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The γ-ray emission toward HESS J1813-178 with *Fermi*-LAT

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HESS J1813-178 is one of the brightest and most compact objects detected by the HESS Galactic Plane Survey and MAGIC observations. A young supernova remnant (SNR) G12.8–0.0 locates within the TeV extent of HESS J1813-178. And a pulsar wind nebula (PWN) driven by an energetic X-ray pulsar PSR J1813-1749 is embedded in the SNR, together with a young stellar cluster, C1 1813-178, detected in this region. The origin of the γ-ray emission from HESS J1813-178 is still not clear. Previous studies show that the GeV emission around HESS J1813-178 is much more extended than its TeV emission. With the *Fermi*-LAT data analysis, we did a detailed morphological and spectral analysis in the region of HESS J1813-178 and found that the GeV γ-ray morphology above 20 GeV is much smaller, which is close to the TeV γ-ray contours. Meanwhile, the GeV spectrum above 20 GeV is hard with an index of ~ 2.07, which connects smoothly with that of HESS J1813-178.

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1. Introduction

HESS J1813-178 was detected to be nearly point-like with an extension of $\sigma = 2.'2$ by HESS[1]. The TeV γ-ray emission from HESS J1813-178 shows a power-law spectrum with a rather hard photon index of 2.09±0.08, and MAGIC observations give the similar spectrum with index of 2.1±0.2 in the energy range of 0.4 - 10 TeV [2]. HESS J1813-178 is positionally coincident with a young shell-type SNR G12.8-0.0, which lies in the vicinity of a bright star forming region W33. And non-thermal X-ray emission was also detected in this region [3]. Deep X-ray observations revealed a PWN embedded in the SNR, which is powered by an energetic pulsar PSR J1813-1749 [4–6]. The spin-down luminosity of PSR J1813-1749 is $\dot{E} = 5.6 \times 10^{37}$ erg s^{-1}, with a characteristic age of $\tau_c = 5600$ yr [7]. Meanwhile, a young stellar cluster, C1 1813-178, is discovered in the W33 complex [8], which is associated with SNR G12.7-0.0 and G12.8-0.0 at a kinematic distance of 4.8 kpc, together with the TeV γ-ray emission region of HESS J1813-178. Recently, Camilo et al. [9] determined the distance of PSR J1813-1749 to be $d \approx 12$ kpc with the radio data from Green Bank Telescope. If HESS J1813-178 is related to PSR J1813-1749, the >200 GeV luminosity of HESS J1813-178 would be $\approx 3 \times 10^{35}$erg s^{-1} with this distance, which makes it to be one of the most luminous TeV sources in the Galaxy.

It is still not clear for the origin of the γ-ray emission from HESS J1813-178. Fang & Zhang [10] predicted that the TeV γ-ray emission is mainly originated from the PWN, although the contribution from the SNR shell could be enhanced with a denser medium. With the *Fermi*-LAT data, Araya [11] found a much extended GeV γ-ray emission (radius $\sim 0.6°$) around HESS J1813-178. The global spectrum in the energy range of 0.5 - 500 GeV can be fitted by a power-law with an index of 2.14±0.04, which is not consistent with the IC emission characteristic from leptons in a PWN. And Araya [11] argued that the extended GeV emission may be related to the star-forming regions around HESS J1813-178, like W33.

Here we will report the re-analysed results about the γ-ray emission around HESS J1813-178 with the *Fermi*-LAT data, including the spatial and spectral analysis.

2. *Fermi*-LAT Data Reduction

The following analysis is performed using the latest Pass 8 data with “Source” event class from 2008 August 4 (MET 239557418) to 2021 January 4 (MET 631411205). To avoid a too large point spread function (PSF) in the lower energy band, only events from 1 GeV to 1 TeV are selected. In addition, the events whose zenith angle larger than 90° are excluded to minimized the contamination from Earth Limb. The analysis is performed in a $14° \times 14°$ square region, and the latest standard LAT analysis software *Fermitools* is adopted. All sources in the fourth *Fermi*-LAT source catalog (4FGL)[12] are included in the model, together with the Galactic (modeled by `gll_iem_v07.fits`) and isotropic (modeled by `iso_P8R3_SOURCE_V2_v1.txt`) diffuse backgrounds. The binned likelihood analysis method with *gtlike* is adopted to fit the data.

