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Recent Results on Crab Nebula and Mkn-421 observations with TACTIC Imaging Element

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Abstract. The results of our recent observational campaigns on the Crab Nebula and Mkn-421, carried out with the 349-pixel Imaging Element of the TACTIC array, are presented alongwith the details of the data analysis. Analysis of the recorded events reveals presence of significant signals from both these sources.

Key words: Very high energy γ-rays, TACTIC Telescope , Crab Nebula, Mkn-421

1. Introduction

The 4-element TACTIC array of atmospheric Cerenkov telescopes has been recently commissioned at Mt. Abu (24.6° N, 72.7° E, 1400 m asl), Rajasthan, in Western India. Its Imaging Element (IE), placed at the array centre, was first used for observations in April-May 1997 with a 80-pixel prototype camera when it detected Mkn-501 in its, now well-known, high-activity state, which lasted for several months (Bhat et al, 1997). Recently, after equipping it with its full 349-pixel camera, it was used for observations on the TeV gamma-ray standard candle, the Crab Nebula, and the BL-Lac object, Mkn-421. We present here results of these new observations with the IE.

2. Experimental Details

The IE uses a tessellated light-collector of 9.5 m^2 area which is configured as a Davis-Cotton surface, yielding a measured spot-size of 0.3° for on-axis parallel rays. Its PC-controlled 2-axes drive system gives a pointing / tracking accuracy of 5 arc-mins. The pixel resolution of its imaging camera is $\sim 0.31°$ throughout the camera FoV of $\sim 6° \times 6°$. The innermost 240 pixels (15× 16 matrix) are used for event-trigger generation, based on the 3NCT (Nearest Neighbour Non-Collinear Triplets) topological logic, demanding $\geq$ 5 pe's for the 3 pixels which participate in the trigger-generation. Whenever the single's rate of one or more pixels goes outside the preset operational band (3 - 7 kHz), it is automatically restored to within the prescribed range by appropriately adjusting the pixel(s) high voltage(s). The resulting change in the pixel(s) gain is monitored by repeatedly flashing a bright LED lamp, improvised to produce a uniform photon field over the entire camera surface (Bhatt et. al, 2001). From the logged digital counts (dc), the relative gains of all the pixels are derived with respect to 4 'calibration' pixels for which the high voltage is always kept fixed. In addition, these pixels, which are located on the 4 edges of the camera are provided with Am^{241}-embedded scintillator pulsers for on-line absolute calibration. The absolute calibration and the sky pedestal data (dc) of the camera pixels are recorded several times in the course of observations for Cerenkov image-cleaning and calibration purposes. The absolute occurrence time of each individual event is recorded with a resolution of 1μs and an accuracy of a few μs, using GPS provided reference time-markers for synchronization of the local clock.

3. Observation and Discussion

Using the IE, observations were carried out in on/off- source mode on the Crab Nebula (for 41.5 h/30.4 h) between Jan 19-Feb 23, 2001 and the BL-Lac object Mkn-421 (78.6 h/6.9h) between Jan 30-April 27, 2001. The zenith angle range covered during a given on / off source tracking was generally limited to $\theta \leq 45°$. The sky condition varied between good to excellent. The 3-fold Prompt Coincidence Rate (PCR) varied between 2 - 5 Hz and the 2-fold Chance Coincidence Rate (CCR), used as a system- health monitoring parameter, remained steady around $\sim$ 200 Hz.

Before undertaking the actual observation-runs on the Crab, the IE was made to track a nearby optical star for one complete night to measure the overall range and trend of the residual pointing error in the telescope. It was found to reach a maximum value of $\sim$ 0.2° and, accordingly, an appropriate offset was introduced in the drive system software to ensure that the error in tracking the Crab Nebula in the course of our observations was $\leq 0.1°$. A similar exercise carried out, while Mkn-421 observation campaign was nearly midway, revealed an analogous pointing error trend in the case of Mkn-421 (max value $\sim 0.25°$). It is pointed out that, in the preliminary results presented here, the required correction for Mkn-421 offset has not yet been made, resulting in a somewhat broader α-plot ($\alpha \leq 20°$), with a correspondingly lesser statistical significance.

The image data recorded between two consecutive gain calibration cycles was corrected for inter-pixel gain variations and was then subjected to the standard image 'cleaning' procedure. The resulting non-zero digital counts (dc) from each pixel were

added to yield the image size (S). Various image parameters, viz., Length (L), Width (W), Distance (D) and Alpha (α) were calculated for all the cleaned images. Based on guidance from the literature for extended supercuts methodology (Mohanty et al., 1998) and our own CORSIKA-based simulation studies for the TACTIC Imaging Element (Koul et al., 2002, γ-ray-like events were preferentially picked from the overall data-base for a source (Crab Nebula/Mkn-421) by appropriately changing the permitted L, W and D ranges as a function of S. The events thus selected yield an α-distribution as shown in Fig.1 and Fig.2 for the Crab (Jan 19-Feb 23, 2001) and Mkn-421 (Jan 30-April 27, 2001) data, respectively. Quite reassuringly, both the figures display statistically significant excesses of 6.3σ and 7.5σ respectively in the on-source case (Fig.1a and Fig.2a) with respect to the corresponding Residual Background Levels (RBL) estimated from $25° \leq \alpha \leq 65°$ data, while the corresponding off- source α-plots are in an excellent agreement with the expected flat distribution (Fig. 1b and Fig.2b).

