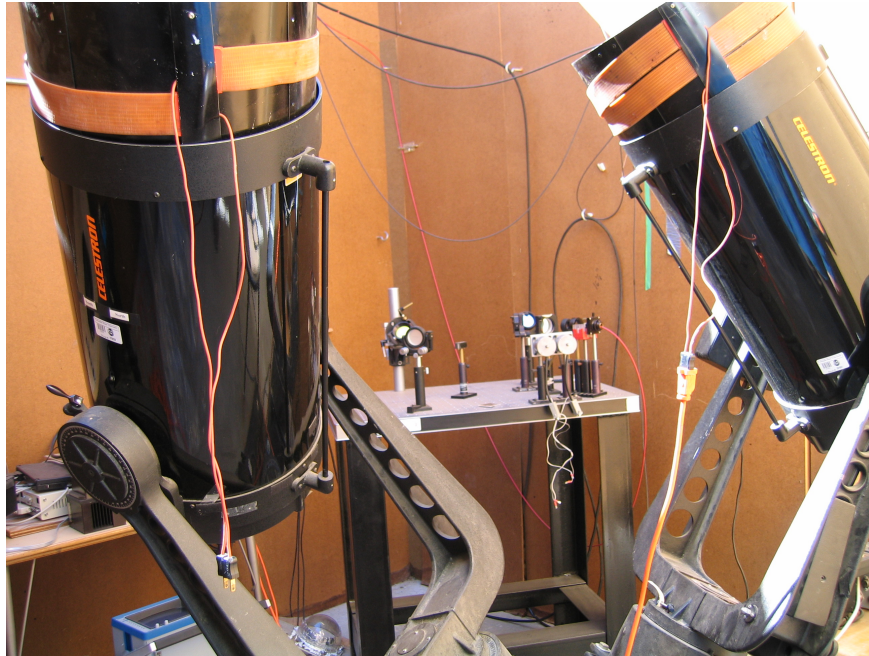


(b)

