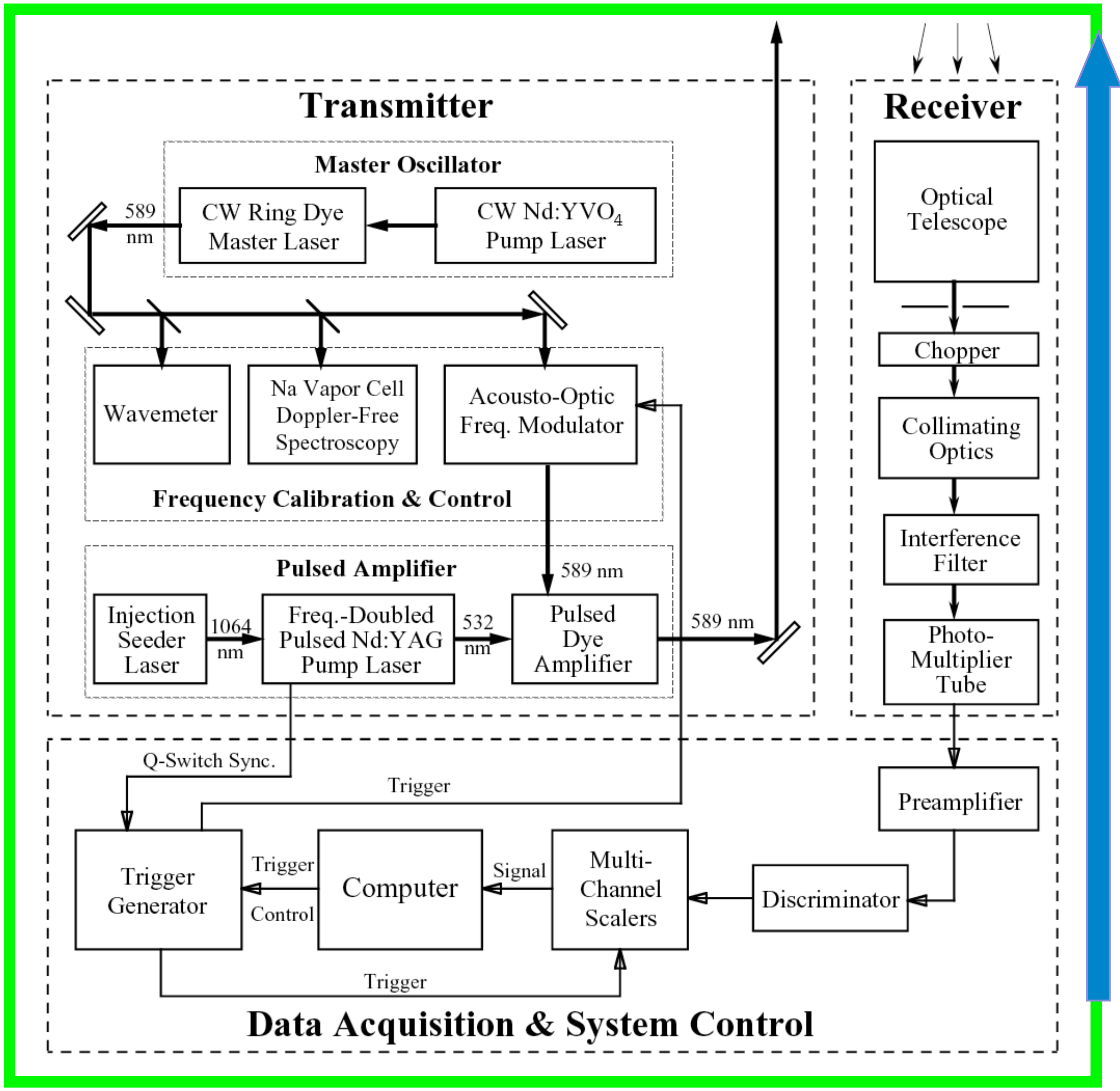
Lecture 29. Na Doppler Lidar – Data Retrieval, Lidar Simulation, and System Optimization

- Data retrieval procedure vs. lidar setup
- STAR Na Doppler lidar simulation
- STAR lidar optimization

Data Inversion – Solving Lidar Equations

- Lidar data inversion deals with the problems of how to derive meaningful physical parameters from raw data.
- Raw data are usually a column or a row of photon counts, where the positions of photon counts in the column or row mark their time bins, thus the ranges or heights.
- Data inversion is basically a reverse procedure to the development of lidar equation, i.e., solving the lidar equations to derive unknowns.
- For Na layers in the MLT region, three main unknown parameters: Temperature, wind and Na density. Therefore, by the minimum, three equations are required to derive three unknowns, which is the basic idea for 3-frequency Na Doppler wind and temperature lidar. The Maui data given in the homework projects were taken by such a lidar.
- It is necessary to understand the detailed physical procedure from light transmitting, to light propagation, to light interaction with objects, and to light detection, in order to conduct data inversion correctly.

