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Reestablishing Observations throughout the Mesosphere with the ALO-USU Rayleigh-Scatter Lidar

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Abstract

In the last few years, the Rayleigh-scatter lidar at the Atmospheric Lidar Observatory at Utah State University (ALO-USU; 41.74° N, 111.81° W) has been upgraded to extend observations from 70 km up to 115 km. This project describes a student project to build and use a complementary Rayleigh-scatter lidar to go from 40 to 90 km, from the upper stratosphere to the upper mesosphere. At the upper end, this new lidar overlaps with the high-altitude lidar. This was done in a period of just over two months. This lidar shares the same lasers, but introduces a 44-cm mirror and a new telescope for the lower altitude observations. The rest of the detector chain is modelled after the one used in the larger lidar. This small lidar will provide a ground-based way of remote sensing the upper stratosphere and mesosphere. Combined with the existing larger lidar, the entire system, covering 40 to 115 km, will provide continuous observations well up into the lower thermosphere. This combined system gives the greatest coverage of any Rayleigh lidar in the world.

Introduction

Introduction

The purpose of this project was to build a small Rayleigh scatter LIDAR to observe the 35 to 80 km altitude range and to obtain initial data. Rayleigh scattering is the scattering of radiation from objects much smaller than the wavelength of the radiation. In this case it is the backscattering of laser light by neutral molecules, mostly N_2 and O_2, in the middle and upper atmosphere. From the signal, it is possible to obtain the relative neutral density and the absolute temperature. This will be discussed in the section on Mathematics. Many of the components of the LIDAR system, listed in the abstract, will be discussed in the Lidar System section and its components. The first results will be shown in the Results/Conclusions section.

