

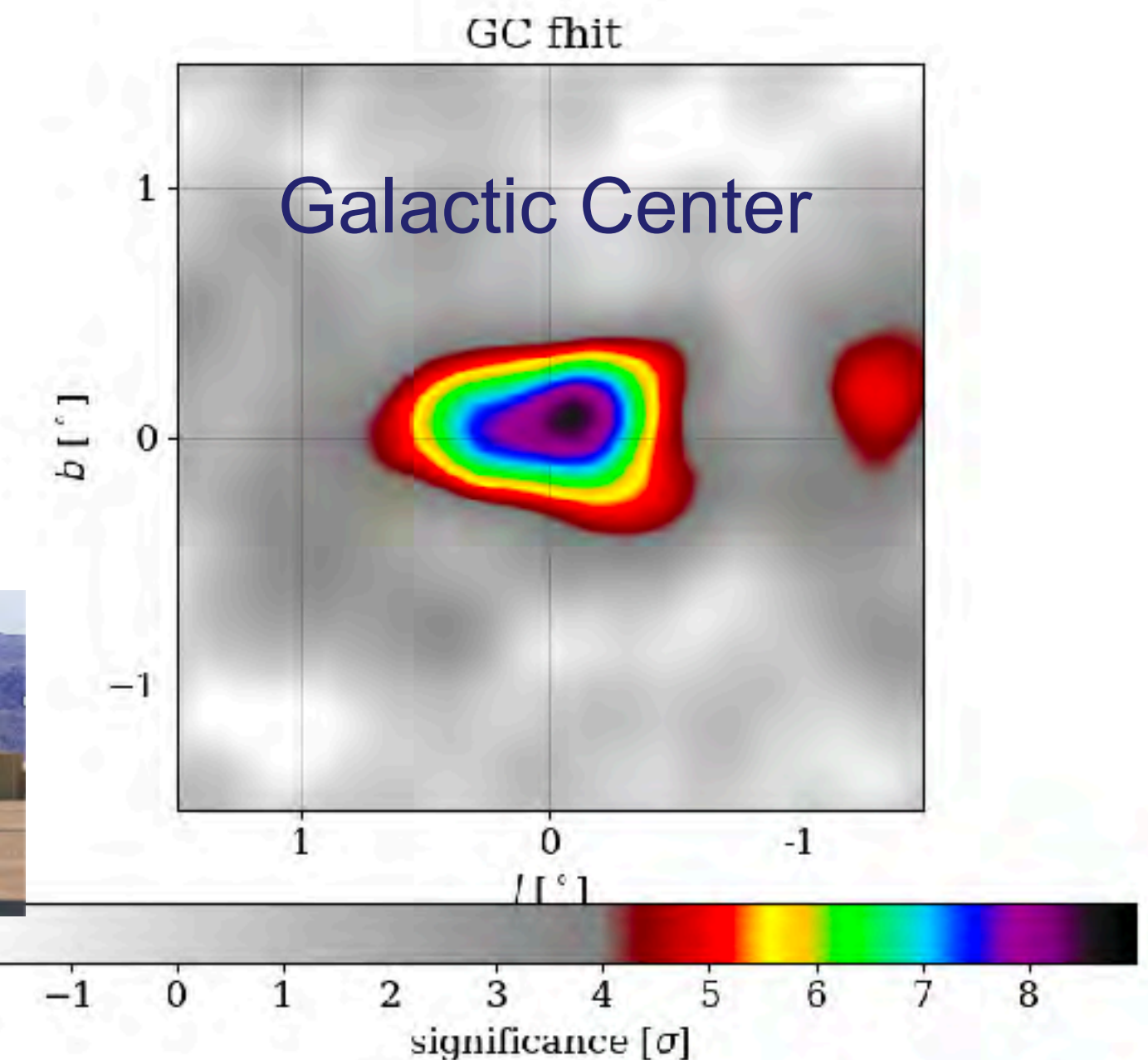
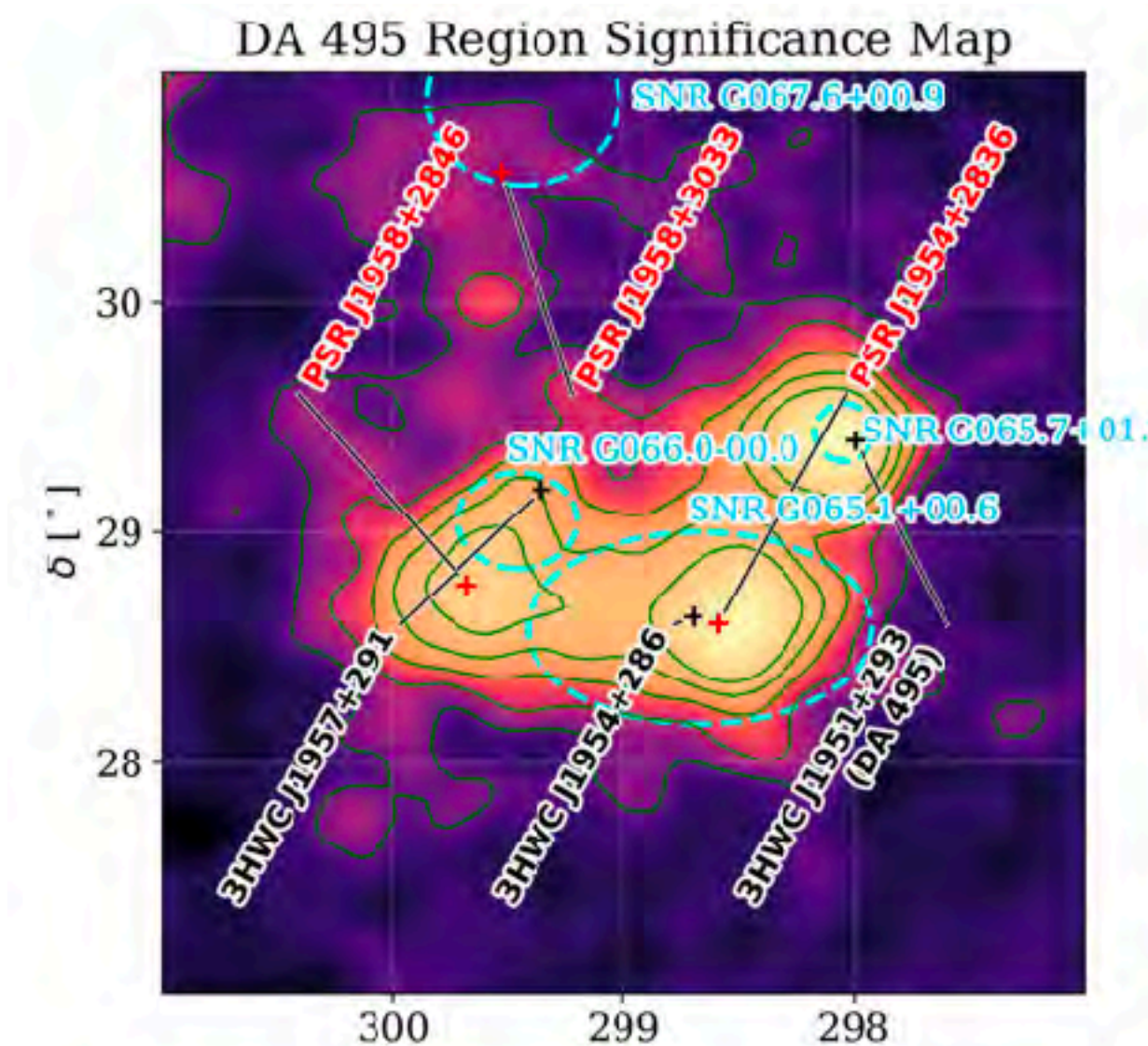
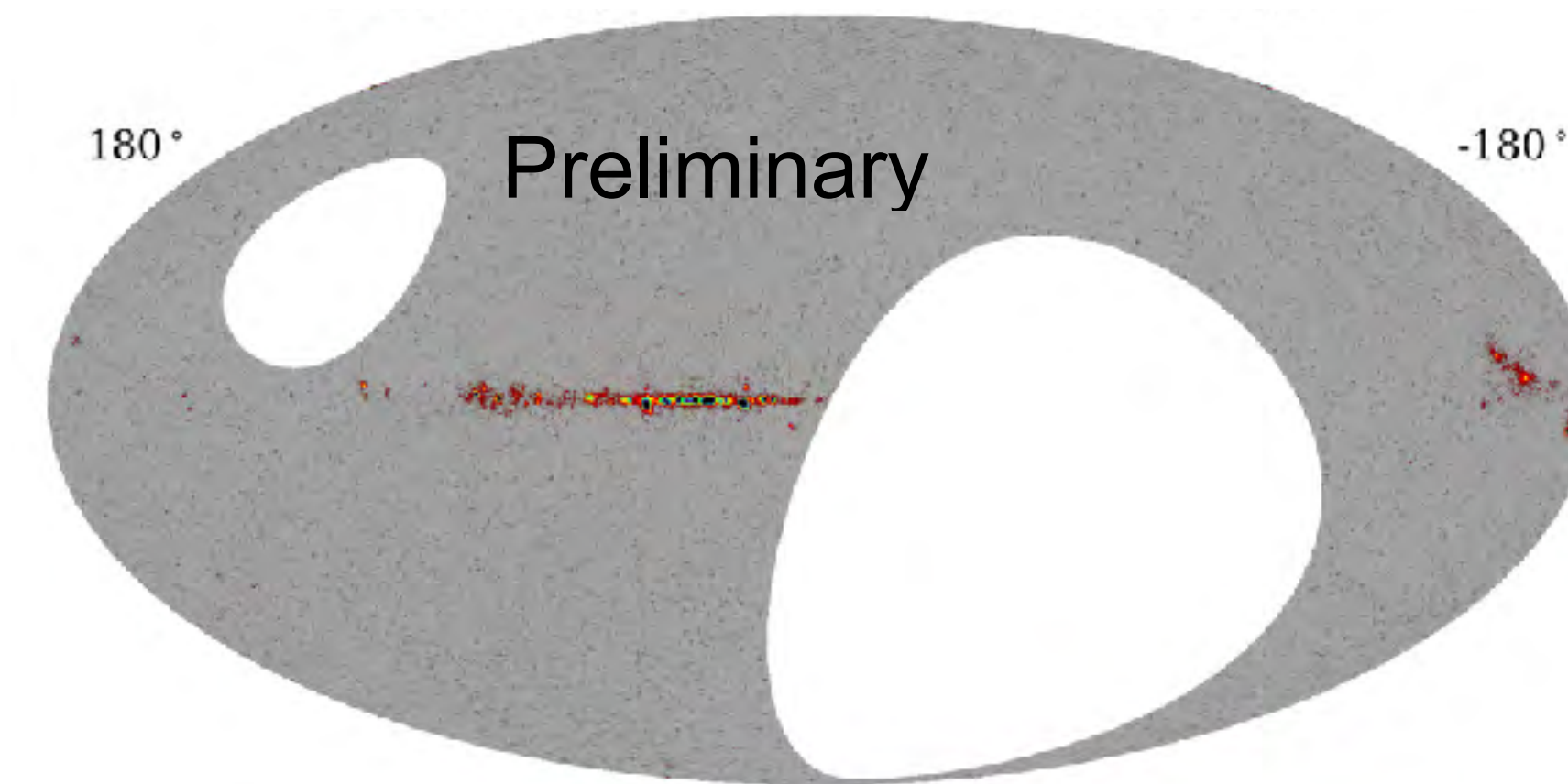


HAWC and SWGO

Jordan Goodman

HAWC - Recent Results

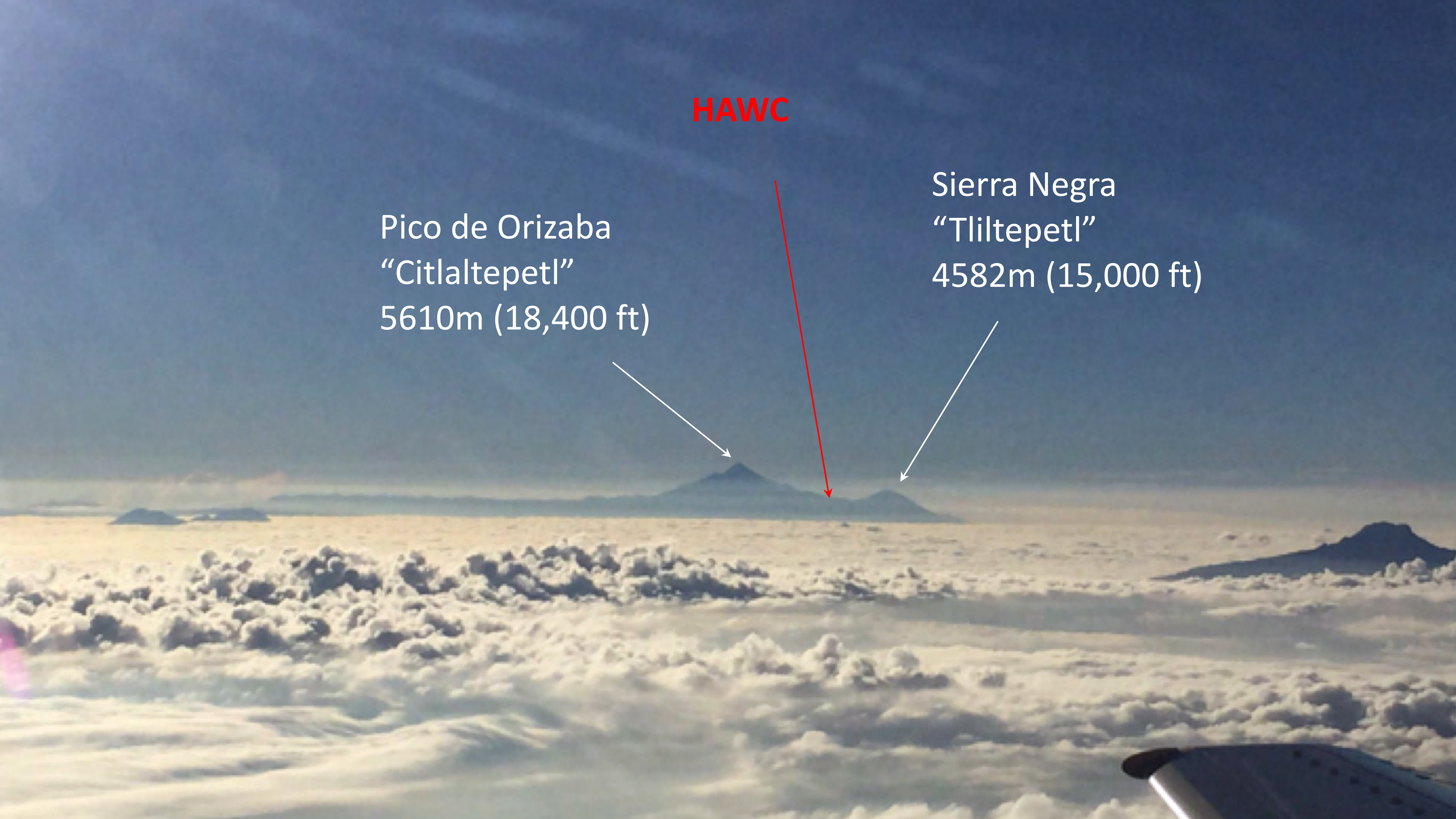
- Updated sky maps:
 - Improved resolution & gamma/hadron rejection with ML
- Highest Energy Sky
- Galactic Center
 - Dark Matter
 - Work with IceCube
- Binaries (micro-quasars)
 - SS 433, V4641SGR, LS 5039
- The DA495 Region
- SWGO
 - Plans
 - Progress



HAWC

Pico de Orizaba
"Citlaltepetl"
5610m (18,400 ft)

Sierra Negra
"Tliltepetl"
4582m (15,000 ft)





USA

United States

University of Maryland

Los Alamos National Laboratory

University of Wisconsin

University of Utah

University of New Hampshire

Pennsylvania State University

University of New Mexico

Michigan Technological University

NASA/Goddard Space Flight Center

Georgia Institute of Technology

Michigan State University

University of Rochester

Mexico

Instituto Nacional de Astrofísica,
Óptica y Electrónica (INAOE)

Universidad Nacional Autónoma
de México (UNAM)

Instituto de Física

Instituto de Astronomía

Instituto de Geofísica

Instituto de Ciencias Nucleares

Universidad Politécnica de Pachuca

Benemérita Universidad Autónoma de Puebla

Universidad Autónoma de Chiapa

Universidad Autónoma del Estado de Hidalgo

Universidad de Guadalajara

Universidad Michoacana de San Nicolás de Hidalgo

Centro de Investigación y de Estudios Avanzados

Instituto Politécnico Nacional

Centro de Investigación en Computación - IPN

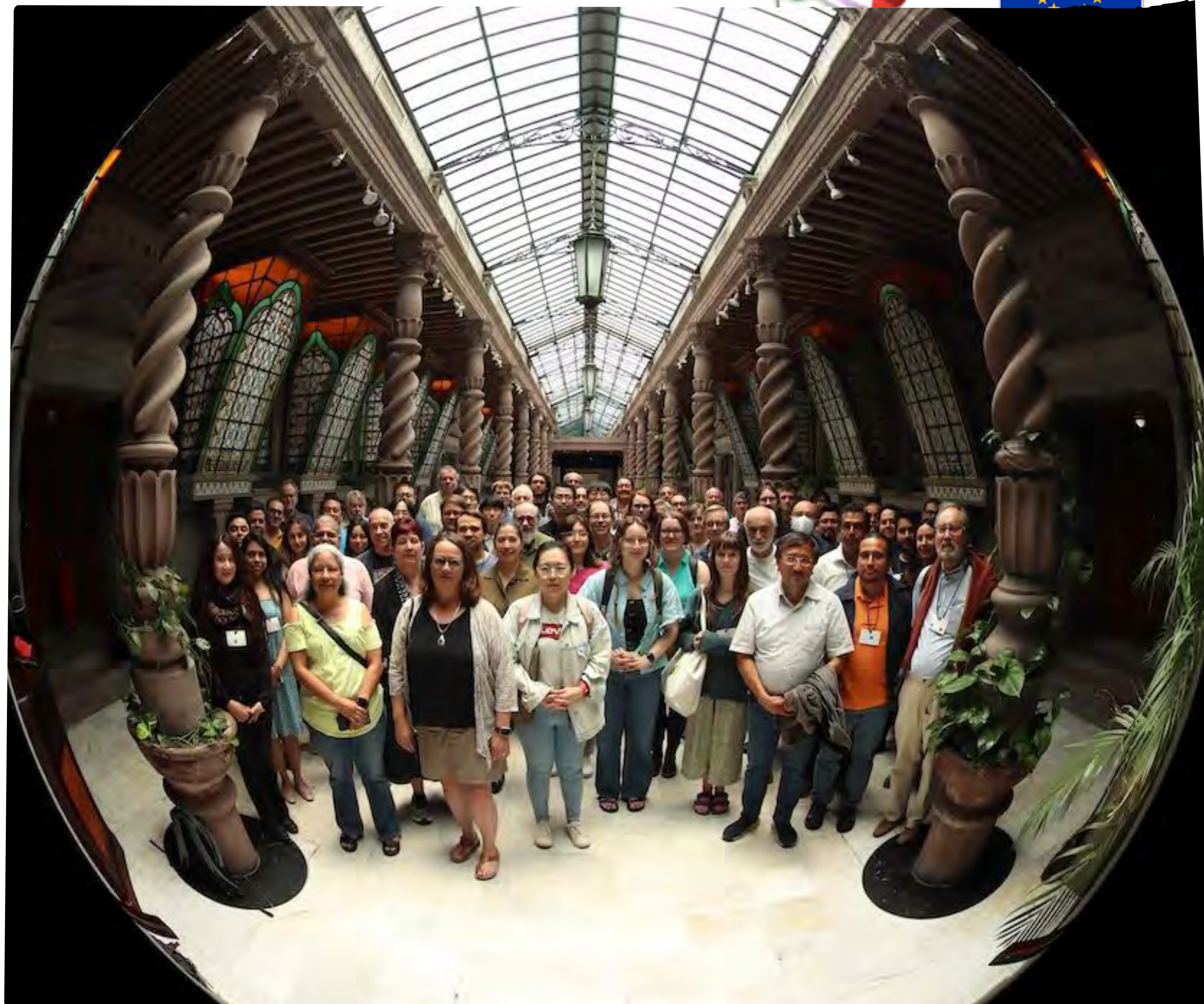
Europe

Max-Planck Institute for Nuclear Physics

IFJ-PAN, Krakow, Poland

The HAWC Collaboration

Mexico

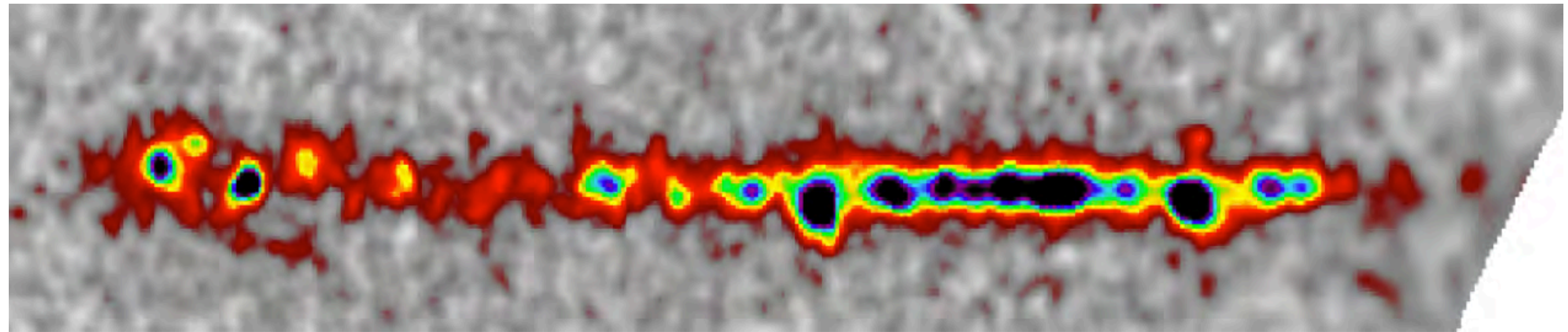


HAWC

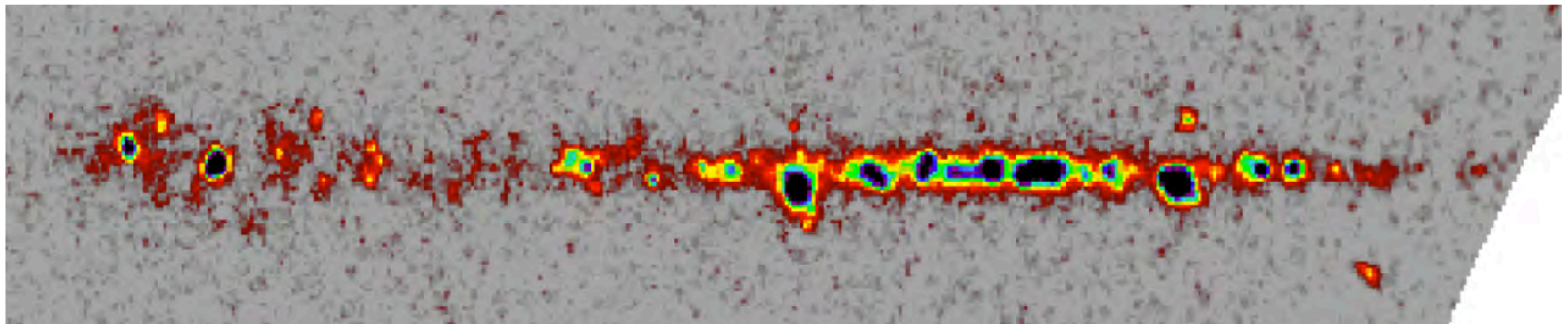


Pass 4 (1523d) vs Pass 5 (2090d)

Pass 4



Pass 5



Cuts from Machine Learning

- **Crab**
 - ~20% improvement in significance is the equivalent of running 40% longer

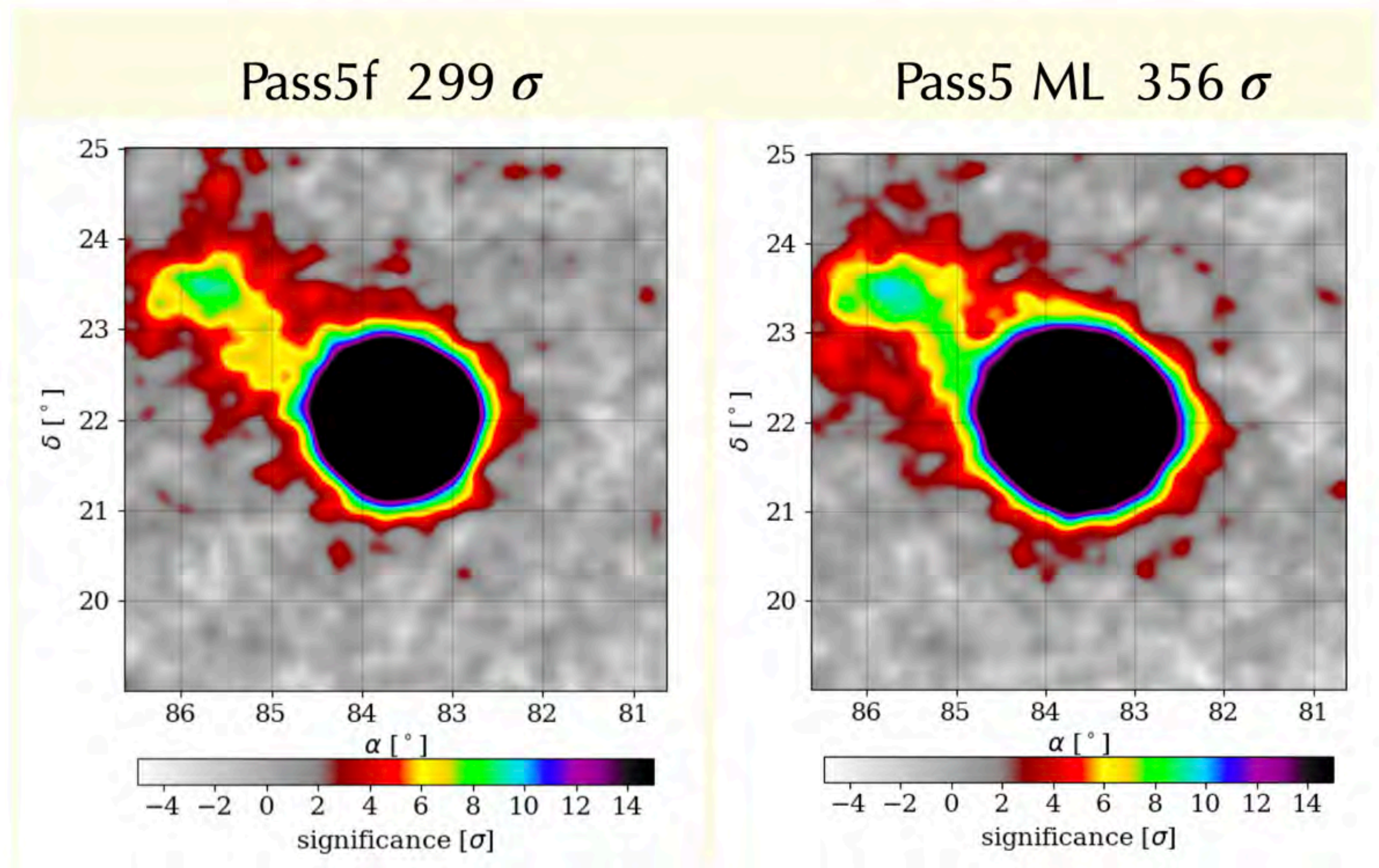
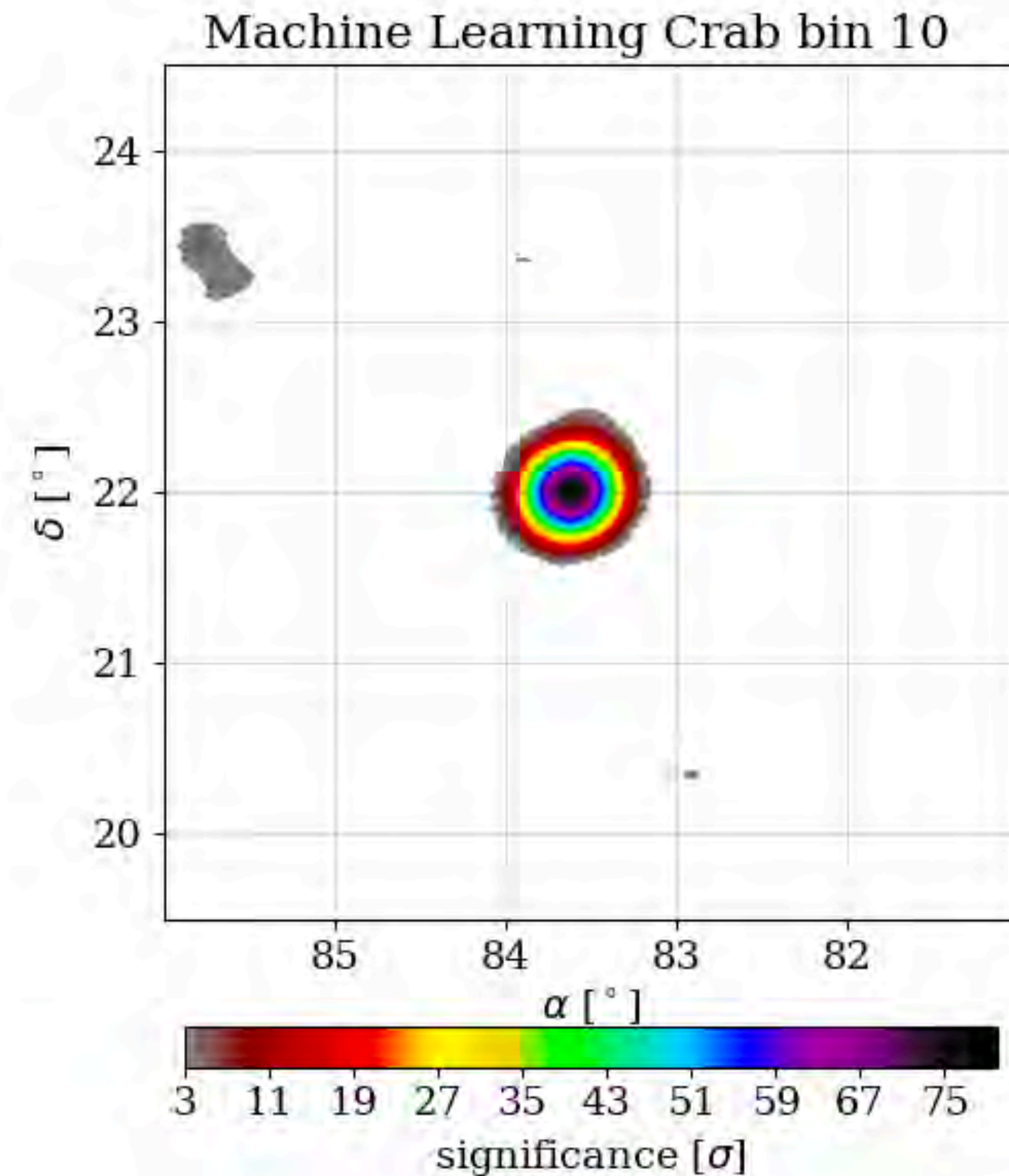
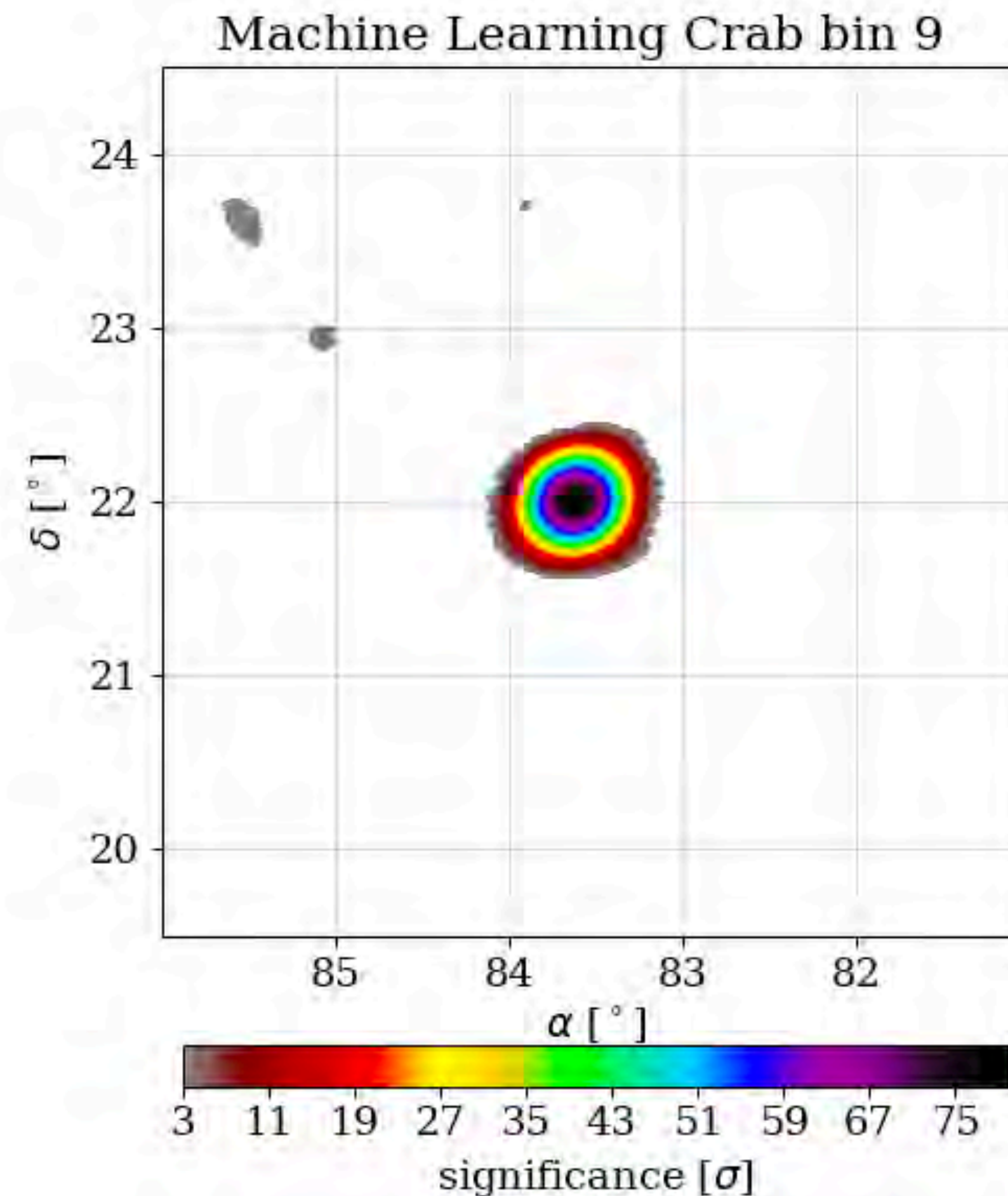


Figure 4. The effect of using Machine Learning (ML) on the HAWC Crab signal. the improvement is 19% for the same dataset.

