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Optical measurements with cooled CCD cameras for CANGAROO-III

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CANGAROO-III consists of four telescopes installed in Woomera, South Australia to observe celestial γ-ray sources by detecting Cherenkov light from air showers. Stereo observations have been performed since March 2004 with an improved angular resolution and a lower energy threshold.
In this paper, we present some preliminary results of optical measurements by cooled CCD cameras.

1. Introduction

In 2004, we have tried some optical measurements using cooled CCD cameras, and here we describe the preliminary results of these measurements; of the reflectivity of the telescope reflectors, the typical air transmittance and the quanta of night sky backgrounds around our observatory site. For all the measurements, we used cooled CCD cameras (ST5C or ST7E , SBIG) which we installed to our telescope. To discuss dependence on wavelength, Johnson-type filters were used together. The center wavelength of transmittance is 533nm (V-band), 434nm (B-band), 362nm (U-band).

2. Reflectivity of telescope reflectors

The reflector, tessellated parabola with a diameter of 10m, consists of 114 spherical segment mirrors [1]. Each mirror has a 78cm diameter and the total effective light collecting area is $54\mathrm{m}^2$. To measure the reflectivity of the telescope reflector which means the average reflectivity of segment mirrors, we compared the light intensity of a star imaged at the PMT camera plane with that of one seen through a camera lens directly. The measurements were done for three newer telescopes which we call T2, T3 and T4, and the procedure was as follows: First, a telescope tracked a bright star so that the reflected star lights could be measured which were focused on a white screen set at the prime focal plane and the image was taken by a CCD camera V-filter. Second, tracking coordinates of telescope were slightly changed so that the star came into a field-of-view of the CCD camera, and the direct star image was taken. The direct and the reflected star images were taken with as short an interval as possible, typically, 3 min, and possible errors introduced by the change of sky conditions are estimated to be $\sim 3\%$ at the maximum during the measurements. This procedure was repeated for all three telescopes, and we calculated the "relative reflectivity" of telescopes as the light intensity of the reflected star image obtained from a CCD image (in CCD counts per second) divided by that of the direct star image. The relative reflectivities between three telescopes is about $\mathrm{T2}:\mathrm{T3}:\mathrm{T4} = 0.84:0.92:1$.

To deduce the absolute reflectivity, the estimation of the screen reflectivity (percent per str) is required. With a He-Ne laser altering the beam direction to the screen, the incident angle dependency of the screen reflectivity was measured using a CCD camera. The absolute reflectivity was calibrated by a spectrometer measurement at a fixed angle of 24 degree. The average reflectivity of the screen calculated for the positions of the segment mirrors with the weight of the their numbers, is $21\pm 2\%/\mathrm{str}$.

Thus we can estimate the absolute reflectivity of the telescope reflectors as
$\mathrm{T2}:66\pm 7(\mathrm{stat})\pm 3(\mathrm{sys})\%$, $\mathrm{T3}:72\pm 2(\mathrm{stat})\pm 4(\mathrm{sys})\%$, $\mathrm{T4}:78\pm 2(\mathrm{stat})\pm 5(\mathrm{sys})\%$, (Fig. 1).

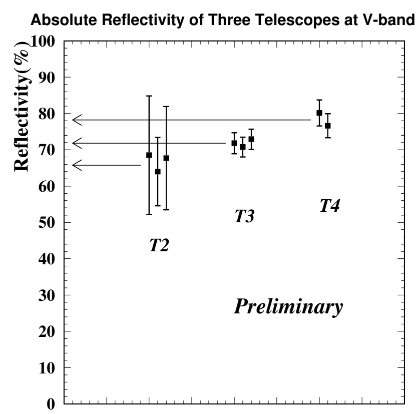

Figure 1. Reflectivity of three telescopes in V-band wavelength range. From right side, T2, T3, T4. There includes only statistical errors and y-axis has systematic errors mainly from the reflectivity of the screen.

3. Atmospheric transmittance

The atmospheric transmittance around our site is an important factor to estimate γ-ray flux and energy from observed Cherenkov light. There are several methods to measure the atmospheric environment such as using LIDAR. This time we used bright stars to see the variation of starlight extinction according to their zenith angle. We applied 3 optical filters (V-band, B-band, U-band) to compare the dependence on wavelength. The concept of measurements is that the light intensity of a star declines exponentially with the thickness of atmosphere (the “air mass”, which is normalized to unity for a star at the zenith) and therefore the measured magnitude of a star which is proportional to logarithm of the brightness will be a linear function of the air mass. So we selected a handful of bright stars at various zenith angles and took the pictures one by one using a CCD camera with a lens.

In Fig. 2, we plot the calculated instrumental magnitudes of stars (which we first calculated as $-2.5\times\log\mathrm{F}-m_0$ and applied a correction of color indices. F : light intensity of a star in CCD counts/second, m_0 : magnitude of a star listed in the BSC catalog [3]) versus air mass which is approximately equal to $\frac{1}{\cos(\theta)}$, θ : zenith angle of a star.

We regard the intercept of fitting line as the origin where the atmospheric transmittance equals 1, and estimate the effect of atmospheric transmittance on each measured star light (Fig. 3). The calculation with an atmospheric simulation code, Modtran[2] assuming the ”desert aerosol model” have been done and the results are plotted together to compare with our measurements (Fig. 3).

