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

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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 variation of very high energy gamma-rays was studied. The highest activity during our observations was seen early night in July 28 up to 180 % 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 Enegry(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 vilorent 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 $6.8\ \sigma$ 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 $45\,\sigma$ at enegies 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 Cherennkov telescope system operated in Woomera, South Australia. It is located at latitude $31°06'$ south and logitude $136°47'$ 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, respsctively. 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 obseravtion 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 parametarize 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 $(z < 60°)$ and large zenith angle data $(z > 60°)$, respectively. The estimated analysis threshold energies are 620 GeV for small zenith angle data and 1 TeV for large zenith angle data.

Time variations

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

Top panel of 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. The data between July 28 and August 2 are plotted on a half night basis using small zenith angle data, where two-fold data before culmination and three-fold data after culmination are used. An averaged integral flux between August 17 and 25 is also plotted in the same figure, where the data is only for after culmination. In this figure, the flux in the early night of July 28 reaches $\sim 180\,\%$ Crab flux, and it drops rapidly to less than a half during the same night on a time scale of ~ 2 hours. On av-

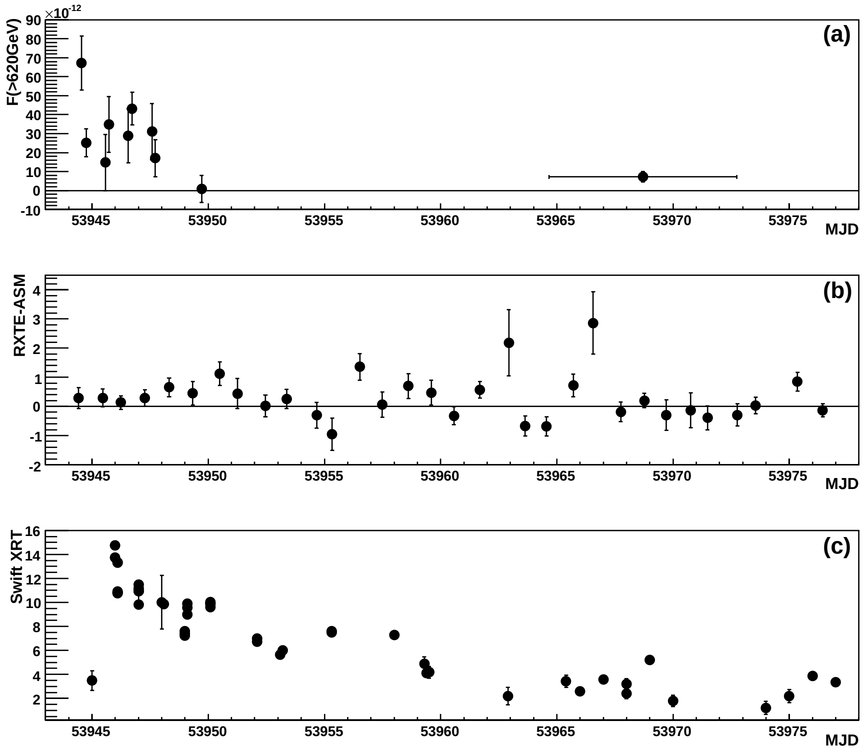

Figure 1: Light curve of PKS 2155-304 at various wavelength. (a) Variations of integral flux in unit of $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ obtained by the CANGAROO-III. Two data points for each night taken from two-telescope coincidence before culmination and three-telescope coincidence after culmination are plotted between July 28 and August 2. An averaged integral flux between August 17 and 25 is also plotted, where the data is only for after culmination. Analysis threshold energy is justified to 620 GeV for all data, where only data taken at zenith angles smaller than 30° are used. (b) X-ray [2–10 keV] counts in one day averaged ASM unit quoted from quick-look results provided by the ASM/RXTE team. (c) X-ray [0.3–10 keV] counts in unit of count s^{-1} by XRT on Swift [9].

erage a decresing tendency is also seen. A chance probability of this time variation assuming a constant flux is 1.0×10^{-3}, where the data of August lunation is not considered.

We further divide the data of July lunation into ~ 50 minutes width bins for each night, and the intra-night flux variation above 1 TeV are investigated, which include the large zenith angle data. The results are shown in Figure 2. Assuming the constant excess events, a χ^2 fit yields a value of 39.2 for 25 degree of freedom which corresponds to a χ^2 probability of $3.5\ \%$. In July 28 observations, there seems to be an intra-night variation. However, a chance probability of such a variation assuming a constant flux is estimated to be $4.5\ \%$.

In Figure 1, we also 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]. 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 larger than those of X-ray bands.

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

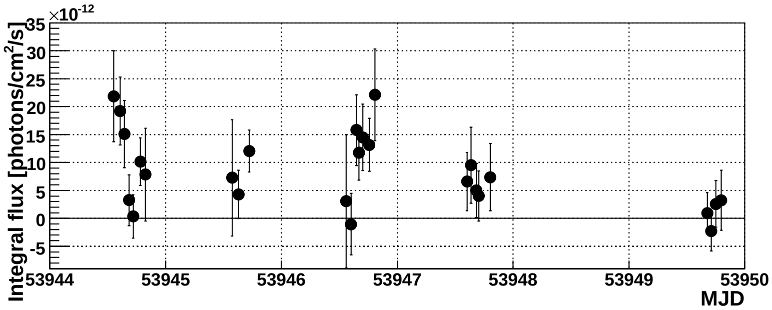

Figure 2: Light curve of PKS 2155-304 between July 28 and August 2, expressed by the integral flux above 1 TeV. Bin width is 50 minutes. Data taken at zenith angles larger than 30° are also used.

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

above 620 GeV during our observations reached $\sim 180\ \%$ Crab flux.

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