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Atmospheric extinction and background light measurements at Jammora, Jammu

S. R. Kaul, V. K. Dhar, M. K. Kaul, R. K. Bhat, M. L. Sapru,
R. K. Kaul and C. L. Bhat
Bhabha Atomic Research Centre, Nuclear Research Laboratory, Trombay, Bombay 400 085

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Abstract. Atmospheric extinction and background light measurements have been carried out at Jammora for the period 1991 October-November, with a view to evaluate its suitability as a site for our new ground-based gamma-ray observatory. A value of (0.62 ± 0.03) for the extinction coefficient and a value of (1.89 ± 0.53) × 10^8 photons cm^{-2} s^{-1} sr^{-1} for the flux of background night sky light, both averaged over the wavelength interval λ = 310-560 nm, have been derived for the site under normal viewing conditions.

Key words : site evaluation—gamma-ray observatory—extinction coefficient—optical band—night sky light flux

1. Introduction

A thrust area-activity of Nuclear Research Laboratory of the Bhabha Atomic Research Centre has been the field of very high energy (VHE) gamma-ray astrophysics. In pursuance of this objective, an Atmospheric Cerenkov Telescope (Koul *et al.* 1989) has been operated at Gulmarg, Kashmir, during the period 1984-1989 to study cosmic gamma-ray sources at photon energies ≥ 10^{12} eV (10^{12} eV = 1TeV). Several important results have been reported from observations carried out with this system, including the first-ever possible detection of a TeV gamma-ray signal from the prototype polar AM-Herculis (Bhat *et al.* 1991a). In order to further consolidate our knowledge about cosmic gamma-ray sources, we have recently initiated work on two new, international-class experiments for carrying out detailed investigations of cosmic gamma-rays in the energy range 0.2 TeV-10 PeV (2 × 10^{11} eV-10^{16} eV). The two experiments, namely, TACTIC (TeV Atmospheric Cerenkov Telescope with Imaging Camera) and MYSTIQUE (≡ MEUSTEQUE, Multi-Element Ultra-Sensitive TElescope for Quanta of Ultra-high Energies) are expected to significantly contribute towards making comprehensive studies of temporal and spectral characteristics of cosmic gamma-ray sources, in addition to revealing the presence of other, presently unknown, gamma-ray sources at a reasonably high significance level (Bhat *et al.* 1991b; 1993).

An important pre-requisite for carrying out these experiments successfully is the identification of an astronomically suitable site, which satisfies the following main conditions :

1. Cloud-free nights as far as possible throughout the year.
2. Relative freedom from artificial sources of background illumination.
3. Dust-free and pollution-free atmosphere.
4. Operational ease (Good logistics and mild climate).
5. Reasonably flat terrain of up to 0.25 km^2 in area (A requirement for MYSTIQUE).

It may be noted that, unlike in optical astronomy, the parameter 'seeing' is not of main concern in recording Cerenkov events produced by a primary gamma-ray or a charged particle, in view of the non-negligible beam-width ($\geq 1°$) of the atmospheric Cerenkov pulses.

A detailed survey has been made to look for a proper site in the Jammu region of the J&K state, in view of its proximity to our existing laboratories in Kashmir and the relatively milder weather conditions encountered there throughout the year in comparison with the Kashmir and Ladakh regions of the state, especially during the winter months. Based on physical visits covering a major part of the Jammu province, it has become possible to identify some potentially promising sites which satisfy conditions (4) and (5). With regard to the fulfillment of condition (1), we have visually monitored the night-time cloud cover at Jammu regularly during the period 1990 March-1991 December and find that this region can provide comparatively more clear nights than our existing observatory site at Gulmarg. In order to quantify this advantage in terms of the actual number of observation hours possible, we have examined the cloud-imagery data provided by the INSAT group of satellites for the 5-year period 1987-1991. Satellite cloud imageries taken at 2100 hr, 0000 hr, 0300 hr and 0900 hr (all Infrared) and 0900 hr (Visual) have been looked at for generating the required database for Jammu and Gulmarg. A detailed analysis of these data has revealed that the average annual percentage of clear nights (2100-0600 hrs) is ~ 20% for Gulmarg and ~ 40% for Jammu. These figures have been used to estimate the total effective observation time per year expected to be available at the two stations, taking the duration of a typical observing night as 8 hrs and the fraction of dark nights per year as 60%. The effective average observation time per year (clear, dark hours) is thus found to be 390 hrs and 680 hrs for Gulmarg and Jammu respectively, thereby suggesting an increase in effective observation time at Jammu by a factor of ~ 1.7 compared with that at Gulmarg. A comparable study, using the all-sky camera data recorded at Leh (altitude ≈ 3500 m), has revealed that this place has almost the same percentage of clear nights as Gulmarg. In effect, Leh, does not offer any significant advantage so far as the important condition (1) is concerned.

