



Time variation of the flux of TeV gamma-rays from PKS 2155-304

K. NISHIJIMA¹, Y. SAKAMOTO², E. YAMAZAKI¹, T. MIZUKAMI³, J. KUSHIDA¹, G. BICKNELL⁴, R. CLAY⁵, P. EDWARDS⁶, R. ENOMOTO⁷, S. GUNJI⁸, S. HARA⁹, T. HARA¹⁰, T. HATTORI¹, S. HAYASHI¹¹, Y. HIGASHI³, Y. HIRAI¹², K. INOUE⁸, C. ITOH⁹, S. KABUKI³, F. KAJINO¹¹, H. KATAGIRI¹³, A. KAWACHI¹, T. KIFUNE⁷, R. KIUCHI⁷, H. KUBO³, Y. MATSUBARA¹⁴, Y. MIZUMOTO¹⁵, R. MIZUNIWA¹, M. MORI⁷, H. MURAISHI¹⁶, Y. MURAKI¹⁴, T. NAITO¹⁰, T. NAKAMORI³, S. NAKANO³, D. NISHIDA³, M. OHISHI⁷, A. SEKI¹, V. STAMATESCU⁵, T. SUZUKI¹², D. SWABY⁵, T. TANIMORI³, G. THORNTON⁵, F. TOKANAI⁸, K. TSUCHIYA³, S. WATANABE³, Y. YAMADA¹¹, S. YANAGITA¹², T. YOSHIDA¹², T. YOSHIKOSHI⁷, AND Y. YUKAWA⁷

¹Department of Physics, Tokai University, Hiratsuka, 259-1292, Japan

²Graduate School of Science and Technology, Tokai University, Hiratsuka, 259-1292, Japan

³Department of Physics, Kyoto University, Kyoto, 606-8502, Japan

⁴Research School of Astronomy and Astrophysics, Australian National University, ACT 2611, Australia

⁵School of Chemistry and Physics, University of Adelaide, SA 5005, Australia

⁶Narrabri Observatory of the Australia Telescope National Facility, CSIRO, NSW 1710, Australia

⁷Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, 277-8582, Japan

⁸Department of Physics, Yamagata University, Yamagata, 990-8560, Japan

⁹Ibaraki Prefectural University of Health Sciences, Sagami-hara, 228-8555, Japan

¹⁰Faculty of Management Information, Yamanashi Gakuin University, Kofu, 400-8575, Japan

¹¹Department of Physics, Konan University, Kobe, 658-8501, Japan

¹²Faculty of Science, Ibaraki University, Mito, 310-8512, Japan

¹³Department of Physical Science, Hiroshima University, Higashihiroshima, 739-8526, Japan

¹⁴Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, 464-8601, Japan

¹⁵National Astronomical Observatory of Japan, Mitaka, 181-8588, Japan

¹⁶Faculty of Medical Engineering and Technology, Kitasato University, Sagami-hara, 228-8555, Japan

E-mail: kyoshi@tkikam.sp.u-tokai.ac.jp

Abstract: We have observed the blazar PKS 2155-304 between 2006 July 28 to August 2 and between August 17 to 25 with the CANGAROO-III imaging atmospheric Cherenkov telescope in South Australia, which was triggered by the alert from the H.E.S.S. that the strong outburst of TeV gamma-ray emission was detected. The flux of very high energy gamma-rays above 590 GeV from the CANGAROO-III observations shows variability on time scale of an hour. The highest activity during our observations was seen early night in July 28 up to 140 % Crab flux level. The source activity had decreased in August.

Introduction

PKS 2155-304 ($z = 0.116$) is a well known high-frequency-peaked BL Lacertae objects (HBL), which is repeatedly observed over a wide range of frequencies from radio to Very High Energy (VHE) gamma rays (e.g., [16], [17], [20], [14], [1], [6], [2]). One of the distinguished characteristics of

this source is, like other HBL, a rapid and violent broadband variability of the flux.

In 1997 November, Durham group observed PKS 2155-304 with the Mark 6 telescope, and reported the first detection of VHE gamma-rays at the 6.8σ level above 300 GeV[4]. At that time, a gamma-ray and X-ray flare from PKS 2155-304 was detected by EGRET[18], BeppoSAX[5] and RXTE[19].

PKS 2155-304 was confirmed as a TeV gamma-ray source by the H.E.S.S. group in 2005[2]. A clear signal with a significance level of 45σ at energies greater than 160 GeV was reported. The flux variability on various time scales from months to hours, and the steep power law shape energy spectrum with a photon index of 3.3 was also reported. In July 2006, the H.E.S.S. group reported that TeV-outburst of PKS 2155-304 was detected at VHE gamma-rays above 200 GeV [3]. CANGAROO-III observations of PKS 2155-304 was started from 2006 July 28, and we successfully detected a signal[15].