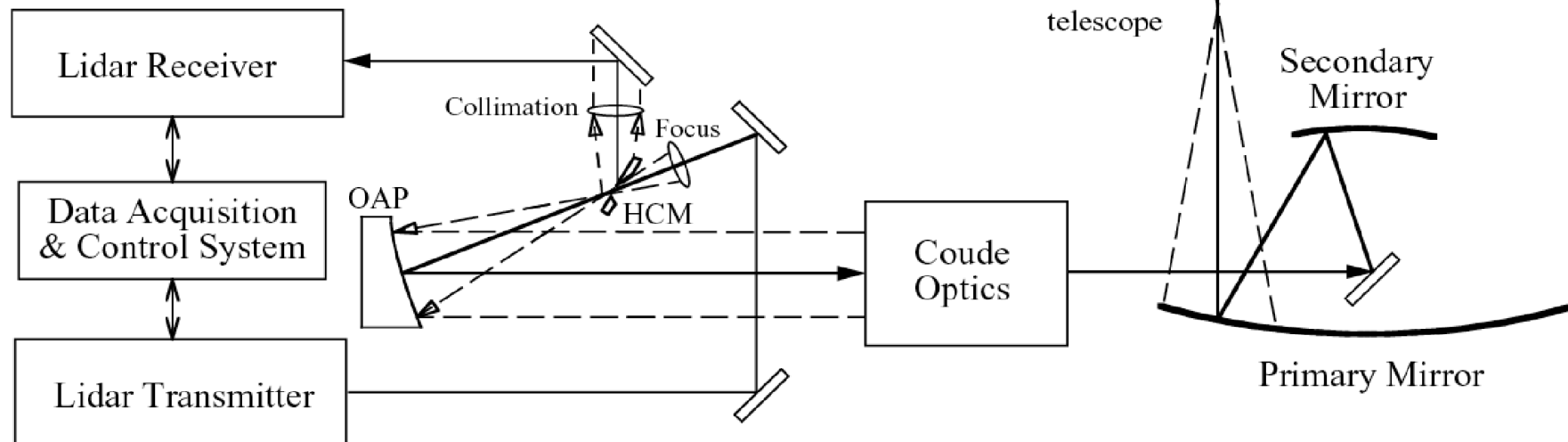




# Na Doppler Lidar Receiver



CSU Multibeam Receiver  
With Fiber coupling



**UIUC Large-Aperture Steerable Na Doppler Lidar**

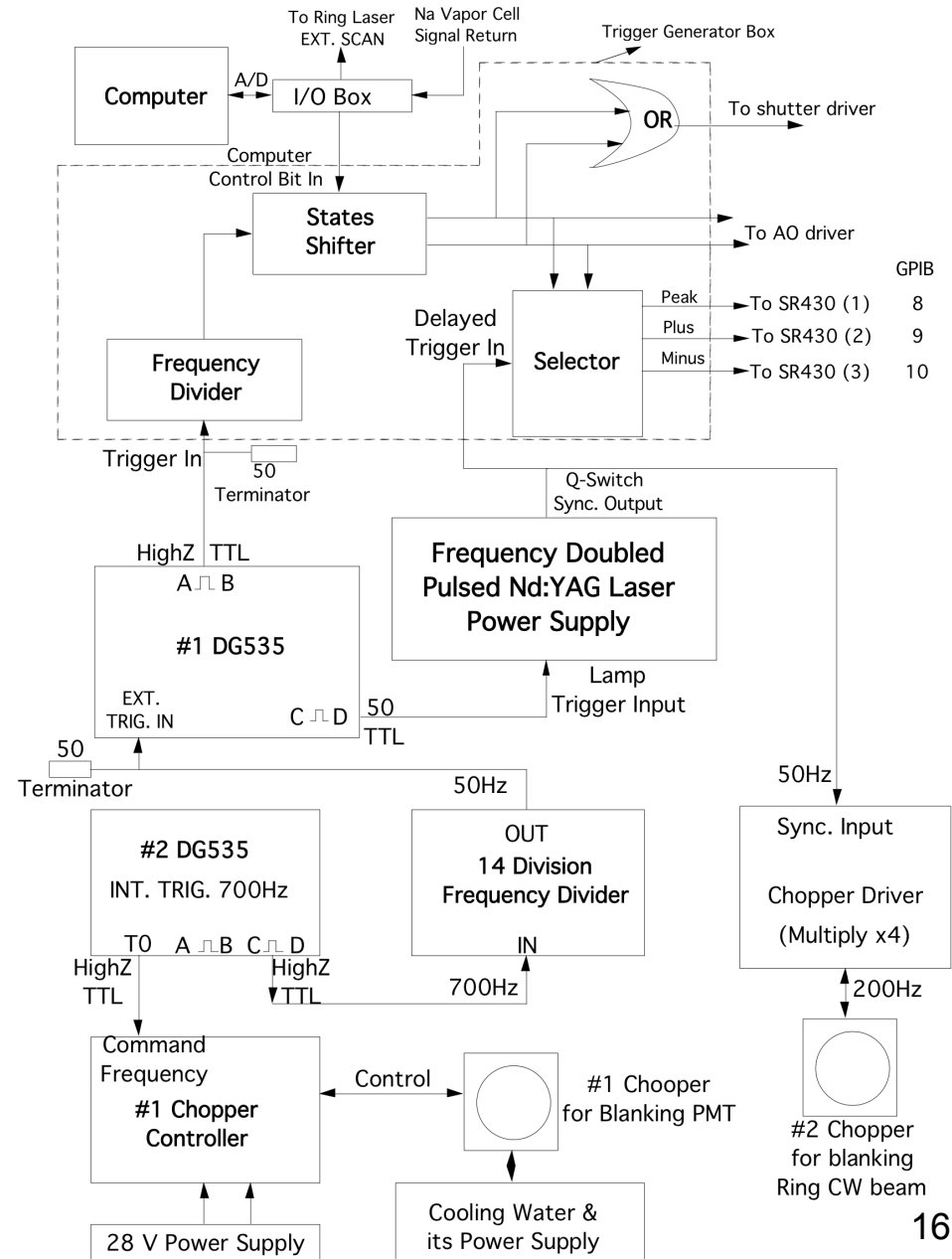


# Na Doppler Lidar Control System and Data Acquisition

## Recent improvements:

- 1) Seed laser frequency locking: phase-sensitive
- 2) Computer-card based multichannel scalars
- 3) High-QE PMTs (but issues with max cnt rate)
- 4) Self-made larger aperture telescope
- 5) LabVIEW-based DAQ
- 6) Daytime capability ...

