

Observations of the unidentified VHE gamma-ray source HESS J1614-518 with CANGAROO-III

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Abstract. HESS J1614-518 is one of the unidentified VHE gamma-ray sources discovered with the H.E.S.S. observatory in their Galactic plane survey. We observed HESS J1614-518 with the CANGAROO-III imaging atmospheric Cerenkov telescope array located in South Australia, from May to August in 2008. We detected a diffuse gamma-ray emission above 760 GeV at more than 5 sigma level during an effective exposure of 54 hours. The differential flux is consistent with H.E.S.S.. We discuss the possible counterpart using results of the follow-up observations by the X-ray satellites Suzaku and Swift.

Keywords: Gamma-ray astronomy, observation, galactic source

I. INTRODUCTION

A Galactic plane survey was performed by the H.E.S.S. imaging atmosphere Cerenkov telescope (IACT) in 2004[1][2]. HESS J1614-518 is one of the VHE gamma-ray sources which was discovered first by the survey and no obvious counterpart had not been

found. The unidentified sources are the majority type in discovered VHE gamma-ray sources, the most of which are located in Galactic plane. Revealing possible radiation mechanism is therefore quite important to investigate the origin of cosmic-rays.

HESS J1614-518 has a high flux level of 25 % Crab above 1 TeV with a photon index of 2.4. The follow-up observations were made by several observatories. The X-ray satellite Suzaku observed this region with XIS and found three X-ray sources [10]. Two of three sources have a diffuse emission region and a single power law spectrum which indicates non-thermal emission by the accelerated high energy electrons. One of these, called Suzaku source A, located very close to the VHE gamma-ray peak position. The X-ray satellite Swift also observed this region and found six point-like X-ray sources [12] [13]. G. Rowell et al. investigated the origin of the emission and speculated that the young stellar cluster Pismis 22 might be the origin from their energy budget [11].

	Obs. time [min]	Livetime [min]
2005 May	987	862
2005 June	1535	1297
2005 July	1010	868
2005 August	238	189
Total	3770	3217

TABLE I: Observation times and livetimes after rejecting data taken under the cloudy conditions.

II. OBSERVATIONS

CANGAROO-III is an array of four IACTs, located at Woomera, South Australia ($136^{\circ}47\text{E}$, $31^{\circ}06\text{S}$, 160 m a.s.l.). The oldest telescope, T1, which was CANGAROO-II telescope, has not been in use since 2004 due to its smaller FOV and higher energy threshold. We also did not use T2 since it was very difficult to determine a muon factor to calculate mirror reflectivity. Each telescope has a 10 m diameter reflector which consists of 114 segmented FRP spherical mirrors mounted on a parabolic frame [8]. The imaging camera system consists of 427 PMTs and has a FOV of 4.0 degrees [9]. The PMT signals are digitalized by charge ADCs and multi-hit TDCs [7]. The observation was carried out from May to August in 2008 using discrete rotation mode in which the pointing position was shifted both in declination and right ascension between ± 0.5 degree every 20 minutes from the target position. The target position was (RA,Dec [J2000])=(243.579° , -51.820°) which is the center position of the reported source position.

The light-collecting efficiency, including the reflectivity of segment mirrors, the transparency of light guides, and quantum efficiency of photomultipliers (PMTs) was monitored by muon-ring analysis with individual trigger data taken in same period. The average quantity of light per unit arc-length of muon rings is approximately proportional to the light-collecting efficiencies. From the muon-ring analysis for the data taken in this period, the light-collecting efficiency of each telescope, which is used in the Monte Carlo simulations, was respect to the original mirror production time of 0.58 and 0.50 for T3 and T4.

We reject the data whose trigger-rate were under 6 Hz to remove data taken under the cloudy condition. The observation times and livetimes of each month are listed in Table I.

III. DATA ANALYSIS

The standard analysis of CANGAROO-III collaboration [5][4] was applied to the data. The calibration for cameras and ADCs were taken daily with LEDs. After the calibration, the recorded charges of each pixel in the camera were converted to the number of photo-electrons. Time walk correction for TDC data were done by using the data taken by changing the luminosity of LEDs. After the calibration, every shower image was cleaned through the following criteria. Only pixels that had ≥ 5.0

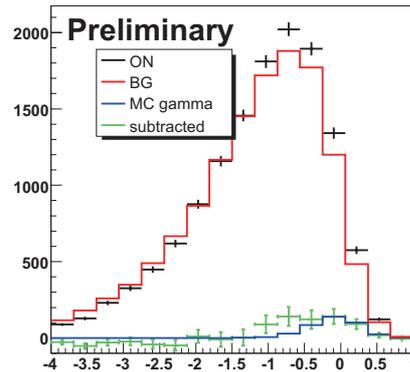


Fig. 1: FD distribution. The black crosses show the FD obtained from ON source region, $\theta^2 < 0.1 \text{ deg}^2$. The red and black line are the background and gamma-ray component estimated by the fit procedure described in the text. The green crosses are the subtraction of the background from the ON source region.

photo-electrons were used as "hit pixels". Then cluster of five or more hit pixels whose arrival times were within 30 nsec from the average hit time of all pixels were recognized as shower cluster.

