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Observations of Mkn 421 with TACTIC

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Abstract : The TACTIC imaging element has observed the extragalactic BL Lac object Mkn 421 for ~ 78h during Jan. – April 2001. Analysis of the overall data set, using the dynamic supercuts methodology, has revealed the presence of a ~ 7.5 σ strong signal at Eγ ≥ 1 TeV. The signal is found to be variable on a day-to-day basis and is more or less absent during April 2001.

Key words : Mkn 421 – XBL Lac – TeV emission.

1. Introduction

Markarian 421 (Mkn 421) is a nearby (z = 0.031) BL Lac object of the X-ray loud (XBL) type which was first discovered as a TeV gamma-ray source by the Whipple group in 1992 (Punch et al, 1992) and subsequently confirmed as a TeV source by the HEGRA and other Cerenkov telescope systems (Ong, 1998 and references therein). Regular monitoring of this source by various groups has revealed that its TeV gamma-ray emission generally varies on a time-scale of ~ 1 day. During an extensive multiwavelength campaign of this source in April –May 1995, covering wavelengths from the optical to the TeV band, a strong correlation was found between the light curves at various wavelengths with maximum variability observed in X-rays and TeV gamma-rays (Buckley et al, 1996). The Whipple group has also detected two extremely short-duration flares from Mkn 421 during 1996, involving the doubling of gamma-ray rates from the source in 15 min and 1.5 h respectively, suggestive of very small dimensions for the particle acceleration and gamma-ray emission region (Gaidos et al, 1996). The inferred gamma-ray spectrum from MeV – GeV to TeV energies cannot be fitted with a single power law and a cut off is suggested in the spectrum around ~ 10 TeV, possibly related to the absorption of TeV gamma-rays in the intergalactic medium through γ- γ interactions with the background IR fields.

The TACTIC Imaging Element (IE) has been used to observe Mkn 421 during Jan. – April, 2001, using the full 349 – pixel Cerenkov imaging camera in its focal plane. Here we present the main results obtained from this observational campaign and compare our results with those obtained from other Cerenkov systems operated during this period.

2. Experimental System

The TACTIC IE has been recently commissioned at Mt. Abu (24.6^0 N; 72.7^0 E; 1400 masl), Rajasthan, in Western India. The IE, placed at the centroid of the 4-element TACTIC array (Bhat and Kaul, 2002), is equipped with a 349- pixel, photomultiplier tube-based, Cerenkov light imaging camera in its focal plane, covering an overall field of view of ~ 6^0x6^0 and a uniform pixel resolution of 0.31^0. The IE uses a tessalated light collector of ~9.5m^2 area, which is configured as a Davis-Cotton surface, yielding a measured spot size of 0.3^0 for on-axis rays and a pointing/tracking accuracy of ~5 arc min. The innermost 240 pixels (15x16 matrix) are used for trigger generation, based on the 3NCT (Nearest Neighbour Non-Collinear Triplets) topological logic, demanding ≥ 5 photo electrons from the 3 pixels which produce the trigger. The absolute occurrence time of each event is recorded with a resolution of 1μs and an accuracy of a few μs, using GPS reference time markers. The trigger threshold (as well as the image threshold) has been estimated to be ~ 1 TeV from system simulations.

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Observations were carried out in the on-off mode during Jan. 30 – April 27, 2001, at source zenith angles $\leq 45^0$. The sky condition throughout the observational spell varied from very good to excellent. The 3 fold prompt coincidence rate varied between 2-5 Hz while the 2-fold chance coincidence rate (used as a system 'health' monitoring parameter) remained steady around ~ 200 Hz.

3. Observations and results

The observational strategy is presented in detail in Bhatt et al (2002). The image data recorded between two consecutive gain calibration cycles was corrected for inter-pixel gain variations and 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) and various image parameters (Length (L), Width(W), Distance (D) and Alpha (α)) were calculated for the cleaned images. Using the supercuts methodology (Mohanty et al, 1998) and guidance from our own CORSIKA – based simulations for the TACTIC IE (Koul et al, 2002), γ-ray like events were preferentially picked up from the overall data-base by appropriately choosing the image parameter (L,W,D) domains as a function of image size (S).