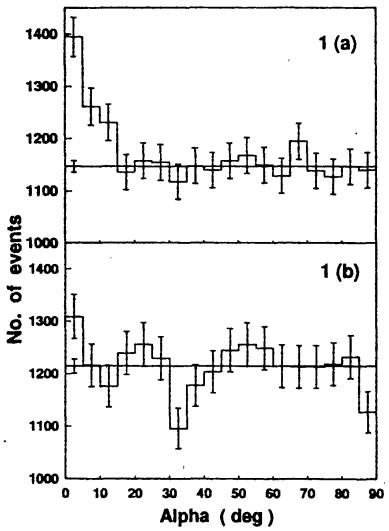

Fig 1. Alpha plot for Crab. (a) On-source (b) Off-source.

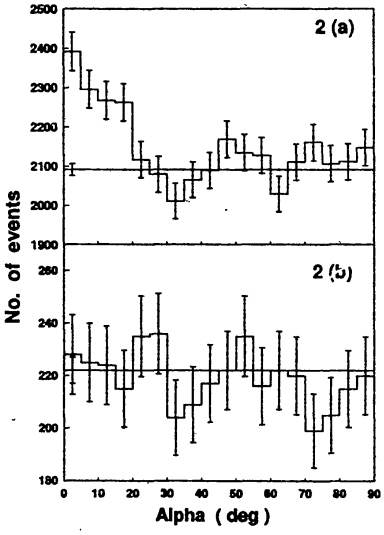

Fig 2. Alpha plot for Mkn 421. (a) On-source (b) Off-source.

The apparent gamma-ray signal (excess events in $\alpha \leq 15°$ for Crab and $\alpha \leq 20°$ for Mkn-421) detected by the IE on a daily basis from the direction of the Crab Nebula (Fig.3a) and Mkn-421 (Fig.4a). Also, shown for comparison are the corresponding off-source plots, both of which are consistent with a no-emission hypothesis, as expected.

Referring to Fig.3a, on the other hand, we find a clear evidence for the well-known Crab signal, essentially constant at a detected average rate of (10.8 $\pm$ 1.7) gamma-rays/h, which we designate here as 1 'Crab Unit' (CU). Expressed in these units for direct comparison, the inferred gamma-ray light curve for Mkn-421 (Fig.4a) is found to exhibit significant day-to-day flaring activity, with signal strength varying upto 4 CU during the period of our observations. These values are found to be in good agreement with the daily flux levels reported by the HEGRA group for the corresponding period (Rowell, 2001).

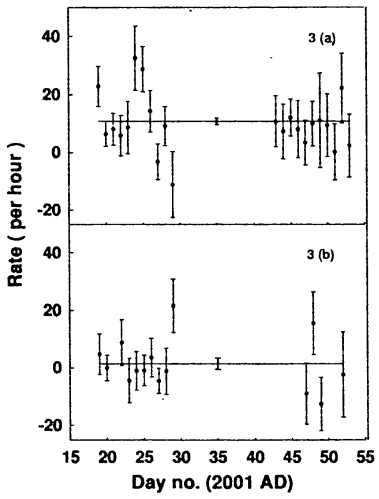

Fig 3. Daily Rate Plot for Crab. (a) On-source (b) Of-source.

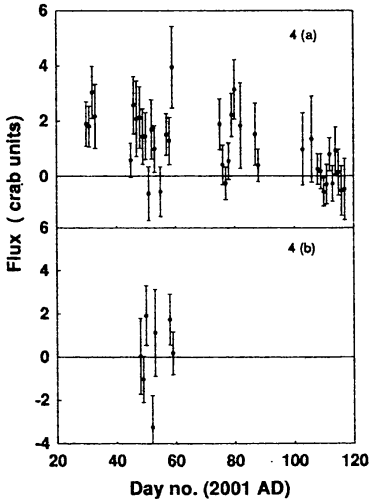

Fig 4. Daily Rate Plot for Mkn 421. (a) On-source (b) Of-source.

Turning now to the estimation of the flux corresponding to 1 CU, as defined above, it turns out to be $\sim$ (1.02$\pm$ 0.16) $\times 10^{-11} \gamma cm^{-2} s^{-1}$ for an assumed γ-ray acceptance value of$\sim$ 65% and an effective-range of $\sim$ 120 m for the IE. This value is in good agreement with the known nebular integral photon flux above the estimated image threshold energy of $\sim$ 1.3 TeV for the IE (Aharonian et al, 2000). Work is in progress on confirming these estimates and on inferring the source spectra with appropriate inputs from related simulation studies (Koul et al, 2002]

4. Conclusion

The TACTIC Imaging Element, now deploying its full 349-pixel imaging camera, has detected the Crab Nebula and Mkn-421 gamma-ray signals with time histories analogous to those reported in literature for these sources (Ong, 1998). The inferred sensitivity level of 1 CU at $\sim$ 6.3 σ in 41.5 h of overall on-source observations (no data-cuts, gamma-ray threshold $>$ 1 TeV) needs to be further improved, and there is ample scope for it, both at the level of the IE (by a factor of $\sim$ 2) and after incorporating corresponding data from the 3 VE's of the TACTIC.

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