29th International Cosmic Ray Conference Pune (2005) **00**, 101-104

Land and sea BRDF laboratory measurements at 360 nm in view of ground reflected Cherenkov light detection in EUSO.

J-F. Muraz, M. Tur, D. Lebrun, J.Chauvin, P.Stassi,
Laboratoire de Physique Subatomique et de Cosmologie, Grenoble 38026, France
Presenter: D. Lebrun (lebrun@lpsc.in2p3.fr), fra-lebrun-D-abs1-he15-poster

The EUSO telescope will detect from space the fluorescence UV light from EAS. The associated Cherenkov light will propagate downwards and then be reflected on ground towards the telescope. Working as a gigantic Time Projection Chamber, EUSO will be able to measure the shower development time profile. The delayed Cherenkov reflected light flash will act as a shower altitude reference signal, allowing a precise Xmax determination. The amount of detected light is strongly dependent upon ground reflectivity and anisotropy. Here we report on laboratory measurement of Bidirectional Reflectance Diffuse Function on various land material samples. First results on simulated sea water will also be presented. In the latter case the reflectivity off the specular plane, and the strong dependence upon the sea surface conditions lead to reconsider the initial estimations.

1. Introduction

The Extreme Universe Space Observatory (EUSO)[1] is designed to detect air fluorescence photons induced by extremely high energy cosmic ray air showers by pointing at Nadir from the International Space Station. Photons will be detected in the 300-400 nm bandwidth within a Field of View of $\pm$ 30 degrees. The Cherenkov light generated by relativistic particles in the shower is focused in a downward cone with 1.4 degree aperture with respect to the shower axis. The Cherenkov light, bunched in a very narrow time window, will hit the ground and then be diffused. The diffused light captured in the 10^{-11} sr solid angle will appear as a short flash arriving after the fluorescence photons. This footprint at ground level will give an absolute calibration for the time to altitude shower profile reconstruction. In the Phase-A of the EUSO program, first order estimations were made by using realistic ground reflectance and assuming pure Lambertian diffusion. Since in orbit EUSO will mainly fly over sea and ocean during 70% of its lifetime, a value of 5 to 8% of reflectivity was used as a baseline leading to a 50 photoelectrons flash detected for a shower at 10^{20}eV. However it is known that most of the earth ground materials are far from being lambertian, and that diffuse anisotropy will lead to consider the exact geometry of the observed shower. In order to have a correct estimation of the amount of detected light all along the EUSO trajectory, various ground based experiments were initiated to validate the concept of Cherenkov diffused light detection in EUSO. The ULTRA ground validation experiment [2] is designed and scaled to detect Cherenkov light reflection on various grounds in coincidence with a surface detector array to trigger on air showers at a cosmic incident energy around 1 PeV. We report here on another kind of validation experiment consisting in laboratory measurement of ground sample reflectivity at 360 nm, in the center of the BG3 filter and at the mean wavelength of the standard Johnson U filter. Indeed Bidirectionnal Reflectance Function are widely studied in various area of science and industry mainly in computer graphics. Radiative transfer modeling and experiment of Ocean and landscape surface are intensively developed in Atmospheric physics [3]. However data in the near UV bandwidth are rather scarce and not suited for our purpose.

2. The Spectro-Gonio-Reflectometer

A cooled deuterium lamp is coupled to a grating spectrometer and delivers light at selected wavelength onto a bundle of quartz fiber. The fiber is guided into a dark vessel where it is mounted and fixed on one arm of a wo-arm semi-spherical goniometer. The head of the fiber equipped with lens, illuminates a horizontal area at the goniometer center where the sample is located. The spot is Φ=5 cm, and a black mask with the same diameter hole is added. The other arm is equipped with a ½" Photo-Multiplier Tube R960 from Hamamatsu mounted with a fused silica window for UV measurements. The current sensitivity of the PMT allows a dynamical range of 10^3; the current is read on oscilloscope with GPIB interface. The apparatus is driven by a PC under LabView. Measurements are acquired by programmable steps either in incident (θi,ϕi) or diffuse reflected (θr,ϕr) angles, and stored in memory as text files. The initialization procedure includes a pedestal noise level measurement via a shutter on/off control at the fiber entrance. The control of the mechanical precision is obtained by measuring the specular reflection on a mirror located at the sample position. Overall calibrations of the detection scheme, including lamp intensity spectrum and fiber wavelength transmission, were performed via measurements at various stages of the light track from the source to the fiber head.