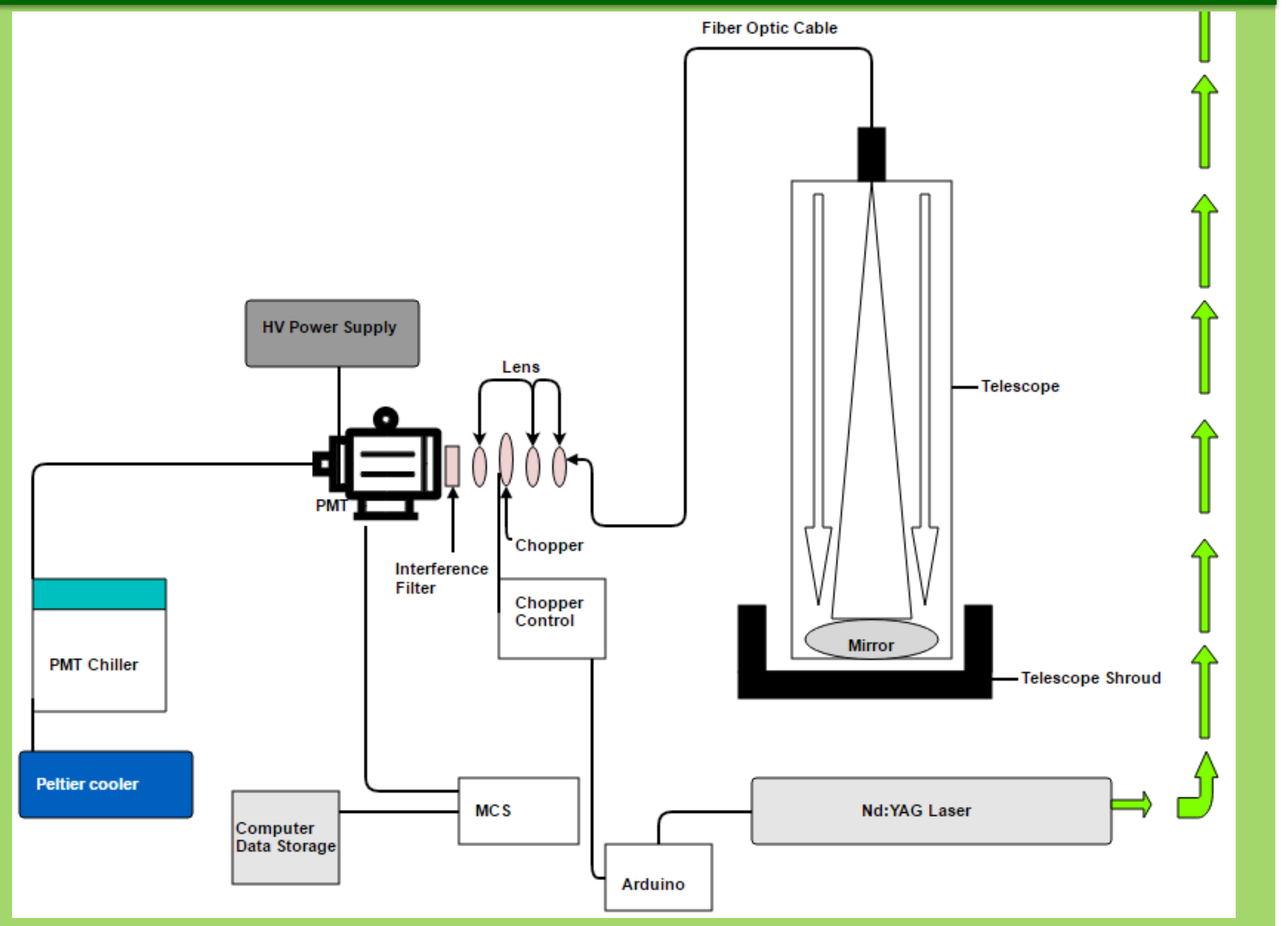

Fig. 1 LIDAR Setup

Lidar System

The small LIDAR system is shown schematically in Fig. 1. The components are described and shown in a series of Figures. The laser, Fig. 2, produces 7 ns pulses 30 times a second for a 24 W output. The laser pulse goes through a 4-times beam expander and is reflected by 90° to make it vertical, Fig. 3. The vertical beam is seen in front of the moon in Fig. 4. The beam expander makes the spot in the sky small enough that its image fits onto the tip of the fiber. To make the system work, there is considerable critical timing. An existing 44 cm diameter mirror was used to build a simple Dobson telescope, Fig. 5, with a 1.99 m focal length. At the focal point there is 1.5 mm diameter red fiber with a 0.39 numerical aperture to take the light to the detector area on the floor below, Fig. 6. Two achromatic doublets take the light from the fiber and produce a small spot on the chopper, Figs. 6 and 7. A chopper controller, Fig. 8, controls the rotational speed of the chopper blade and gives rise to the timing pulses that control the timing of the whole LIDAR system. The chopper is needed to block very bright low-altitude light that would hurt the detector. The light then passes through another achromatic doublet, which produces a parallel beam of light that goes through a 1-nm wide (FWHM) interference filter. It is to block out any light (moonlight, starlight, airglow, city lights) except that from the backscattered green laser beam at 532 nm. It then goes into the actual detector that is in a big housing, Fig. 6. Inside, a photomultiplier tube (PMT) converts incident photons into electrical pulses and, through a series of 12 dynodes, amplifies the pulses by 10^7. To operate, a high voltage power supply, provides -1900 VDC to the PMT photocathode. A PMT socket with appropriate wiring gets the appropriate voltage to each dynode. To minimize thermionic emission of electrons from the photocathode, which create system noise, the PMT housing is cooled to -25 C by a combination of chilled water and a Peltier cooler. The PMT output goes to a multichannel scaler (MCS), Fig. 9, which starts counting the moment the laser pulse is emitted and counts the successive return photons at altitude intervals of 37.5 m. It continues up to 525 km. It co-adds the counts for every laser pulse for 2 minutes and then writes the results to the computer. It starts with the chopper. Other timing pulses to control the laser flash lamps and Q-switch, and the MCS are then generated in an Arduino microprocessor.