Connection of Na Wind/Temperature Lidar System at MSSC

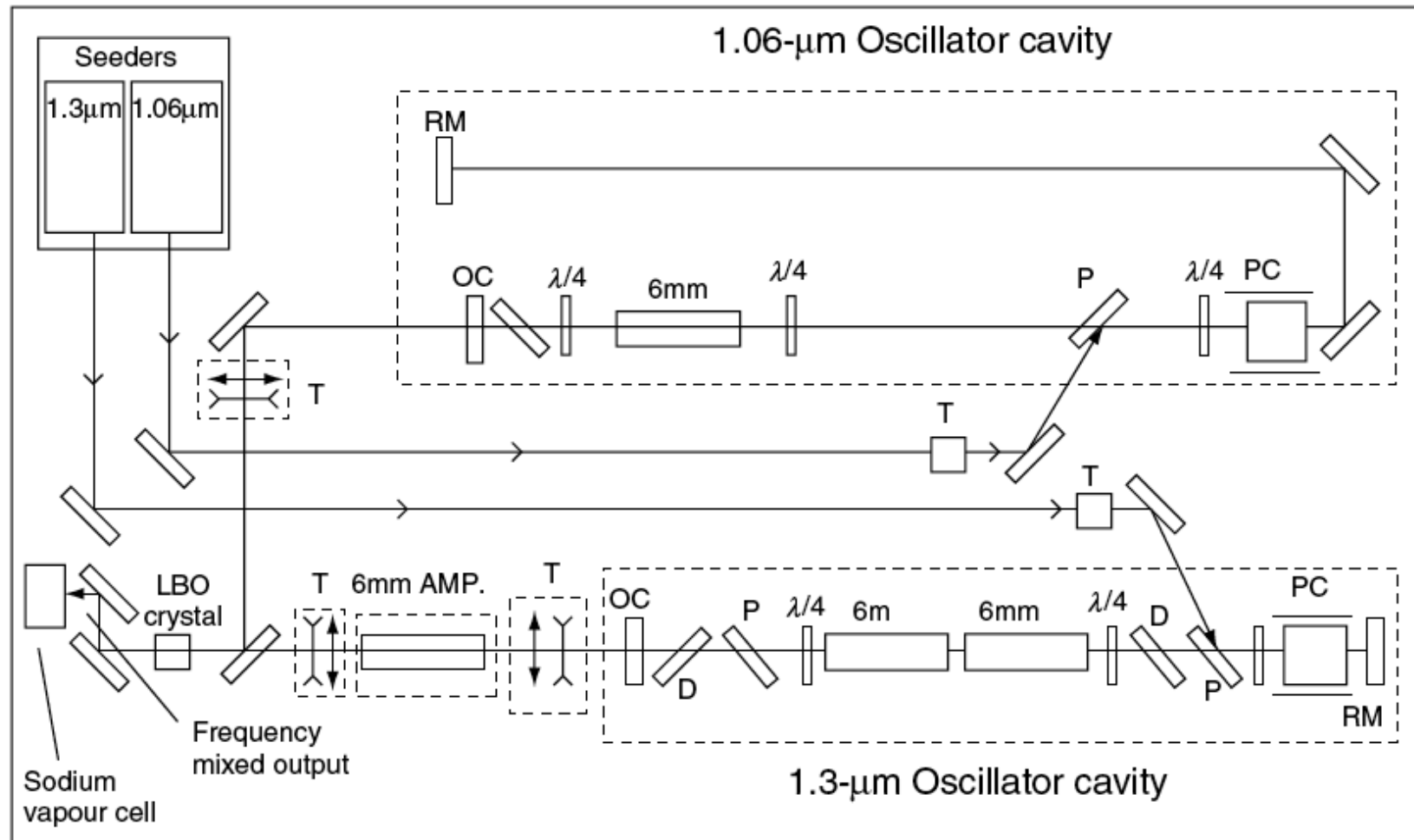






# Solid-State Na Doppler Lidar

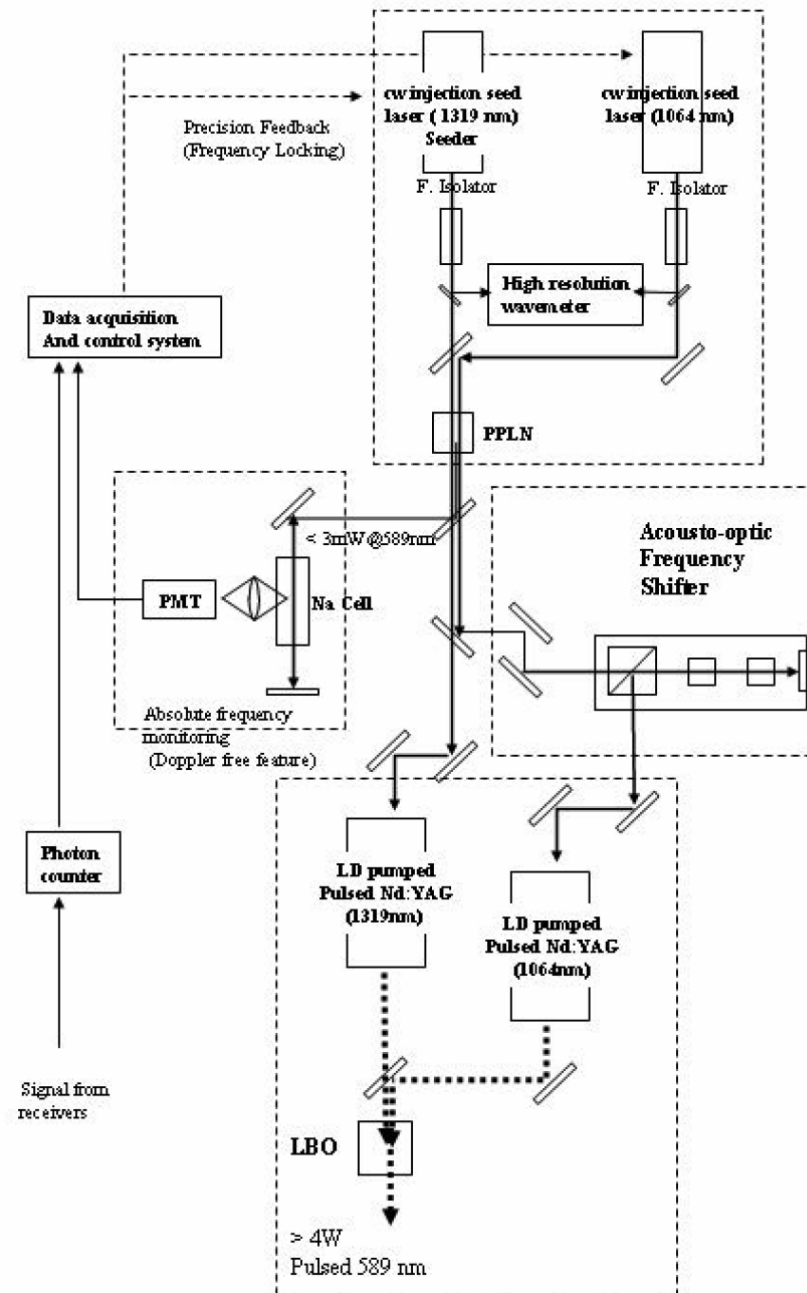
❑ Japanese Shinshu system by Kawahara et al.: Frequency mixing of two Nd:YAG lasers at 1064 and 1319 nm





# Solid-State Na Doppler Lidar Based on Diode-Laser- Pumped Nd:YAG Lasers

[Kawahara et al.,  
ILRC, 2008]



