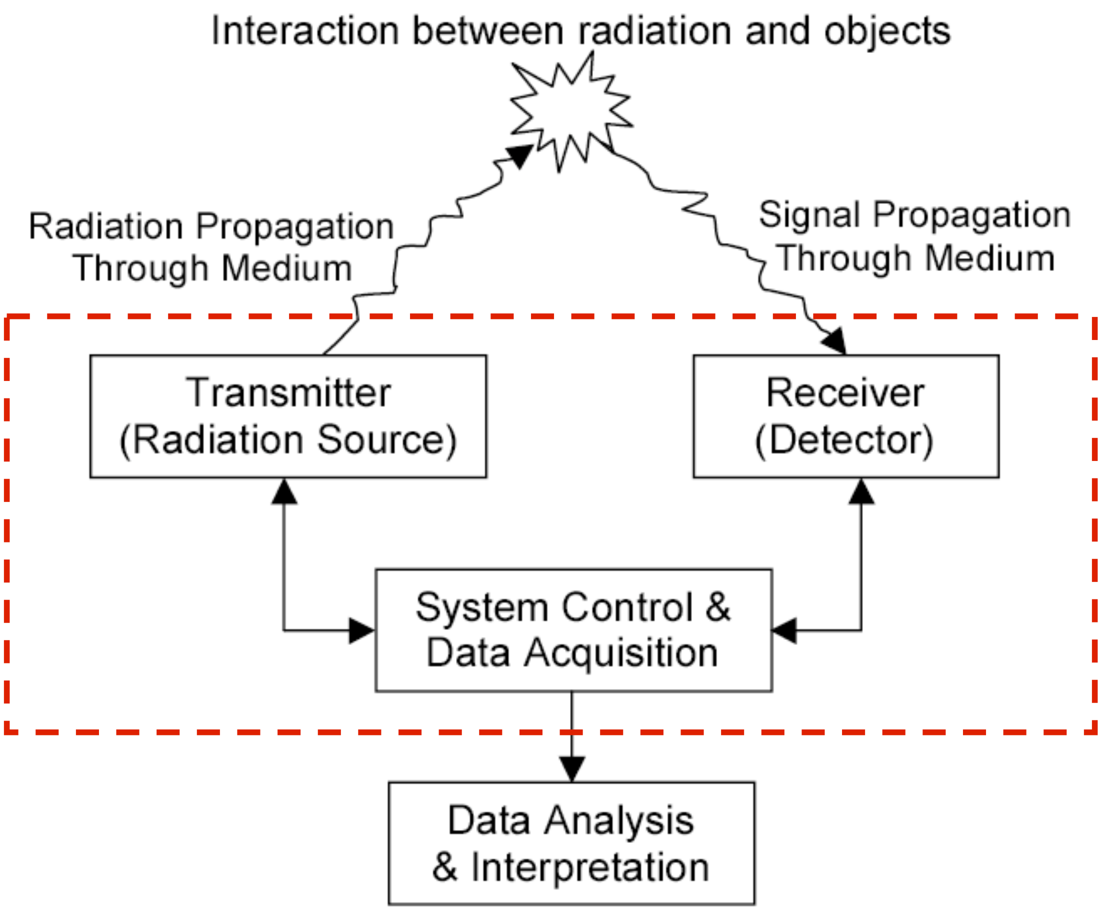
Lecture 13. Lidar Architecture

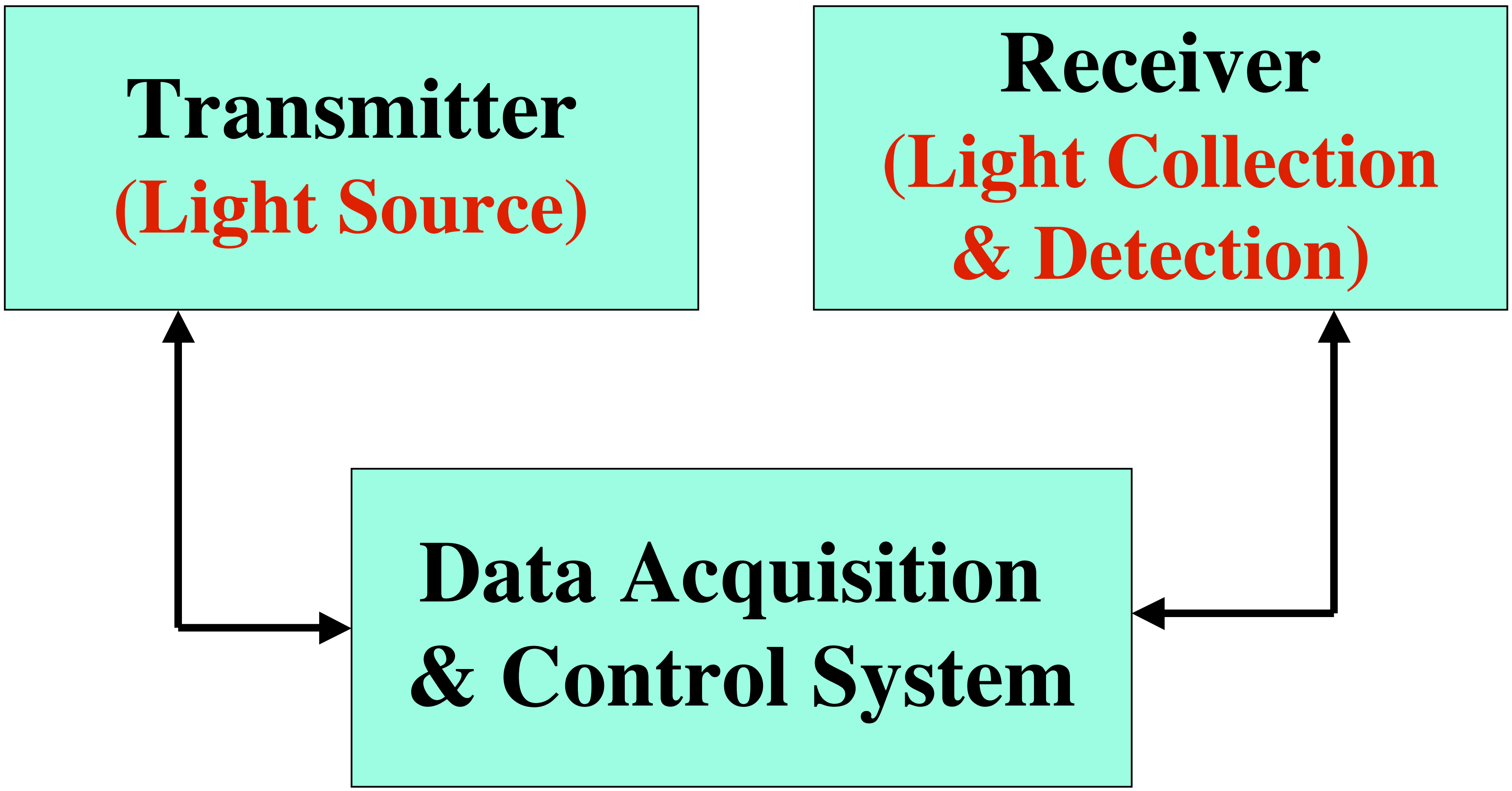
- Introduction
- Basic Architecture
- Basic Configuration
- Basic Arrangement
- Considerations on Lidar Instrumentation
- Example: Na Doppler lidar
- Example: Fe Boltzmann lidar
- Summary

Introduction

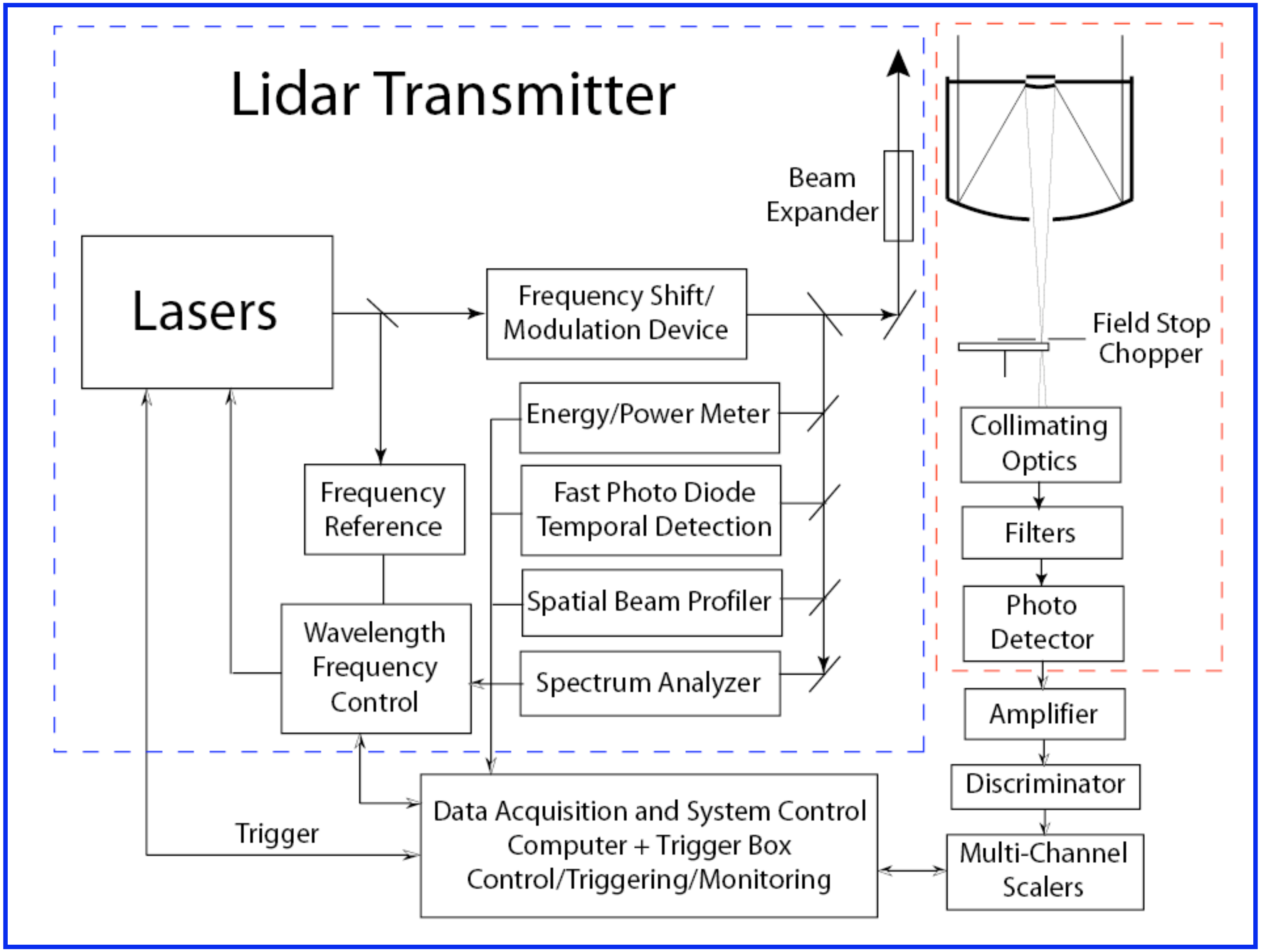
❑ Lidar architecture is the art of lidar system instrumentation (including hardware and software).



Basic Architecture of LIDAR



Basic Architecture of LIDAR



Lidar Transmitter

- A transmitter is to provide laser pulses that meet certain requirements depending on application needs (e.g., wavelength, frequency accuracy, bandwidth, pulse duration time, pulse energy, repetition rate, divergence angle, etc).
- Usually, a transmitter consists of laser(s), frequency shift/modulation device, wavelength control system, diagnostic equipment, and collimating optics.
- This is usually the most challenging part of a lidar system and also the key to a successful lidar system.

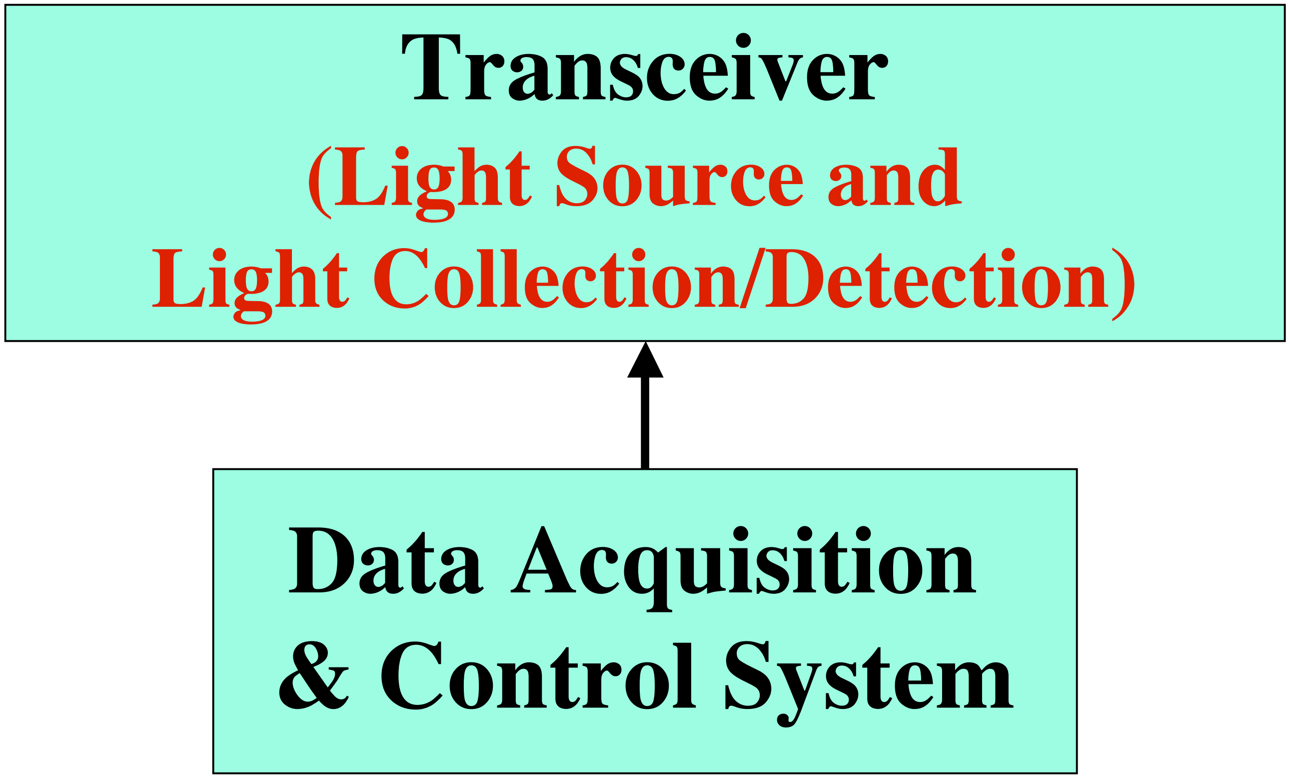
Lidar Receiver

- A receiver is to collect returned photons and detect these photons to generate electronic signals while compressing background noise.
- Usually, it consists of an optical telescope, field-stop, chopper or shutter, collimating optics, filters, and photon detectors, etc.
- The bandwidth of the filters determines whether the receiver can spectrally distinguish the returned photons.