Components

Fig. 2. Nd-YAG Laser

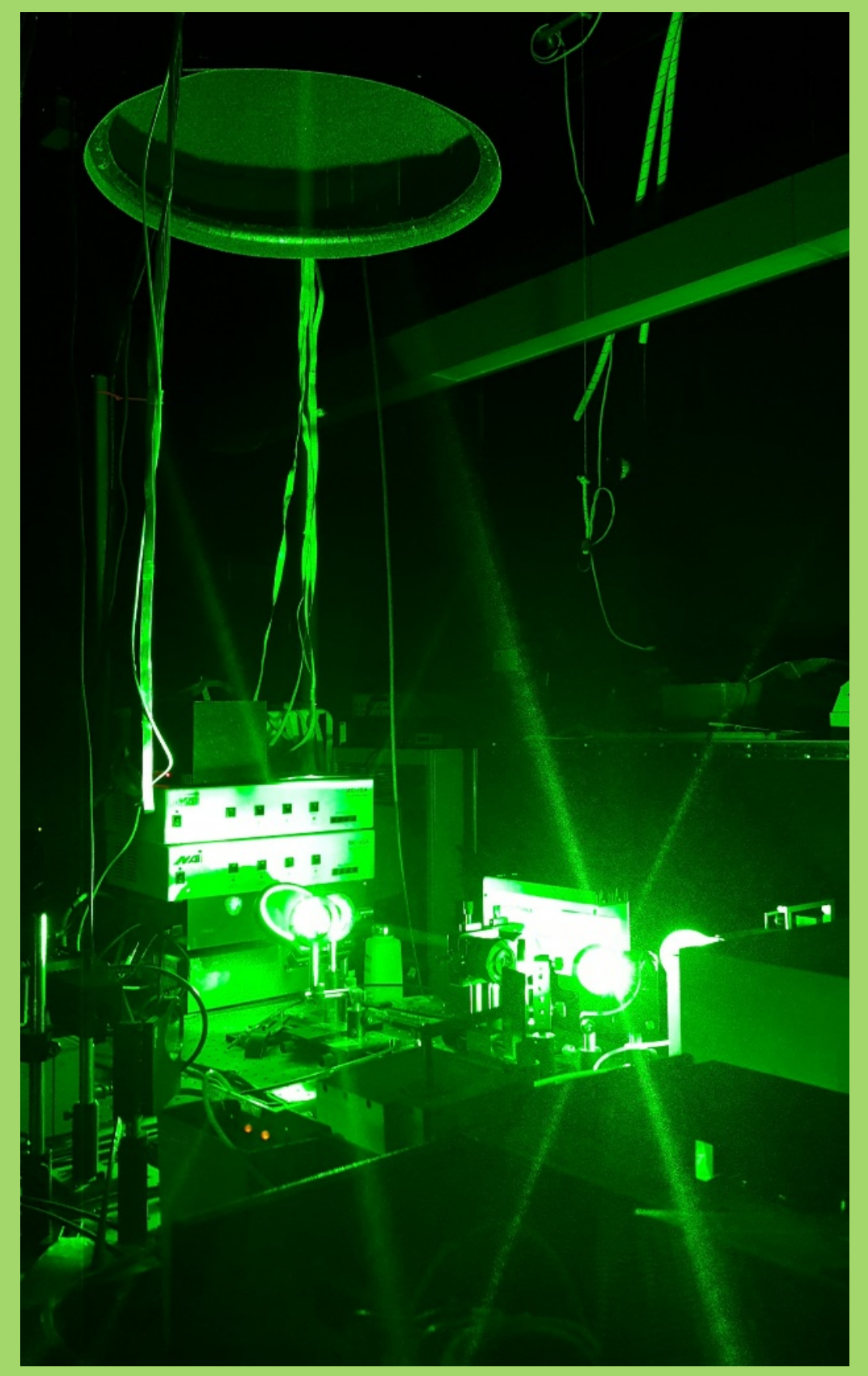

Fig. 3. 4x Beam Expander

Fig. 4. Laser Beam & Moon

Fig. 5. Dobson Type Telescope

Fig. 9. Two Multichannel Scalers (MCS)

