Discovery of TeV Gamma-Ray Emission from the Jet Interaction Regions of Microquasar SS 433 with HAWC

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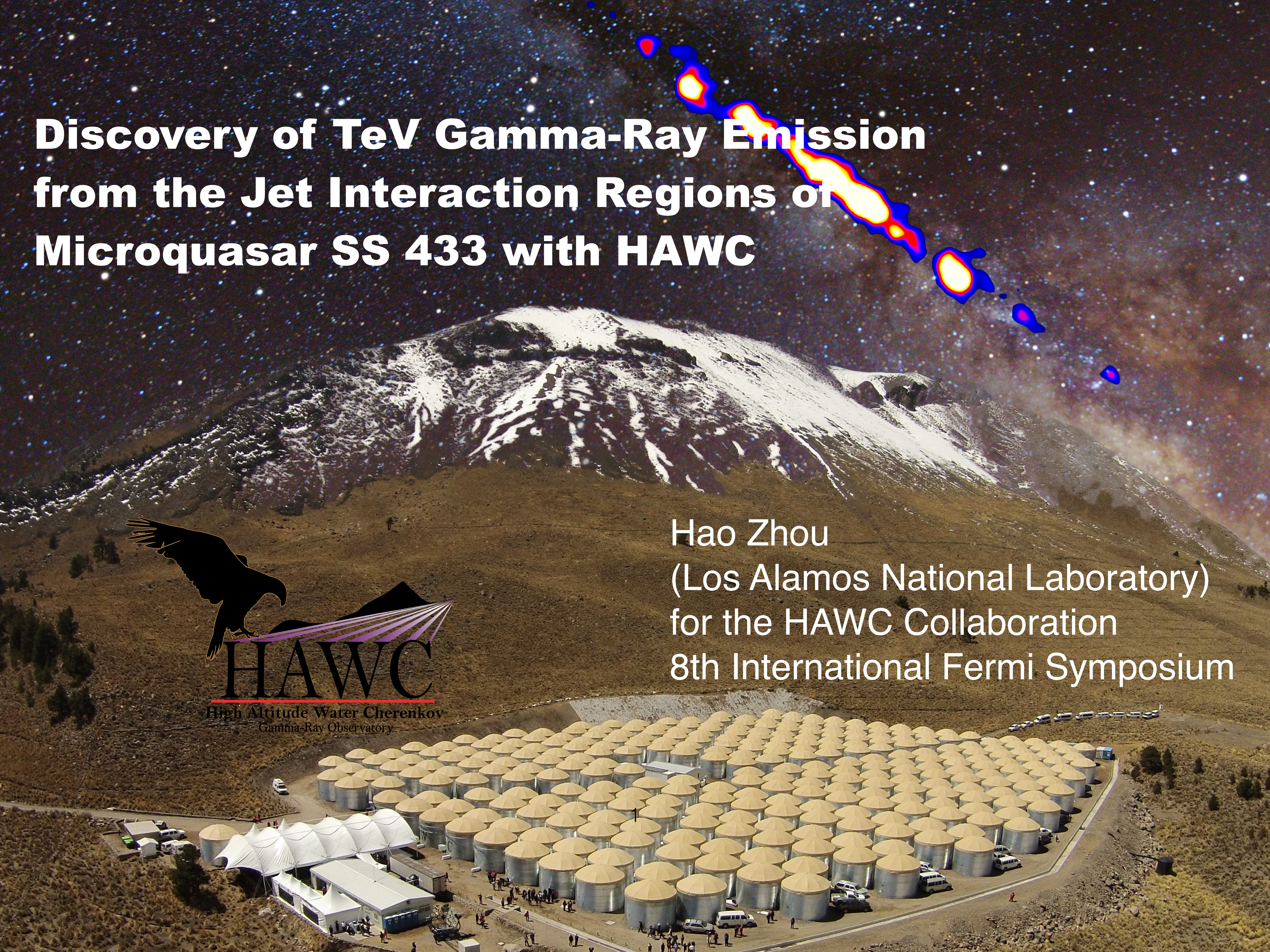
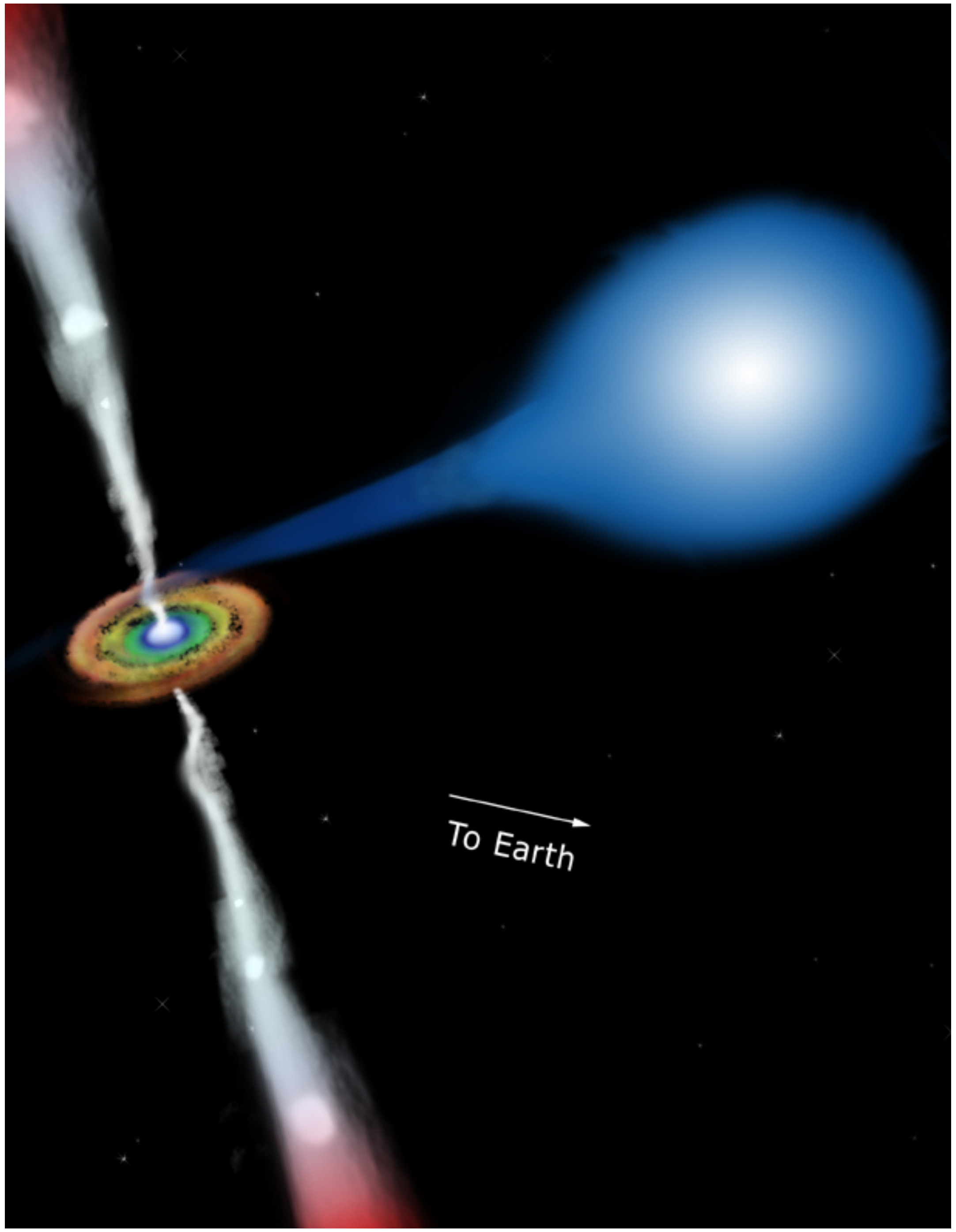
8th International Fermi Symposium