On the other hand, in view of the comparatively more encouraging picture about Jammu, it is in order to further evaluate the suitability of this region as a potential astronomical site, with the specific objective of seeking answers to the remaining conditions (2) and (3). For this purpose, we have monitored the local atmospheric extinction coefficient and have also determined the intensity of background light of night sky (LONS) at one of the candidate sites, Jammora, ($\lambda = 74.87°$E, $\phi = 32.74°$N), which is located at a crow-flight distance of ≈ 30 km from Jammu city and has an altitude of 570 m. These observations have been carried out for a period of 10 nights during 1991 October-November. In this paper, we present the results of these observations.

2. Instrumentation and observations

The measurements referred to above, have been made with an equatorially-mounted, steerable extinction photometer using a 100 cm-long telescope (STAR TRACKER-80, manufactured by M/s Tejram & Co., Bombay) having a primary mirror of 10 cm aperture and 100 cm focal length. A head-on-type photo-multiplier tube (EMI 9524), with an average photocathode quantum efficiency of ≈ 15% in the wavelength region (λ = 310-560 nm), is fitted at the eye-piece of the telescope as the basic detector. The photomultiplier is fed from a low-ripple, stabilized EHT supply (~ 800 V) and its d.c. anode output is recorded after a suitable amplification. It is ensured through actual calibrations, carried out at regular intervals, that the overall gain of the photometer remains uniform throughout the observation-spell considered here.

The incident light on the detector is accepted through a circular mask with a central exposed portion of diameter 0.5 cm. Geometrical considerations suggest an approximate value of 0.2° diameter for the field of view (FOV) of the photometer. A more accurate value for this parameter follows from the considerations of the point-spread function (PSF) of the telescope (figure 1). This function was determined experimentally, by recording the photomultiplier anode-output voltage, alongwith the corresponding absolute time of measurement, while a reference star (Vega or Deneb in the present case) drifted through the telescope aperture. The angular distance θ travelled by the reference star between any two measurement-epochs is given by the relation :

$$\cos \theta = \cos z_1 \cos z_2 + \sin z_1 \sin z_2 \cos (A_1 - A_2) \qquad \ldots (1)$$

where z_1 and z_2 are the respective zenith distances, and A_1 and A_2 are the corresponding azimuth values. Figure 1 leads to a value of ≈ 23.8 arcmin diameter for FOV of the system, corresponding to an effective solid-angle $\Omega_{eff} = 3.76 \times 10^{-5}$ str for the detector system.

The extinction coefficient measurements have been carried out in the wavelength interval λ = 310-560 nm, primarily determined by the spectral response of the detector photocathode (figure 2). This method is somewhat different from the one commonly used, where extinction measurements are made separately for the standard *U*, *B* and *V* bands by using appropriate filters. This departure from the convention was accepted because of experimental convenience as also in view of the fact that, in atmospheric Cerenkov experiments, it is found advantageous from the point of view of sensitivity considerations, to operate over the wavelength region λ ~ 310-560 nm, in order to maximize Cerenkov signal contribution and simultaneously keep the LONS-generated background within a manageable level.