Na Doppler Lidar



Read Data File

PMT/Discriminator Saturation Correction

Chopper Correction

Subtract Background

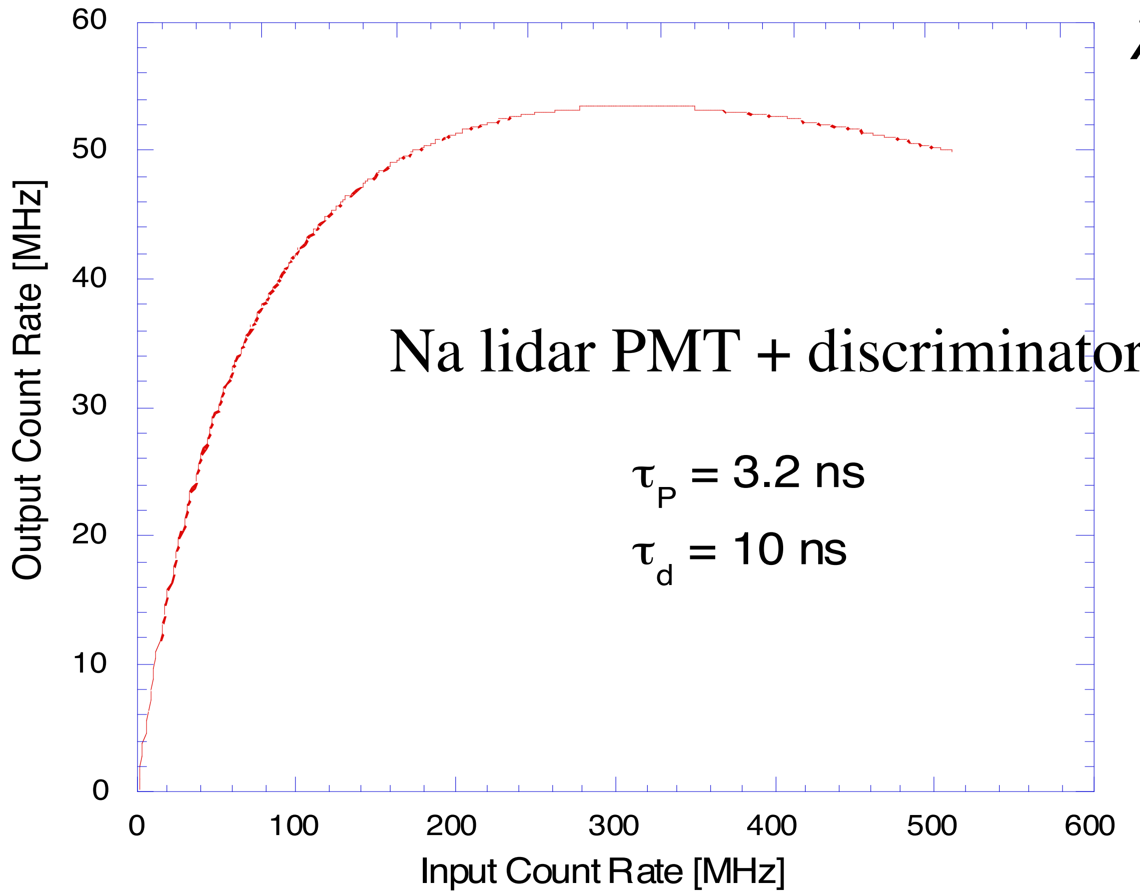
Remove Range Dependence (x R²)

