29th International Cosmic Ray Conference Pune (2005) **00**, 101–106

Atmospheric monitoring for the H.E.S.S. Cherenkov telescope array by transmissometer and LIDAR

Brown A.M., Chadwick P.M., Dickinson H.J., Hadjichristidis C., Latham I.J.,
Le Gallou R., McComb T.J.L., Nolan S.J., Noutsos A., Orford K.J.,
Osborne J.L., Rayner S.M., Spangler D., for the H.E.S.S. Collaboration
Durham University, Physics Department, South Road, Durham DH1 3LE, United Kingdom
Presenter: Osborne J.L. (j.l.osborne@durham.ac.uk), uki-osborne-JL-abs1-og27-poster

A transmissometer has been installed at the H.E.S.S. site to supplement information on atmospheric absorption obtained by a LIDAR operating at 905 nm. The transmissometer monitors the absorption at this LIDAR wavelength and at 3 shorter wavelengths for the lowest 550 m of the atmosphere. The relationship between the absorption measurements and the triggering rate due to air showers produced by hadronic cosmic rays is investigated with the aim of refining the measurements of flux and energy spectra of gamma ray sources. In particular when searching for source variability, the detection of any changes in Cherenkov light extinction is of crucial importance.

1. Introduction

As for all ground based high energy γ-ray telescopes, the γ-ray effective collection area of the H.E.S.S. array [1] is calculated using simulations of air shower development, of the generation and propagation of Cherenkov light and of the array itself. The main causes of extinction of Cherenkov light are absorption and Rayleigh scattering by molecules, and Mie scattering by aerosols. The H.E.S.S. photomultiplier tubes and mirrors are sensitive to light between 250 and 700 nm. In this range the only light absorbing molecule is ozone, but the most significant loss of Cherenkov light in the case of a clear sky is caused by Rayleigh scattering off all atmospheric molecules dominant at lower wavelengths due to its λ^{-4} dependence, and Mie scattering off aerosols which becomes dominant above approximately 400 nm [2]. The aim of the LIDAR and the transmissometer installed on the site of the H.E.S.S. array is to quantify the absorption of the Cherenkov light caused by Mie scattering off aerosols with the aim of refining the measurements of flux and energy spectra of gamma ray sources.

2. Measurement of the effect of aerosols on the array trigger rate

The LIDAR installed on the H.E.S.S. site is the commercial instrument VAISALA CT25K, which features a built-in atmospheric data reduction code. It measures the backscatter at 905 nm with a range of 7.5 km, showing any aerosol layer and detailing its structure. It has been mounted on a pan and tilt head in order to track the telescopes' orientation when observations are being carried out. Refs [3, 4] show that the backscattered light of the LIDAR can vary significantly from night to night, and that the amplitude of this variation varies seasonally.

We do not currently calculate the optical depth profile of the atmosphere as described in [5] because of problems due to low signal/noise ratio at high altitude, and to the fact that the ceilometer wavelength is outside the range of the Cherenkov spectrum. The acquisition of a more powerful LIDAR working at 350 nm has been planned and will allow the optical depth profiles to be measured at this wavelength. Meanwhile, one can use the VAISALA CT25K to estimate the amount of aerosols and as ref [4] shows, this already allows useful corrections to be done on the γ-ray data. Fig 1 shows that there is indeed a correlation between the array's cosmic ray trigger rate and the amount of aerosols derived from the backscatter measured by the LIDAR.

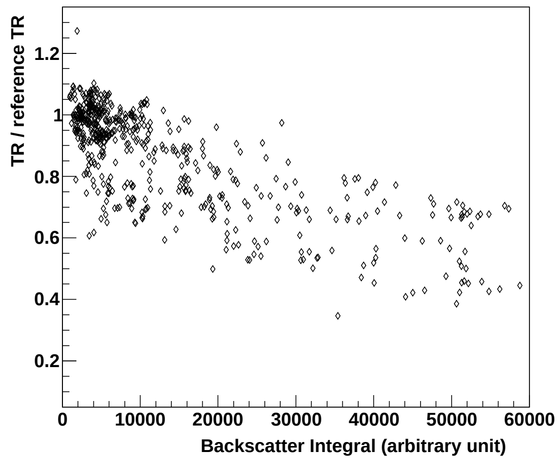

Figure 1. Ratio between the measured array trigger rate and a reference trigger rate determined by taking into account the zenith angle dependence and gain changes vs geometry corrected integral backscatter signal measured by the LIDAR. This graph shows that a clear correlation exists between the trigger rate and the amount of aerosols.

