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

Search for Diffuse Galactic/extra-galactic TeV γ rays : possible measurements from IACT observations

C.K.Bhat and R.K.Kaul

Bhabha Atomic Research Centre, Nuclear Research Laboratory, , Mumbai 400 085, India

Presenter: C.K.Bhat (ckbhat@apsara.barc.ernet.in), ind-bhat-ck-abs1-og21-poster

We show from a detailed Monte Carlo-based simulation study of the TACTIC array that non-imaging parameters, like the fractal and wavelet dimensions of the Cerenkov images, can provide almost complete segregation of the isotropic γ-ray initiated events and use the results to obtain a preliminary estimate of the galactic diffuse γ-ray flux above 5 TeV.

1. Introduction

The diffuse high energy γ ray background from the galactic plane, as revealed by the EGRET data at photon energies above 100 MeV is generally attributed to nucleon-nucleon scattering and the decay of neutral pions produced in cosmic-ray interactions with the interstellar matter ([2] and references therein). As the galactic cosmic ray spectrum (from canonical sources like supernova remnants and pulsars) is expected to extend upto at least 10^{15} eV energy band, the diffuse γ ray spectrum resulting from cosmic-ray / interstellar material collisions, can easily extend into the energy range around 10^{12}-10^{13} eV which is accessible to ground-based imaging Cerenkov telescopes. An additional component of diffuse VHE gamma-ray flux is also expected from the ensemble of unresolved galactic γ ray sources and unknown sources like the EGRET unidentified objects whose high energy emission may extend into the TeV range. A small extragalactic component of isotropic γ-rays is expected from the cumulative contributions from unresolved active galactic nuclei and other potential extragalactic TeV γ-ray sources [1]. Imaging Cerenkov telescope systems, which allow the reconstruction of Cerenkov event directions from stereoscopic observations, have been used for detailed sky surveys and searches for diffuse γ-ray emission from the galactic plane at energies $\geq$ 1 TeV. Upper limits on diffuse γ-ray emission at VHE energies ($\geq$ 500 GeV) have been reported by the Whipple [3] [5] and the HEGRA groups [6] and at $\geq$ 10 TeV by the Tibet array group [4] and in most cases the diffuse gamma-ray fluxes are found to be $\leq 10^{-3}$ of the cosmic-ray flux. Since single Cerenkov imaging telescopes have an inherently low sensitivity for differentiating between the background cosmic-ray initiated events and the off-axis (isotropic) gamma-ray initiated events, a firm detection of diffuse galactic gamma-ray flux has eluded the observers so far. In the present communication we show from a detailed simulations-based study that pattern recognition tools like fractal and wavelet analysis applied to Cerenkov images, recorded in a TACTIC-like IACT system, enables a clear separation of cosmic-ray and isotropic gamma-ray initiated events. We use these results to derive a preliminary estimate of the diffuse galactic gamma-ray flux at $>$ 5 TeV energy from a 2 h long observation scan with the TACTIC imaging telescope at a zenith angle direction centred on 50°.

2. Simulation methodology

The CORSIKA (version 5.61) air shower simulation code, developed by the KASCADE group [8] has been used for simulating the extensive air shower development and production of Cerenkov photons in the atmosphere at Mt. Abu (24.6°N; 72.7°E; 1300m asl) by cosmic-ray protons and gamma ray primaries. A total of 400 showers each have been generated for CR protons of energy 20 , 40 , 60 , 100 and 200 TeV and gamma-rays of 10, 20, 30, 50 and 100 TeV. The primary particles in both the cases are considered to be isotropically incident within the trigger field of view of 4°of the TACTIC imaging element [10] centred at a zenith angle of $\sim 50°$. The high value of zenith angle has been considered to take advantage of the larger effective collection area (alongwith a proportionate increase in the threshold energy) available in the large zenith angle mode of operation. Atmospheric extinction of Cerenkov photons has been taken into account and the photon distribution in the 349-pixel TACTIC camera derived through appropriate ray tracing for all events passing the 3 NCT trigger criterion ([10] and references therein). The recorded images have been subjected to the usual flat fielding, cleaning and calibration procedure before deriving the various Hillas image parameters and the additional fractal and wavelet parameters for both the CR initiated events and the isotropic gamma-ray intiated events. For all parameters, the domain of parameter values which passes the maximum number of gamma-initiated events and rejects the largest number of CR events has been identified to quantify the gamma/hadron segregation capability. The efficiency of each parameter for gamma/proton segregation has been quantified in terms of the Quality Factor (Q) defined as

$$\mathrm{Q} = \frac{N_\gamma}{N_{\gamma T}} \left(\frac{N_p}{N_{pT}}\right)^{-1/2}$$

where N_γ is the number of gamma ray events accepted out of the total number of gamma-initiated events $N_{\gamma T}$ after applying the parameter cut and N_p is the number of CR initiated events (out of the total N_{pT} CR events) retained after the cut.

