Observation of the Southern High Energy Peaked BL Lac Object PKS 2155–304 with CANGAROO-II Telescope

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Abstract

We observed PKS 2155–304 in Aug.- Sep. 2000 and in Jul.- Sep. 2001 with the CANGAROO-II atmospheric Cherenkov telescope above $\sim 400\ GeV$. Total exposure time for this object was $ON/OFF = 64.4\ hours/61.1\ hours$. Analysis shows that no significant excess of gamma-ray events is found for each observation period. The estimated energy thresholds for these observations are $\sim 420\ GeV$ (2000) and $\sim 420\ GeV$ (2001), respectively. The upper limits on the fluxes above these theresholds are $F(>420GeV) < 1.0\times10^{-11}\ cm^{-2}\ sec^{-1}$ (2000) and $F(>420GeV) < 1.2\times10^{-11}\ cm^{-2}\ sec^{-1}$ (2001), respectively.

1. Introduction

The multiband spectra of BL Lac objects show a *double humped* shape, as seen in high-energy peaked BL Lac(HBL) objects such as Markarian 421($z = 0.030$) and Markarian 501 ($z = 0.034$). 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. So far, six BL Lacs have been detected at TeV gamma-ray energies. Extreme variability on a wide range of time scales and good temporal correlation with X-rays are observed.

It was pointed out ([8], [12]) that TeV gamma-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. However, it has generaly been believed that TeV gamma-rays emitted beyond $z \sim 0.1$ cannot reach the Earth because of absorption by the EIRB soft photon field (Fig. 1.)

Recently, detection of TeV gamma-rays from the BL Lac object H 1426+428 ($z = 0.129$) was reported by the Whipple [10], HEGRA [1], and CAT [4] groups, encouraging us to observe distant HBLs such as PKS 2155–304 ($z = 0.116$) in the southern sky.

HBL object PKS 2155–304, which is bright at optical and hard X-ray band,

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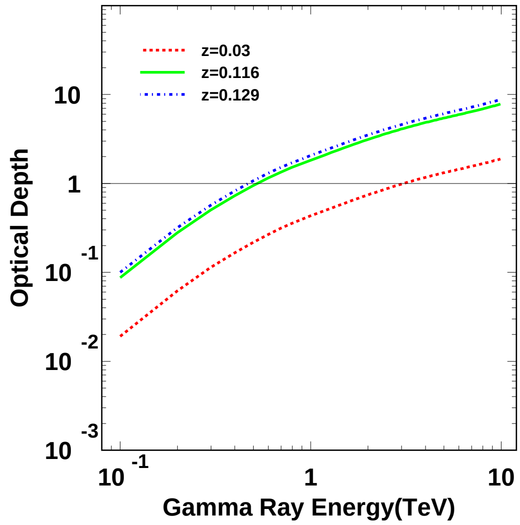

Fig. 1. Optical depth for EIRB absorption.

has been considered as a strong candidate for a TeV gamma-ray source because of its high synchrotron peak energy even though it is rather distant compared to Markarian 421 and Markarian 501. The Durham group claimed detection of TeV gamma-rays from this object when Beppo-SAX observed a large X-ray flare in 1997 [2].

If we do detect TeV gamma-rays and a spectral cut-off in PKS 2155–304, the gamma-ray spectrum of this object will provide strong constraints on the poorly known EIRB spectrum [14].

In this article, we report our observation of PKS 2155–304 in 2000 and 2001 with CANGAROO-II telescope and show the preliminary results of our analysis.

2. Observation

PKS 2155–304 is located at $(\alpha, \delta) = (21^h58^m52.0^s, -30°13'32'')$ (J2000). We observed this object in August and September (2000) and in July to Setember (2001) with CANGAROO-II atmospheric Cherenkov telescope. This imaging telescope is located at Woomera, South Australia $(136°47'E,\ 31°06'S,\ 160\ m$ above sea level) and has been in operation since 1999.

When PKS 2155–304 reaches culmination, its elevation is $\sim 90°$ at the site of CANGAROO-II telescope. This means that we can observe this object at lowest energy limit of the telescope; The higher the source elevation becomes, the lower the detectable energy threshold of an atmospheric Cherenkov telescope can be obtained.

Table 1. Monthly observation summary.

Epoch		ON [hours]	OFF [hours]
2000	August	11.6	10.8
	September	24.0	24.3
2001	July	8.1	7.4
	August	9.4	8.9
	September	11.3	9.7
	Total	64.4	61.1

The observations of PKS 2155–304 with the CANGAROO-II telescope were carried out in the so-called on–off scan mode under a clear and moon-less dark night sky. Total exposure time was $ON/OFF = 35.6\ hours/35.1\ hours$ for observations in 2000 and $ON/OFF = 28.7\ hours/26.2\ hours$ for observations in 2001. The observation times for each monthly observation epoch are summarized in Table 1. After selecting the data set with good conditions, effective exposure times in 2000 and in 2001 were $ON/OFF = 17.5\ hours/15.0\ hours$ and $ON/OFF = 19.2\ hours/14.3\ hours$, respectively.

