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Observation of AGNs with PACT

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We report our observations on 4 AGNs viz., Mkn 421, Mkn501, IES1426+428 and ON231 belonging to a class of objects called blazars. The observations were carried out using the Pachmarhi Array of Čerenkov Telescopes (PACT) and span about 5 year period from 2000 to 2004. We discuss our methods of analysis adopted to extract the gamma-ray signal from cosmic-ray background. We present our results on the emission of TeV gamma rays from these objects.

1. Introduction

AGNs have dominated extragalactic astronomy by virtue of their great luminosities. It is generally accepted that these AGNs are powered by black holes of mass 10^{8-9} $M_{\odot}$. About 10% of all AGNs are more luminous at radio wavelengths than at optical ones and are, hence, called radio-loud. The radio emission is believed to originate in the associated jets which are aligned with the poles of the spinning black hole. If the jets aim straight towards us, both the waves and the durations of outbursts are compressed by a large Doppler factor. This greatly enhances the power we receive. Such AGNs with jets directed towards us are also called Blazars. Blazars are characterised by two parts in their Spectral Energy Distributions (SEDs). First part in SED rises smoothly from radio wavelengths upto a broad peak spanning the range from microwave to infrared wavelengths and is due to relativistic electrons radiating via synchrotron process. Second part is probably due to inverse compton scattering of synchrotron photons by the same electrons and is characterised by a peak in SEDs in hard X-ray-γ-ray band. On a power plot these SEDs show a two-humped shape [1]. One of the characteristic features of these blazars is their time variability on scales ranging from hours to years. Blazars are further subdivided into two classes, BL Lac and optically violent variables (OVVs). BL Lacs are also classified into two groups, Low-frequency BL Lacs (LBLs) and High-frequency BL Lacs (HBLs). Mkn 421, Mkn 501, 1ES1426+428, ON231 are examples of high frequency peaked BL Lac objects with γ-ray emission extending upto TeV energies. They are found to be in quiescent state most of the time but occasionally they flare up. In the flaring state often they are the brightest objects in VHE γ-rays. There are mainly two models which are proposed to explain the production as well as variability of γ-rays in these sources. One is called 'lepton model' and the other 'hadron model' depending on the particle that is responsible for the production of γ-rays. The HE and VHE γ-ray observations constrain both the models but do not rule either out. To further constrain these models and also to understand the astrophysical processes in the environment of these objects they are being observed extensively by the ground based γ-ray telescopes and also in other wavelengths. We have observed these sources with PACT on several occasions. In the following sections we will present our analysis procedure and results for the data collected on these sources from year 2000 to 2004.

2. PACT Array

Pachmarhi array of Čerenkov telescopes (PACT) is located at Pachmarhi in central India (latitude 22° 28′ N, longitude 78° 25′ E, altitude 1075 m) [2]. PACT consists of 5 × 5 array of 25 telescopes spread over an area of 80m × 100m. Each telescope consists of 7 parabolic mirrors of diameter 0.9m with f/d $\sim$ 1 mounted para-axially. Total reflector area is 4.45 m^2 per telescope. A fast phototube (EMI9807B) of 2 in. diameter

Table 1. Observation log for Blazars

year	*observation duration (mins.)*			
	Mkn 421 z=0.030	Mkn 501 z=0.034	1ES1426+428 z=0.129	ON 231 z=0.102
2000	3510.	710.	–	–
2001	1960.	–	–	–
2002	1860.	510.	1520.	–
2003	1770.	840.	570.	510.
2004	2270.	780.	870.	550.
2005	930.	–	960.	–