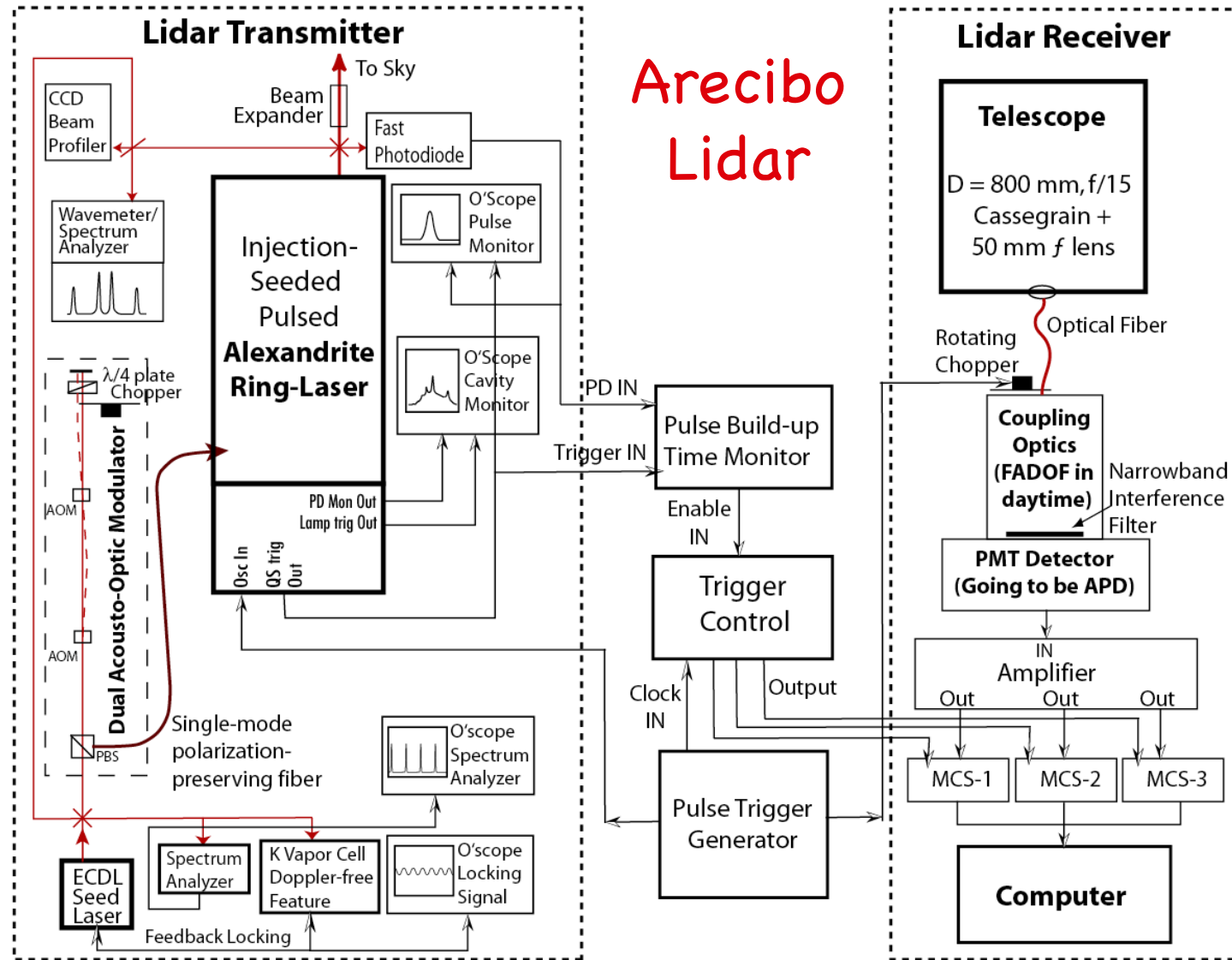


# Options for Na Doppler Lidar

- ❑ Conventional: Ring Dye Laser + PDA
- ❑ Hybrid: Solid-state cw 589nm source + PDA
  - CW Nd:YAG lasers SFG (1064 and 1319 nm)
  - CW fiber lasers SFG (1583 and 938 nm)
  - Raman shifted fiber laser SHG (1178 nm)
- ❑ Full solid-state pulsed 589nm laser
  - Flashlamp pumped Nd:YAG lasers SFG
  - Diode-laser pumped Nd:YAG laser SFG
  - Other laser options
- ❑ Solid-state cw 589nm laser + pseudorandom modulation or cw 589nm laser + bistatic configuration



# K Doppler Lidar Instrumentation

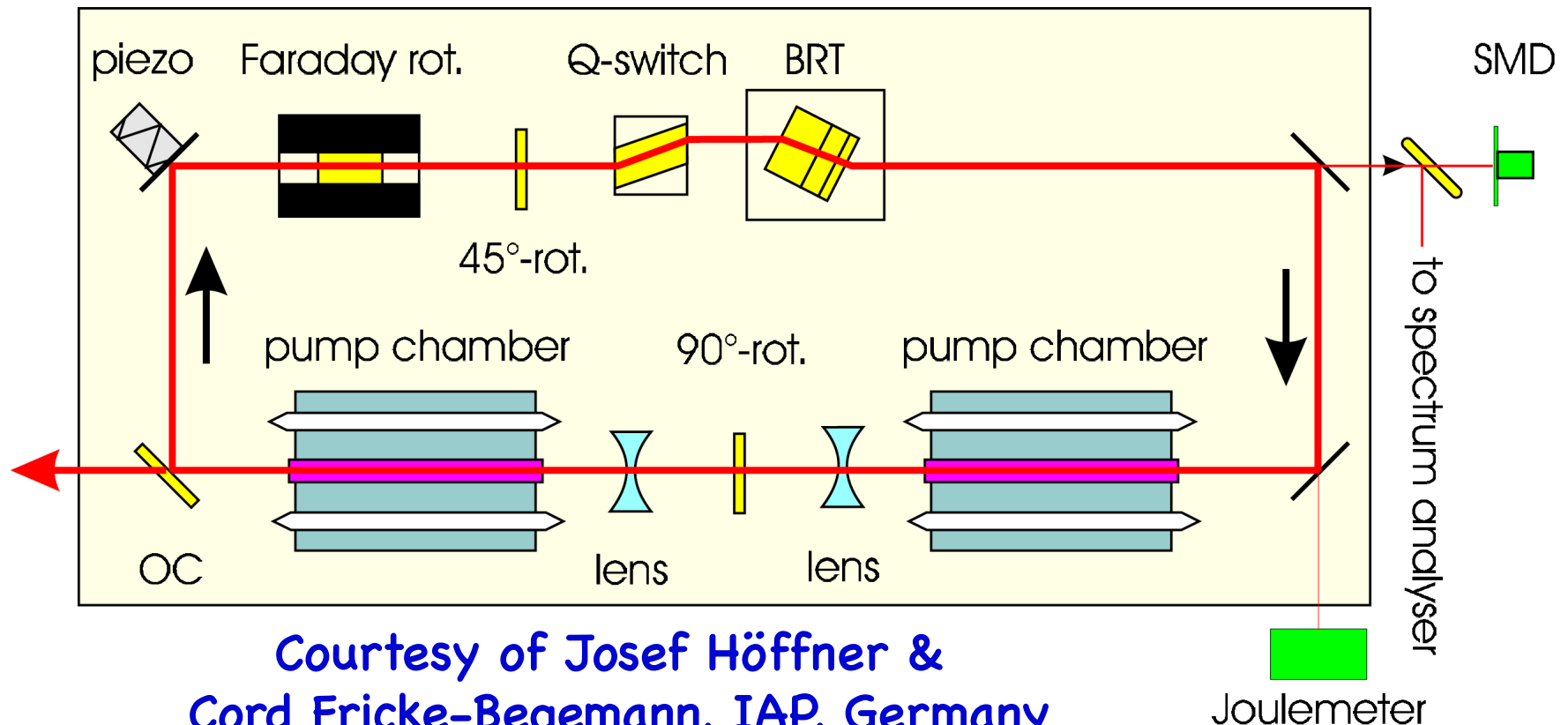


[Friedman and Chu, JGR, 2007]