Here we present our results, particularly the time variation of the flux, obtained from observations in July and August 2006.

Observations and analysis

We have observed PKS 2155-304 using the CANGAROO-III imaging atmospheric Cherenkov telescope system operated in Woomera, South Australia. It is located at latitude $31^{\circ}06'$ south and longitude $136^{\circ}47'$ east (160 m a.s.l.). Details of the CANGAROO-III telescope system was described in [11],[10] and [7]. Observations were performed for five moonless night in July lunation between 2006 July 28 to August 2 and six moonless night in August lunation between August 17 to 25. Total observation time is 48.1 hours.

Due to a mechanical tracking problem with one (T3) of three working telescopes (T2, T3, and T4), stereoscopic observations with three telescopes were done only after culmination during these periods. Observation times with three telescopes are 17.6 hours for July lunation and 19.1 hours for August lunation, respectively. Averaged zenith angles during these observations for each lunation are 20.4° and 20.9° , respectively. A local trigger condition for each telescope is described in [15], and a global trigger system of CANGAROO-III is explained in [12] and [13]. The average trigger rate of three-fold coincidence including cloud effects is ~ 11.4 Hz for July lunation and ~ 10.9 Hz for August lunation, respectively. The data in July 29 were affected by cloud.

Stereoscopic observations with two telescopes (T2 and T4) were made before culmination from July 28 to August 2 in order to compensate for the lack of observation time with three telescopes. Average zenith angle is 26.6° in these two-fold stereo observations, and the total observation time is 11.4 hours. A local trigger condition is the same as that of the case of three telescopes.

We have done standard image cleaning for night sky background rejection and rate cut for avoiding the effect by cloud, and then calculate the moments of the shower image to parameterize by the Hillas parameters. After reconstructing arrival direction using IP-fit, the Fisher discriminant method is applied to eliminate numerous cosmic ray background events. Then the final θ^2 distribution is obtained. These analysis procedures are described in [15] and the details are explained in [8].

It is confirmed that the results obtained from the data taken with two telescopes are consistent with those from three-fold data. The details are presented in [15].

Each dataset taken by two telescopes and three telescopes is divided by the zenith angle into two dataset, small zenith angle data ($z < 60^{\circ}$) and large zenith angle data ($z > 60^{\circ}$), respectively. The estimated analysis threshold energies are 620 GeV for small zenith angle data and 1 TeV for large zenith angle data, respectively.

Time variations

The live time t_{liv} , number of excess events N and significance s for each night using all shower events are summarized in Table 1.

Figure 1 shows an obtained light curve of PKS 2155-304 expressed by the integral flux of VHE gamma-rays at energies greater than 620 GeV on a half night basis using small zenith angle data. This figure indicates there is at least a nightly variation of the flux, and on average a decreasing tendency can be seen. In particular, the flux in the early night of July 28 reached $\sim 140\%$ Crab flux, and $\sim 100\%$ Crab was detected also in July 30. The H.E.S.S. group reported the averaged flux of ~ 8 Crab in July 27 and was decreased to ~ 1 Crab in July 28 above 200 GeV. Considering the 8 hours time difference between

Obs. Date	t_{liv} [hrs]	N [events]	s [σ]
July 28	3.4/3.5	169/66	5.4/3.3
July 29	2.2/0.9	35/28	1.4/2.4
July 30	2.8/3.5	29/128	1.0/5.8
July 31	1.7/3.6	32/46	1.2/2.4
Aug. 2	- /3.5	- /20	- /1.1
Aug. 17-25	- /17.1	- /106	- /2.7

Table 1: Summary of nightly results for PKS 2155-304 from 2006 July 28 to August 2 and combined results from August 17 to 25. The data before (two-fold) and after (three-fold) culmination are shown separately by slash

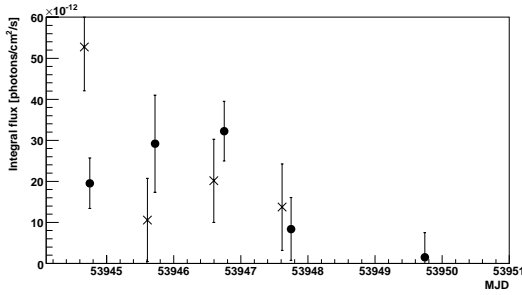


Figure 1: Light curve of PKS 2155-304 between July 28 and August 2. Closed circles indicate the data taken by three-telescope coincidence and cross indicate those by two-telescope before culmination. Analysis threshold energy is justified to 620 GeV for both data, where only data taken at zenith angles smaller than 30° are used.

the CANGAROO-III site and the H.E.S.S. site due to the longitude difference, and also considering the difference of threshold energies, obtained light curve in July 28 seems to be smoothly connected to their flux.