Data Acquisition & System Control

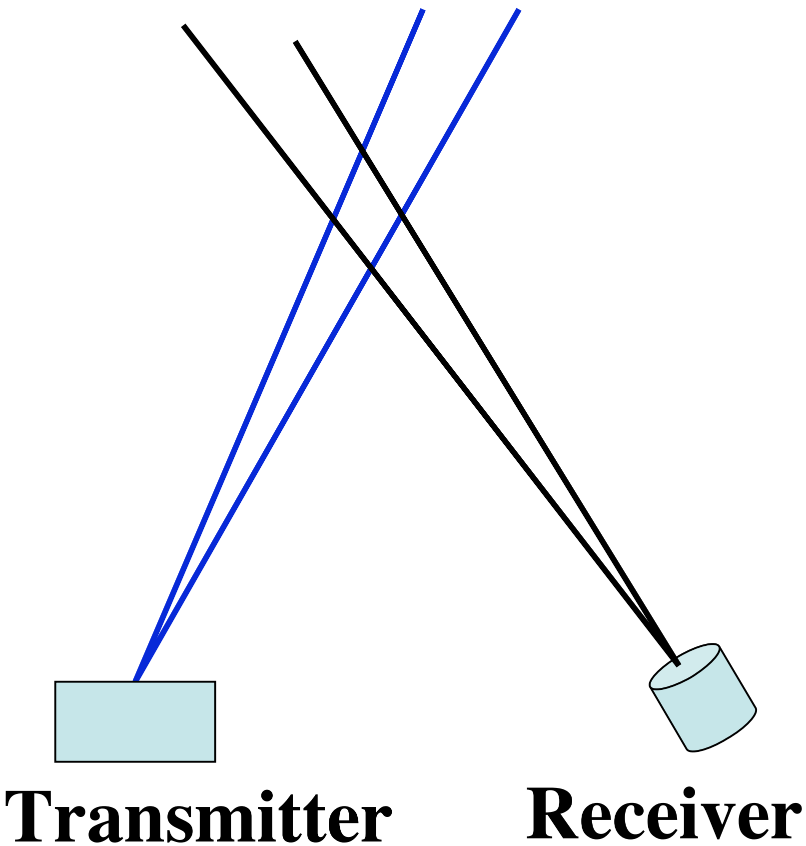
- Data acquisition and control system are to record data and corresponding time-of-flight, provide system control and coordination to transmitter and receiver.
- Usually, it consists of amplifier, discriminator, multi-channel scaler (which has very precise clock so can record time precisely), computer hardware and software, trigger control, etc.
- This part has become more and more important to modern lidars. Recording every single pulse return has been done by some group, but still challenging to the community.

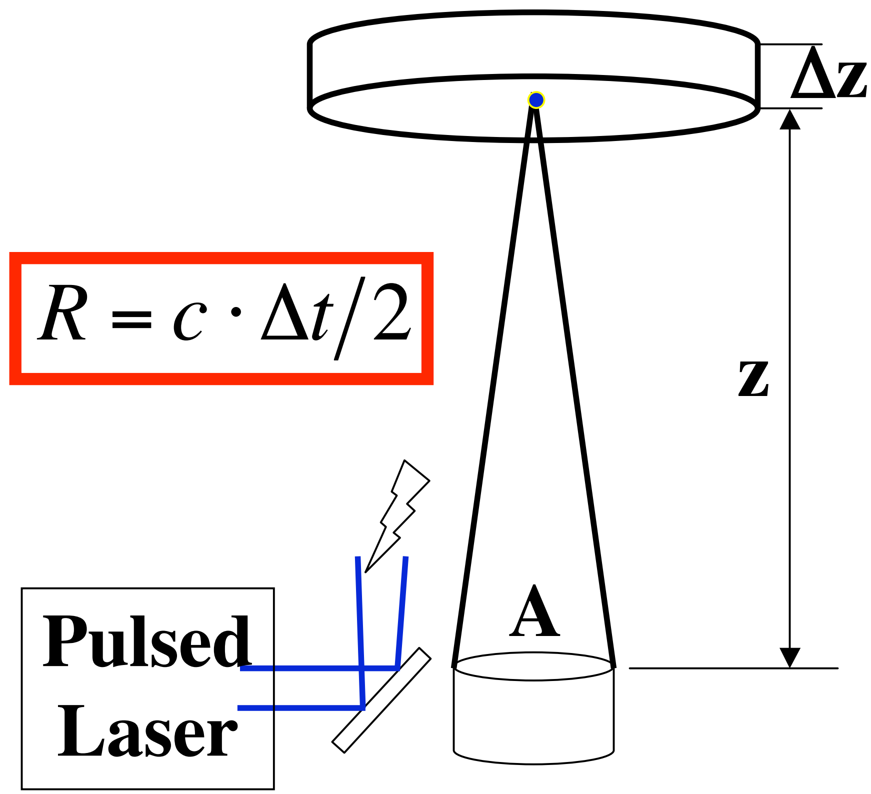
More Architecture of LIDAR



- Transceiver is becoming more and more popular for compact lidars for mobile systems like airborne and spaceborne lidars in the lower atmosphere detection.

Basic Configurations of LIDAR
Bistatic and Monostatic



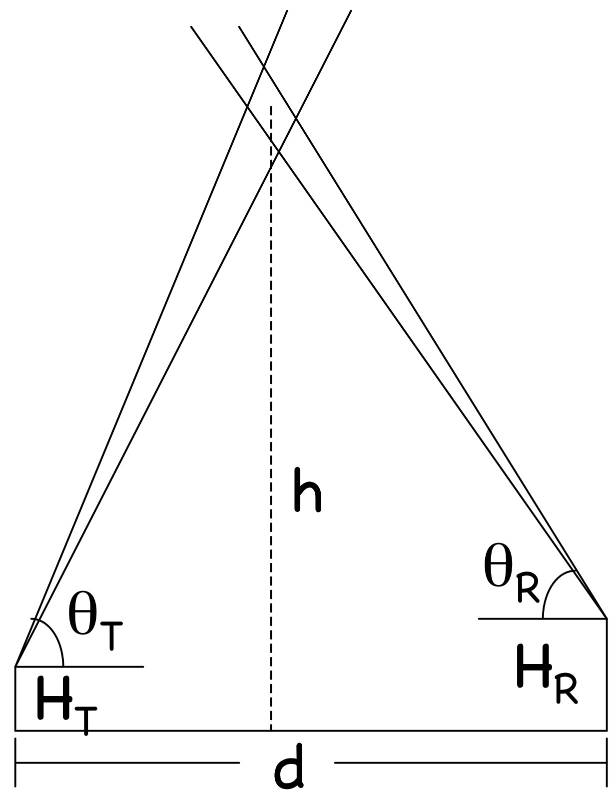


Bistatic Configuration **Monostatic Configuration**

Bistatic Configuration

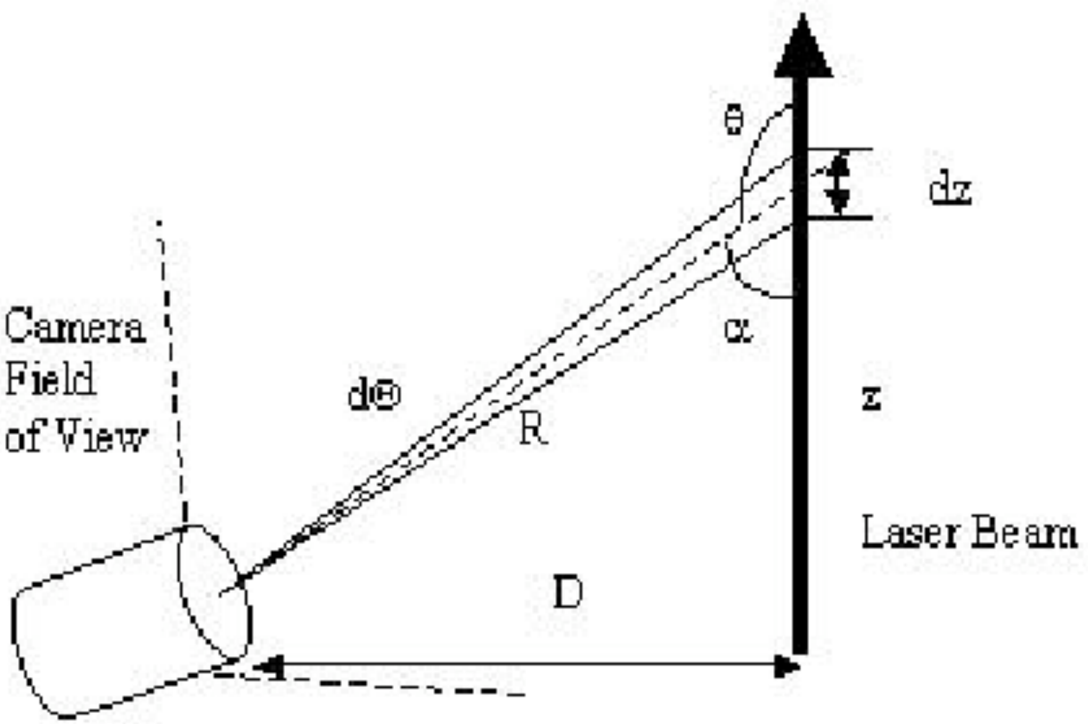
- Bistatic configuration involves a considerable separation of the transmitter and receiver to achieve spatial resolution in optical probing study.
- It originated from CW light, and modulation was used to improve SNR.
- The range information is determined from geometry configuration, rather than the time-of-flight.

$$h = \frac{d \cdot \tan(\theta_T) \cdot \tan(\theta_R) + H_T \cdot \tan(\theta_R) + H_R \cdot \tan(\theta_T)}{\tan(\theta_T) + \tan(\theta_R)}$$



Bistatic Configuration

- Now some pulsed lidars utilize bistatic configuration to overcome the problem of lack of overlapping between receiver field-of-view and laser beam in the near field.
- These are especially useful for boundary layer aerosol study.

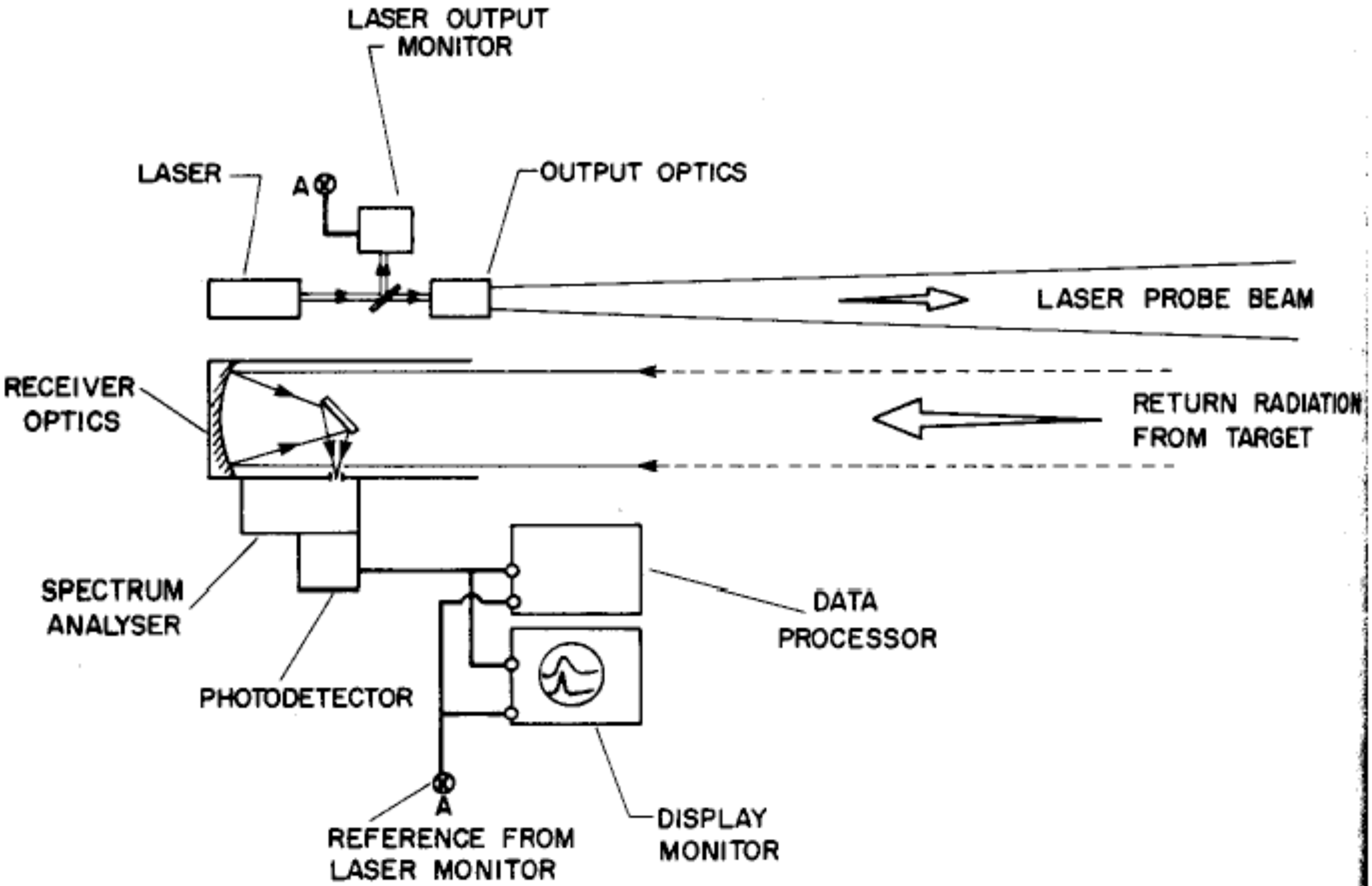


Monostatic Configuration

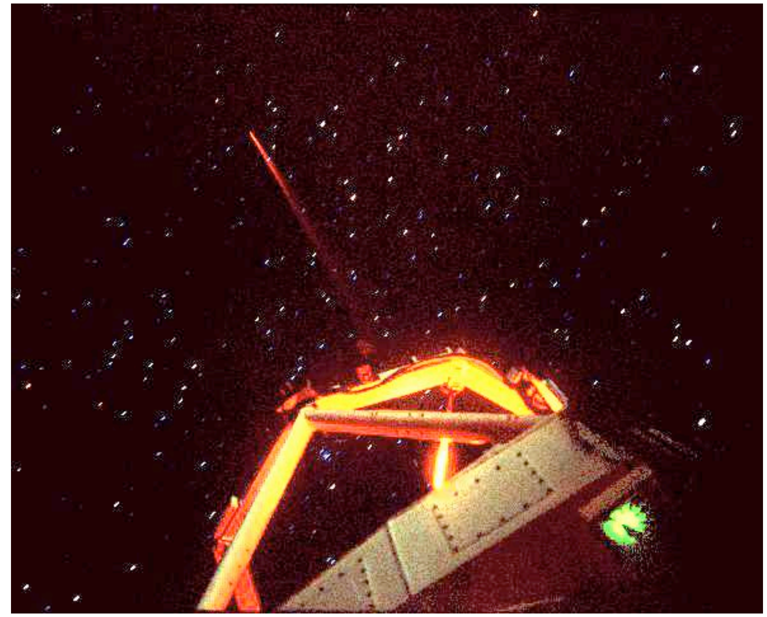
- Monostatic configuration has the transmitter and receiver locating at the same location, so that in effect one has a single-ended system. The precise determination of range is enabled by the nanosecond pulsed lasers.