Add Base Altitude

Take Rayleigh Signal @ zR km

Normalize Profile By Rayleigh Signal @ zR km

PMT+Discriminator Saturation Correction



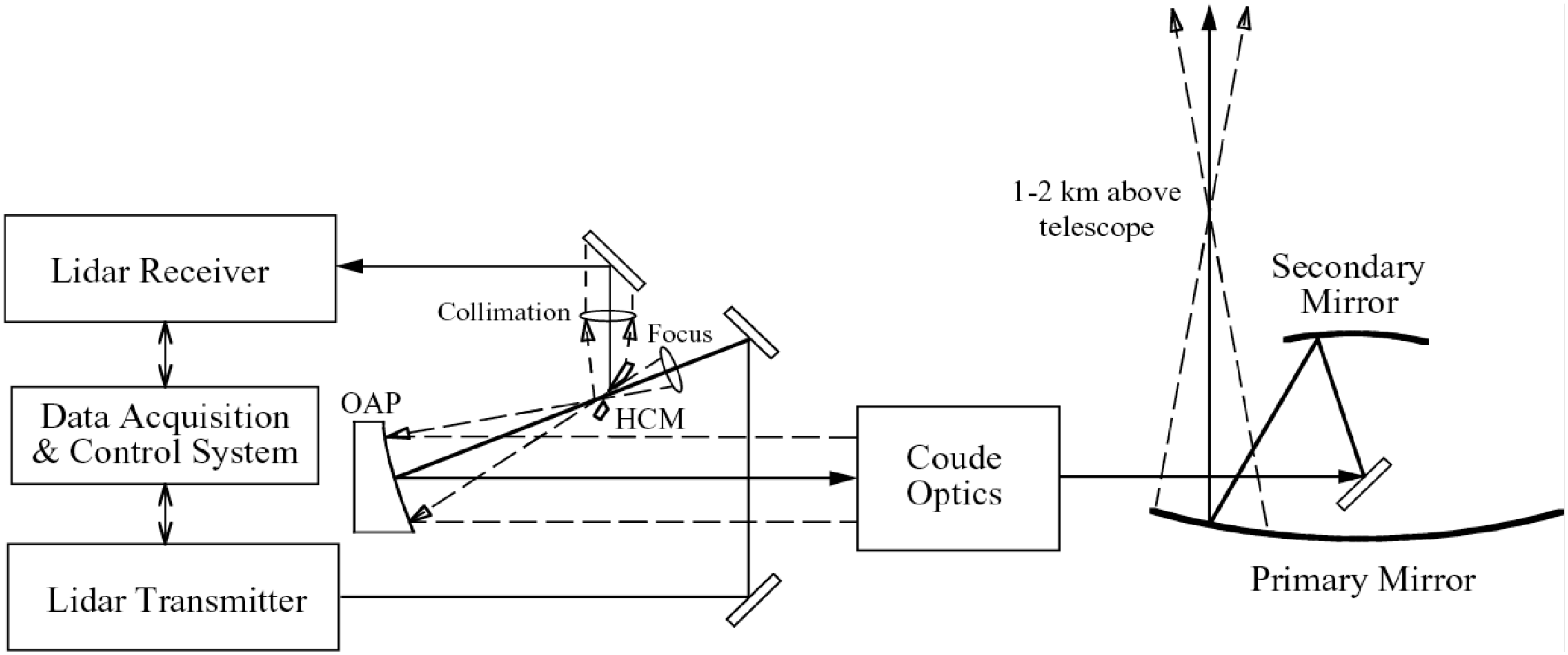
λ_S

$$\lambda_o = \frac{\lambda_S e^{-\lambda_S \tau_p}}{1 + \lambda_S \tau_d e^{-\lambda_S \tau_p}}$$