Fig. 1 shows the α-distribution for the resulting Mkn 421 on-source data (top) and a representative α-distribution for off-source data (~7h; bottom). A 7.5σ excess is seen in the on-source data for $0^0 \leq \alpha \leq 20^0$ as compared to the corresponding residual background, derived from data in the $25^0 \leq \alpha \leq 65^0$ domain, indicating the presence of a statistically significant $\geq$ 1 TeV gamma-ray signal in the overall data. The off-source α-distribution is found to be reasonably flat, as expected for isotropic cosmic-ray hadron-initiated events.

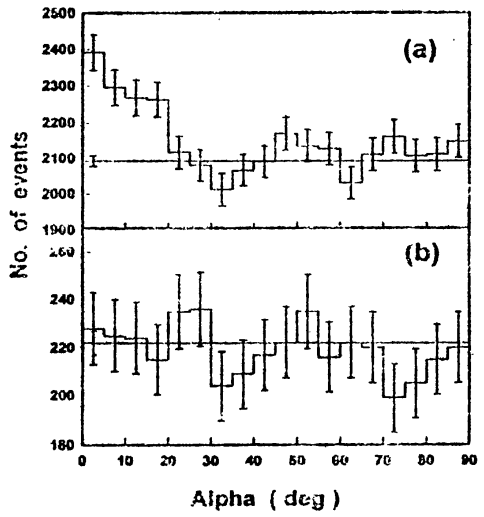
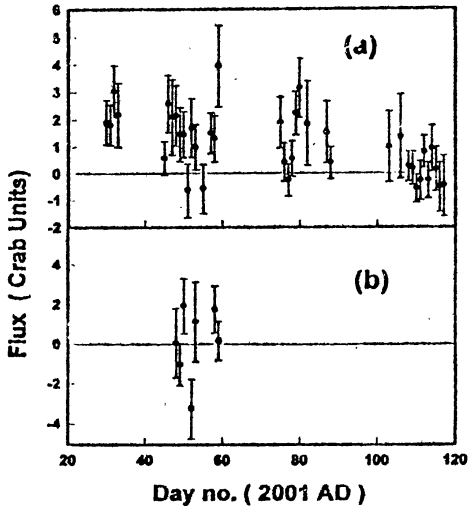


Fig.1. α - plot for image parameter selected events (a) on - source and (b) Off – source



Fi g.2. Daily gamma - ray rate for Mkn 421 (a) On-source (b) Off - source

Fig. 2 shows a daily plot of the apparent gamma-ray signal from Mkn 421 (excess events in $\alpha \leq 20^0$) and the corresponding off-source plot which is found to be consistent with a non-emission hypothesis. The inferred gamma-ray light curve for Mkn 421 (top) is found to exhibit significant variations (flaring activity) on a day-to-day basis, with the signal strength going up to ~ 4 Crab units on some days. The variability is found to be consistent with the daily flux values reported by the HEGRA group for this epoch of observations (Rowell, 2001) and the results reported from other observatories as presented in this session. Interestingly, the TeV gamma-ray activity reverts to a quiet state (almost no TeV gamma-ray emission) during April 2001, when the source was reported to be in an optically quiescent phase from observations at the Gurushikhar Optical/IR observatory (Joshi et al, 2002).

