

VERITAS Detection of LS 5039 and HESS J1825-137

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ABSTRACT

With 8 h of observations, VERITAS confirms the detection of two very high energy gamma-ray sources. The gamma-ray binary LS 5039 is detected with a statistical significance of 8.8σ . The measured flux above 1 TeV is $(2.5 \pm 0.4) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$ near inferior conjunction and $(7.8 \pm 2.8) \times 10^{-13} \text{ cm}^{-2} \text{ s}^{-1}$ near superior conjunction. The pulsar wind nebula HESS J1825-137 is detected with a statistical significance of 6.7σ and a measured flux above 1 TeV of $(3.9 \pm 0.8) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$.

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1. Introduction

We report observations of two known, bright, very-high-energy (VHE; $E > 50 \text{ GeV}$) gamma-ray emitting objects: the gamma-ray binary LS 5039 and the very extended pulsar wind nebula (PWN) HESS J1825-137. These two objects are separated by about 1° on

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the sky and can both be observed in a single field of view with the Very Energetic Radiation Imaging Telescope Array System (VERITAS).¹

Gamma-ray binaries are an established class of VHE objects that involve the interaction of a star with a compact object. The VHE emission from these objects is almost entirely inverse-Compton scattering from relativistic electrons and the compact object can be determined by time-dependent spectral modeling including gamma-rays. For a review of gamma-ray binaries, see [1]. Gamma ray emission from PWN is also due to inverse-Compton scattering as relativistic electrons boost photons to TeV energies in the strong shock at the termination of the pulsar wind. Please see [2,3] for current reviews of PWN.

The observations are described in Section 2. Background, spectra, timing, and morphological studies are described for each source in Section 3.

2. Observations

VERITAS is a four-telescope array exploiting the imaging atmospheric Cherenkov technique to detect VHE gamma rays and is most sensitive to energies between 0.085–30 TeV. The array is located at the Fred Lawrence Whipple Observatory (FLWO) in southern Arizona (31°40'N, 110°57'W, 1.3 km above sea level). For a performance summary, see [4].

VERITAS observed the field in late spring of 2013 and 2014 with an average zenith angle of 48°. Standard analysis was performed [5] with background extracted from regions near the sources excluding a 0.35° radius region around LS 5039 and a 0.75° radius region around HESS J1825-137. With 7.9 h of usable observations after quality cuts, we confirm the HESS detections of these sources [6,7]. Fig. 1 shows the VERITAS skymap made with an integration region radius of $\theta = 0.089^\circ$. The average low-energy threshold for VERITAS observations is 420 GeV due to the relatively large zenith angle of the observations.

3. Results

3.1. LS 5039

LS 5039 was identified as a high mass X-ray binary in the ROSAT Galactic plane survey [8] and radio emission was detected using the VLA [9]. It was also detected as a gamma-ray binary with EGRET [10] and at VHE with HESS [6]. Periodic emission is also detected by *Fermi*-LAT above 300 MeV [11]. The companion star is spectral type O6.5V [12], while the mass and nature of the compact object is undetermined [13]. However, some evidence exists for a neutron star being present in the system. Orbital modulation in TeV gamma-rays peaks when the star and compact object are aligned relative to the observer which can be explained by the outward flow of relativistic particles from a PWN boosting emission from the star [14].

We detect VER J1826-148, the VHE source associated with LS 5039, at a significance of 8.8 standard deviations (σ) [15] with 101 excess counts within a region of radius $\theta = 0.089^\circ$ centered at the known position from HESS (α, δ) = (276.563°, −14.848°) (J2000) [16]. Each observation was a single ~ 20 –30 min exposure, and consecutive exposures were separated by 1–2 nights. This provided approximately daily coverage of the 3.9 day orbital period [16] for 8 days in 2013 and 12 days in 2014. Spectra separated into two orbital phase intervals, see Fig. 2, agree within the uncertainties of those measured with HESS [16]. The flux above 1 TeV is $(2.5 \pm 0.4_{\text{stat}} \pm 0.5_{\text{sys}}) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$ near inferior