is mounted at the focus of each mirror. All the telescopes are equatorially mounted and are independently steerable in both E-W and N-S direction within ± 45°. The movement of the telescopes is remotely controlled by a low cost control system called Automated Computerized Telescope Orientation System (ACTOS). The system can orient to the putative source from an arbitrary initial position with an accuracy of ∼ (0.003±0.2) [3]. The array is divided into 4 sectors with 6 telescopes in each. At the center of each sector there is a Field Signal Processing Center (FSPC) where pulses from individual PMTs of telescopes in a sector are brought through coaxial cables of type RG213 and processed. High voltage to PMTs are controlled through a high voltage divider unit (C.A.E.N. model SY170) which is controlled by CAMAC based controller module (C.A.E.N. model CY117B). A coincidence of 4 out of 6 telescopes generates the event trigger for a sector. Once an event trigger is generated CAMAC controller initiates the data recording process. A $linux$ based PC records TDC (timing) and QDC (photon density) information of 6 peripheral mirrors of telescopes along with other house keeping informations for that event. In addition, information relevant to entire array is recorded in the central Master Signal Processing Center (MSPC) in the control room at the centre of the array. PACT has energy threshold of $\sim$ 800 GeV for $\gamma-$rays incident in the vertical direction and the corresponding collection area is $\sim 10^5 m^2$.

3. Observations

Since the year 2000 we have collected data on Mkn 421, Mkn 501, 1ES1426+428 and ON231 using PACT. Most of these runs were taken with all 4 sectors pointing to the source direction (ON-source). On the same night background runs (OFF-source) were taken before or after the source runs with all telescopes pointing to a dark region (a region with same declination as that of source but offset in RA) such that zenith angle coverage is same as source run. Some of the runs in year 2002 and in 2003 were taken with 2 sectors pointing at the source and other 2 sectors at a background region. Data were also collected on fictitious sources, in these cases the source region is an arbitrary one (a region devoid of any known $\gamma-$ray sources). Table 1 summarises durations for ON-source observation of these blazars. Similarly OFF-source observations were also carried out for each of them with same durations.

4. Data Analysis and Results

A number of preliminary checks on the data were carried out before doing actual analysis. A large fraction of data collected ($\sim$ 50%) were rejected as they were found to be noisy. Telescopes having similar efficiencies for source and background runs were retained for further analysis. The arrival direction of each shower is determined by reconstructing shower front using the relative arrival time of Čerenkov front at the telescopes. This Čerenkov photon front is fitted with a plane, the normal to this plane gives the direction of shower axis. By comparing the observed and expected arrival times of pulses at the telescopes events with bad fits are rejected. Thus the space angle between the direction of shower axis and the direction of source is obtained for all events with $\geq$ 8 telescopes. The space angle distribution peaks around $\sim$1.5° and has a FWHM of $\sim$2.5°. The space angle distribution become narrower and the peak shifts to lower angle as the degrees of freedom (no. of telescopes with timing information) increases. Space angle distributions of all the source runs are compared with respective distributions of background runs. For this comparison it is ensured that both source and background runs have the same zenith angle coverage as well as similar distribution of events as a function of the no. of telescopes triggered. Further background space angle distribution is normalized with the source distribution by comparing the shape of the distribution in 2.5° to 6.5° window. We chose this region because the angular resolution of the array in the estimation of arrival direction is such that we do not expect any $\gamma-$ray events beyond 2.5° [4]. Beyond 6.5°, the statistics is poor, besides, this region is populated by events with poor estimation of direction of arrival angles. Normalisation of distributions corresponding to the background with that of the source is necessary as these two data sets were taken at different times. The normalisation constant is obtained as follows. We define

$$\chi_k^2 = \sum_{i=2.5}^{6.5} (S_i - c_k B_i)^2$$

where S$_i$, B$_i$ are the no. of source and background events in ith bin. The normalisation constant c_k is chosen such that χ_k^2 is minimum. After normalising the source and background distributions, the $\gamma-$ray signal is obtained as excess of source events over background in 0° to 2.5° region i.e.

$$no.\,of\ \gamma - rays\ = \sum_{i=0}^{2.5} (S_i - c_k B_i)$$

This procedure is tested for fictitious source from which we do not expect to receive any $\gamma-$rays. We get a rate of $\gamma-$rays as 0.5±0.7 per minute, which sets the noise level for our $\gamma-$ray signal. The rate of $\gamma-$ ray events were calculated for each run or part of a run using the respective duration of observation. Figure 1 gives the light curves ($\gamma-$ray rate vs MJD) for all the above mentioned sources from 2000 to 2004.