Fig. 8. Chopper Timer

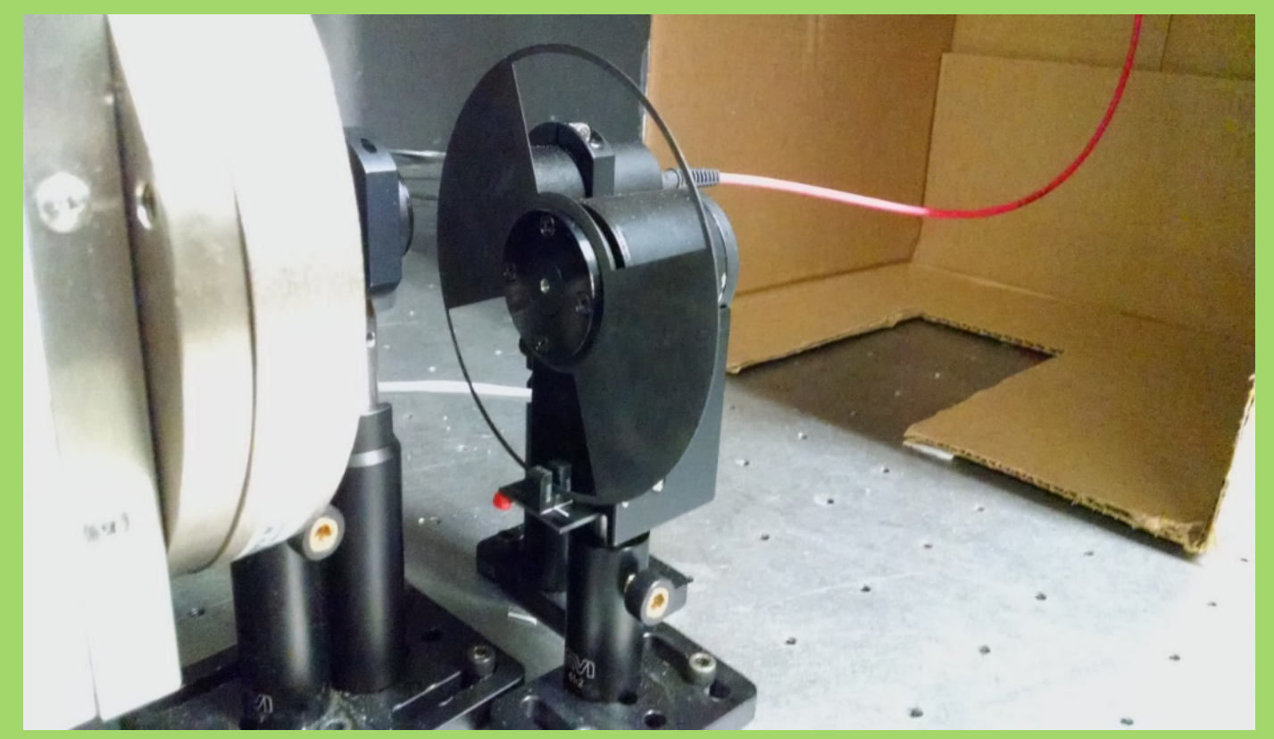

Fig. 7. Fiber, Chopper & PMT Housing

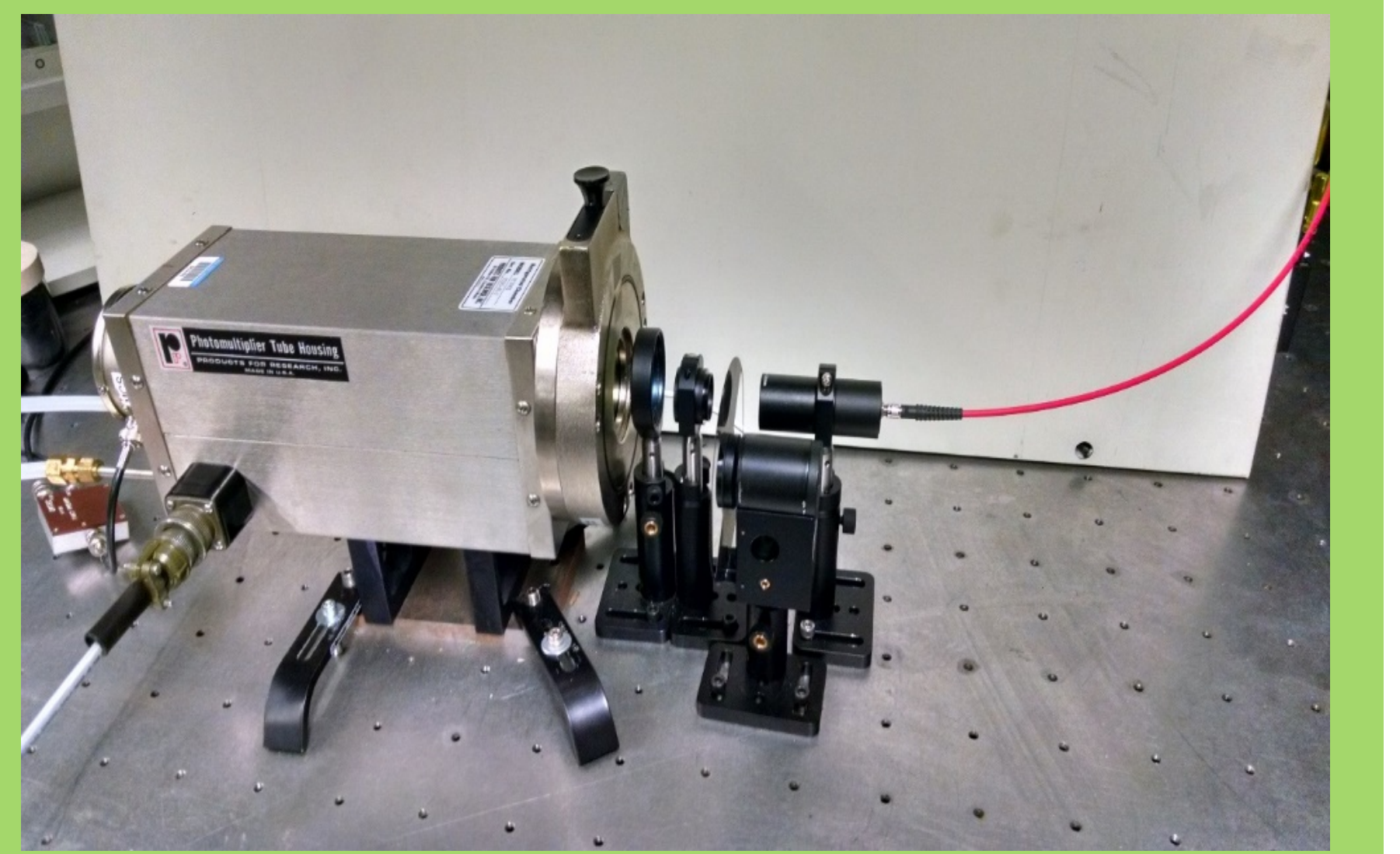

Fig. 6. Detector Area showing Fiber, Chopper, Lens, Interference Filter and PMT Housing

Mathematics

To convert relative densities to atmospheric temperatures [1], start with hydrostatic equilibrium in SI units

$$dp = -n(h)m(h)g(h)dh,$$

where at height h, p is pressure, n is molecular number density, m is mass, and g is gravitational acceleration.

Integrate from height h on the profile to the maximum height h_{max}

$$\int_h^{h_{max}} dp = p(h_{max}) - p(h) = -\int_h^{h_{max}} n(h')m(h')g(h')dh'.$$

To put in terms of temperature, apply the ideal gas law,

$$p(h) = n(h)kT(h),$$

where k is Boltzmann's constant, and T is temperature. Get

$$T(h) = T(h_{max})\frac{n(h_{max})}{n(h)} + \frac{1}{k}\int_h^{h_{max}} \frac{n(h')}{n(h)} m(h')g(h')dh'$$

Note that this expression only depends on relative number density.

Results/Conclusions

Results

The telescope was aligned and data recorded for the night of 8 April 2016 from 3:00 to 10:30 UT. The data was then run through the data reduction program and temperatures calculated. This meant subtracting out the background noise, multiplying the resultant signal by the altitude squared to obtain the relative density, and then performing the temperature integration as described in the mathematics section. The slightly offset signal profiles at 2-minute intervals are shown in Fig. 10. Initially, the chopper is closed giving essentially zero signal below 30 km. Some very strong, low-altitude light scatters around the detector light baffles below 5 km. Light scattered from cirrus clouds shows up on occasion at 12 km. The chopper opens between 32 and 37 km. The Rayleigh back-scattered signal from atmospheric particles falls off exponentially above ~37 km. The derived temperatures are shown at 1-hour intervals in Fig. 11. For each profile the curve is shifted by +50 K. Several waves show up starting just below 70 km. More waves appear towards dawn. The all-night temperatures are shown in Fig. 12 along with their uncertainties for two types of signal smoothing. With the extra averaging, the stratopause shows up clearly at 48 km, and a wave with a 5-to-7 km vertical wavelength appears.