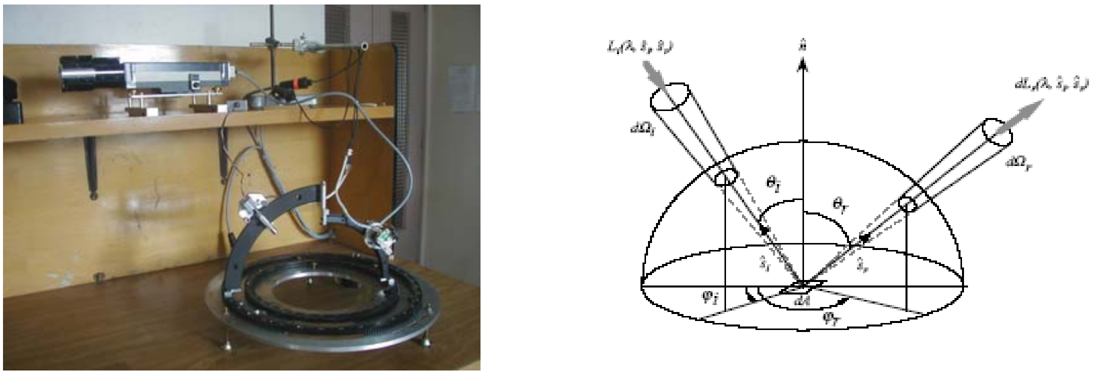

Figure 1. Picture of the spectro-gonio-reflectometer out of its dark vessel. From the top left one see the D2 Lamp (black), the spectrometer (grey) out of which the grey fiber cable is driven and fixed on one arm of the goniometer; on the other arm on the left the PMT is fixed. On the right is shown a schematic drawing of the measurement principle with notations.

BRDF is defined by the ratio of outgoing radiance to the incoming irradiance $f(\lambda,\theta i,\varphi i,\theta r,\varphi r) = dLr(\lambda,si,sr)/dEi(\lambda,si)$. In the comparative method we used here, BRDF was measured relative to a known reflectance material. We used as a reference the highly diffuse standard material Spectralon which is a hardened polytetrafluoroethylene (PTFE) manufactured by LabSphere Inc and is a widely used white reference in the field of reflectometry. The integrated sphere reflectivity is greater than 99%.

For convenience and for intermediate calibrations we measured other highly diffusive materials as standard PTFE foils, Tyvek fiber sheets or standard white paper at various wavelength and angles relative to Spectralon

3. Result on various materials

Several ground samples have been studied; in the present paper we shall limit ourselves to the most significant ones and for an incident angle of θi=25° (figure 2). This angle is the most probable zenith angle value the acceptance of a ground array air shower detector as the ULTRA one. Remaining data will be published elsewhere. Each experimental run was accompanied with a PTFE sample run to normalize and to avoid any variation in the experimental condition from one sample to another.

PTFE is comparable to the Spectralon while less lambertian; this explains that at the incident angle considered here a small anisotropy is observed and leads to a reflectivity value a little bit higher than the reference. A highly diffuse natural material is represented by snow (taken in a cooled plate while snowing outdoor at temperature near -3°C). Except for reflected grazing angles greater than 70°, the reflectance is almost 90% of PTFE.

Ground rock material was sampled in a granitic area in the Alps at Italy-France border where first test of the ULTRA experiment took place. The granularity of the sample was variable from microns to few millimeters. The reflectance is also rather quiet flat but the magnitude is reduced to less than 10% of the PTFE. It must be noted here that apart from granularity, absorption at 360 nm should play a significant role in the reflectance value since a parallel investigation of light transmission in a solved sample exhibits a strong absorption peak near 420 nm, characteristic of the presence of moisture, and whose width extend below 360 nm. Further investigation are in progress to study the wavelength dependence. Indeed a sand sample with a similar granularity reaches a 30% reflectance.
Natural Water with quiet surface is quoted to notify the large difference in reflectance distribution when compared to previous material. The specular reflection peak at $\theta r=25°$ is easily distinguished on the left part of figure 2. Out of the specular reflection angle (left part of figure 2) and off the specular plane (right part of figure 2) the reflectance is less than 1% of the PTFE.
In the case of water the light diffusion is dominated volumic diffusion and refraction, and by the reflectivity on the bottom of the vessel as well. Several studies on water reflection were carried out varying the depth of the vessel together with the bottom reflecting material, exhibiting strong modulations off the specular plane. These study, beyond the scope of this presentation, explain the oscillating behaviour of reflectance function for angles greater than 35° in figure 2 (both side). If extrapolated to oceanic conditions, this behaviour will predict strong variations with oceanic depth and bottom floor nature; this is in fact what is observed in ocean-atmosphere radiative transfer studies [3].

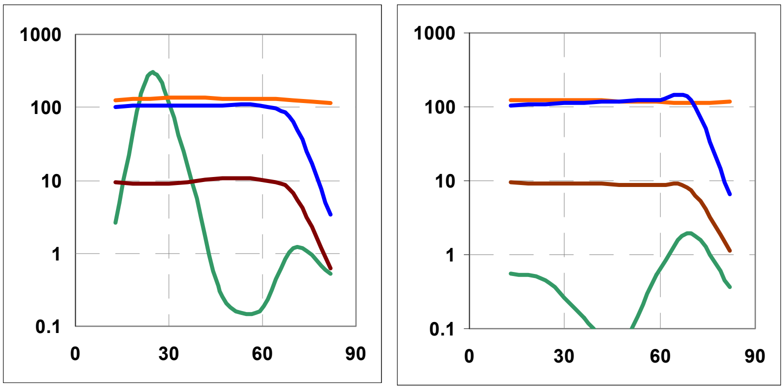

Figure 2. Relative reflectance function $f(25°,0°,\theta r,0°)$ in the incident-specular plane (Left) and $f(25°,0°,\theta r,90°)$ in off-specular plane (right). Data are for PTFE (red), Snow (blue), Mountain Rock (brown) and clear Water (green)

