

Revealing Ultra-High-Energy Gamma-Ray Emission from the eHWC J1825-134 Region with HAWC

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Located in the southern field of view of the High Altitude Water Cherenkov (HAWC) observatory, the eHWC J1825-134 region is one of the most complicated gamma-ray emission sites on the galactic plane. The region contains a few PeVatron candidates that can accelerate particles up to PeV energies. Disentangling the overlapping gamma-ray emission and associating it with accelerators is crucial to understand the mechanism of cosmic-ray acceleration and gamma-ray production near the accelerators. In this talk, I will present each of the gamma-ray sources resolved in this region using 1910 days of HAWC data, including their spectra. Also, we have studied their potential association with astrophysical accelerators, the binary system LS 5039, two pulsar wind nebulae, and a young star cluster.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan



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1. Introduction

The eHWC J1825-134 is recognized as the brightest region within the field of view of HAWC above 50 TeV, as reported in the HAWC high energy source catalog [2]. This region has been well studied in the γ -ray energy range, with observations from Fermi-LAT[9], VERITAS [3], and H.E.S.S. [6] [1]

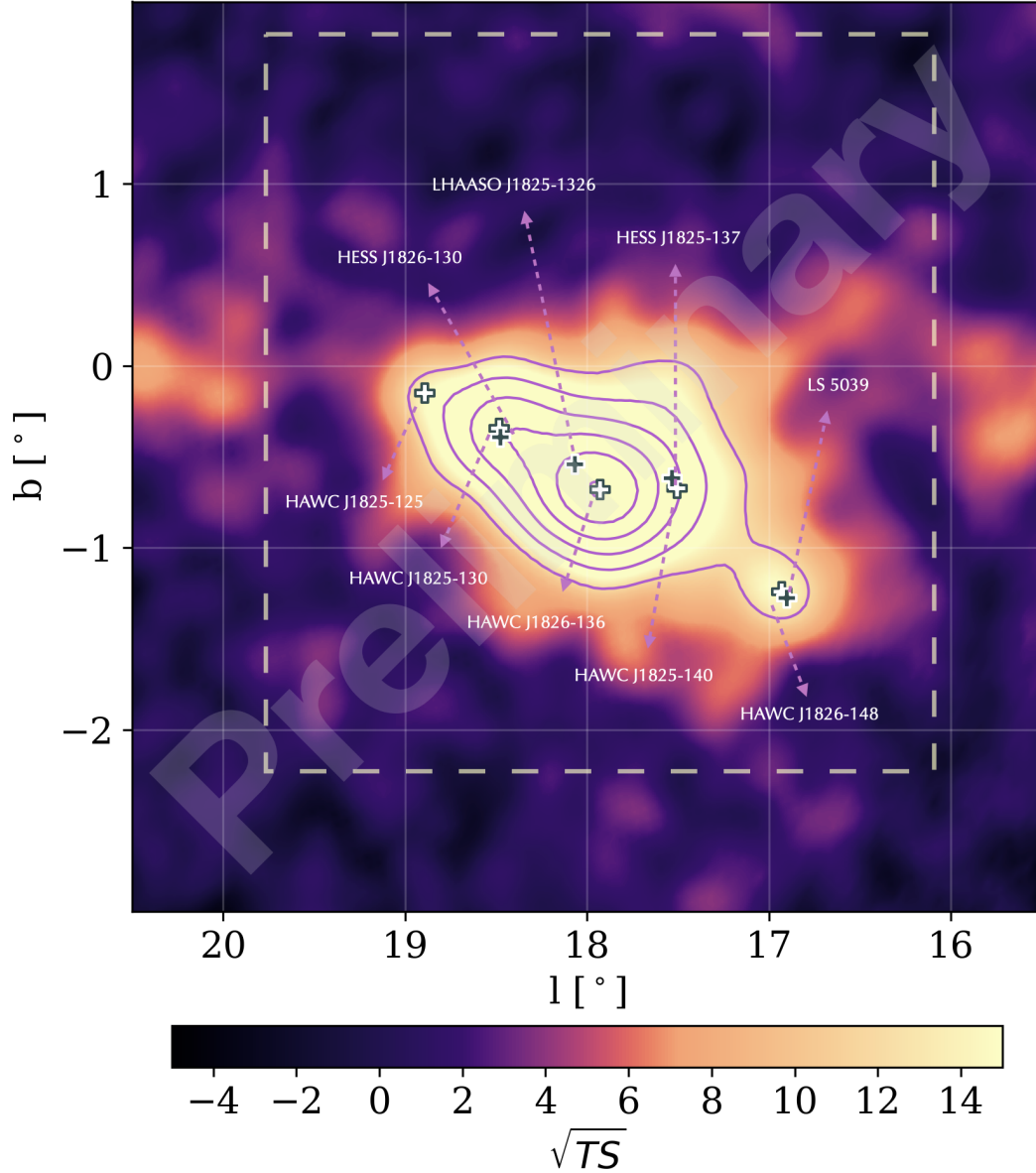


Figure 1: 1910 days HAWC significance map made by assuming a point-source hypothesis and a power-law spectrum with -2.6 index

Within the eHAWC J1825-134 region, there exists two pulsar-powered systems, a star-forming area, a binary system, and four supernova remnants, all of which have the potential to accelerate charged particles to PeV levels [7]. γ -ray emissions are subsequently produced when these accelerated particles interact with their surroundings.