However, it would be best to measure directly the transmissivity in the wavelength range of the Cherenkov spectrum. This is why a transmissometer has been installed on the H.E.S.S. site.

3. The transmissometer

A fully automated multi-wavelength transmissometer has been installed on the H.E.S.S. site in January 2005. It measures the atmospheric transmissivity at four wavelengths (390, 455, 505 and 910 nm) between the H.E.S.S. array site (1800 m a.s.l.) and the top of the Gamsberg mountain (2350 m a.s.l, 30 km away), hence at the altitude where any aerosol layer is most often found. The transmissometer consists of a radio-controlled light source on the Gamsberg and a receiver at the H.E.S.S. site. The method used to interpret the data of this instrument is presented here, illustrated by results obtained using test data taken between the 7th and 19th of April 2005. At this stage only nights with a stable transmissivity have been studied, so that we can assume safely that the atmosphere is homogeneous over the 30 km baseline between the Gamsberg and the H.E.S.S. site. If this assumption is valid, we expect to see some correlation between the measurements of the LIDAR and the transmissometer.

From the transmissometer measurements at each wavelength we obtain the vertical total transmissivity in the l=550 m thick atmospheric layer immediately above the H.E.S.S. site. This total transmissivity can be split to take into account the effects of molecular absorption, Rayleigh scattering and Mie scattering, by writing $\tau(l) = \tau_A(l) \times \tau_R(l) \times \tau_M(l)$. Then, one can calculate $\tau_M(l)$ by assuming that $\tau_A(l) \times \tau_R(l) = \tau(l)$ during clear nights, defined as nights when the LIDAR does not see any significant aerosol layer.

Since the output of the LIDAR is proportional to the aerosol density, one must compare its data with τ_M. Moreover, the LIDAR being steerable, it points at a zenith angle θ. Hence, one must compare the amount of backscatter integrated over the distance $d = l/\cos\theta$ with the transmissivity calculated over the same distance d, $\tau_M(d)$:

$$\tau_M(d) = \left(\frac{\tau(l)}{\tau_A(l)\tau_R(l)}\right)^{d/l} = \left(\frac{\tau(l)}{\tau_A(l)\tau_R(l)}\right)^{1/\cos\theta} \tag{1}$$

Fig. 2 shows that there is indeed a correlation between the LIDAR and the transmissometer measurements.

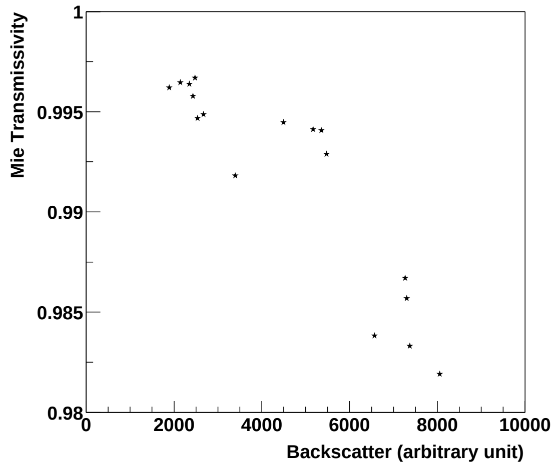

Figure 2. Mie transmissivity at 455 nm of the first 550 m of atmosphere above the site along the line defined by the array's pointing angle as in eq. 1 vs geometry corrected backscatter signal integrated along the same line. The graph shows a clear correlation between the two variables.