3. Analysis and Results

In the 4FGL catalog, an extended source named 4FGL J1813.1-1737e described by an uniform disk with a radius of 0.6°, is regarded as the GeV counterpart of HESS J1813-178. However, the size of the uniform disk, following the analysis result by Araya [11], is much larger than that of the TeV γ-ray emission of HESS J1813-178. Besides, there is a point source (4FGL J1814.1-1710) located in the region of 4FGL J1813.1-1737e, which is suggested to be associated with SNR G13.5+0.2 in the 4FGL catalog. Using the model including all 4FGL sources within a radius of 20° from the ROI center, we first investigate the spectrum of 4FGL J1813.1-1737e by adopting the spatial model recommended in 4FGL. The data are divided into 15 equal logarithmic energy bins from 1 GeV to 1 TeV. And the same likelihood fitting is done for each energy bin. The resulting spectral energy distribution (SED) of 4FGL J1813.1-1737e is shown as the black dots in Figure 1, and the black arrows represent the 95% upper limits for energy bins with TS values smaller than 4.0. The SED shows a spectral upturn in the energy of $\sim$ 20 TeV. And then we divided the global energy range into two parts: 1 GeV - 20 GeV and 20 GeV - 1 TeV.

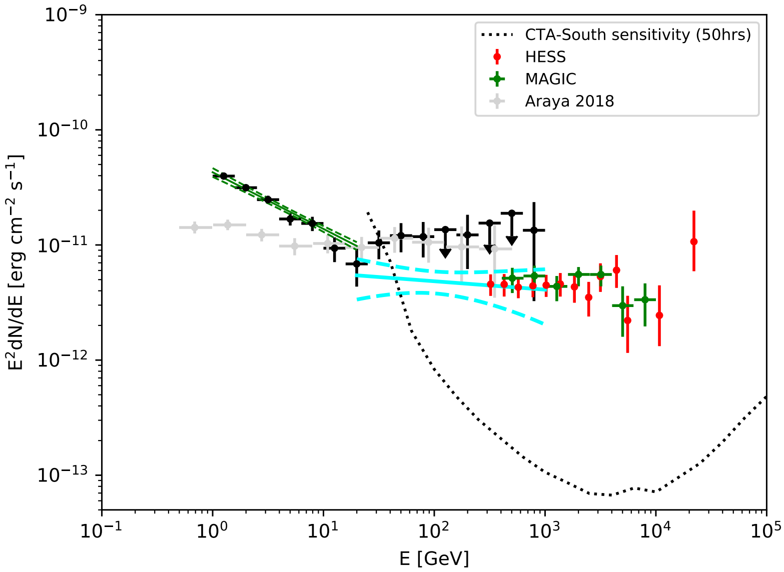

Figure 1: The SED of HESS J1813-178. The black dots depict the results of *Fermi*-LAT data in the energy range of 1 GeV - 1 TeV. The global best-fitting power-law spectra with 1σ statistic errors in the range of 1 GeV - 20 GeV and 20 GeV - 1 TeV are shown as the green and cyan butterflies, respectively. The gray dots are from Araya [11]. The observational data by HESS [1] and MAGIC [2] are marked by the red and green dots. The black dotted line shows the differential sensitivity of Cherenkov Telescope Array in the south hemisphere (CTA-South; 50 hr)[14].

