OG.4.5.17

Atmospheric Monitoring for the Telescope Array Project

M Chikawa[1], N Hayashida[2], M Teshima[2], T Yamamoto[2], S Kawakami[3], P Sokolsky[4], L Wiencke[4], J A Matthews[5]
and the Telescope Array collaboration
[1] *Department of Physics, Kinki University, Higashi-Osaka, Japan*
[2] *Institute for Cosmic Ray Research, University of Tokyo, Tokyo, Japan*
[3] *Department of Physics, Osaka City University, Osaka, Japan*
[4] *Department of Physics, University of Utah, Utah, USA*
[5] *New Mexico Center for Particle Physics, University of New Mexico, NM, USA*

Abstract

The Telescope Array Project is an experiment to investigate the highest energy above 10^{20}eV cosmic rays. In the project the energy of the cosmic ray is determined by means of detecting air fluorescent light propagating long distance from location of extensive air shower to the detectors.
An experiment to determine the attenuation length of the atmosphere using a steerable laser system and a steerable telescope system has been studied at the desert in Utah. We found a value from our very preliminary experiment to measure the attenuation length in the desert atmosphere for UV light which is consistent with the value of past data obtained by Fly's Eye group. Present status of atmospheric monitoring will be presented.

1. Introduction:

a. Purpose of the Experiment

The Telescope Array Project is just starting Japan-US International collaboration. The project is a next generation experiment to investigate the highest energy above 10^{20}eV cosmic rays. In this project, the energy of the cosmic ray is determined by means of detecting air fluorescent light propagating long distance from location of extensive air shower(EAS) to the detectors as shown in Fig.-1. The Telescope Array Project is presented in detail elsewhere at this conference.

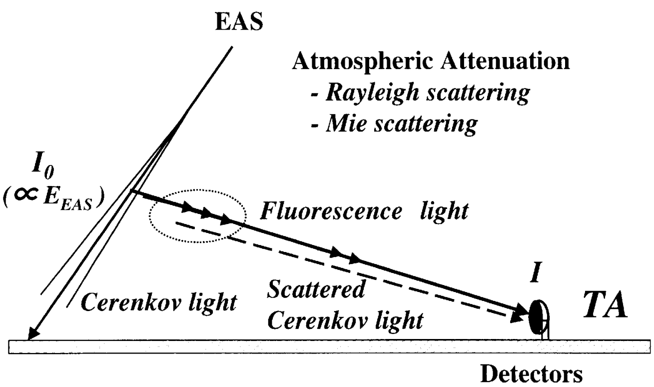

Fig.-1 Propagation of fluorescent light generated by EAS in the atmosphere.

Study of atmospheric monitoring for the Telescope Array Project is in progress at Utah. Purpose of this study is to calibrate the estimated energy of extensive air showers by means of detecting air fluorescent light.

b. Propagation Mechanism of the Light in the Atmosphere

In general, the intensity of the light attenuates in the atmosphere by absorption and scattering by molecular, dust, aerosol, and so on. The attenuation is described, so-called Lambert-Beer law. This law behaves its attenuation by exponential form. Even balance of the propagation length and attenuation length is a very important point for this project. The accuracy to determine the initial intensity of the light at the EAS axis relates to the accuracy of attenuation length.

There are two mechanisms of attenuation of the light in the atmosphere mainly, Rayleigh scattering and Mie scattering. The former one is molecular scattering, calculatable by theory exactly varying only with the atmospheric pressure and later one is aerosol scattering basically, difficult to predict because having strong dependence of the atmospheric condition. A lot of studies have been published about Rayleigh and/or Mie scattering by theory and laboratory experiment using ordinary and polarized light from 70's(Lentz, 1976 etc.). There are many useful knowledge to separate them in the real atmospheric condition.

2. Experimental Setup

The experiment is in progress at the desert atmosphere in Utah. The experimental system is consisting of a laser gun with steerable optical system at Camels Back and detectors of 3m diameter telescopes at Cedar Mountain. They are apart from about 21km each other and locates around 113E, 40N.