5. Discussions and Conclusions

Mkn 421 was found to be in flaring state in 2000, 2001 and in 2004 [6, 5], as confirmed by other ground based $\gamma-$ray experiments. At present the 'Lepton model' in which Self Synchrotron Compton (SSC) process is responsible for the production of TeV $\gamma-$rays is the widely accepted model for blazars. One of the features of this model is a strong correlation between X-ray and $\gamma-$ray emission. Mkn421 was indeed found to be quite active by RXTE in these periods most of the time. Over the last few years several multiwavelength campaigns are carried out to study correlations between different wavebands for Mkn421. At present correlation study between PACT data and data at other wavelengths that are simultaneous with PACT observations is in progress. Mkn501 was not found in flaring state over the last several years although in the past it was detected in flaring state [7]. No out-burst is reported so far for 1ES1426+428 and ON231.

All the data available so far, for Mkn421 and Mkn501, suggests strong correlation between X-ray and $\gamma-$ray. But recently Whipple observation has shown a flare where X-ray emission reached the peak a few days after the TeV emission [6]. This is very significant because if it is true then it will pose a serious challenge to the

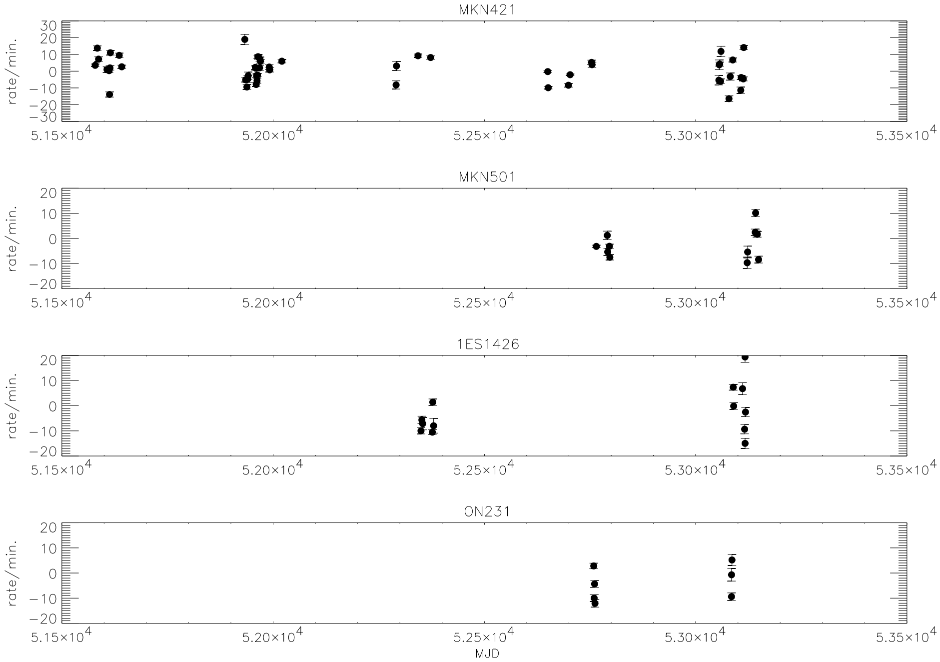

Figure 1. Light Curves for Mkn421, Mkn501, 1ES1426 and ON231 from 2000 to 2004.

standard SSC model as well the hadronic model. Therefore to understand the astrophysical processes in these Blazar class of objects, it is necessary to study correlation between different wavebands through coordinated multiwavelength campaigns and also on more such objects.

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