$$\lambda_S = \lambda_i \eta_{QE}$$

Maui Na Doppler Lidar
Detector Parameters

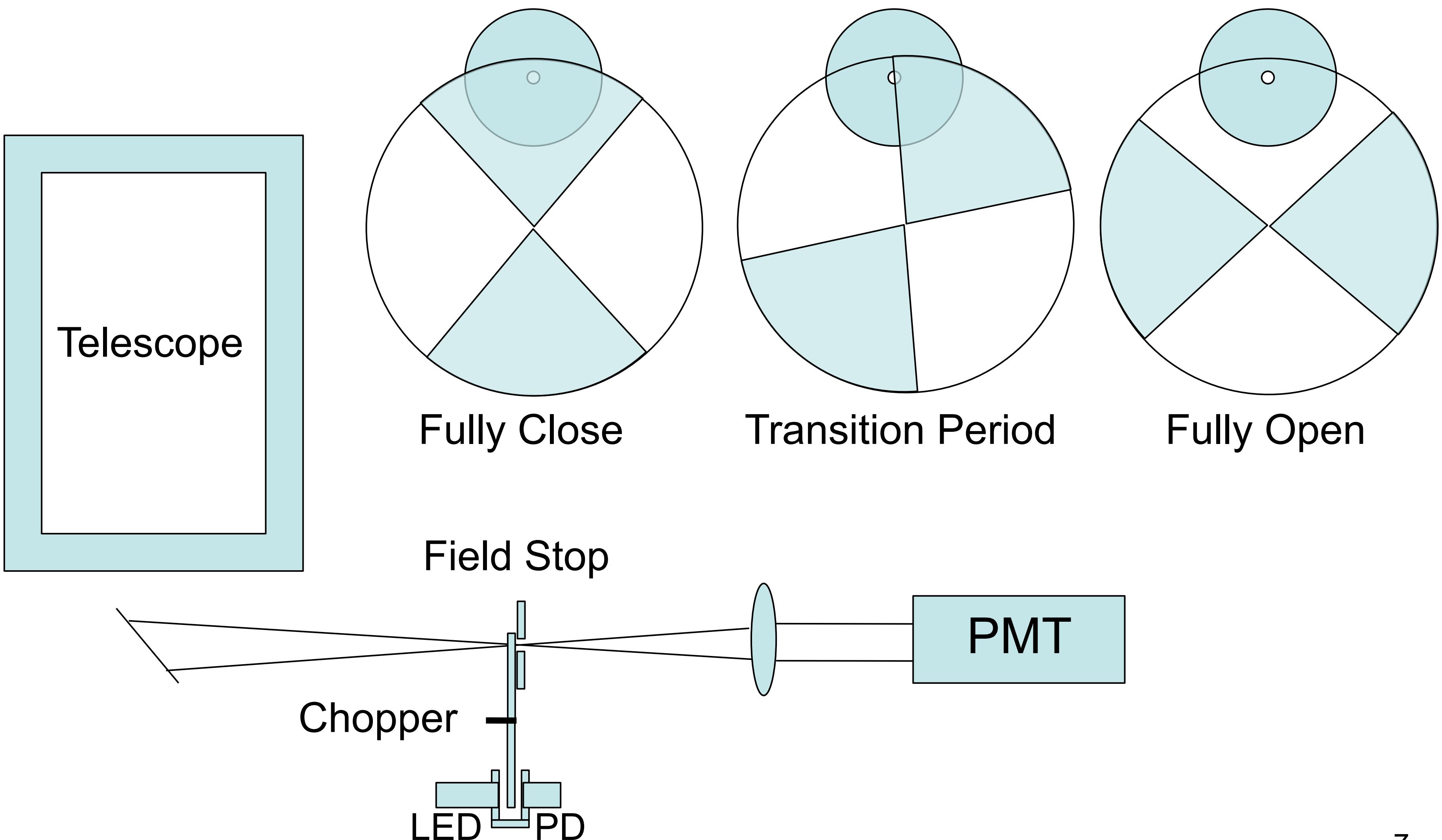
Na Doppler Lidar at Maui



UIUC Large-Aperture Steerable Na Doppler Lidar

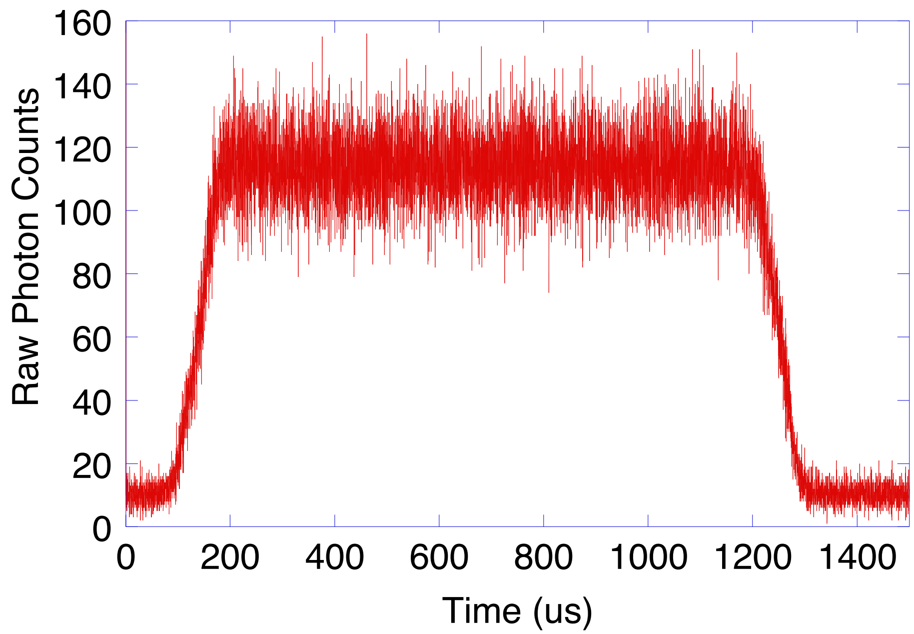

Na Doppler Lidar
@ Maui

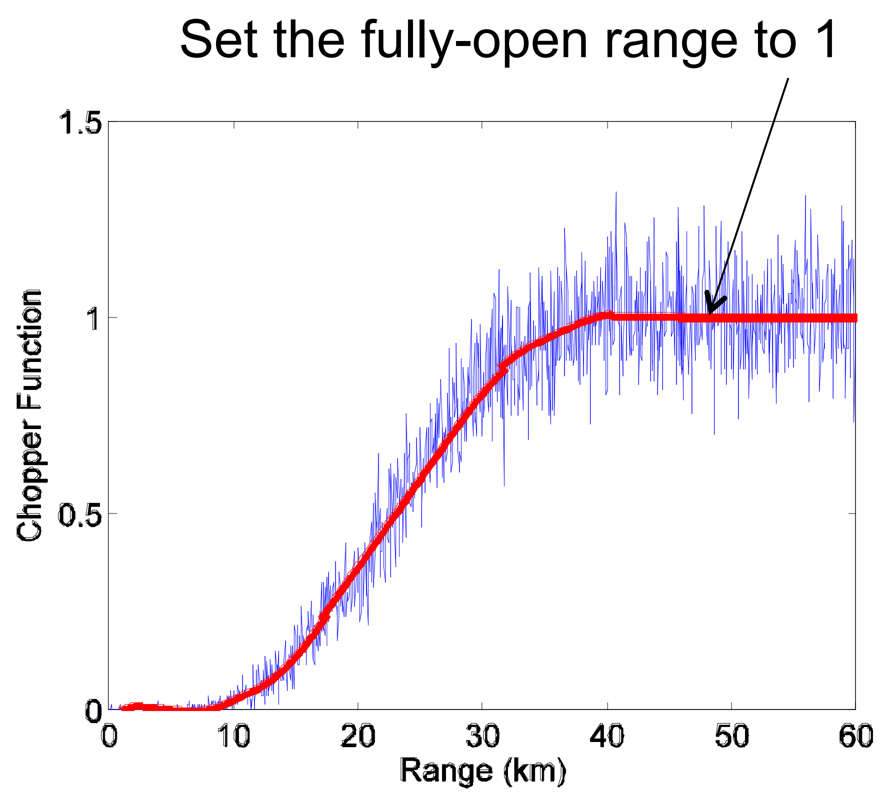
Na Doppler Lidar Receiver



Chopper Function - Transmission

- Chopper function is measured and then used to do chopper correction for lower atmosphere signals