4. Combined LIDAR and transmissometer study of the array trigger rate

Assuming that the composition of any aerosol population is homogeneous vertically as well as horizontally as discussed previously, it is possible to combine LIDAR and transmissometer data in an attempt to extrapolate the transmissivity along the array's pointing direction through the whole of any aerosol layer extending above the vertical range of the transmissometer. If l' is the top of the aerosol layer as measured from ground level at the H.E.S.S. site, and using $d' = l'/\cos\theta$, one can write:

$$\tau_M(d') = \tau_M(d)^\alpha \text{ where } \alpha = \frac{\int_0^{\mathrm{d}'} \mathrm{B(x)dx}}{\int_0^{\mathrm{d}} \mathrm{B(x)dx}} \tag{2}$$

where $B(x)$ is the differential backscatter measured by the LIDAR at the distance x, in which the Rayleigh contribution is negligible. During cloudless nights, the top of the aerosol layer is mostly below 2500 m a.s.l., and has never been detected above 4500 m a.s.l. Its effect on the absorption of Cherenkov light can therefore be approximated as that of a filter placed just above the detectors. Hence, we expect that the array's trigger rate should be correlated with $\tau_M(d')$ generally and with $\tau_M(d)$ when the amount of aerosols above d is not significant, which LIDAR data can determine. Fig. 3 shows that the latter appears to be true in our test data, but is not conclusive on the former.

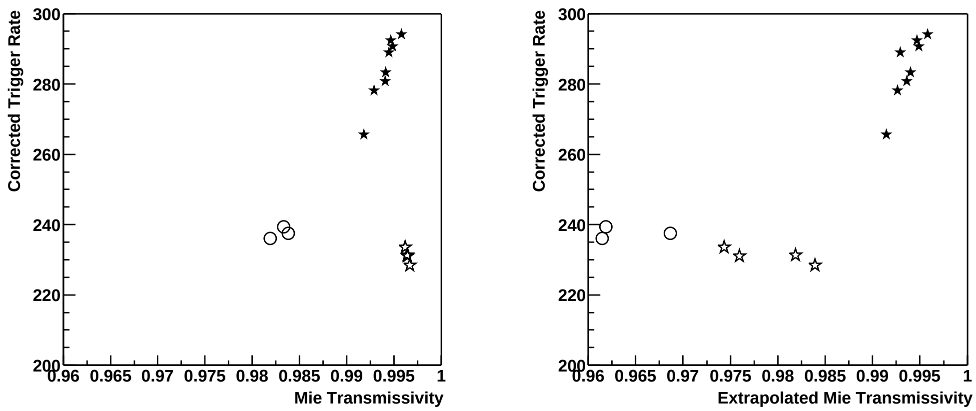

Figure 3. Left: Zenith angle dependence corrected array trigger rate vs Mie transmissivity at 455 nm of the first 550 m of atmosphere above the site along the line defined by the array's pointing angle as in eq. 1. The white stars correspond to a particular night where the aerosol layer lies almost entirely above the altitude reached by the transmissometer, as we have seen in the LIDAR data. Right: same array trigger rate vs extrapolated Mie transmissivity through the whole aerosol layer as defined in eq. 2. The correlation between transmissivity and trigger rate is substantially improved but far from perfect in those cases where most of the backscatter was detected above the lowest 550 m.

5. Conclusion and perspectives

Combining a transmissometer working in the Cherenkov spectral region and a commercial LIDAR working in the infra-red is a viable way to estimate the transmission of the atmosphere to Cherenkov light. The output of such a system can then be used to refine γ-ray measurements as described in [4]. The method shown here will in the future be studied in more detail, notably by using more data, by taking into account the vertical structure of the aerosol profile in more detail and by including nights with variable transmissivity. The question of variability is important in determining the emitting region and acceleration mechanism in sources like, for example, the microquasar LS 5039 or the Galactic Centre. In the case of LS 5039, the density of the time coverage over an orbital period and the accuracy of the flux measurements are both crucial. A new LIDAR working at 350 nm should be installed on the H.E.S.S. site towards the end of 2005. This instrument will allow us to further refine the measurement of the atmospheric transmissivity in the Cherenkov spectrum. Moreover, an automatic telescope for optical monitoring (ATOM) also scheduled to be installed will provide accurate nightly average values for the starlight extinction as a by-product.

References

[1] Benbow, W., for the H.E.S.S. collaboration, AIP Conf. Proc. 745, 611 (2004)
[2] Bernloehr,K., Astropart. Phys. 12, 255-268 (2000).
[3] Brown, A.M. et al for the H.E.S.S. collaboration, proceedings of Towards a Network of Atmospheric Cherenkov Detectors VII, Palaiseau, France (2005)
[4] Brown, A.M. et al for the H.E.S.S. collaboration, these proceedings (2005)
[5] Aye, K.-M. et al for the H.E.S.S. collaboration, 28th ICRC, Tokyo, Universal Academy Press (2003)