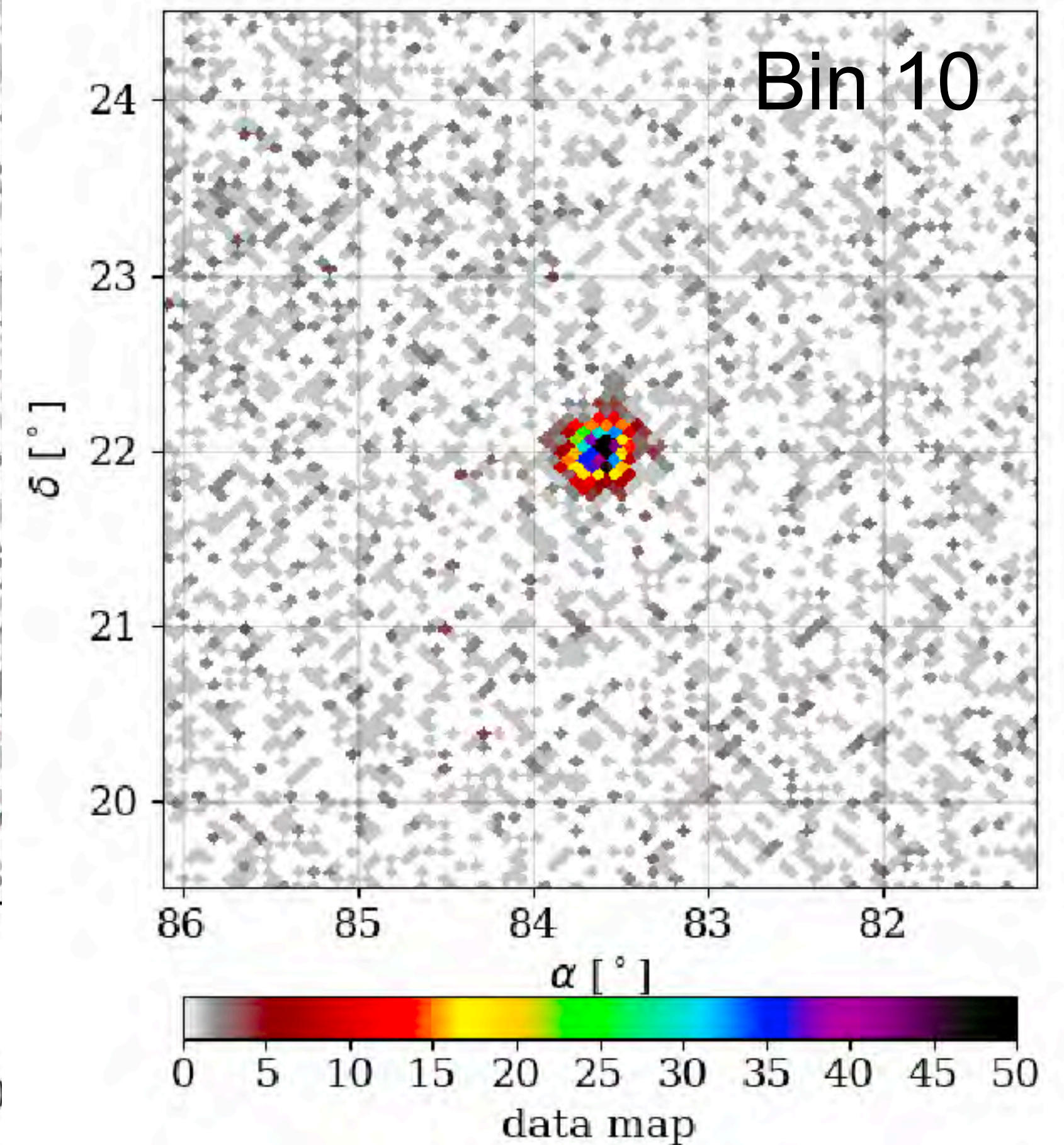
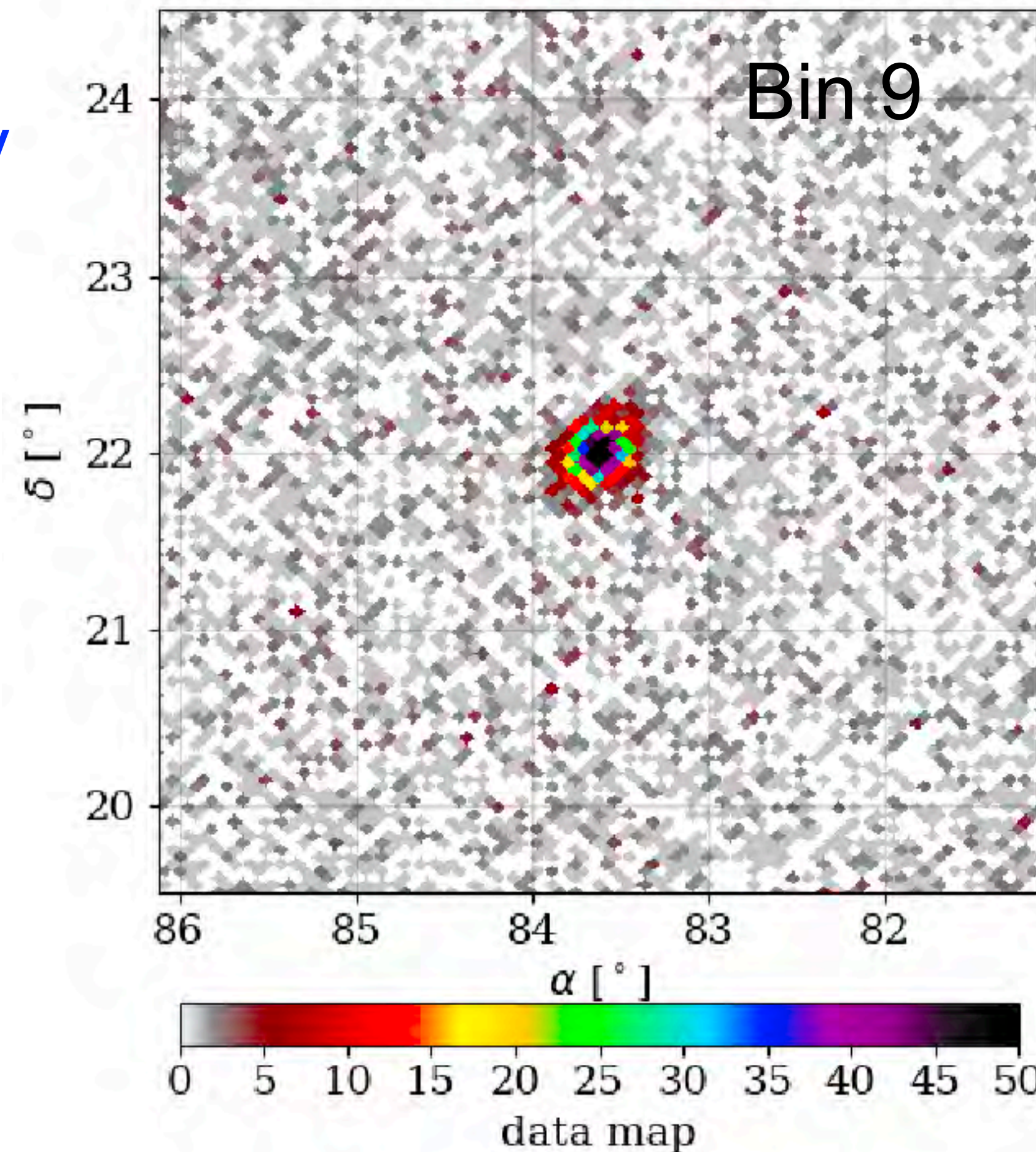
Cuts from Machine Learning

- Crab
 - Almost background free at highest energies
 - Can be used to train AI
 - Real data is significantly better than Monte Carlo

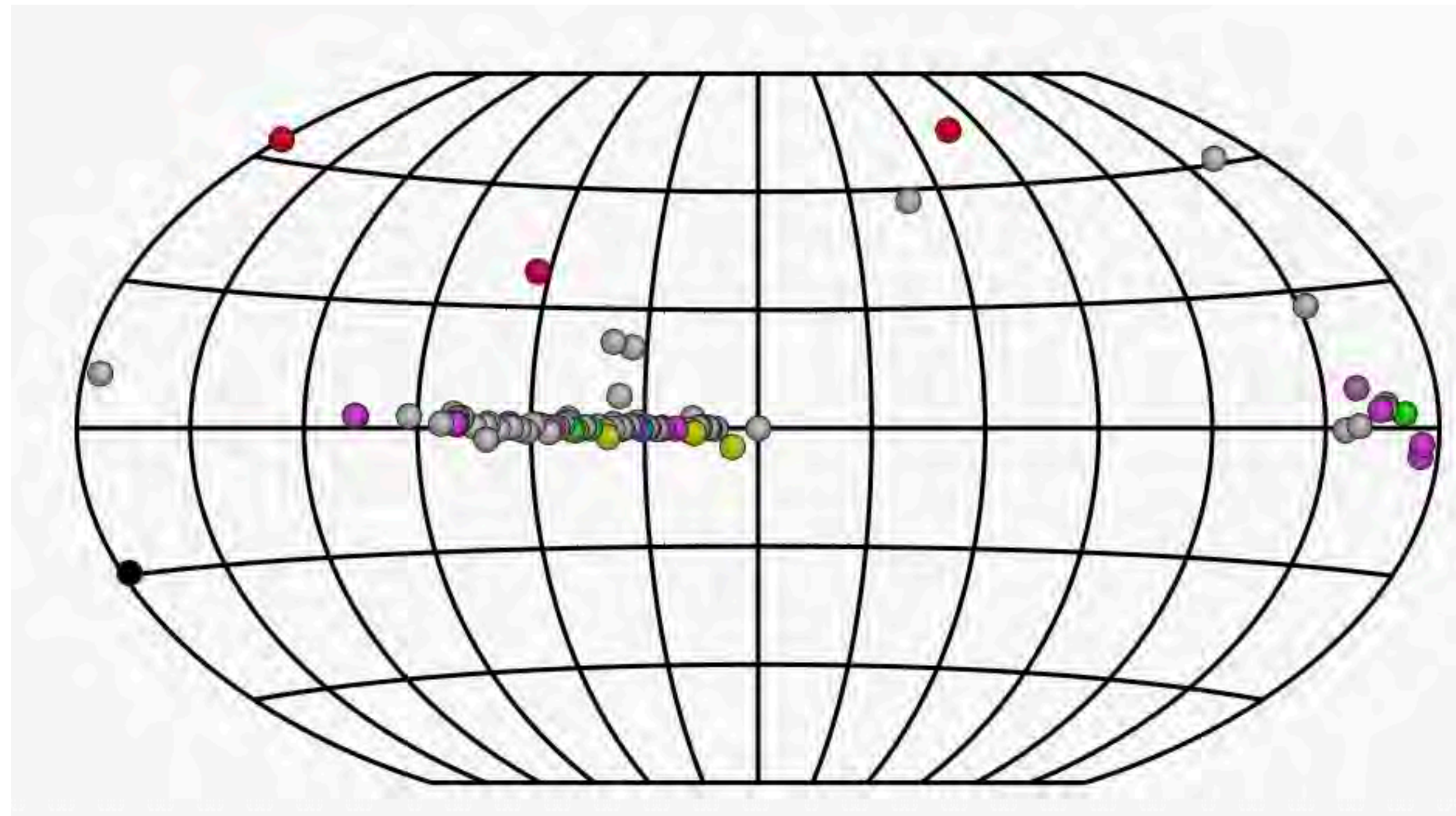


Cuts from Machine Learning

- Crab
 - Almost background free at highest energies
 - Can be used to train AI
 - Real data is significantly better than Monte Carlo



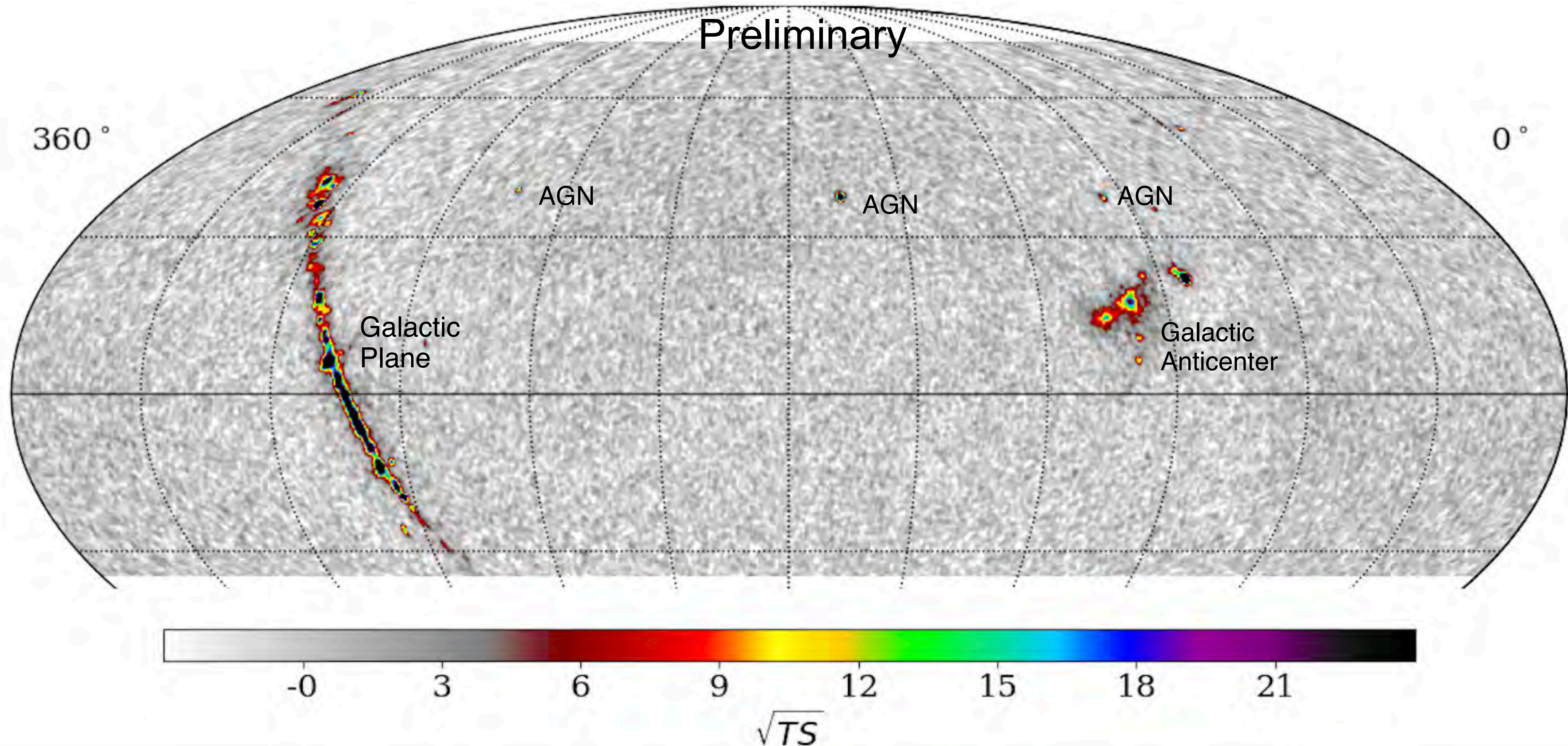
84 TeVCat HAWC Sources



Legend

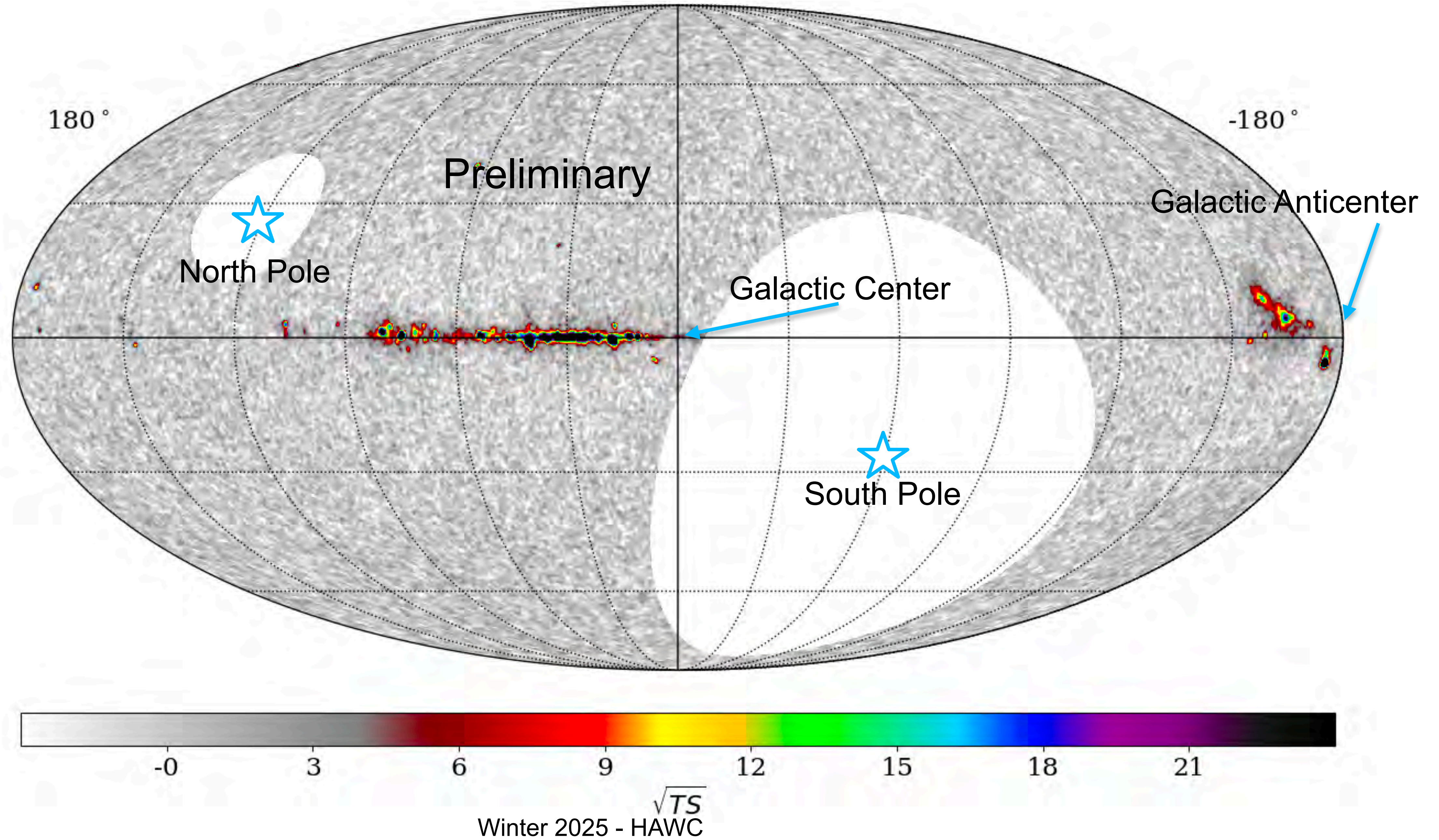
-  PWN/TeV Halo, TeV halo, BIN, Composite SNR
-  UNID, DARK, TeV halo
-  HBL, Blazar
-  Nova, PSR, BIN, Binary
-  GRB, Superbubble
-  Shell, SNR/Molec. Cloud, Composite SNR, Giant Molecular Cloud
-  Globular Cluster, Massive Star Cluster

HAWC Sky Map 3040 Days of Data - Pass 5

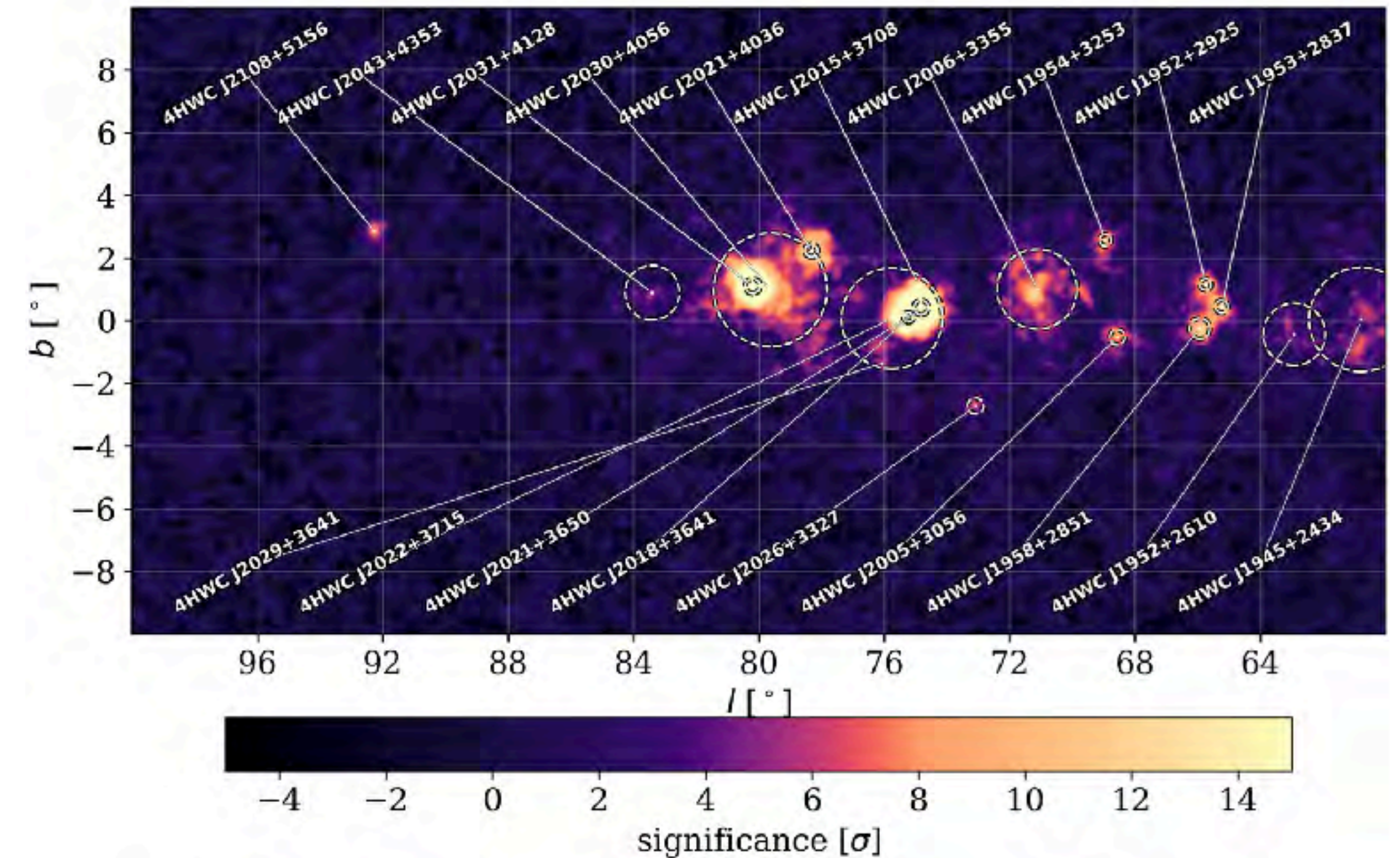
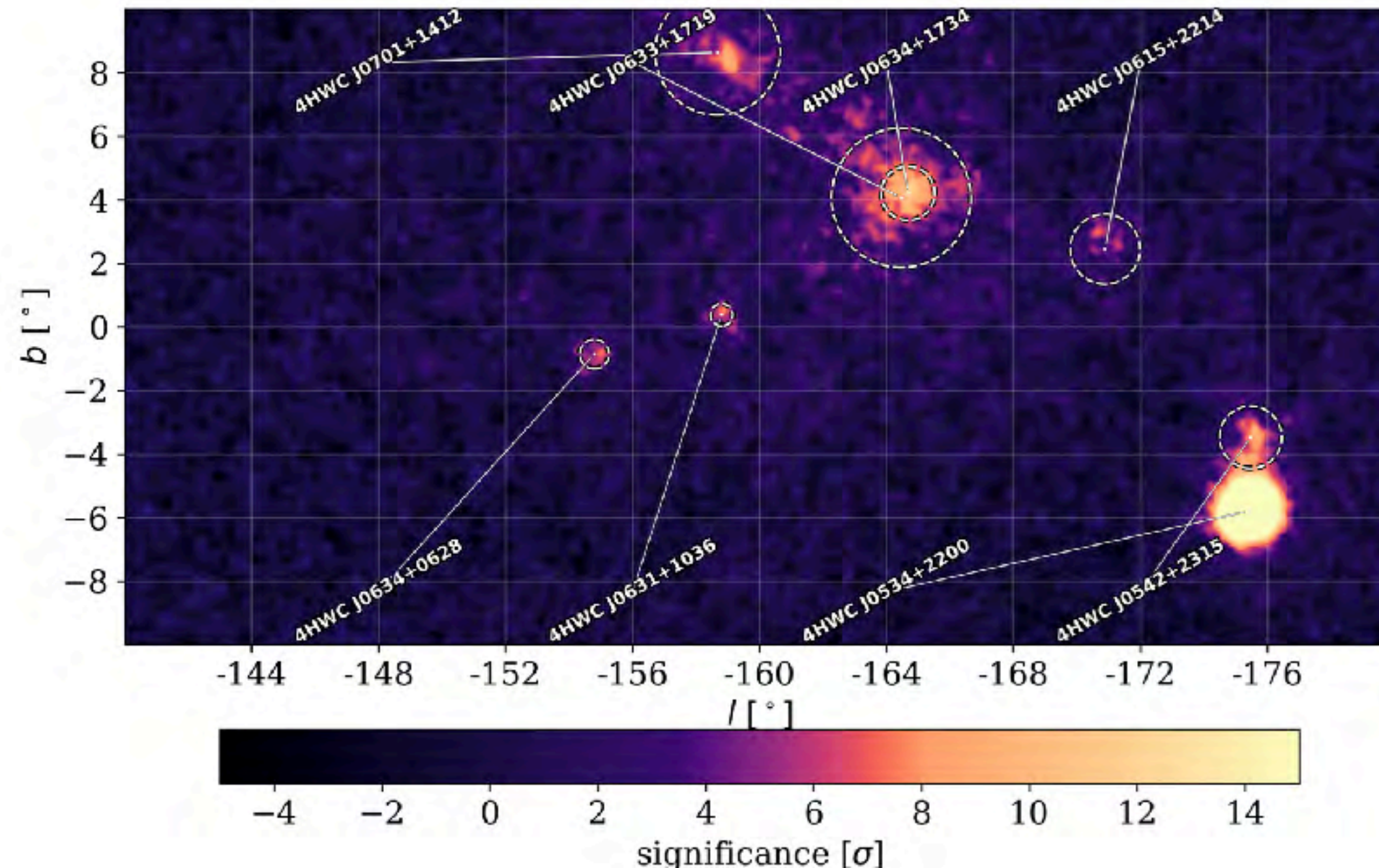
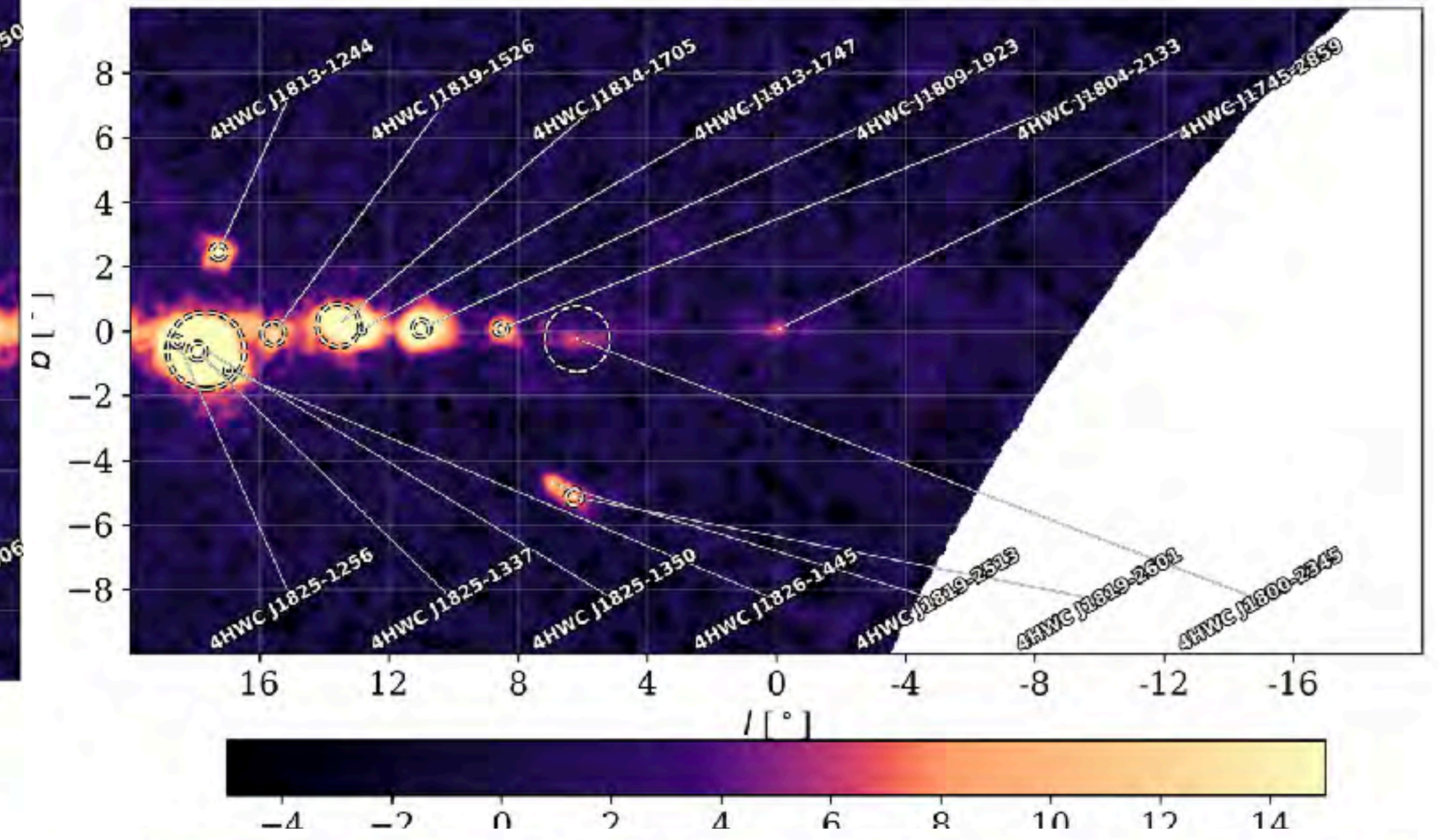
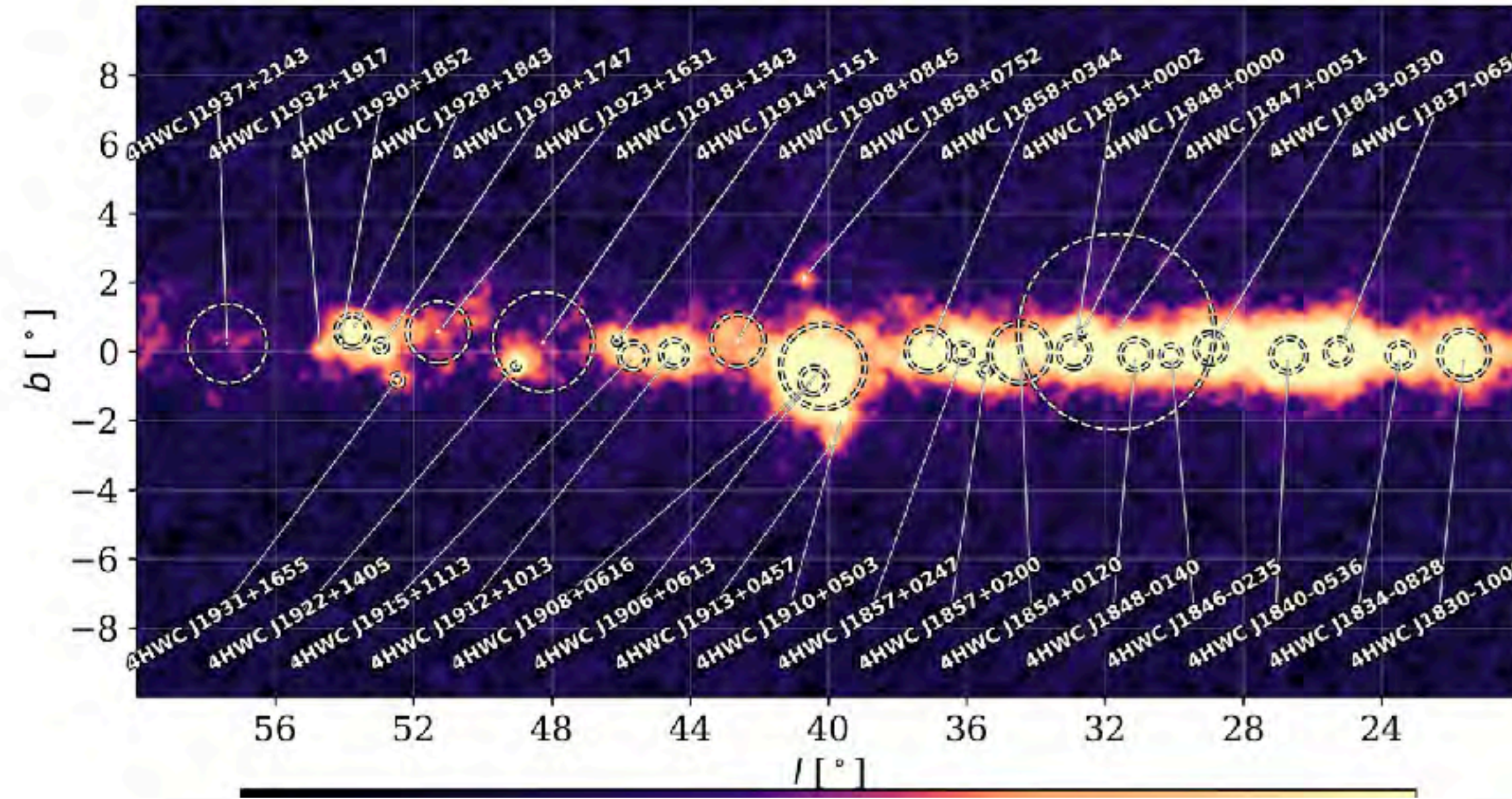




