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Search for Very High Energy Gamma-Rays from Active Galactic Nuclei with the CANGAROO-III Telescope

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We observed two high-energy-peaked BL Lacs (HBL), PKS 2155-304 (z = 0.116) and Mrk 421 (z = 0.031) in 2004, with the CANGAROO-III atmospheric Cherenkov telescope system located at Woomera in South Australia. Observations are carried out with each telescope independently and the stereo multiplicity requirement is performed off-line using GPS time stamps and event number (off-line stereo). Here we report the status of these observations and analyses.

1. Introduction

One of the most astonishing contributions to the astrophysics from the ground –based IACTs has been the detection of active galactic nuclei (AGNs) at energies above several hundred GeV. To date, ten AGNs has been reported to emit very high energy gamma-rays. Particularly Mrk 421 (z=0.031) has been a target of simultaneous multi-wavelength observations since their first detection [1]. The broadband spectral energy distributions show that they have two components, one of which extends from radio to hard X-ray frequencies and has a peak at X-ray band, and the other one has a peak around gamma-ray frequencies. They are well explained by the synchrotron emission produced by relativistic electrons in the jet and inverse Compton photons scattered by the same population of electrons [2].

In the southern hemisphere, Durham group reported the detection of VHE gamma-rays from PKS 2155-304 (z=0.117) [3] during strong flare up of X-ray flux in November 1997 [4]. Confirmation of PKS2155-304 as a very high energy gamma-ray emitter was done by H.E.S.S group [5]. They reported that PKS 2155-304 has been detected with high significance of ~45 σ at energies greater than 160 GeV, and the observed flux shows variability on time scale of months, days, and hours with a time-averaged photon index of $\Gamma = 3.32\pm0.06$. We had observed PKS 2155-304 with the CANGAROO 3.8 m telescope in 1993 and 1994 [6], and with the CANGAROO-II 10 m telescope in 2000 and 2001 [7], respectively. Unfortunately, we could not detect significant signals from PKS 2155-304 in those periods.

Another important aspect of spectral studies of AGNs is the absorption of gamma-rays owing to pair production with low energy photons in the intergalactic space. The evidences of the exponential cutoff in the spectrum of Mrk 421 observed in the years 2000 and 2001 were reported at around 4 TeV by HEGRA [8] and VERITAS [9], and around 8 TeV by CANGRAOO [10]. Recently the cutoff energy of 3.1 TeV was reported by H.E.S.S [11] from the observations in 2004, and they concluded that this cutoff is intrinsic to the source and not due to absorption. For PKS 2155-304, H.E.S.S. group found only marginal cutoff in the energy spectrum observed in 2002 and 2003 [5].

In this paper, we describe the summary of stereoscopic observations of Mrk 421 and PKS 2155-304 in the year 2004 with the CANGAROO-III telescope.

2. Observations

Observations of Mrk 421 and PKS2155-304 were made using the CANGAREOO-III imaging atmospheric Cherenkov telescope system. The CANGAROO-III telescopes are located near Woomera, South Australia (136º47′ E , 31º06′ S, 160m altitude), which have composite parabolic reflectors of 10 m diameter with an 8 m focal length [12]. The imaging cameras of T2, T3 and T4 have 427 pixels of 0.17° size and a field of view of 4° [13]. The performance of these telescopes is briefly described in [14]. Although the oldest telescope, T1 was also operated at the same time, since it has a higher energy threshold and poorer efficiency for stereo observations, we don’t use the data obtained by T1 here.

PKS 2155-304 was observed for 11 nights from August 8 to 22 in 2004 by so called the wobble mode where all telescopes point with ±0.5° offset in declination alternately every 30 minutes. At least 4 PMTs exceeding 6 p.e. were required to trigger the data acquisition at each telescope, and the stereo multiplicity requirement was performed off-line using GPS time stamps and event number (off-line stereo). We also observed off source regions by wobble mode to avoid a fake peak due to some systematic errors. For a redundancy check, observations by so called the long on/off mode was also made for 2 nights in July 2004. These observation times are summarized in Table 1. Activities at the X-ray energy regions monitored by the ASM onboard the RXTE satellite in August 2004 is shown in Figure 1 which indicates there is no clear increase of a level of X-ray emission during this period.