# IAP Scanning K Doppler Lidar

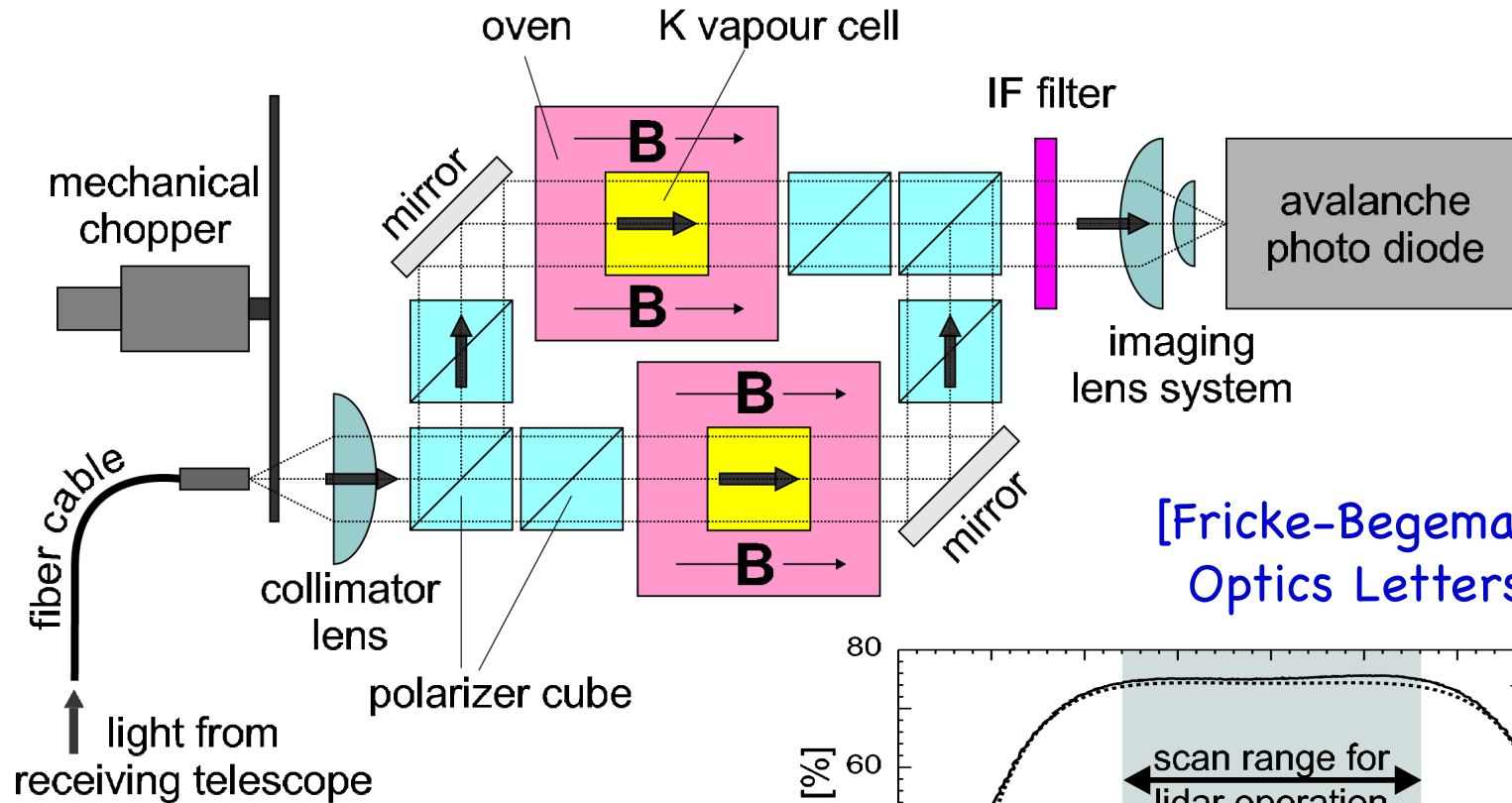


Courtesy of Josef Höffner &  
Cord Fricke-Begemann, IAP, Germany

- ❑ Based on Light Age, Inc. pulsed alexandrite ring laser, but IAP engineers performed significant in-house development and upgrade.
- ❑ The laser frequency is scanned in about 18 channels for temperature-only measurements in MLT region.