HAWC Sky Map 3040 Days of Data - Pass 5

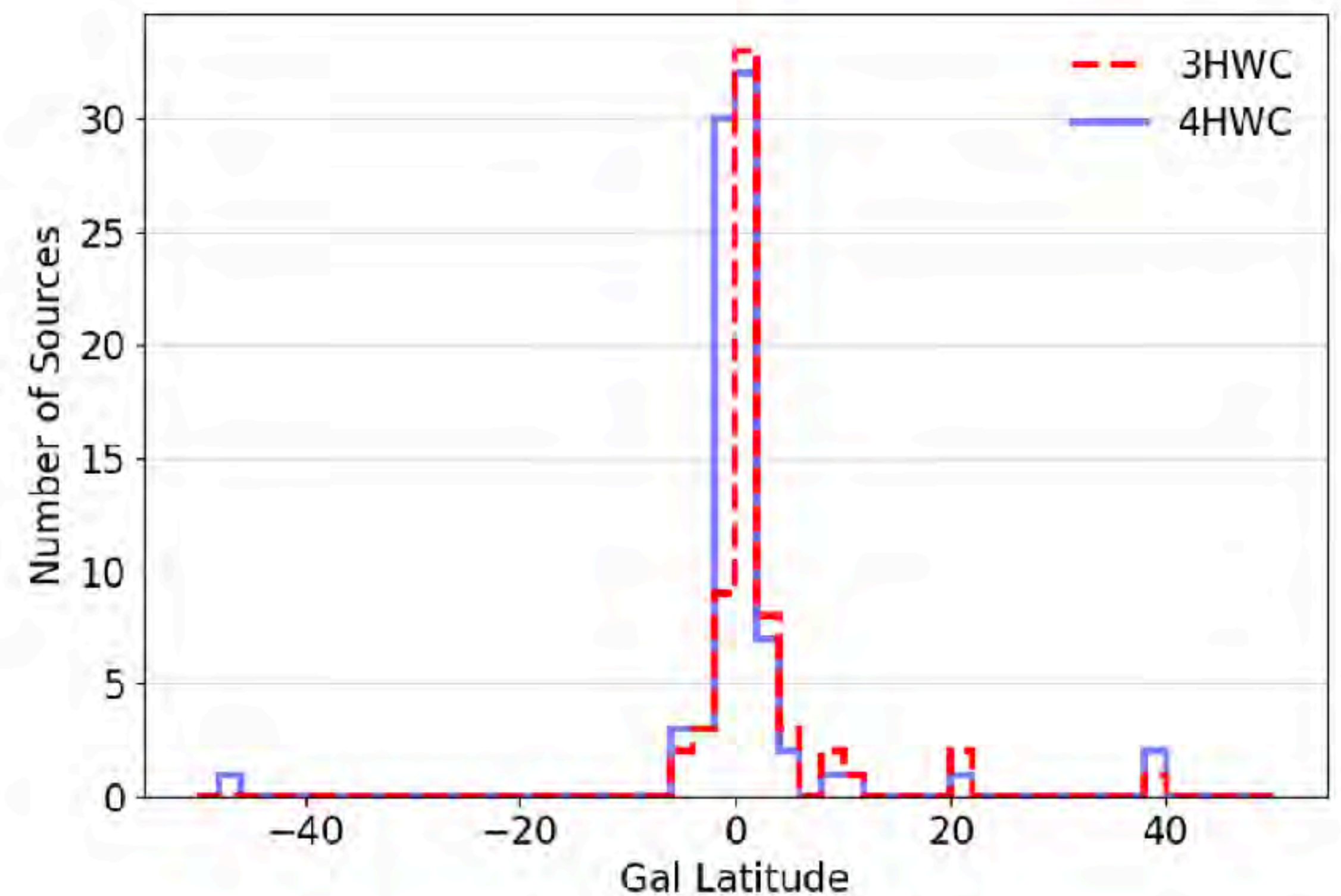
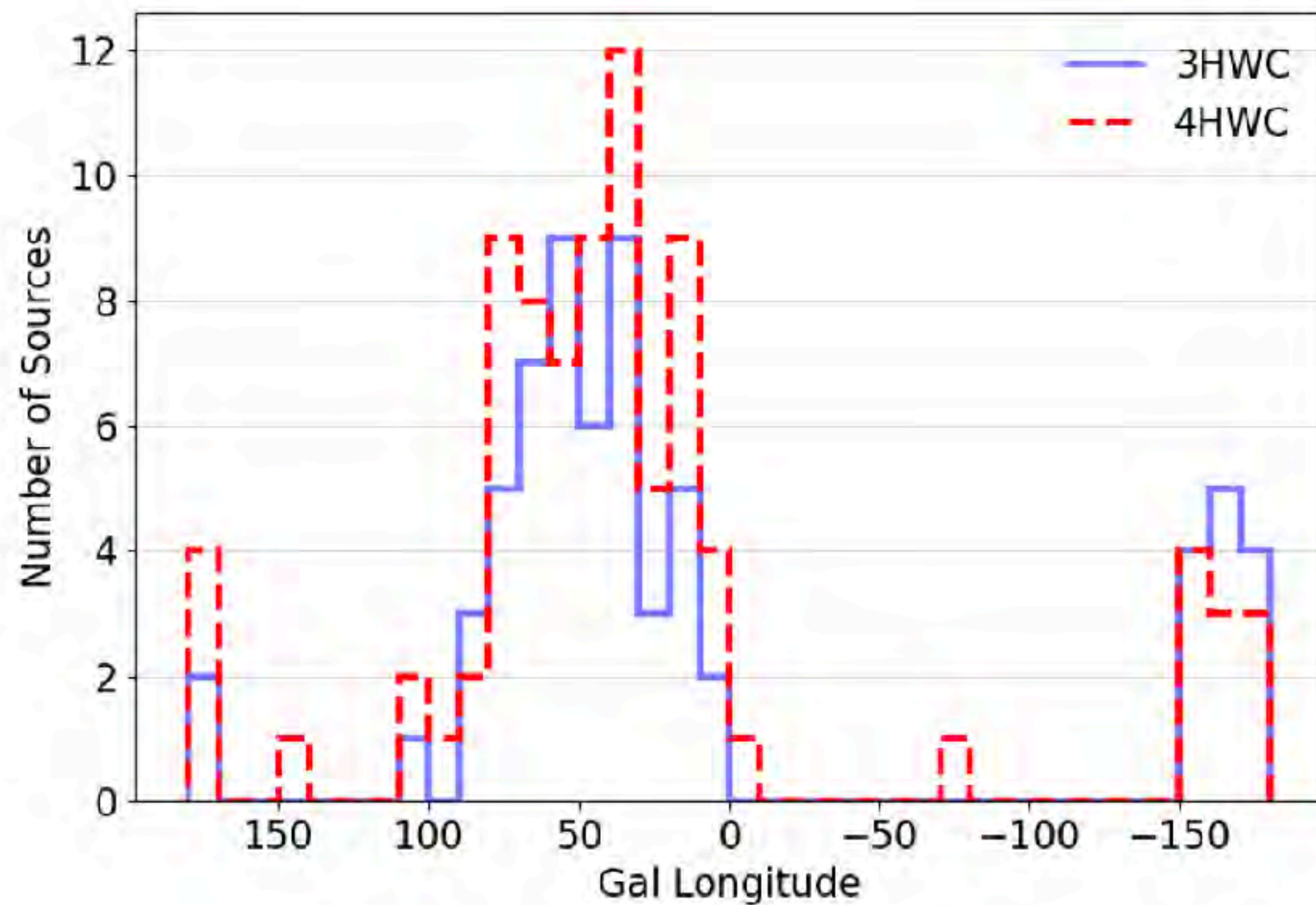


4HWC Catalog



4HWC Catalog

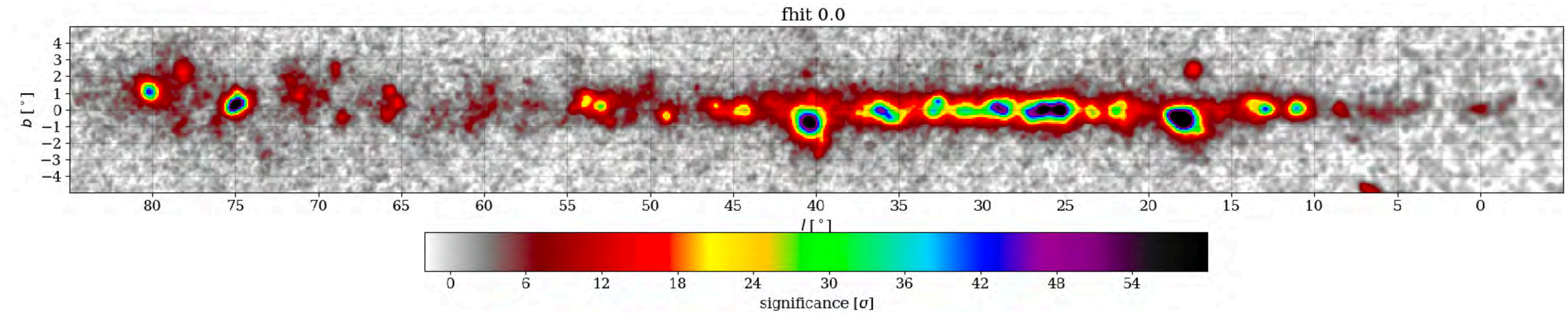
The catalog reports 85 sources detected at the 4σ significance level from the automated fitting procedure, including 11 not associated with any TeVCat sources from a proximity-based association criterion



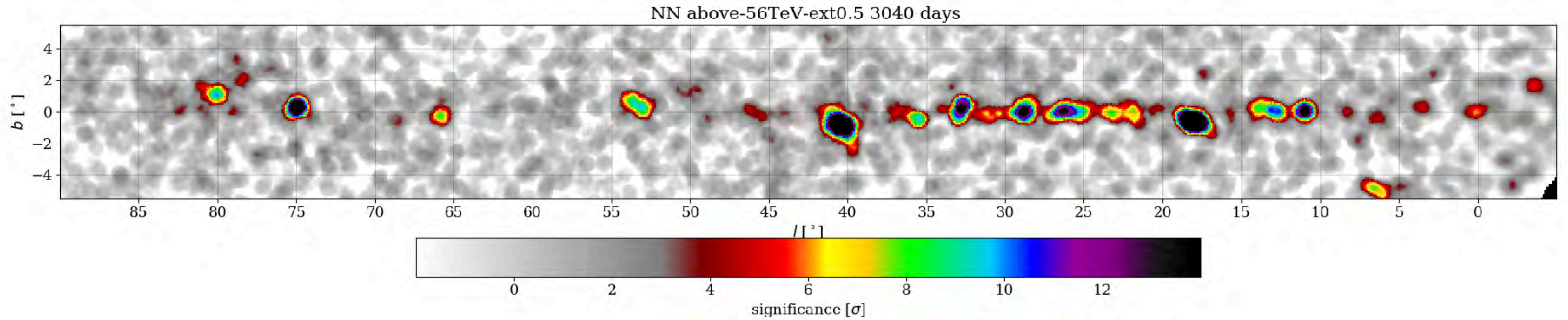
The Fourth HAWC Catalog of Very-High-Energy Gamma-Ray Sources (4HWC)
arXiv: 2602.00263 (30 Jan 2026)

We posted it on the arXiv and got several requests from theorists for more specific energy information on the sources. We are updating the results to give them this info and will submit it to the journal shortly.

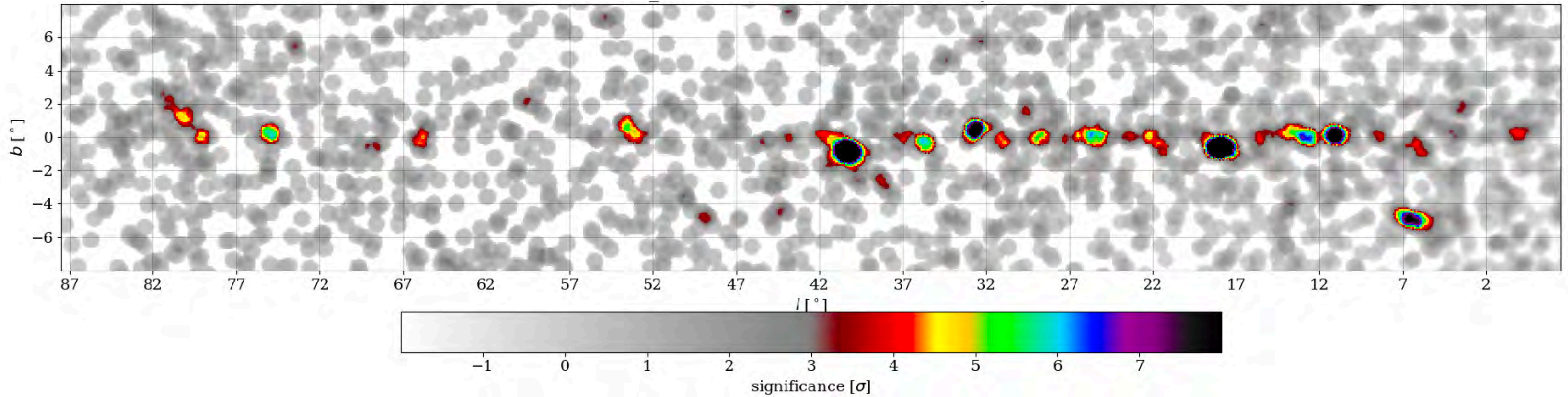
Pass 5 Machine Learning Cuts



Pass 5 Machine Learning Cuts Above 56 TeV



Pass 5 Machine Learning Cuts Above 100 TeV



2eHC extends the HAWC survey above 177 TeV

28

sources above 56 TeV

21

sources above 100 TeV

7

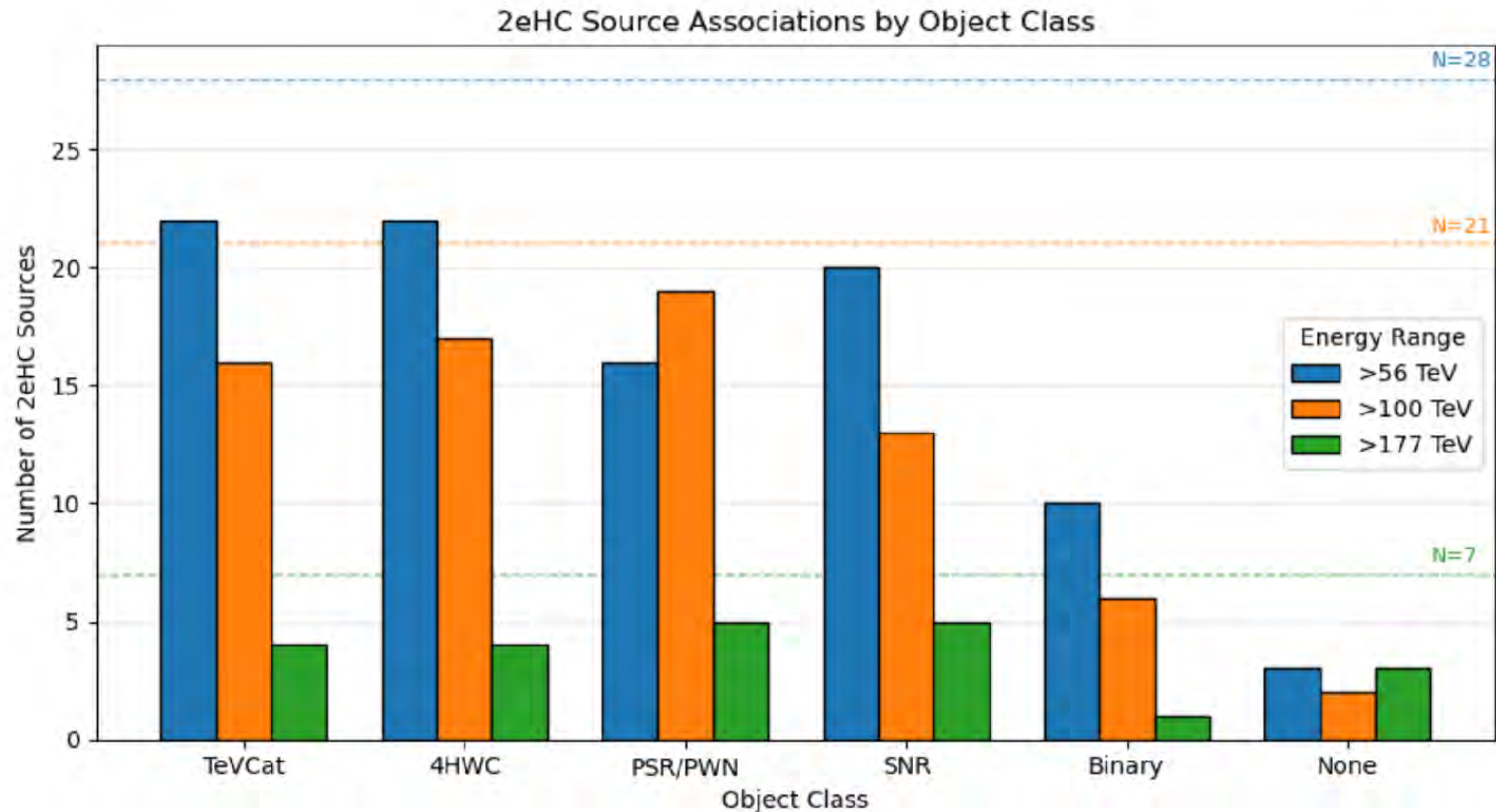
sources above 177 TeV

About three times as many sources above 56 TeV as the first catalog

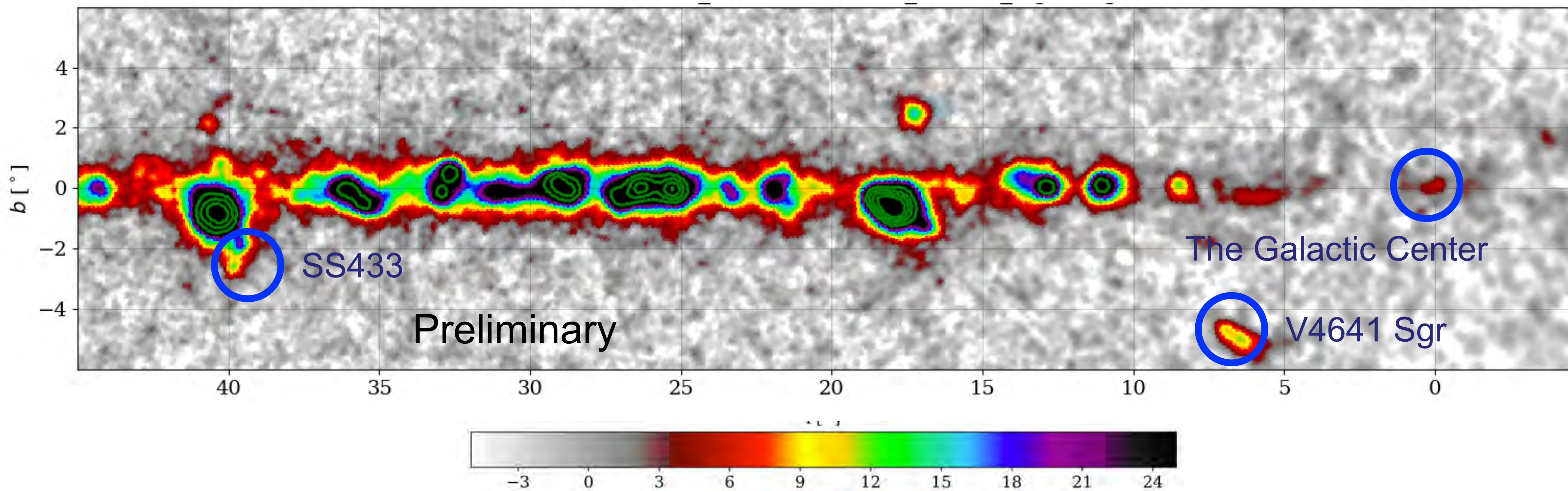
~2800 days of data, improved reconstruction and simultaneous source fitting

Independent GP and NN energy estimators provide cross-checks

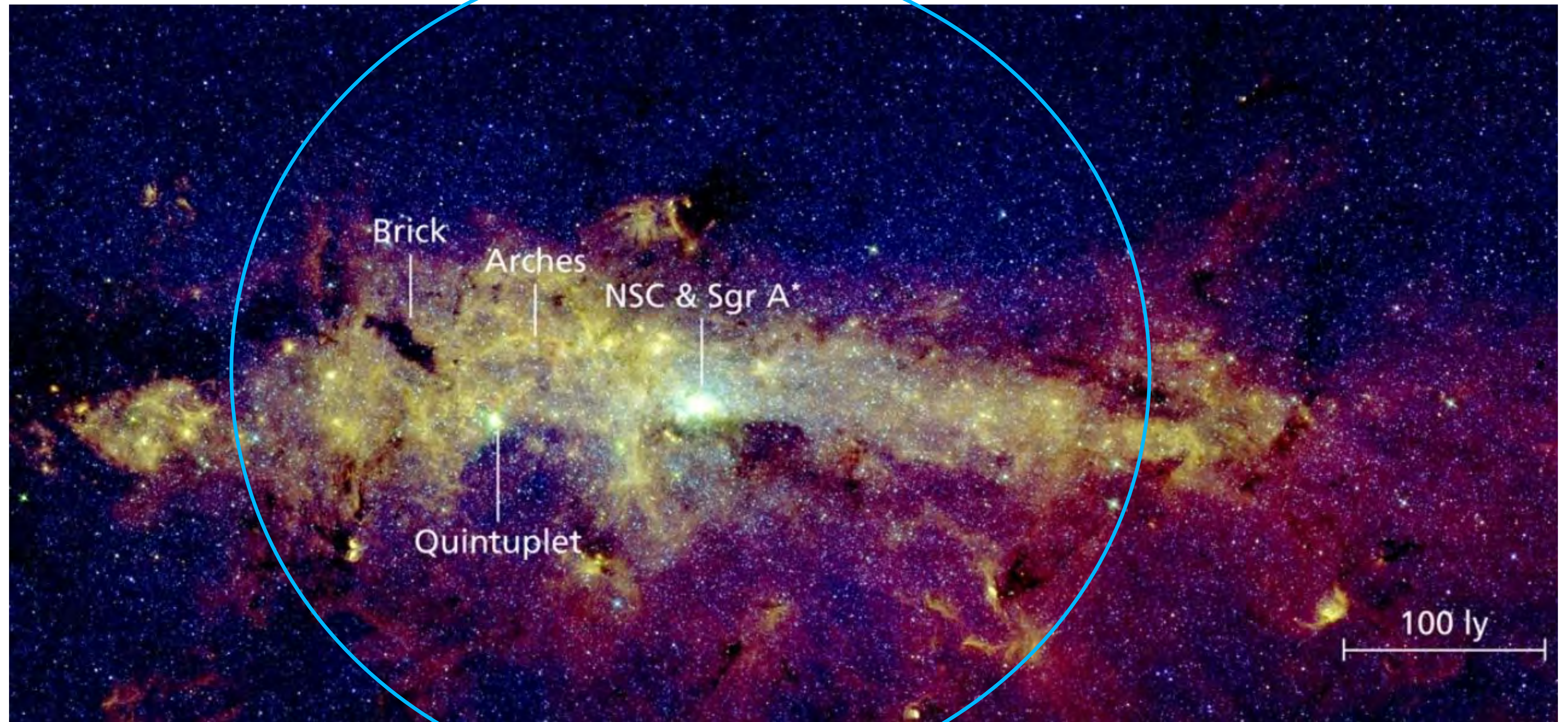
Potential associations across energy thresholds



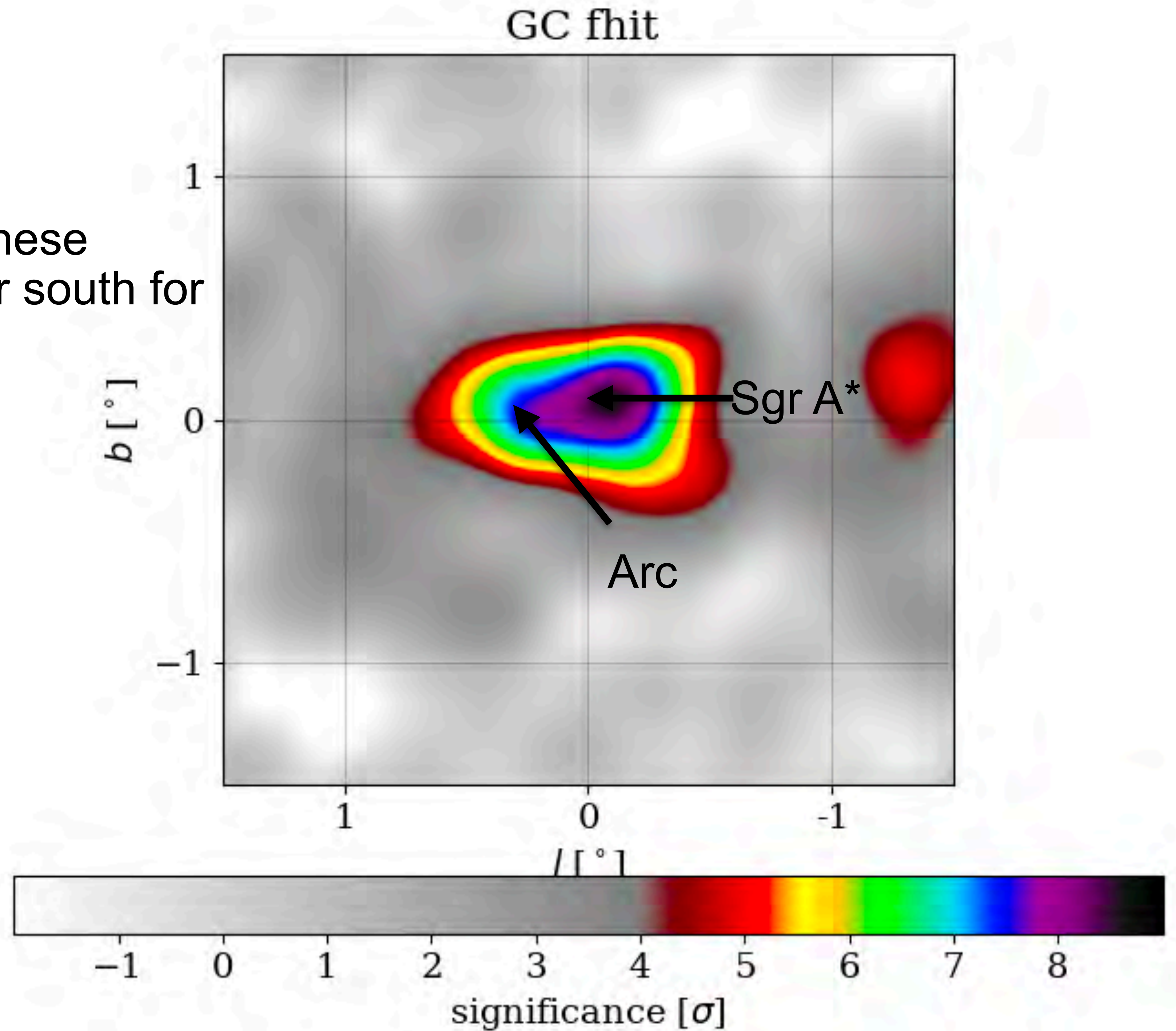
Positional matches can overlap across classes. They are not confirmed identifications.



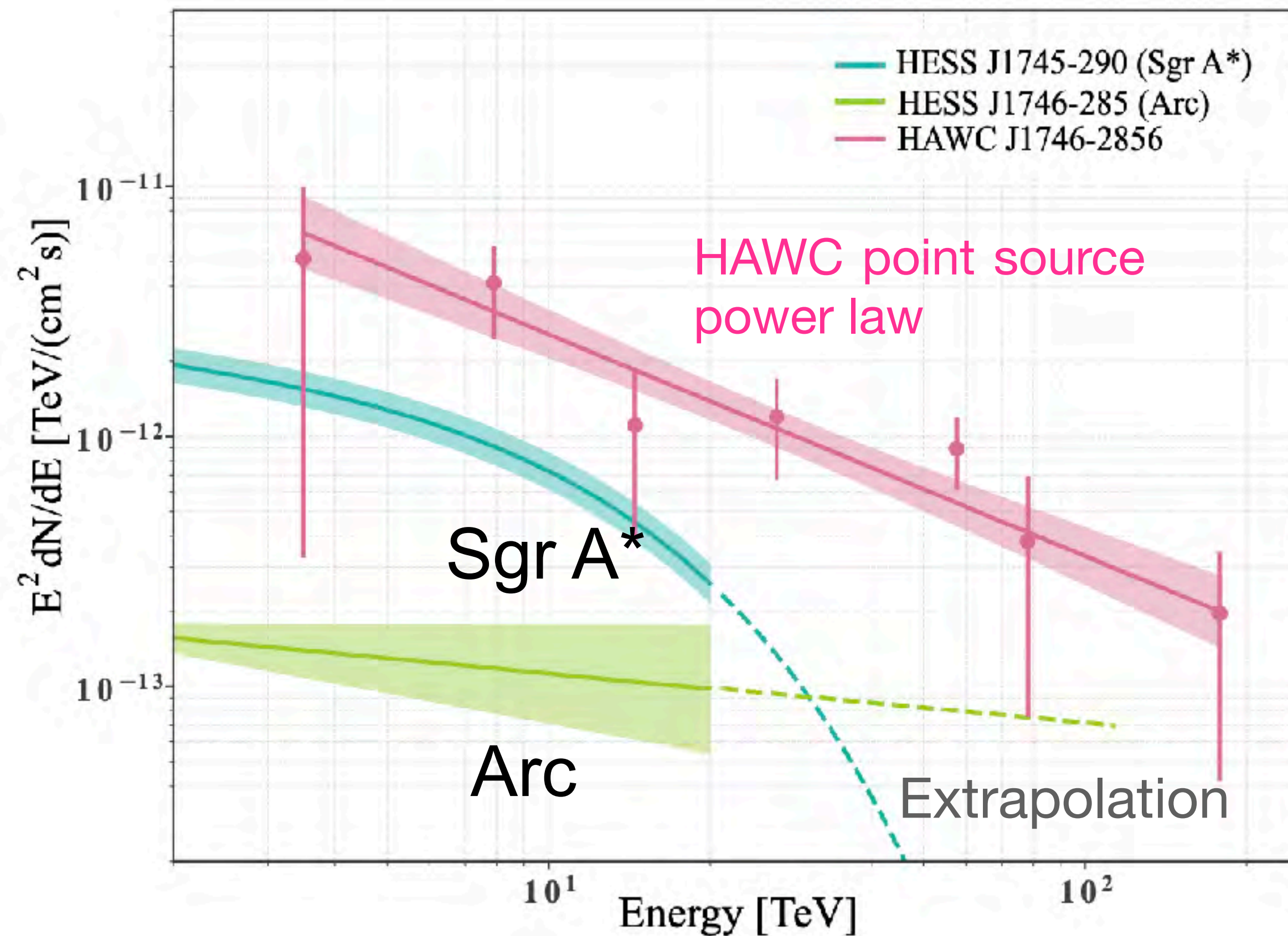
The Galactic Center



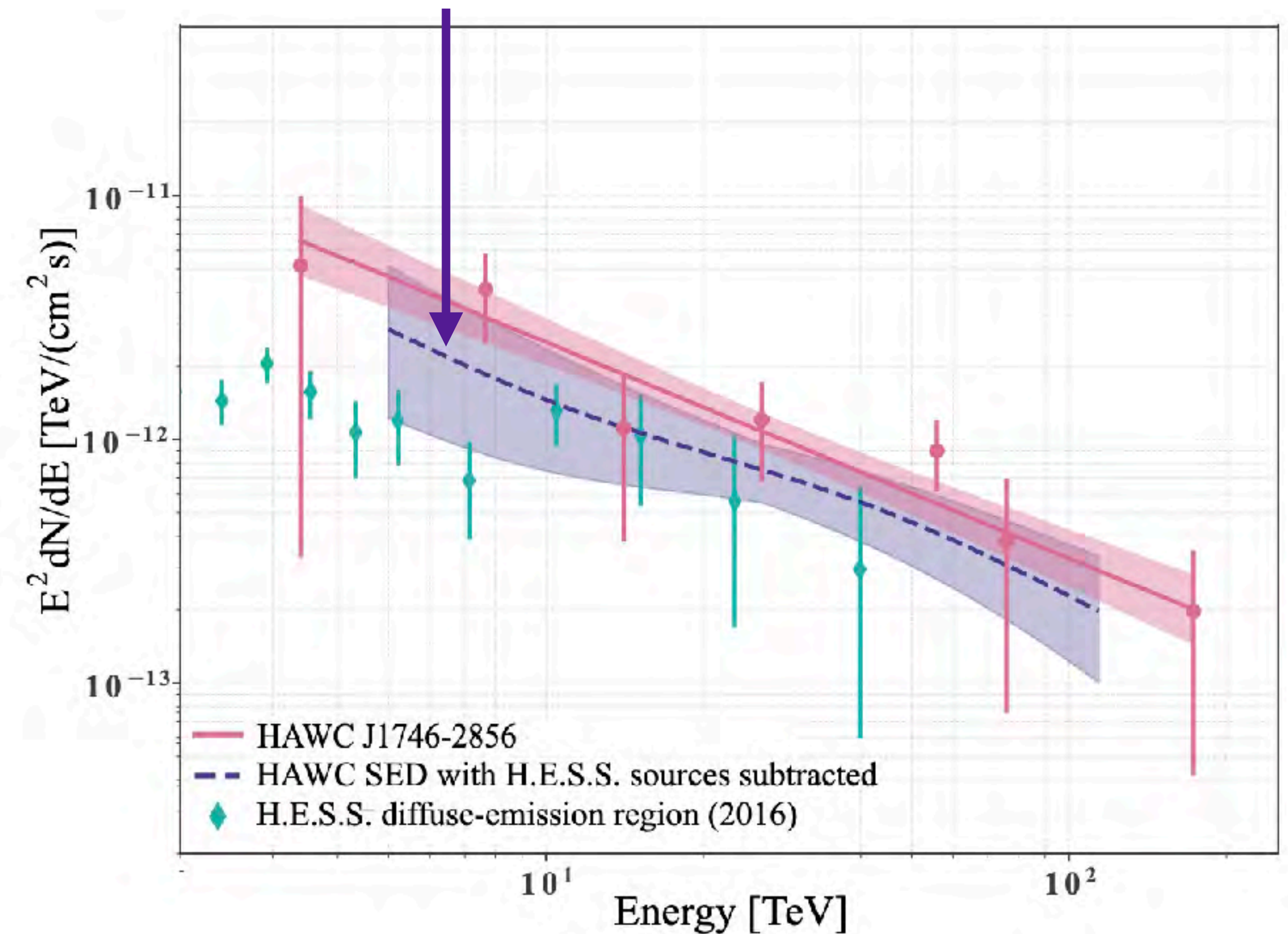
HAWC can see the
the Galactic Center at these
energies - but it's too far south for
LHAASO