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We have derived the Mkn 421 differential energy spectrum in the energy range 1-10 TeV by following the following strategy. First, the image size from the recorded CDC counts is converted to the corresponding photoelectron number using appropriate calibration (1 pe = 3 CDC counts). Using an appropriate size cut (S ≥50 pe), we have applied dynamic shape cuts (L,W and D) to select gamma-ray like events and the gamma-ray excess for each energy range has been evaluated from the corresponding α plot. The differential flux is then estimated from the relation

$$(dJ^i_\gamma/dE) = (dN^i_\gamma/dE)\ \Sigma^4_{j=1}\ (T/Aj\ Tj) * (1/T)$$

where (dN^i_γ/dE) and (dJ^i_γ/dE) are the number of events and differential flux at energy E^i, measured over the zenith angle range of 0^0-45^0 respectively. Tj is the observation time in the jth zenith angle bin with corresponding effective area Aj (estimated from simulations) and T is the total observation time. The four zenith angle bins (j = 1-4) used are $0^0 - 15^0$, 15^0- 25^0, $25^0 - 35^0$ and 35^0-45^0. Fig. 3 shows the derived Mkn 421 differential energy spectrum in the 800 GeV – 10 TeV energy range.

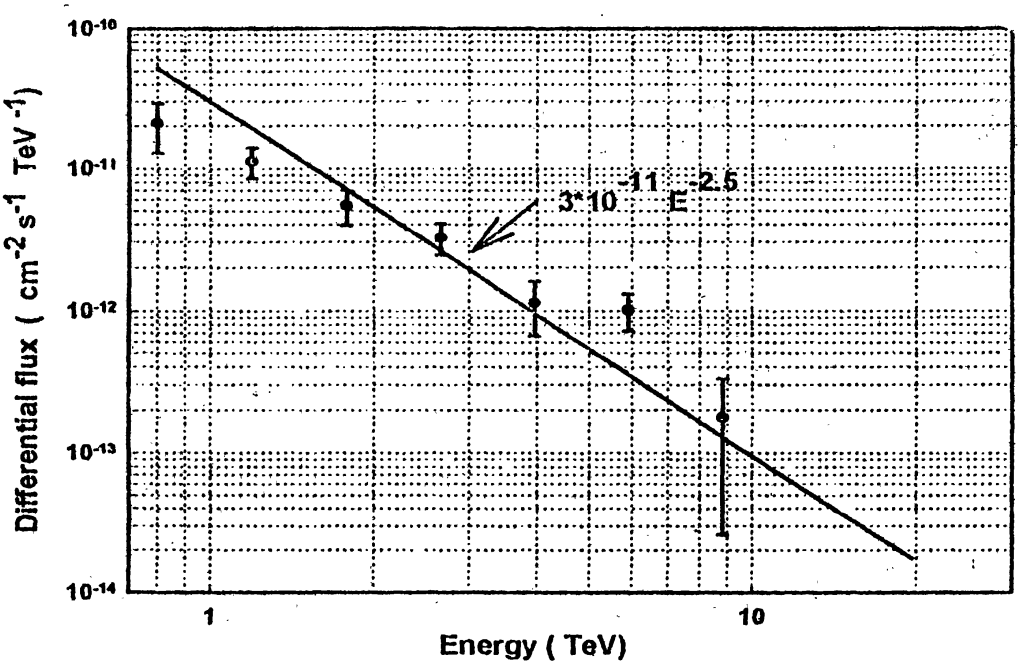

Fig 3. Differential energy spectrum of Mkn 421 from the TACTIC observations.Also plotted is a representative differential power law spectrum with exponent 2.5, typical of the flare time spectrum of this source.

Also shown for comparison is a representative Mkn 421 differential energy spectrum, dN / dE ~ $3x10^{-11}$ $E^{-2.5}$, where the power law exponent is taken to be 2.5, in agreement with the results obtained for TeV flare spectra of Mn 421 derived by the Whipple group (Krennrich et al, 1999). A reasonably good agreement found in the ~ 1 TeV – 10 TeV range, except at 6 TeV where the derived flux is larger than expected, indicates that the differential spectrum of Mkn 421 in the TeV range does not change substantially with time, as previously noted from the Whipple observations also.

4. Conclusions

The TACTIC Imaging Element has detected a statistically significant TeV gamma-ray signal (~7σ) from Mkn 421 during Jan. – April 2001, with significant variability on a day-to-day basis. The inferred differential energy spectrum is found to be of a power law type with an exponent of ~ 2.5, consistent with previous observations of this source.

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