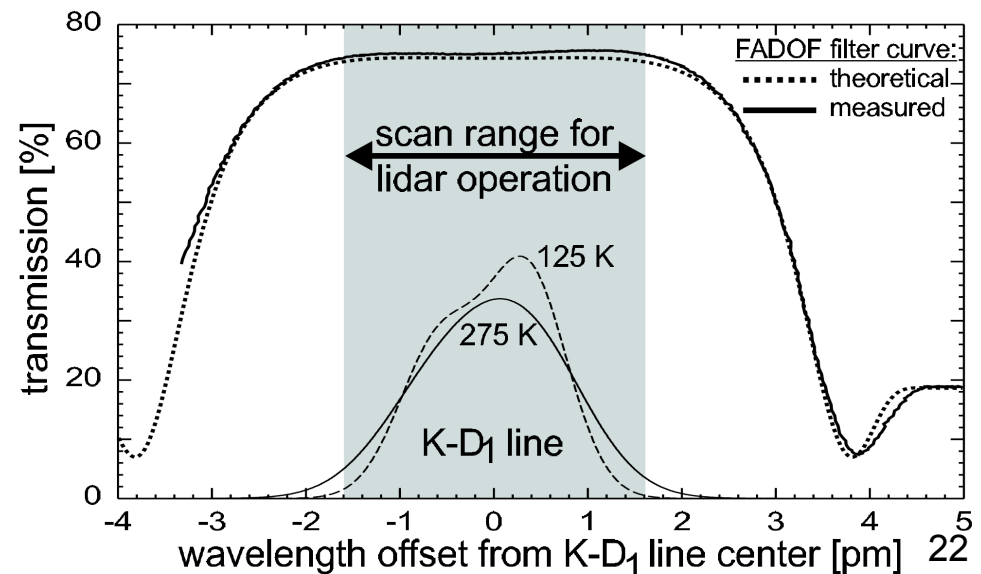


# Dual K-Faraday Filter



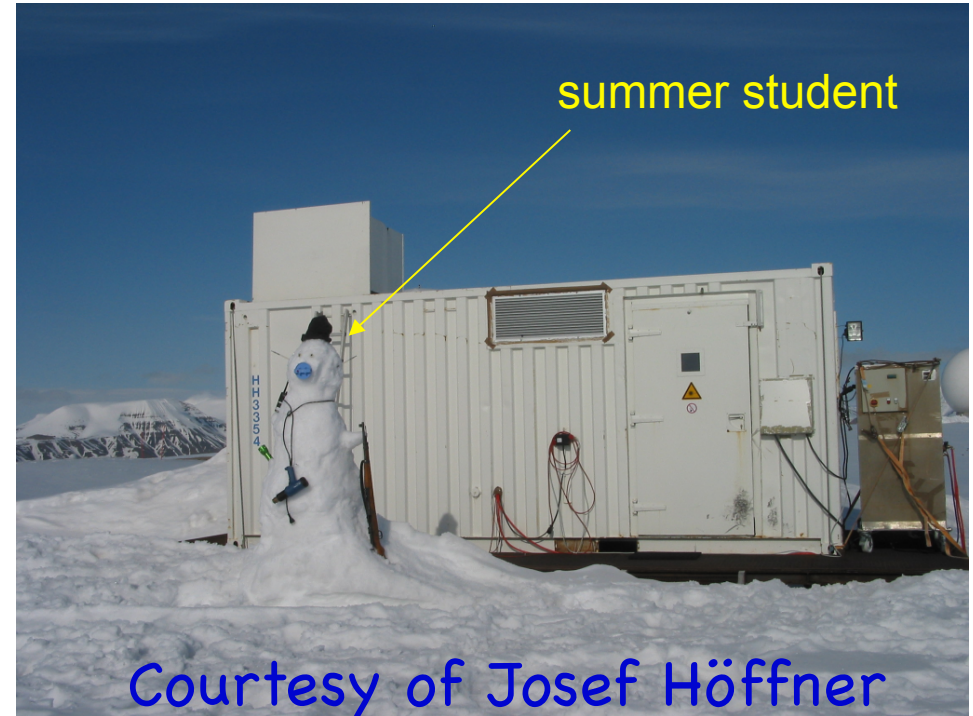
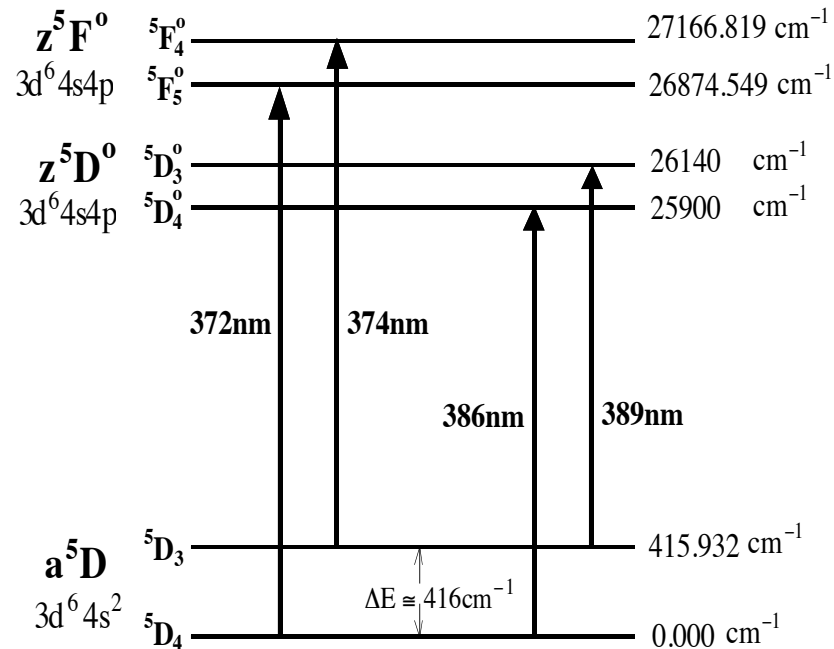
[Fricke-Begemann et al.,  
Optics Letters, 2002]

□ Due to closer spacing of  $D_{1a}$  and  $D_{1b}$ , the K Faraday filter can be made nearly flat in the range we care.





# IAP Scanning Fe Doppler Lidar



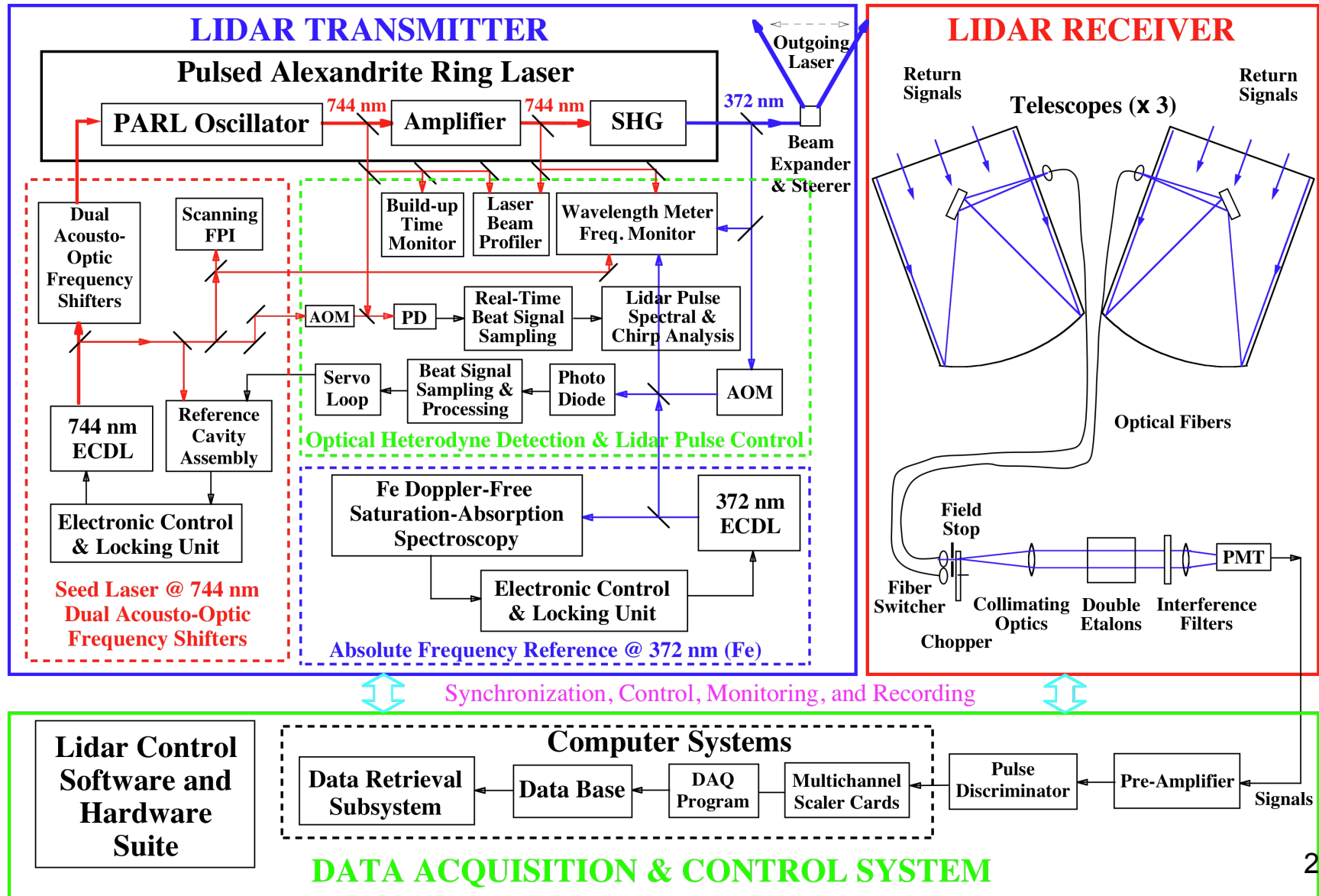
❑ IAP pulsed alexandrite ring laser was tuned from 770 nm to 772 nm, and then frequency doubled to probe the 386-nm Fe absorption line for temperature measurements with scanning technique developed for K Doppler lidar.

