PROCEEDINGS OF SCIENCE

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

Dezhi Huang,[a,b,*] **Hazal Goksu**[c] **and on behalf of the HAWC Collaboration on behalf of the HAWC Collaboration**

[a] *Michigan Technological University, Department of Physics 1400 Townsend Drive, Houghton, USA*

[b] *University of Maryland, Department of Physics, College Park, USA*

[c] *Max-Planck Institute for Nuclear Physics Saupfercheckweg, Heidelberg, Germany*

E-mail: dezhih@mtu.edu, hazal.goksu@mpi-hd.mpg.de

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.

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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]

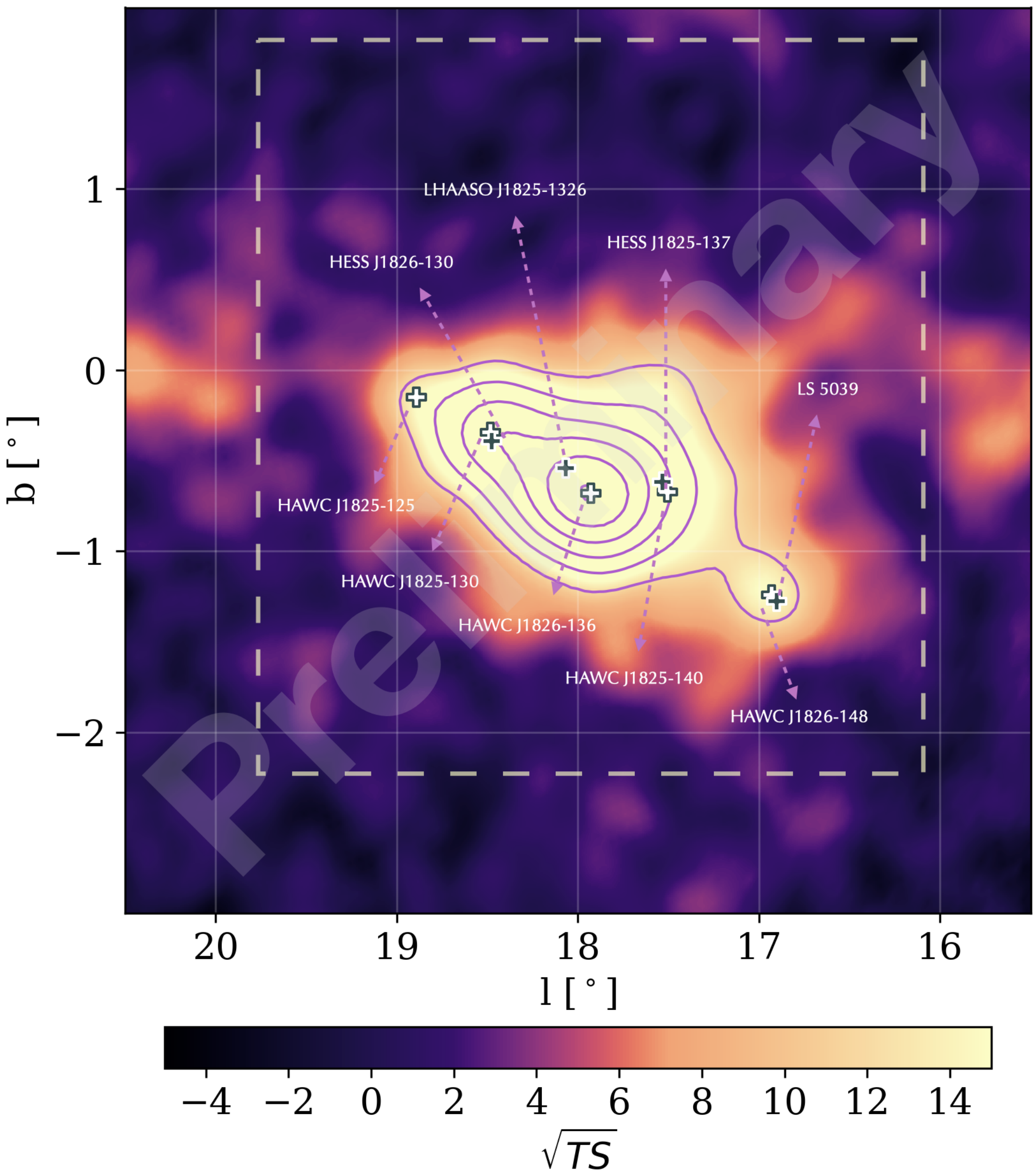

Figure 1: 1910 days HAWC significance map made by assuming a point-source hypothesis and a power-law spectrum with −2.6 index