$$\boxed{R = c \cdot \Delta t / 2}$$

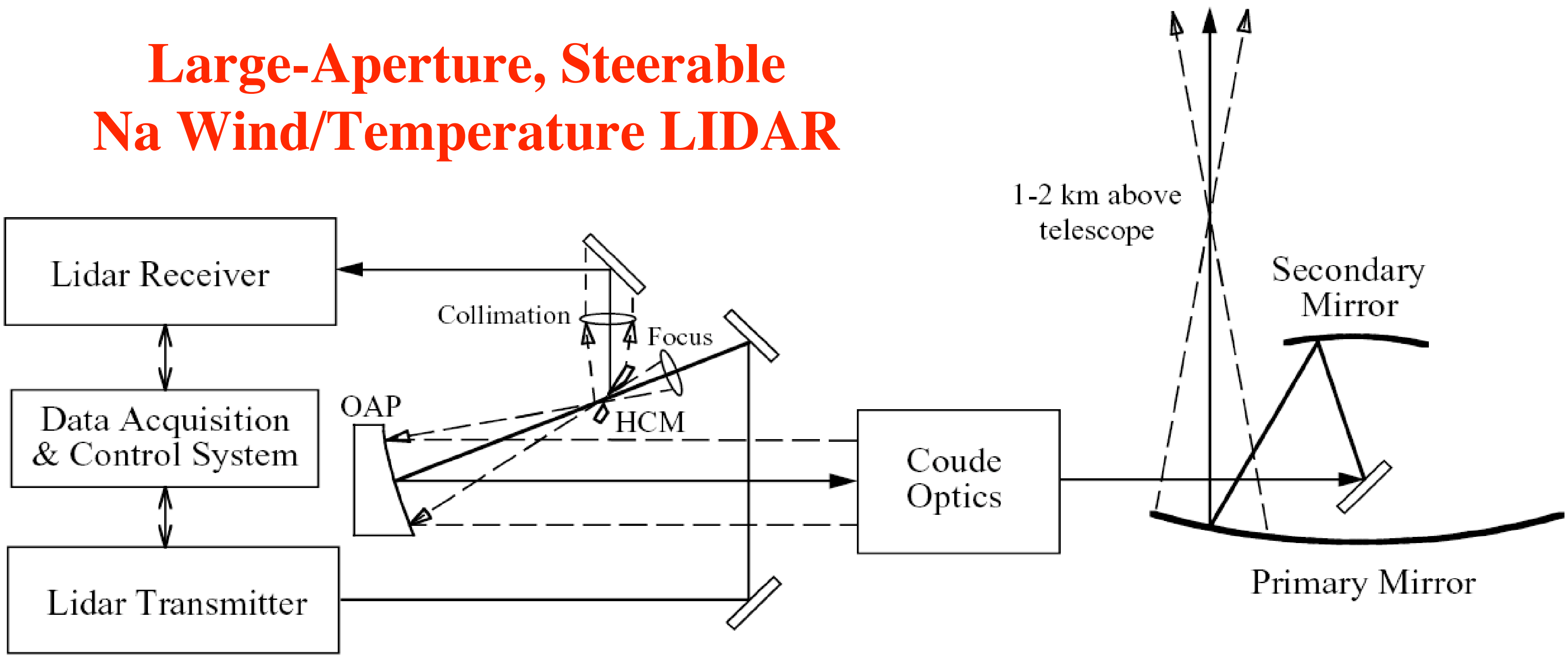
Monostatic Configuration Example



Monostatic Configuration SOR/Maui Na Lidar



Large-Aperture, Steerable Na Wind/Temperature LIDAR



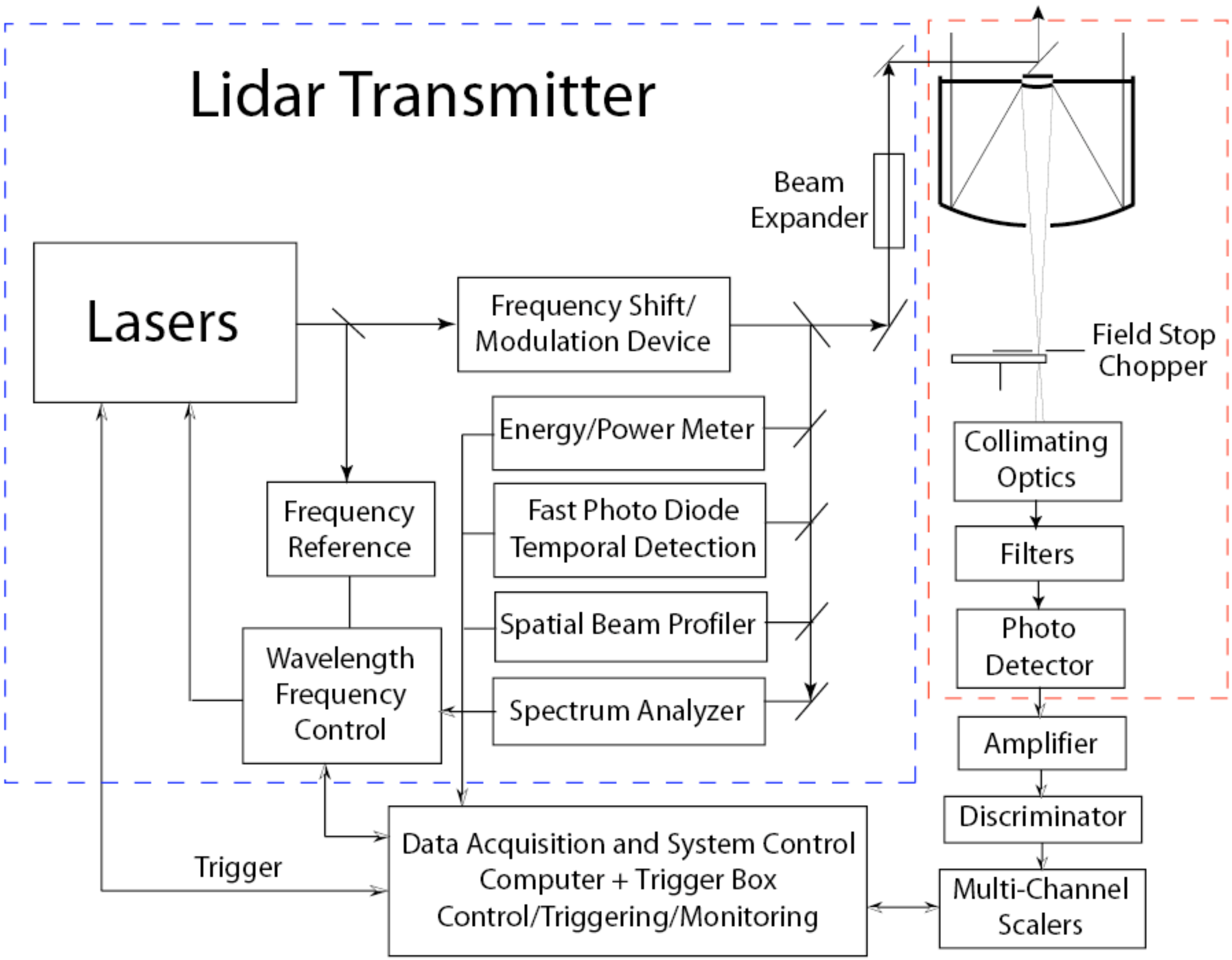
Basic Arrangements of LIDAR
Biaxial and Coaxial

- There are considerable amount of lidars using biaxial arrangements although they have monostatic configurations.
- In the biaxial arrangement, the laser beam and the receiver axis are separated, and the laser beam only enters the field of view of the receiver optics beyond some predetermined range.
- Biaxial arrangement helps avoiding near-field backscattered radiation that may saturate photo-detector.

Basic Arrangements of LIDAR
Biaxial and Coaxial

- In the coaxial arrangement, the axis of the laser beam is coincident with the axis of the receiver optics.
- Therefore, the receiver can see the laser beam since the zero range bin.
- The near-field backscattering problem in a coaxial system can be overcome by either gating of the photo-detector or use of a fast shutter or chopper to block the near-field scattering.

Example of Coaxial Arrangement



Considerations on Lidar Needs

- Bistatic or monostatic?
- Biaxial or coaxial?
- Geometrical overlap
- Uplooking or downlooking?
- Care about scattering or only timing?
- Wavelength for transmitter and receiver
- Tunable or not?
- Bandwidth for transmitter and receiver
- Power/energy consideration
- Bin width - pulse duration time, repetition rate
- Nighttime or full diurnal capability?
- Volume, mass, cost, reliability, robustness, operation, etc?

Configuration & Arrangement

- Most modern lidars use monostatic configuration with either biaxial or coaxial arrangement.
- The choice of biaxial or coaxial arrangement is usually determined by the detection range. If near-field range is desired, coaxial arrangement is preferred as it provides full overlap of receiver field-of-view with laser beam. If near-field range is not desired, biaxial arrangement may help prevent the saturation of photo-detector by strong near-field scattering. Scanning capability can also come into play for the selection of biaxial or coaxial.
- Groundbased lidars are usually uplooking, while spaceborne lidars are usually downlooking. Airborne lidars can be either uplooking or downlooking, depending on application needs.

Bandwidth Consideration

- Possible combinations of transmitter and receiver

Broadband Transmitter	+	Broadband Receiver	Conventional Mie, Rayleigh, Raman Scatter lidar, Broadband Resonance Fluorescence lidar, Differential Absorption lidar
Narrowband Transmitter	+	Broadband Receiver	Narrowband Resonance Fluorescence Doppler lidar, Differential Absorption lidar
Narrowband Transmitter	+	Narrowband Receiver	Coherent Doppler lidar, Direct-Detection Wind lidar, Rayleigh Doppler lidar. High-Spectral-Resolution lidar
Broadband Transmitter	+	Narrowband Receiver	Potential broadband resonance fluorescence temperature lidar, Potential Rayleigh and Raman temperature lidar

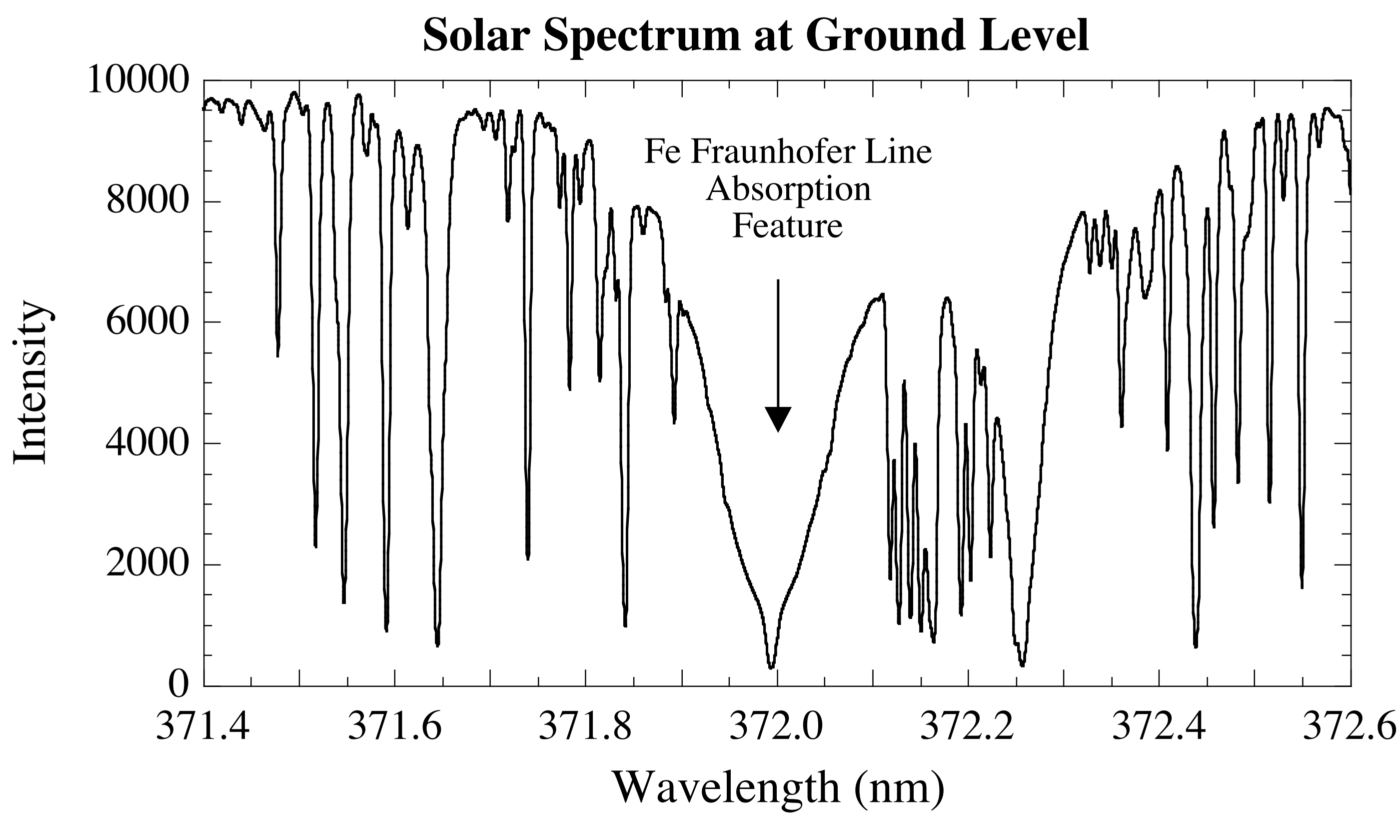
Wavelength Consideration

- Two main factors to determine wavelength selection: first, the detection subject – whether a specific wavelength is required, e.g., Na or Fe atomic transition wavelength, or H_2O differential absorption wavelength; second, the solar spectrum intensity – low solar radiation is desirable to benefit signal-to-noise ratio (SNR) in daytime. Usually UV solar radiation is lower than visible and IR.

- Fraunhofer lines in solar radiation are a set of several hundred dark lines appearing against the bright background of the continuous solar spectrum and produced by absorption of light by the cooler gases in the Sun's outer atmosphere at frequencies corresponding to the atomic transition frequencies of these gases, such as atomic H, Fe, Na, K, Ca, Mg, Li, etc, or by oxygen of the Earth's atmosphere.