We further divide a part of small zenith data in July 28 and 30 into \sim an hour width bins and the intra-night flux variation are investigated. Then we found the decreasing of the flux less than a half during July 28 observations on a time scales of an hour to a few hours for both energy thresholds of 620 GeV and 1 TeV. In July 30 observations, increasing tendency can be seen, but it is not clear.

In Figure 2, we compare the light curve which we obtained in this work to those of the X-rays (quoted from quick-look results provided by

the ASM/RXTE team and from [9]), UV and optical wavelength [9]. As Foschini et al. [9] pointed out this figure shows that the amplitude of the flux variation at TeV energies is larger than by a factor of ten and is the largest compared to other wavelength.

Conclusion

Time variations of the flux of TeV gamma-rays from PKS 2155-304 was studied using the CANGAROO-III imaging atmospheric telescope. Observations has been done in July and August 2006 which was triggered by the H.E.S.S. report that the PKS 2155-304 was very strong TeV active state. Time variations of the flux on the time scales of a few hours was detected, and the highest flux above 620 GeV during our observations reached $\sim 140\%$ Crab flux. Obtained flux are smoothly connected to the flux reported by the H.E.S.S., which is offset in time by about eight hours from contemporaneous H.E.S.S. observations.

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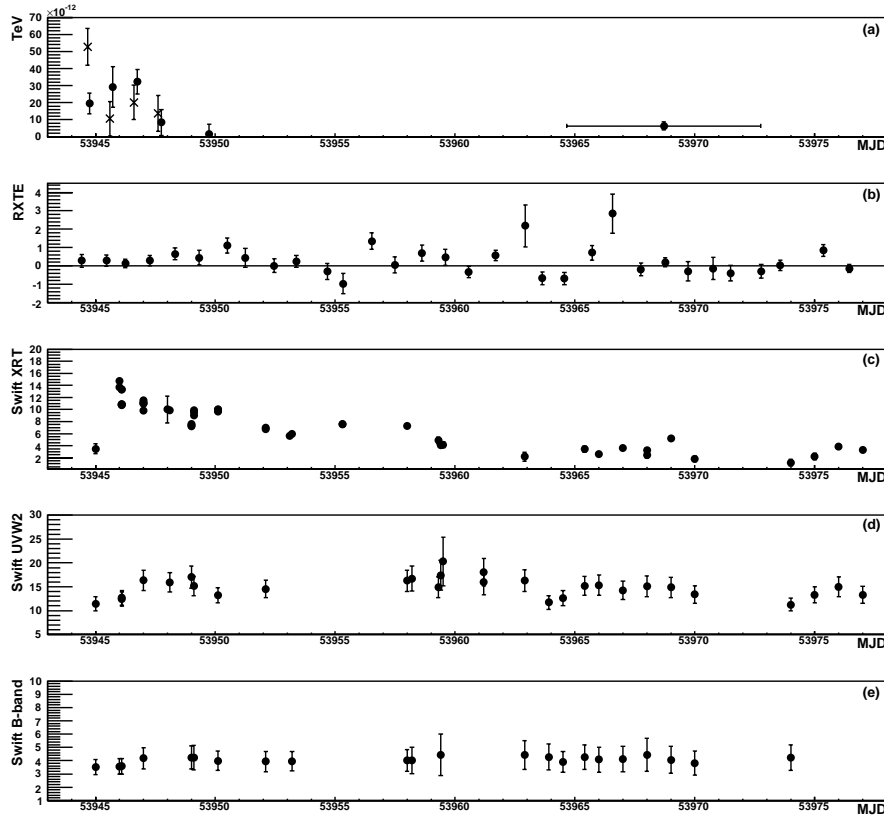


Figure 2: Light curves of PKS 2155-304 at various wavelength. (a) Variations of integral flux at energies greater than 620 GeV obtained by the CANGAROO-III. Plotted data and symbols are the same as in Fig. 1. An averaged integral flux between August 17 and 25 is also plotted. (b) X-rays [2–10 keV] quoted from quick-look results provided by the ASM/RXTE team. (c) X-rays [0.3–10 keV] by XRT on Swift [9]. (d) UV-band [1880Å]:UVW2 data by UVOT on Swift [9]. (e) B-band [4390Å] by UVOT on Swift [9].

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