Main Process Step 1: Starting Point & Deriving T and V_R

1. Extinction (Tc) at the bottom of Na layer is 1
2. Calculate the normalized photon count for each frequency

$$\boxed{N_{Norm}(\lambda,z) = \frac{N_S(\lambda,z) - N_B}{N_S(\lambda,z_R) - N_B} \frac{z^2}{z_R{}^2} \frac{1}{T_c^2(\lambda,z)} - \frac{n_R(z)}{n_R(z_R)}}$$

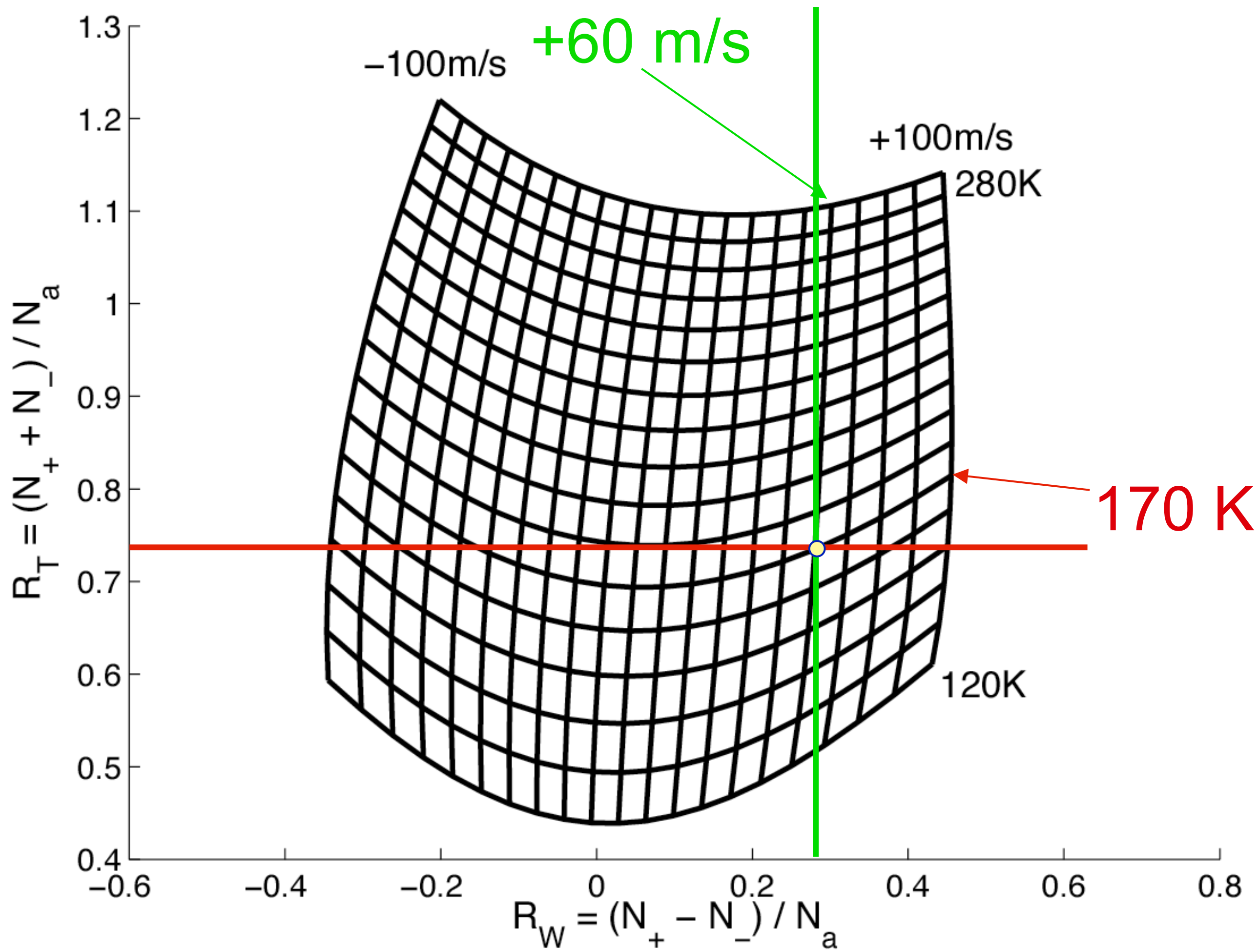
3. Based on the normalized photon counts, you get R_T and R_W

