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TeV γ-ray Observations of the Blazar Markarian 421 from January to April 2004 with TACTIC Imaging Element

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We have observed the blazar Markarian 421 (z=0.031) with the TACTIC gamma- ray telescope having threshold energy of 1.5TeV at Mt. Abu Rajasthan India from January to April 2004. Observations were made in tracking mode for a total of 84(on) /16 (off-source) hours with its imaging element equipped with a 349- pixel PMTs camera. During this period, we find an evidence of a TeV gamma-ray signal with a statistical significance of 6.8 σ. The differential energy spectrum derived in the energy range 2 - 9 TeV is well represented by a simple power law, with a differential spectral index of 2.80 $\pm$ 0.20.

1. Introduction

Markarian 421 (Mrk 421, z=0.031) is a BL Lac type active galactic nucleus and was detected as the first extragalactic source of VHE gamma-rays in 1992 by the Whipple Observatory [1]. It has been confirmed as a source of VHE gamma-rays by the HEGRA [2], the Telescope Array Project [3] , the SHALON [4], the CAT [5] and the TACTIC [6] collaborations. Recently it was also observed and detected by the most advanced HESS system [7] at large zenith angles. One of the most distinctive observed features of such objects is extreme variability on time-scales from minutes to years. Earlier observations of Mrk 421 have revealed several distinct episodes of flaring activity and indicated that the VHE emission from Mrk 421 was best characterized by a succession of day-scale or shorter flares. We have also observed this source in 2004 using the imaging element of the TACTIC gamma -ray telescope. Results of these observations are being presented here.

2. Experimental details

TACTIC array of atmospheric Cerenkov telescopes is located at Mt. Abu, Rajasthan (24.6 $^\circ$ N, 72.7 $^\circ$ E, 1400m asl), in Western India. Its Imaging Element (IE) uses a tessellated light-collector of 9.5 m^2 area which is configured as a quasi parabolic surface, yielding a measured on axis spot-size of 0.3°. The telescope has a pointing / tracking accuracy of better then 5 arc-mins and the pixel resolution of its imaging camera is $\sim$ 0.31° throughout the camera FoV of $\sim 6^\circ \times 6^\circ$. We have used 225 pixels (15$\times$ 15 matrix) of the camera for present studies and event-trigger generation is based on the 3NCT (Nearest Neighbour Non-Collinear Triplets) topological logic, demanding $\geq$ 7 pe's for the 3 pixels which participate in the trigger-generation. The trigger is derived from the inner 121 pixels. For more detail we refer to [8].

3. Observations and data analysis

Observations were carried out on Mrk421 during January - April , 2004 using the IE of the TACTIC telescope. The zenith angle range covered during a given on /off source tracking runs was generally limited to $\theta \leq 45^\circ$ and the sky condition varied between good to excellent. The durations of on- and off- source observations were

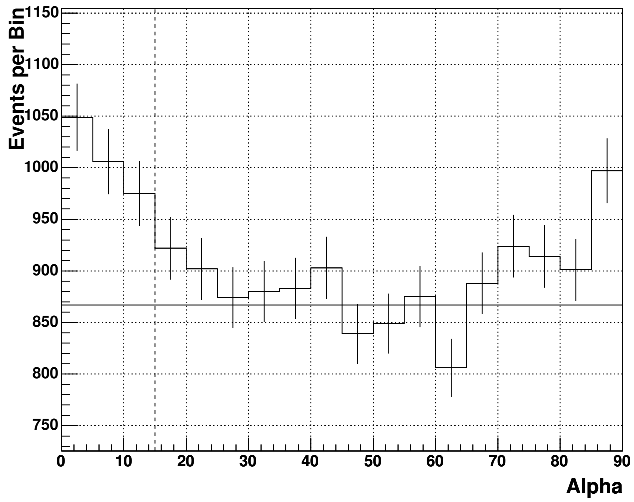

Figure 1. Distribution of the α(in degree) parameter of Mrk 421 for all 2004 data runs. The signal is clearly seen in the first three bins.

Table 1. Imaging cuts used in the present analysis.

Parameters	Values
Length	$0.11° \leq$ L$\leq$(0.155 + 0.0260*log(size))°
Width	$0.06° \leq$ W $\leq$ (0.080 + 0.01250*log(size))°
Distance	$0.4° \leq$ D $\leq 1.3°$
Npix	Npix ≥ 4
Size	S ≥ 270

84 and 16 hours respectively. Data quality checks were applied using chance rates, number of dead pixels and zenith angle dependence of events. As a result, the durations of the cleaned 2004 data set from the on and off-source directions were reduced to 78.7 and 14 hours respectively.