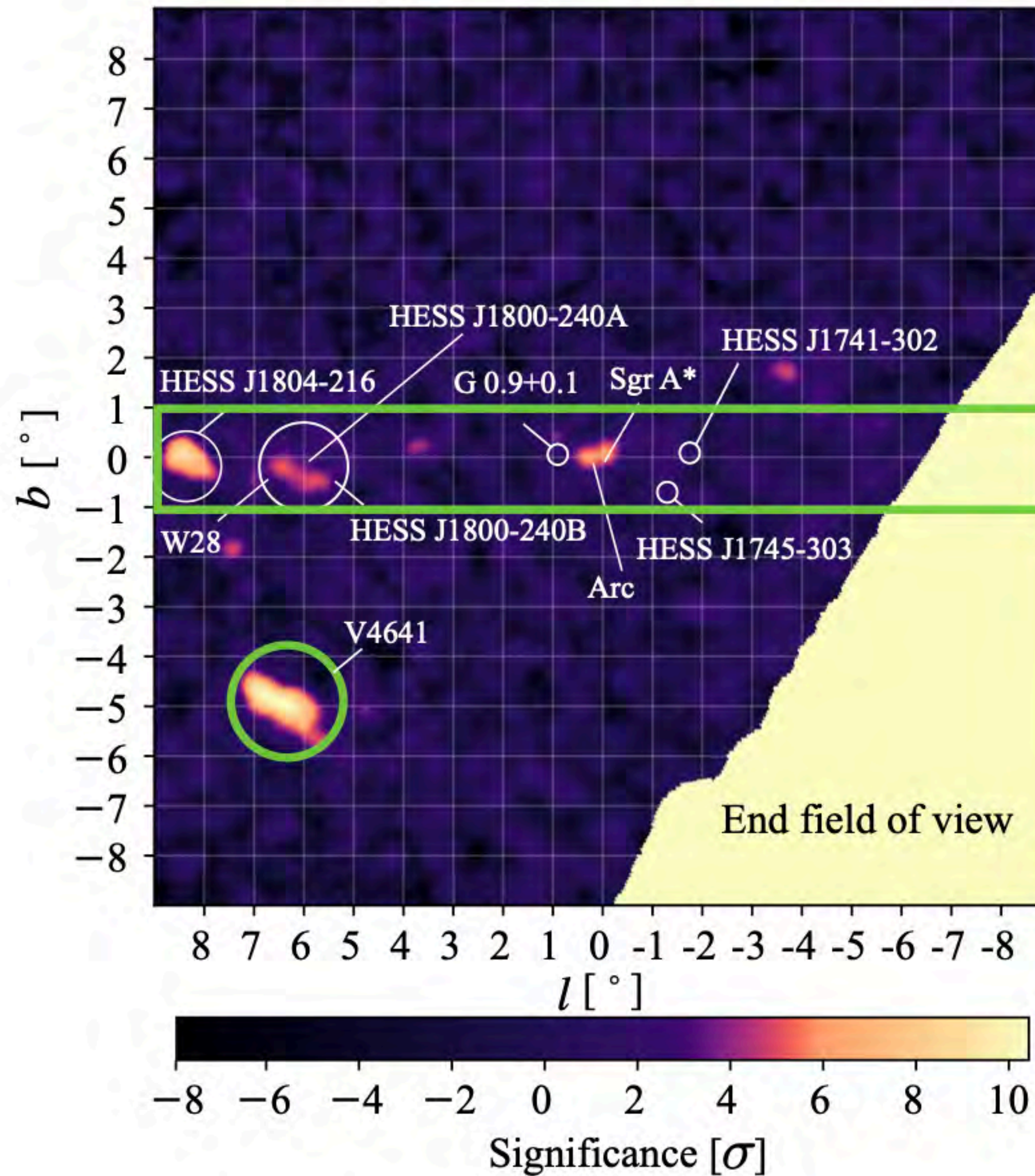


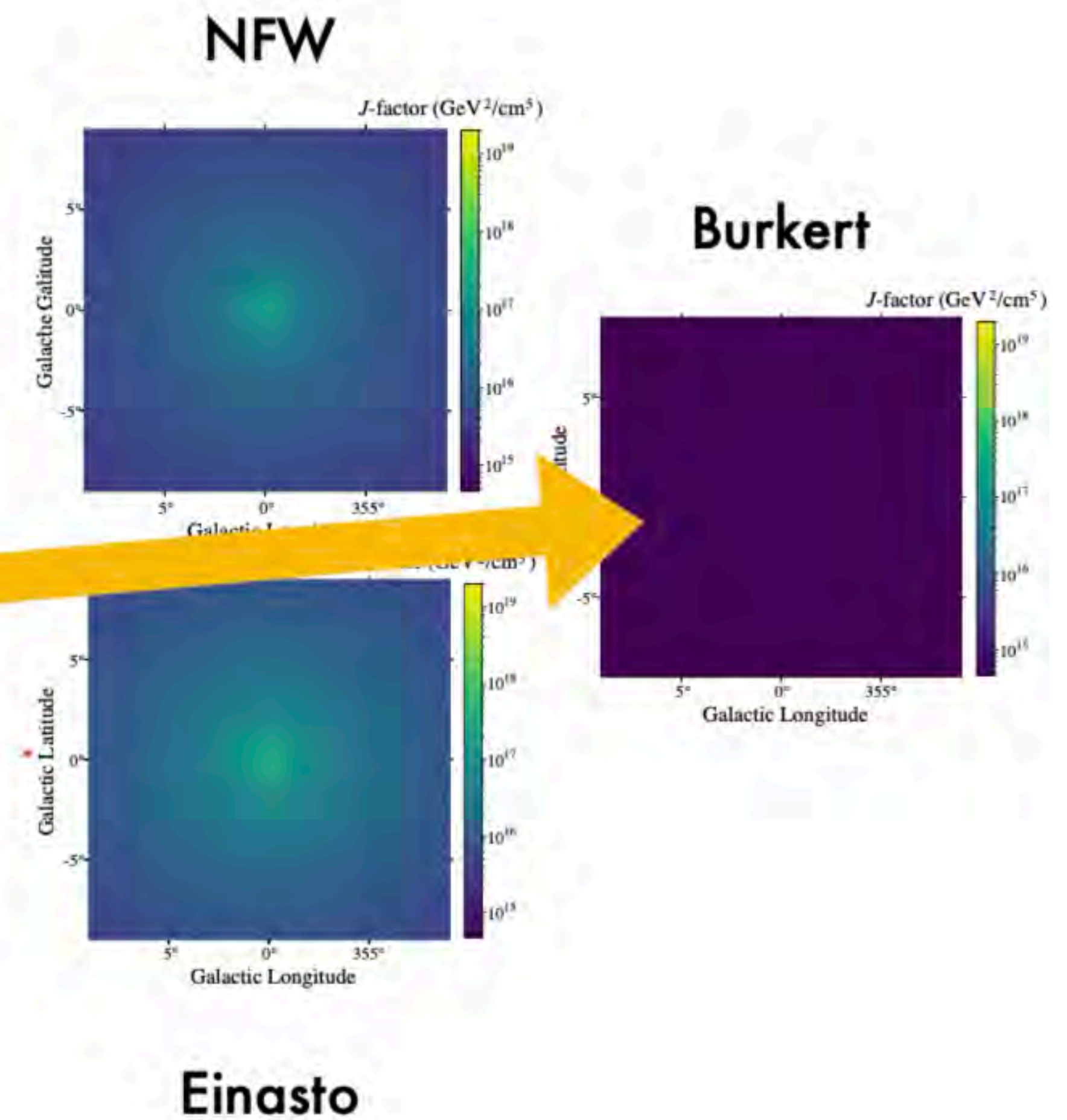
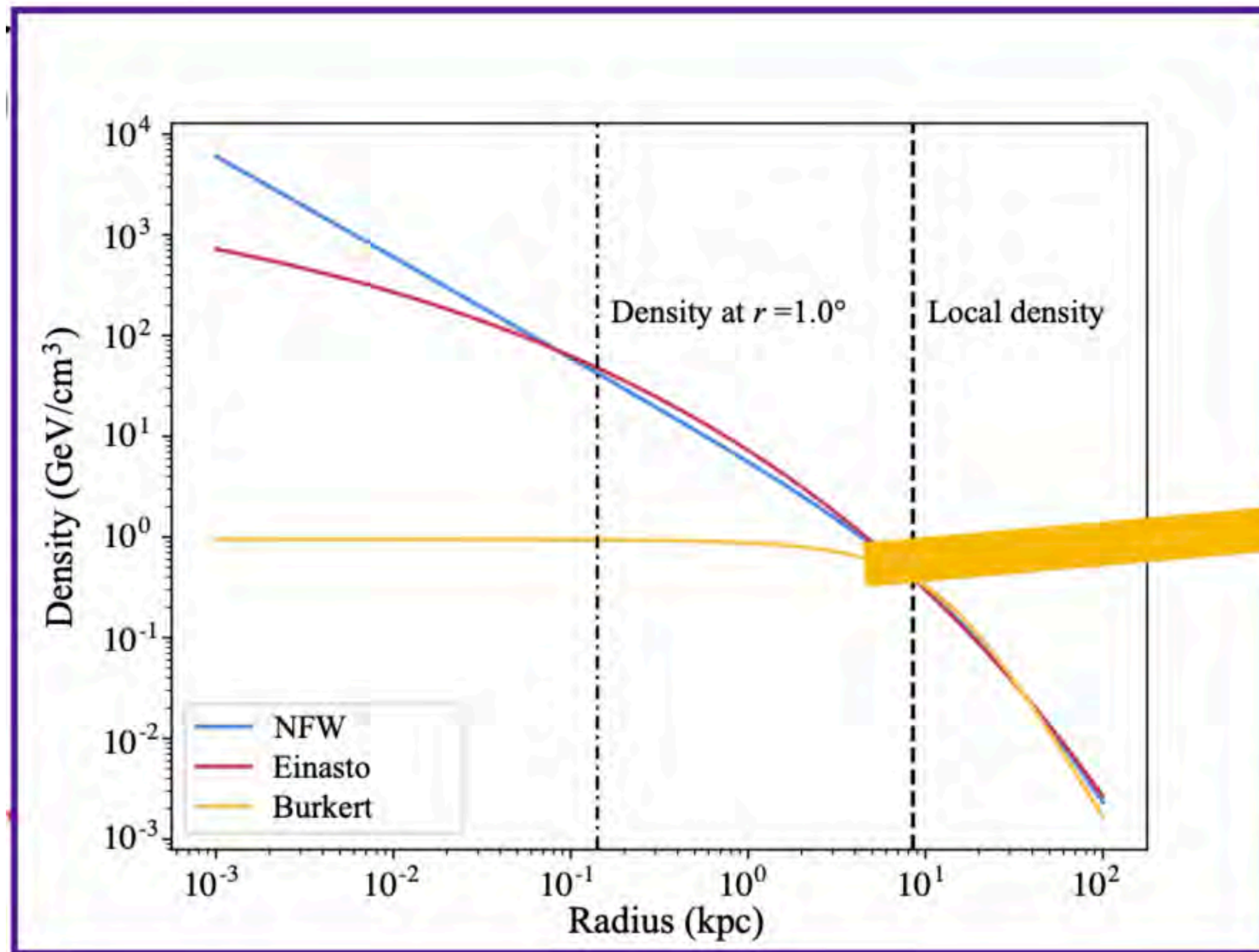
HAWC cannot resolve H.E.S.S. point sources



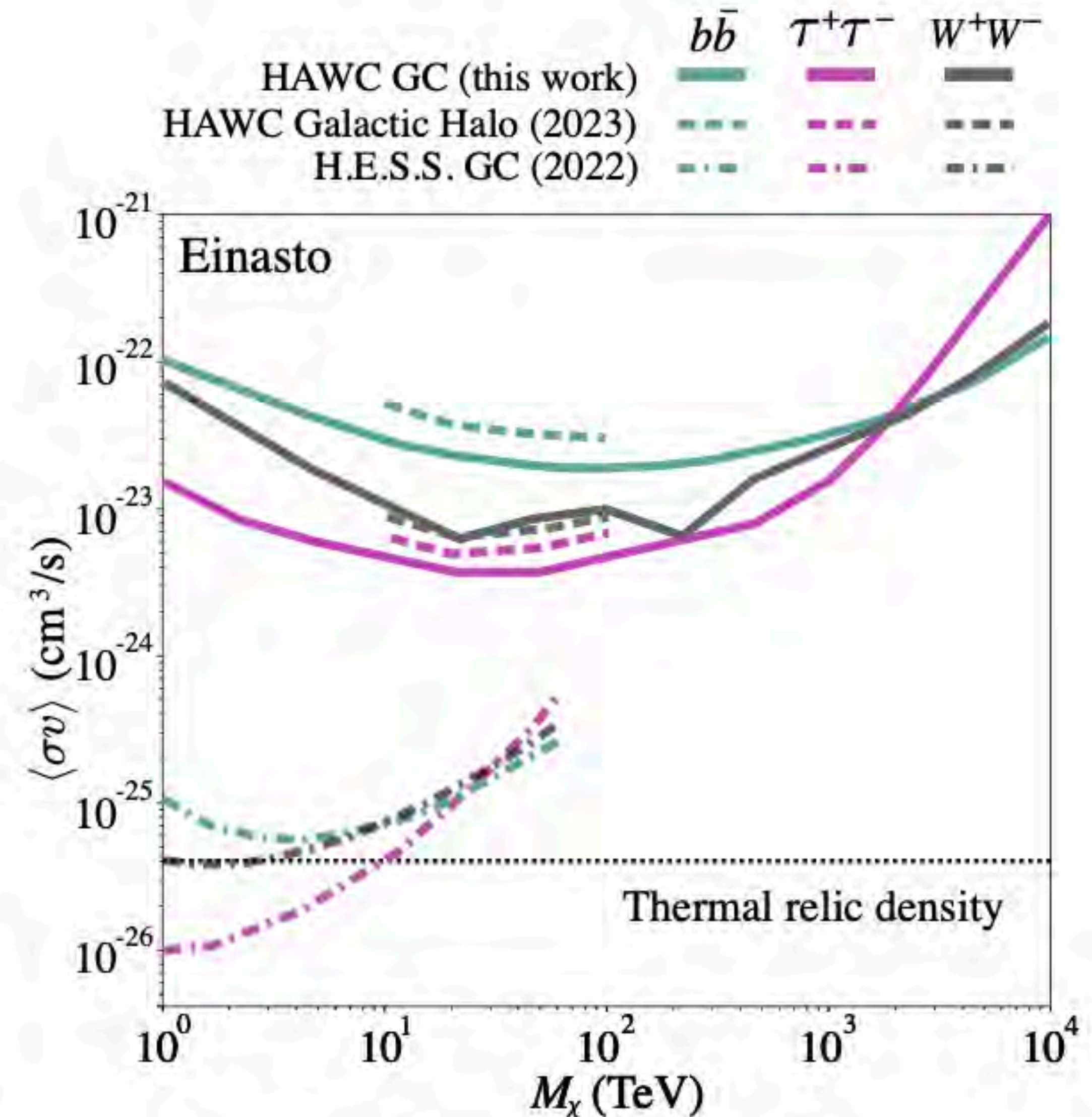
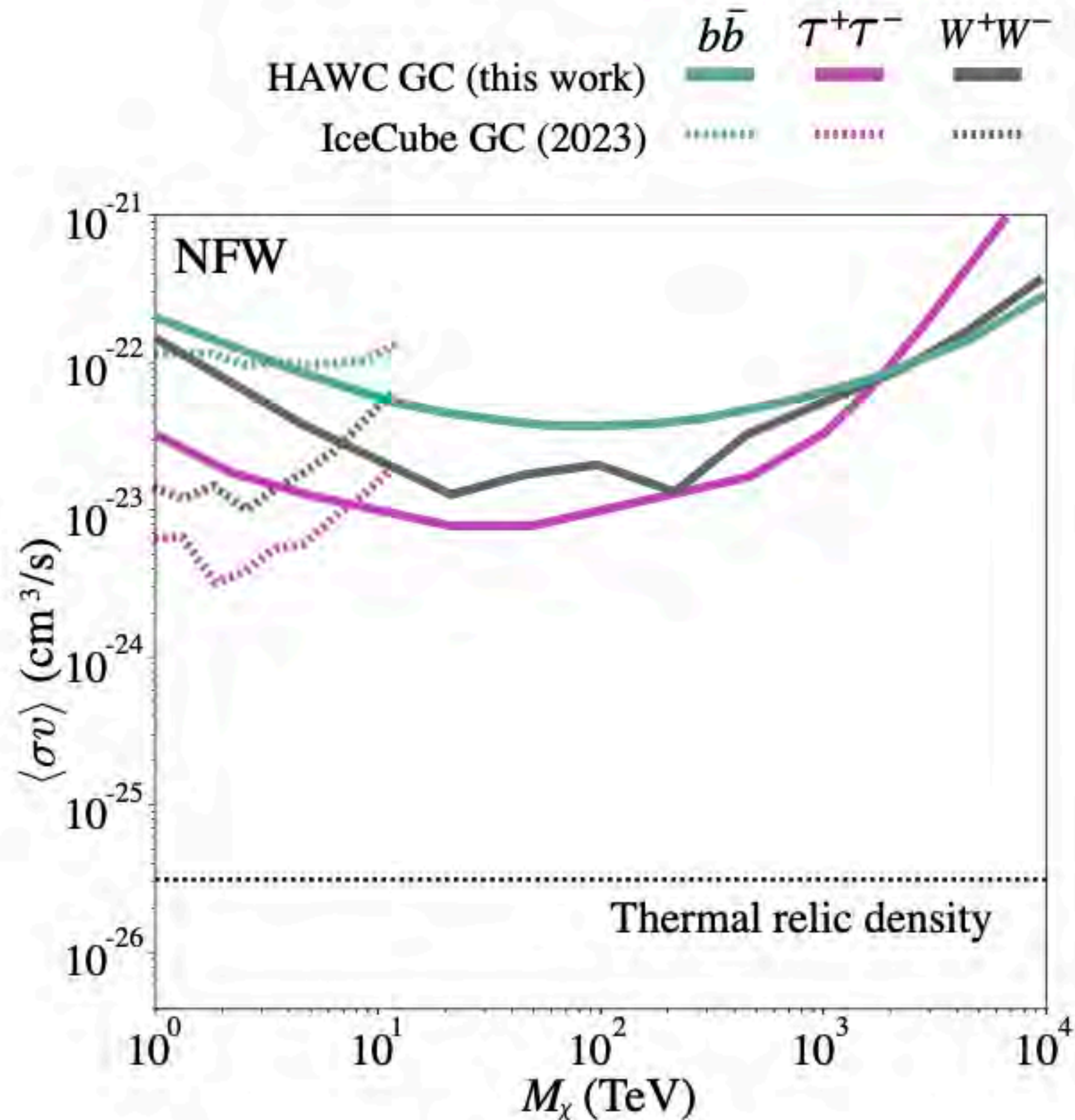
HAWC power law with H.E.S.S. sources subtracted.

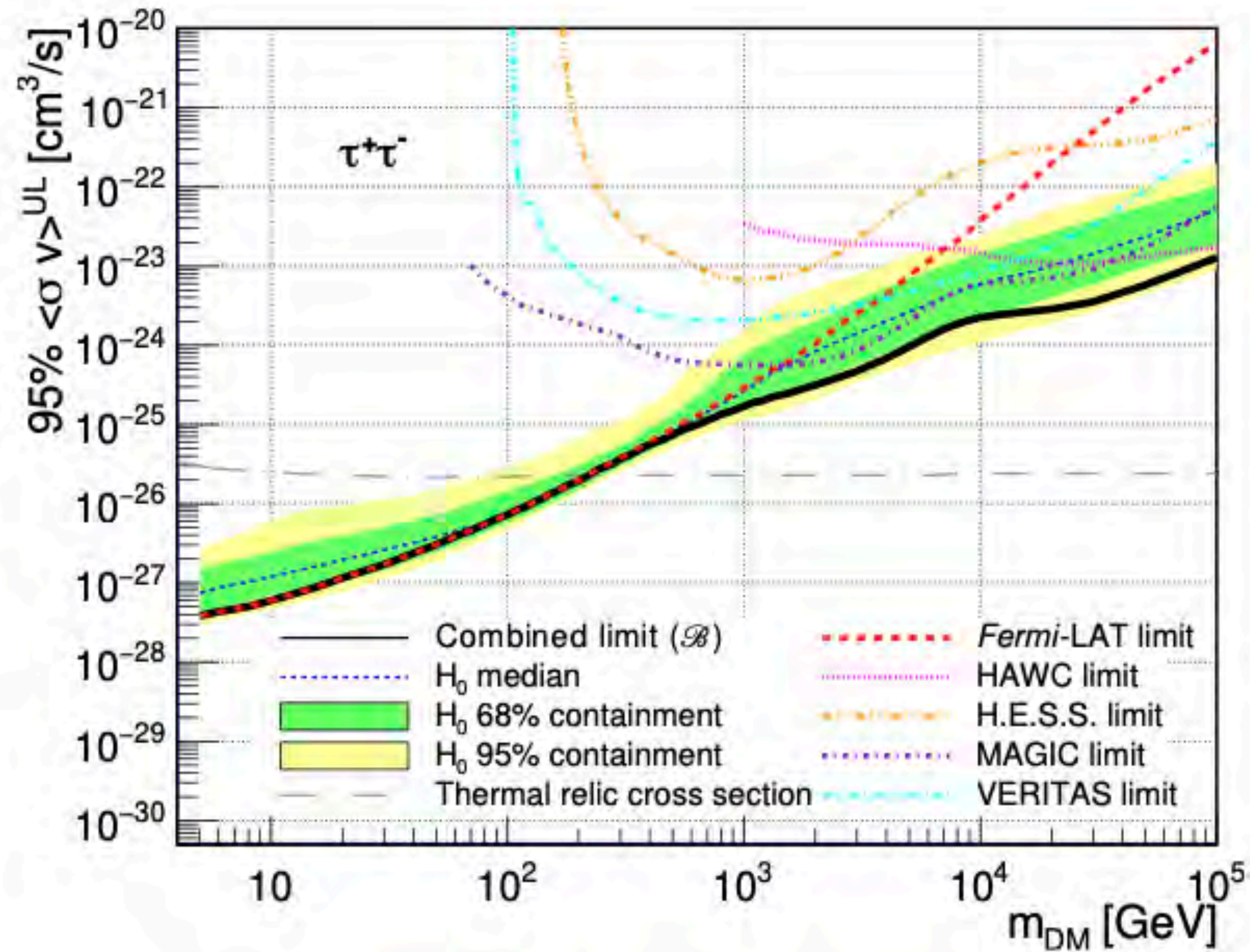






Dark Matter around the Galactic Center





Joint paper with Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS



IceCube-HAWC Analysis of the Galactic Center

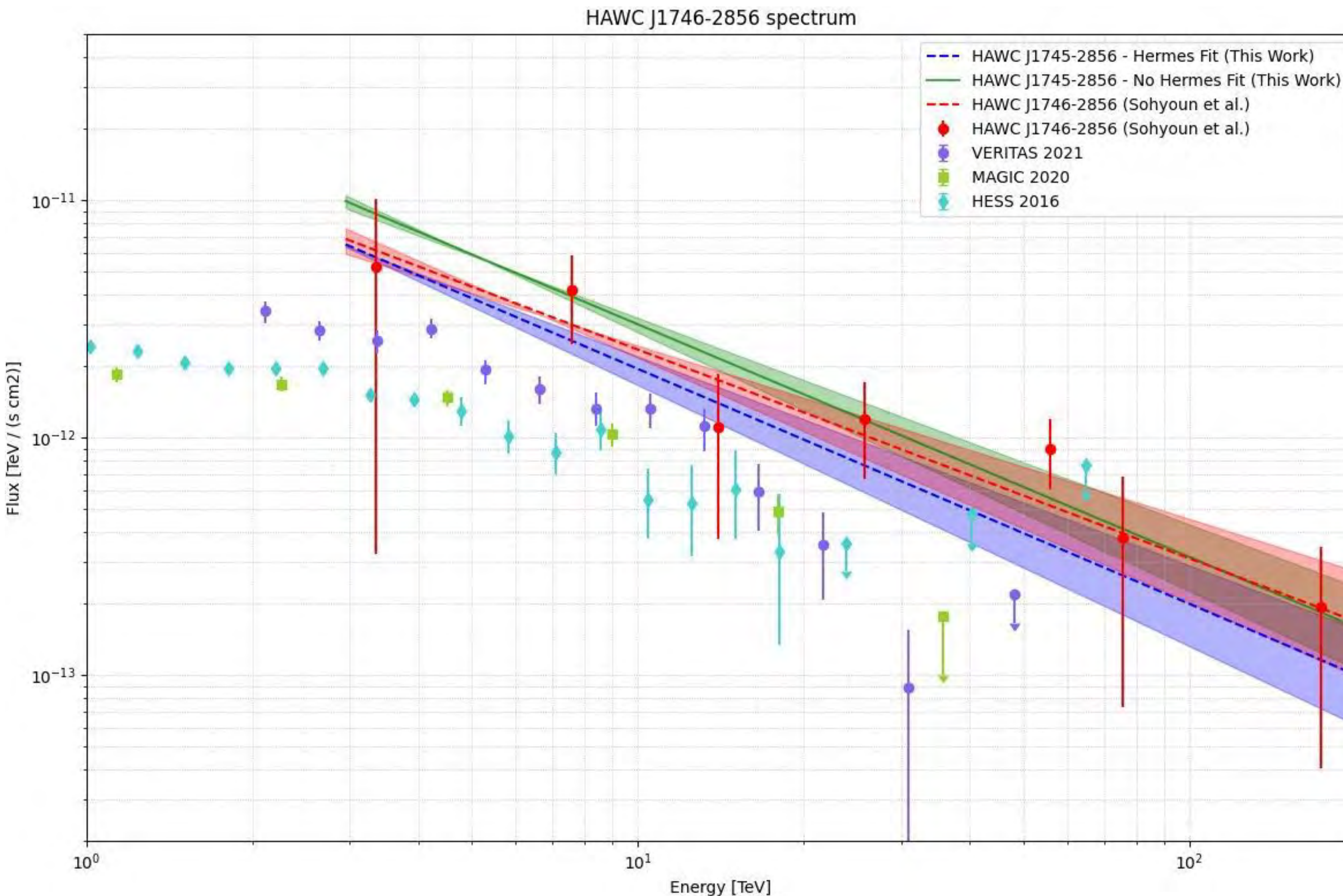
Sohyoun Yun Carcamo, Rishi Babu

IceCube-HAWC Collaboration

Michigan State University
Drexel University

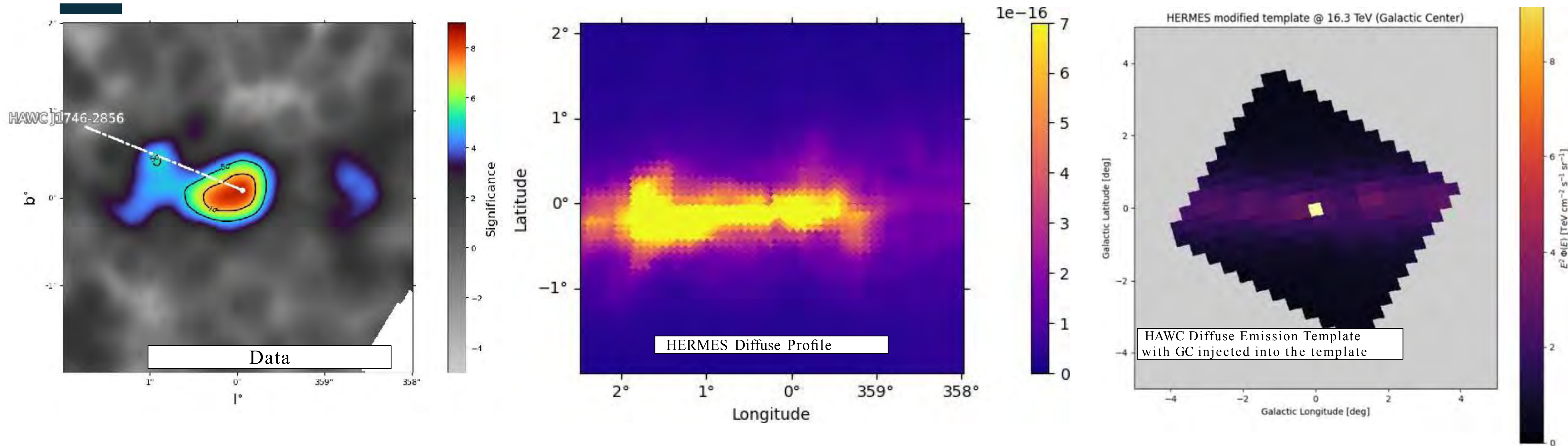


HAWC Galactic Center Analysis: Spectrum



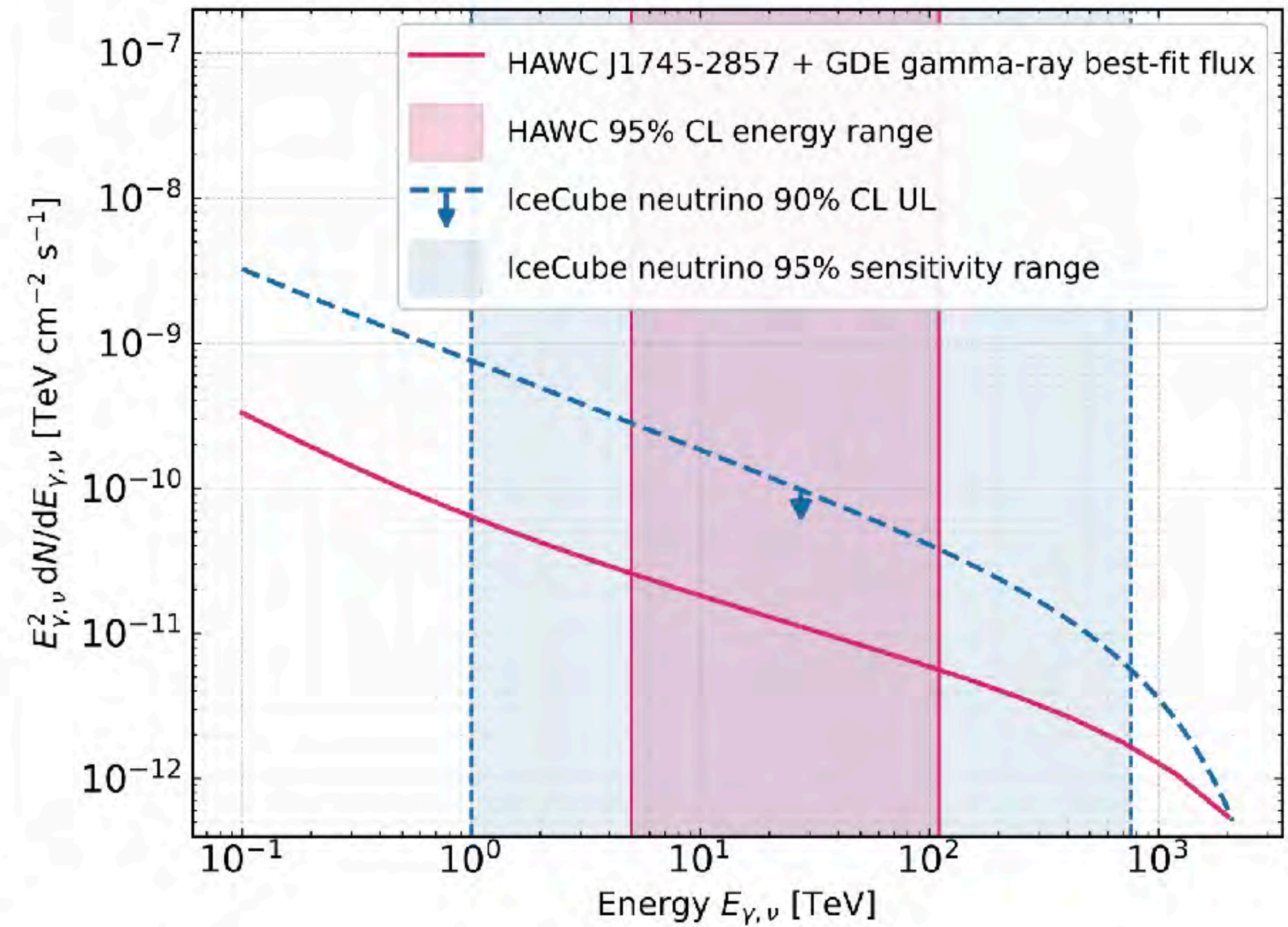
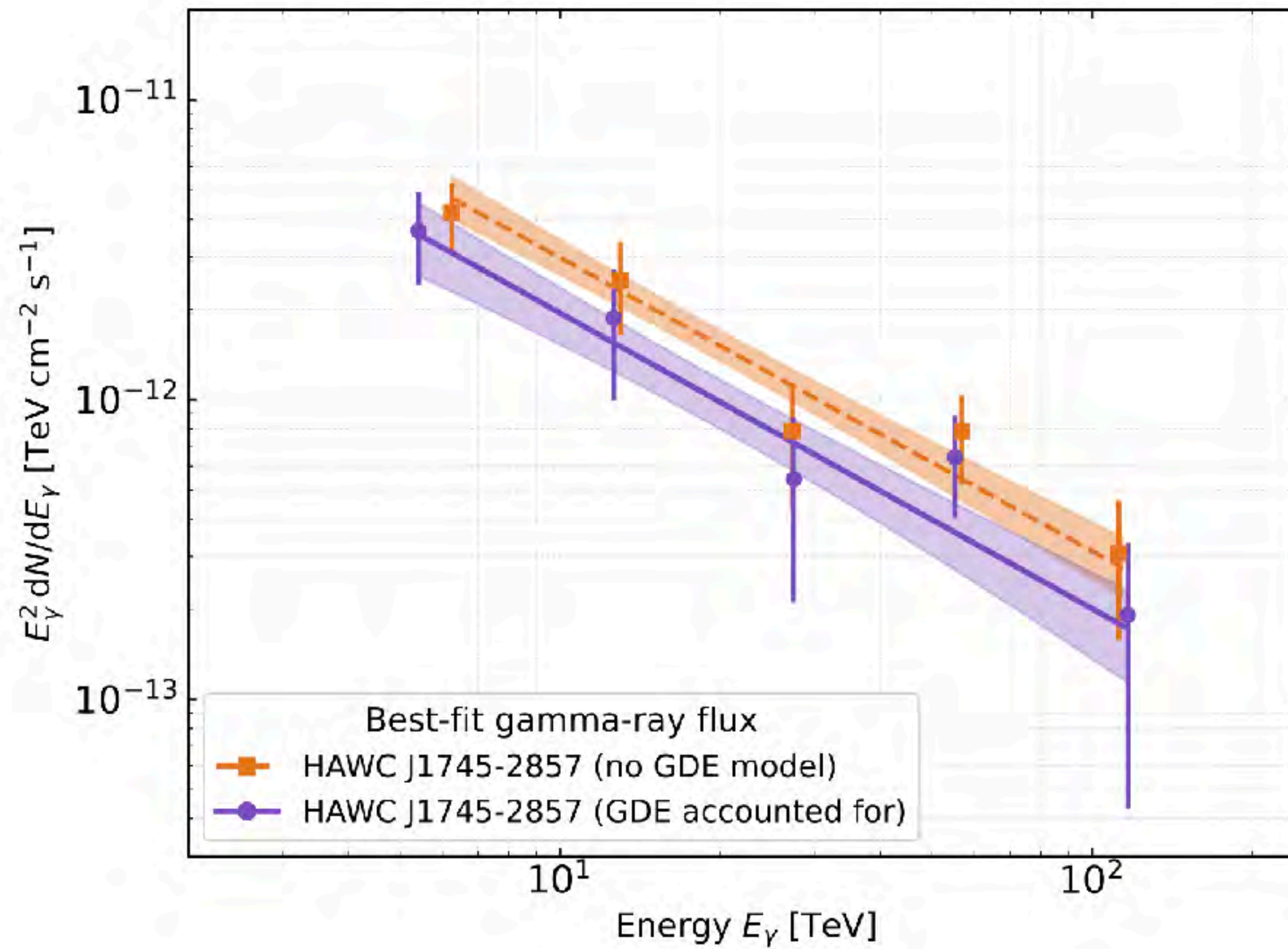
- **Blue** - HAWC GC (with HERMES)
- **Green** - HAWC GC (no HERMES)
- **Red** - HAWC GC 2024
- PS spectrum from 1PS higher than the GC 2024 result.
- PS spectrum from 1PS + HERMES - comparable to 2024 result
- Fraction of diffuse emission contributing to the single point source fit is ~ 0.35 of total flux or 35% of the total emission