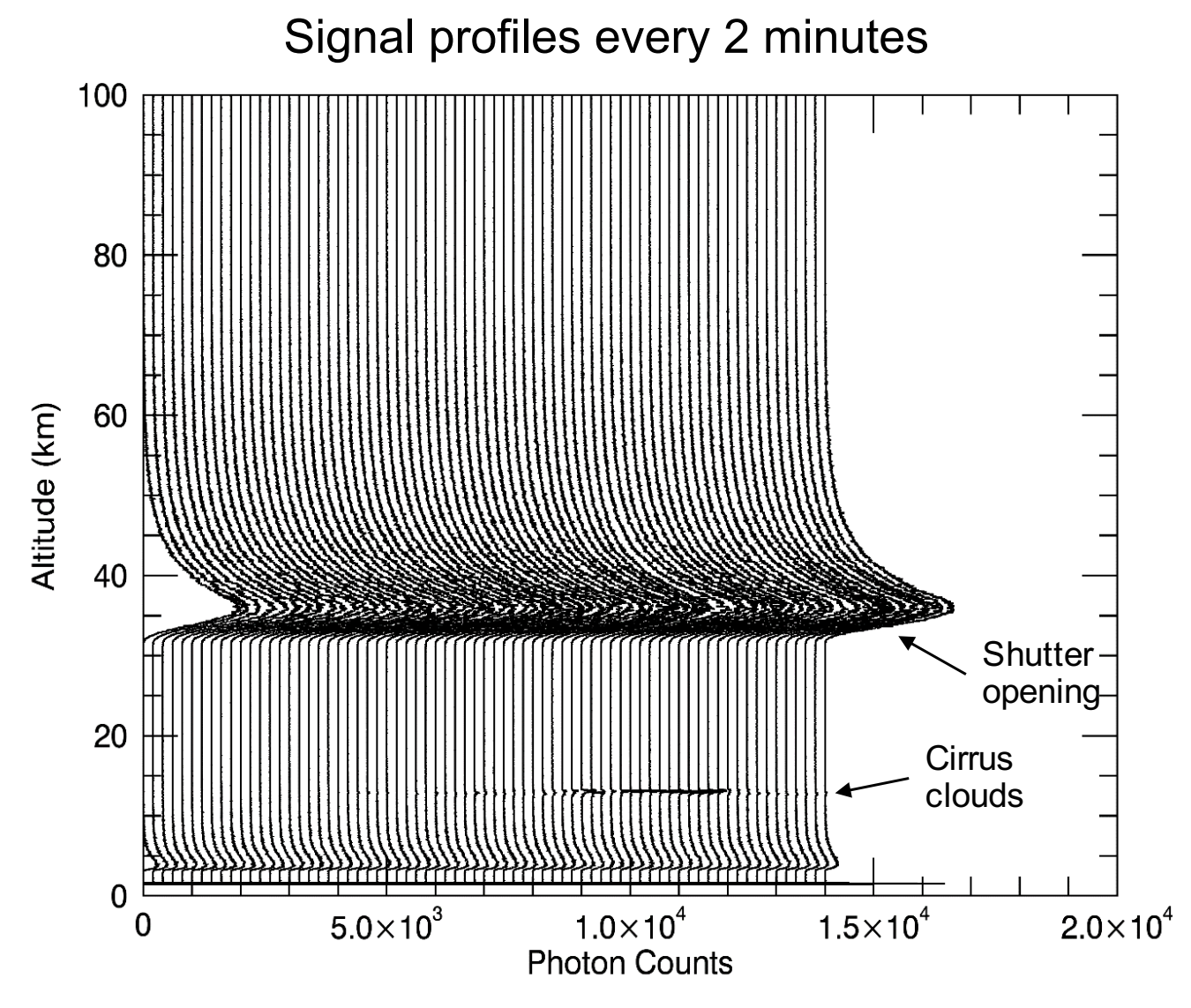

Fig. 10. Signal profiles.

