HESS J1826−130: A Very Hard γ-Ray Spectrum Source in the Galactic Plane

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Abstract. HESS J1826−130 is an unidentified hard spectrum source discovered by H.E.S.S. along the Galactic plane, the spectral index being $\Gamma = 1.6$ with an exponential cut-off at about 12 TeV. While the source does not have a clear counterpart at longer wavelengths, the very hard spectrum emission at TeV energies implies that electrons or protons accelerated up to several hundreds of TeV are responsible for the emission. In the hadronic case, the VHE emission can be produced by runaway cosmic-rays colliding with the dense molecular clouds spatially coincident with the H.E.S.S. source.

INTRODUCTION

In the past decade, observations with the High Energy Stereoscopic System (H.E.S.S.) have discovered tens of very high energy (VHE, $E > 0.1$ TeV) γ-ray sources1 by scanning a large fraction of the Galactic Plane [1].

HESS J1826−130 is an unidentified extended source discovered by the H.E.S.S. telescope array in the multi-TeV domain. The source had been previously hidden in the extended tail of emission from the bright nearby source HESS J1825−137 [2]. For such sources affected by source confusion, an investigation in energy bands can provide an additional powerful tool for new discoveries [3]. HESS J1826−130 shows one of the hardest spectra ever observed in VHE γ-rays, extending up to at least few tens of TeV. The shell-type supernova remnants (SNRs), G018.1−00.1 and G018.6−00.2 [4], are located in the vicinity of the source along with the γ-ray pulsar PSR J1826−1256.

In this work, the analysis of 206 h of H.E.S.S. data from the region around HESS J1826−130 will be presented. Finally, possible VHE γ-ray emission scenarios related to the origin of the source will be briefly discussed.

H.E.S.S. OBSERVATIONS and RESULTS

The H.E.S.S. Telescopes

H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes located in the Khomas Highland of Namibia, 1800 m above sea level. H.E.S.S. in phase I comprised of four 13 m diameter telescopes which have been fully operational since 2004. A fifth telescope was added in the center of the array and has been operational since September

1See http://tevcat.uchicago.edu for an updated list of known VHE γ-ray sources.
2012. The H.E.S.S. phase I array configuration is sensitive to γ-ray energies between 100 GeV and several tens of TeV. With the addition of the fifth telescope, the energy threshold was lowered to some tens of GeV. The VHE H.E.S.S. data presented in this paper were taken with the H.E.S.S. phase I array configuration, which can measure extensive air showers with an angular resolution better than 0.1° and an average energy resolution of 15% at an energy of 1 TeV [5].

Detection and Morphological Analysis

The observations of the field of view around HESS J1826−130 were carried out between 2004 and 2015, corresponding to an acceptance corrected live-time of 206 h of H.E.S.S. phase I data after the application of the quality selection criteria [5]. The data have been analyzed with the H.E.S.S. analysis package for shower reconstruction and the multivariate analysis technique [6] has been applied for providing an improved discrimination between hadrons and γ rays. In order to provide improved angular resolution and reduce contamination from the bright and nearby source HESS J1825−137, the source position and morphology have been obtained with a hard cut configuration which requires a minimum of 160 photo-electrons per image. The cosmic-ray background level was estimated using the ring background model [7]. Using this dataset, HESS J1826−130 is detected with a statistical significance of 21.0σ, determined by using Equation (17) in [8]. Figure 1 shows the acceptance corrected and smoothed with the H.E.S.S. point spread function (PSF) VHE γ-ray excess map of the region around HESS J1826−130 at energies greater than E = 2 TeV.

![Excess H.E.S.S. Preliminary](image)

**FIGURE 1.** Map of excess events with energies E > 2 TeV for the region around HESS J1826−130 smoothed with the H.E.S.S. PSF. The white contours indicate the significance of the emission at the 15σ and 20σ level. The color scale is in units of excess counts per smoothing Gaussian width. The 68% containment radius of the H.E.S.S. PSF is shown with the white circle at the lower left corner. The green circle shows the integration region used for deriving the source spectrum shown in Fig. 3, while the green cross indicates the value and 1σ uncertainty of the best fit position of the source. The nearby SNRs, G018.6−00.2 and G018.1−00.1 are marked with yellow circles, while the white triangle indicates the position of the γ-ray pulsar PSR J1826−1256.

The source remained unnoticed and hidden for the standard source detection techniques due to its relatively low brightness with respect to the nearby bright source HESS J1825−137. During a study of a possible energy-dependent morphology of HESS J1826−130, a collection of images for events with energies above a set of energy thresholds (E > 1, 2, 3, 4, and 5 TeV) was created (see Fig. 2). As it can be seen from the figure, HESS J1826−130 becomes more visible with increasing energy threshold.
FIGURE 2. Energy dependent VHE $\gamma$-ray excess maps of the region around HESS J1826$-$130 for the same field of view given in Fig. 1.

The position and extension of HESS J1826$-$130 was determined by fitting a two-dimensional Gaussian model convolved with the H.E.S.S. PSF to the excess event distribution. The centroid of the 2D Gaussian corresponding to the best fit position of the source is R.A. (J2000): $18^h 26^m 0.2'' \pm 7.0''$ stat $\pm 1.3''$ sys and Dec. (J2000): $-13^\circ 02' \pm 1.8'$ stat $\pm 0.3'$ sys. The extension of the source is estimated as $0.17'' \pm 0.02''$ stat $\pm 0.05''$ sys.

