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HAWC observations of microquasars as powerful particle accelerators

Xiaojie Wang,[a,*] **Dezhi Huang**[a,*] **and Chang Dong Rho**[b,*] **for the HAWC collaboration**

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

[b] *Sungkyunkwan University, Department of Physics, Suwon 16419, South Korea*

E-mail: xwang32@mtu.edu, dezhih@mtu.edu, no397@naver.com

Microquasars are one of the classes of powerful Galactic particle accelerators that emit gamma rays beyond multi-TeV energies. Recently, gamma-ray emission above tens of TeV has been detected from some of these objects. The High Altitude Water Cherenkov (HAWC) observatory has previously reported gamma-ray emission with a median energy of 25 TeV from the microquasar SS 433, suggesting that gamma-ray binaries can accelerate particles to above 100 TeV inside the jets. With 2,321 days of data and better reconstruction algorithms, the HAWC observatory detected emissions above 20 TeV from two other binaries, V4641 Sagittarii and LS 5039. The V4641 Sgr is detected with a significance great than 9 sigma. It's a low-mass X-ray binary(LMXB) that has been observed with a small-scale jet-like structure in the radio wavelength. In this talk, I will present the preliminary results from V4641 Sgr and discuss possible scenarios for gamma-ray production. We will also present future plans to search for additional X-ray binaries with HAWC.

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1. Introduction

X-ray binaries, including microquasars, have long been regarded as promising candidates for very high-energy (VHE) gamma-ray emission, since the 1990s. The intricate emission mechanisms within these systems give rise to a diverse range of behaviors. In recent years, the detection of microquasars and other X-ray binaries emitting multi-TeV gamma rays has witnessed a notable surge, amplifying their significance as compelling candidates for cosmic-ray acceleration. This growing body of observations presents an increasingly exciting and powerful avenue for unraveling the mysteries surrounding cosmic-ray acceleration in these astrophysical environments and studying the origins of VHE gamma-ray radiation in the vicinity region.

Microquasars, are compact binary systems consisting of a stellar-mass black hole or a neutron star and a companion star. These fascinating objects exhibit properties akin to active galactic nuclei (AGN) but on a much smaller scale. Their characteristic feature is the presence of relativistic jets, similar to those observed in AGN, which emit radiation across the entire electromagnetic spectrum. Compared with AGNs, microquasars present a unique opportunity for studying the dynamics of jets on significantly shorter spatial and temporal scales. Their relatively compact size allows for detailed monitoring of jet behavior and changes over shorter timescales.

Furthermore, microquasars typically have Eddington luminosities that are 2 to 4 orders of magnitude larger than those observed in AGNs [2]. This enables the observations of jets with substantial Doppler boosting. By examining the Doppler factor of the approaching and receding jet components, it becomes possible to detect and analyze both components, providing valuable insights into the underlying physics of the jets.

2. Unveiling Microquasars: Insights from HAWC

The High-Altitude Water Cherenkov (HAWC) Observatory is a ground-based water Cherenkov detector array located in Puebla, Mexico. It consists of 300 water tanks for the main array. Each tank is equipped with four photomultiplier tubes (PMTs) facing up-towards that detect Cherenkov light produced by secondary particles in extensive air showers (EAS). With an area of about 22,000 m^2, HAWC is optimized to detect gamma rays in the energy range between 300 GeV and above 100 TeV. With better reconstruction and more data, HAWC has detected three microquasars (SS433 [1], LS 5039 [4], and V4641 Sgr)that are above tens of TeV in its Field of View (FOV), making the microquasars an interesting category as a particle accelerator.

2.1 SS 433

SS433 is the first microquasar that HAWC has observed, its close proximity to the bright extended source MGRO J1908+06. In the previous study, the TeV emission from the east and west lobes showed that powerful jets can accelerate particles beyond 100 TeV. With about double the amount of data accumulated, and improved reconstruction algorithms, the significance of the observations has increased to 7.6 for the east lobe and 9.2 for the west lobe. Furthermore, a forthcoming spectral analysis of the west lobe is undergoing, promising further insights into the intriguing phenomena observed. Figure 1 shows the significance map with the latest HAWC data.