Before calculating image moments – the " Hillas parameters" [3] – we applied the "edge cut" to the data [6]. We rejected events having hit pixels in the outermost layer of the camera. The orientation angles were determined by minimizing the sum of the squared widths with a constraint given by the distance predicted by Monte Carlo simulations.

In order to derive the gamma-ray likelihood, we used the Fisher Discriminant method [14][5]. The input parameters were

$$\vec{P} = (W_3, W_4, L_3, L_4)$$

where W_3, W_4, L_3, L_4 are energy-corrected *Widths* and *Lengths* for T3 and T4 camera images. The Fisher Discriminant (hereafter FD) is defined as $FD = \vec{\alpha} \cdot \vec{P}$, where $\vec{\alpha}$ is a set of coefficients mathematically determined in order to maximize the separation between two FD distributions for gamma-ray and hadrons.

For a background study we selected a ring region around the target, $0.2 \leq \theta^2 \leq 0.5 \text{ degree}^2$, where θ is the angular distance to the center of HESS J1614-518. We obtained the FD distribution of hadrons F_b from this region. We obtained FD distributions of gamma rays F_g from Monte Carlo simulations. Finally, we could fit the FD distribution of the events from the target with a linear combination of these two components. The observed FD distributions F could be represented as

$$F = \alpha F_g + (1 - \alpha) F_b$$

where α is the ratio of gamma-ray events to the total number of events. Here only α is optimized and the obtained FD distributions are shown in Fig 1.

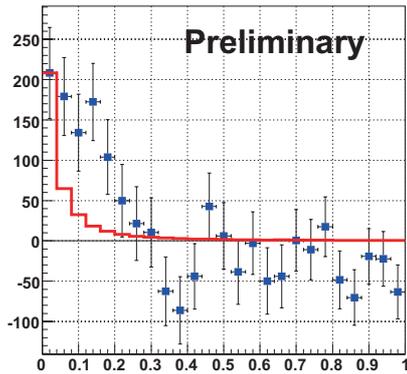


Fig. 2: The θ^2 plot. $\theta^2 = 0$ corresponds to the center position of the HESS results. The red histogram represents our PSF derived from the Monte-Carlo simulation.

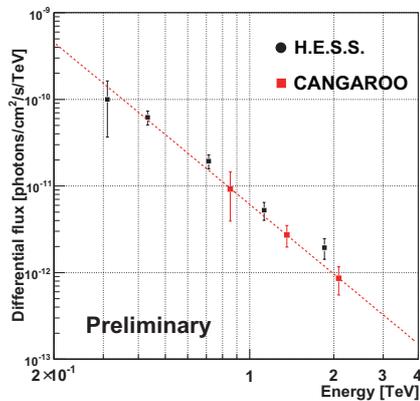


Fig. 3: Differential flux of HESS J1614-518. Red squares show the CANGAROO-III data points. Black circles the H.E.S.S. data points.

IV. RESULTS

The obtained θ^2 plot is shown in Fig 2 with the point spread function (hereafter PSF) of our telescopes. Above 760 GeV we detected 387 ± 74 excess events within $\theta^2 \leq 0.1$ degree². Its emission region is slightly broader than our PSF. The reconstructed VHE gamma-ray differential flux is shown in Fig 3 with the H.E.S.S. measurements. The spectrum is compatible with a single power-law: $(6.1 \pm 2.1_{stat} \pm 1.2_{sys}) \times 10^{-12} \times (E/1\text{TeV})^{-\alpha} \text{ cm}^{-2}\text{s}^{-1}\text{TeV}^{-1}$ with a photon index α of $2.7 \pm 0.7_{stat} \pm 0.5_{sys}$. The relevant systematic errors are due to the atmospheric transparency, night sky background fluctuations, uniformity of camera pixels, and light-collecting efficiencies. The flux obtained by CANGAROO-III was consistent with that of H.E.S.S. experiment.