IceCube Galactic Center Analysis: Overview

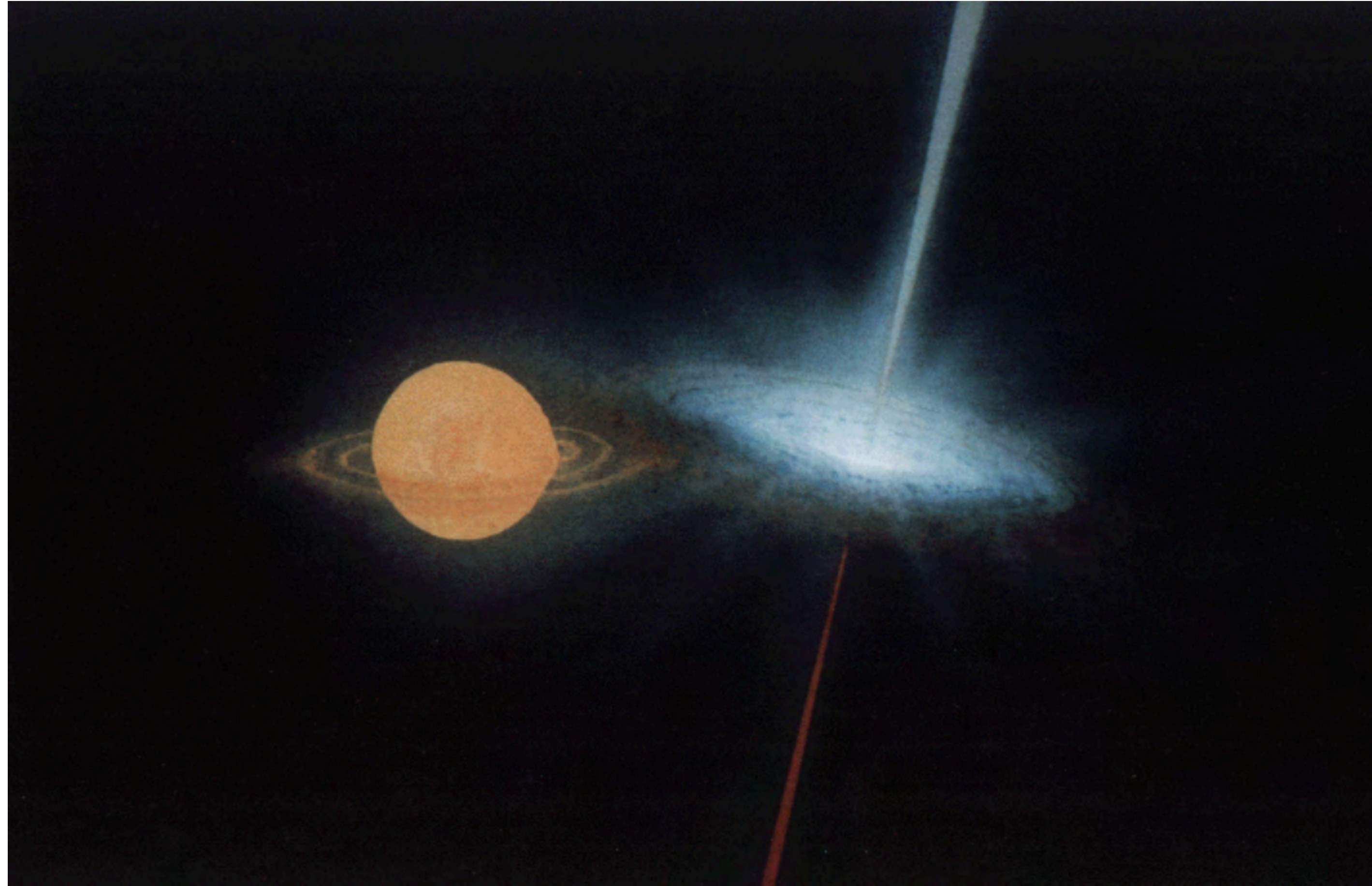


- Use a HERMES template for diffuse neutrino emission
- Inject a GC PeVatron point source into the HERMES template with the HAWC Spectrum
- The relative flux of injection and the background template is assuming the flux ratio calculated from HAWC in the last slide
- Use IceCube Neutrino Tracks to compare the diffuse only hypothesis to the diffuse+injected source hypothesis

Results



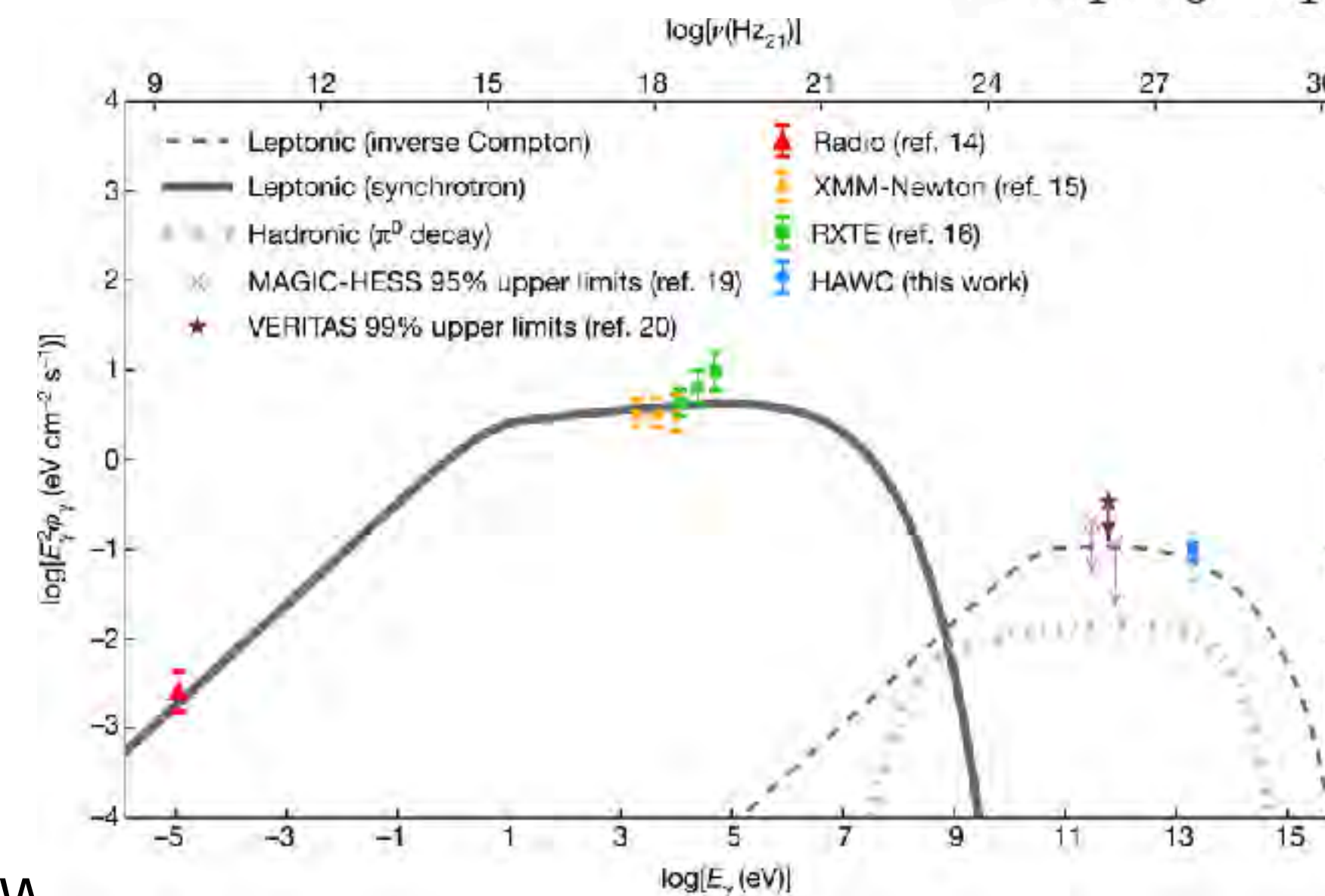
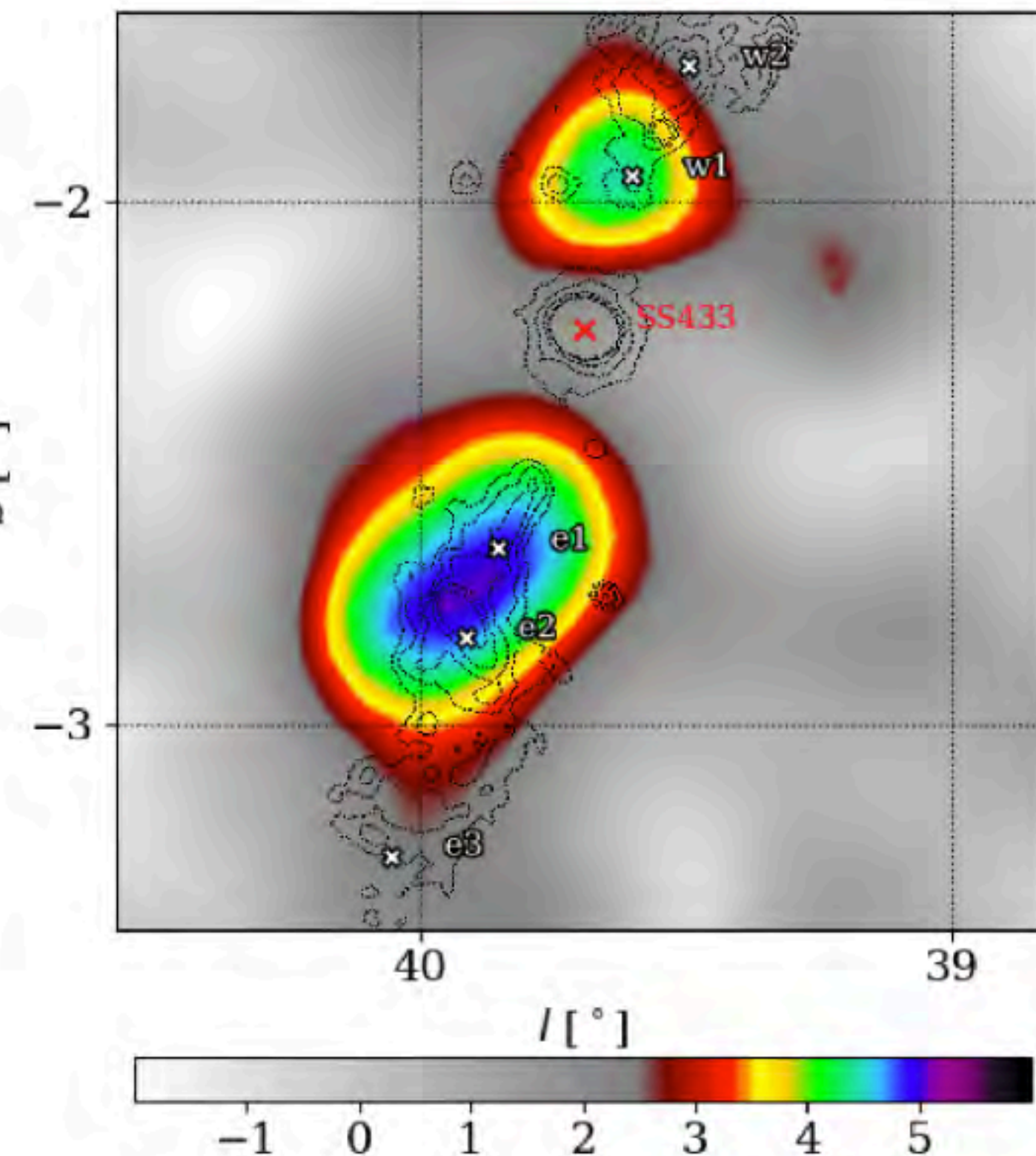
Microquasars



Possible an A-type supergiant and a very extended disk around a black hole.

Microquasar SS-433

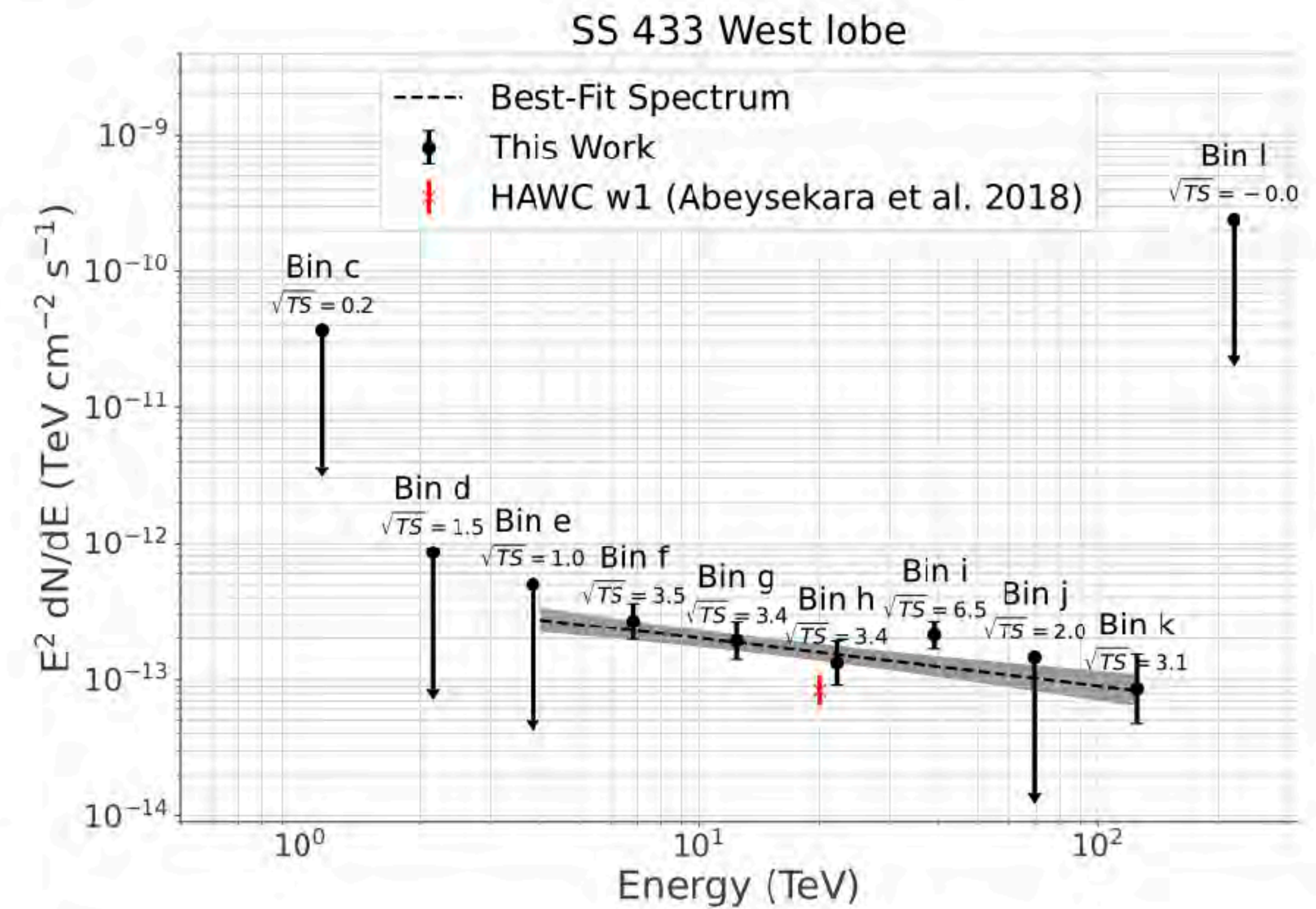
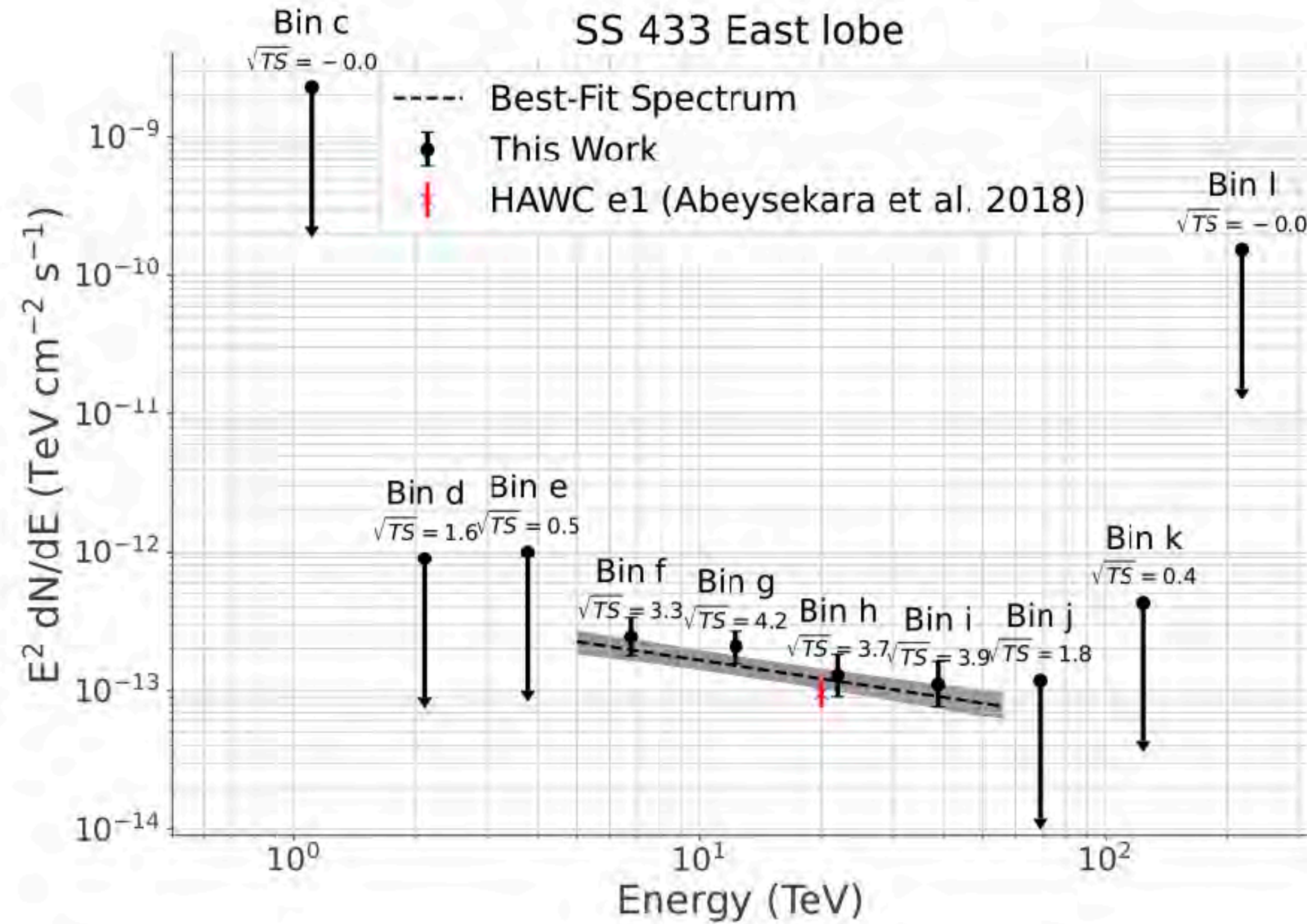
- HAWC observation of SS433 is the first direct evidence of particle acceleration to $\sim \text{PeV}$ in jets
- Jets are observed edge-on so the gamma rays are not Doppler boosted to higher energies or higher luminosities
- Hadronic acceleration disfavored due to extreme energetics required
- Acceleration does not happen at the black hole because the cooling time of the electrons is too short to make the observed gamma-rays
- Fermi observes similar phenomena in AGN (Cen A & Fornax)

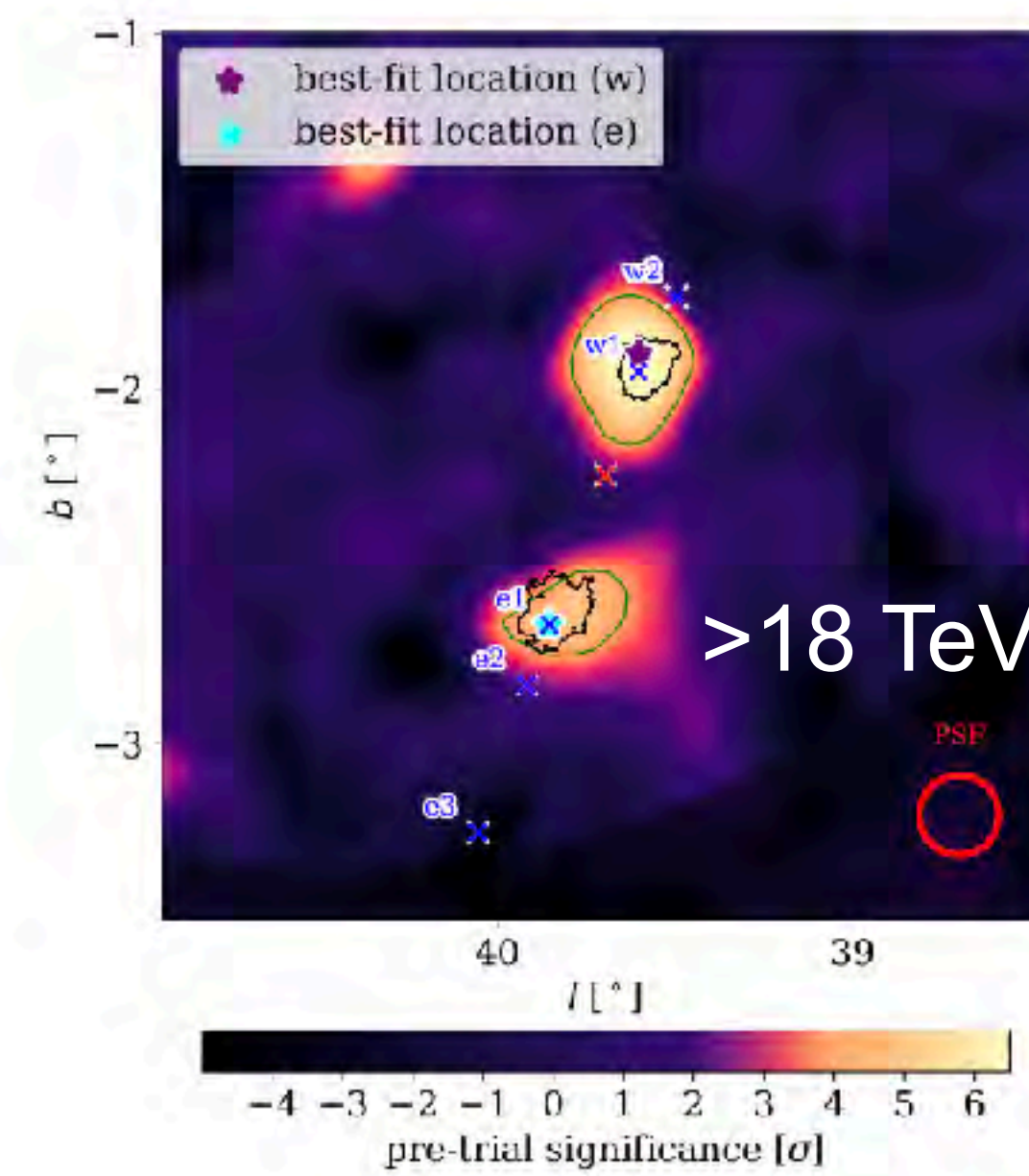
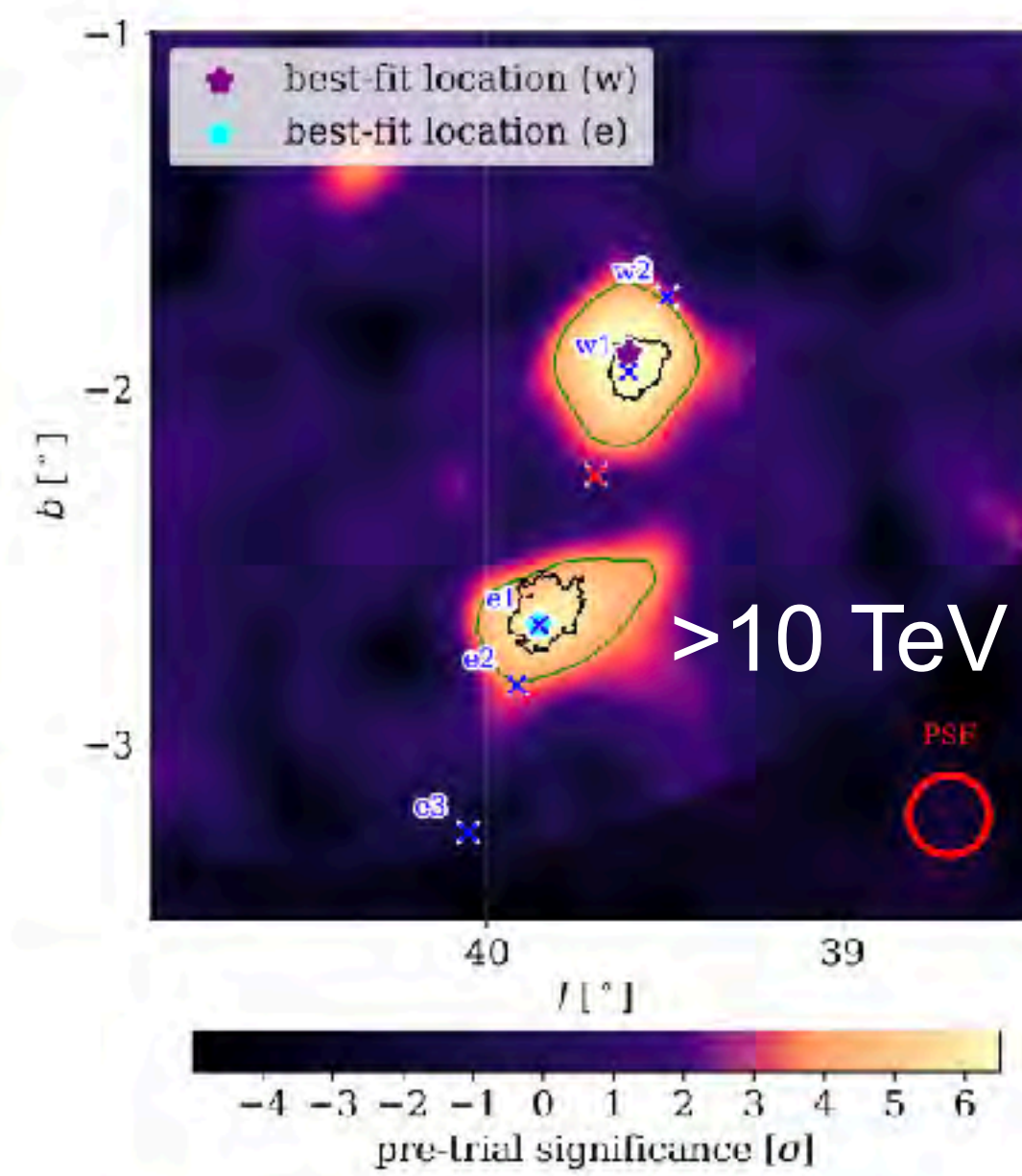
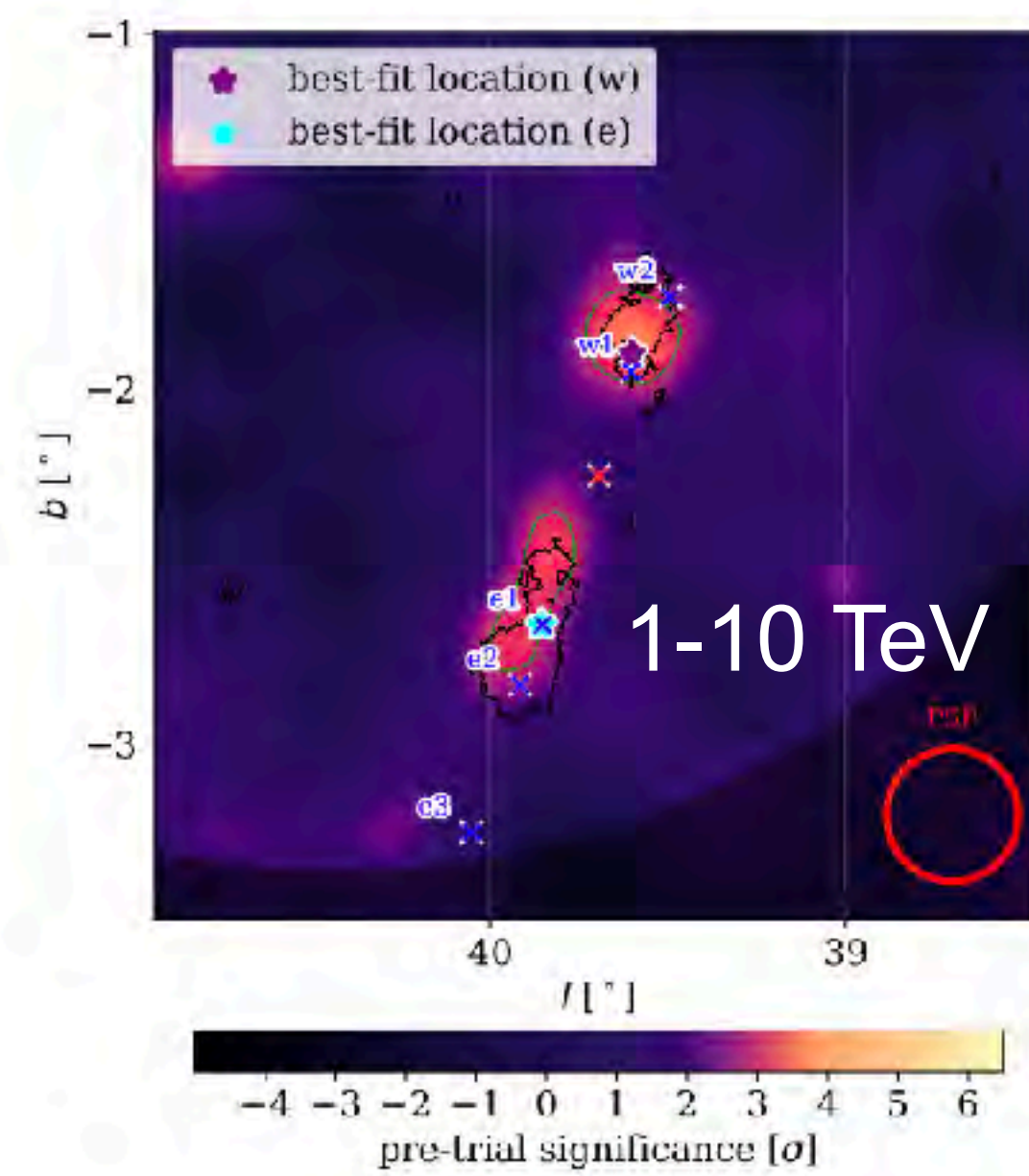