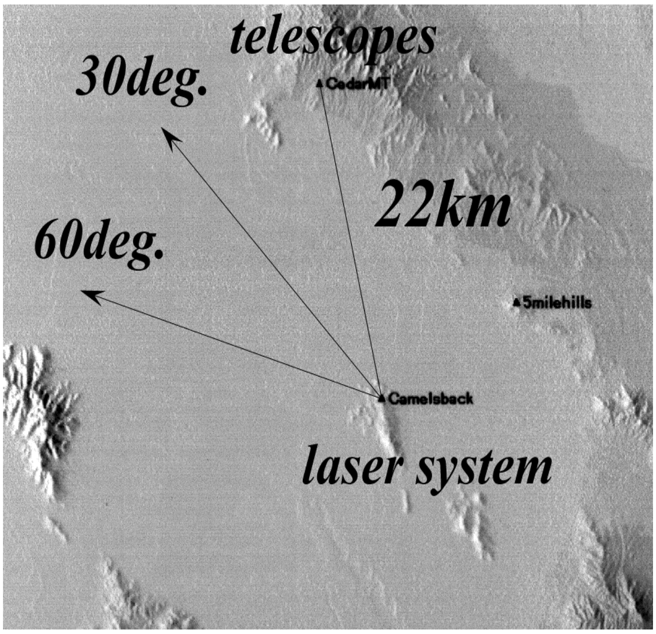

Fig.-2 Location of the experimental site in Utah. Seven telescopes at Cedar Mt. (top centre, 113.0E, 40.3N), the laser system at Camels Back(middle centre).

a. Equipment

There is a computer controlled 5mJ YAG laser gun with steerable optical system at Camels Back, high-resolution Fly's Eye (HiRes) site. The laser gun emits wave length of 355nm, pulse width of 6ns, polarized laser light. We've got computer controlled steerable seven 3m telescopes with 256PMTs imaging camera at Cedar Mt. site. The telescope system at Cedar Mt. is reported elsewhere(Hayashida, 1989).

b. Experimental Method

The pulsed laser shots from Camel's Back were observed by some of seven telescopes at Cedar Mt. swing their direction so that to acquire the data of scattering angle dependence. We have done next two experiments in clear and excellent condition nights. This is very first experiment for us to detect the laser pulse using steerable telescope system between HiRes group and Japanese group. We select simple geometrical relation for laser direction and observed direction at first.

(1) observed laser shots opening angle of 30 degrees and 60 degrees towards telescopes laying on the horizontal plane

(2) observed laser shots toward the telescopes inclined 3 degrees elevation angle

For these laser shots telescopes were traced along laser beam trajectories from near laser location to observable limit.

3. Data Analysis

The data are analyzed with assumption of the intensity of light attenuating exponentially by its path length of the light as following expression:

$$S_{obs} = \frac{1}{R^2} \cdot C_{dev} \cdot E_0 \cdot T(z) \cdot f_{phase}(\theta,\lambda) \cdot f_{polarize} \cdot e^{-\left[\left(\frac{l_1}{\Lambda_1(\lambda)}\right)+\left(\frac{l_2}{\Lambda_2(\lambda)}\right)\right]}$$

Where S_{obs} is the intensity of observed light at the detector, R is the distance of scattering point of the light and detector, C_{dev} is the detector dependent constant, E_0 is the intensity of the scattered light at the scattering point, $T(z)$ is a function of the altitude z for scattering location, f_{phase} is a function of scattering angle θ and wave length λ of the light, $f_{polarize}$ is a function of polarized condition, l_1, l_2 and $\Lambda_1, \Lambda_2 (\Lambda_1 \approx \Lambda_2)$ are the path length of the light and the attenuation length for emitted laser light and for scattered laser light, respectively. This time the laser pulses were shot 0 degrees and 3 degrees elevation angles. This means the function $T(z)$ is supposed to be constant.

The plot of path length against corrected ADC value of the detectors is shown in Fig.-3. The values of tangent of the fit lines are different between the line for 30 degrees and 60 degrees. The application of the least squared line fit for these data, the attenuation length of (9.2+/-0.4)km for 30 degrees and of (13.7+/-0.3) km for 60 degrees were obtained. These two values may be consistent with each other if the data were taking into account of polarization effect of the laser beam.

Also the plot of scattering angle against corrected ADC value of the detectors is shown in Fig.-4.