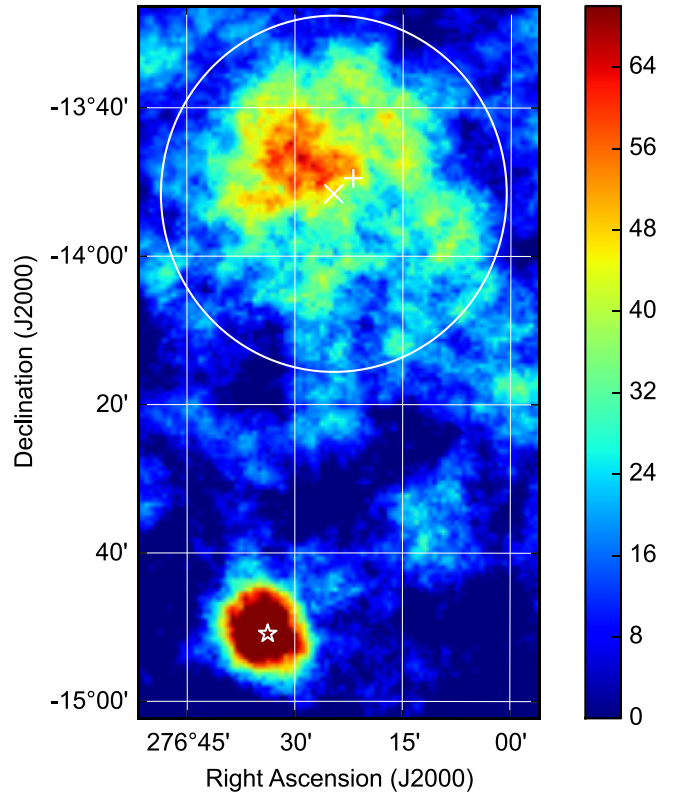


Fig. 1. Excess counts skymap of the region containing LS 5039 and HESS J1825-137. LS 5039 is marked with a star and HESS J1825-137 is enclosed within a 0.4° radius circle. A cross and x respectively mark the VERITAS and HESS [19] centroids of the PWN.

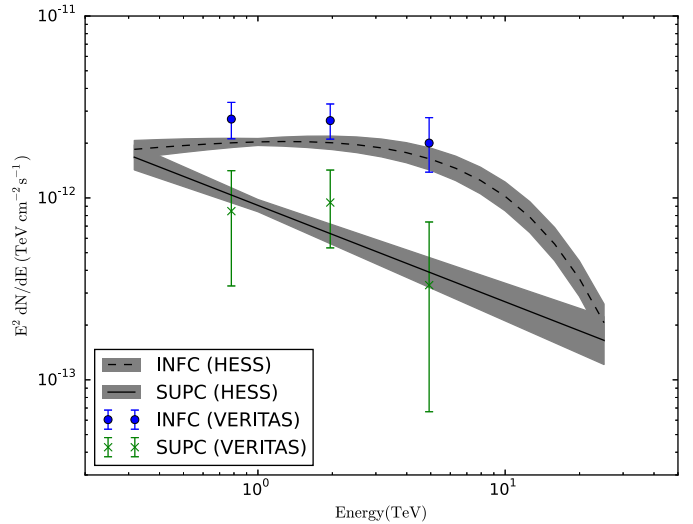


Fig. 2. Spectra of LS 5039 separated by orbital phase. The filled circles and dashed line are at inferior conjunction. The x's and solid lines are at superior conjunction. Points are from this analysis and the fit spectra with shaded errors are from [16].