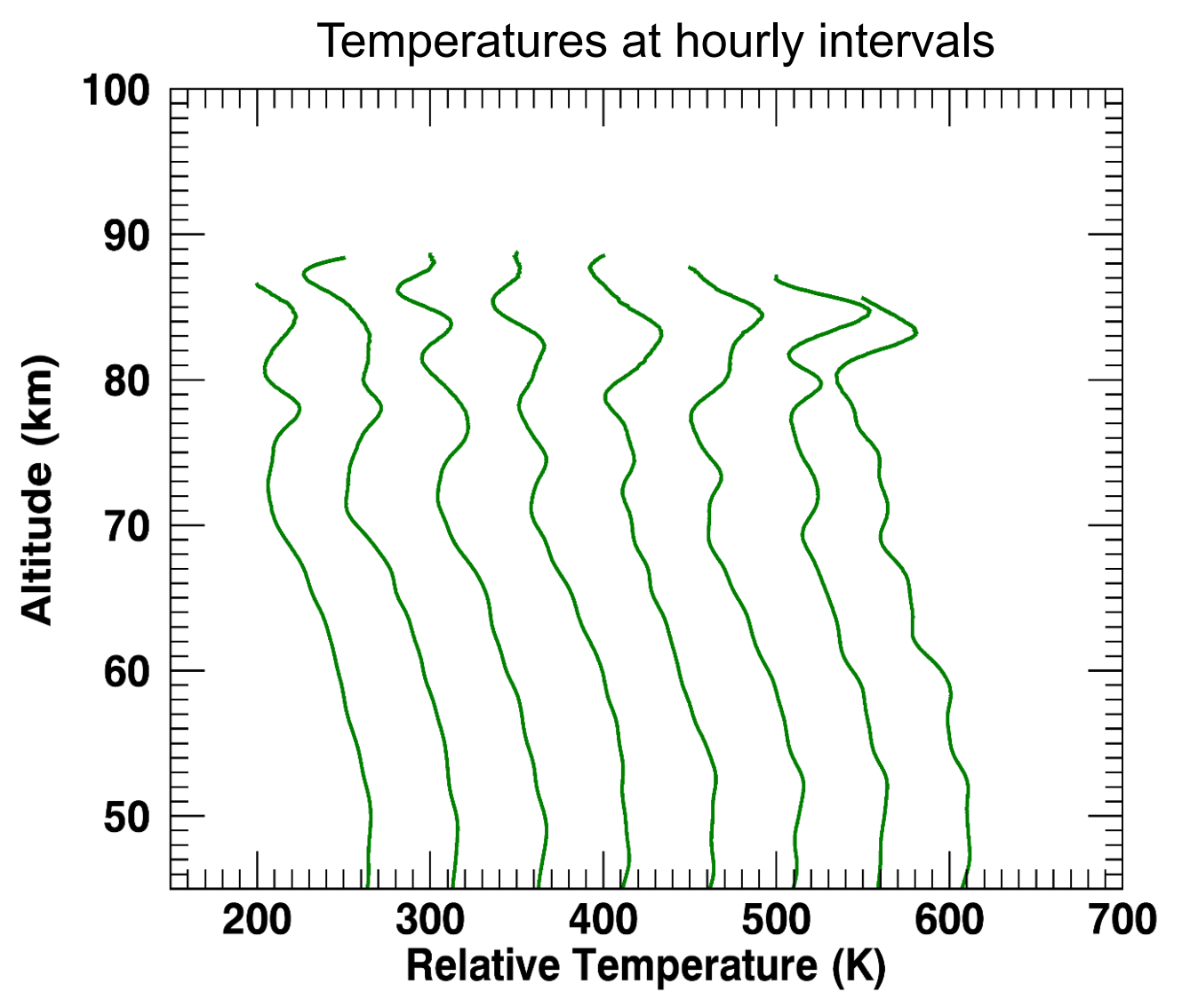

Fig. 11. Absolute temperatures.

