

## LIDAR system in Central Laser Facility of Telescope Array Experiment

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**Abstract:** The calibration of the scattering of UV fluorescence light from extensive air showers by aerosols and molecules in the atmosphere is important for the air fluorescence technique. Two monitoring devices (LIDAR and CLF) already observe atmospheric transparency for the Telescope Array (TA) experiment. To understand the temporal dependence of the change of transparency on altitude in more detail, a new LIDAR system has been set up at the CLF. This new system (LIDAR@CLF) has been operating since March 2011. The device, analysis method, and latest results of LIDAR@CLF are discussed in this paper.

**Keywords:** UHECR, fluorescence technique, Atmospheric transparency, LIDAR, CLF

## 1 Introduction

The Telescope Array (TA) experiment was constructed in the desert southwest of Delta, Utah in the USA. It is a hybrid detector consisting of a surface detector (SD) array of scintillator counters, and three air fluorescence detector (FD) stations. TA measures the energy spectrum, arrival direction, and composition of ultra-high energy cosmic rays (UHECR) to identify their origin. Three FD stations of air fluorescence telescopes, called Black Rock FD (BRFD), Long Ridge FD (LRFD), and Middle Drum FD (MDFD), have been installed around the SD array.

Some of the UV fluorescence light generated by an air shower is scattered and lost along the path of propagation to the FD telescopes. The main cause of this loss is due to Rayleigh scattering from air molecules, and Mie scattering from aerosols in the atmosphere. The calibration of this loss due to scattering is very important to the calibration of the FDs.

Rayleigh scattering can be estimated from information on how the temperature and pressure of the atmosphere varies with altitude. This information is gathered daily by ra-

diosonde from Elko Nevada which is just a little west of the TA site.

It is necessary to measure the scattering due to aerosols regularly because the shape and amount of aerosols can vary rapidly with time and location. So aerosols should be measured as close to the time and place of the FD observations as possible.

The existence of clouds interrupts a telescope's field of view and changes the active aperture of the FD. Therefore it is also important in observations of EAS to monitor cloud cover at the site.

In TA, we employ a variety of measuring systems for atmospheric monitoring, consisting of two laser systems and a cloud camera. The first laser system is LIDAR (Light Detection and Ranging), which observes the back scattered light from a laser. LIDAR is widely used for ground based aerosol measurement. The LIDAR system at BRFD is operated before the beginning and after the end of an FD observation, twice a night. The second laser system is the Central Laser Facility (CLF) which is located at the center of the fields of view of all three FD stations.[4][5] It fires a vertical beam of UV light, the scattered photons from which is seen by all three FDs. In addition we have in-

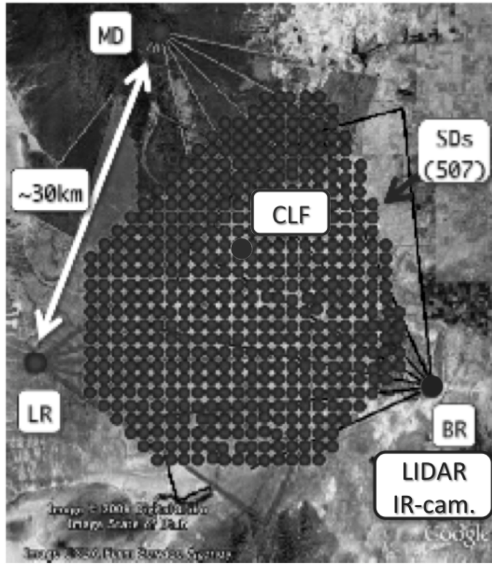


Figure 1: Location of the atmospheric monitoring system. A figure is a map of the TA experiment. A purple point is SDs, and three FD stations are shown by BR, LR, and MD. Therefore, the red point is LIDAR and IR-cloud monitor, and the light green point is CLF.

stalled an infrared CCD camera for cloud monitoring near the LIDAR system that takes pictures of the night sky every hour during FD observations.[6]

## 2 LIDAR system

The LIDAR system was constructed about 100 m north of the BRFD. A LIDAR system fires a short laser pulse into the atmosphere, then measures the amount of backscattered light that returns to the LIDAR. Our system is shown in figure 2. The LIDAR fires pulses of 355 nm laser light with a pulse width of  $\sim 5$  nsec at a rate of 1 Hz. The maximum energy of the laser is 4 mJ.