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

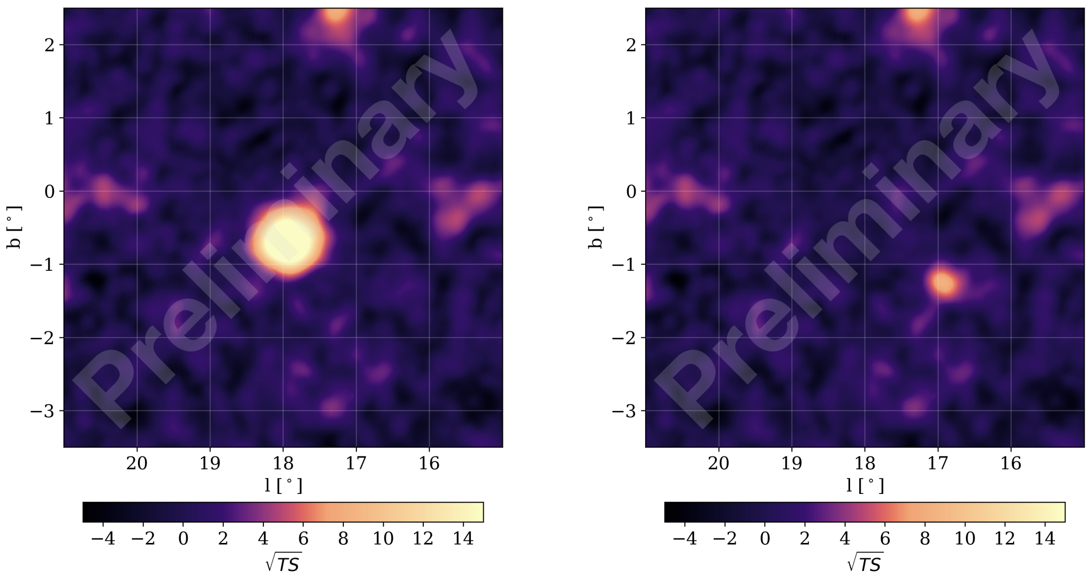

Figure 2: Left: HAWC J1826-136 only map, Right: HAWC J1826-148 only map

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

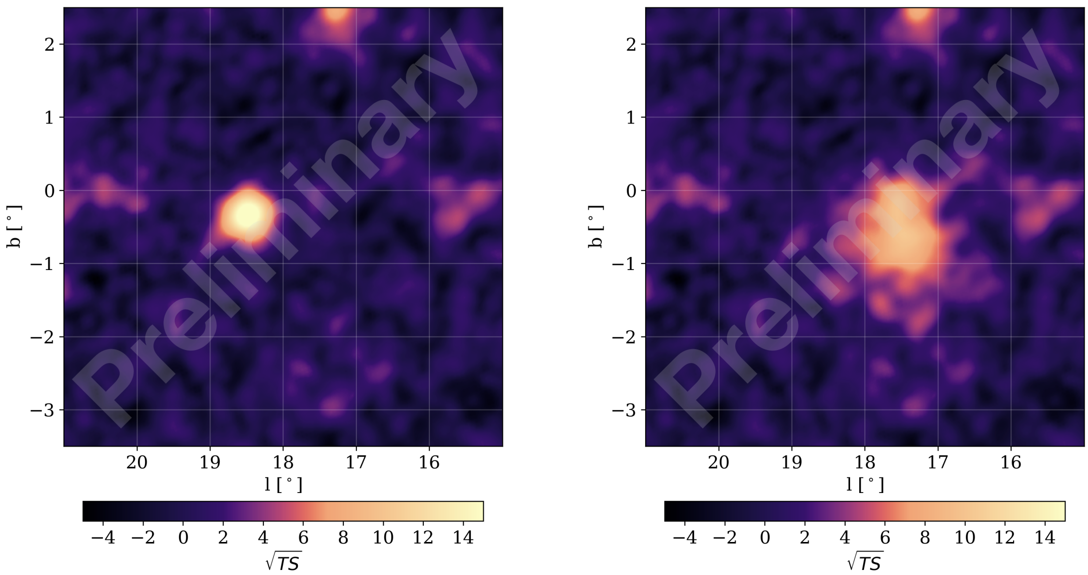

Figure 3: Left: HAWC J1825-130 only map, Right: HAWC J1825-140 only map

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

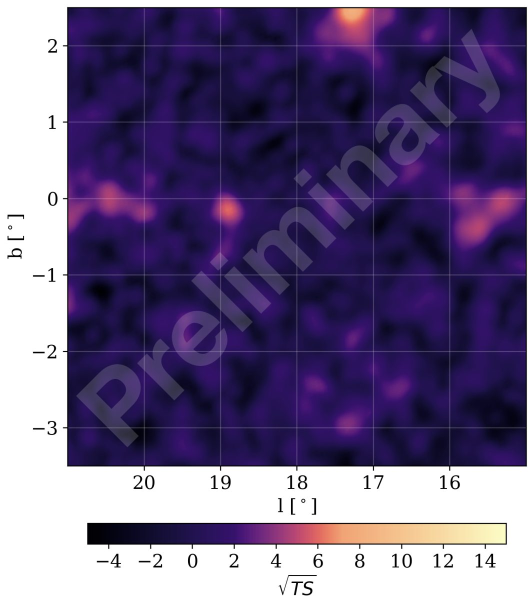

Figure 4: HAWC J1825-125 only map

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.

