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Observations of SNR Candidate HESS J1614-518 with Fermi-LAT

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HESS J1614-518 is a TeV gamma-ray source discovered by H.E.S.S., and shows a shell-like morphology in TeV band. Since no associated supernova remnant (SNR) is observed in other wavelengths, it is classified as a SNR candidate. In this work, we analyze the GeV gamma-ray emission from HESS J1614-518 using more than 12 years of *Fermi* Large Area Telescope data. We refine the morphology of the GeV emission. We find that the GeV spectrum is harder than previous work, and the GeV spectrum connects smoothly with the TeV spectrum of HESS J1614-518.

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1. Introduction

It is widely believed that SNRs are the main accelerators of Galactic cosmic rays (CRs) with energies up to the knee. This is supported by the non-thermal X-ray emission detected in many SNRs, which indicates the acceleration of electrons to hundreds of TeV energies [1]. The GeV gamma-ray observations of SNR W44 and IC 443 found the evidence of the acceleration of nuclei in SNRs [2] Gamma rays can be produced by the decay of neutral pions due to the inelastic $p-p$ collisions (the hadronic process), the Inverse Compton Scattering (ICS) or bremsstrahlung process of relativistic electrons (the leptonic process).

HESS J1614-518 was first discovered in the survey of the Galactic plane of H.E.S.S., and considered to be a “dark” particle accelerator without plausible counterpart at other wavelength [3]. Th very high energy (VHE, $E > 100$ GeV) gamma-ray emission from HESS J1614-518 was also detected by CANGAROO-II with a significance level of 8.9σ [4]. Recently, H.E.S.S. performed detailed observations of this region, and found shell-like morphology from its TeV gamma-ray emission [5]. Thus, HESS J1614-518 is considered to be a SNR candidate.

Swift X-Ray Telescope (XRT) performed observations toward HESS J1614-528, but only two faint point-like sources were observed [6]. Subsequently, *Suzaku* discovered three X-ray sources within this region, called Src A, Src B and Src C [7]. Src A is an extended located at the TeV gamma-ray peak of HESS J1614-518, while Src B is located towards the relatively dim region in TeV image [7], which is found to be comprised of multi point sources in the follow-up *XMM-Newton* observations [8]. Src B is dominated by XMM-Newton Src B1 [8], and Src C is a foreground late-type B star [7].

While there are several HII regions in the vicinity of HESS J1614-518, none of them is coincident with the TeV gamma-ray emission, and the distribution of interstellar medium (ISM) was also explored [9]. The diffuse molecular gas appears to overlap HESS J1614-518. However, no obvious morphological conrrespondence was found, and only a peculiar open ring-like feature of dense gas towards the center of HESS J1614-518 was seen [9]. In addition, the distance of Src A and Src B1 was considered to be ~ 3 kpc, based on the estimation of total column density from both atomic and molecular hydrogen gas [9], which is closer than the distance derived by [7, 8].

The GeV counterpart of HESS J1614-518 named 3FGL J1615.3–5146e was reported in the *Fermi* Large Area Telescope (LAT) third source catalog [3FGL; 10]. The GeV spectrum of 3FGL J1615.3–5146e is described by a power law with an photon index of $\Gamma = 1.86$.

2. *Fermi*-LAT Data Analysis

2.1 Data Reduction

We selected the Pass 8 version of the *Fermi*-LAT data with “Source” event class, recorded from August 4, 2008 to January 4, 2021. The region of interest (ROI) was chosen to be a $10^\circ \times 10^\circ$ box centered at HESS J1614-518. In order to have a good angular resolution, the events in the energy range of 10-800 GeV were used . In addition, the data with zenith angles larger than 90° were excluded to reduce the contamination from the Earth Limb. The data were analyzed with *Fermitools* [1] and the binned likelihood analysis method. The model includes all nearby sources

[1]http://fermi.gsfc.nasa.gov/ssc/data/analysis/software/

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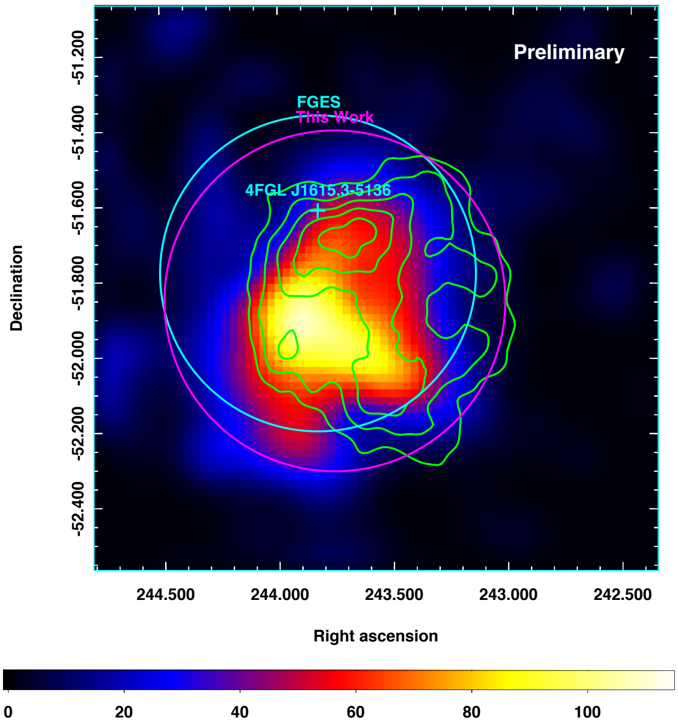