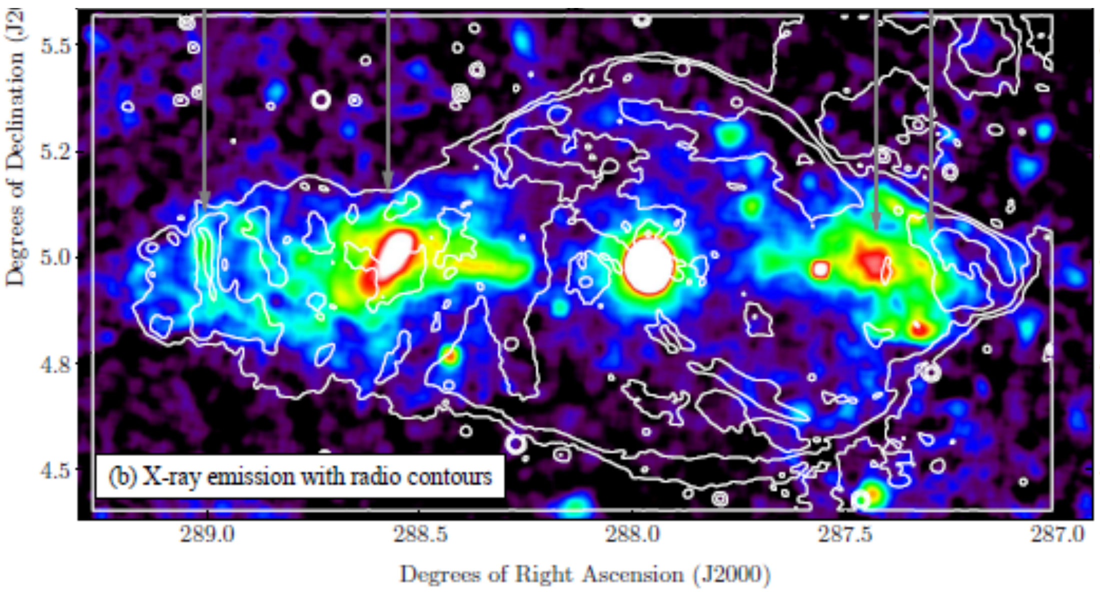
Microquasars



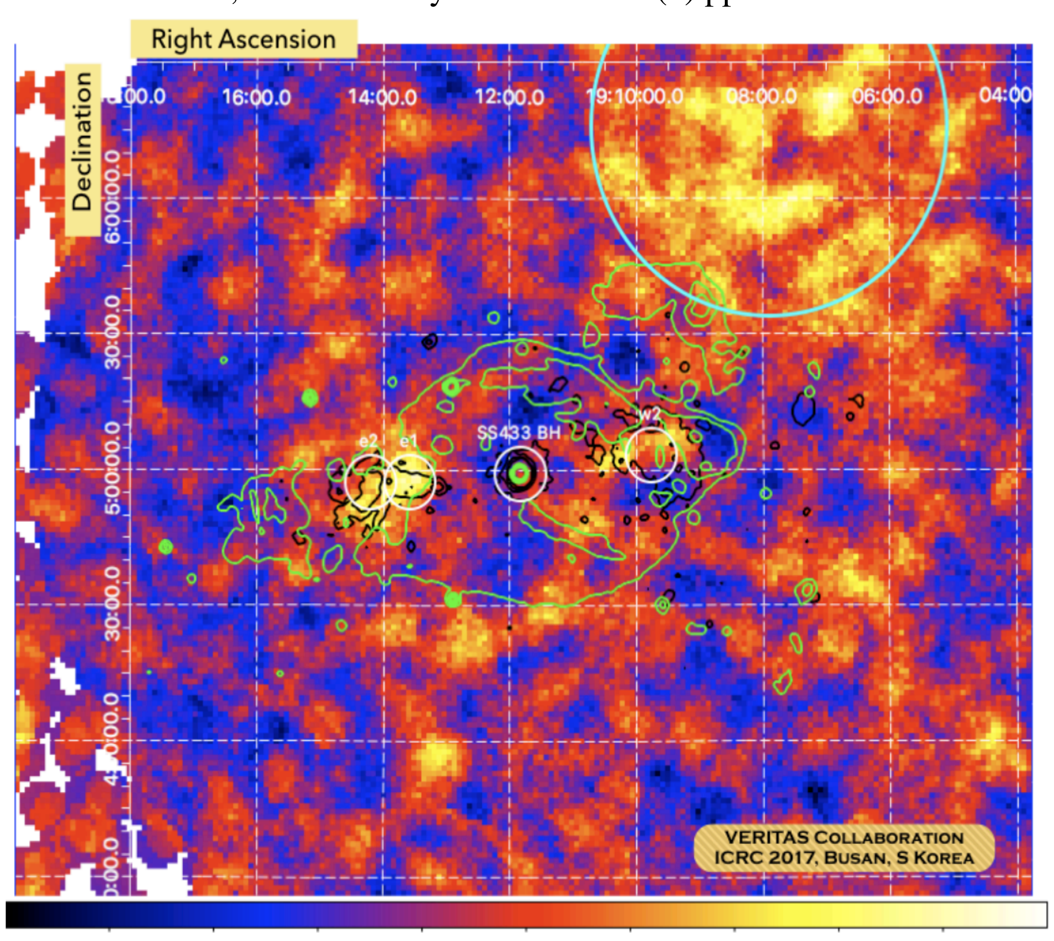
Credit: NASA/CXC/M.Weiss

- Binary system with a compact object (black hole or neutron star) and companion star.
- The companion star is overflowing its matter accreting onto the compact object, producing two jets.
- Microquasars are scale models in our Galaxy of the much larger and more powerful jets in AGNs, which are believed to be the sources of highest-energy cosmic rays.