The observations were carried out in the following manner : The photometer was first pointed towards a known reference star and the anode voltage from the PMT, (V_{on}), recorded at regular intervals as the telescope tracked the star. The photometer was then shifted 1° away towards north, east, south and west of the reference star in succession and the off-source anode voltage (V_{off}) was measured as before in the four directions. The average of these four values gives the mean off-source voltage $\langle V_{off} \rangle$. The telescope objective was then covered with a thick black cloth and the anode voltage was similarly measured to obtain a measure of the PMT dark voltage. The difference between V_{on} and $\langle V_{off} \rangle$ represents the anode voltage, V_s, proportional to the incident light flux from the reference star, while the difference between $\langle V_{off} \rangle$ and the average dark voltage is proportional to the LONS intensity. The

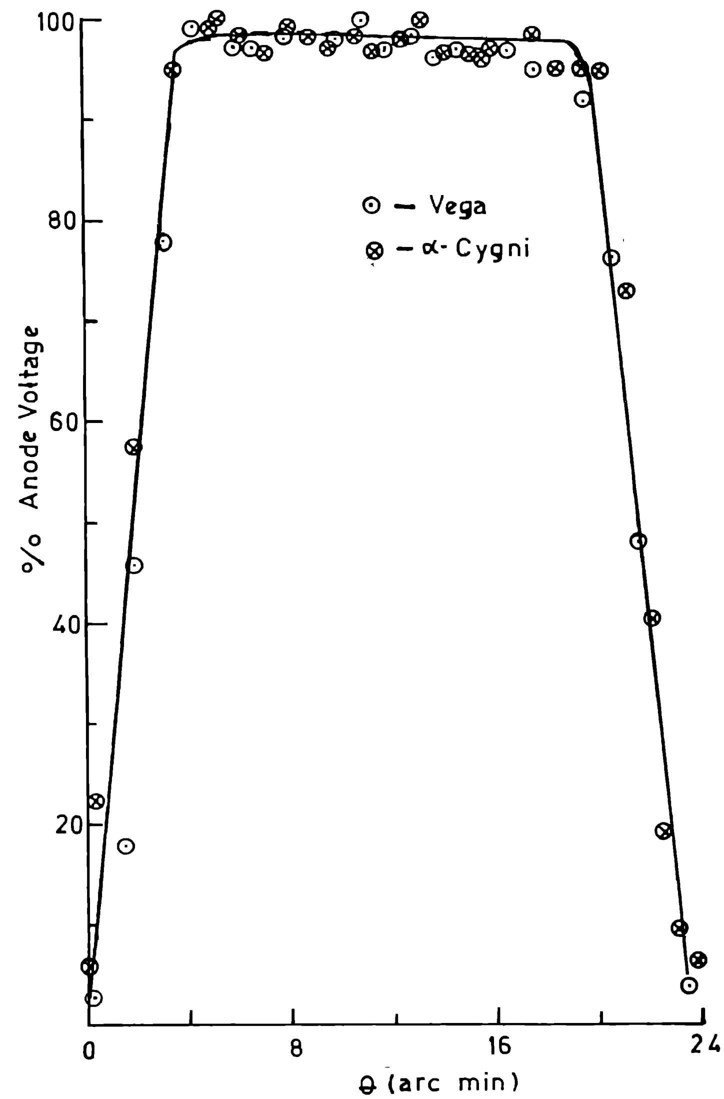

Figure 1. The photometer point spread function (PSF) derived using two reference stars : (i) Vega and (ii) Deneb (α-Cygni).

measurements were repeated in the same sequence once every 15 minutes during the transit of the reference star to obtain values of $V_s \equiv (V_{on} - <V_{off}>)$ as a function of source zenith angle z. The measurements were carried out with different reference stars and the data were fed to a PC-based data-acquisition system for subsequent analysis.

3. Results

3.1. *Extinction coefficient*

From a visual inspection of the sky condition encountered during the ten observation nights, it was noted that eight nights were clear, while the other two appeared to be slightly hazy. The data obtained on all the nights were treated in the same manner, as described below :