Published in Nature Oct 4, 2018

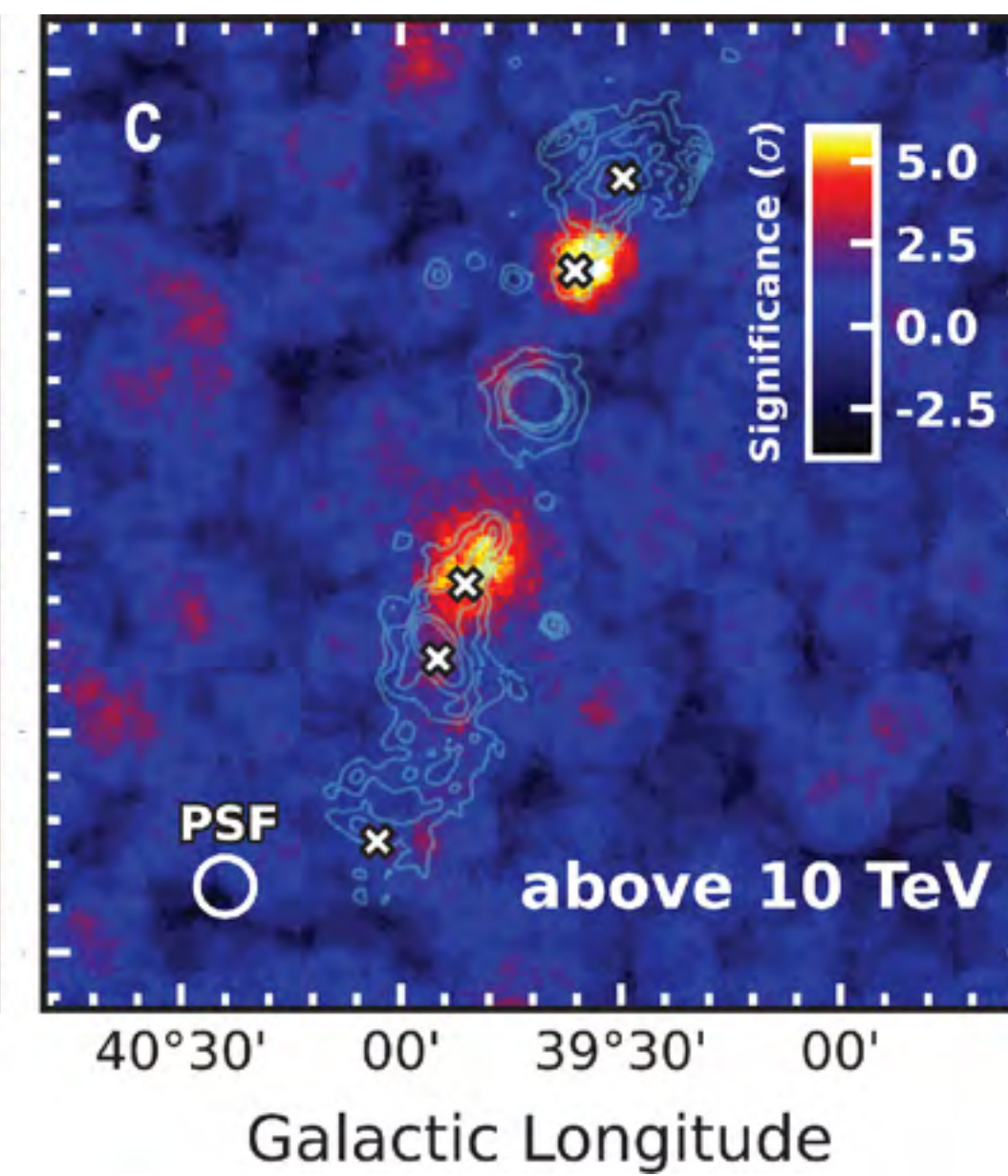
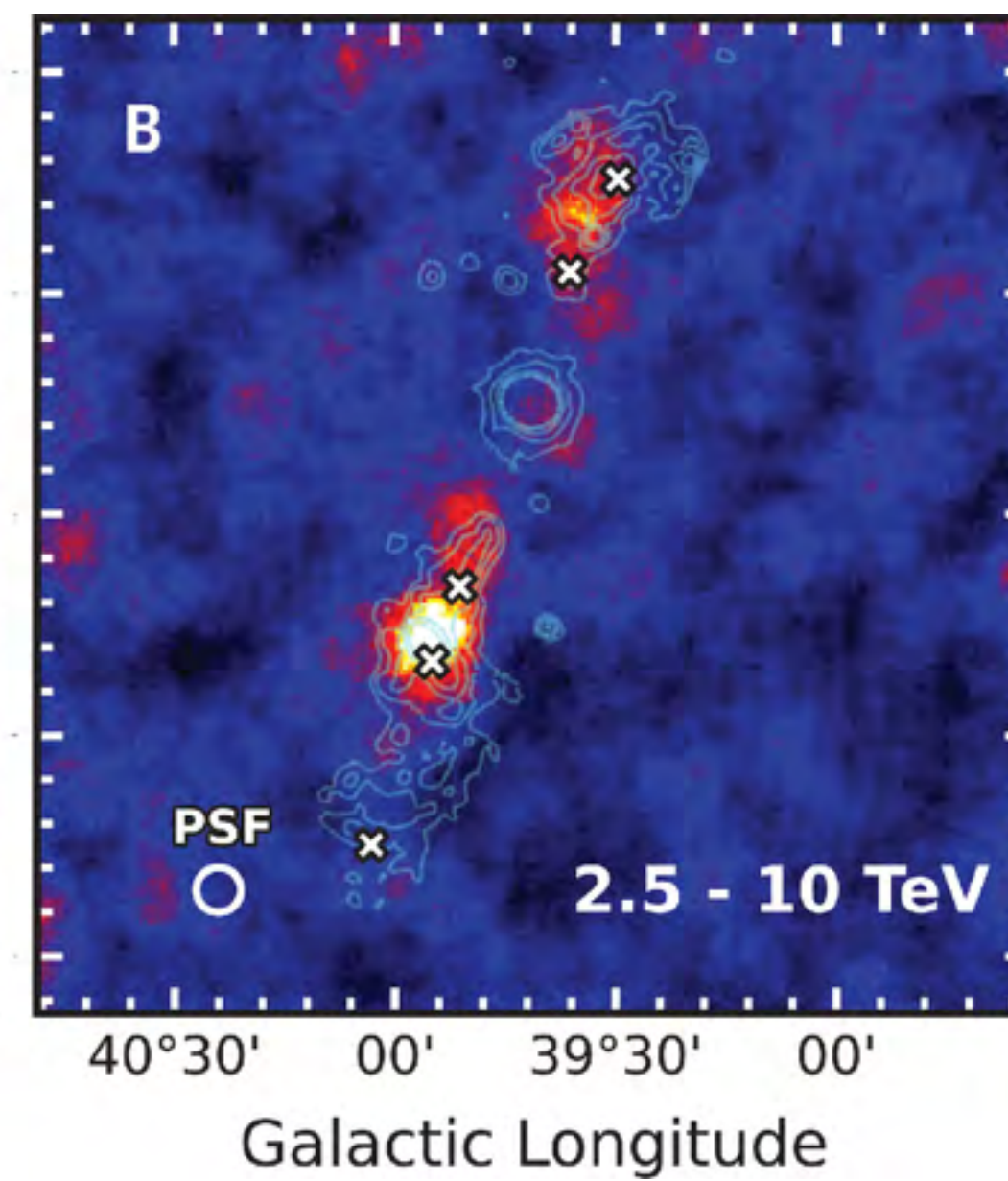
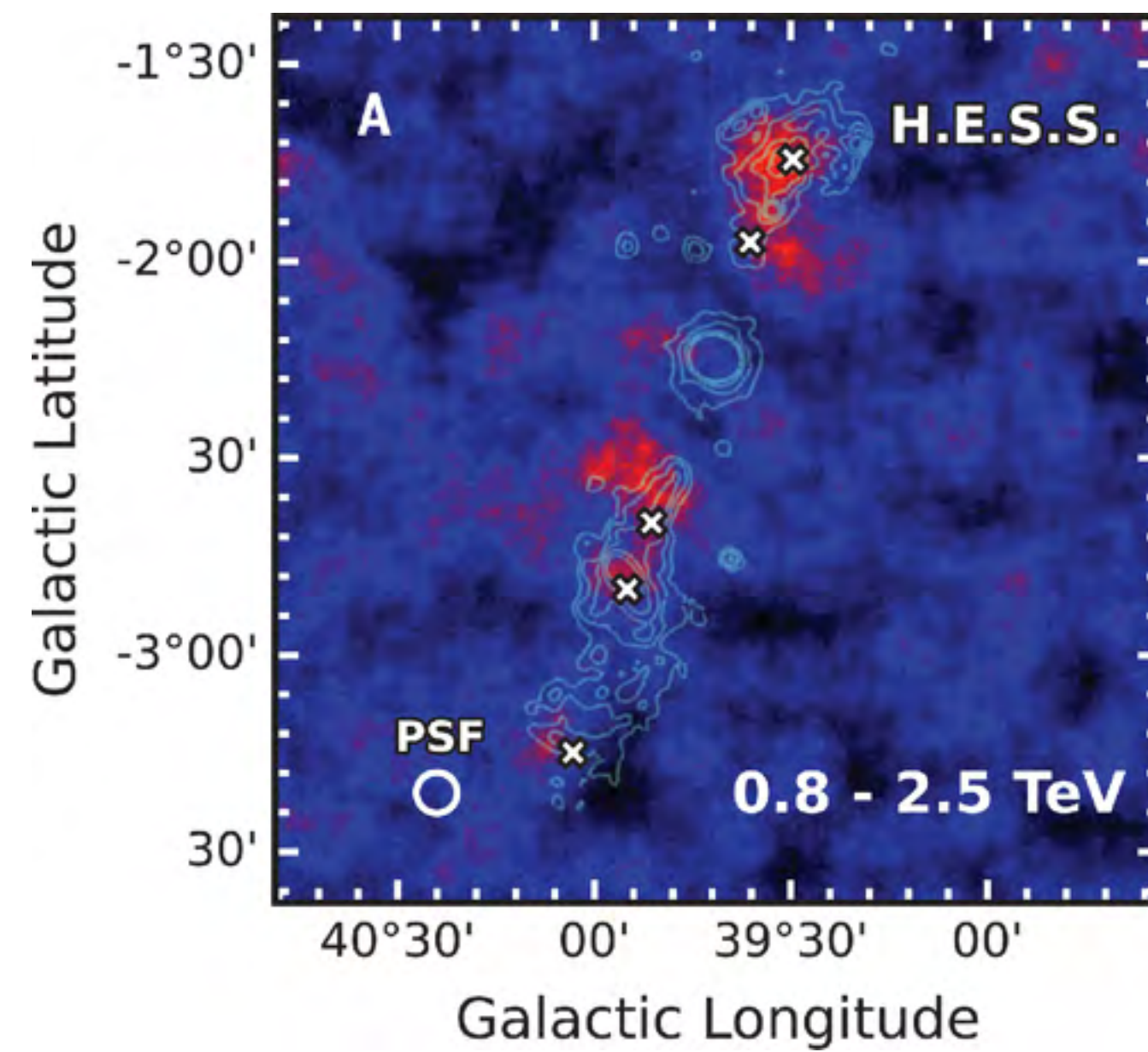
Updated results on SS433

SPECTRAL STUDY OF SS 433

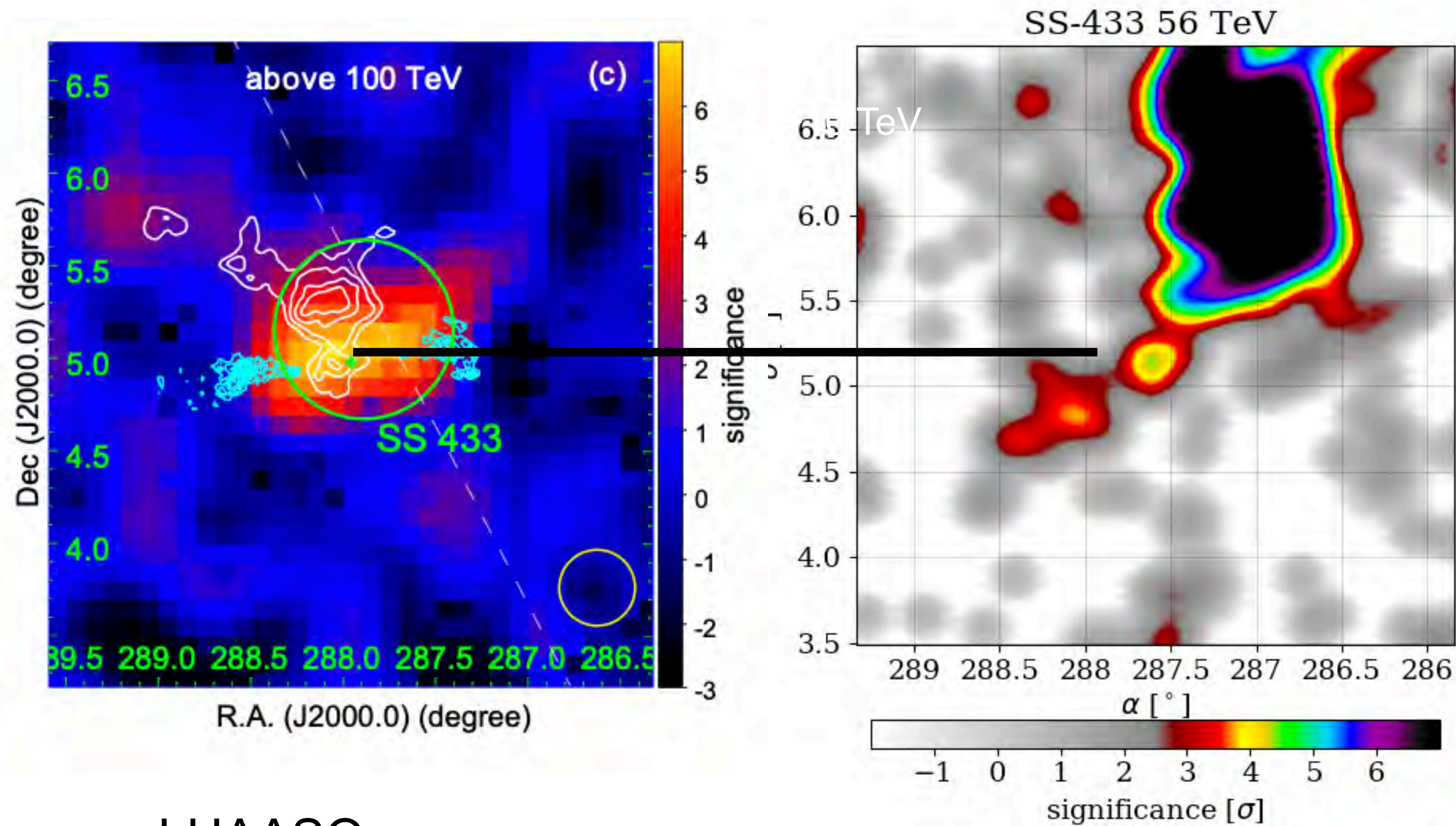




HAWC

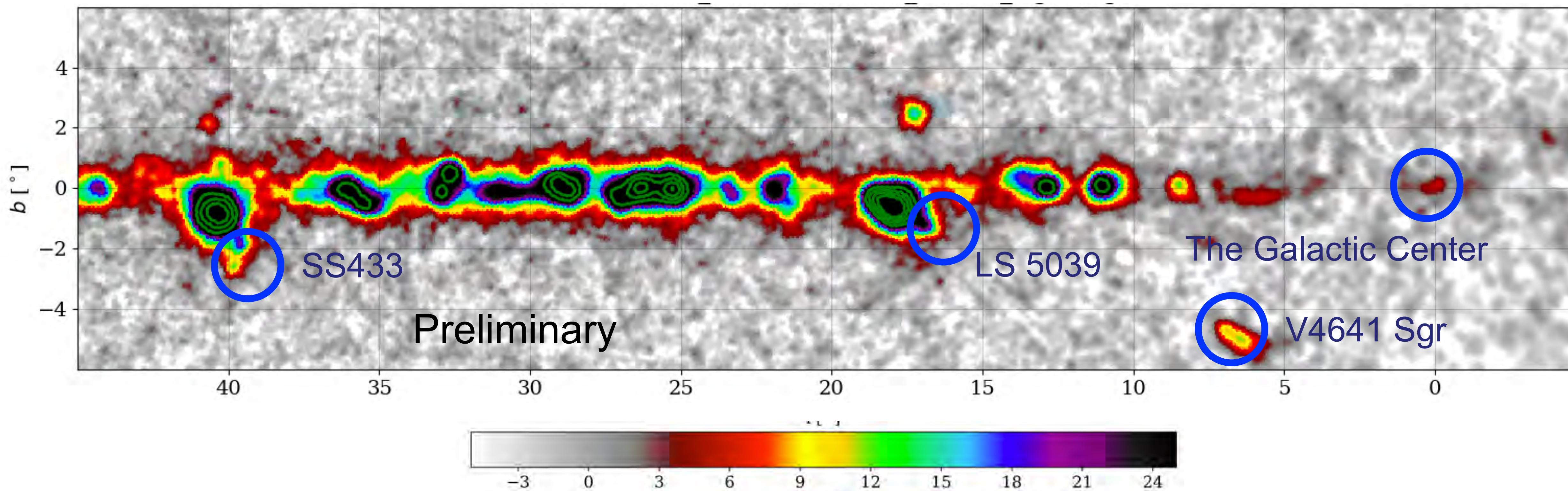


H.E.S.S.



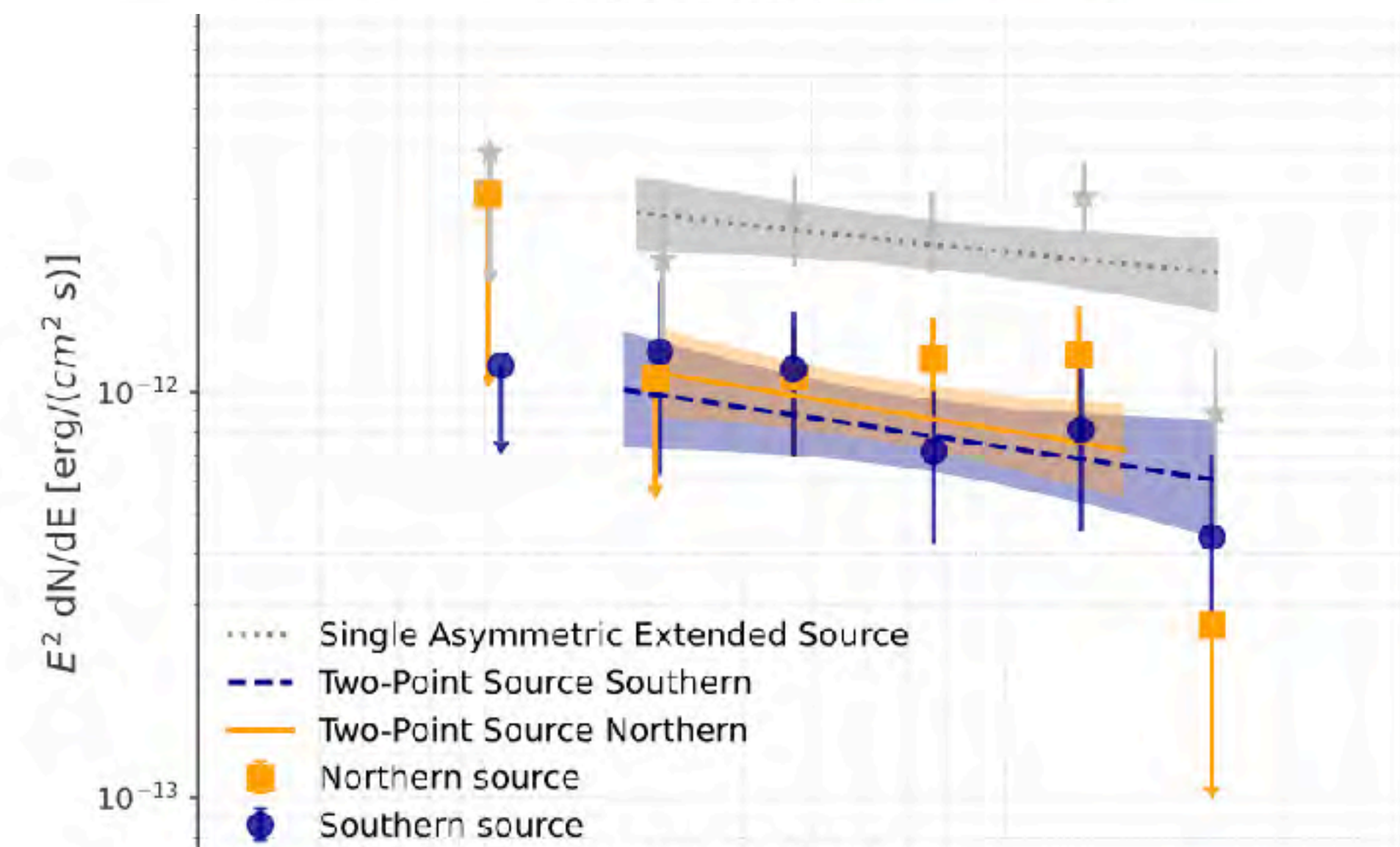
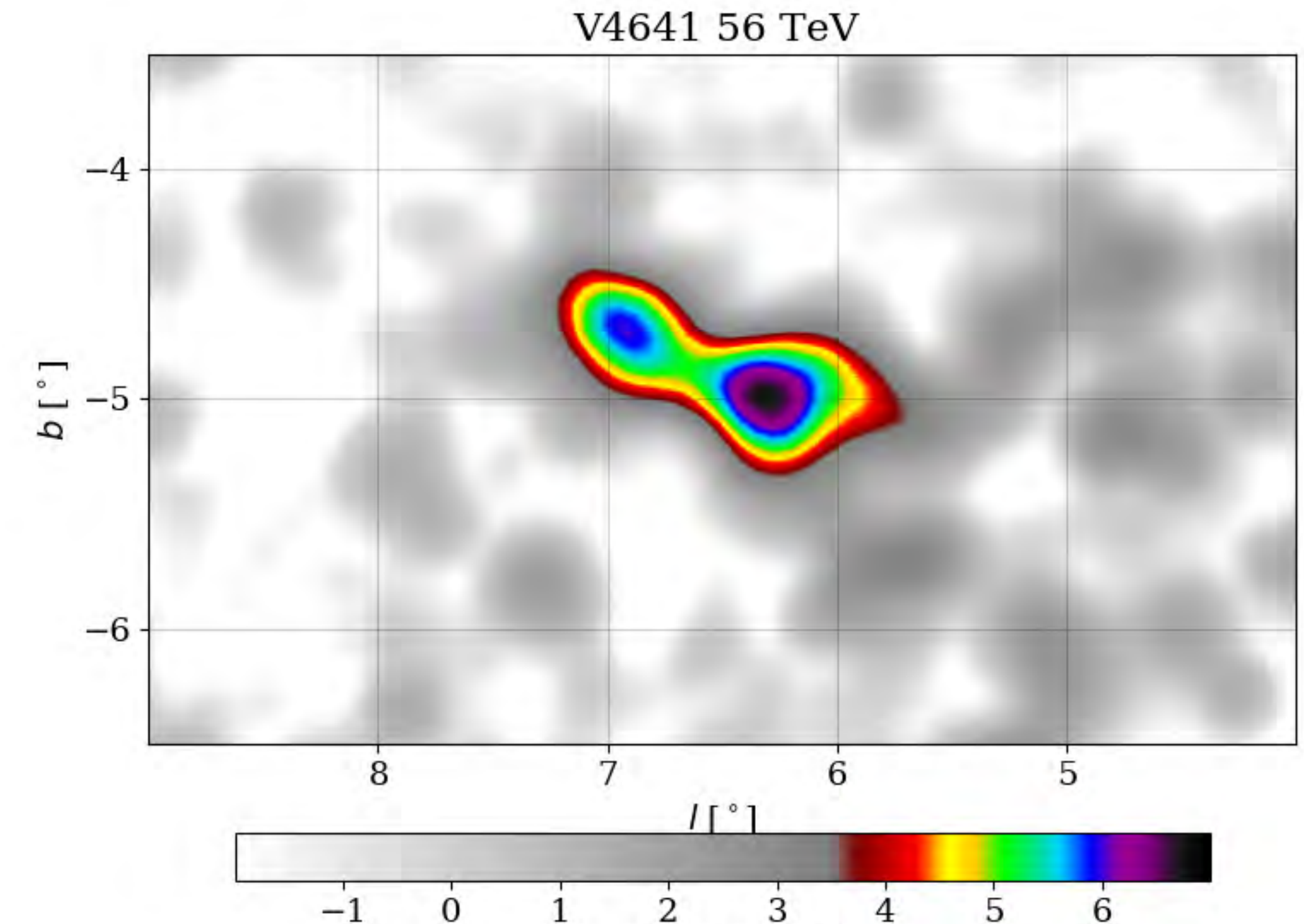
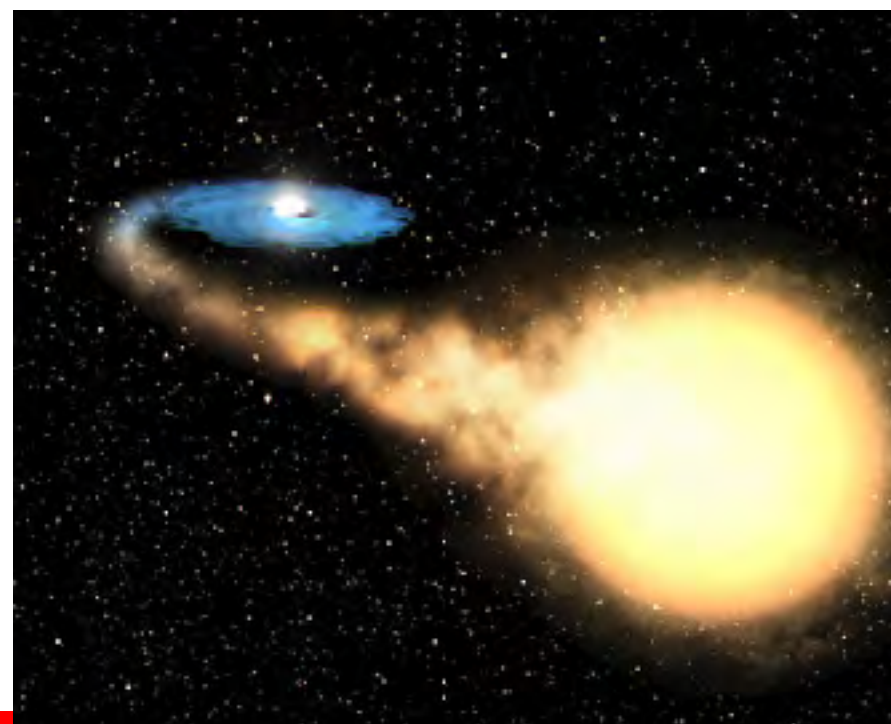
LHAASO

HAWC - ML J1908+06 not subtracted

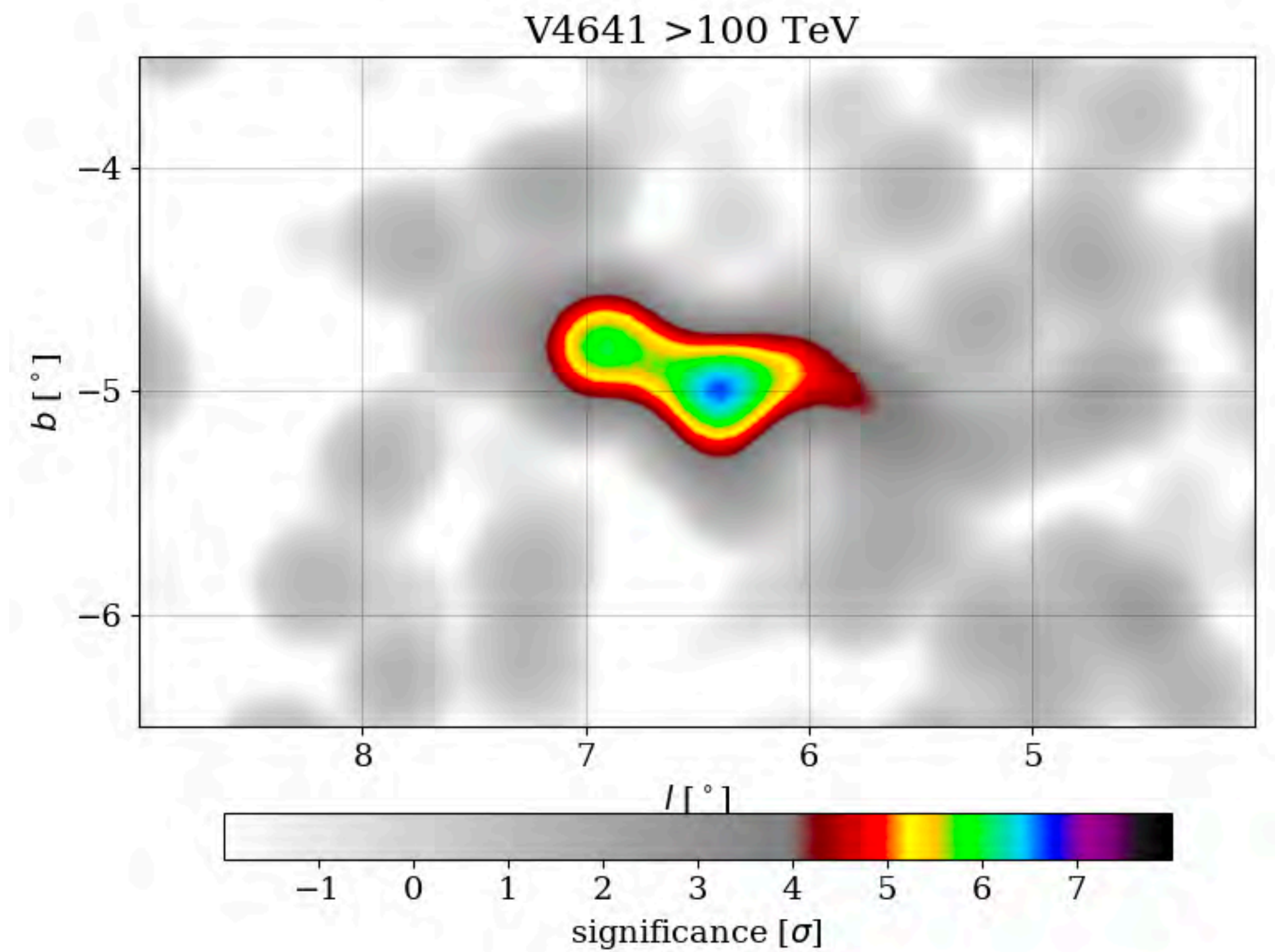
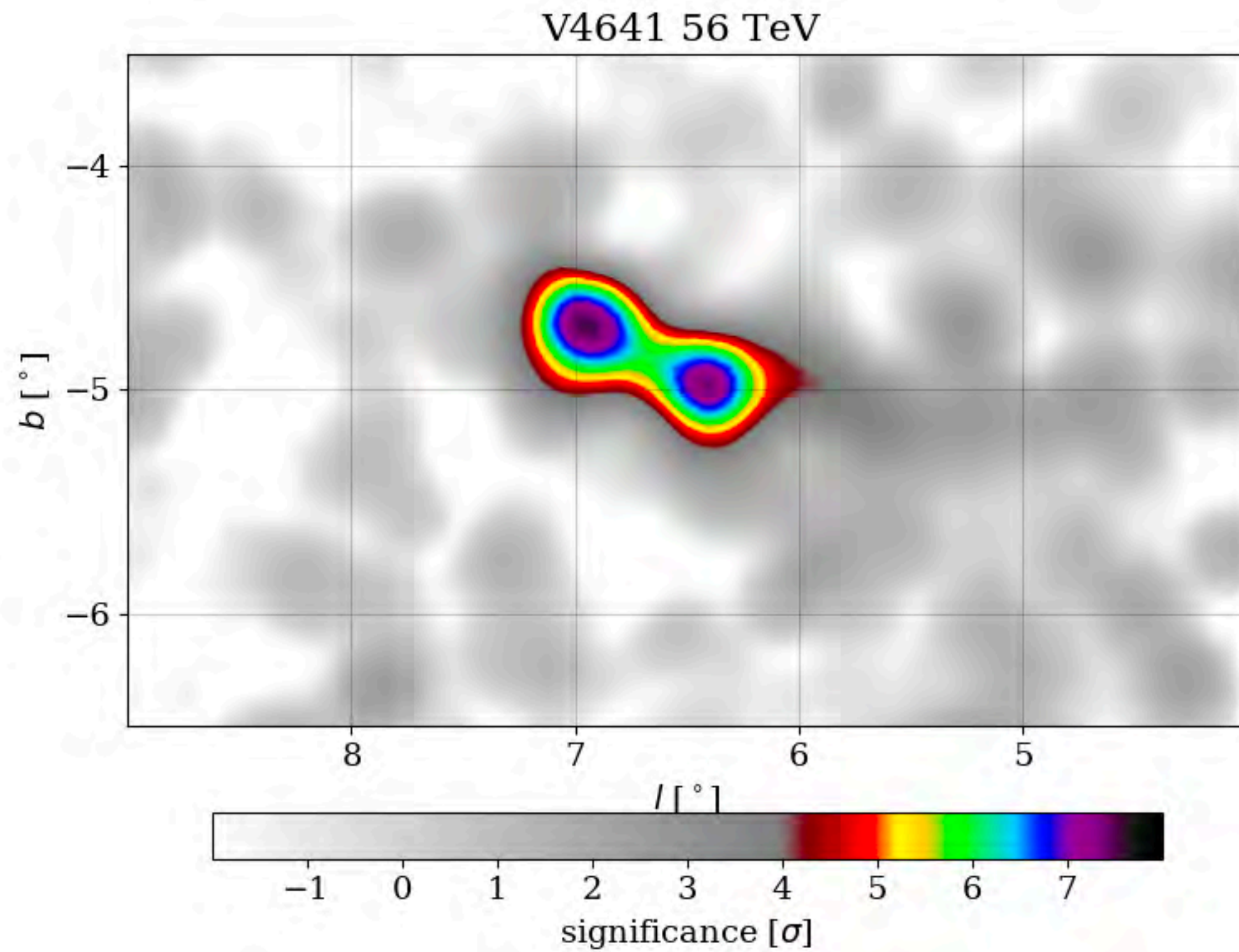


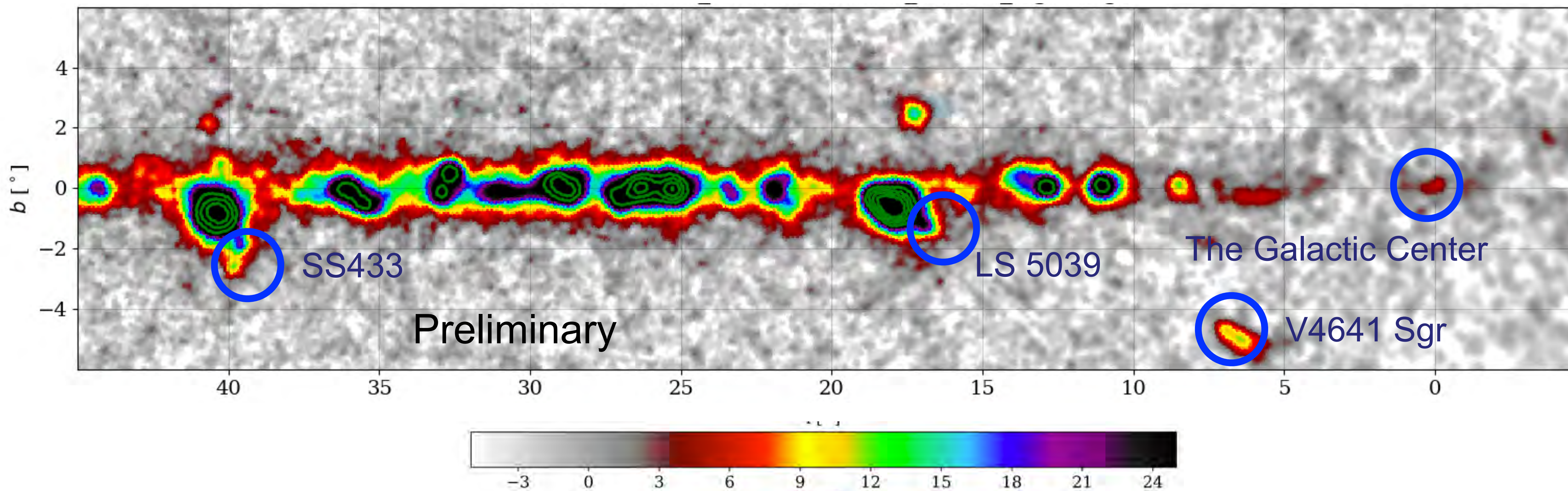
V4641 Sgr - Binary System

- TeV micro-quasar discovered by HAWC.
- We measure photon energies from 300 GeV to above 100 TeV, with no sign of a cutoff above 200 TeV.
- The source is surrounded by a bubble of very high energy emission with a size of roughly ~ 100 pc, much more extended than the radio jet.
- If hadronic this indicates that micro-quasars could be PeVatrons.