Fraunhofer Lines

- Fraunhofer lines are named after the German physicist Joseph von Fraunhofer (1787–1826).
- Lidar operating at the wavelengths in deep Fraunhofer lines benefits from the lower solar background



http://bass2000.obspm.fr/solar_spect.php?PHPSESSID=b1fb4b5e30286b1698ae5b2f330b3318

Nighttime-Only & Full Diurnal

- This is mainly a consideration on background suppression.
- Even for nighttime-only operation, interference filters are necessary to suppress background (like moon or star or city light) and ensure safe operation of photo detectors.
- Daytime operation needs extra suppression on much stronger solar background, when compared to nighttime-only operation. Not only extra spectral filters with very narrow bandwidth are needed, but also spatial filter or minimized field-of-view is necessary to largely suppress the solar background. Of course, this is also limited by layer saturation or geometrical overlap issues.
- Two major narrowband spectral filters: F-P etalons and atomic spectral filters (like Faraday filter).

Lidar Types & Hardware

- Conventional Mie, Rayleigh, Raman lidar:
- Broadband resonance fluorescence lidar:
- Narrowband resonance fluorescence lidar:
- Broadband differential absorption lidar:
- Narrowband differential absorption lidar:
- Coherent Doppler lidar:
- Direct-detection wind lidar:
- Rayleigh Doppler:
- High-spectral-resolution lidar:

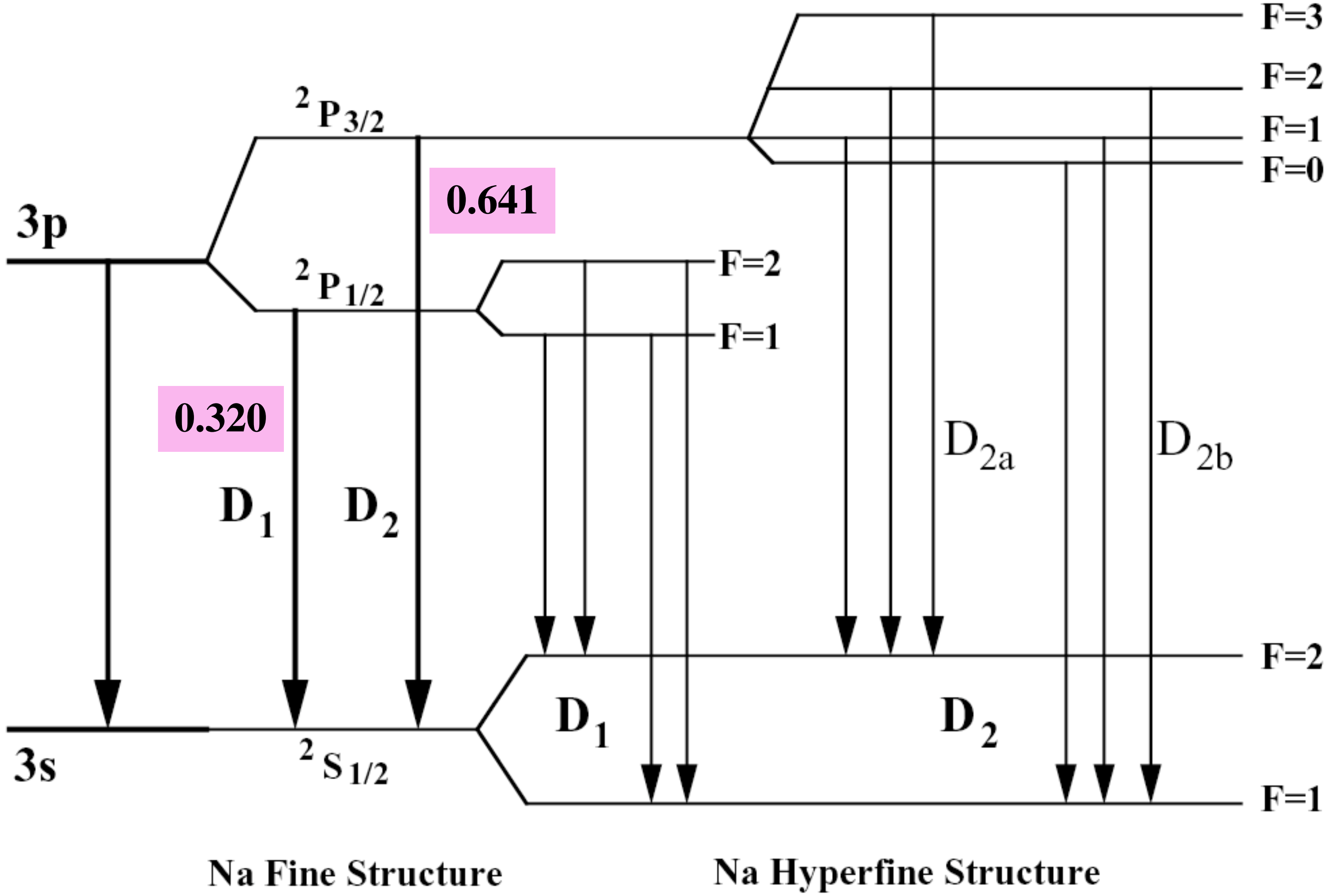
Transmitter & Receiver

- Depending on application needs and lidar types, there may be several possible combinations of transmitter and receiver to satisfy the same goal. Choose the best one depending on science need, technical feasibility, cost, performance, reliability, etc.
- To choose tunable lasers or not depends on the application needs, e.g., resonance fluorescence and DIAL lidars need to be tunable, while conventional Mie, Rayleigh, and Raman scattering lidars only need fixed wavelengths.
- Selection of pulse energy, repetition rate, and duration time mainly concerns the SNR, measurement resolution, as well as cost, volume, mass, etc to the entire system.

Consideration on Data Acquisition

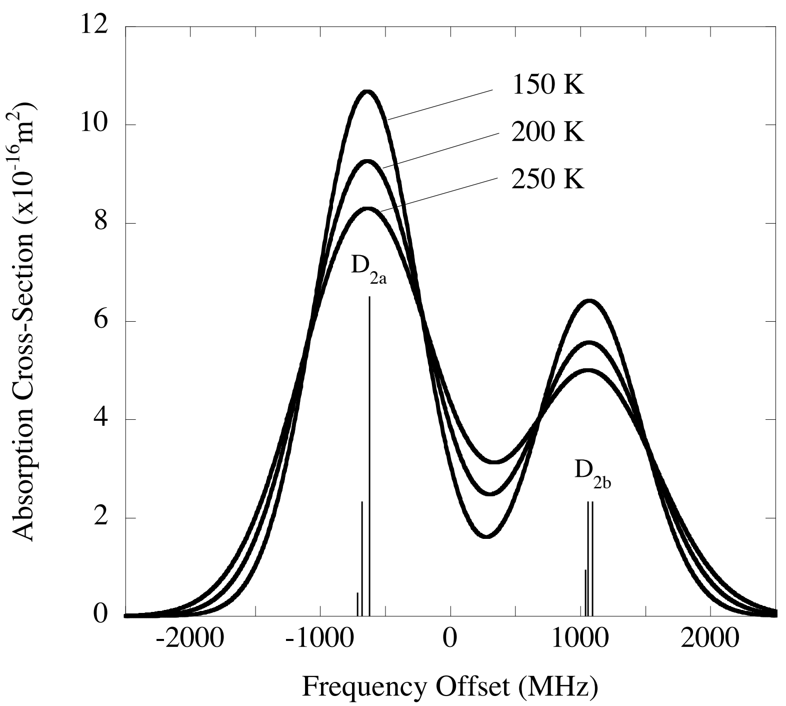
- Record every pulse or not?
- Bin width or resolution
- Record system parameters or not?
- Timing control