Figure 1: $1.5^\circ \times 1.5^\circ$ TS maps centered on the position of HESS J1614-518 for the data above 10 GeV. The cyan plus indicates the position of 4FGL J1615.3-5136, and the cyan circle is the spatial template given by FGES. The magenta circle describes the 68% containment radius (r_{68}) of the best-fit 2D Gaussian template. And the green contours represent the TeV image observed by H.E.S.S. [5].

listed in the *Fermi*-LAT 10-year source catalog [4FGL-DR2; 11], Galactic and isotropic diffuse gamma-ray backgrounds.

2.2 Results

After fitting the data, we created a $1.5^\circ \times 1.5^\circ$ TS map centered at HESS J1614-518 (see Figure 1). As shown in Figure 1, the GeV gamma-ray emission overlaps the VHE emission shown by the green contours [5]. We notice that there is a new point source 4FGL J1615.3-5136, which is not included in 3FGL [10] and considered to be associated with pulsar PSR J1615-5137 [11]. In addition, the GeV emission from HESS J1614-518 does not fully overlap with the TeV image, and the peak of the GeV emission does not coincide with that of TeV observation. Moreover, the GeV emission extends southeast beyond the TeV source.

2.2.1 Spatial Extension

Since the GeV extension of HESS J1614-518 was constrained by FGES catalog [12, 13], we carried out an extension analysis using more than 12-year data with different spatial models. We

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refined the extension of GeV gamma-ray emission with *Fermipy*[2] package [14]. A shell structure defined by [5] and the TeV image were also used as the spatial template. The TS values for different spatial models are listed in Table 1. We found that a 2D Gaussian model with $\sigma \sim 0.30^\circ$ gives the highest TS value. In the following analysis, the 2D Gaussian template is used as the spatial model of HESS J1614-518.

Table 1: TS values of HESS J1614-518 with different spatial models

Spatial Model	TS	Degrees of Freedom
0.42° Uniform Disk (FGES)	317	6
0.49° Uniform Disk	336	6
2D Gaussian($\sigma = 0.30$)	353	6
Shell	271	7
TeV Image	307	3

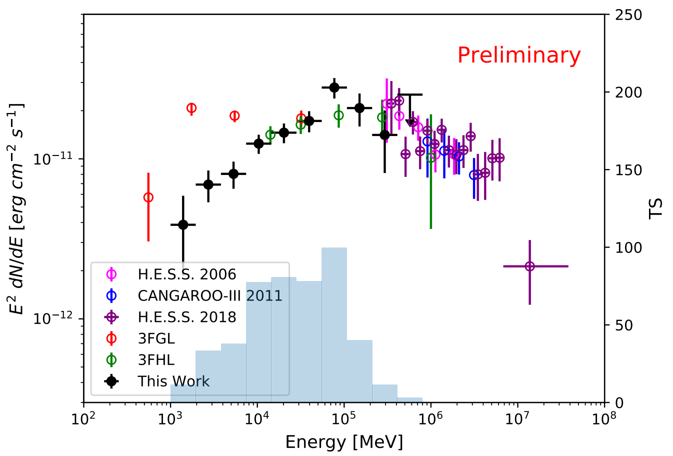

Figure 2: The *Fermi*-LAT SED of HESS J1614-518 (black dots). Shaded blue regions (right axis) show the TS values of the ten energy bins. The red and green dots present the GeV SED in 3FGL [10] and 3FHL [15], respectively. The blue, magenta and purple dots are the CANGROO-III and H.E.S.S. observations of HESS J1614-518 in the VHE band [4, 5, 16].

2.2.2 Spectral Analysis

We performed the spectral analysis in the energy range of 1-800 GeV. After a preliminary fit, we found additional excess not included in 4FGL-DR2, and we added to the model using a point source with a power-law spectrum. The best-fit position of this source is R.A.= 245.739°, Dec.= −51.2127°. The spectrum of HESS J1614-518 is described by a LogParabola, and the global fit gives spectral indexes of $\alpha = 1.644 \pm 0.05$ and $\beta = 0.11 \pm 0.03$.

To study the spectral energy distribution (SED) of HESS J1614-518. The data is further divided into ten energy bins with equal width in logarithmic space. The results of the SED are shown in

[2]https://fermipy.readthedocs.io/en/latest/

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Figure 2. The GeV SED connects smoothly with the TeV spectrum of HESS J1614-518, indicating the same origin. In addition, we found that the GeV spectrum is harder than previous work. Such a hard spectrum is similar to SNR RCW 86 [17], RX J0852.0-4622 [18] and HESS J1731-347 [19]. Future more multi-wavelength observations will be helpful to explore the radiation mechanism.

3. Conclusion

In this work, we report the GeV γ-ray emission from the direction of HESS J1614-518 with more than 12 years of Pass 8 data recorded by the *Fermi*-LAT. We perform the morphology analysis and refine the spatial template in GeV band. The GeV spectrum we analyzed is harder than previous work. Future more multi-wavelength observations will be helpful to explore the radiation mechanism.

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