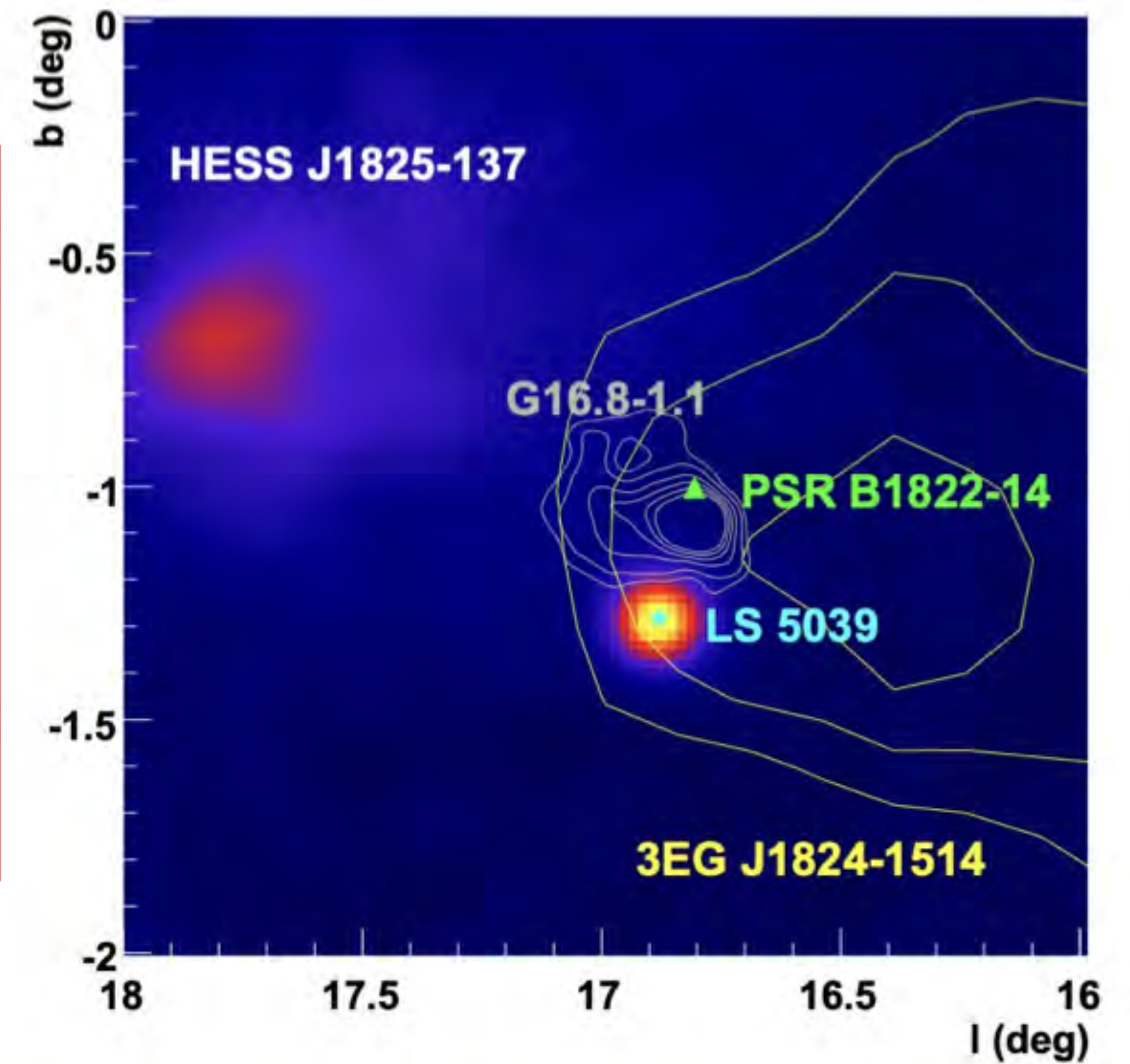
V4641 in Machine Learning Data



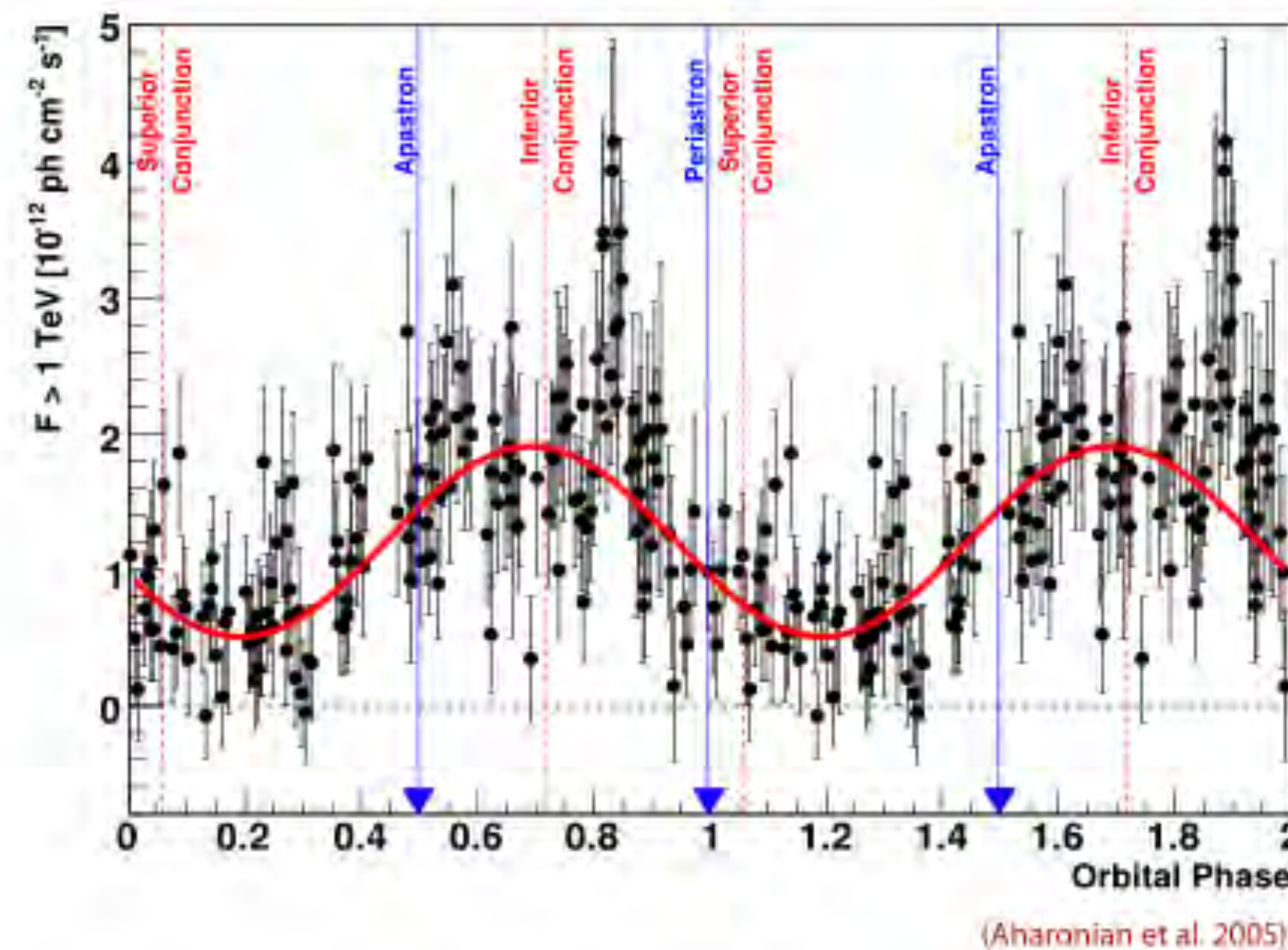
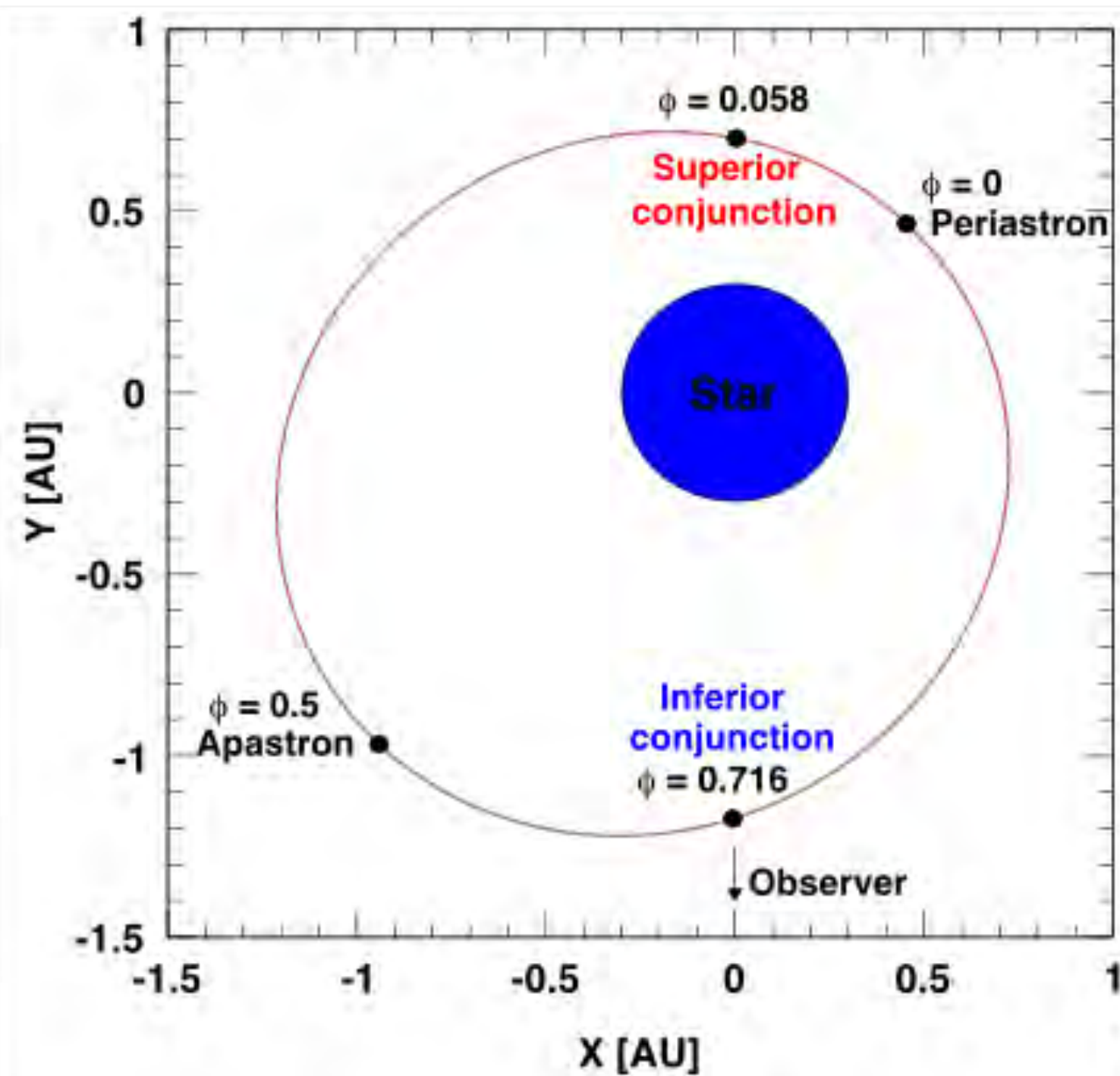


LS 5039

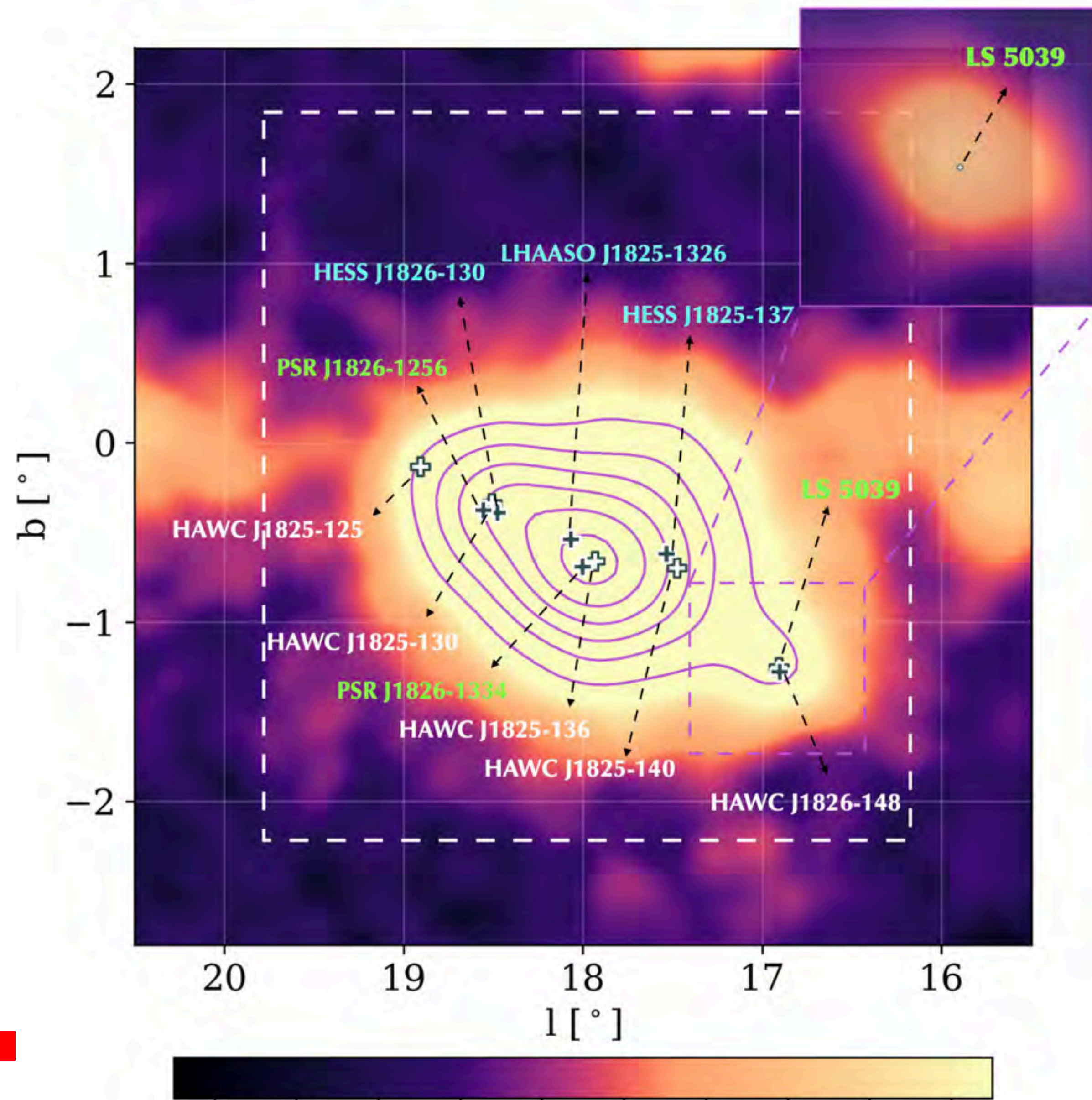
- Either microquasar with relativistic jet formation through matter accretion onto the compact object or acceleration resulting from the interaction between pulsar and star winds
- Distance = 3.5 kpc , O6.5V star and compact object with a mildly eccentric 3.9 day orbit. Mass companion star $23 M_{\odot}$, mass compact object = $3.7 M_{\odot}$
- From radio to TeV energies. Flux and spectral modulation as a function of its orbital period.



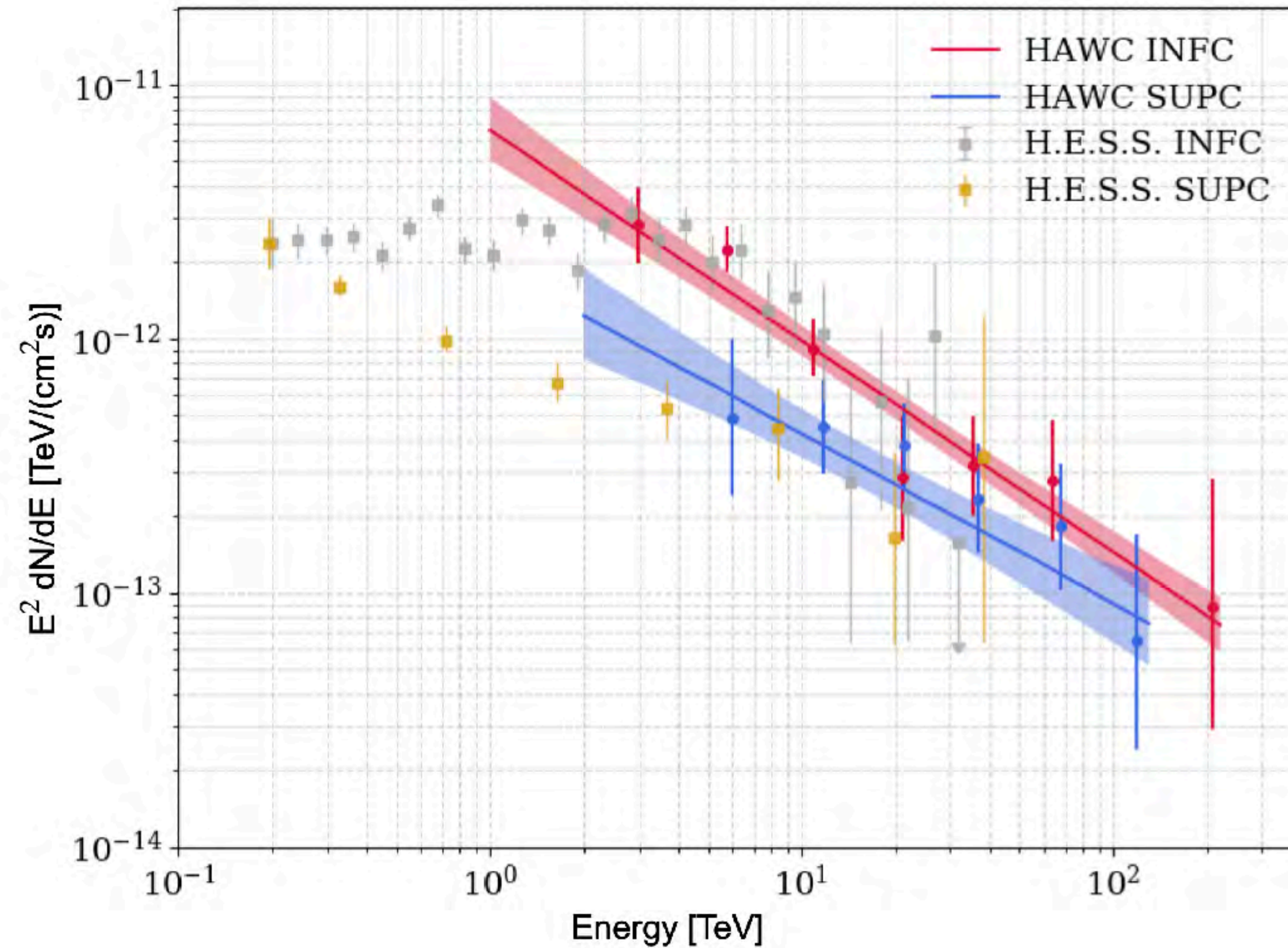
HESS Coll 2005-2007



(Aharonian et al. 2005)

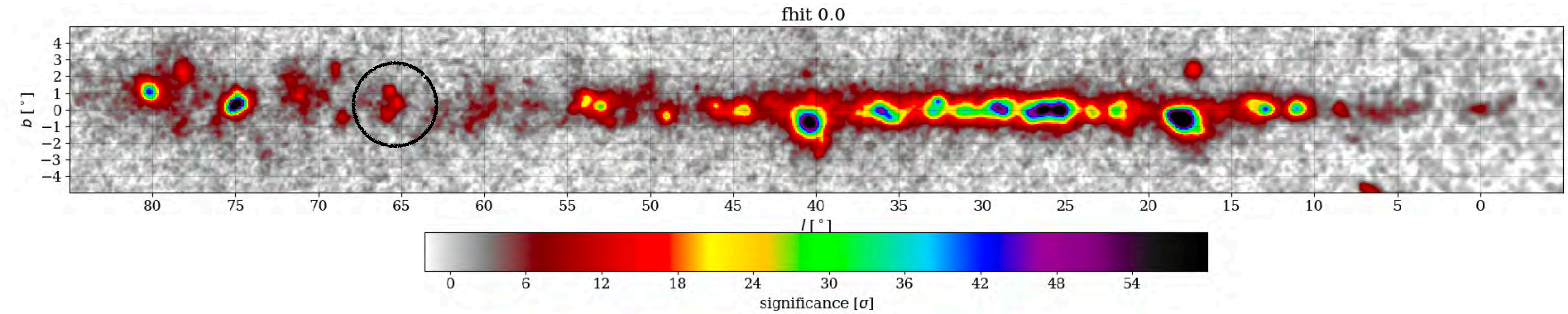


- 1910 days of data
- Simultaneously likelihood fit with diffuse emission and background sources
- About 8σ
- PL preferred up to at least 100 TeV



R. Alfaro *et al* 2025 *ApJL* **987** L42

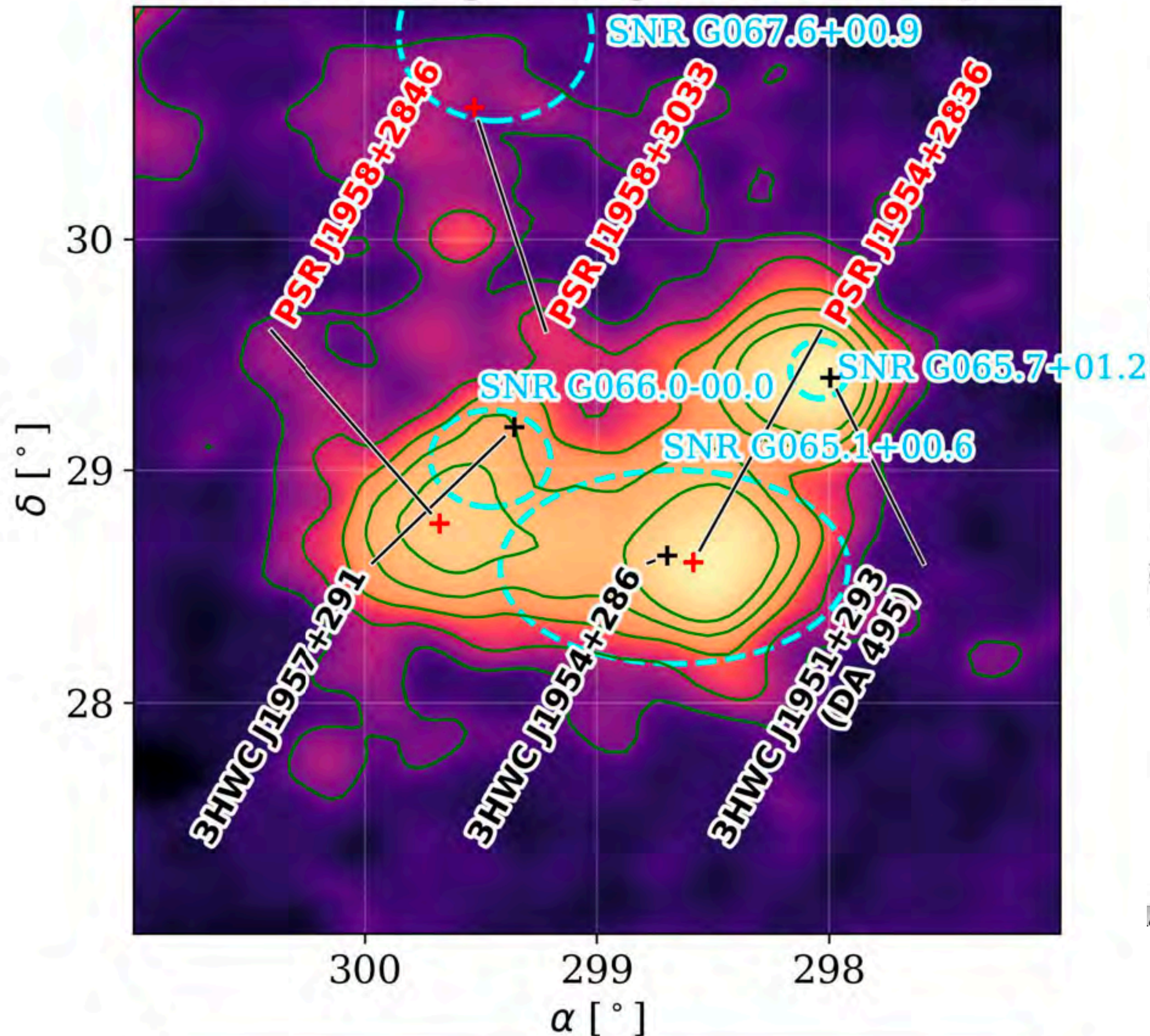
DA 495 Region



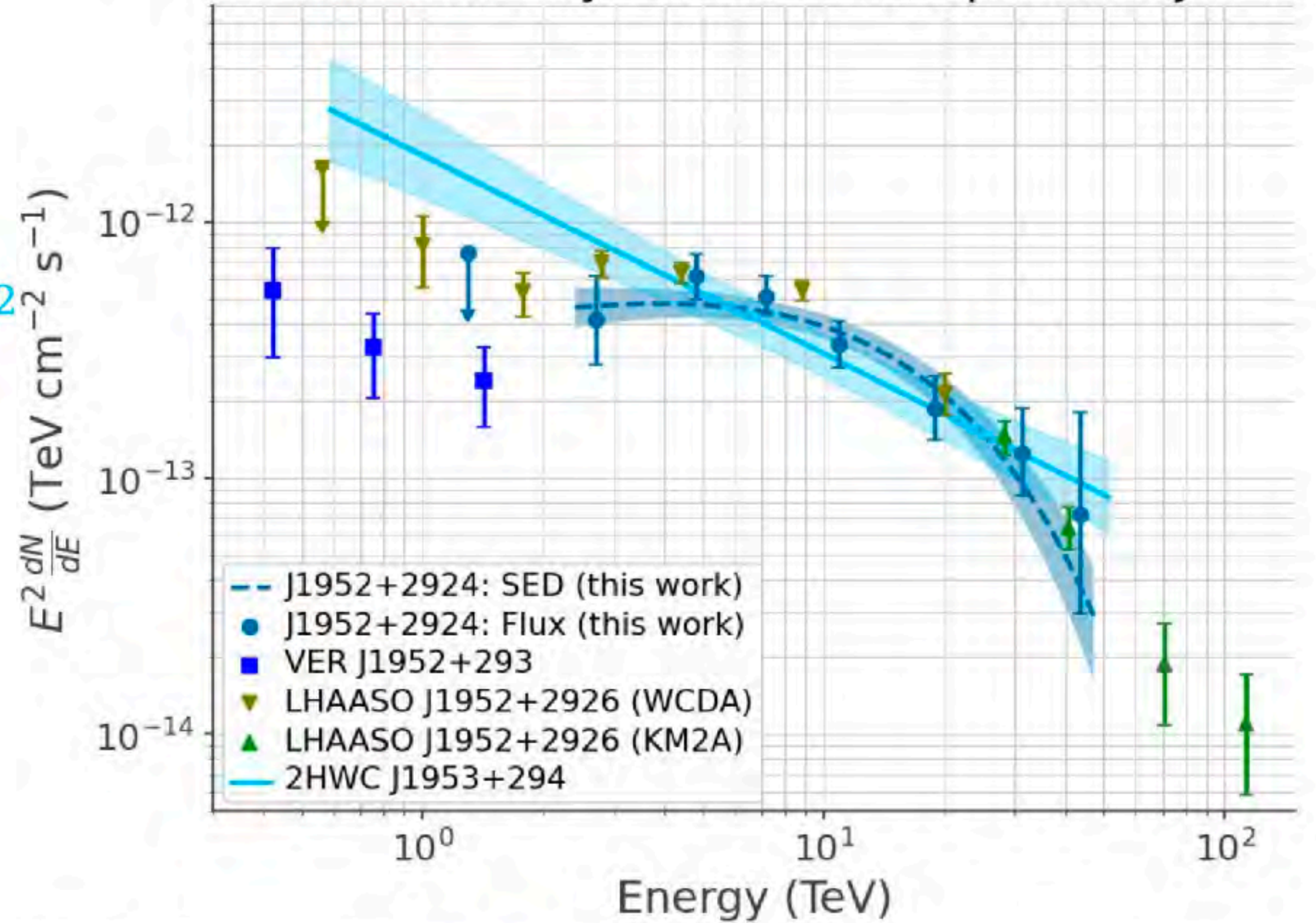
- DA 495 is a pulsar wind nebula surrounded by at least two other sources
- 3071 days of HAWC data in the DA 495 region's measured flux and source count.
- Three extended sources with curved spectra are identified: HAWC J1952+2924 (DA 495), HAWC J1954+2837, and HAWC J1958+2848, with a hint of a fourth source.
- DA 495's extended emission favors a leptonic origin, with an inferred magnetic field of $B \sim 10 \mu\text{G}$; no hadronic component is required.
- Two candidate TeV halos are associated with PSR J1954+2836 and PSR J1958+2846, although these counterparts remain unconfirmed.

DA495 Region

DA 495 Region Significance Map

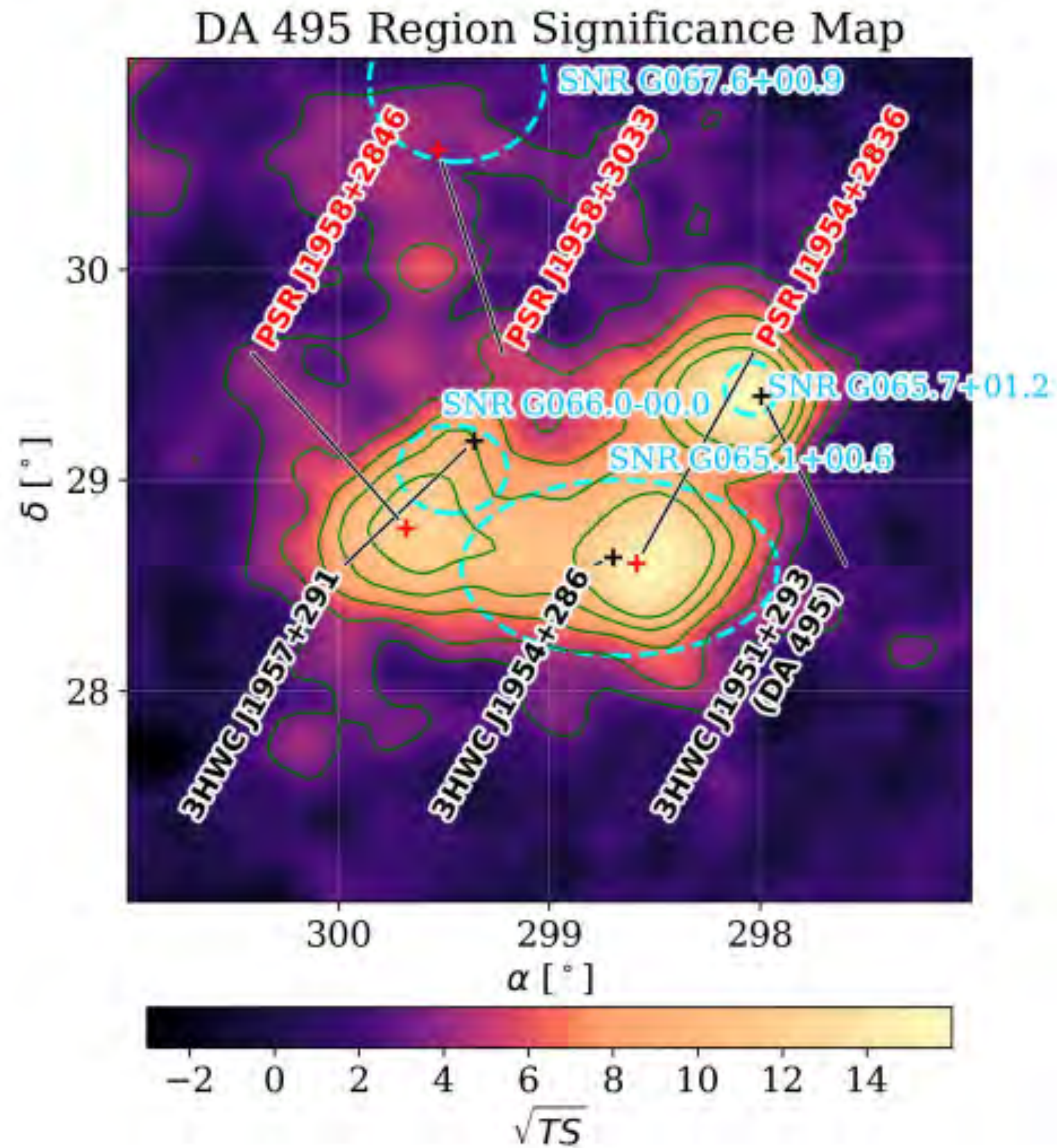


VHE Gamma-Ray Emission Comparison: J1952



dominant source class for PeVatrons is still (e.g. et al. 2013). Recent observations have suggested that

Three extended sources in the DA 495 region



3071 days of HAWC data

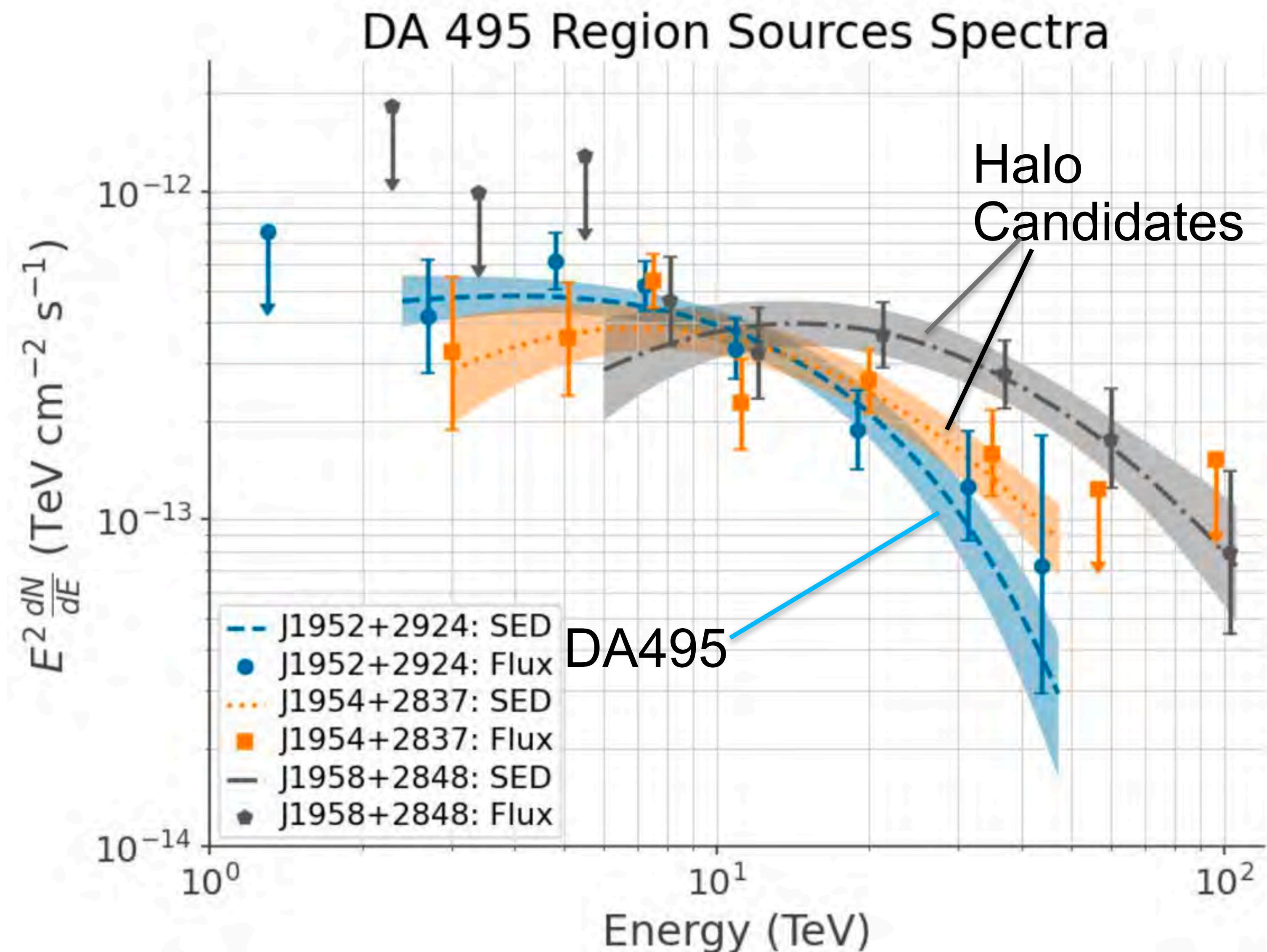
DA 495, J1954+2837 and J1958+2848 show curved TeV spectra.