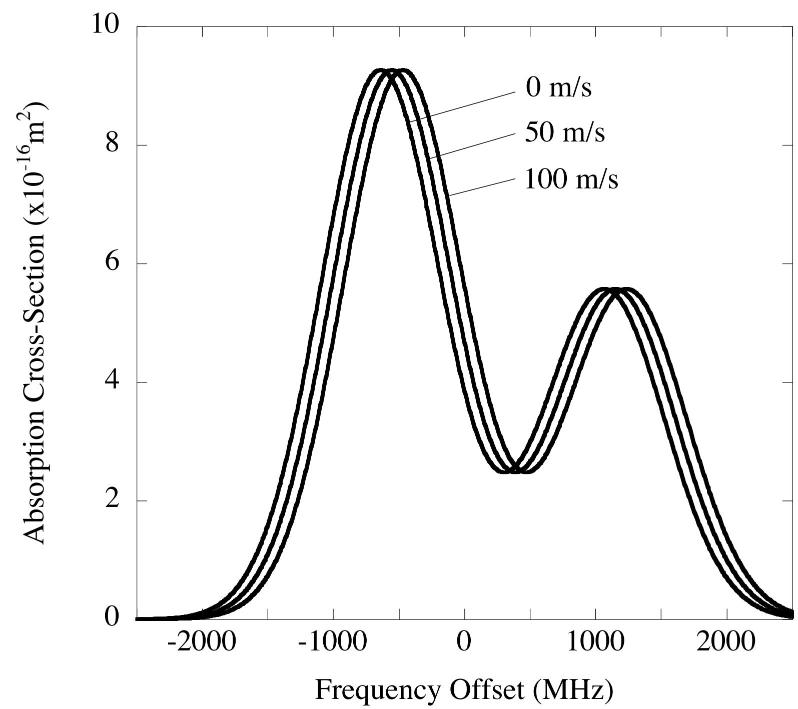
Example: Na Doppler Lidar Principle



Energy Level Diagram of Atomic Na

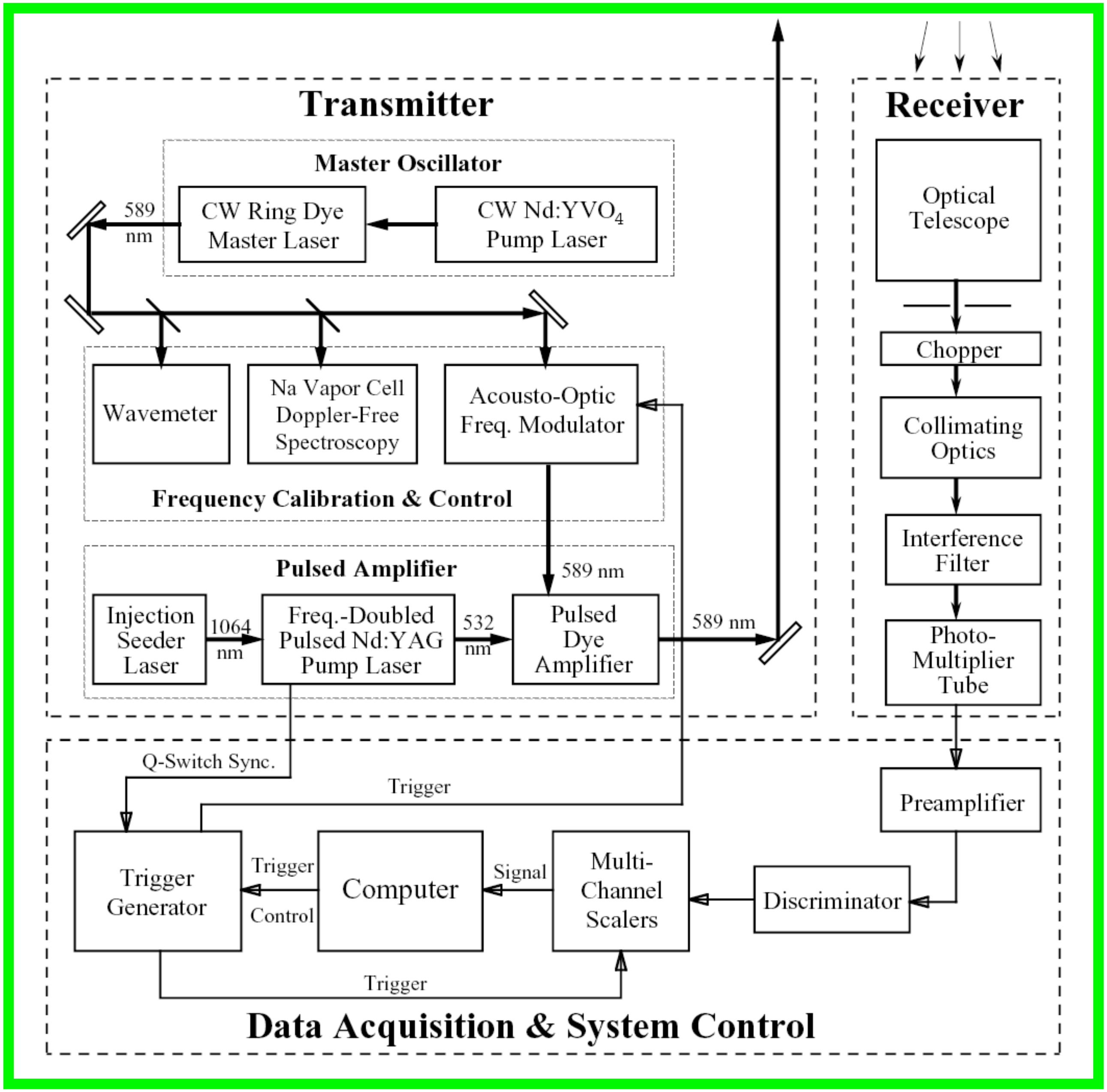
Na Wind/Temperature Lidar Principle



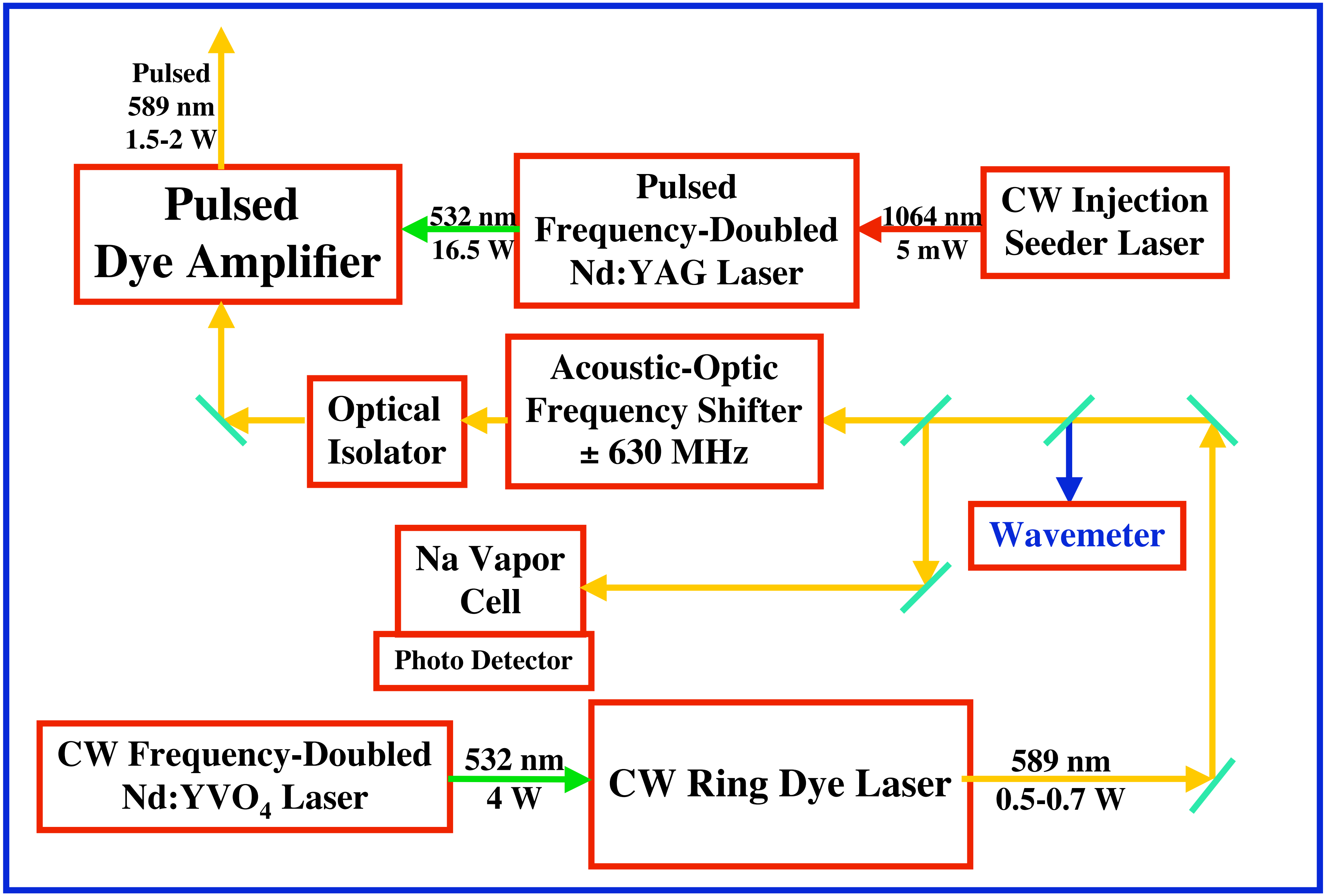


Doppler Width ⇒ Temperature; Doppler Shift ⇒ Wind Velocity

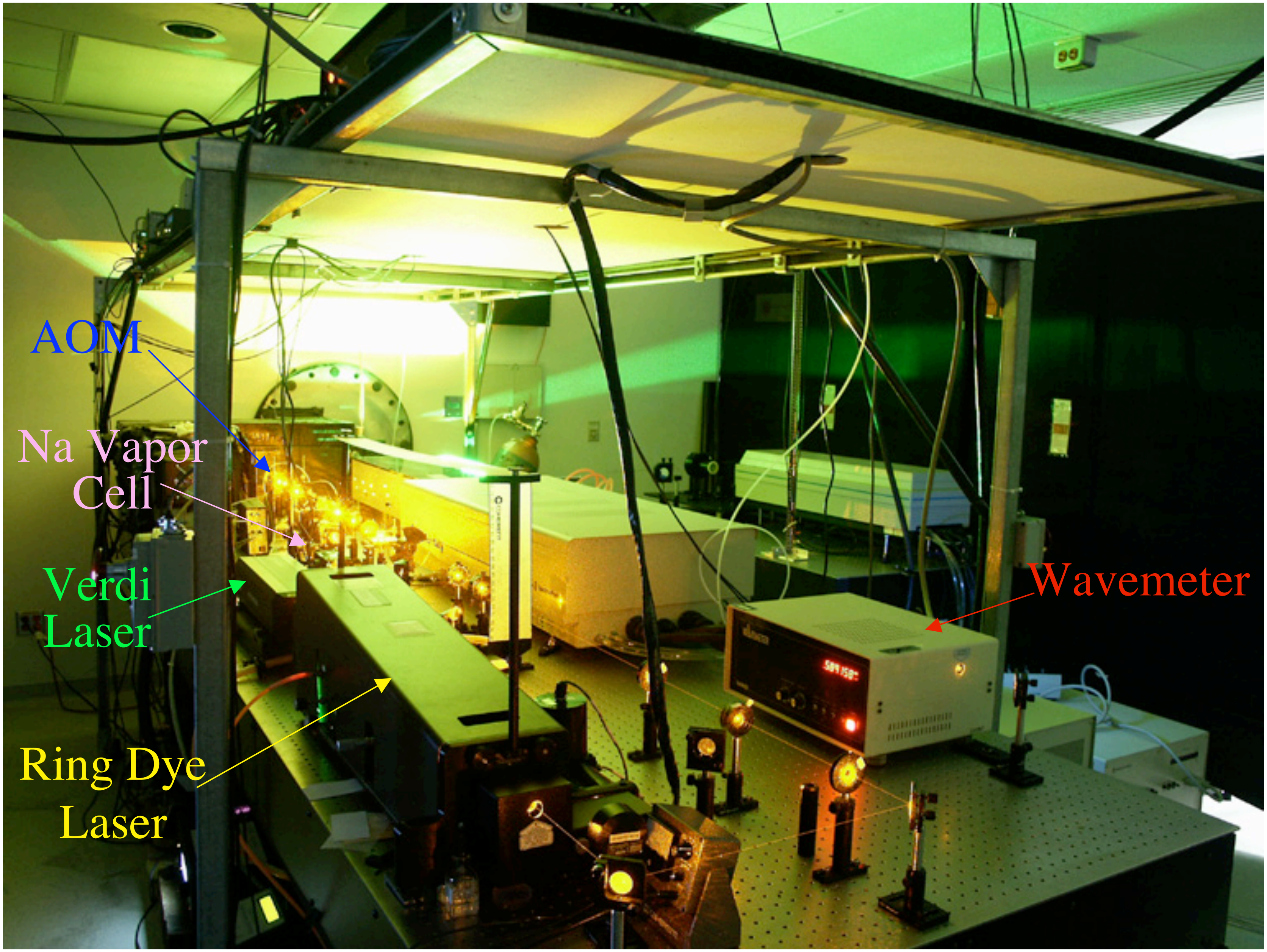
Na Doppler Lidar Schematic



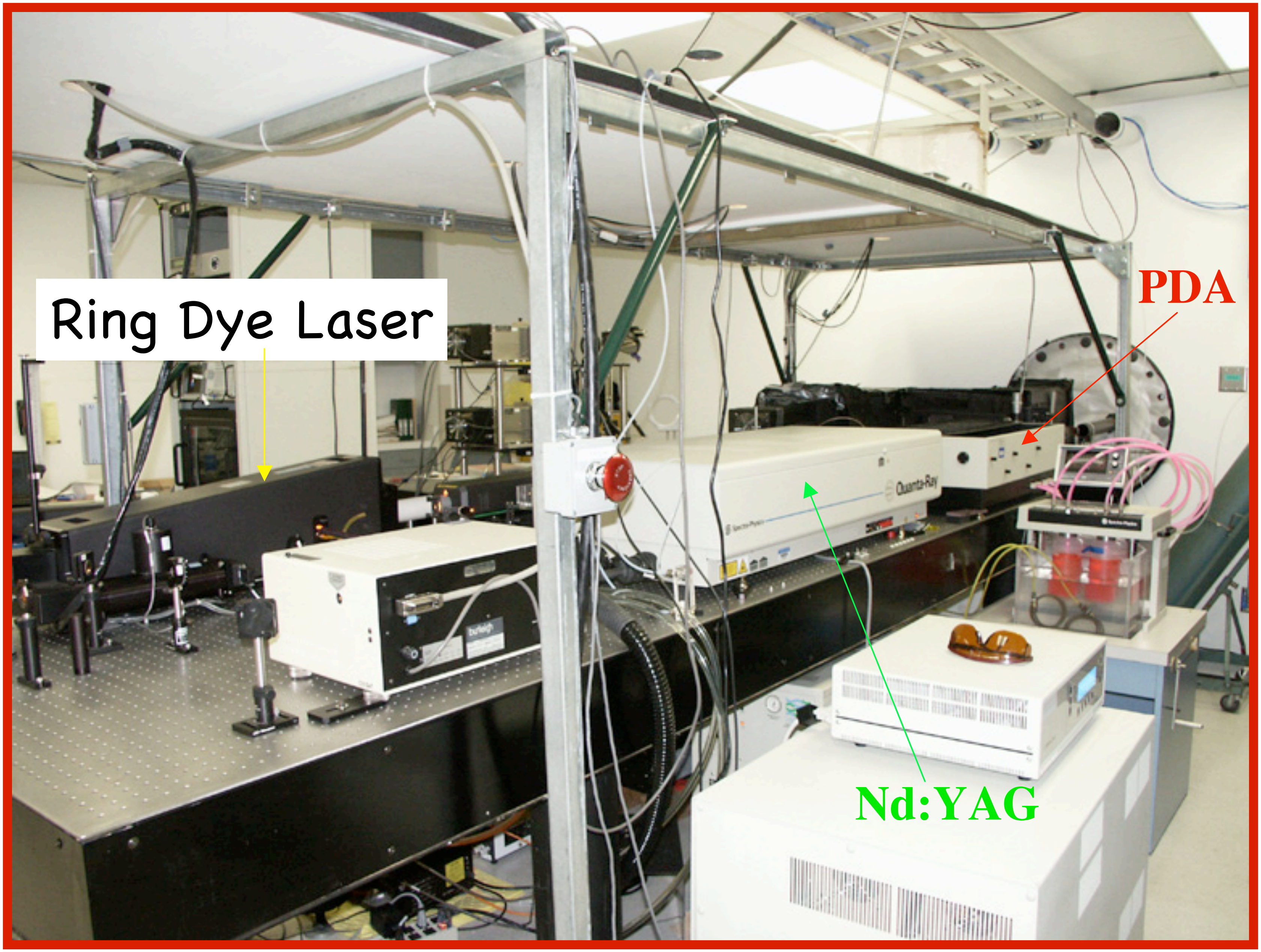
Na Doppler Lidar Transmitter



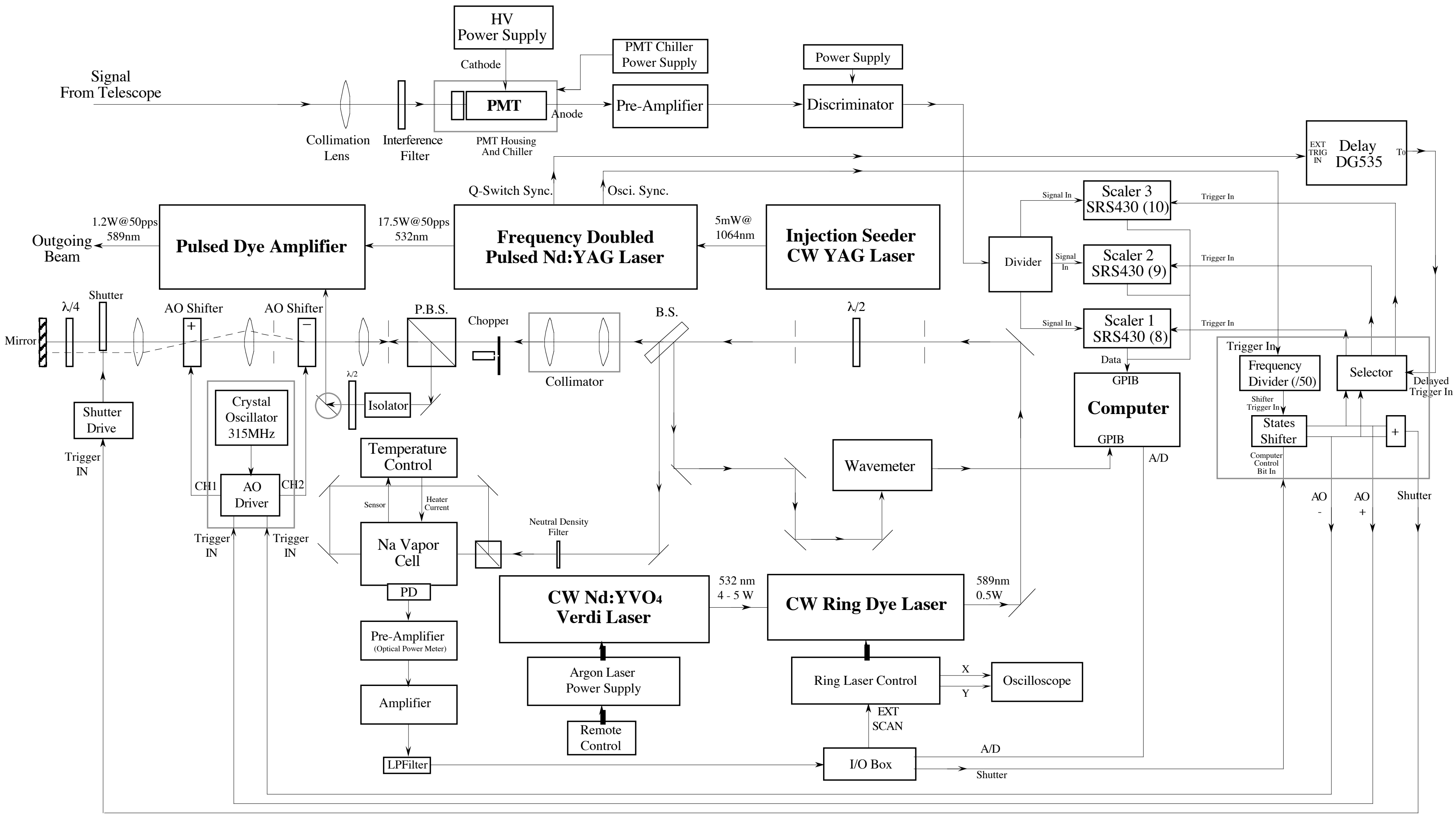
Na Lidar Transmitter



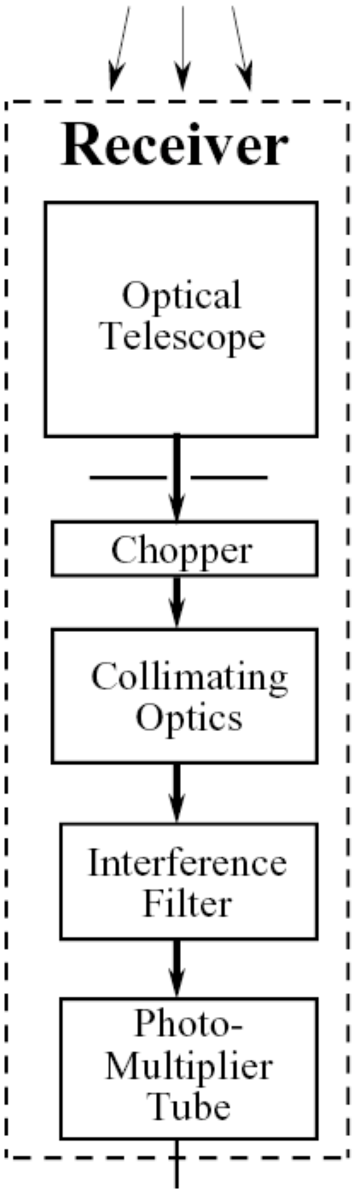
Na Lidar Transmitter

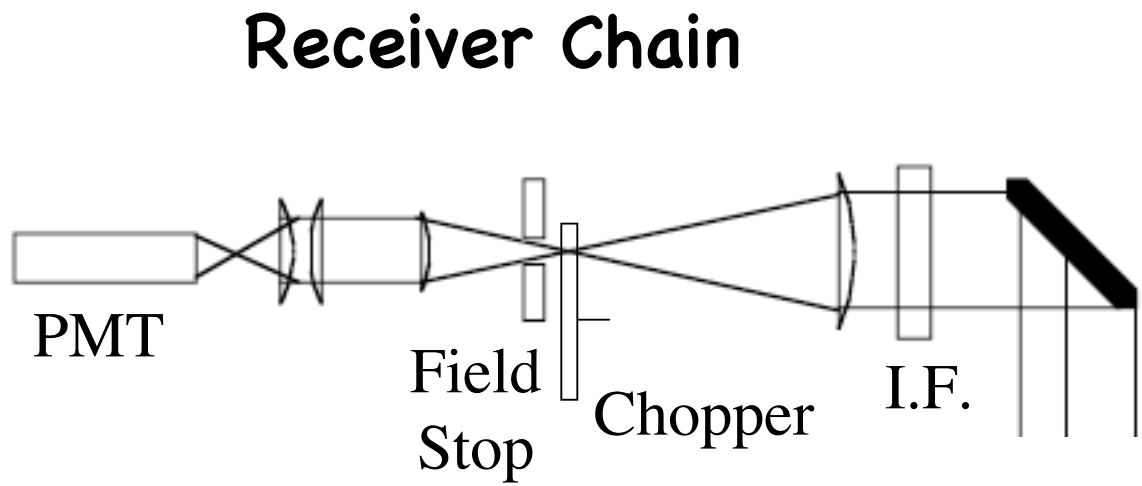


Detailed Diagram of Na Lidar



Na W/T Lidar Receiver