3. Fractal and Wavelet analysis of Cerenkov images

The pattern recognition technique for gamma-hadron segregation, based on fractal and wavelet analysis of Cerenkov images exploits the differences in the structure of Cerenkov images due to differences in the height of shower maximum and the number of relativistic electrons and muons in the two shower types. The fractal and wavelet moments and dimensions, which characterise the image structure on different scale lengths, have been shown to be very sensitive to the nature of the primary and recommended for efficient gamma-hadron segregation [9] and cosmic ray mass segregation [7] in Cerenkov imaging systems. As described in detail in [9], the procedure involves dividing the Cerenkov image into M = 4, 16, 64, 256 equally-sized cells and by calculating the number of ADC counts in each cell, M is related to the fractal scale-length ν by $\nu = log_2$M . The different parameters are defined as

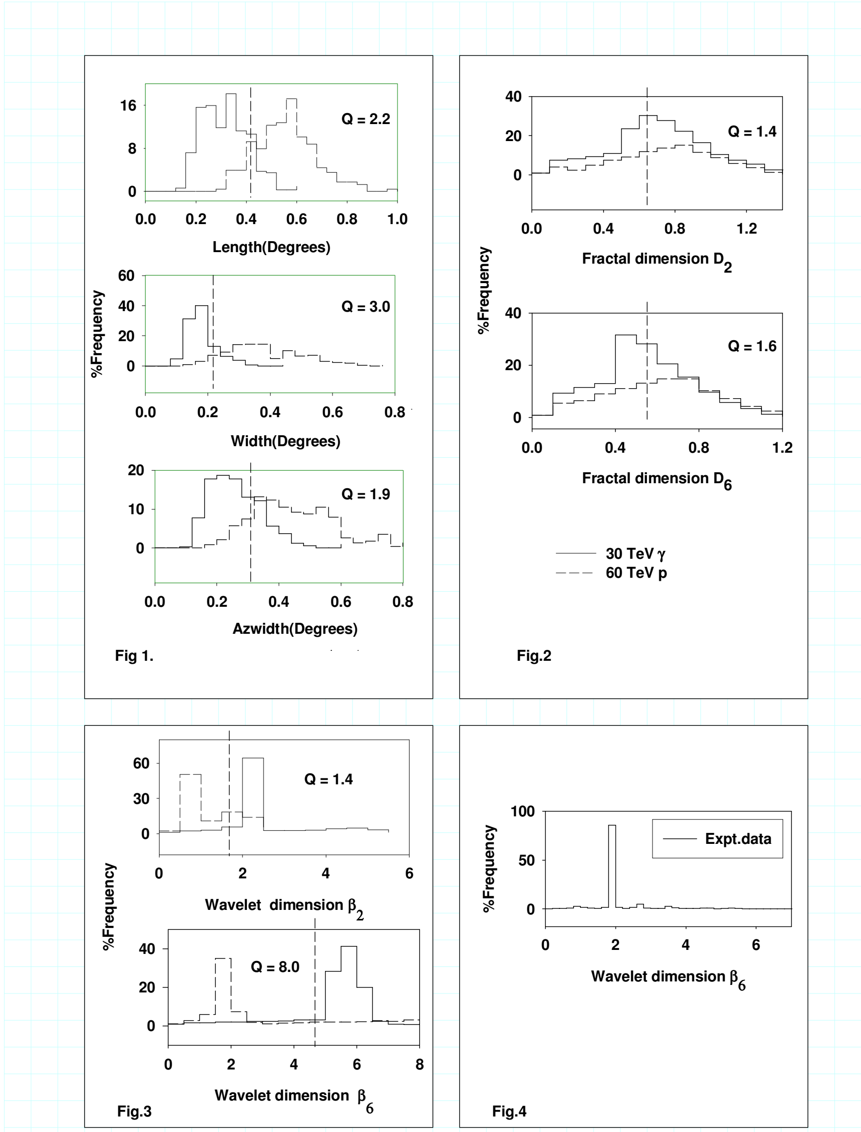
$$\text{Fractal moment} \quad G_q(M) = \sum_{j=1}^{M} \left[\frac{K_j}{N}\right]^q \tag{1}$$

$$\text{Wavelet moment} \quad W_q(M) = \sum_{j=1}^{M} \left[(\frac{K_{j+1} - K_j}{N})\right]^q \tag{2}$$

$$\text{Fractal dimension} \quad D_q = \frac{\tau_q}{q-1} \tag{3}$$

$$\text{Wavelet dimension} \quad \beta_q = \frac{\beta_q}{q-1} \tag{4}$$

where N is the total number of ADC counts in the image, K_j is the number of counts in the jth cell and q represents the order of fractal moment (q = 2, 3, 4, ...).