V. DISCUSSION AND CONCLUSION

Both CANGAROO-III and H.E.S.S. observation results show HESS J1614-518 is a bright and extended VHE gamma-ray source. Since it is an extended source,

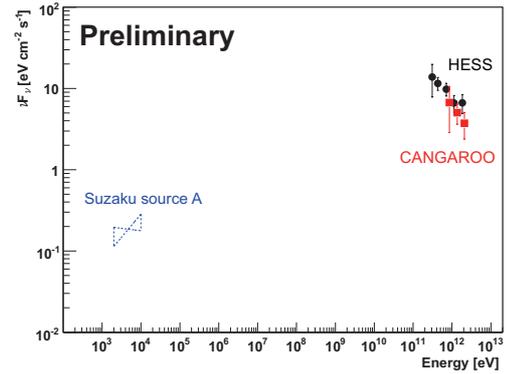


Fig. 4: Spectral energy distribution of HESS J1614-518. Blue dotted line shows a spectrum of Suzaku source A.

HESS J1614-518 is probably a Galactic source. H.E.S.S. group pointed out young open cluster Pismis 22, which located at a near distance of 1 pc from the earth and thus have an enough power to account the observed VHE gamma-ray luminosity, as a possible counterpart [11]. The other and major candidates in the Galaxy seem to be Supernova Remnant (SNR) or Pulsar Wind Nebulae (PWN). Suzaku source A, located very close to the VHE gamma-ray peak position, is also a possible counterpart [10]. The multi wavelength spectrum of HESS J1614-518 is shown in Fig. 4. Here we take the X-ray spectrum from Suzaku source A.

The ratio of the observed VHE gamma-ray and X-ray flux is unusually large (~ 30). The low X-ray flux requires a low magnetic field of $B \leq 1\mu \text{ G}$, if the origin of VHE gamma-ray emission is the inverse Compton scattering of the cosmic microwave background by a single population of high energy electrons. The large ratio, on the other hand, could appear in old supernova remnants whose age are $\sim 10^5$ yr, where the accelerated electrons have lost most of the energy and only nucleonic cosmic rays are left over [15]. The large ratio is also explainable in the time-evolving PWN model [16] [17]. In this scenario, the VHE gamma-ray were emitted from the old and relatively low energy electrons (~ 1 TeV) accelerated by the early stage of the pulsar. On the other hand, the X-ray emission were emitted from the young and high energy electrons (~ 100 TeV) accelerated by the present pulsar, while such high energy electrons accelerated by the early stage of the pulsar had lost their energy by synchrotron cooling. The early stage of the pulsar was more powerful than the present pulsar and could accelerate more electrons. This scenario can also explain the size difference of the emission region between the VHE gamma-ray and the X-ray.

In conclusion, the observation of HESS J1614-518 with CANGAROO-III telescopes confirms the VHE gamma-ray emission reported by H.E.S.S.. The differential energy spectrum can be fitted with a single power law, $\Gamma = 2.7 \pm 0.4_{stat} \pm 0.5_{sys}$. If we take Suzaku source A as the counterpart, we can explain the multi wavelength spectrum by the old SNR scenario or the

time-evolving PWN scenario.

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REFERENCES

- [1] Aharonian, F., *Science*, 307, 1938 (2005)
- [2] Aharonian, F., *ApJ*, 636, 777 (2006)
- [3] Hillas, A. M., *Proc. 19th ICRC(La Jolla)*, 3, 445 (1985)
- [4] Kabuki, S., et al., *ApJ*, 668, 968 (2007)
- [5] Enomoto, R., et al., *ApJ*, 638, 397 (2006)
- [6] Enomoto, R., et al., *ApJ*, 652, 1268 (2006)
- [7] Kubo, H., et al., *Proc. 27th ICRC*, 2900 (2001)
- [8] Kawachi, A., et al., *Astropart. Phys.*, 14, 261 (2001)
- [9] Kabuki, S., et al., *Nucl.Inst.Meth.*, A500, 318 (2003)
- [10] Matsumoto, H., et al., *PASJ* 60, 123 (2008)
- [11] Rowell, G., et al., *Proc. HDGS*, 241 (2008)
- [12] Landi R., et al., *ApJ* 651, 190 (2006)
- [13] Landi R., et al., *ATel* 1047 (2007)
- [14] Fisher, R. A., *Annals of Eugenics* 7, 179 (1936)
- [15] Yamazaki, R., et al., *MNRAS* 371, 1975 (2006)
- [16] Higashi, Y. et al., *ApJ* 683, 957-966 (2008)
- [17] Funk, S., et al., *ApJ* 662, 517 (2007)