The SS 433/W50 Complex



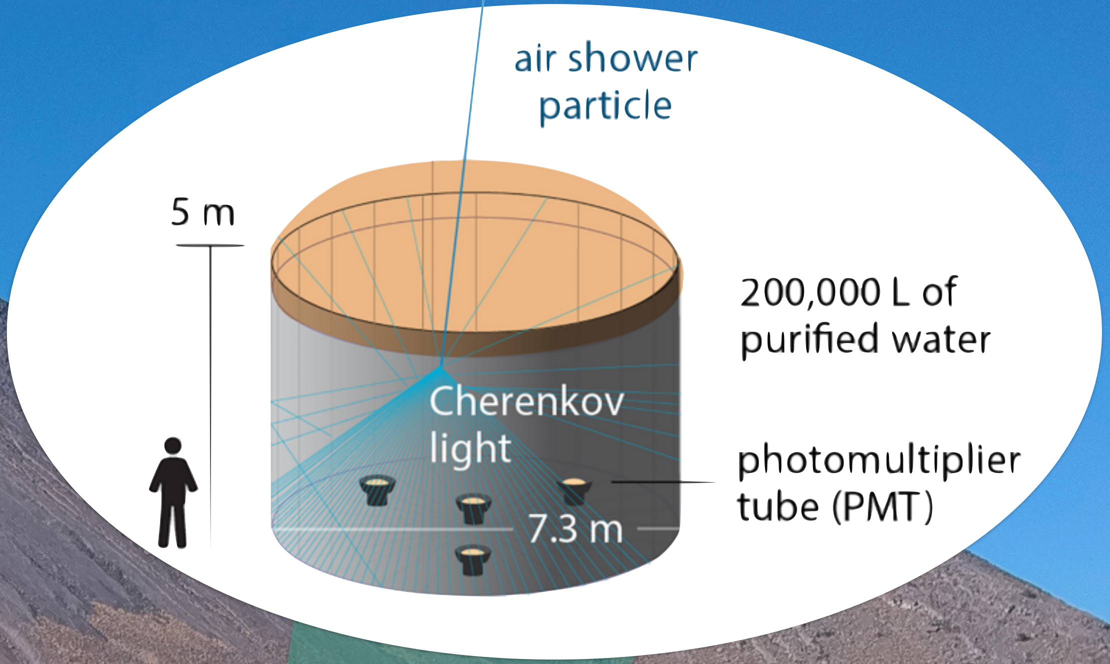
Credit: Goodall, P.T.; Alouani-Bibi, F.; Blundell, K.M., Mon.Not. Roy. Ast. Soc. 414 (4) pp. 2838-2859.



- One of the most powerful microquasars.
- Two jets with a bulk velocity of 0.26c extend from the binary, perpendicular to the line of sight.
- Known Galactic microquasar observed in radio/X-rays; jets terminate in nebula W50, producing X-ray lobes (east and west). Strong TeV candidate, no discovery claimed before now.