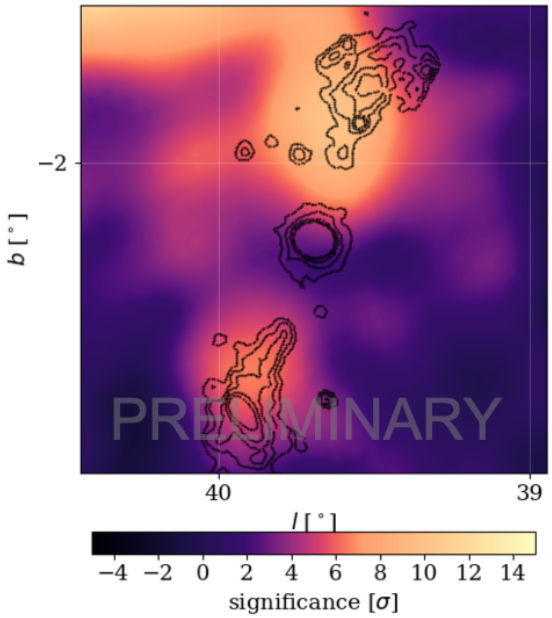

Figure 1: Significance plot of the SS433 region. Black contours are X-ray observations.

2.2 LS 5039

The analysis of the eHWC J1825-134 region with the latest HAWC data has disentangled the emission originating from the binary system LS 5039. LS 5039 is composed of a compact object, potentially a black hole or pulsar, and a binary companion, consisting of 23 $M_\odot$ type O stars[3]. The star and compact object orbit each other for a period of 3.9 days, resulting in intricate dynamics within the system [3]. Notably, observations from HAWC have revealed flux modulations, with the flux reaching twice during the inferior conjunction phase than the superior conjunction of the binary orbit. These findings provide valuable insights into the behavior of LS 5039 and a detailed analysis is ongoing. Figure 2 shows a similar significance map as SS433.

2.3 V4641 Sgr

A newly detected off-plane source was identified in the southern region of the field of view from the recent HAWC data. This source, whose location coincides with V4641 Sgr, exhibits a pre-trial significance of 9.7 σ above the background. Particularly at energies surpassing 25 TeV, the newly detected source demonstrates a notable significance level of 7 σ. The forthcoming spectral analysis will shed light on the nature of this binary system in the near future.

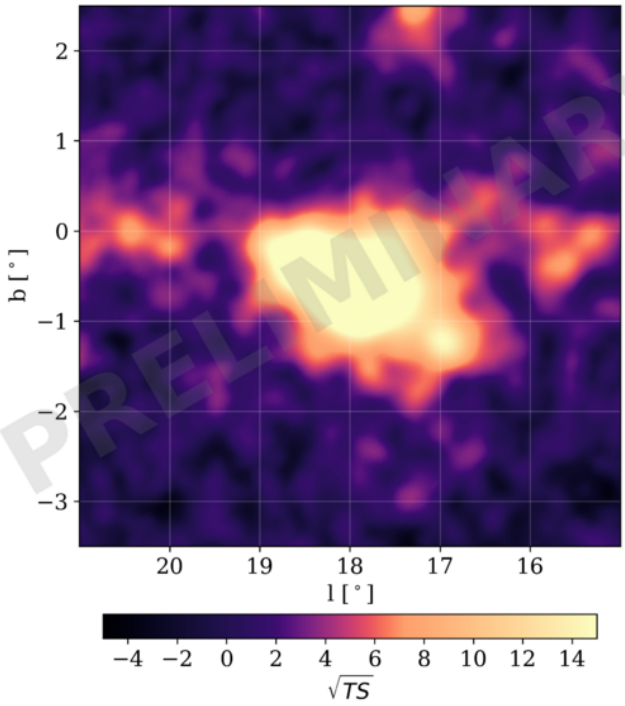

Figure 2: Significance plot of the J1825 region.

3. Conclusions and Outlook

Microquasars have emerged as an important category of sources in the observations conducted by HAWC. It has detected three microquasars exhibiting emissions above 10 TeV, thus establishing microquasars as a newly recognized class of very-high-energy gamma sources within the HAWC field of view. The observations made by HAWC reveal that microquasars serve as exceptionally potent particle accelerators, capable of propelling charged particles to energies greater than 100 TeV. This raises the intriguing question of whether microquasars could potentially represent a new class of PeVatrons. Future observations, particularly multi-wavelength and multi-messenger analysis, will hold great promise for shedding further light on this.

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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

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