Recently, a new round of reconstruction has been applied to the HAWC data. This marked the fifth iteration of data reconstruction, referred to as Pass 5. With the increased amount of data, improved angular resolution, and better γ /hadron separation [11], the detailed analysis in the region was performed using 3ML [10]. Figure 1 shows more detailed structures that appeared in the Pass5 map.

Inspired by the Fermi-Lat extended source search method in the Galactic plane [4], we have developed a systematic, unbiased analytical method for modeling the HAWC data. In contrast to the Fermi-Lat's method of incorporating seed source candidates on top of previous catalogs, our systematic approach begins by adding point sources into the model. This procedure continues until the Test Statistic (TS) of the newly added source falls below 25. In the next phase, both extension testing and curvature testing are applied to each point source from the previous step. This procedure results in an initial model that is not biased by previous knowledge. More details on modeling can then be applied on top of this initial model derived from the systematic approach. More detail of the analysis pipeline is described in [8]. Using this multi-source method, we have found three extended sources, and two point sources from the HAWC Pass5 data.

2. PeVatron Candidates

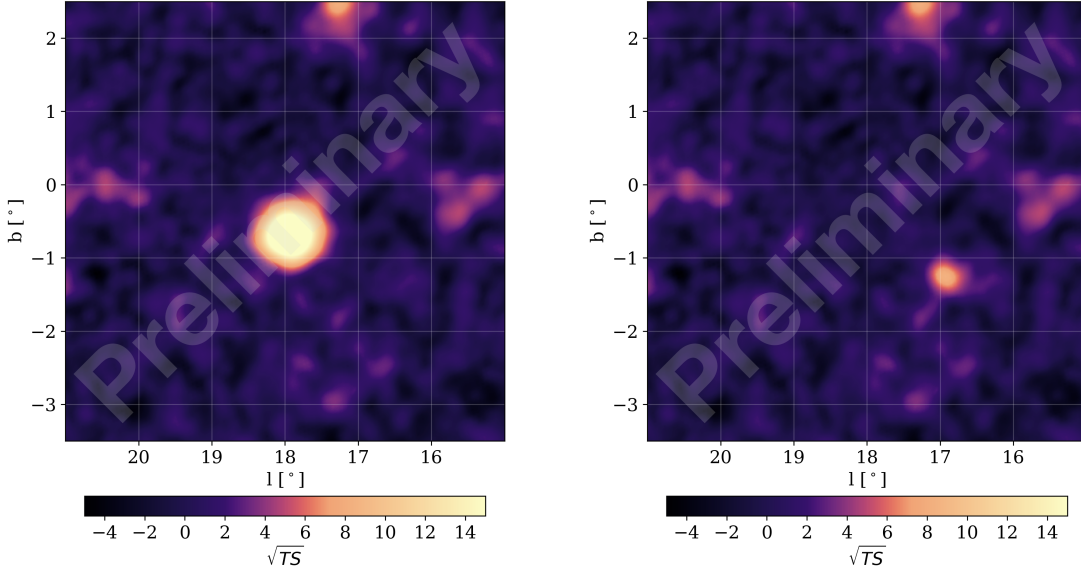


Figure 2: Left: HAWC J1826-136 only map, Right: HAWC J1826-148 only map

The HAWC measurements from two sources, HAWC J1825-136 and HAWC J1826-148, extend beyond 100 TeV. The detection of ultra-high-energy (>100 TeV) gamma rays from these sources

suggests that the accelerators involved may have the potential to boost the energies of parent particles over 1 PeV.