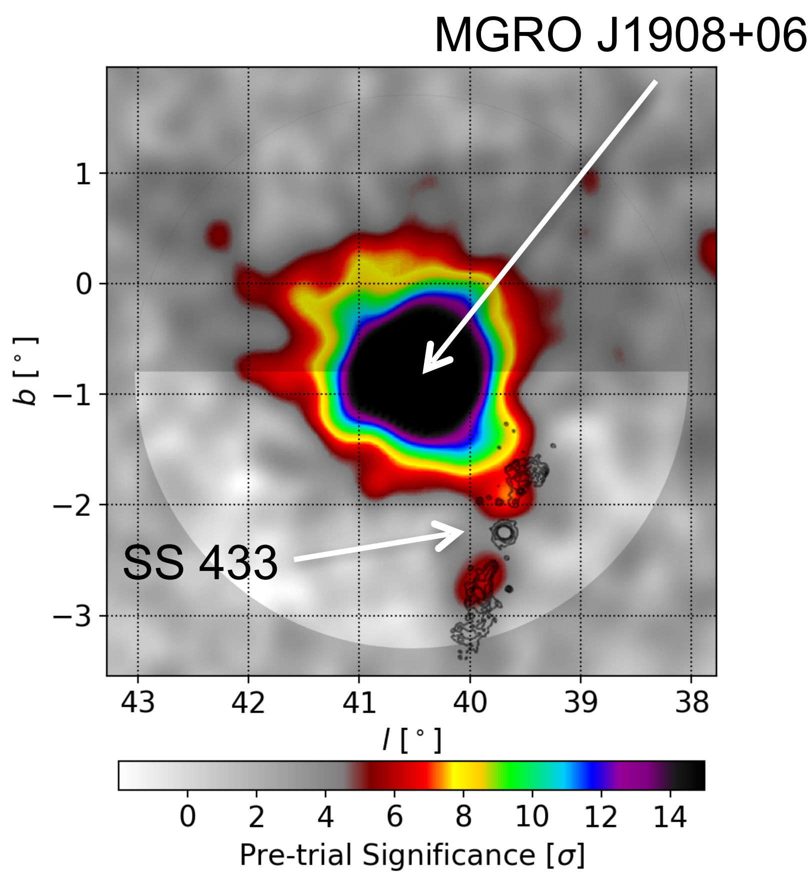
The HAWC Observatory

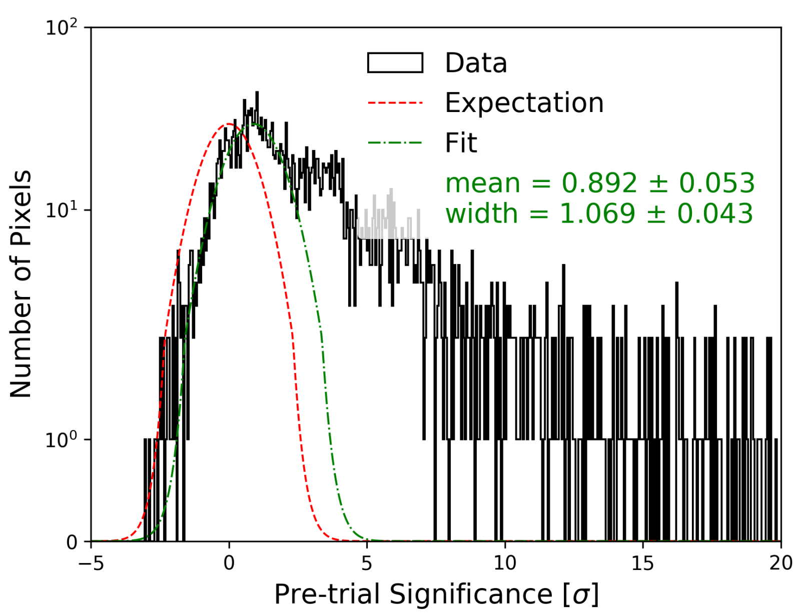
- 300 Water Cherenkov Detectors
- 22,000 m^2 detector area
- Sub TeV - >100 TeV Sensitivity
- Wide field of view: ~2 sr
- High duty cycle: >95%