Observations of Mrk 421 in 2004 were carried out as so called a ToO observation when X-ray emission level detected by the RXTE-ASM increased (see Fig. 2). These observations with a large zenith angle between

Table 1. Net observation time of PKS 2155-304 in 2004

Obs. term	nights	Obs. mode	T2 (hrs)	T3 (hrs)	T4 (hrs)
Aug., 2004	12	Wobble ON	37.9	37.0	36.5
Aug., 2004	12	Wobble OFF	15.0	13.0	12.6
July, 2004	2	Long ON	3.1	3.0	3.0
July, 2004	2	Long OFF	2.7	2.6	2.6

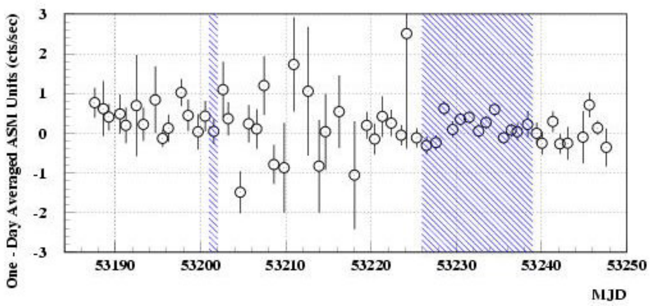

Figure 1. X-ray counts from PKS 2155-304 obtained by the RXTE-ASM. Hatched regions correspond to our observation periods.

Table 2. Net observation time of Mrk 421 in 2004

Obs. term	nights	T2 ON (hrs)	T2 OFF (hrs)	T3 ON (hrs)	T3 OFF (hrs)	T4 ON (hrs)
Feb. 15, 16, 17	3	4.2	2.1	4.1	1.9	–
Mar. 15, 16, 17	3	2.4	–	2.3	–	2.5
Apr. 19, 20	2	4.7	–	4.9	–	4.7

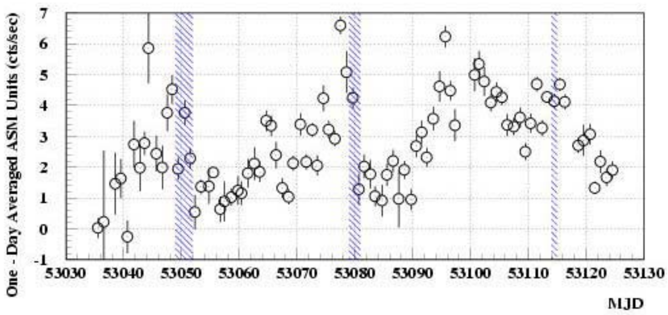

Figure 2. X-ray counts from Mrk 421 obtained by the RXTE-ASM. Hatched regions correspond to our observation periods.

69.3° and 72.4° were done for 8 nights by a long on/off mode during from February to April. The trigger threshold of each telescope was set to 3~4 PMTs exceeding 5~6 p.e, and the stereo multiplicity requirement was performed off-line in the same way for the case of PKS 2155-304. Unfortunately a complete set of on-source and off-source run were obtained only in February observations.

3. Analyses

The relative gain and the timing of each pixel are calibrated by using data from an LED flasher runs which are performed every night in addition to observations. Conversion from ADC counts to the number of photo-electrons is performed using photo-electron statistics assuming a Poisson distribution. Time-walk corrections, which is due to the amplitude dependence of the discrimination time of analog signals, are also carried out. Detail descriptions about these calibrations are given in [13].

The image cleaning for selecting shower images is done by requiring that more than five adjacent pixels having a signal greater than 4 p.e. form a cluster within ±30 nsec from the average shower timing. On average, the stereo shower rate is ~10 Hz for T2-T3 coincidence and ~11 Hz for T2-T4 coincidence for PKS 2155-304, and ~2 Hz for T2-T3 coincidence for Mrk 421, respectively.

After the image cleaning is performed image analysis using so-called *Hillas parameters* [15] is applied to the final sample data to reduce the proton background events. In these analyses, the parameters, *width*, *length*, and *distance*, are calculated. Considering the energy dependence of the distribution of each parameter obtained from the Monte Carlo simulation study, cut criteria are decided. Arrival direction of each shower is reconstructed using stereoscopic techniques. In order to reduce miss fits of intersection point particularly in the case of small opening angle, we use *IPdistance* which is defined as a distance between the intersection point and the image center of gravity. Details of the analysis procedure based on the *IP distance* is described in [16].

4. Summary

We observed HBL objects, PKS 2155-304 and Mrk 421 in 2004 with the CANGAROO-III imaging Cherenkov telescope system by *off-line stereo* method. The total observation times including low quality data due to bad weather condition are ~37 hours for PKS 2155-304 with the wobble mode and ~11 hours for Mrk 421 with the long ON mode, respectively. Now the analyses are in progress and will be reported in this conference.

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