❑ Superior performance over K lidar due to Fe abundance, ..<sup>23</sup>



# MRI Fe Doppler Lidar

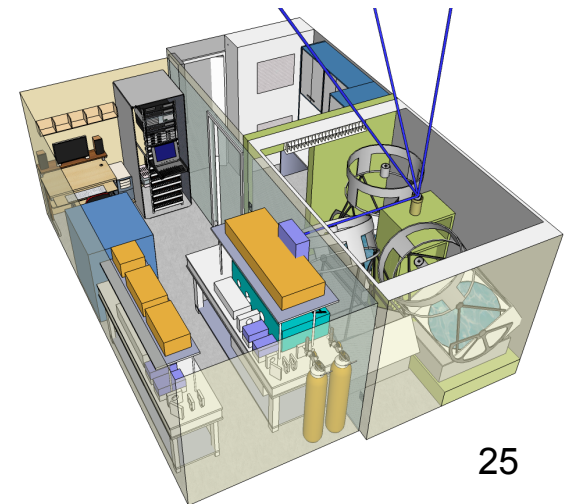
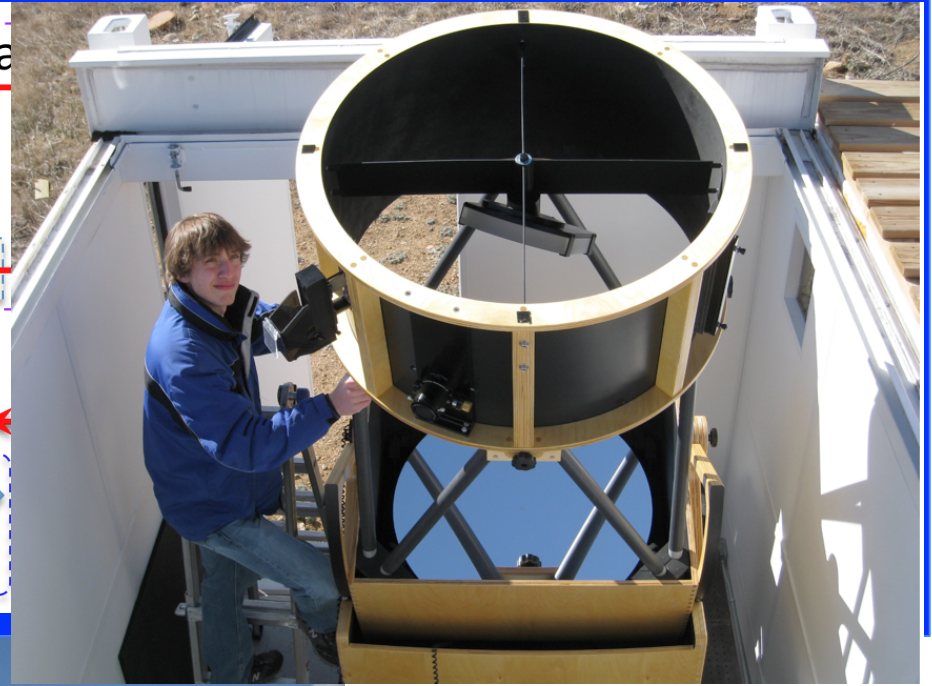
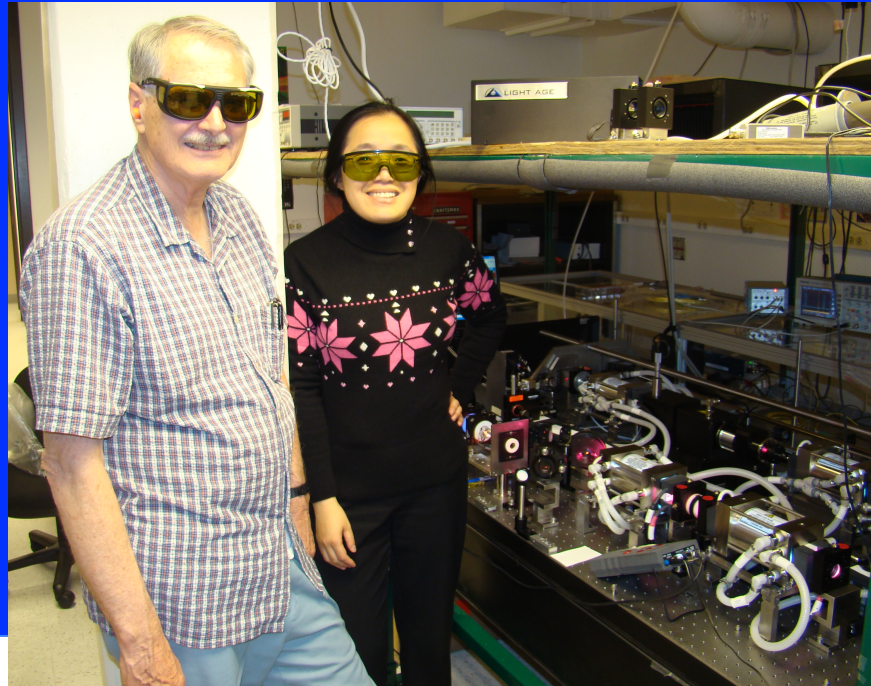
[Chu et al., ILRC, 2010]







