TeV Gamma-Ray Observations of Southern Hemisphere BL Lacertae Objects with CANGAROO-II/III Telescope

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Abstract

Since 1999, several BL Lac objects, such as PKS 2155–304 (z=0.116) and PKS 2005–489 (z=0.072) have been observed with the CANGAROO-II imaging atmospheric Cherenkov telescope. We obtained flux upper limits for these objects. Here we present the results of our observations of these objects, particularly those observed since 2000, and discuss the implications for the emission models and the absorption by the extra-galactic infrared background.

1. Introduction

The multi-band spectra of BL Lac objects show a *double humped* shape, as seen in high-energy peaked BL Lac (HBL) objects such as Mkn 421 (z = 0.030). These features are interpreted as the synchrotron emission from high-energy electrons and the inverse Compton scattering of synchrotron photons by the same population of electrons (Synchrotron Self-Compton model). So far, five BL Lacs have been detected at TeV γ-ray energies. Extreme variability on a wide range of time scales and good temporal correlation with X-rays are observed.

It was pointed out that TeV γ-ray emitting BL Lac objects can be used as a probe of the extragalactic infrared background (EIRB) photons from their absorption resulting from pair creation ([7, 14]). However, it has generally been "believed" that TeV γ-rays emitted beyond $z \sim 0.1$ cannot reach the Earth because of heavy absorption by the EIRB soft photon field. But recently, detection of TeV γ-rays from the BL Lac object H 1426+428 ($z = 0.129$) was reported by the Whipple [9], HEGRA [1], and CAT [3] groups, encouraging us to observe distant HBLs such as PKS 2155–304 ($z = 0.116$) in the southern sky. The detection of TeV γ-rays and spectral cut-offs in the γ-ray spectrum of such BL Lacs will provide strong constraints on the poorly known EIRB spectrum [15].

2. Observation and Analysis

The observations of BL Lacs with the CANGAROO-II 10 m telescope (S 31°06′, E 136°47′, 160 m a.s.l.) [13, 15] were carried out in the so-called long on–off scan mode under a clear and moon-less dark night sky. In 2002 Dec.,

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Table 1. Total telescope time.

				T1		T2	
Target	z	Year	Mode	ON	OFF	ON	OFF
PKS 2005–489	0.072	2000	Single	32.6h	29.3h	—	—
PKS 2155–304	0.116	2000	Single	35.6h	35.2h	—	—
		2001	Single	28.8h	26.1h	—	—
EXO 0556.4–3838	0.034	2002	Single	20.8h	21.6h	—	—
		2003	Stereo	17.8h	15.3h	15.2h	10.9h
Markarian 421	0.030	2003	Stereo	6.0h	4.7h	5.8h	5.3h

the construction of our new second telescope (T2) was completed and the stereo operation have begun with the CANGAROO-III telescope [2]. The observations reported here are of PKS 2005–489 and PKS 2155–304 with the CANGAROO-II 10 m telescope (T1). The total telescope time for each target is summarized in Table 1. (including also other BL Lacs under analysis.) Mkn 421 was observed at times when large flaring activity is seen in hard X-ray band (RXTE-ASM), to increase the possibility of TeV γ-ray detection.

Analysis procedures are as follows: First, the image cleaning and shower candidate selection, as explained in [6], are applied. Next, the image parameters known as the "Hillas parameters" [8] are calculated. Finally, analysis of the image parameters is carried out in order to select γ-ray like images. In image analysis, the parameters, *width*, *length*, *distance*, and *alpha* are used for selecting γ-ray like events. The image selection criteria are determined using the Likelihood method [4, 5] instead of the conventional image parameter cuts.

3. Results

At the time of writing, data for the two BL Lacs have been analyzed and no γ-ray excess is found. Table. 2. shows the status of analysis. In this table, the 2σ integrated flux upper limits derived from and the energy thresholds of our observations with the CANGAROO-II/III telescope are reported.

Fig. 1. shows the multi-band spectral energy distribution (SED) for PKS 2155–304 with an expected flux from the SSC model [10] with and without EIRB absorption. This model calculation assumes that the object is in a quiescent (non-flaring) state. Fig. 2. shows the energy spectrum around TeV γ-ray region. These figures include the limits from other epochs and observatories. All of the reported fluxes from other observations are integral ones, so we converted for the SED by assuming a single power-law of index -2.5. As can be seen from these figures, our flux upper limits do not conflict with the model flux and we set lower limit to the tangled magnetic field strength of emission region

Table 2. The status of analysis of BL Lacs.

Target	Epoch	E_{th} [TeV]	Excess	$F(> E_{th})$ $[cm^{-2}\ sec^{-1}]$
PKS 2005–489	2000	0.57	-1.3σ	$< 7.0 \times 10^{-12}$
PKS 2155–304	2000	0.42	-1.6σ	$< 8.2 \times 10^{-12}$
	2001	0.42	0.7σ	$< 9.5 \times 10^{-12}$
EXO 0556.4–3838	2002	~ 0.5	Now Analyzing	
	2003	~ 0.5	Now Analyzing	
Markarian 421	2003	~ 10	Now Analyzing	

which have an order of $\sim 0.1\ G$. And our flux limit may rule out some model assumption such as the SSC model with high electron injection [10] and/or the proton initiated cascade (PIC) model [11, 12].