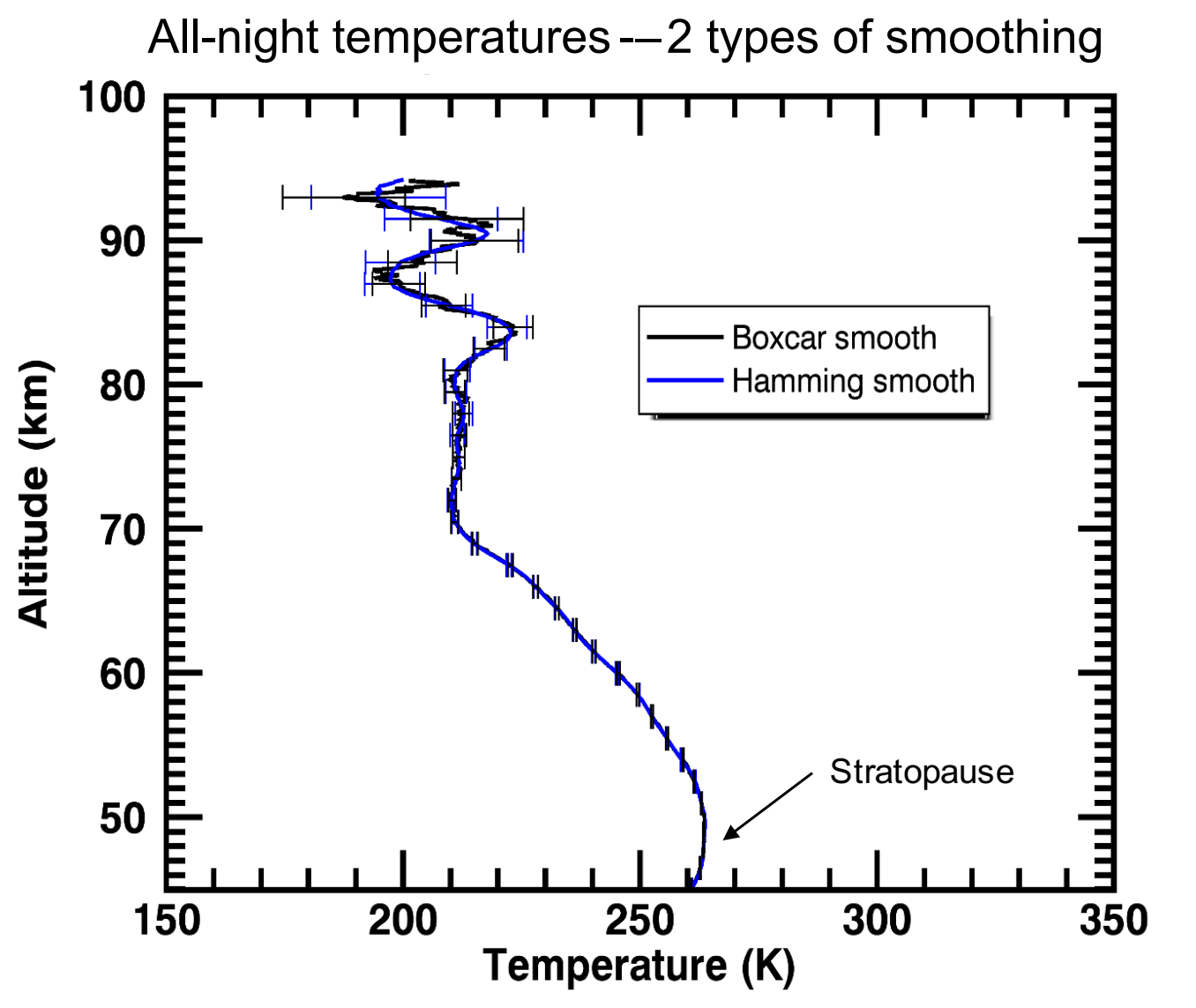

Fig. 12. Temperatures & uncertainties.

Conclusions

To build and obtain first light with the small LIDAR involved many tasks typical of experimental research: learning about many specialized pieces of equipment and software, and making them work alone and together. With this system functioning, it can be used by itself or with the ALO-USU large LIDAR. They can provide critical information for a number of scientific studies involving much of the atmosphere. These include the propagation of waves through the atmospheric regions, or their reflecting; extensive investigation of densities and temperatures in the lower thermosphere and their dependence on what happens lower in the atmosphere; long-term climate change (by combining new observations with an earlier 11-year set of observations [2]); and, of course, the possibility of finding new phenomena.

References

[1] Herron, Joshua P. (2004). *Atmospheric Temperature Climatology Above Utah State University*, MS Thesis, USU.

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