conjunction (orbital phase $0.45 < \phi \leq 0.9$, 232 min exposure) and $(7.8 \pm 2.8_{\text{stat}} \pm 1.6_{\text{sys}}) \times 10^{-13} \text{ cm}^{-2} \text{ s}^{-1}$ near superior conjunction ($0.0 \leq \phi \leq 0.45$ and $0.9 < \phi \leq 1.0$, 230 min). This difference in flux demonstrates that the previously observed orbital flux variability [6] is detected by VERITAS as well. Fitting a power law to the spectrum for each orbital phase interval gives a photon index near inferior conjunction of $\Gamma = 2.1 \pm 0.2_{\text{stat}} \pm 0.2_{\text{sys}}$ with $\chi^2/\text{DoF} = 0.19/1$ and $\Gamma = 2.4 \pm 0.5_{\text{stat}} \pm 0.2_{\text{sys}}$ with $\chi^2/\text{DoF} = 0.57/1$ near superior conjunction. The VERITAS flux points match the best fitted spectral

¹ <http://veritas.sao.arizona.edu>

models from HESS with $\chi^2/\text{DoF} = 1.60/3$ and $\chi^2/\text{DoF} = 0.55/3$ for the phase intervals near inferior and superior conjunction, respectively, and support the PWN interpretation [14].

3.2. HESS J1825-137

The first indication of a PWN in this region was due to ROSAT observations of an extended ($\sim 5'$) X-ray nebula associated with the young (21 kyr) and energetic ($\dot{E} = 2.8 \times 10^{36} \text{ ergs s}^{-1}$) pulsar PSR B1823-13 [17]. HESS J1825-137 has a radius at least 5 times larger in VHE than X-ray, and the larger extent is consistent with the longer lifetime of TeV emitting electrons [7]. The spectrum in the 1–100 GeV range, as detected by the *Fermi*-Large Area Telescope [18], supports models of inverse-Compton emission being the dominant GeV–TeV emission within the nebula. The large angular size of HESS J1825-137 makes it ideal for resolved VHE study of PWN to better understand the particle transport within [19].

Using the same observations and analysis described for LS 5039, VERITAS detected HESS J1825-137, at the center of the PWN reported by HESS $(\alpha, \delta) = (276.421^\circ, -13.839^\circ)$ (J2000) [19] with a significance of 5.3σ ; the peak significance of 6.7σ within a 0.4° radius region. Fitting a spectrum extracted from this region to a power law model gave a normalization at 1 TeV of $A = (5.0 \pm 0.7_{\text{stat}} \pm 1.0_{\text{sys}}) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$, a photon index $\Gamma = 2.28 \pm 0.15_{\text{stat}} \pm 0.2_{\text{sys}}$, and $\chi^2/\text{DoF} = 2.27/1$. We found the PWN (named VER J1825-138) to be centered at $(\alpha, \delta) = (276.37^\circ \pm 0.02^\circ_{\text{stat}} \pm 0.01^\circ_{\text{sys}}, -13.83^\circ \pm 0.02^\circ_{\text{stat}} \pm 0.01^\circ_{\text{sys}})$ (J2000) using a weighted centroid. The region of interest, HESS centroid and VERITAS centroid are marked in Fig. 1. Summing in azimuth around the PWN, the radial profile is defined by a Gaussian with $\sigma = 0.27^\circ$ (1σ confidence interval of $0.22^\circ - 0.28^\circ$).

HESS reports a power-law fit from a 0.4° region of $A = (6.81 \pm 0.07_{\text{stat}} \pm 0.2_{\text{sys}}) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$ with a photon index $\Gamma = 2.28 \pm 0.01_{\text{stat}} \pm 0.02_{\text{sys}}$ [19]. The VERITAS flux normalization is consistent with that found by HESS. Similarly, the position of the PWN measured with VERITAS is within 0.04° of that detected by HESS. The radial extent of the nebula measured by VERITAS is consistent with the original HESS observations of $\sigma = 0.24^\circ \pm 0.02^\circ$ with a 52 h exposure [20], but the exceptionally deep observations from HESS [19] yields a different, larger, energy dependent extent.

4. Conclusion

VERITAS has confirmed the TeV gamma-ray detections of LS 5039 and HESS J1825-137 and analysis agrees with previous findings about the energetics and morphology.

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