3. Analysis

After calibrating the recorded light yields (ADC counts) and arrival timing (TDC counts) of signals, images are reconstructed and selected as follows. First, we require that the signals from air showers should have $> 300\ ADCcounts$ ($\sim 3.3\ p.e.$) for each pixel. Secondly, they should arrive within $\pm 30\ nsec$ from an average arrival time. Thirdly, accidentally triggered events by night sky background are rejected with the requirement of clustering that the shower event candidates must have signals from more than three adjecent pixels (T3a pattern). Finally, the image parameters known as the "Hillas parameter" [9] are calculated. In this analysis, the parameters, *width*, *length*, *distance*, and *alpha* are used for selecting gamma-ray like events.

The methods applied to select gamma-ray like events for the data in 2000 and for those in 2001 are slightly different. The conventional cuts for each parameter are applied for the data obtained in 2000, and the events which pass all cuts of four parameters are accepted as gamma-ray like events. For the data in 2001, the cut criteria are set with the Likelihood method ([6], [7]) instead of the conventional image parameter cut.

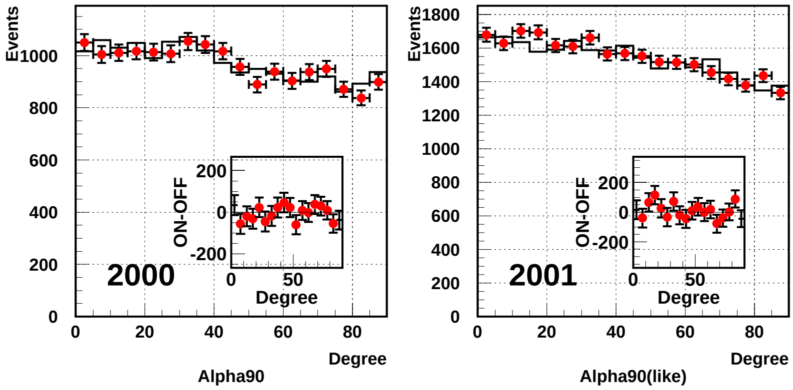

Fig. 2. The *alpha* parameter distributions.

4. Preliminary Results

Fig. 2. shows the distribution of *alpha*, which describes the image orientation angle, after selection with other parameters. These are shown for each observation period in 2000 (left) and in 2001 (right), respectively. The inserted figures show the residual distrbutions denoted as ON–OFF for each *alpha* parameter interval. If a sufficient number of TeV gamma-rays were to be detected, an excess of events between 0 and 15 degree would appear in these figures. Our results shows no significant excesses around $alpha = 0$ degree. The statistical significances of the excess of gamma-ray like events are 1.2σ for 2000 observation period and 1.3σ for 2001 observation period, respectively.

Fig. 3. shows the 2σ integrated flux upper limit derived from our observations with the CANGAROO-II telescope together with other observations. Here, published values of statistical confidence level of other than 2σ are converted into the same significance level. Energy thresholds estimated from the Monte Carlo simulation studies are $\sim 420\ GeV$ both in 2000 and 2001. Finally, as the upper limits of the integrated gamma-ray flux from PKS 2155–304, we obtain $F(> 420GeV) < 1.0 \times 10^{-11}\ cm^{-2}\ sec^{-1}$ for observations in 2000 and $F(> 420GeV) < 1.2 \times 10^{-11}\ cm^{-2}\ sec^{-1}$ for observations in 2001, respectively.

5. Multiwavelength Observation

Fig. 4. show the daily integrated flux upper limit (2σ, top) and observed excess flux (middle) of gamma-rays from the direction of PKS 2155–304 obtained with CANGAROO-II telescope. These daily flux and flux limit are calculated using only the data which include complete pairs of observations of both ON source and OFF source in each night. There is no evidence for gamma-ray flares

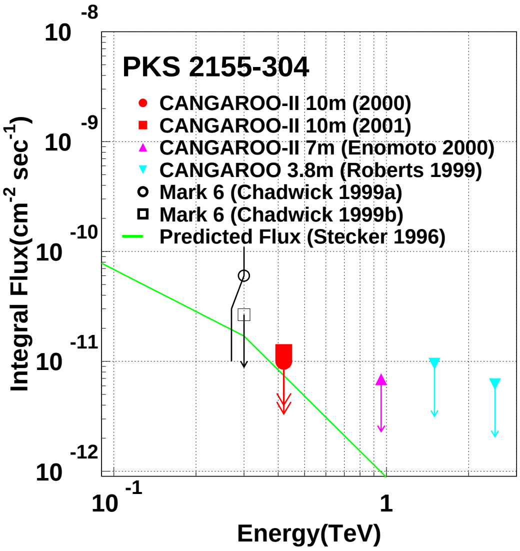

Fig. 3. Derived flux upper limits.

on the time scale of about one night during our observation periods.