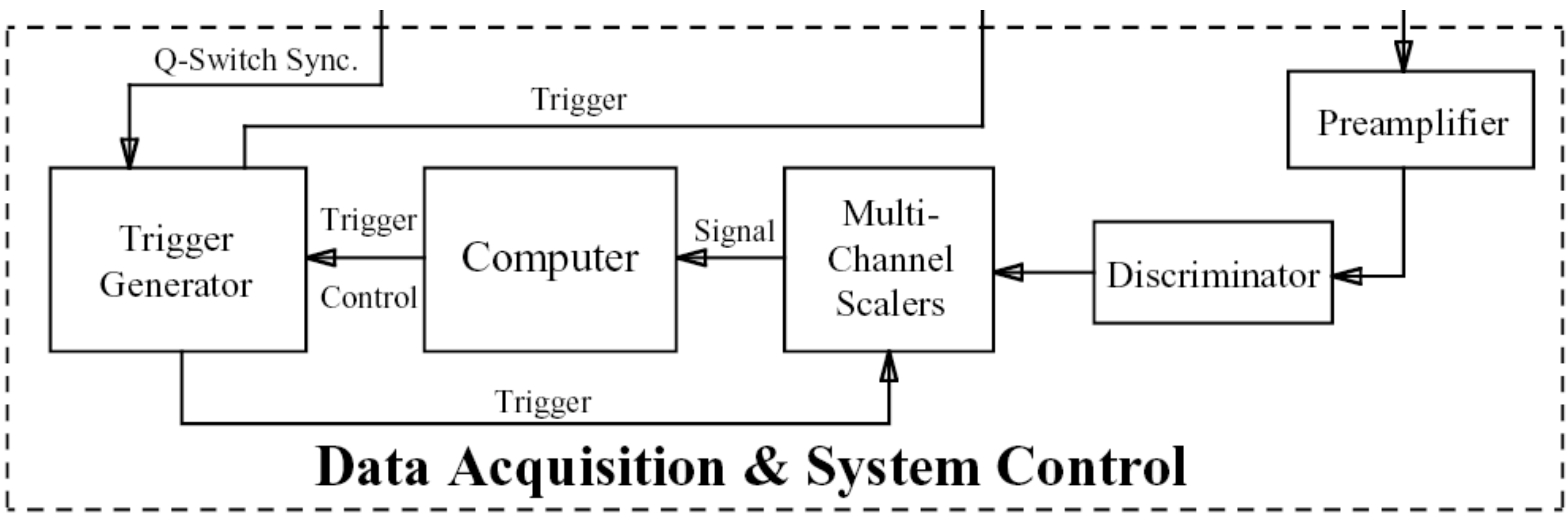




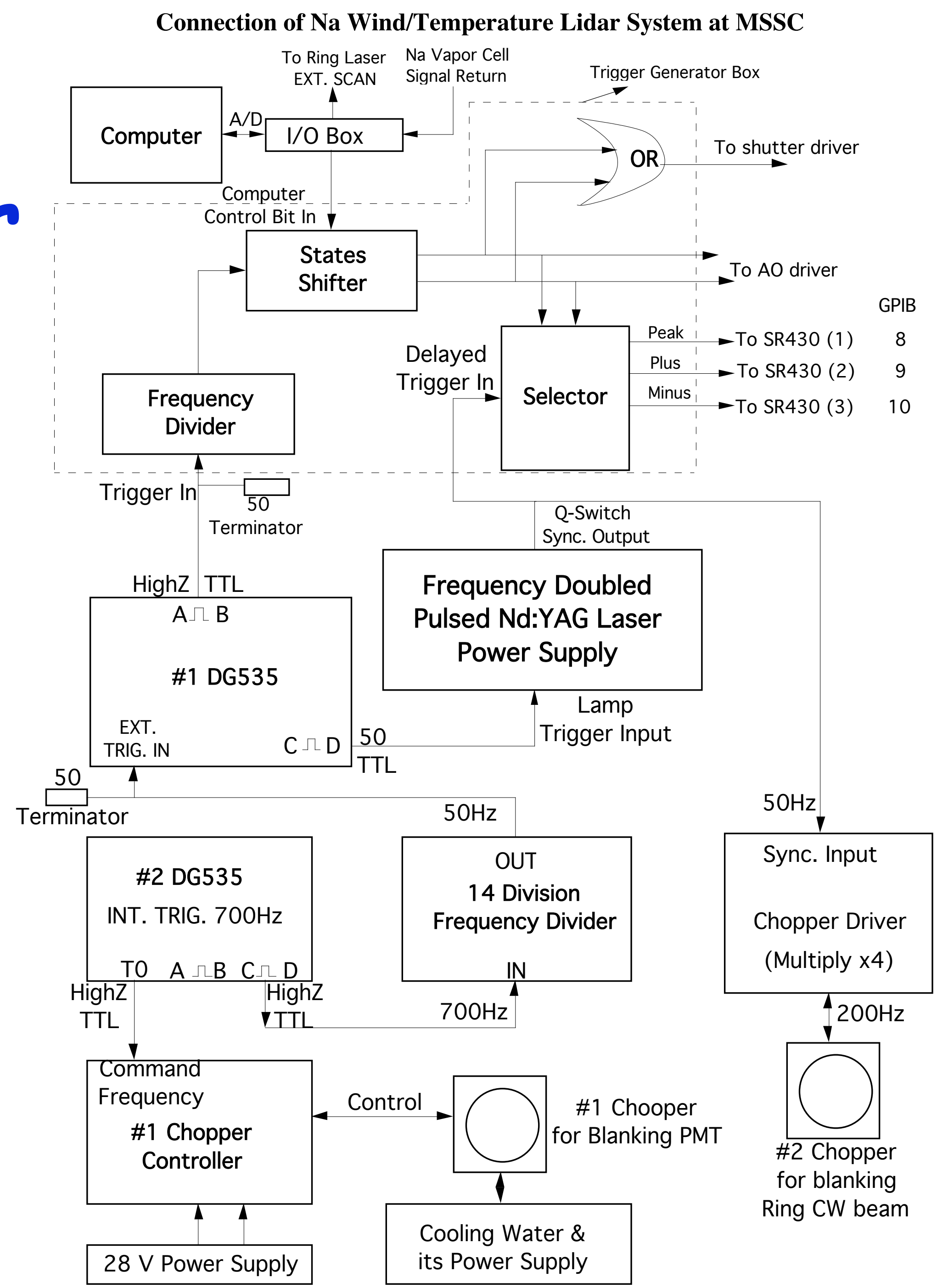
- ❑ Interference filter
- ❑ Faraday filter
- ❑ chopper, PMT

Data Acquisition and System Control

- Discriminator
- Multichannel scaler

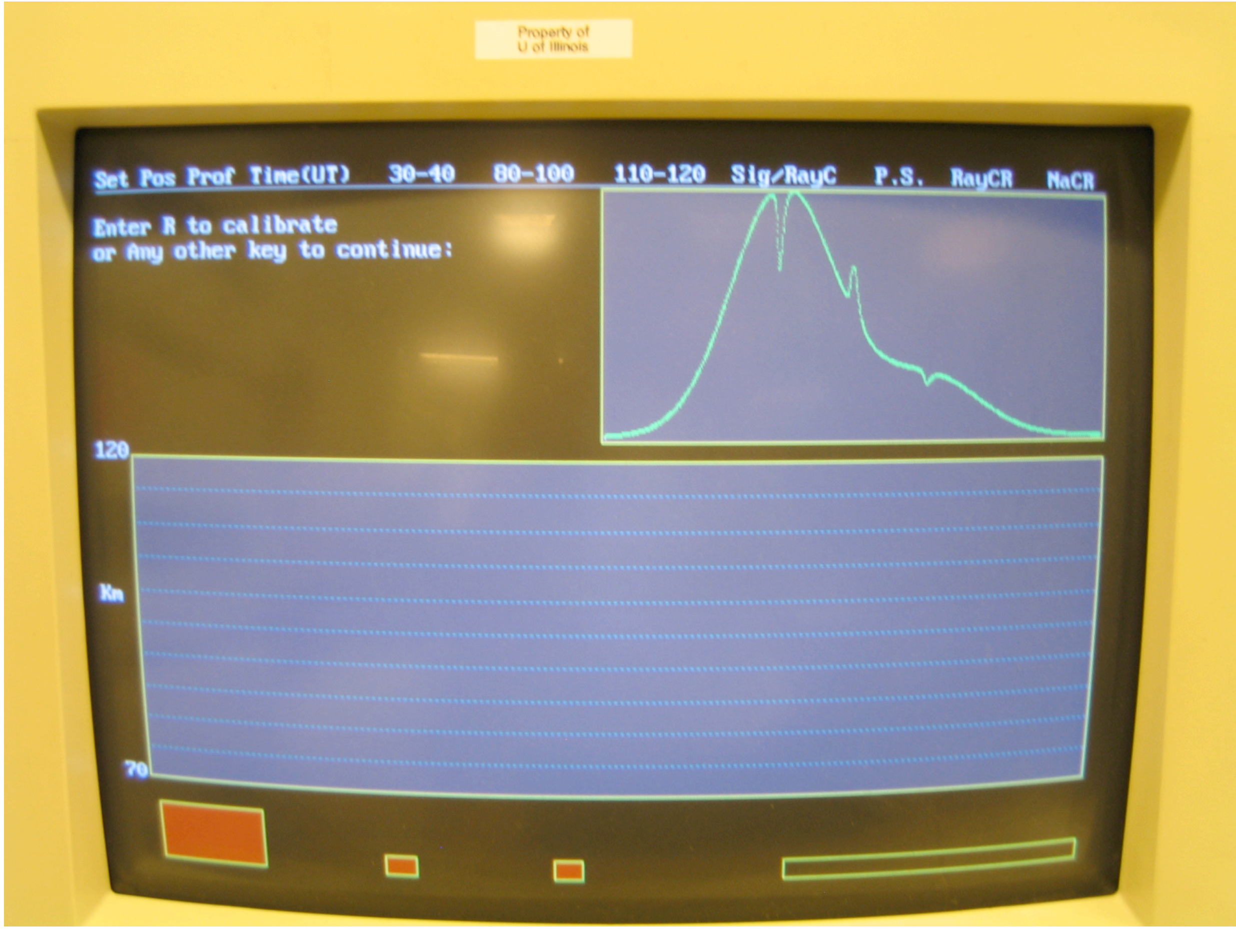


Na Doppler Lidar System Control



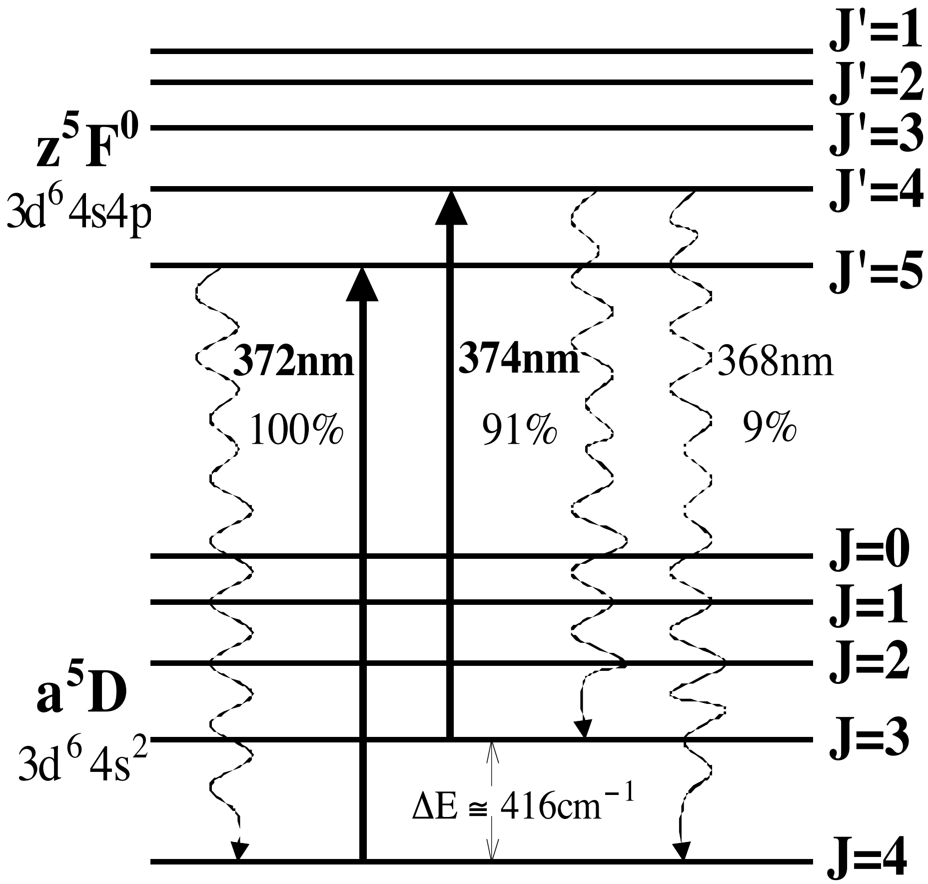
Data Acquisition and System Control

- Software design



Laser Frequency Scan Movie

Example: Fe Boltzmann Temp Lidar



Atomic Fe Energy Level

[Gelbwachs, 1994; Chu et al., 2002]

Maxwell-Boltzmann Distribution in Thermal-dynamic Equilibrium

$$\frac{P_2(J=3)}{P_1(J=4)} = \frac{\rho_{Fe(374)}}{\rho_{Fe(372)}} = \frac{g_2}{g_1} exp(-\Delta E / k_B T)$$