The best fit for HAWC J1825-136 assumes an extended source (2D Gaussian model) with a cutoff power-law spectrum. The most favorable fit location is situated 0.08° away from the pulsar PSR J1825-1334.. The highest emission is likely generated by newly accelerated electrons from the pulsar wind nebula, which is powered by PSR J1826-1334. Inverse Compton (IC) scattering the Cosmic Microwave Background (CMB) photons in close proximity to the pulsar. However, we cannot dismiss the possibility of a hadronic origin, in which protons accelerated from the nearby star-forming region [BDS2003]8 interact with the giant molecular cloud [MML2017]99.

HAWC J1826-148 is associated with a gamma-ray binary system LS 5039. To investigate the flux modulation, we have divided the HAWC data into two integral phases. We equated the inferior conjunction (INFC) phase ($0.45 < \phi < 0.9$) with the similar phase observed in the H.E.S.S. analysis [5], with the superior conjunction (SUPC) phase acting as its complement. We have observed that the flux in the INFC phase is nearly double that of the SUPC phase at the pivot energy (16.8 TeV).

3. Pulsar Wind Nebula and TeV Halo Candidate

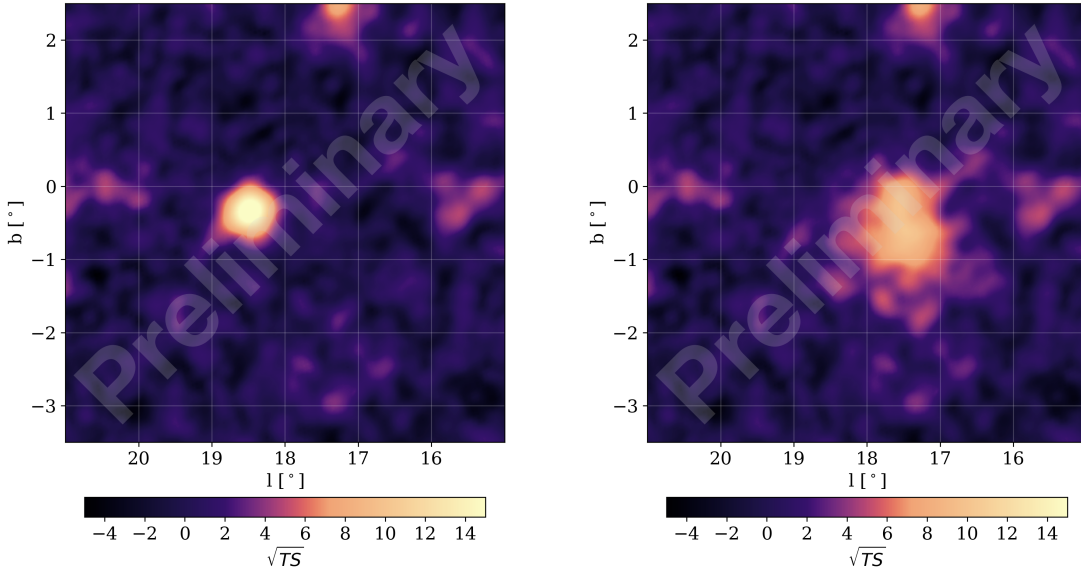


Figure 3: Left: HAWC J1825-130 only map, Right: HAWC J1825-140 only map

Surrounding the PeVatron candidate HAWC J1826-136, HAWC observes a more extended source, HAWC J1825-140. This source fits best with a 2D Gaussian model, exhibiting a width of 0.73° as its best-fit extension. Given its extensive span of more than 100 parsecs, this source might be undergoing a transition from a pulsar wind nebula (PWN) to a TeV Halo. This suggests that the electrons have started to escape and are freely diffusing into the interstellar medium.