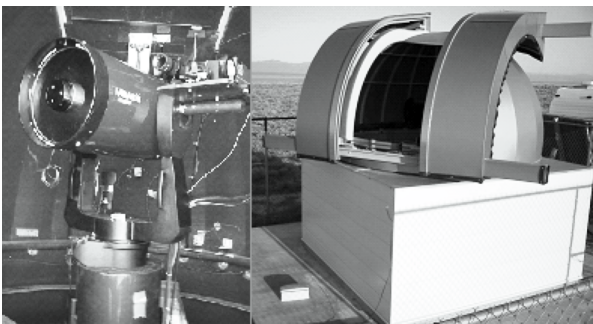


Figure 2: LIDAR system.

This system is able to obtain the extinction coefficient  $\alpha$  (e.g., the reciprocal of the attenuation length) as a function of height. From  $\alpha$ , the attenuation factor  $T(x)$  for photons that propagate in the atmosphere for a distance  $x$  is given

by Equation 1.

$$T(x) = \exp \left[ - \int_0^x \alpha(x') dx' \right]. \quad (1)$$

The  $\alpha$  for aerosols is obtained by subtracting the calculated  $\alpha$  for Rayleigh scattering at each height from the  $\alpha$  measured by the LIDAR at the corresponding height. LIDAR measures the *alpha* in detail at ground level by taking a horizontal shot and with altitude by taking a vertical shot. However, low altitudes (less than 1 km) are not measured in the vertical shot because too much light is scattered from close by the LIDAR and saturates the system. The LIDAR observations are done twice a night, before and after the FD observations, because the laser is very bright in the FD field of view and we need 30 minutes to take the series of shots needed for a measurement.

## 3 Central Laser Facility

The CLF was constructed at the center of the fields of view of all three FD stations. The vertical laser of the CLF has a series of shots every 30 minutes during FD observations to calibrate each FD's efficiency including atmospheric conditions. The CLF (shown in figure 3) only fires laser pulses, and does not detect any because the FD's are used to observe its pulses. The CLF laser fires a 355 nm pulse of width  $\sim 7$  ns at 10 Hz synchronized with the GPS 1PPS signal. This synchronization allows us to remove CLF pulses from the data stream by merely observing time stamps. The maximum energy of the CLF laser is 10 mJ.

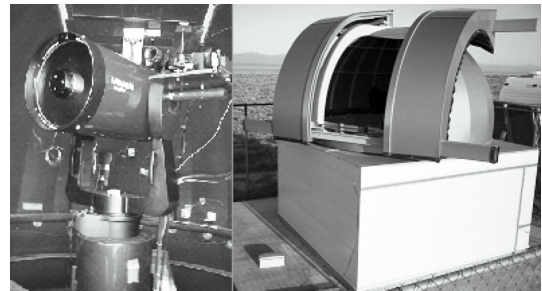


Figure 3: CLF system.

This system can obtain the Vertical Aerosol Optical Depth (VAOD) by adjusting for Rayleigh scattering and the detection efficiency of the FDs. VAOD( $h$ ) is equal to the integral of  $\alpha(h)$  from 0 to  $h$  km. So the attenuation factor  $T(h)$  for photons that propagate vertically through the atmosphere from height  $h$  is given by equation 2.

$$T(h) = \exp [-VAOD(h)]. \quad (2)$$

The VAOD obtained from CLF measurements accurately reflects the total amount of aerosols because the photons pass at low altitude from the CLF to the FD like from an

EAS. In addition, since we fire the CLF every 30 minutes, we can measure any temporal variation of the aerosol. However, the VAOD in low altitude is indistinct because angular distributions of the scattering cross section of the aerosol greatly influence in calculation of VAOD in the low altitude where a lot of aerosols exist.

#### 4 New LIDAR system at CLF

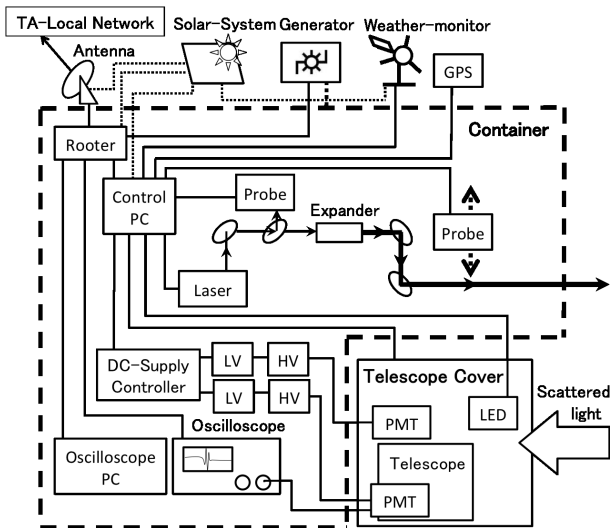


Figure 4: The block diagram of New LIDAR system at CLF.