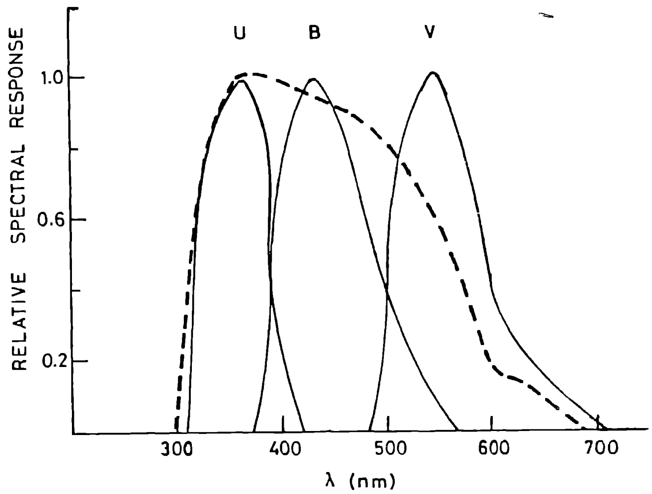

Figure 2. The standard *U*, *B* and *V* band transmission coefficients plotted as a function of wavelength and superimposed on the spectral response curve of the PMT photocathode (dashed curve). The relative spectral response of the PMT has been normalized to unity at $\lambda = 350$ nm.

$V_s = (V_{on} - \langle V_{off} \rangle)$ represents the anode voltage proportional to the starlight intensity at the ground level. Its value, V_0, outside the atmosphere is given by

$$V_s = V_0 e^{-\tau X} \quad \ldots (2)$$

where the atmospheric optical thickness τ is related to the corresponding extinction coefficient k by

$$\tau = \frac{k}{2.5 \log_{10} e} = 0.92\,k. \quad \ldots (3)$$

The relative air mass, X, is given by the following empirical relation (Schlosser 1991) :

$$X = (\sec z - aY - bY^2 - cY^3) \quad \ldots (4)$$

where $Y = (\sec z - 1)$ and $a = 0.0018167$, $b = 0.002875$ and $c = 0.000808$. This relation is expected to be valid for $z \leq 80°$. Equation (2) can also be written in the form :

$$\ln V_s = \ln V_0 - 0.92\,k \cdot X. \quad \ldots (5)$$

Knowing V_s as a function of z experimentally, the least-squares method has been used to obtain the value of the two unknowns, k and $\ln V_0$, in equation (5). The slope of the best-fit line gives the extinction coefficient k, while the intercept $\ln V_0$ is related to the expected light flux from the source at the top of the atmosphere. The extinction coefficient values thus derived are listed in table 1 alongwith the corresponding errors. Some relevant characteristics of the 9 reference stars used in the present work are also listed in table 1. The observed variations in k on a given night reflect the possibility that the extinction coefficient may vary with the colour of the star and also with the viewing direction (Singh *et al.* 1989). The following

Table 1. Daily extinction coefficient (k) values averaged over the spectral band λ = 310-560 nm. The second row indicates the error in the corresponding value of k

Star name (Spectral type)	Oct. 11	Oct. 12	Oct.* 13	Oct. 16	Oct. 17	Oct. 18	Nov.* 6	Nov. 7	Nov. 8	Nov. 10
Vega	.63	.65	.67				.95	.65	.82	.76
(A0 V)	.003	.005	.029				.045	.007	.005	.012
Deneb		.71	.84	.63	.63	.68	.82	.88	.93	.69
(A2 Ia)		.029	.041	.022	.024	.076	.026	.008	.018	.013
Capella		.51	.42				.89	.68	.75	.62
(G8 III)		.008	.019				.024	.028	.009	.010
Betelgeuse				.48	.53		.59	.60	.62	.45
(M2 Iab)				.044	.060		.017	.021	.013	.013
Castor				.56	.61	.76	.78	.88	.90	.63
(A1 V)				.035	.032	.041	.015	.039	.016	.023
Pollux				.49	.52	.53	.68	.83		
(K0 III)				.019	.011	.074	.010	.035		
Procyon				.44		.47		.01	.65	.44
(F5 III)				.008		.044		.064	.017	.018
Aldebaran							.73	.53	.70	.47
(K5 IV)							.033	.024	.010	.012
Rigel									.64	.54
(B 8Ia)									.013	.016
Mean k	.63	.63	.71	.59	.63	.66	.81	.65	.66	.58
s.d.	.003	.005	.011	.006	.006	.013	.006	.005	.005	.006

*Indicates poor sky condition days.