$$\boxed{R_T = \frac{N_{Norm}(f_+,z) + N_{Norm}(f_-,z)}{N_{Norm}(f_a,z)}} \quad \boxed{R_W = \frac{N_{Norm}(f_+,z) - N_{Norm}(f_-,z)}{N_{Norm}(f_a,z)}}$$

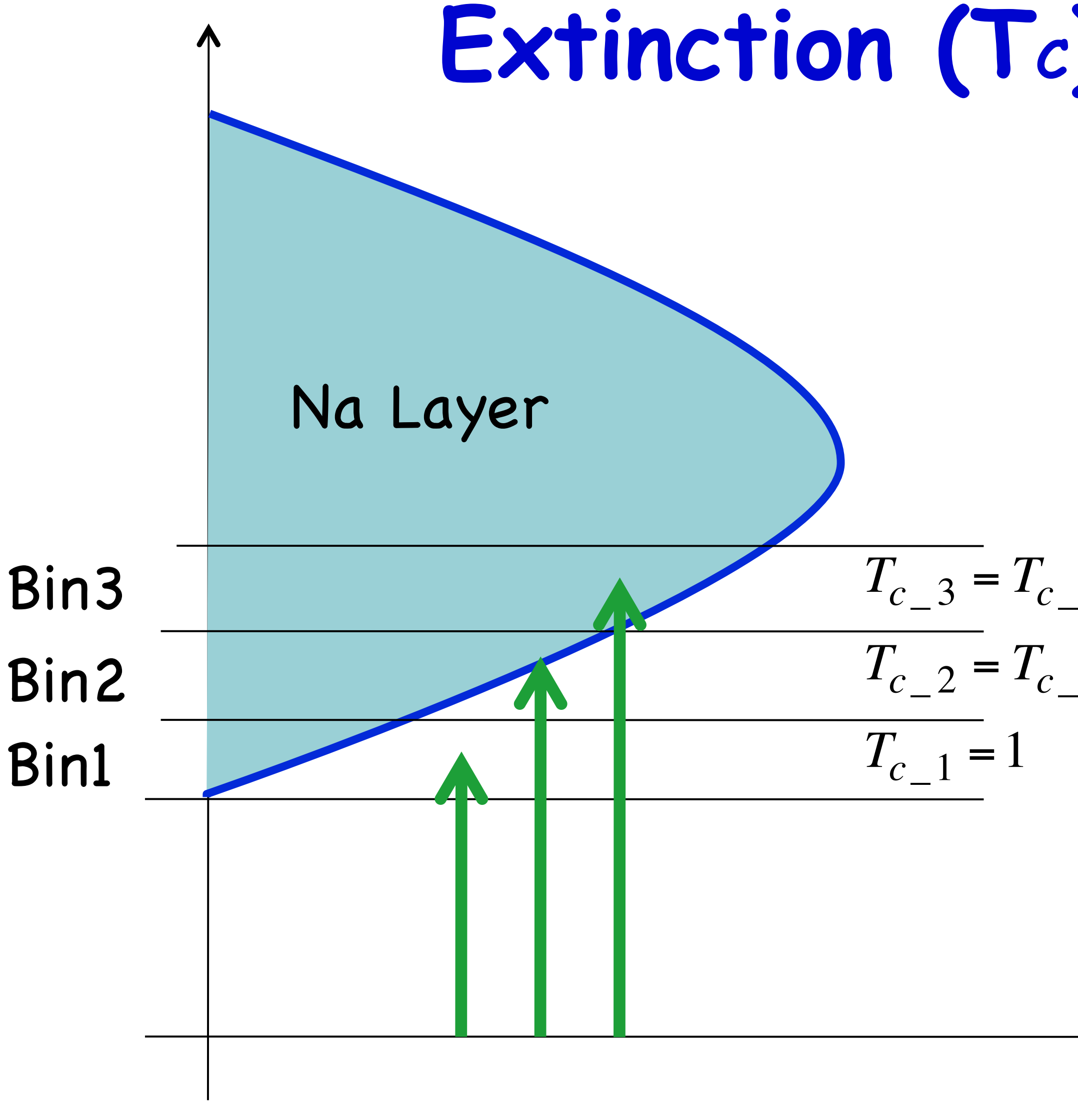
4. Estimate the temperature and wind using the calibration curves computed from physics (iteration vs. look-up table)

Iteration vs. Look-up Table

- Look up these two ratios on the calibration curves to infer the corresponding Temperature and Wind from isoline/isogram.