While doing data analysis, the images recorded between two consecutive gain calibration cycles were corrected for inter-pixel gain variations and then subjected to the standard image cleaning procedure. In this procedure, after carefully subtracting the contribution of the light of night sky from each camera pixel, image boundaries were located in the camera plane. For this we have used a picture threshold of 6.8 σ , boundary threshold of 3 σ and an isolated pixel threshold of 9 σ. Then various Hillas[10] image parameters, viz., Length (L), Width (W), Distance (D) , Alpha (α) size (S) were calculated for all the cleaned images. Based on supercuts methodology [12] and CORSIKA-based simulation studies of the TACTIC Imaging Element [9], γ-ray-like events were preferentially picked from the overall data-base of the source by appropriately changing the permitted L, W and D ranges as a function of S. The imaging cuts used in the analysis are listed in the Table 1. The events thus selected yield an α-distribution as shown in Figure 1 for the 78.7 hours of observations from the on-source direction. Clearly, first three bins of the distribution (being a signal domain for the telescope) show relatively higher events as compared to the rest of the distribution, thereby indicating the presence of TeV signal in the

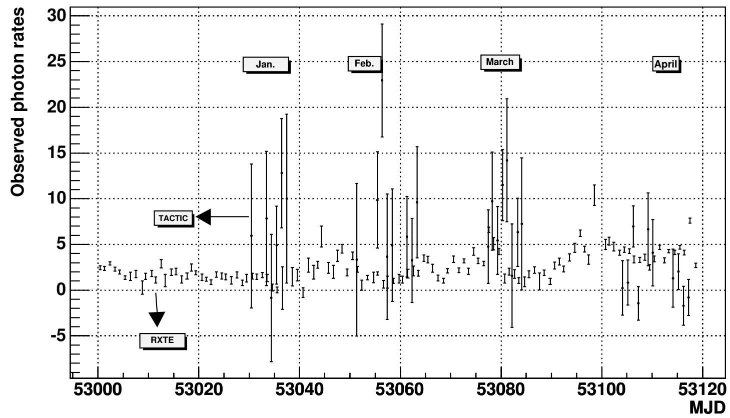

Figure 2. Mrk 421 nightly observed hourly γ -ray rate (2- 9 TeV) and RXTE X-ray (2-12 KeV) counts per sec.

database. The corresponding off -source database was also subjected to the similar analysis and alpha plot thus obtained is consistent with flat distribution. As the off-source database was much less as compared to that of on -source, we have not used it for deriving gamma-ray signal strength. Instead, we have used the same on-source data base, after applying dynamic cuts for estimating the background, which is the methodology used by [11]. For this, we have used after cuts data which is in the alpha range of 25 to 65 degree, wherein there is a possibly minimum contribution of gamma -ray signal from the source region. The overall signal detected from Mrk 421 amounts to a statistical significance of 6.8σ in 78.7 hrs of observations.

In addition, we have also estimated excess/deficit of events from source direction on nightly basis, to detect flaring state of the source, by analysing the database of each observational night, durations of which varies from 2-5 hours. The resulted nightly variations in terms of the γ-ray like events/hr are shown in the Figure 2 alongwith RXTE (2-12 keV) X-ray counts/sec (we have used the RXTE X-ray data from RXTE web site [13]. As is clear from this Figure, there is a possible weak indication for flaring activity on few nights. Because of the low statistics and poor sensitivity of the telescope , it is difficult to draw a firm conclusion of the flaring of source during this observational period. We have also attempted to reconstruct the energy spectra of the source with the limited on -source excess. For this, collection areas were calculated from simulated air showers as a function of energy and zenith angle. The derived collection area for individual event was used as a weight to calculate the flux in the bins of energy by summing over the events in the on and off -source regions. Then the obtained off-source energy spectrum was subtracted from that of the on -source and the resulting differential source spectrum thus obtained in the energy range of 2- 9 TeV is shown in the Figure 3. A differential function of the form Kx E $^{-\gamma}$ (where E is in TeV) was fitted to the source spectrum and the value of K= 1.692x10 $^{-11}$ $\pm$ 3.887x10^{-12} cm^{-2}sec^{-1} TeV^{-1} and γ =1.80 $\pm$0.20 were obtained.

4. Results and Conclusion

We have detected TeV γ-ray signal from Mrk 421 direction with a statistical significance of 6.8 σ in 78.7 hrs of on -source observations. These observations indicate that the source was emitting TeV photons but nightly flaring episodes for only a few nights cannot be ruled out.

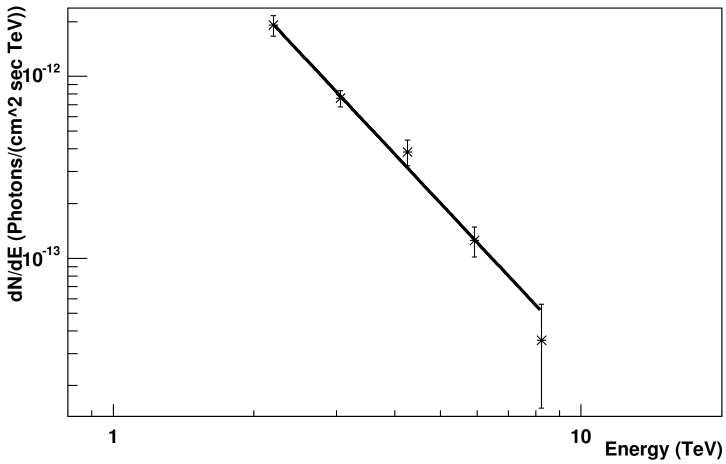

Figure 3. Differential flux of Mrk 421 for the total period of 2004 TACTIC observations. Error bars are statistical and full line represents the power law function obtained by fitting the flux points.

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