4. Summary

We observed PKS 2005–489, PKS 2155–304, EXO 0556.4–3838, and Markarian 421. The analysis shows that two PKS objects are do not emit detectable TeV γ-ray during 2000 and 2001. The other BL Lacs are now under analysis.

The multi-band analysis of PKS 2155–304 shows that the flux limit derived from our observation do not conflict with the SSC model but may rule out some model assumption.

5. References

1. Aharonian, F., *et al.*, 2002, A&A Lett. 384, 23
2. Asahara, A., *et al.*, 2003, this proceedings. (Full author list)
3. Djannati-Ataï, A., *et al.*, 2002, A&A Lett. 391, 25
4. Enomoto, R., *et al.*, 2002a, Astropart. Phys. 16, 235
5. Enomoto, R., *et al.*, 2002b, Nature 416, 823
6. Itoh, C., *et al.*, 2003, A&A 402, 443
7. Gould, R. J., and Schréder, G. P., 1967, Phys. Rev. 155, 5
8. Hillas, A. M., 1982, J. Phys. G 8, 1475
9. Hollan, D., 2001, Proc. of 27th ICRC (Hamburg), pp.2622
10. Kino, M., Takahara, F., and Kusunose, M., 2002, ApJ 564, 97
11. Mannheim, K., 1993, A&A 269, 67
12. Mücke, A., and Protheroe, R. J., 2001, Astropart. Phys. 15, 121
13. Mori, M., *et al.*, 2001, Proc. of 27th ICRC (Hamburg), pp.2831
14. Stecker, F. W., *et al.*, 1992, ApJ Lett. 390, 49
15. Tanimori, T., Prog. Theor. Phys. Suppl. 143, 78
16. Vassiliev, V. V., 2000, Astropart. Phys. 12, 217

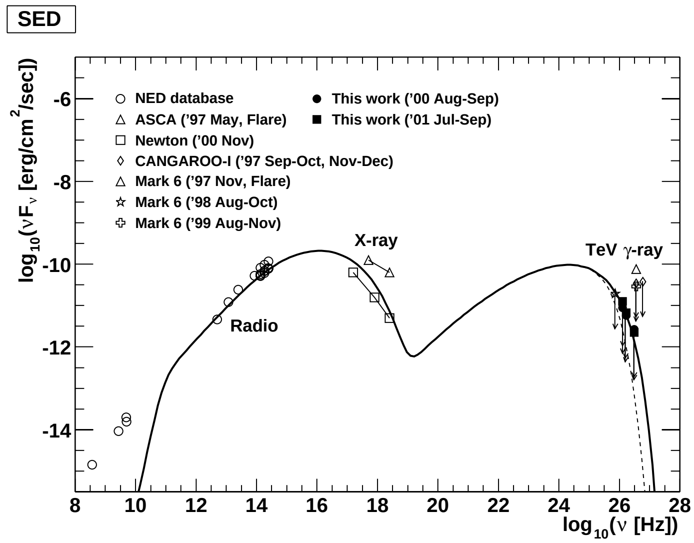

Fig. 1. Spectrum energy distribution of PKS 2155–304. Solid line: one-zone SSC model [10]. Hollow markers: Non-simultaneous observations. Filled markers: This work (2σ U.L.). The SSC model flux indicated here with solid line is provided by M. Kino (priv. comm.) and dashed line shows the case of strong absorption by the EIRB.

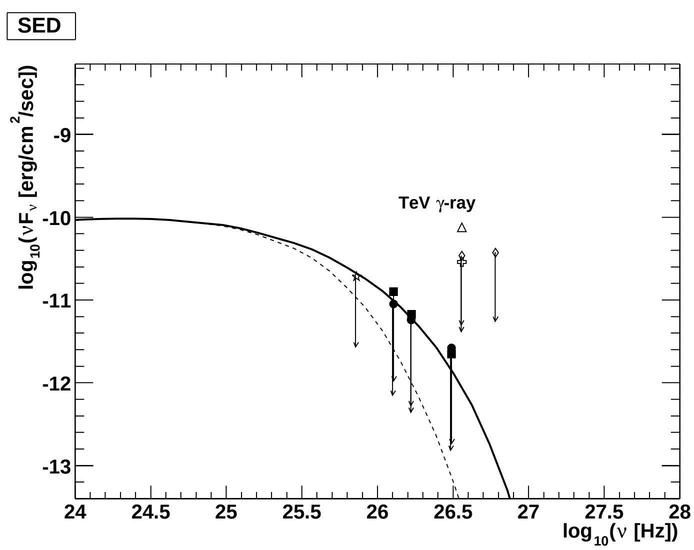

Fig. 2. Spectrum energy distribution of PKS 2155–304 around TeV region. Lines and markers indicated in this figure are same as in Fig. 1.