Main array inaugurated on March 20, 2015

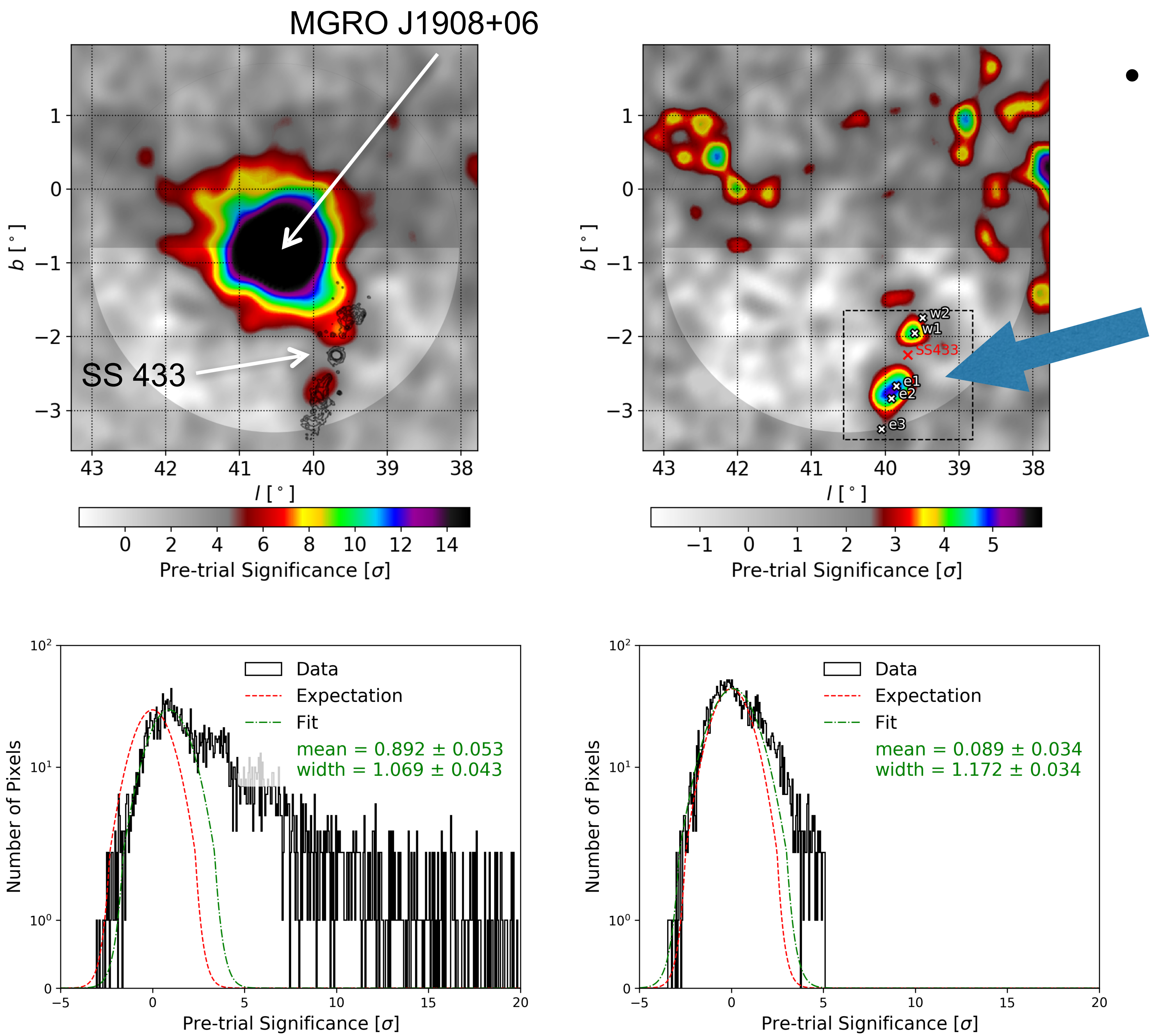
SS 433 in HAWC Data





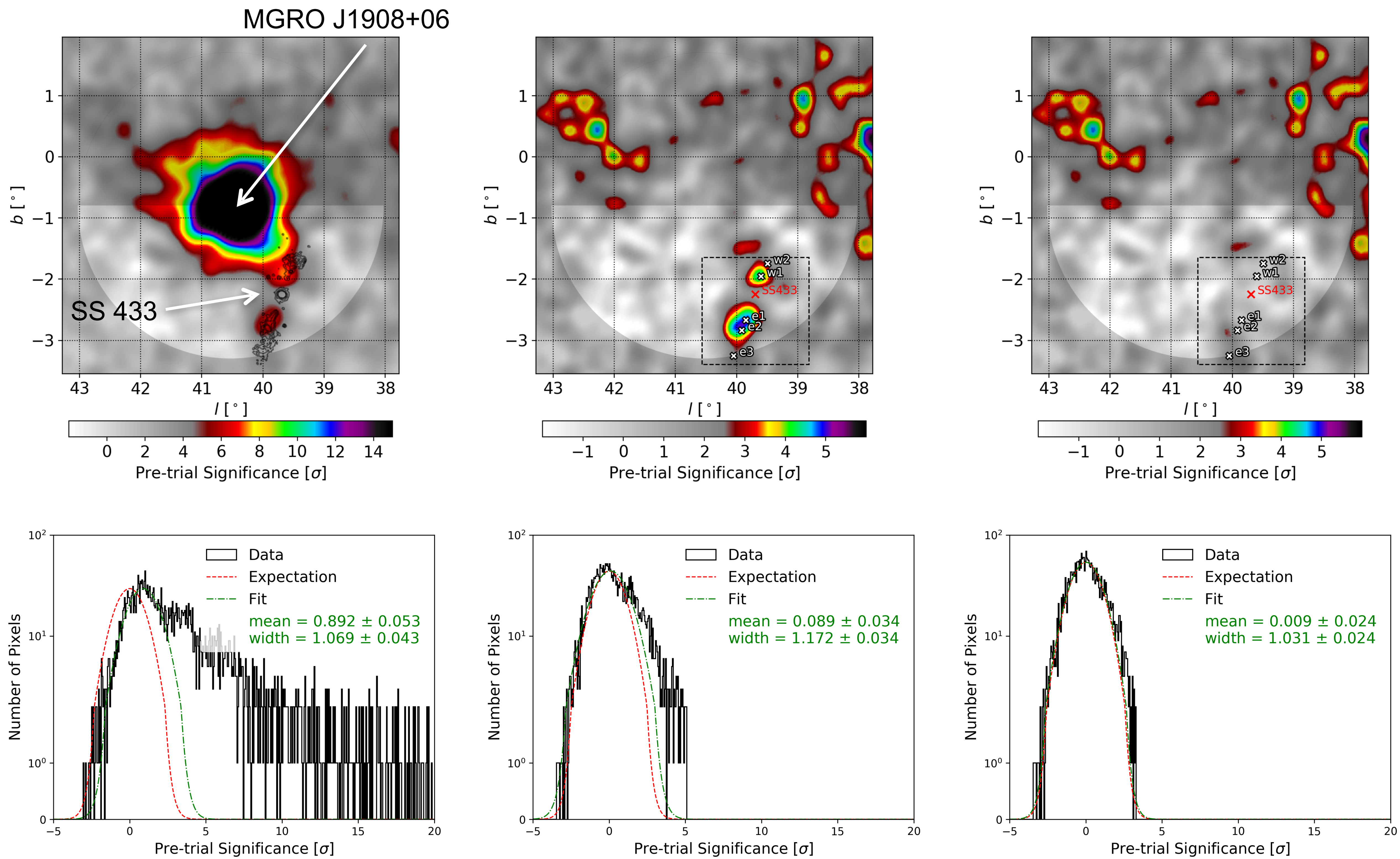
- SS433 is about 2° from the Galactic plane and <2° from a very bright extended source MGRO J1908+06.
- Simultaneous likelihood fit with J1908, east lobe, west lobe in the model.
- Semi-circular RoI to reduce contamination from Galactic Diffuse Emission.