A Key Step to Main Process Extinction (T_c)



$$T_{c\_3} = T_{c\_2} \times \exp(-\sigma_{eff\_2} \cdot n_{c\_2} \cdot \Delta z)$$

$$T_{c\_2} = T_{c\_1} \times \exp(-\sigma_{eff\_1} \cdot n_{c\_1} \cdot \Delta z)$$

$$T_{c\_1} = 1$$

Main Process Step 2: Bin-by-Bin Procedure & Loop

5. Calculate the Na effective cross section using temperature and wind derived.
6. Using the effective cross-section and Tc = 1 (at the bottom), calculate the Na density using peak frequency signal or weighted 3-frequency signals.
7. From effective cross-section and Na density, calculate the extinction for the next bin.

$$\boxed{T_c(\lambda,z) = \exp\left(-\int_{z_{bottom}}^{z} \sigma_{eff}(\lambda,z) n_c(z) \mathrm{d}z\right) = \exp\left(-\sum_{z_{bottom}}^{z} \sigma_{eff}(\lambda,z) n_c(z) \Delta z\right)}$$

8. Loop through to repeat the procedure for the next bin for normalized counts, T and V_R, and Na density, until reaching the end of the Na layer.

Na Density Derivation

- The Na density can be inferred from the peak freq signal

$$n_{Na}(z) = \frac{N_{norm}(f_a, z)}{\sigma_a} 4\pi n_R(z_R)\sigma_R = \frac{N_{norm}(f_a, z)}{\sigma_a} 4\pi \times 2.938 \times 10^{-32} \frac{P(z_R)}{T(z_R)} \cdot \frac{1}{\lambda^{4.0117}}$$

- The Na density can also be inferred from a weighted average of all three frequency signals. The weighted effective cross-section is defined as

$$\sigma_{eff\_wgt} = \sigma_a + \alpha\sigma_+ + \beta\sigma_-$$

where α and β are chosen so that

$$\frac{\partial \sigma_{eff\_wgt}}{\partial T} = 0; \qquad \frac{\partial \sigma_{eff\_wgt}}{\partial \mathrm{v}_R} = 0$$

This method is to make the weighted effective cross-section insensitive to T and V_R, in order to minimize the Na density errors caused by the errors in derived T and V_R.

- The Na density is then calculated by

$$n_{Na}(z) = 4\pi n_R(z_R)\sigma_R \frac{N_{norm}(f_a, z) + \alpha N_{norm}(f_+, z) + \beta N_{norm}(f_-, z)}{\sigma_a + \alpha\sigma_+ + \beta\sigma_-}$$

STAR Lidar Simulation Results

- See MatLab code demonstration

For very moderate lidar pulse energy (16.7 mJ/pulse), relatively low receiver efficiency (80% reflectivity at 589 nm for primary and secondary mirrors, respectively) and the 40-cm diameter true-Cassegrain telescope, the simulation results show that

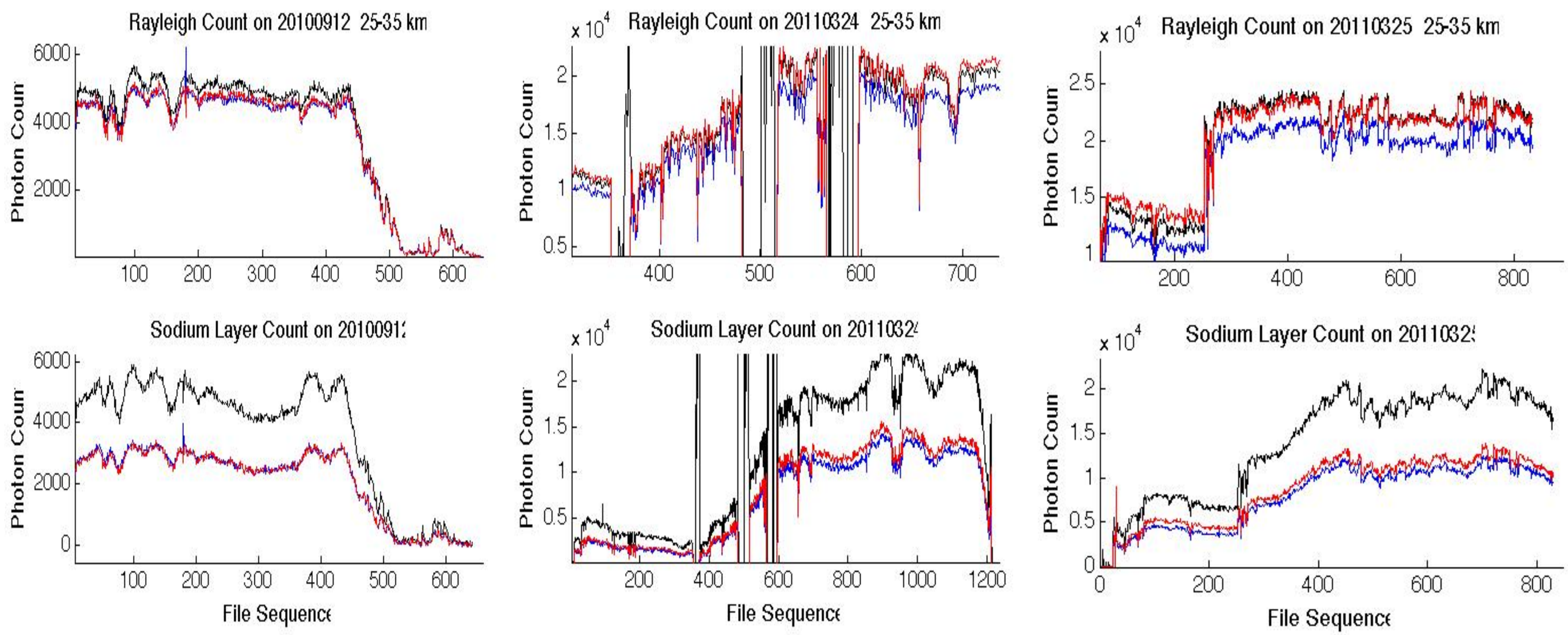
(1) Rayleigh sum of 300 shots for 25-35 km is about 26,900 counts