For the γ-ray emission in 1 GeV - 20 GeV, we refitted the spatial size of 4FGL J1813.1-1737e using *fermipy*, a PYTHON package that automates analyses with the Fermi Science Tools [13]. Adopting the spatial template of an uniform disk, the radius is fitted to be 0.561° at the centroid of (RA., Dec. = 273.379°, -17.677°), which is similar to the values in 4FGL. The spectrum of 4FGL J1813.1-1737e in the energy range of 1 GeV - 20 GeV can be well fitted by a power-law model with an index of 2.49±0.04, which is shown as the green butterfly in Figure 1. And the corresponding photon flux is calculated to be (1.77±0.06) $\times 10^{-8}$ph cm^{-2} s^{-1}. For the data analysis in 20 GeV - 1 TeV, the γ-ray centroid is fitted to be (RA., Dec. = 273.421°, -17.814°). And the spatial size of 4FGL J1813.1-1737e is much smaller, with a radius of 0.232°. Figure 2 shows the γ-ray emission of 4FGL J1813.1-1737e above 20 GeV. And the γ-ray morphology is consistent with the TeV emission from HESS J1813-178 marked as the cyan contours. With the smaller spatial size, the γ-ray spectrum of 4FGL J1813.1-1737e in the energy range of 20 GeV - 1 TeV is hard, with an index of 2.07±0.20 for a power-law model. And the corresponding photon flux is (1.56±0.28) $\times 10^{-10}$ph cm^{-2} s^{-1}. The global spectrum is shown as the cyan butterfly in Figure 1. And it can be connected smoothly with the TeV spectrum of HESS J1813-178 by HESS [1] and MAGIC [2], which suggests that the GeV γ-ray emission above 20 GeV may has the same origin with HESS J1813-178.

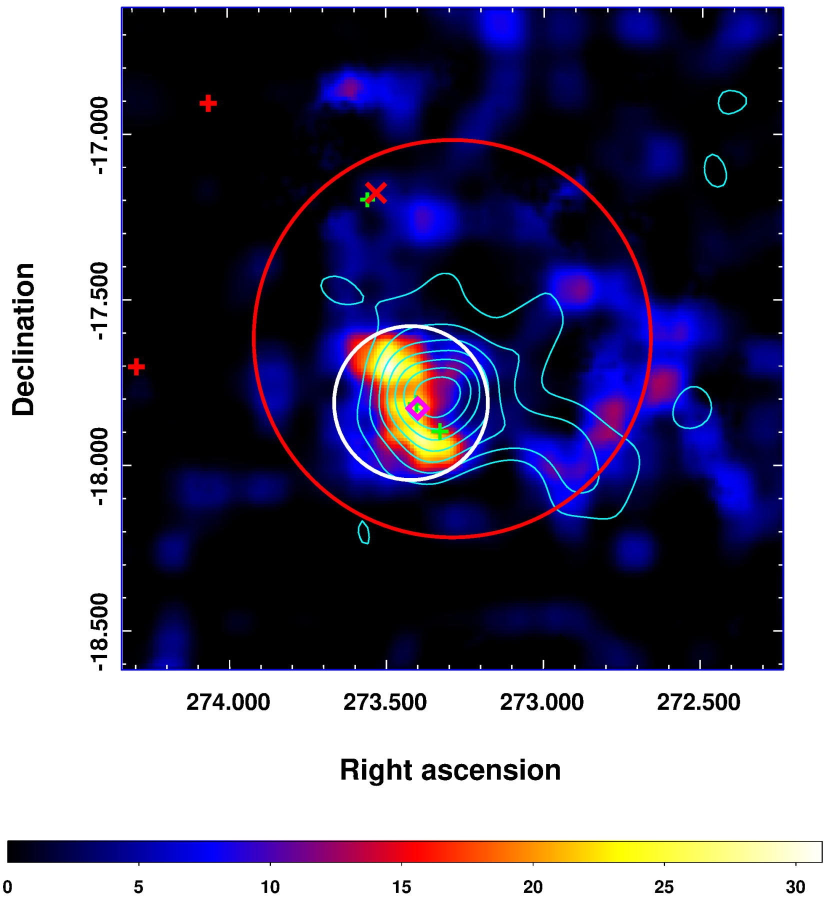

Figure 2: TS map for a region of 2.0° × 2.0° above 20 GeV. The positions of 4FGL sources are shown as the red pluses, and the spatial size of 4FGL J1813.1-1737e is marked by the red circle. The red cross represents 4FGL J1814.1-1710, which is suggested to be associated with SNR G013.5+00.2. The smaller spatial size with the data above 20 GeV is shown as the white circle. The centroid position of the TeV γ-ray emission from HESS J1813-178 detected by HESS [1] is marked by the magenta diamond, and the cyan contours represent the TeV γ-ray emission from HESS J1813-178 detected by MAGIC [2]. Three SNRs in this region (G12.8-0.0, G12.7-0.0, G13.5+0.2) are marked by the green pluses.

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