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Full Authors List: HAWC Collaboration

A. Albert[1], R. Alfaro[2], C. Alvarez[3], A. Andrés[4], J.C. Arteaga-Velázquez[5], D. Avila Rojas[2], H.A. Ayala Solares[6], R. Babu[7], E. Belmont-Moreno[2], T. Capistrán[4], Y. Cárcamo[26], A. Carramiñana[9], F. Carreón[4], U. Cotti[5], J. Cotzomi[26], S. Coutiño de León[10], E. De la Fuente[11], D. Depaoli[12], C. de León[5], R. Diaz Hernandez[9], J.C. Díaz-Vélez[11], B.L. Dingus[1], M. Durocher[1], M.A. DuVernois[10], K. Engel[8], C. Espinoza[2], K.L. Fan[8], K. Fang[10], N.I. Fraija[4], J.A. García-González[13], F. Garfias[4], H. Goksu[12], M.M. González[4], J.A. Goodman[8], S. Groetsch[7], J.P. Harding[1], S. Hernandez[2], I. Herzog[14], J. Hinton[12], D. Huang[7], F. Hueyotl-Zahuantitla[3], P. Hüntemeyer[7], A. Iriarte[4], V. Joshi[28], S. Kaufmann[15], D. Kieda[16], A. Lara[17], J. Lee[18], W.H. Lee[4], H. León Vargas[2], J. Linnemann[14], A.L. Longinotti[4], G. Luis-Raya[15], K. Malone[19], J. Martínez-Castro[20], J.A.J. Matthews[21], P. Miranda-Romagnoli[22], J. Montes[4], J.A. Morales-Soto[5], M. Mostafá[6], L. Nellen[23], M.U. Nisa[14], R. Noriega-Papaqui[22], L. Olivera-Nieto[12], N. Omodei[24], Y. Pérez Araujo[4], E.G. Pérez-Pérez[15], A. Pratts[2], C.D. Rho[25], D. Rosa-Gonzalez[9], E. Ruiz-Velasco[12], H. Salazar[26], D. Salazar-Gallegos[14], A. Sandoval[2], M. Schneider[8], G. Schwefer[12], J. Serna-Franco[2], A.J. Smith[8], Y. Son[18], R.W. Springer[16], O. Tibolla[15], K. Tollefson[14], I. Torres[9], R. Torres-Escobedo[27], R. Turner[7], F. Ureña-Mena[9], E. Varela[26], L. Villaseñor[26], X. Wang[7], I.J. Watson[18], F. Werner[12], K. Whitaker[6], E. Willox[8], H. Wu[10], H. Zhou[27]

[1]Physics Division, Los Alamos National Laboratory, Los Alamos, NM, USA, [2]Instituto de Física, Universidad Nacional Autónoma de México, Ciudad de México, México, [3]FCFM-MCTP, Universidad Autónoma de Chiapas, Tuxtla Gutiérrez, Chiapas, México, [4]Instituto de Astronomía, Universidad Nacional Autónoma de México, Ciudad de México, México, [5]Instituto de Física y Matemáticas, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán, México, [6]Department of Physics, Pennsylvania State University, University Park, PA, USA, [7]Department of Physics, Michigan Technological University, Houghton, MI, USA, [8]Department of Physics, University of Maryland, College Park, MD, USA, [9]Instituto Nacional de Astrofísica, Óptica y Electrónica, Tonantzintla, Puebla, México, [10]Department of Physics, University of Wisconsin-Madison, Madison, WI, USA, [11]CUCEI, CUCEA, Universidad de Guadalajara, Guadalajara, Jalisco, México, [12]Max-Planck Institute for Nuclear Physics, Heidelberg, Germany, [13]Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Ave. Eugenio Garza Sada 2501, Monterrey, N.L., 64849, México, [14]Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA, [15]Universidad Politécnica de Pachuca, Pachuca, Hgo, México, [16]Department of Physics and Astronomy, University of Utah, Salt Lake City, UT, USA, [17]Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad de México, México, [18]University of Seoul, Seoul, Rep. of Korea, [19]Space Science and Applications Group, Los Alamos National Laboratory, Los Alamos, NM USA [20]Centro de Investigación en Computación, Instituto Politécnico Nacional, Ciudad de México, México, [21]Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, USA, [22]Universidad Autónoma del Estado de Hidalgo, Pachuca, Hgo., México, [23]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Ciudad de México, México, [24]Stanford University, Stanford, CA, USA, [25]Department of Physics, Sungkyunkwan University, Suwon, South Korea, [26]Facultad de Ciencias Físico Matemáticas, Benemérita Universidad Autónoma de Puebla, Puebla, México, [27]Tsung-Dao Lee Institute and School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai, China, [28]Erlangen Centre for Astroparticle Physics, Friedrich Alexander Universität, Erlangen, BY, Germany