The absolute value of the BRDF for a perfect lambertian flat reflector is constant $f=1/\pi\ sr^{-1}$. Then for a constant incoming irradiance of 100 $photons.m^{-2}$, 32 $photons.m^{-2}.sr^{-1}$ outgoing radiance are expected. This can be applied to the PTFE red line of figure 2. The hemispherically integrated radiances give the normalization to 100. In this particular case here, the water data integrated would amount for 8 outgoing $photons.m^{-2}$ irradiance (one speaks generally of 8% albedo) ; this is to be compared with the value of 8% given in the introduction for the EUSO simulation. But for detection the significant parameter is not the integrated value or irradiance but the differential or radiance. Then, in a very small fraction of solid angle around the specular angle, the reflectance is greater than the perfect diffuse material, but off-the specular angle reflectivity drops to less than 1% of PTFE, corresponding to less than 0.32 $photons.m^{-2}.sr^{-1}$ outgoing radiance for 100 incoming photons. This lead to re-evaluate the expectation for the Cherenkov peak in EUSO from 50 photo-electrons to less than 2 photo-electrons for showers at 10^{20} eV and zenith angle 25 in a very large fraction of the Field of view out of the specular angle: it will be indistinguishable from background.

4. Surface wave effects on water.

Tentative to simulate surface effect of ocean was carried out by simulating waves. This was realized by blowing valve-regulated compressed air through pipes directed slightly parallel above the water surface.
The intensity and the reproductibility of the generated waves were controlled via their waveform on oscilloscope tuned on long time base (1s). The generated "wind"speed was always much smaller than 0.2meter/second. While wavelengths and amplitude are rather far from oceanic conditions, this test allows to understand one of the most important effect of light reflection on water surface .For parallel waves, there is a slight diminution and broadening of the specular peak intensity but nothing important happens. While for perpendicular waves, the peak is reduced at least by a factor of 10 and the reflectance function shape is strongly modified.

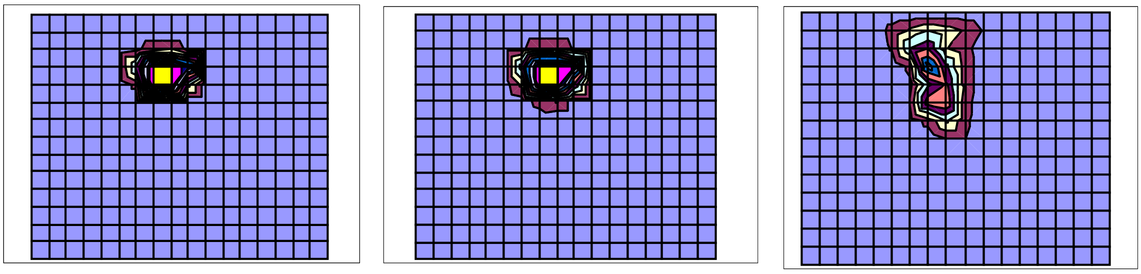

Figure 1. Bi-directional reflectance of Quiet Water (left), water with waves parallel to the incident plane (center) and waves perpendicular to the incident plane (right). For (θi,ϕi)=(25°,0°), the axis are θr (vertical) and ϕr (horizontal). Plot is in Log scale.

One can expect that for a realistic oceanic reflective surface, and even in the most favorable conditions, i.e. at specular angle, the reflection will be strongly affected depending upon wind direction and wave propagation. A realistic experimental condition should reside in a combination of parallel and perpendicular wave effect. The magnitude of the reflected peak should be almost unpredictable unless a real time and complete description of sea surface is provided. Moreover, if the incident shower zenith angle is greater than the Field of View of EUSO, the specular peak, if any, will lie outside the acceptance. One should add that in the present study light absorption in water was not considered yet. The presence of phytoplancton in ocean should strongly affect the water volumic reflective part; work is in progress on real sea water to answer this question

5. Conclusions

The measurement of bidirectional diffuse reflectance function at 360 nm was realized on various material sample simulating the landscape and ocean surface surveyed by EUSO. This work was done in view of the validation of the concept of detection of the reflected Cherenkov light on ground by the EUSO telescope in orbit on ISS. First results obtained with a spectro-gonio-reflectometer indicate that a re-evaluation of the signal amplitude in EUSO has to be made. Except flying over specific ground conditions as over highly reflective snow, or under specific geometrical conditions – specular reflection on flat ocean within the EUSO field of view- the Cherenkov signal will hardly be distinguished from background.

Références

[1] EUSO Report on Phase A Study (2004) http :// www.euso-mission.org
[2] G.Agnetta et al. ULTRA experiment, ICRC2005,Pune HE1.2, This conference
[3] A. Morel, B. Gentili Appl. Optics 32, 6864 (1993) & 35, 4850(1996)
Z.Jin et al. Journal of Atmospheric and Oceanic Technology, vol.19 ,1585 (2002)