Spectral Analysis

A circular region with a radius of 0.22$''$ centered at the best fit position of HESS J1826$-$130 (e.g. Fig. 1, green circle) was used as an integration region for extracting the differential VHE $\gamma$-ray spectrum of the source. The spectrum was derived using the forward folding technique [9], and is well described by a power-law with an exponential cut-off function $dN/dE = \Phi_0 (E/1 \text{ TeV})^{-\Gamma} \exp(-E/E_c)$ with $\Phi_0 = (8.62 \pm 0.73_{\text{stat}} \pm 1.72_{\text{sys}}) \times 10^{13} \text{ cm}^{-2} \text{s}^{-1} \text{TeV}^{-1}$, $\Gamma = 1.61 \pm 0.11_{\text{stat}} \pm 0.20_{\text{sys}}$ and a cut-off energy of $E_c = 12.5^{+4.0}_{-2.4} \text{ TeV}$. This spectral model is preferred over a simple power-law model at a statistical significance level of $4.0\sigma$ from log-likelihood ratio test. The time variability of the emission of the source was investigated at different timescales by fitting the integral flux to a constant. In all the timescales, from run-wise (~30 min) to year-wise light curves, the $\chi^2$ fit results in compatibility of the emission with a constant flux.

The integration region used for extracting the VHE spectrum of HESS J1826$-$130 is strongly contaminated by HESS J1825$-$137, especially at lower energies (~40% below 1.5 TeV and ~20% above 1.5 TeV), and the spectrum
FIGURE 3. VHE γ-ray spectrum of HESS J1826−130 extracted from the source region shown in Fig. 1. The black dots show the flux points with errors. The 68% error band of the best fit ECPL model (blue shaded region) and the best fit power-law model (red line) are also shown. The differential flux upper limit in the shown energy band is at 99% confidence level. The VHE spectrum of RXJ1713.7−3946 is shown for comparison.

presented in this section is affected by this contamination. Further spectral studies (simultaneous fitting of both source spectra) are being performed for obtaining the intrinsic spectrum of HESS J1826−130. Given the relatively softer spectrum of HESS J1825−137, the intrinsic spectrum of HESS J1826−130 is expected to be even harder with respect to the spectral results presented in this section.

MULTIWAVELENGTH COUNTERPARTS

Two giant molecular clouds (GMC) with masses of few $10^5 \, M_\odot$ at 3.7 kpc and 4.7 kpc have been found along the line of sight of to HESS J1826−130 when studying NANTEN data [10]. The ambient gas densities of these GMCs are estimated of the order of $\sim 600 \, \text{cm}^{-3}$.

The SNR G018.1−00.1 is located between 4 and 6.3 kpc [4] (corresponding to the projected physical distance of $\sim 33$ pc from the best fit position of HESS J1826−130), while the SNR G018.6−00.2 is located between 4 and 5.2 kpc [4] (corresponding to the projected physical distance of $\sim 18$ pc from the best fit position of HESS J1826−130).

The γ-ray pulsar PSR J1826−1256 is also located in the vicinity of the source as shown in Fig. 1. This pulsar has a spin-down luminosity of $\dot{E} = 3.6 \times 10^{36} \, \text{erg/s}$ and a characteristic age of $\tau_c = 14.4$ kyr. Note that pulsars with $\tau_c < 150$ kyr and with $\dot{E}/D_{\text{PSR}}^2 \geq 10^{34} \, \text{erg s}^{-1} \, \text{kpc}^{-2}$ are known to power pulsar wind nebulae (PWNe) that are detectable at very high energies [11]. This pulsar has been detected both in X-ray energies [12] and in high energy γ-rays [13]. No distance estimation for this pulsar is known from dispersion measure [14] since it is a radio-quiet pulsar.

DISCUSSION

The emission from HESS J1826−130 is characterized by a very hard spectrum ($\Gamma = 1.6$) with an exponential cut-off at about 12 TeV. Such a spectrum, together with a spatial coincidence of a dense molecular hydrogen region, suggests that the radiation could be produced by several hundred TeV protons colliding with the gas. To explain the very hard spectrum, one can think of a hadronic scenario in which runaway protons accelerated by the close shell-type SNRs G018.1−00.1 or G018.6−00.2 are emitting TeV photons when interacting with the dense ambient gas found along the
line of sight. The proton spectrum should extend up to at least several hundreds of TeV. The γ-ray luminosity, \(L_\gamma\), of the source is \(8 \times 10^{33}\) ergs for a distance of 4 kpc. This translates into an energy output in accelerated protons, \(W_{pp} = L_\gamma \times t_{pp}\), of \(6 \times 10^{46} (n / 1 \text{ cm}^{-3})^{-1}\) erg, while ambient gas densities from NANTEN data analysis are of the order of 600 cm\(^{-3}\). In the hadronic scenario, the hardness of the photon spectrum could be the effect of the highest energy protons diffusing in dense clouds, while the lower energy protons might be still confined within the accelerating source or efficiently excluded from the clouds if diffusion coefficient inside the clouds is suppressed.

A leptonic scenario, where electrons accelerated by the pulsar PSR J1826−1256 are up-scattering CMB or IR photons, can also explain the VHE emission. Such as hard spectrum at H.E.S.S. energies can be produced by an uncooled electron population with spectral index close to -2.0 and a cutoff at around 70 TeV. The energy output \(W_e\) in accelerated electrons is \(2 \times 10^{47}\) ergs for a distance of 7 kpc. This source has a spectrum very similar to other few PWNe, in particular, Vela X [15]. HESS J1826−130 could be an indication of a distinctive PWN population, with very hard spectra and relatively high cutoff energies.

**CONCLUSIONS**

The unidentified TeV source, HESS J1826−130, stands out in the H.E.S.S. Galactic Plane Survey for its particularly hard spectrum. A proton or electron population extending up to several hundred TeV is needed to produce the TeV emission from HESS J1826−130. Currently, studies to better constrain its spectrum are under way.

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