4. Results and discussion

Fig.1 shows a representative frequency distribution plot of the three image parameters, namely, Length (L), Width(W) and Azwidth (A) for 30 TeV gamma-ray and 60 TeV proton-initiated events. The vertical lines in the three plots represent the optimum parameter value which segregates isotropic gamma-ray events from CR proton-initiated events. The highest segregation efficiency ($Q\sim3$) is achieved in case of W with ∼92% gamma-ray acceptance and ∼90% proton rejection for $W\leq 0.24°$. However, in view of the rather large spread in the distribution of W, the quality factor is expected to deteriorate when account is taken of the actual CR spectrum in the simulations with lower energy CR initiated events leading to images with smaller W as observed for gamma-initiated events. Figs. 2 and 3 show representative frequency distribution plots of fractal dimensions

D_2 and D_6 and the wavelet dimensions β_2 and β_6 for 30 TeV gamma-ray initiated and 60 TeV CR proton-initiated events. Except in the case of wavelet parameter β_6, the quality factor Q in the other three cases is found to be ≤ 1.5, indicating a poor efficiency for gamma-hadron segregation. The frequency distribution of the wavelet dimension β_6, however, shows two distinct and well separated peaks, one centred at β_6 = 5.75 for gamma-ray initiated events and the other centred at β_6 = 1.75 for proton-initiated events. As seen from Fig.3, there appears to be very little overlap in the two distributions indicating an almost complete segregation of isotropic gamma and CR proton-initiated events. As already mentioned, although this picture is likely to change somewhat when the simulations take into account the CR energy spectrum properly, the derived quality factor of Q=8 for the single energy case depicted here promises excellent gamma/hadron segregation using the β_6 parameter. Fig.4 shows the frequency distribution of β_6 for actual data recorded with the TACTIC imaging camera. The data was recorded during a 2h Crab off-source scan from a zenith angle direction centred at 50°. The total number of events recorded during the scan was 12870. While 11340 $\pm$ 110 events out of the total events($\sim$88%) fall within the proton domain of β_6 = 2 $\pm$ 0.5, only 35 $\pm$ 6 events fall in the gamma-ray domain of β_6 = 5 $\pm$ 1. Taking into account the exposure time of 7200 s, an effective area of 7.07×10^8cm^2 (obtained from TACTIC simulations at 50° zenith angle) and a field of view of 3.8×10^{-3} sr, the isotropic gamma-ray flux above the TACTIC threshold energy of 5 TeV (at 50° zenith angle) is estimated as,

$$J_\gamma(>5TeV) = (1.8 \pm 0.3)10^{-9}\text{photons} \quad cm^{-2}s^{-1}sr^{-1} \tag{5}$$

Although it is a preliminary estimate based on only a 2h recorded data set and using simulations-based parameter cuts which require optimization, our estimate compares favourably with the reported upper limit of 3×10^{-8}cm^{-2}s^{-1}sr^{-1} above 0.5 TeV by the Whipple group [5] and $\leq1.96\times10^{-10}$ cm^{-2} s^{-1}sr^{-1} above 10 TeV by the Tibet air shower array [4]. We hope to improve the simulations-based results by incorporating the cosmic-ray spectrum and extending the simulations to the energy range in which TACTIC operates at large zenith angles.

5. Conclusions

It has been shown on the basis of a fractal and wavelet analysis of simulated atmospheric Cerenkov images that it is possible to segregate cosmic-ray proton initiated events from isotropic gamma-ray initiated events with high efficiency using the β_6 wavelet dimension parameter. Using these results, a 2h data set from the TACTIC imaging Cerenkov telescope has been analysed to arrive at a preliminary value for the diffuse galactic background gamma-ray flux above 5 TeV energy.

References

[1] Sreekumar, P., et al,ApJ, 494, 523(1998).
[2] Sreekumar, P., et al,BASI(2002)
[3] Reynolds, P.T. et al, ApJ, 404, 206(1993)
[4] Amenomori, M., et al, Proc. 25th ICRC, 3, 117(1997).
[5] LeBohec, S., et al, ApJ, 539, 209(2000).
[6] Aharonian, F.A., et al, A & A, 375, 1008(2001).
[7] Haungs, A. and Knapp, J.,Proc. 27th ICRC, 3, 315(2001).
[8] Heck, D., et al, FZKA 6019, Forschungszentrum Karlsruhe(1998).
[9] Haungs, A., et al, Astro. Part. Phys., 12, 145(1999).
[10] Tickoo, A.K., Ph.D Thesis, University of Mumbai(2002).