SS 433 in HAWC Data

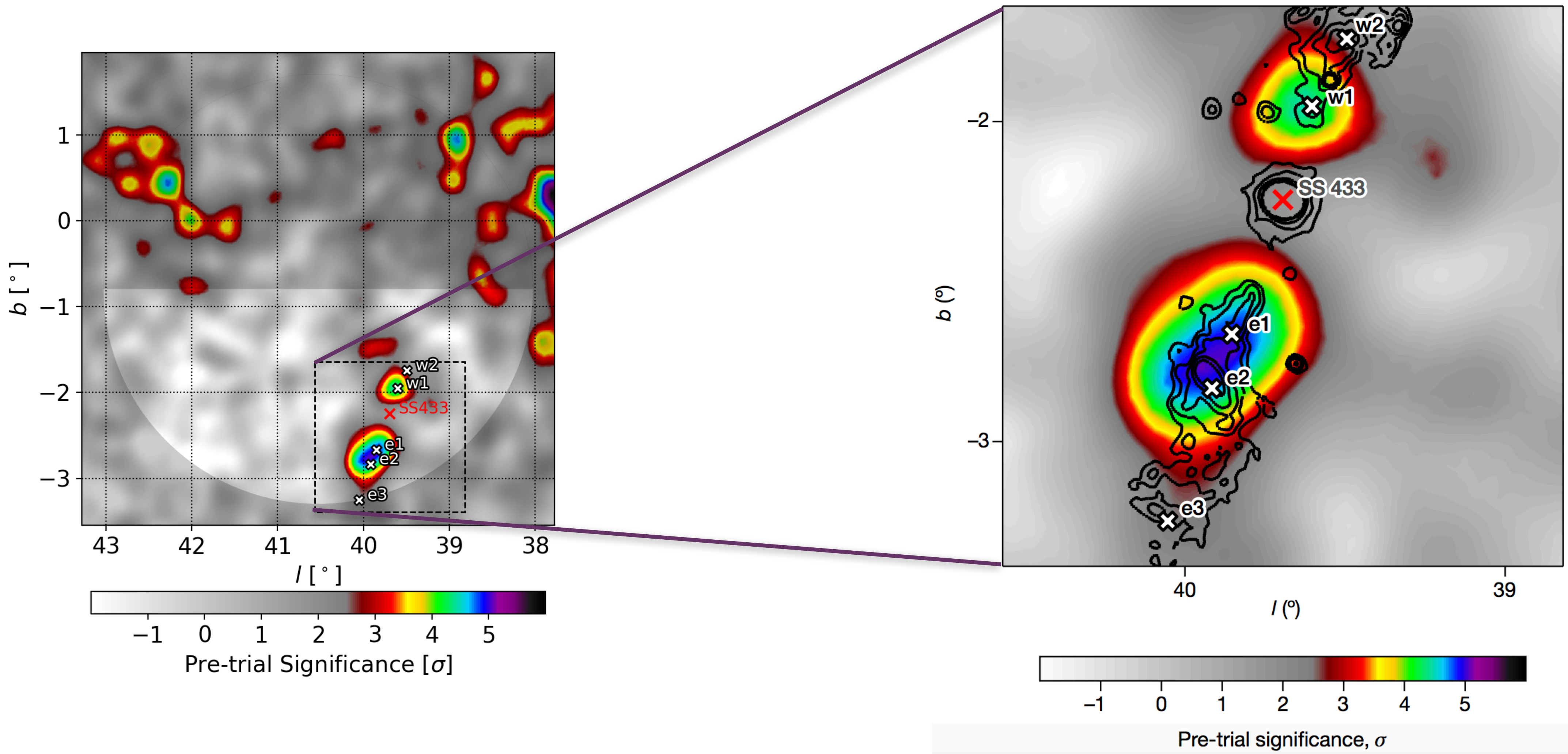


- After subtracting J1908, HAWC sees two hot spots to the either side of the known location of SS 433, spatially in coincidence with the X-ray contours.
  - Grey contours: X-ray emission from SS 433 east lobe, west lobe and the central binary