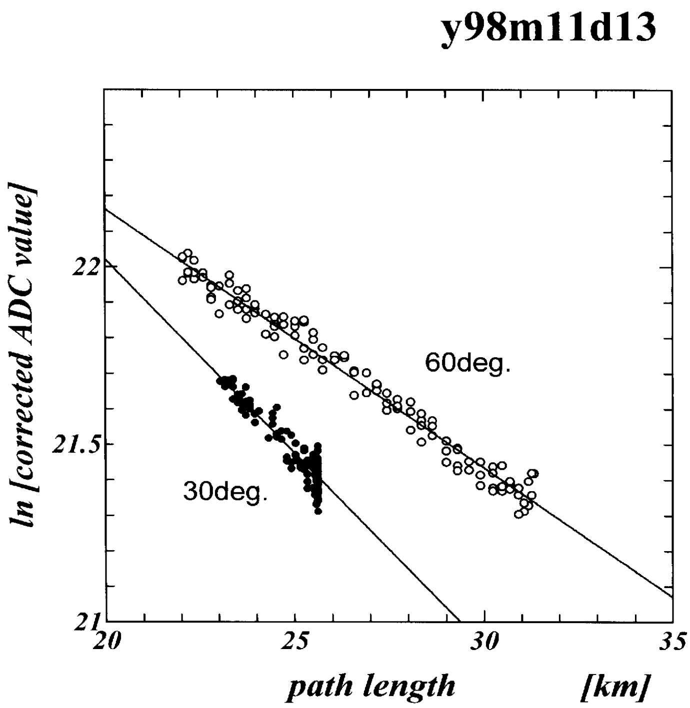

Fig.-3 The plot of path length against the intensity of observed light. The directions of the laser shots were 30 degrees and 60 degrees towards Cedar Mt. with elevation angle of 0 degree.

In this experiment, different polarization state of the beam, i.e., vertical polarization(s), horizontal polarization(p), and circular polarization were used. Exact speaking, these s- and p-state of polarization were not complete state owing to slightly incline their polarization plane against the horizontal plane. It seems that the expected dependence of the scattering angle are represented well, that is, Rayleigh and Mie scattering are separated by the polarized laser beam of different state. The effect of the polarization is expressed as following:

$$\sigma_R = f(\lambda, n)\sin^2\alpha$$

where σ_R is Rayleigh scattering cross section, f is a function of wave length λ and refractive index of medium n, and α is angle between detector direction and the polarization plane of laser beam. The angle of polarization plane against vertical plane is determined about 47 degrees from ratio of circular and linear data at scattering angle of 90 degrees. There is overwhelming bump correspond to very forward Mie scattering around ten degrees.

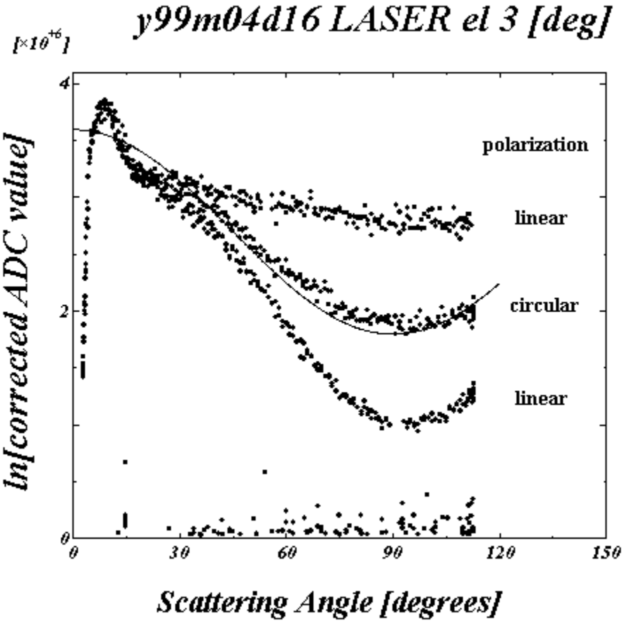

Fig.-4 The distribution of scattering angle against the intensity of the observed light. Polarized laser pulses were shot with elevation angle of 3 degrees above the detector. The line in the figure denotes 1+cos^2(scattering angle).

4. Summary

Study of atmospheric monitoring for the Telescope Array Project is in progress at Utah. The polarized laser beam experiment has done at desert atmosphere. A preliminary value for the attenuation length of @approximately 14km is found from this experiment. This value is consistent with previous value obtained by the Fly’s Eye group. The experiment with polarized beam is very useful method to separate Rayleigh and Mie scattering differential cross section.

Further atmospheric data are in need to determine the attenuation length more precisely and to check the atmospheric condition over long time period. Also the simulation data are necessary to know behaviour of desert atmosphere by comparison with the real data in detail.

References

Proc. 25th ICRC(Durban, 1997), OG10.6.13
W Lentz, Appl. Opt., 15, no3, pp667-671(1976)
N Hayashida, Astrophys. J., 504, L71-L74(1998)