The extended source HAWC J1825-130 with a best-fit extension of extended 0.13° , is associated with the PWN HESS J1826-130, powered by one of the most energetic pulsars, PSR J1826-1256. The hardness of the spectral index implies that the gamma-ray emission might extend beyond 100 TeV. However, more data are required to better understand the mechanisms of acceleration at these extreme energy levels.

4. Unidentified Source

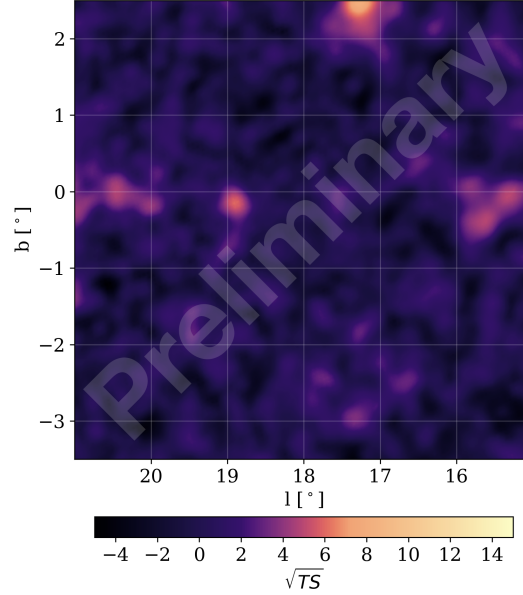


Figure 4: HAWC J1825-125 only map

Lastly, our multi-source analysis has uncovered an unidentified source, HAWC J1825-125. The exact origin of this source remains a mystery. It could potentially be associated with the nearby PWN HAWC J1826-125, emanate from galactic diffuse emission, or originate from other unidentified sources. To reach a more definitive conclusion, the accumulation of more data for future analysis is necessary.

5. Conclusion

By conducting a systematic multi-source analysis in the complex region of eHAWC J1825-134, we have discerned the gamma-ray emissions from various sources. These include the binary system LS 5039, PSR J1826-1254, associated pulsar wind nebulae, and the emission source HAWC J1825-134, which may be associated with either fresh accelerated electrons powered by PSR J1826-1334 up scattering the low energy photons or a young star cluster interacting with a nearby molecular cloud. Notably, the gamma-ray source HAWC J1825-134 stands out as a potential PeVatron candidate, each emitting at least about 200 TeV. Furthermore, we've identified a TeV halo candidate surrounding PSR J1826-1334.

6. Acknowledgements

We acknowledge the support from: the US National Science Foundation (NSF); the US Department of Energy Office of High-Energy Physics; the Laboratory Directed Research and Development (LDRD) program of Los Alamos National Laboratory; Consejo Nacional de Ciencia y Tecnología (CONACyT), México, grants 271051, 232656, 260378, 179588, 254964, 258865, 243290, 132197, A1-S-46288, A1-S-22784, CF-2023-I-645, cátedras 873, 1563, 341, 323, Red HAWC, México; DGAPA-UNAM grants IG101323, IN111716-3, IN111419, IA102019, IN106521, IN110621, IN110521, IN102223; VIEP-BUAP; PIFI 2012, 2013, PROFOCIE 2014, 2015; the University of Wisconsin Alumni Research Foundation; the Institute of Geophysics, Planetary Physics, and Signatures at Los Alamos National Laboratory; Polish Science Centre grant, DEC-2017/27/B/ST9/02272; Coordinación de la Investigación Científica de la Universidad Michoacana; Royal Society - Newton Advanced Fellowship 180385; Generalitat Valenciana, grant CIDEAGENT/2018/034; The Program Management Unit for Human Resources & Institutional Development, Research and Innovation, NXPO (grant number B16F630069); Coordinación General Académica e Innovación (CGAI-UdeG), PRODEP-SEP UDG-CA-499; Institute of Cosmic Ray Research (ICRR), University of Tokyo. H.F. acknowledges support by NASA under award number 80GSFC21M0002. We also acknowledge the significant contributions over many years of Stefan Westerhoff, Gaurang Yodh and Arnulfo Zepeda Dominguez, all deceased members of the HAWC collaboration. Thanks to Scott Delay, Luciano Díaz and Eduardo Murrieta for technical support.

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