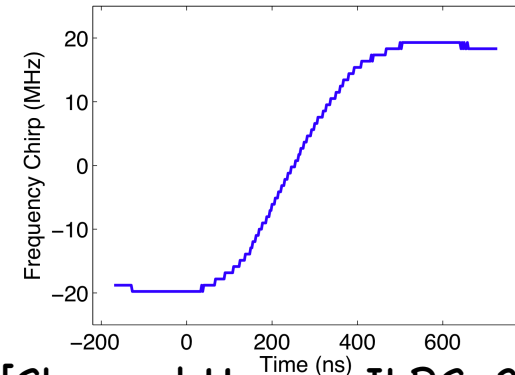
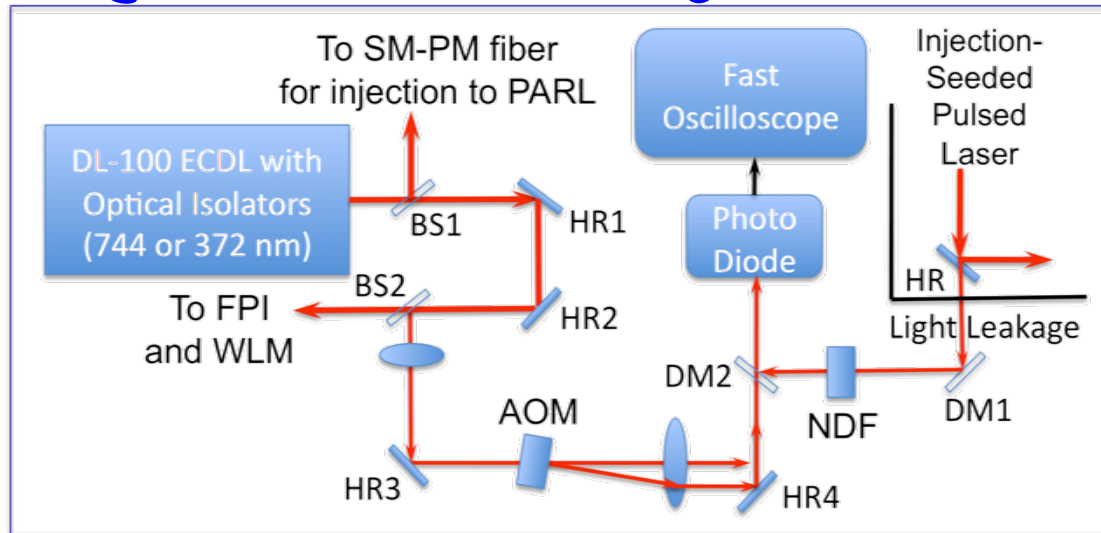
# Mobile MRI Fe Doppler Lidar



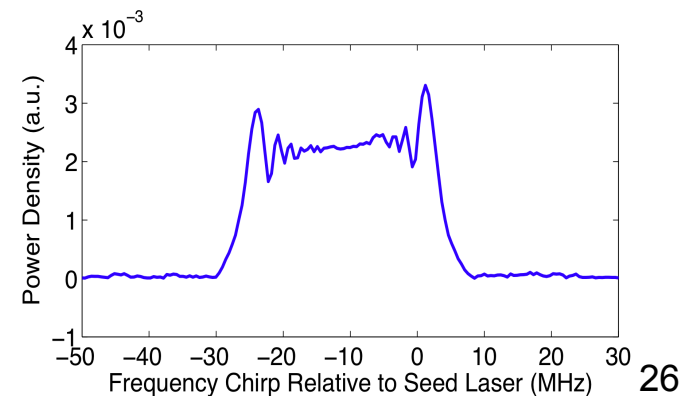
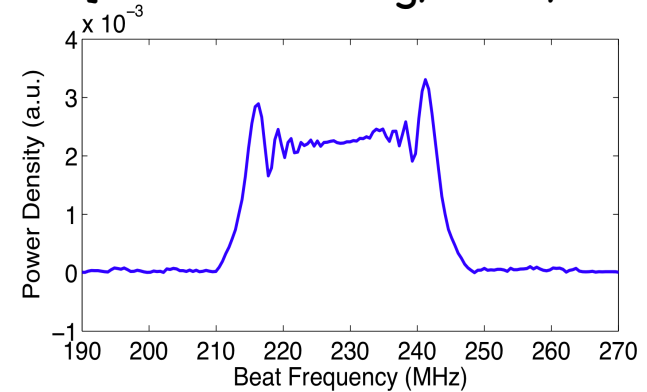
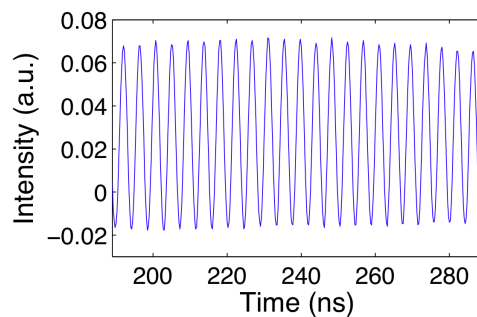
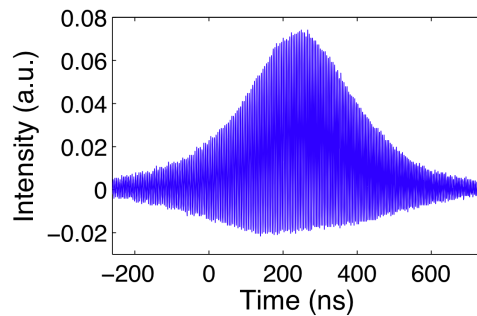




# Optical Heterodyne Detection of Laser Pulse



[Chu and Huang, ILRC, 2010]





# Summary (1)

- ❑ Currently state-of-the-art Na Doppler lidar is the dye-laser-based Na wind and temperature lidar - “ring dye laser + pulsed dye amplifier” configuration.
- ❑ One main feature is the narrowband Na lidar transmitter with precise frequency control and narrow laser linewidth: Na Doppler-free fluorescence spectroscopy for frequency calibration and locking, acousto-optic frequency modulator for generating two wing frequencies with high stability and fast switching, pulsed amplification with very low ASE.
- ❑ The lidar receiver (broadband) and DAQ subsystems have various styles and forms. They are also progressing rapidly.
- ❑ Na Doppler lidar can be realized with other laser configurations, e.g., solid-state Nd:YAG laser frequency mixing, or alexandrite laser Raman shift, etc.



## Summary (2)

- ❑ There are several different atomic species originating from meteor ablation in the mesosphere and lower thermosphere (MLT) region. They all have the potentials to be tracers for resonance fluorescence Doppler lidars to measure the temperature and wind in MLT region.
- ❑ Na and K Doppler lidars are currently near mature status and are making great contributions to MLT science.
- ❑ Fe Doppler lidar has very high potential due to the high Fe abundance, advanced alexandrite laser technology, Fe Doppler-free spectroscopy, optical heterodyne detection technology, and bias-free measurement, etc.
- ❑ Solid-state Doppler lidars are demanded for science advancement, e.g., space exploration, although dye-laser-based Na Doppler lidar is still the golden standard for now. New Doppler lidar will surpass the classic Na lidar soon!