The hard X-ray activities observed with RXTE-ASM which expresses one-day averaged counts extracted from NASA/SOF light-curve generator is also shown in lower panel of Fig. 4. The RXTE multiwavelength campaign period between 51783MJD and 51788MJD is included in this figure. According to the synchrotron self-Compton model, TeV gamma-ray flux variations are expected to correlate with hard X-ray variations. Unfortunately, not only during our TeV gamma-ray observation epochs but also during these other periods no hard X-ray activity was seen.

6. Summary

We have observed PKS 2155–304 for about 60 *hours*, with a similar amount of OFF–source observations, in 2000 and in 2001 with the CANGAROO-II atmospheric Cherenkov telescope. No evidence of detection of gamma-rays was found. The 2σ upper flux limits are $F(>420GeV) < 1.0 \times 10^{-11}\ cm^{-2}\ sec^{-1}$ (2000) and $F(>420GeV) < 1.2 \times 10^{-11}\ cm^{-2}\ sec^{-1}$ (2001), respectively.

References

[1] Aharonian, F., *et al.*, 2002, Astron. and Astrophys. Lett. 384, L23

[2] Chadwick, P. M., *et al.*, 1999a, ApJ 531, 161

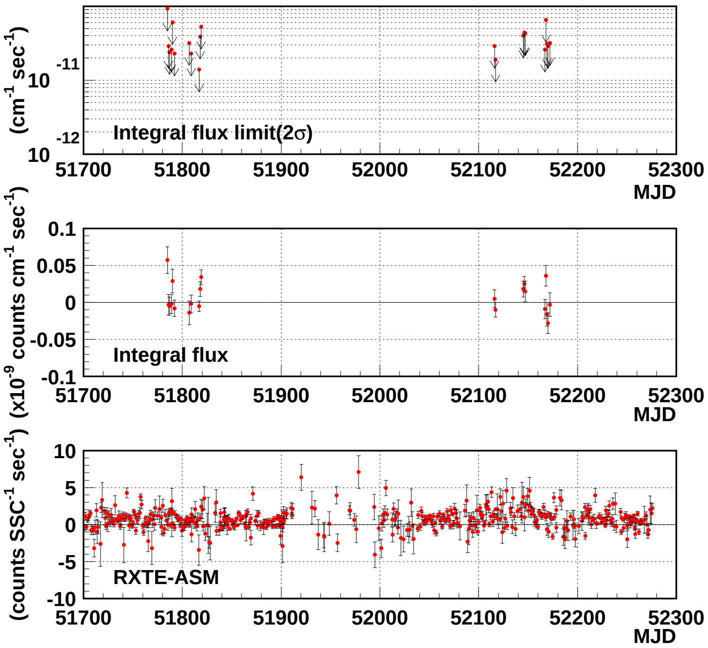

Fig. 4. Multiwavelength light curve from CANGAROO-II and RXTE-ASM.

[3] Chadwick, P. M., *et al.*, 1999b, Proc. of 26th ICRC (Salt Lake City) 3, 338

[4] Djannati-Ataï, A., *et al.*, 2002, Astron. and Astrophys. Lett. 391, L25

[5] Enomoto, R., *et al.*, 2000, at the talk of Kyoudou-riyou seika happyoukai (not published).

[6] Enomoto, R., *et al.*, 2002a, Astropart. Phys. 16, 235

[7] Enomoto, R., *et al.*, 2002b, Nature 416, 823

[8] Gould, R. J., and Schréder, G. P., 1967, Phys. Rev. 155, 5

[9] Hillas, A. M., 1982, J. Phys. G 8, 1475

[10] Hollan, D., 2001, Proc. of 27th ICRC (Hamburg), pp.2622

[11] Roberts, M. D., *et al.*, 1999, Astron. and Astrophys. 343, 691

[12] Stecker, F. W., De Jager, O. C., and Salamon, M. H., 1992, ApJ 390, L49

[13] Stecker, F. W., De Jager, O. C., and Salamon, M. H., 1996, ApJ 473, L75

[14] Vassiliev, V. V., 2000, Astropart. Phys. 12, 217