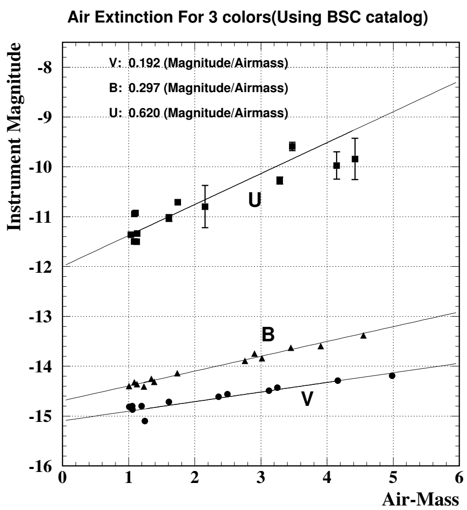

Figure 2. Air extinction measured in 3 color bands (in October 2004). The circle points represent the star measured with V filter, and similarly triangle and square points with B and U filter (adjusted to 0th magnitude). Linear lines as fitting functions are overwritten.

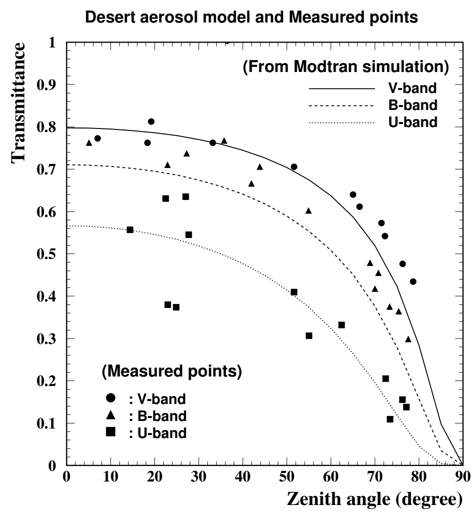

Figure 3. Comparison of measurements and simulation. Color represents each wavelength range as same in Fig 2. Points represent measurement data and lines represent the results of Modtran simulation (’Mid-Latitude Winter’ model atmosphere with ’desert aerozol model’).

4. Night sky background

Night Sky Background (hereafter NSB) is always a major noise for Cherenkov observation. Typically Jelley’s estimated value $6.4\times10^7 photons/\mathrm{cm}^2/\mathrm{str}/\mathrm{sec}$ ($4300\sim5500$Å) is used as a reference [4]. We have measured the NSB flux by CCD camera which was installed at the center of telescope reflector together with B-band filter during Cherenkov observations on November 8th in 2004. The observation targets were Crab nebula:(ℓ,b)=(184.558°, -5.784°) and NGC253:(ℓ,b)=(97.369°, -87.964°).

The procedure of data analysis is as follows. First, we calculated the mean CCD count/pixel/sec at sky region in the CCD image excluding the star region (brighter than 6 mag). The results were about 1.5 ± 0.2count/pixel/sec for Crab nebula sky and 1.0 ± 0.2count/pixel/sec for NGC253 sky. Second, the CCD conversion factor, from photo-excited electrons on one pixel to CCD counts, was estimated by the comparison of the measured light intensity of stars (CCD counts/second) and the combine of the magnitude of stars above the atmosphere converted to a unit of photon flux [5], quantum efficiency of the CCD chip (from catalog), and the measured the transmittance of the atmosphere and the V-filter. After conversion, the measured NSB flux was simply integrated over $430\sim550$ nm to compare the Jelly's estimation (Fig. 4). Our results are a factor of $1\sim2$ larger than the Jelley's result. From the ADC pedestal broadenings during the simultaneous observation, PMT (pixel size = $0^\circ.17$ [6]) hit rates due to NSB of both region is estimated as Crab nebula sky : 1.1×10^2MHz, and NGC253 sky : 0.76×10^2MHz. Therefore the ratio of NSB flux estimated from CCD measurements is consistent with that estimated from observation data.

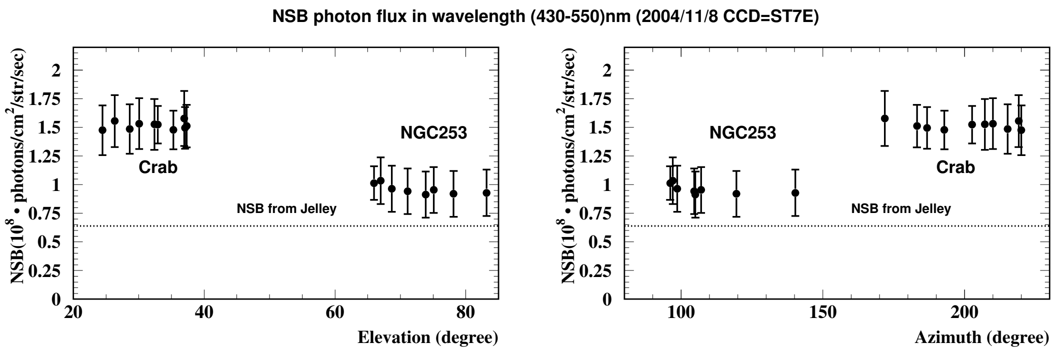

Figure 4. Calculated NSB flux estimated from CCD measurements (Crab nebula and NGC253) and Jelley's estimated NSB flux (dotted line). Left figure shows elevation dependence of NSB, right figure shows azimuth dependence of NSB.

5. Summary

We have measured the optical properties of the CANGAROO-III telescopes using direct and reflected images of stars and have also estimated the night sky background at the Woomera site. Such calibrations are important as input for Monte Carlo simulations and in the analysis of observations in order to optimize the procedures for the detection of TeV gamma-rays.

References

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