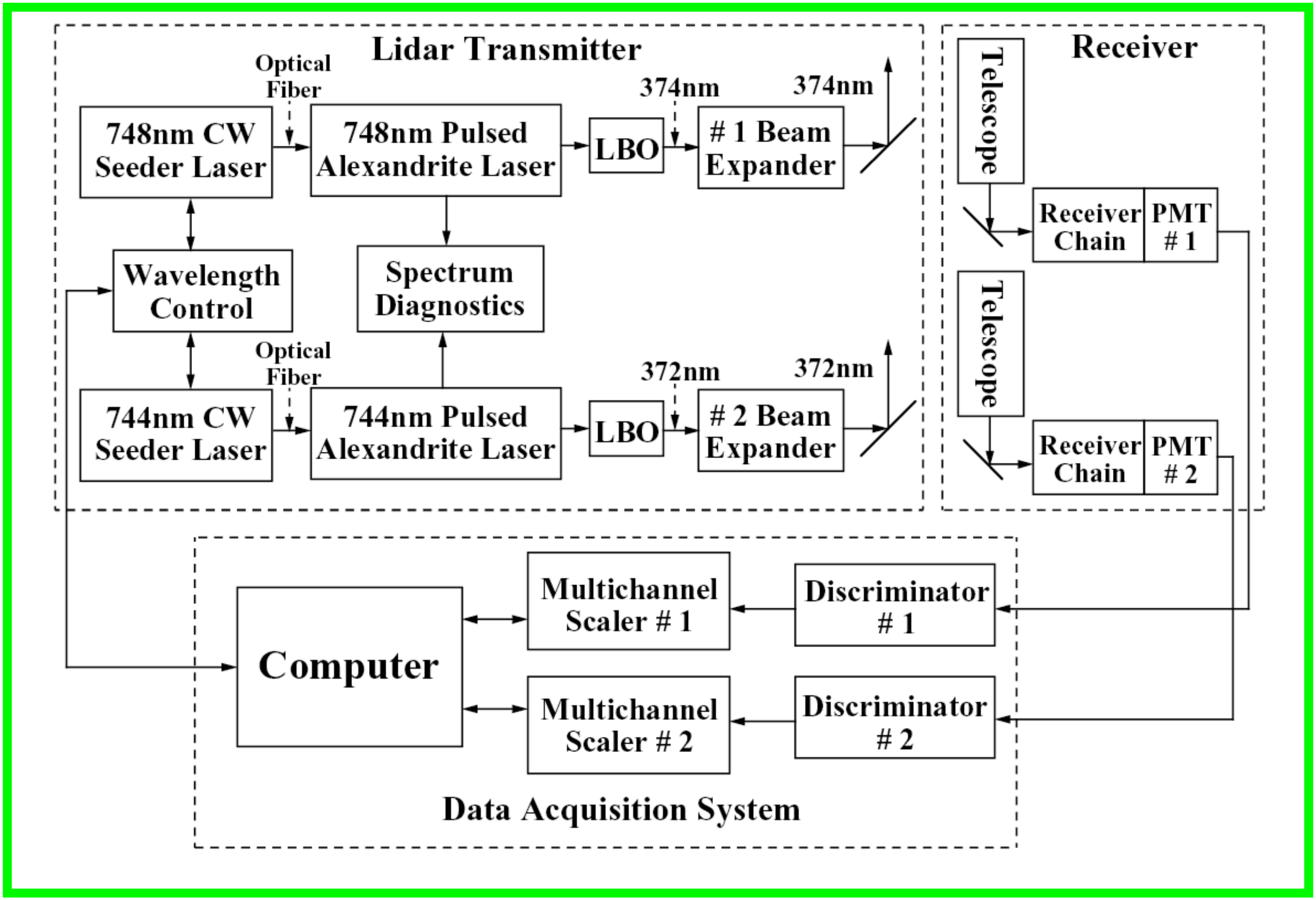
⇩

$$T = \frac{\Delta E / k_B}{ln\left(\frac{g_2}{g_1} \cdot \frac{P_1}{P_2}\right)}$$

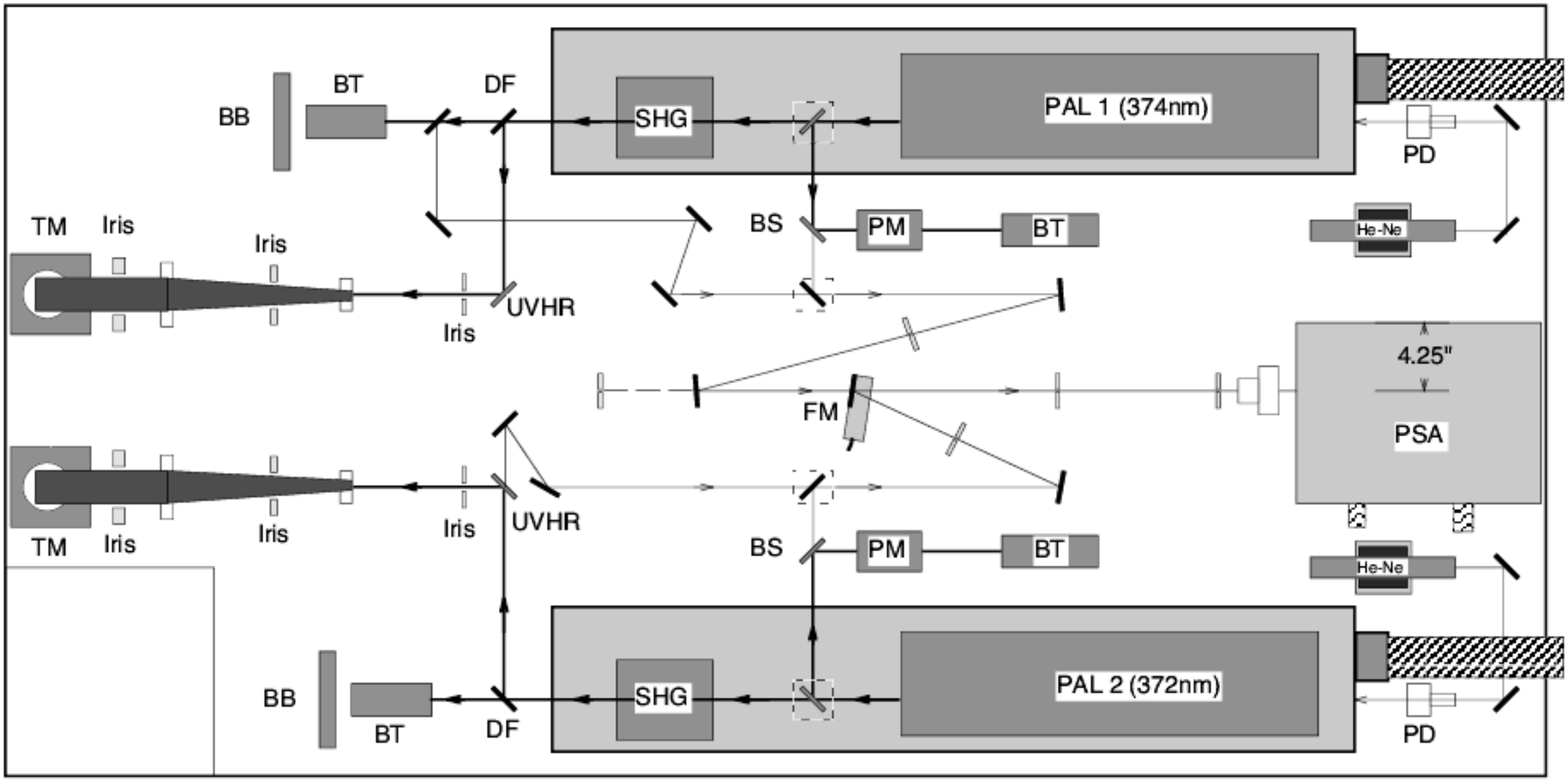
P_1, P_2 -- Fe populations
g_1, g_2 -- Degeneracy
k_B -- Boltzmann constant
T -- Temperature