SS 433 in HAWC Data

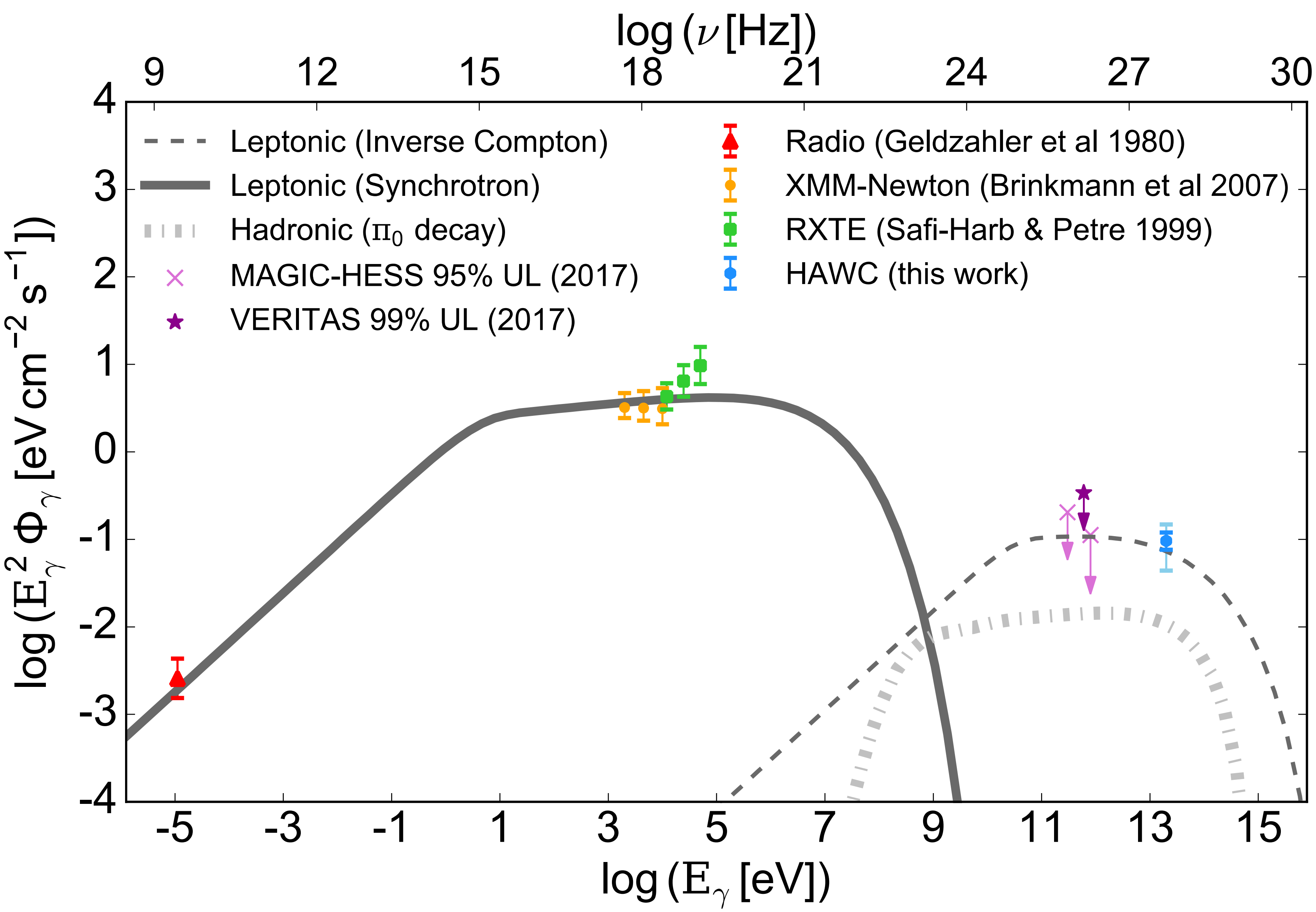


SS 433 in HAWC Data



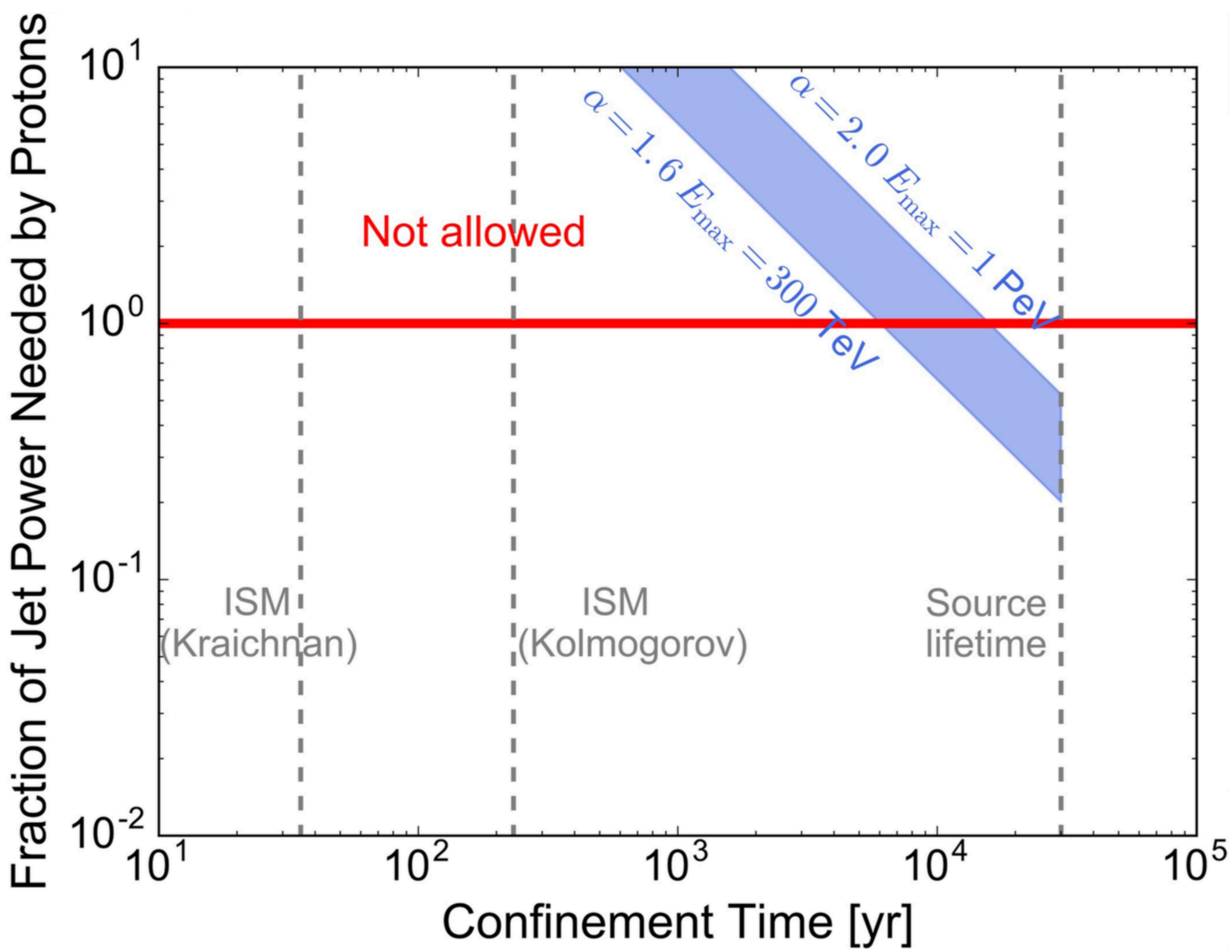
- The two lobes of SS433 are detected at a significance of 5.4σ
  - spatially coincident with the jet termination regions, where x-ray lobes are detected
- Systematics uncertainty are studied including
  - different modeling of J1908 morphology
  - contamination from Galactic diffuse emission