(2) Rayleigh sum of 300 shots for 30-40 km is about 9,100 counts

(3) Na signals of integration through the entire Na layer is about 150 count/shot.

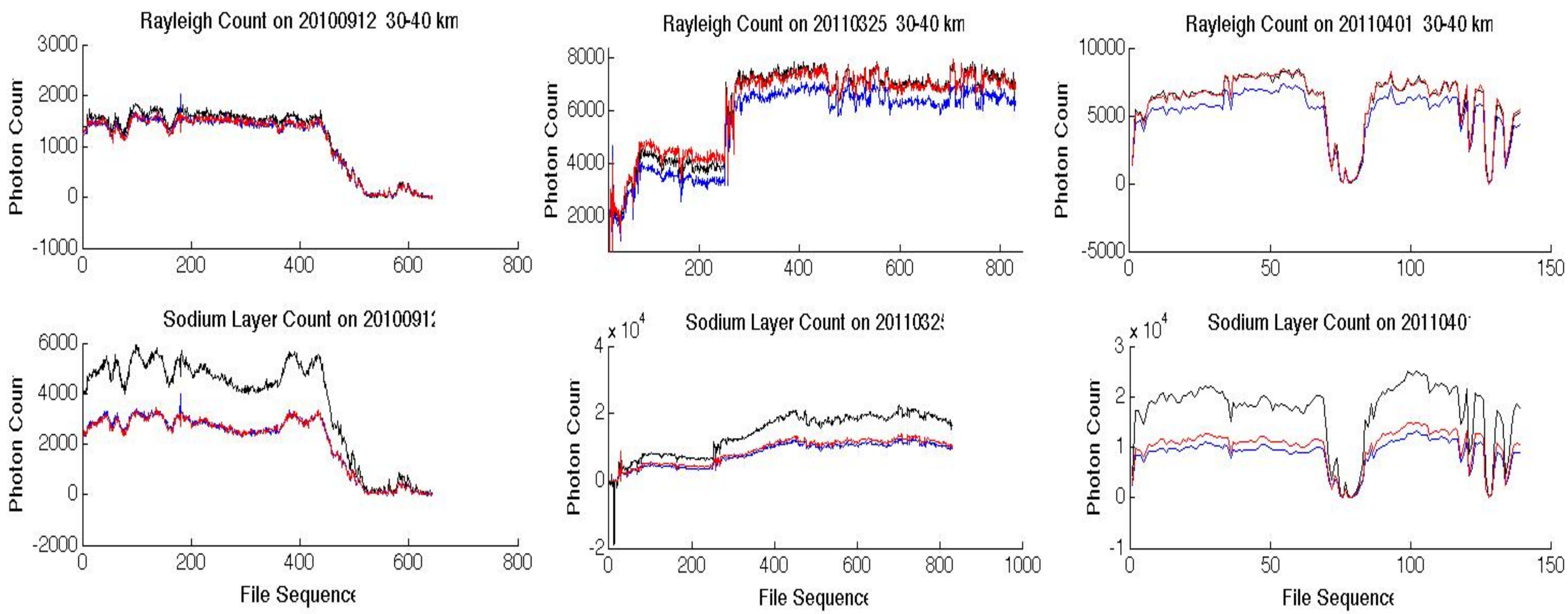
STAR Lidar Receiver Optimization

- Signal strength increased by a factor of 4-5 times from September 2010 to March 2011. It was achieved by much more precise alignment of the telescope and receiver chain.



STAR Lidar Receiver Optimization

- Similar as above, except Rayleigh is from 30-40 km range



- The Na signals have reached 80 counts/shot for the STAR lidar with a receiver consisting of a 40-cm telescope.