2-step iterative process has therefore been followed to obtain a proper mean k (and its associated error) for a given night :

(i) Starting with an assumed value of k (close to expectation), ln V_0 is obtained from the following modified form of equation (5) :

$$\ln V_{0j} = \frac{\Sigma_i(\ln V_{ij} + 0.92\, k \cdot X_{ij})}{N_j} \qquad \ldots (6)$$

where i is the observation number; j, the star number; and N_j, the total number of observations.

(ii) The values obtained in step (i) are used to derive k from the overall data belonging to all the stars observed on a given night. The least square value of k is given by the relation :

$$k = \frac{\Sigma_i \Sigma_j(\ln V_{0j} - \ln V_{ij})\, X_{ij}}{0.92\, \Sigma_i \Sigma_j(X_{ij} * X_{ij})} \qquad \ldots (7)$$

The above two steps are repeated till the change in the standard error of k become insignificant ($\sim 10^{-5}$); the corresponding value of k was accepted as the average value of extinction coefficient for that day. The overall average extinction coefficient <k> obtained for all the clear nights turns out to be (0.62 ± 0.03). This is to be compared with the corresponding value of 0.59 estimated for a standard atmosphere at the Jammora altitude using λ-dependent values given by Elterman (1968). The excellent agreement with expectation is quite reassuring. Another reassuring feature follows from a comparison with the extinction coefficient measurements carried out by Singh *et al.* (1990) at a high-altitude location near Leh. They quote $k = 0.50 \pm 0.03$, 0.27 ± 0.03 and 0.17 ± 0.03 for the U, B and V bands respectively for this station. While, as expected, the actual λ-averaged value for the extinction coefficient is significantly lower at Leh than that obtained here for Jammora, what is particularly noteworthy is that the dispersion in daily k values is comparable at both the places. This vouches for the relative stability of the sky condition at Jammora, despite its lower altitude.

3.2. *Light of night sky (LONS)*

The background voltage (ΔV) for a given z, which is proportional to the LONS flux received within the system field-of-view centred on that z, has been obtained by subtracting dark voltage from the corresponding mean off-source voltage ($\langle V_{\text{off}}\rangle$). As would be expected from the isotropic nature of the LONS intensity, ΔV (in sharp contrast to V_s) is not found to exhibit any marked z-dependence. Figure 3 gives the frequency distribution of the overall ΔV values obtained during the present studies. It is reassuring to note that ΔV is distributed normally, centred on a mean value $\langle \Delta V\rangle = (17.8 \pm 4.8)$ mV. This shows that fluctuations in ΔV are mainly of a statistical origin and do not involve any systematic errors, as would be expected if, for example, there were artificial sources of background light present near the site of observation.

The mean off-source anode voltage $\langle \Delta V\rangle$ is related to the average LONS flux, ϕ_{LONS}, by the relation :

$$\phi_{\text{LONS}} = \langle\rho\rangle \times \langle \Delta V\rangle/\Omega \qquad \ldots (8)$$

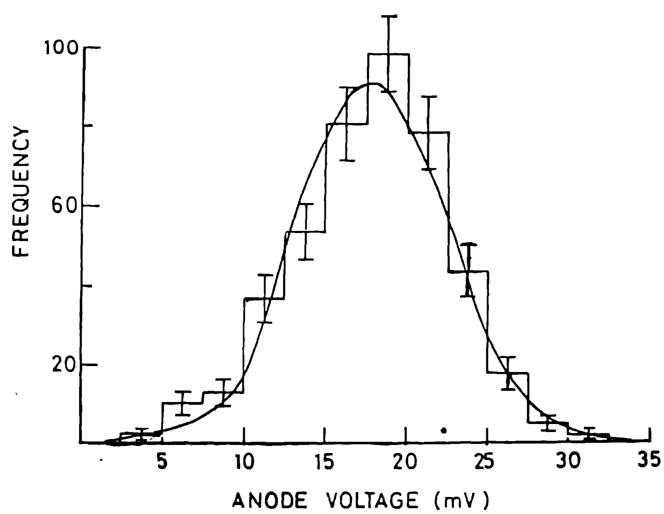

Figure 3. The frequency distribution of LONS-background-induced PMT anode voltage, ΔV, for the overall observation period (1991 Oct.-Nov.). The good matching with the expected normal distribution curve (full-line curve) shows that ΔV values are randomly distributed. The mean background voltage $\langle \Delta V\rangle$ is found to be (17.8 ± 4.8) mV.