Population Ratio ⇨ Temperature

Fe Boltzmann Lidar Schematic

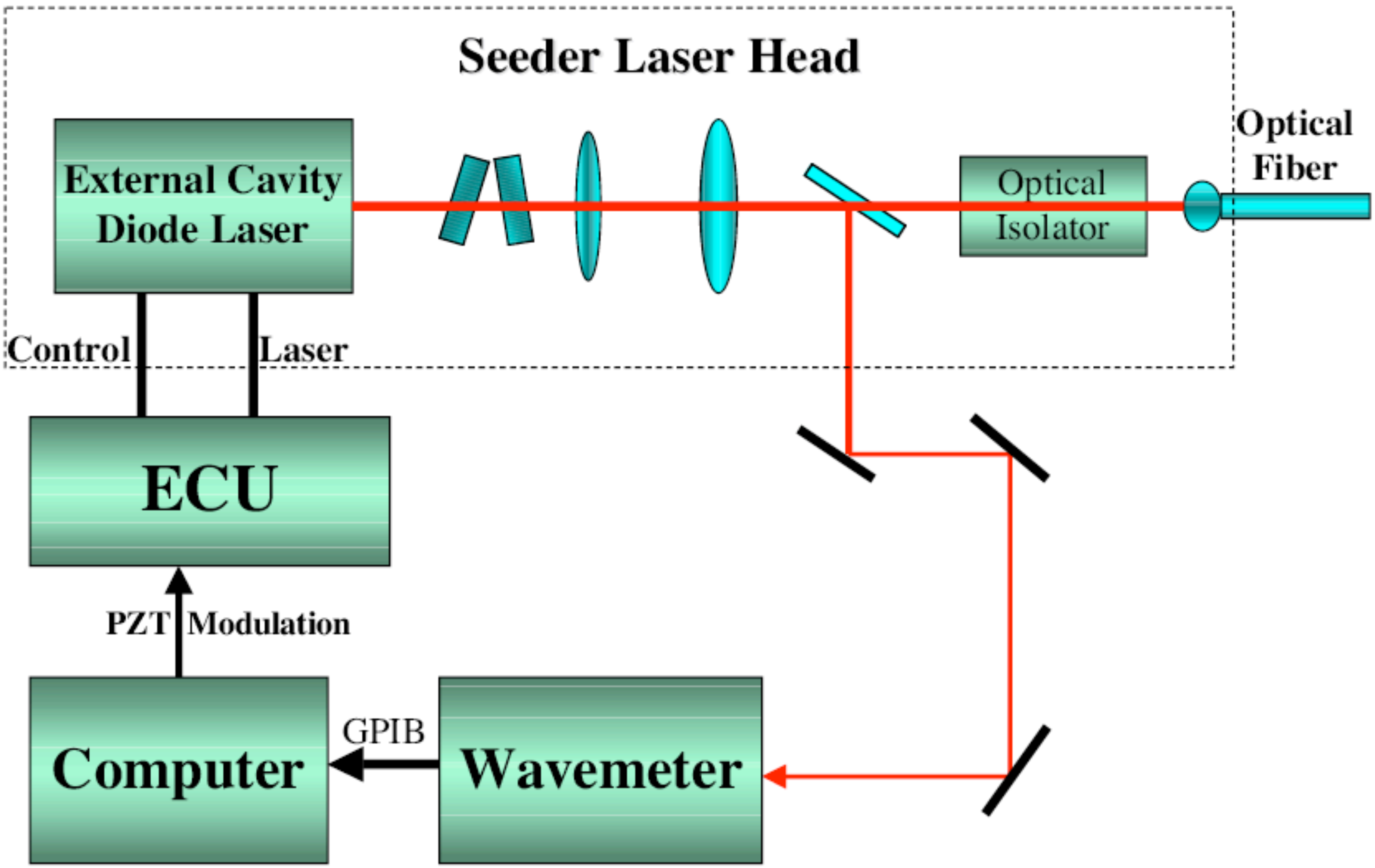


Fe Boltzmann Lidar Transmitter

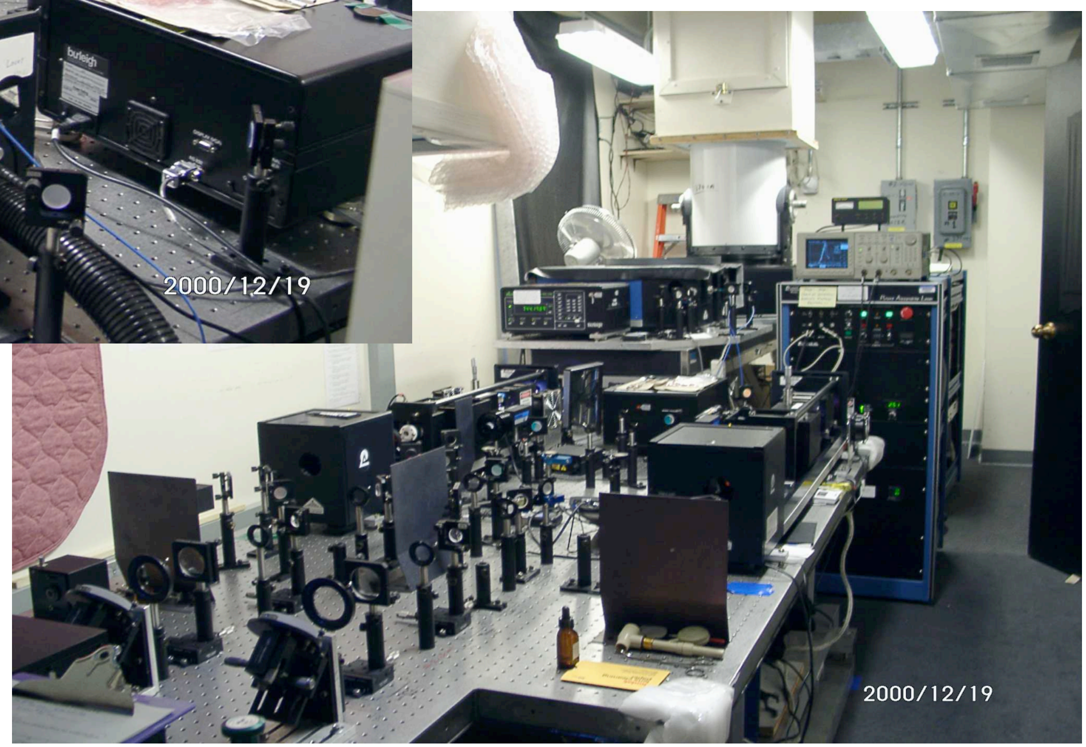


Fe Boltzmann Lidar Transmitter

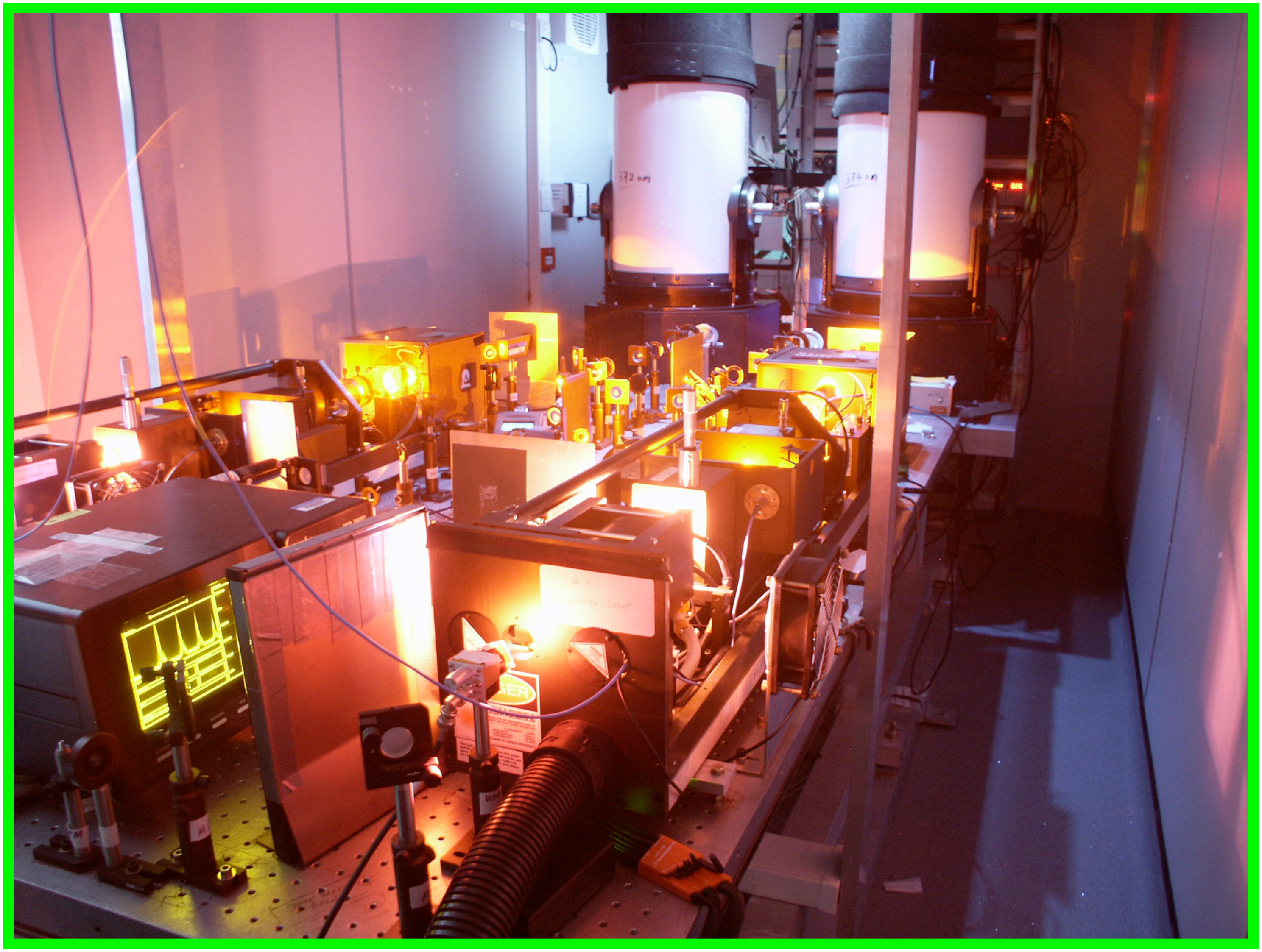
Seeder Laser Structure and Wavelength Control



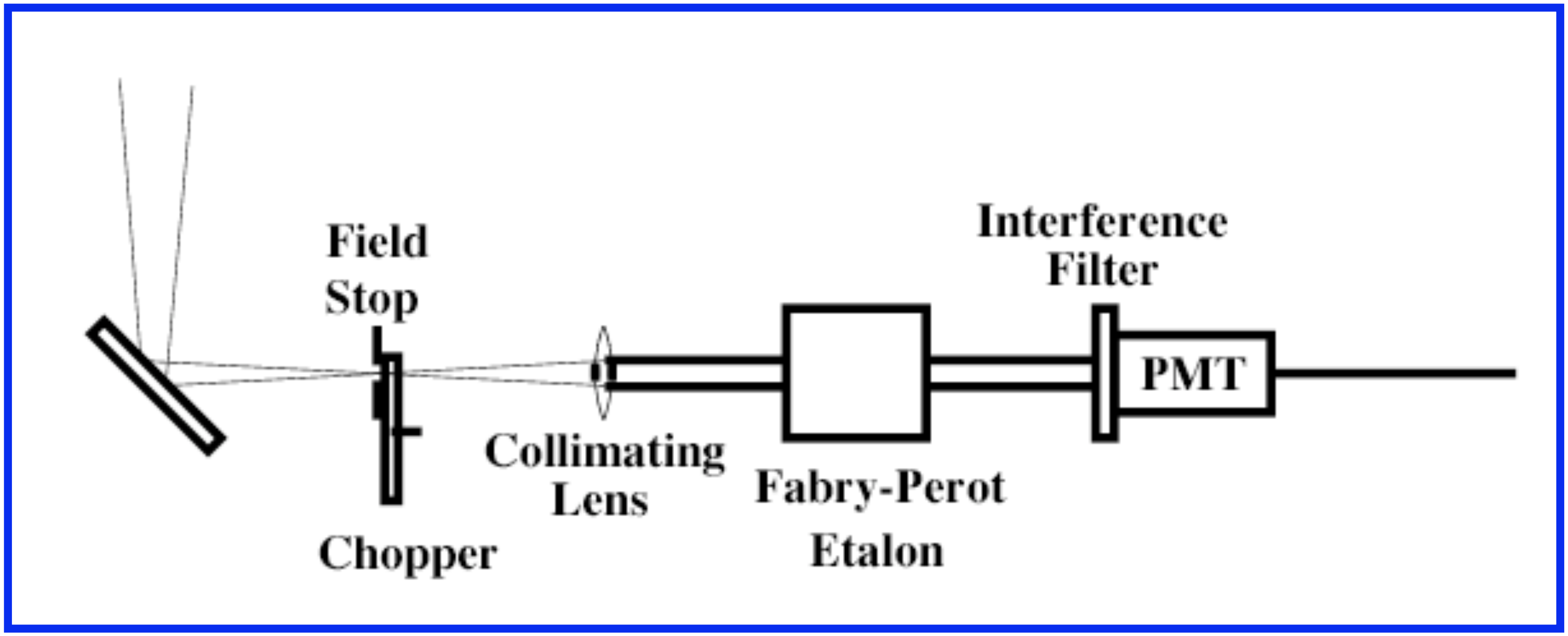
Fe Boltzmann Lidar @ South Pole



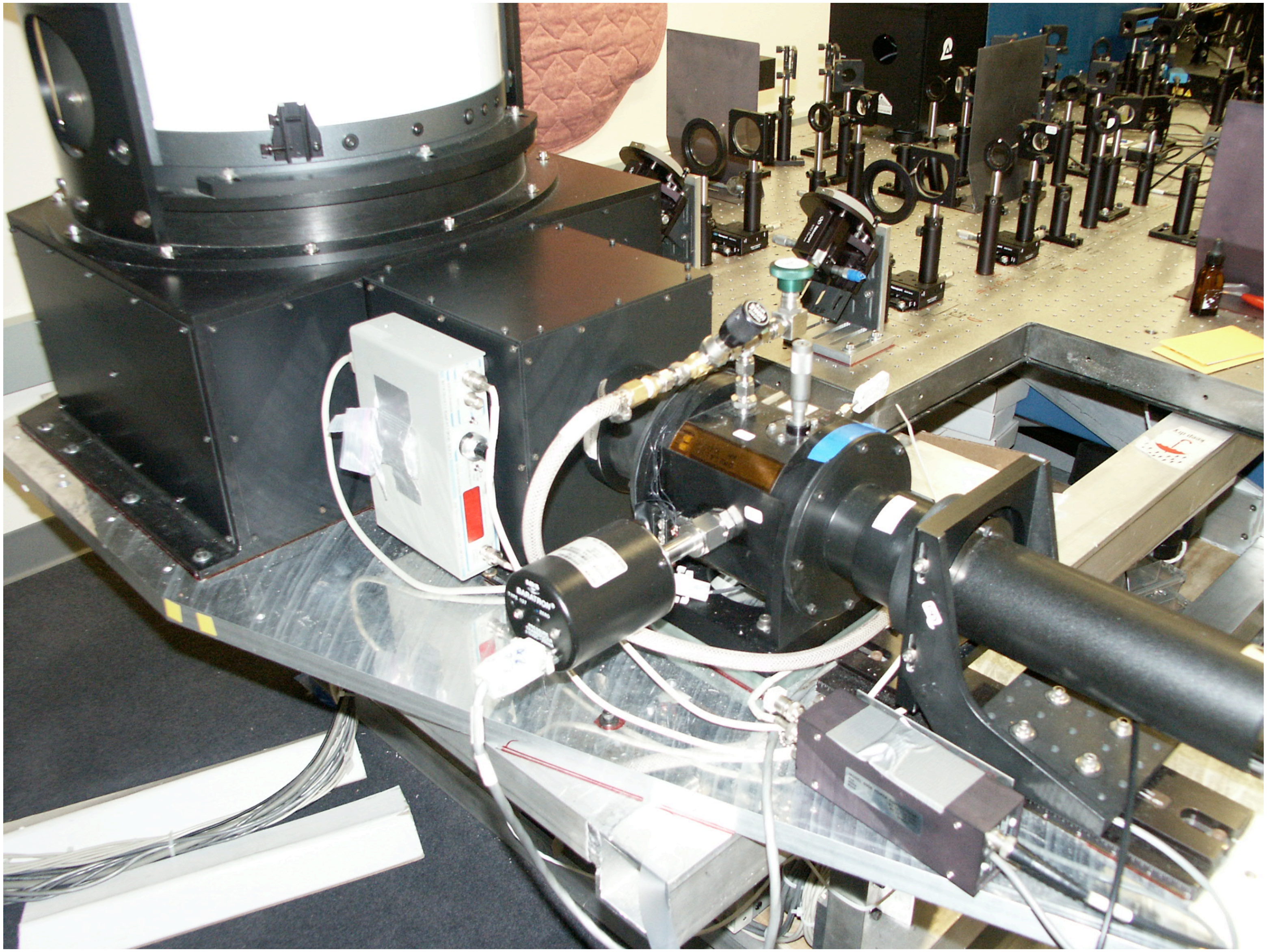
Fe Boltzmann Lidar @ Rothera



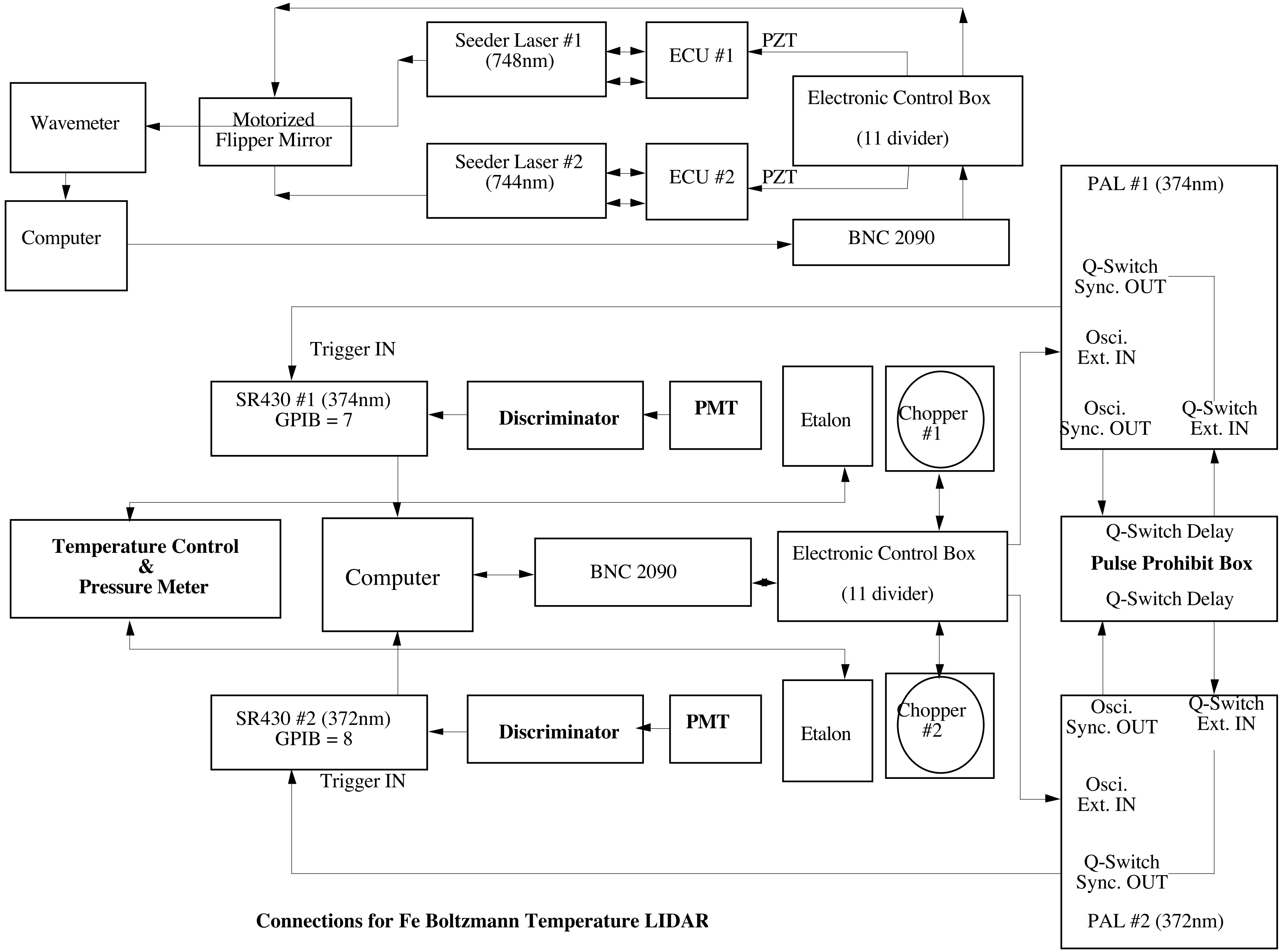
Fe Boltzmann Lidar Receiver



Fe Boltzmann Lidar Receiver



Data Acquisition and Control



Connections for Fe Boltzmann Temperature LIDAR

Summary

- Lidar architecture is the art and science of lidar instrumentation, which concerns the design of lidar hardware and software, considerations of lidar configuration and axial arrangement, etc.
- Basic architecture of lidar consists of lidar transmitter, receiver, and data acquisition and control system. Some have merged transceiver.
- Basic configuration of lidar includes bistatic and monostatic configurations.
- Basic arrangement of lidar includes biaxial and coaxial arrangements.

Summary

- Besides basic architecture, configuration, and arrangement, more considerations should be given to the selection of wavelengths (specific request and solar spectrum intensity), bandwidth of transmitter and receiver (application needs – spectral resolved or not, nighttime-only or full diurnal cycle), laser power/energy, repetition rate, pulse duration time, receiver area, detector efficiency and capability, data acquisition software, and system timing and coordination control. Cost, volume, mass, reliability, etc will also be important when come to reality.

Reading for Next Lecture

- Ring dye laser frequency control
- Acousto-optical modulator
- pulsed dye amplification
- Wavelength meter
- Interference filter
- Fabry-Perot etalon
- Faraday filter
- Injection seeding