Multi-wavelength Spectrum



- Leptonic: radio + X-ray photons are produced via synchrotron emission in a magnetic field and TeV γ rays observed by HAWC are produced via IC scattering of the same e-.

Power Budget – Hadronic Scenario



- The blue region shows the energy injection rate of protons in order to produce the observed HAWC results.
- Anything above the red line is not allowed since that would require jet power >100%.
- The dashed grey lines are for source lifetime and confinement time of 200TeV protons in a 30pc region in the ISM.

❖ But, even with an extremely small diffusion coefficient and a very hard spectral index, the hadronic-only scenario requires > 30% of jet power going into protons.

What we learned from SS 433?

- This is the first time astrophysical jets have been spatially resolved at such high energies.
  - Acceleration is occurring in the jet termination regions, not in the central binary.
  - Leptonic model does a good job of explaining the gamma ray emission, requires ~0.5% of jet power going into electron acceleration.
  - HAWC observation disfavors hadronic-only scenario.
- But there are still many questions.
  - Acceleration mechanism to produce ~1 PeV electrons.

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

Summary and Outlook

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- HAWC has observed SS 433 jet lobes at its known jet interaction regions, with >5σ post-trial significance (combined).

- The gamma-ray emission is likely produced by leptonic process. But there are still properties that we do not fully understand (e.g. acceleration mechanism).

- Microquasars are believed to be scale models of the much larger and more powerful extragalactic jets observed in AGNs.

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Very-high-energy particle acceleration powered by the jets of the microquasar SS 433

A. U. Abeysekara, A. Albert, R. Alfaro, C. Alvarez, J. D. Álvarez, R. Arceo, J. C. Arteaga-Velázquez, D. Avila Rojas, H. A. Ayala Solares, E. Belmont-Moreno, S. Y. BenZvi, C. Brisbois, K. S. Caballero-Mora, T. Capistrán, A. Carramiñana, S. Casanova, M. Castillo, U. Cotti, J. Cotzomi, S. Coutiño de León, C. De León, E. De la Fuente, J. C. Díaz-Vélez, S. Dichiara, B. L. Dingus, M. A. DuVernois, R. W. Ellsworth, K. Engel, C. Espinoza, K. Fang, H. Fleischhack, N. Fraija, A. Galván-Gámez, J. A. García-González, F. Garfias, A. González-Muñoz, M. M. González, J. A. Goodman, Z. Hampel-Arias, J. P. Harding, S. Hernandez, J. Hinton, B. Hona, F. Hueyotl-Zahuantitla, C. M. Hui, P. Hüntemeyer, A. Iriarte, A. Jardin-Blicq, V. Joshi, S. Kaufmann, P. Kar, G. J. Kunde, R. J. Lauer, W. H. Lee, H. León Vargas, H. Li, J. T. Linnemann, A. L. Longinotti, G. Luis-Raya, R. López-Coto, K. Malone, S. S. Marinelli, O. Martinez, I. Martinez-Castellanos, J. Martínez-Castro, J. A. Matthews, P. Miranda-Romagnoli, E. Moreno, M. Mostafá, A. Nayerhoda, L. Nellen, M. Newbold, M. U. Nisa, R. Noriega-Papaqui, J. Pretz, E. G. Pérez-Pérez, Z. Ren, C. D. Rho, C. Rivière, D. Rosa-González, M. Rosenberg, E. Ruiz-Velasco, F. Salesa Greus, A. Sandoval, M. Schneider, H. Schoorlemmer, M. Seglar Arroyo, G. Sinnis, A. J. Smith, R. W. Springer, P. Surajbali, I. Taboada, O. Tibolla, K. Tollefson, I. Torres, G. Vianello, L. Villaseñor, T. Weisgarber, F. Werner, S. Westerhoff, J. Wood, T. Yapici, G. Yodh, A. Zepeda, H. Zhang & H. Zhou -
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- Future measurements from HAWC on the spectra of SS 433 jet lobes with more data, improved analyses, and the outrigger array; future multi-wavelength studies with Fermi and IACT data.

Acceleration Power?

- SS 433 is an object which we **expect particle acceleration**: presence of jets and interaction regions make it a good candidate accelerator.
- But does this system have the power to produce ~1 PeV electrons?
- Acceleration in magnetic fields: possible up to a few hundred TeV. Above that, acceleration time exceeds cooling time for 16 μG fields.
- Acceleration in standing shocks (Fermi acceleration): can reach PeV energies, but at present no multi-wavelength evidence for large shocks in the interaction regions.
- Explaining the emission from SS 433 is a challenge for current acceleration models!