where $<\rho>$ is a constant of proportionality, given by

$$<\rho> = \frac{\Sigma_j \{a\phi(U)_j + b\phi(B)_j + c\phi(V)_j\}}{\Sigma_j <V_{0j}} \quad \ldots (9)$$

Here ϕ's represent the stellar fluxes received at the top of the atmosphere in the standard U, B and V bands. $<V_{0j}>$ represents the average anode voltage proportional to the flux of starlight outside the earth's atmosphere. Finally the coefficients a, b and c represents the fractions of the standard U, B and V spectral bands which lie within the effective pass-band of our photometer and they are used here as weighting factors. Referring to figure 2, where we have superimposed the U-, B- and V-spectral bands on the photocathode spectral response of our detector, it is evident that these weighting factors have the following approximate values :

$$a \approx 1,\ b \approx 1 \text{ and } c \approx 0.78.$$

The stellar photon flux (in $cm^{-2}\ s^{-1}$) in a given wavelength band is related to the corresponding apparent magnitude of the star, by the following relations (Zombeck 1990) :

$$\log \phi(U) = -0.4\ mU + 5.7267 \quad \ldots (10)$$

$$\log \phi(B) = -0.4\ mB + 6.1565 \quad \ldots (11)$$

$$\log \phi(V) = -0.4\ mV + 5.9524 \quad \ldots (12)$$

where mU, mB and mV represent the apparent magnitudes of the star in the U, B and V spectral bands respectively.

Using Equations (9-12), $<\rho> = 399.91 \pm 30.62$ has been estimated for the nine reference stars employed in the present investigation (table 1). Using this value of $<\rho>$ in equation (7) and substituting therein for $<\Delta V>$ and Ω_{eff}, we arrive at a value of $(1.89 \pm 0.53) \times 10^8$ photons $cm^{-2}\ s^{-1}\ sr^{-1}$ for the LONS flux in the wavelength band 310-560 nm. As is evident from table 2, this value is found to be in reasonable accord with the values quoted in literature for several other mid-latitude stations, particularly when proper allowance is made for the differences in the effective pass-bands of various detector systems.

Table 2. Comparison of LONS flux measured at Jammora with some other values for a mid-latitude station

Reference	Wavelength band (nm)	Location	LONS flux ($\times 10^8$ photons $cm^{-2}\ s^{-1}\ sr^{-1}$)
Allen (1973)	320-450	Mid. Lat	1.50
Ramana Murthy and Tonwar (1976)	300-650	Ooty	0.74
Senecha *et al.* (1992)	340-450	Gulmarg	0.94
Sapru *et al.* (1993)	310-560	Gurushikar	1.54
Present Work	310-560	Jammora	1.89

4. Conclusions

The average extinction coefficient values obtained on various clear nights at Jammora are consistent with the values expected for a low-altitude (~ 500 m) station in case of the standard-model atmosphere (Eltermann 1968). Furthermore, the observed dispersion in k is found to be comparable with that logged for a high altitude station Leh by Singh *et al.* (1990). These results reassure about the relative stability of sky condition in Jammora on clear nights. Again the estimated average value of LONS flux, $(1.89 \pm 0.53) \times 10^8$ photons cm^{-2} sec^{-1} sr^{-1} within λ = 310-560 nm, is in good agreement with values quoted in literature for a dark mid-latitude site (table 2). This indicates that the site in question has a negligible interference from man-made sources of light. In these two respects, viz., atmospheric extinction and ambient light level intensity, Jammora is comparable with our present observatory location at Gulmarg. However, from the equally important point of view of cloud cover data, it is observed that Jammora can provide ~ 70% more observation time than Gulmarg. Further, given the additional advantages of its milder climate, lasting more or less throughout the year, as also the availability of a large enough piece of flat terrain, it follows that, on the whole, Jammora offers itself as a more suitable site than Gulmarg for our future gamma-ray experiments. However, as there is a considerable scope for further improvements in the matter of site selection, it is desirable that the quest for a still-better observatory site be continued and the present work extended to some other areas in the country. This additional survey work is in progress at present.

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