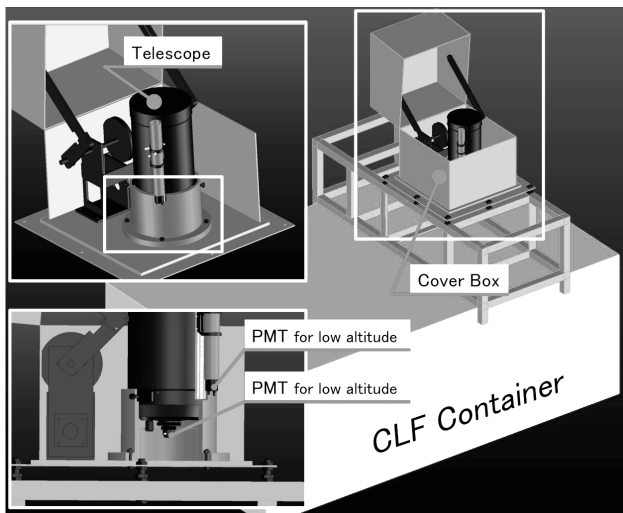


Figure 5: The image of New LIDAR system at CLF.

In March 2010, the TA collaboration authorized a new system to measure the backscattered light from the CLF in order to better parameterize the altitudinal and temporal distribution of atmospheric transparency. This new LIDAR system was constructed on the roof of the CLF to obtain data every 30 minutes during FD observations.

#### 4.1 Devices and operation

The new LIDAR system (LIDAR@CLF) is only made up of a telescope, PMTs, and DAQ system, since the laser it observes is the CLF laser. The telescope with PMTs is installed in a box that is set on a platform affixed to the roof of the CLF container. The cover of the box automatically opens and closes for observation. The telescope is aligned in the vertical direction.

Backscattered photons from the CLF pulse are received by a telescope (Celestron C11 AL(XLT), 30 cm aperture) and sent to a PMT (Hamamatsu R7899, 31 mm diameter) that measures atmospheric transparency between 3 and 10 km above the surface. A second PMT (Hamamatsu R580, 47 mm diameter) whose view is limited is attached to the side of the telescope, and measures transparency between 0.5 and 4 km. Both PMTs are covered with a BG3 UV filter (SHIBUYA-KOUGAKU R7899) whose transmittance is 91%. So backscattered photons from high altitudes are observed by the PMT attached to the telescope, and photons from low altitude are observed directly by the second PMT. The original lens of the telescope was exchanged for a wide transmission lens (MITSUBISHI-RAYON UV penetration board #000, transmittance 90.8% at 355 nm).

As a safety measure, we installed software and a light sensitive interlock to control the high voltage power supply and the cover of the box. Neither are allowed to turn on (open up) during daylight.

The DAQ is composed of an oscilloscope (Tektronix DPO3040), a data pc, a high voltage power supply (MATSUADA J4-3N-L) and two low voltage power supplies (KIKUSUI PMC18-2A & PIA4810). The high voltage is controlled by changing the low voltage on one of the supplies. The signals detected by the PMTs are recorded with the digital oscilloscope inside the CLF container, and digital data is transferred to the data PC. Linearity of the PMTs is monitored by a pulsed UVLED simultaneously interleaved with the CLF laser pulses.

All these observations are done by automatically, and weather related problems are avoided by remote operation and monitoring. Personnel at BRFD monitor the weather and in case of rain, snow or high winds they can shut down the system remotely. The system was completed in March 2011, and began observation at that time. See figure 6 for picture of installed system.

#### 4.2 Analytical policy

We obtain the atmospheric transparency using two processes. The extinction coefficient at every altitude is analyzed from LIDAR at CLF data of the vertical shot laser. The Vertical Aerosol Optical Depth (VAOD) at high altitude where aerosol does not exist is analyzed from CLF data observed by FD. By using the below equation,  $VAOD(h')$  as function with the height can be calculated to subtract a value of integrating the extinction coefficient obtained by New LIDAR system from VAOD obtained by



Figure 6: The picture of New LIDAR system at CLF.

CLF. The absolute value of VAOD(H) in high altitude is decided by CLF, and the shape of VAOD of every altitude is decided depending on the extinction coefficient  $\alpha_{AS}(h)$  of LIDAR. This method is expressed by the equation 3.

$$VAOD(h) = VAOD_{CLF}(H) - \int_h^H \alpha_{AS}(h') dh' \quad (3)$$

## 5 Conclusion

Atmospheric calibrations are indispensable for the calibration of air fluorescence detectors. In TA, the atmospheric transparency and existence of clouds are monitored by three systems; LIDAR, CLF and IR camera. A new LIDAR system at the CLF has concentrated the advantages of the two atmospheric transparency monitors and was completed in March 2011 and has started observations.

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