Spectral modeling brings DA 495 into agreement with VERITAS within 1σ at 1 TeV.*

A fourth-source hint depends strongly on the Galactic diffuse emission model.

*HAWC best-fit spectrum extrapolated to 1 TeV.

DA 495 favors a leptonic PWN interpretation



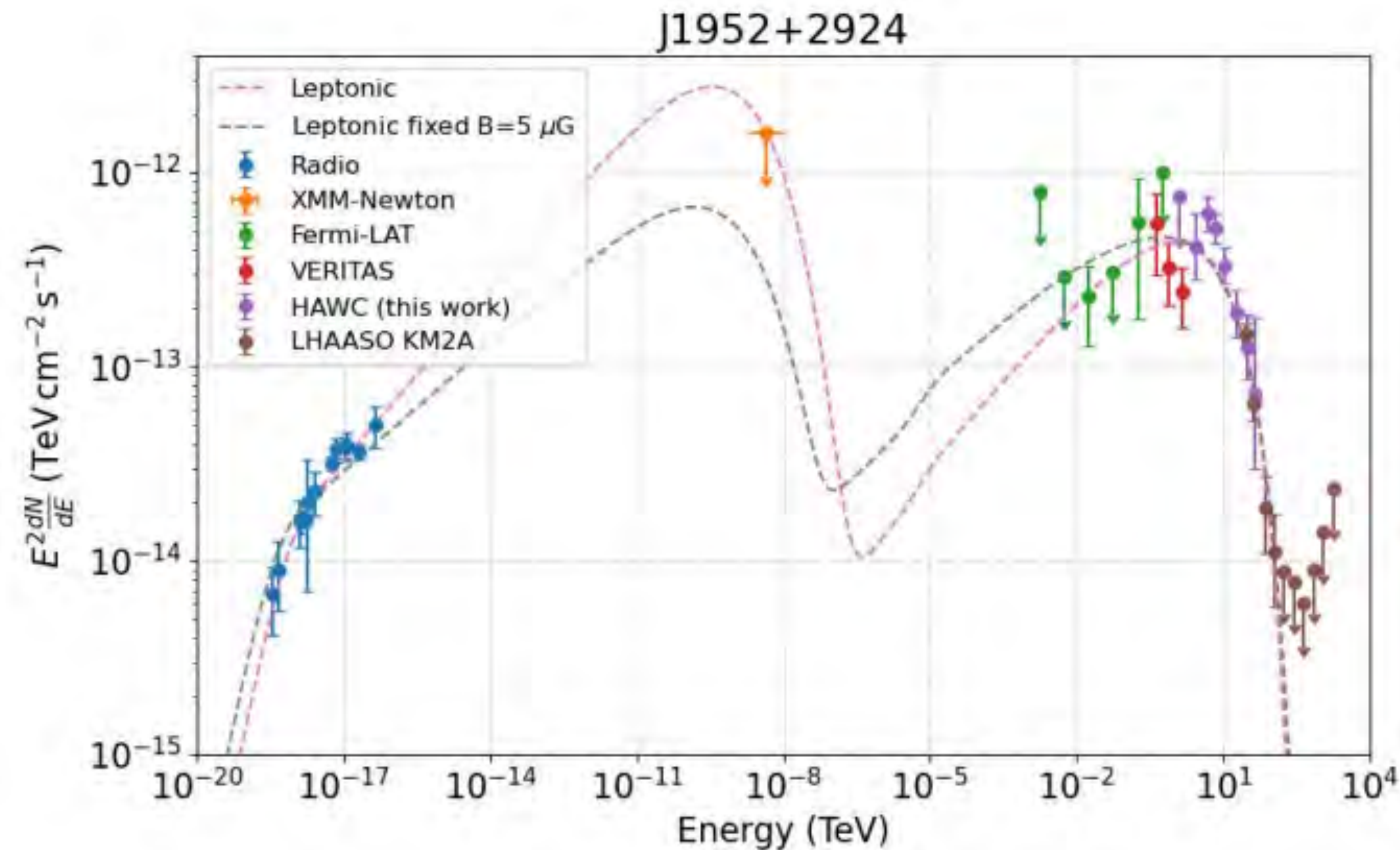
Synchrotron + inverse Compton

Broadband fit favors $B \approx 10 \mu\text{G}$ and an electron cutoff $\approx 50 \text{ TeV}$.

Adding a hadronic component does not improve the fit.

Cooling can explain the electron cutoff.

DA 495 favors a leptonic PWN interpretation



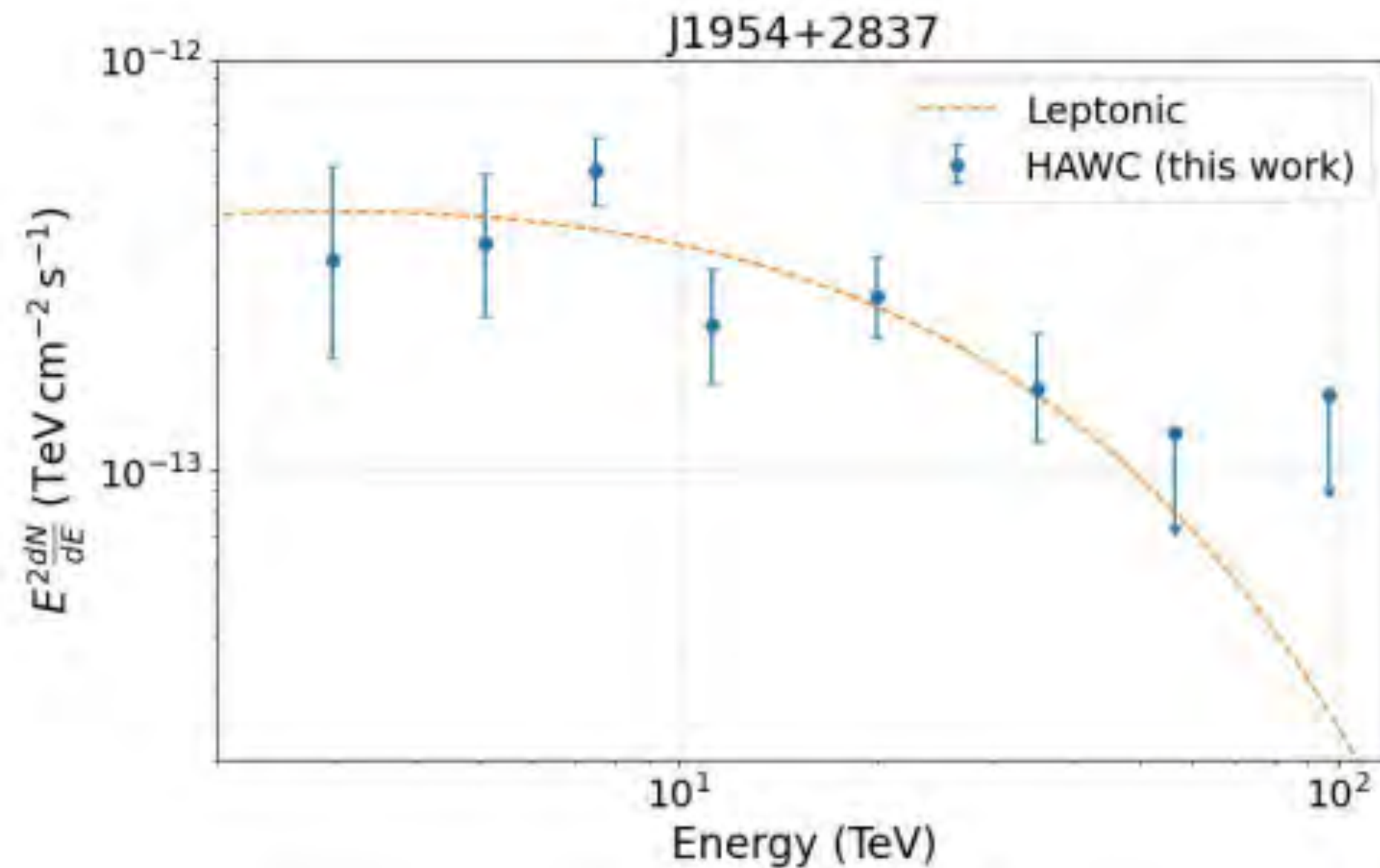
Synchrotron + inverse Compton

Broadband fit favors $B \approx 10 \mu\text{G}$ and an electron cutoff $\approx 50 \text{ TeV}$.

Adding a hadronic component does not improve the fit.

Cooling can explain the electron cutoff.

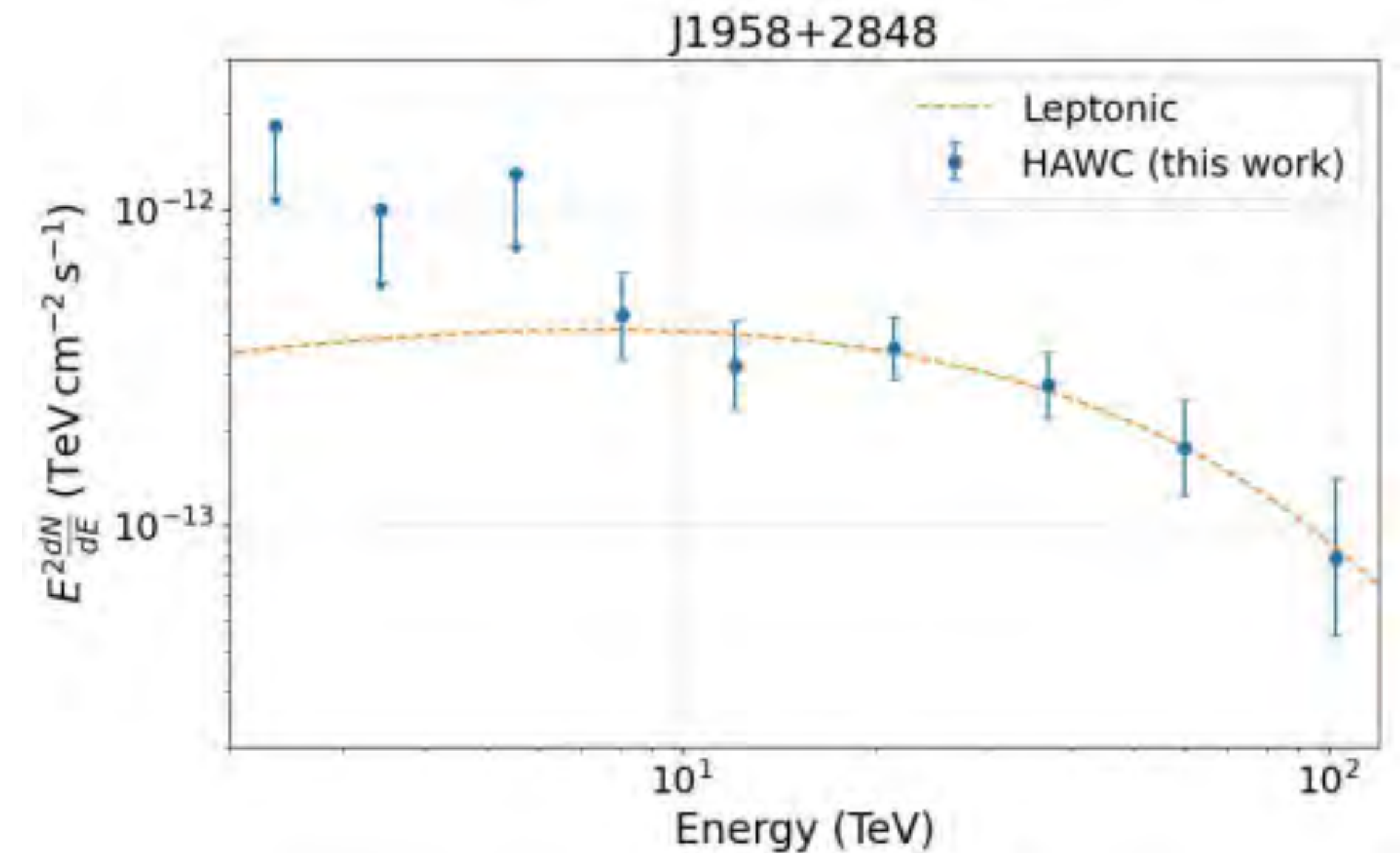
J1954 and J1958 are candidate TeV halos



PSR J1954+2836: offset 0.07°

Escaped electrons and positrons can produce extended inverse Compton emission.

Inferred diffusion is $\sim 10^3$ times slower than in the general ISM.

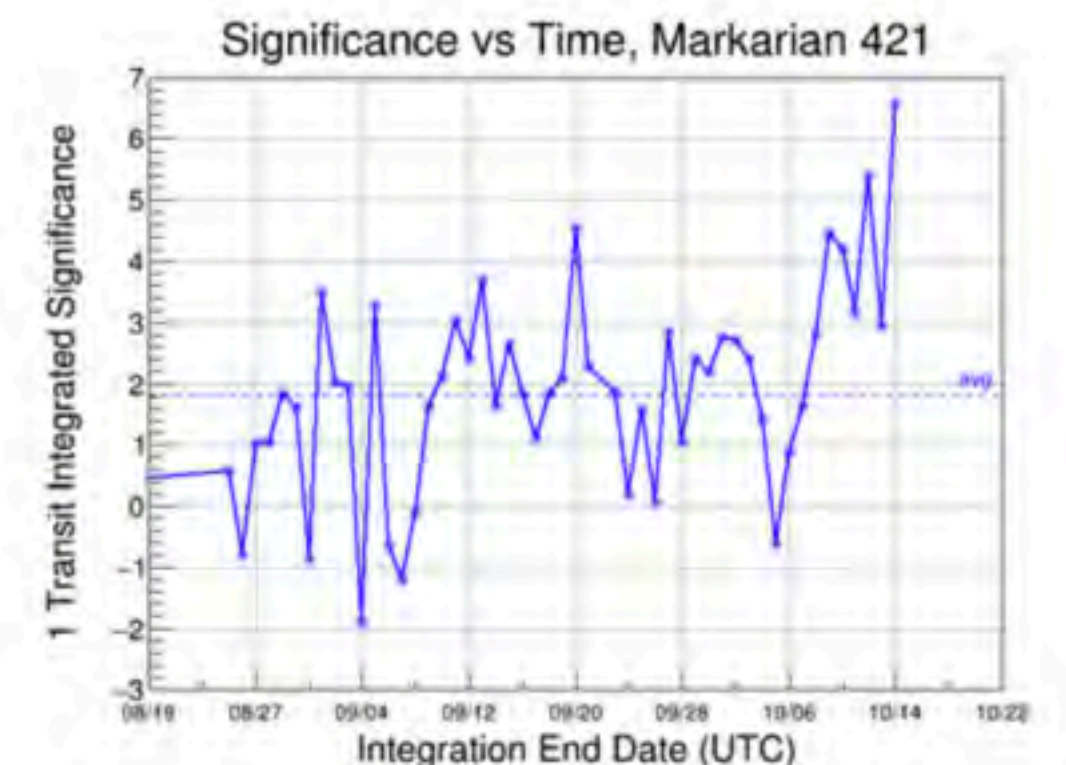
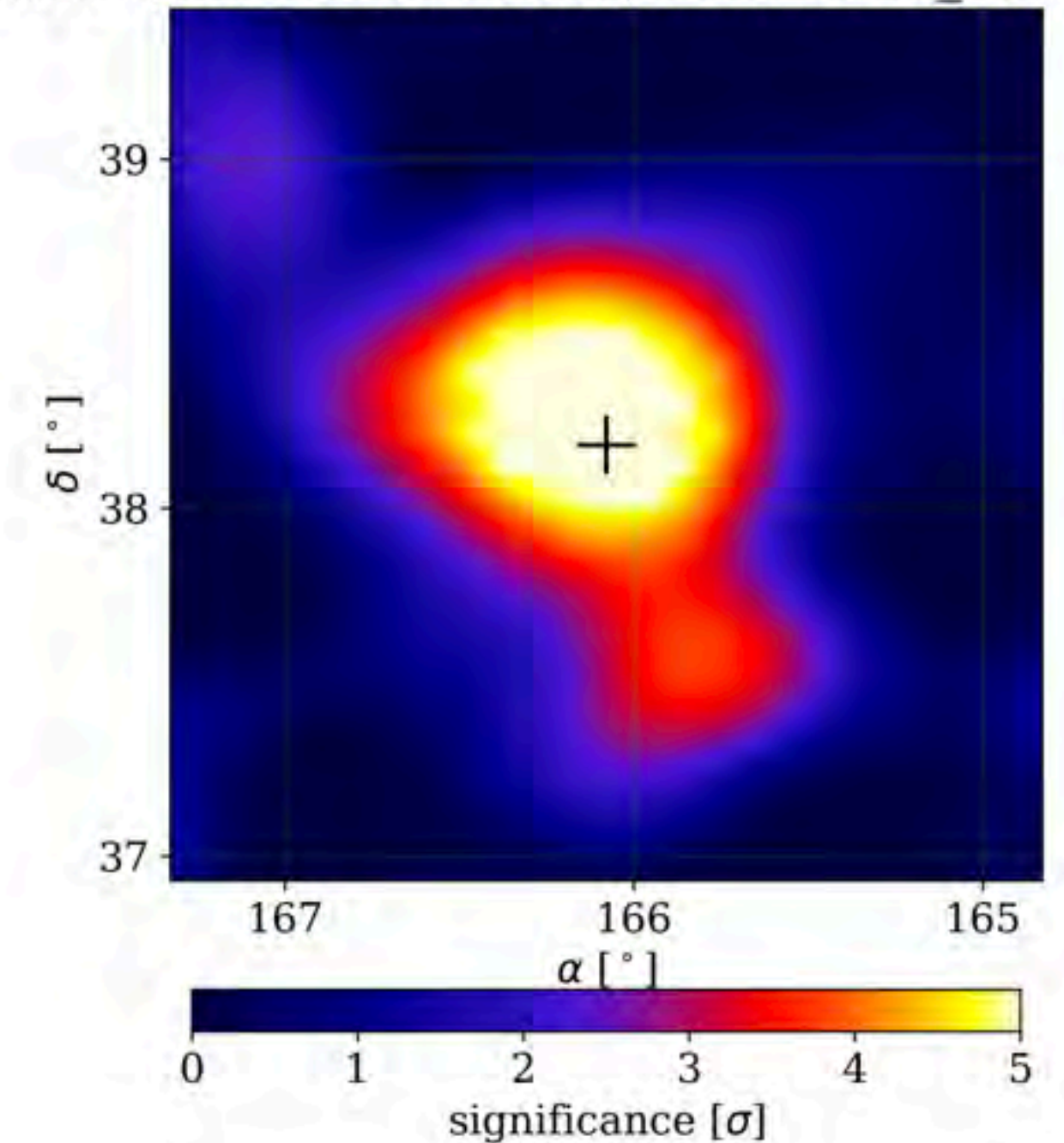


PSR J1958+2846: offset 0.09°

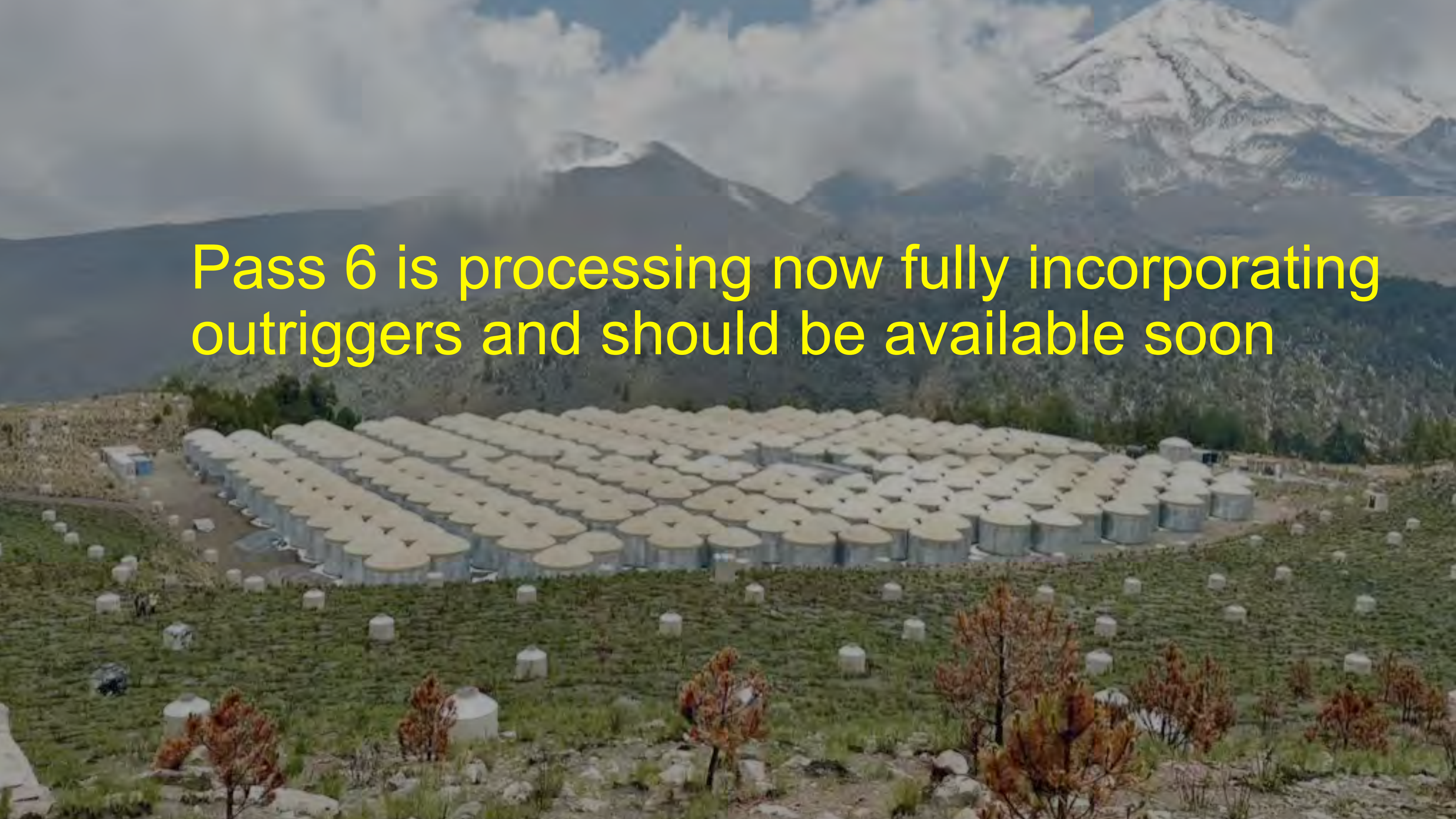
New Transient Searches

- GRBs
 - New search using archival data with Machine learning cuts
- PBHs
 - Using new models that introduce increasing numbers of Dark Sector particles
- Novae
 - T Coronae Borealis
- AGN - today
 - from Fermi - MRK 421 high energy photons
 - 6.58 sigma today in HAWC (online)

Mrk421, Bins B0C0-B10C1, 2026-10-14_2026-10-1

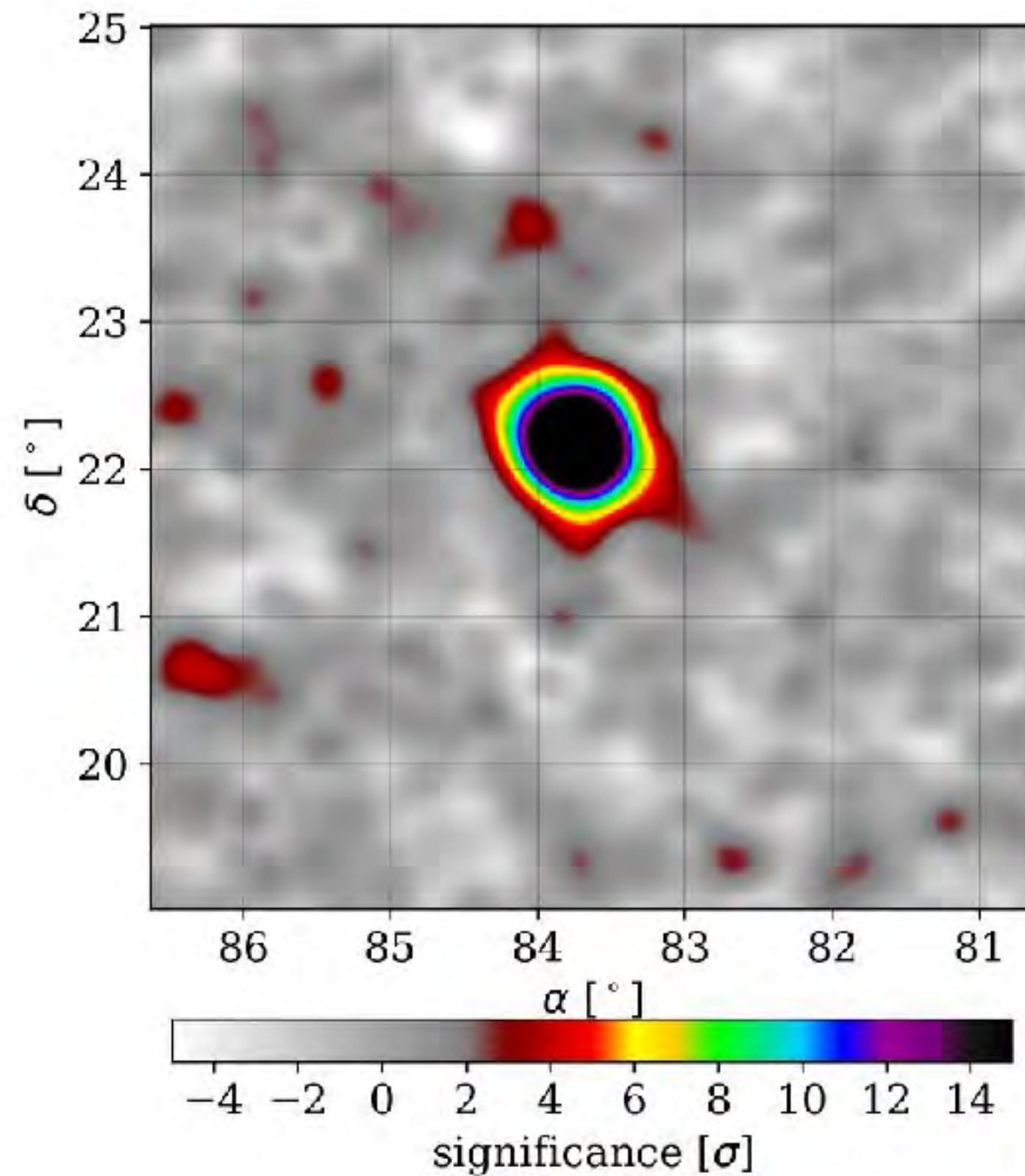


Pass 6 is processing now fully incorporating outriggers and should be available soon



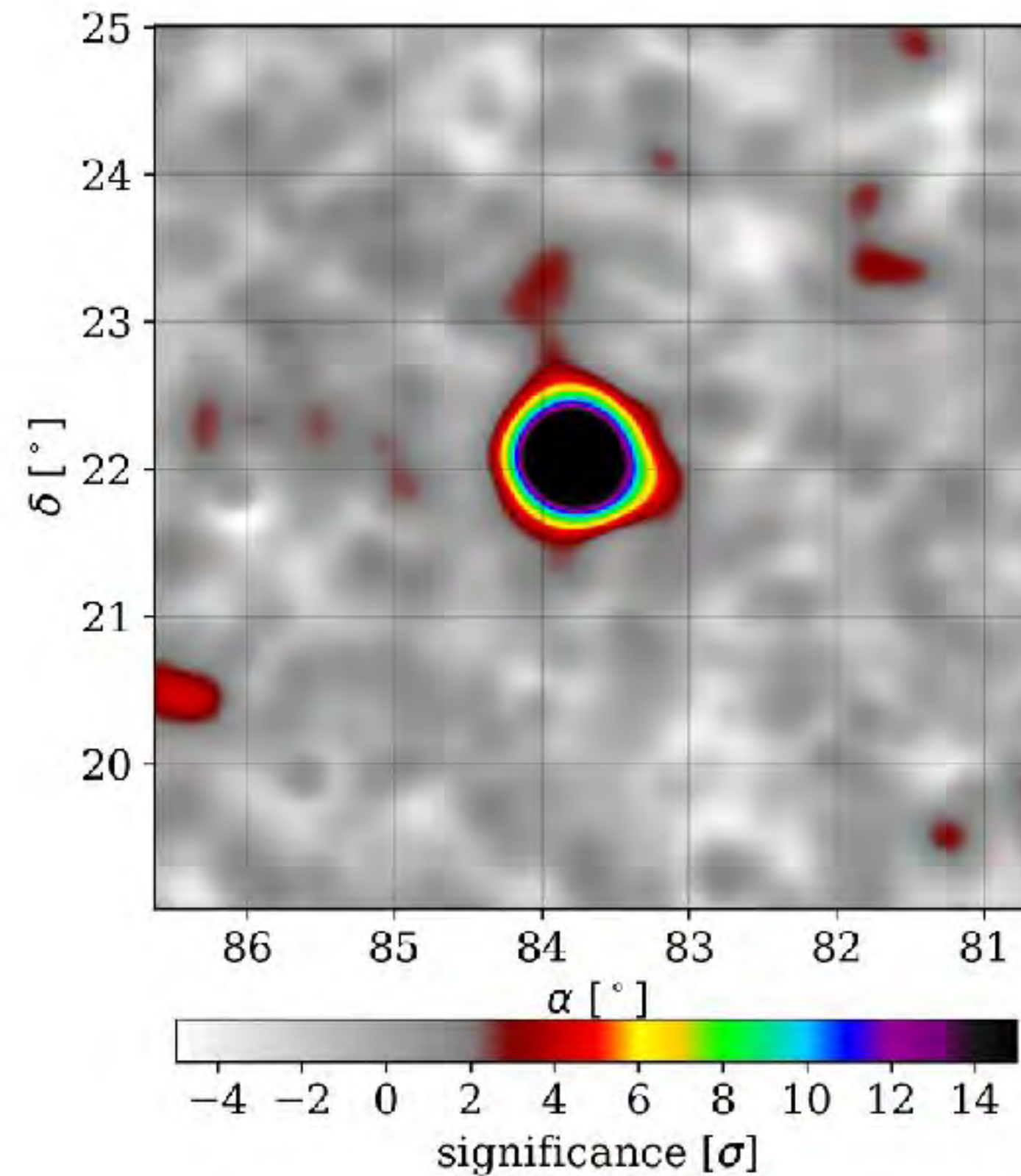
Crab Pass6 Vs. Pass5 One Month

24.90 sigma



Pass 5

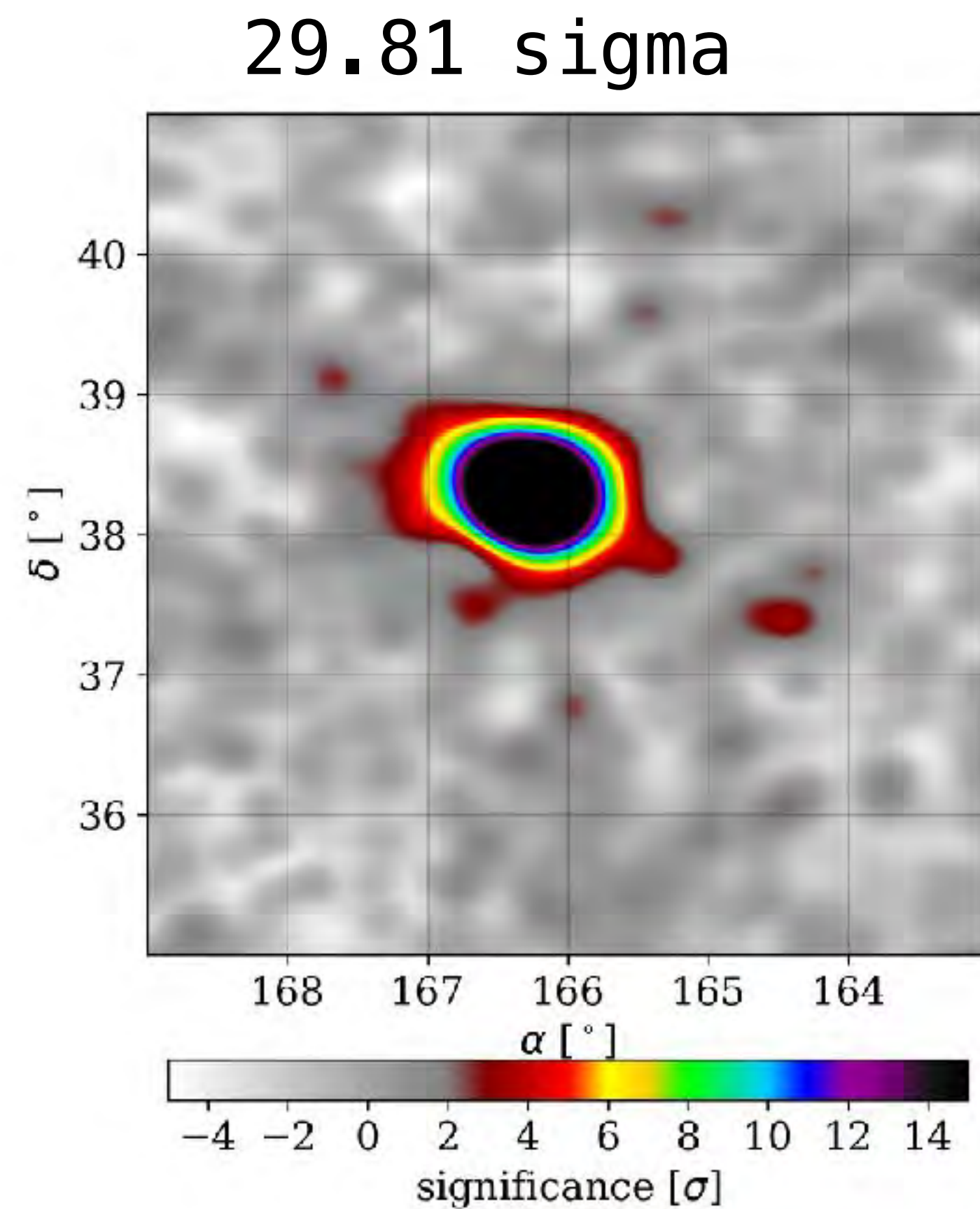
27.84 sigma



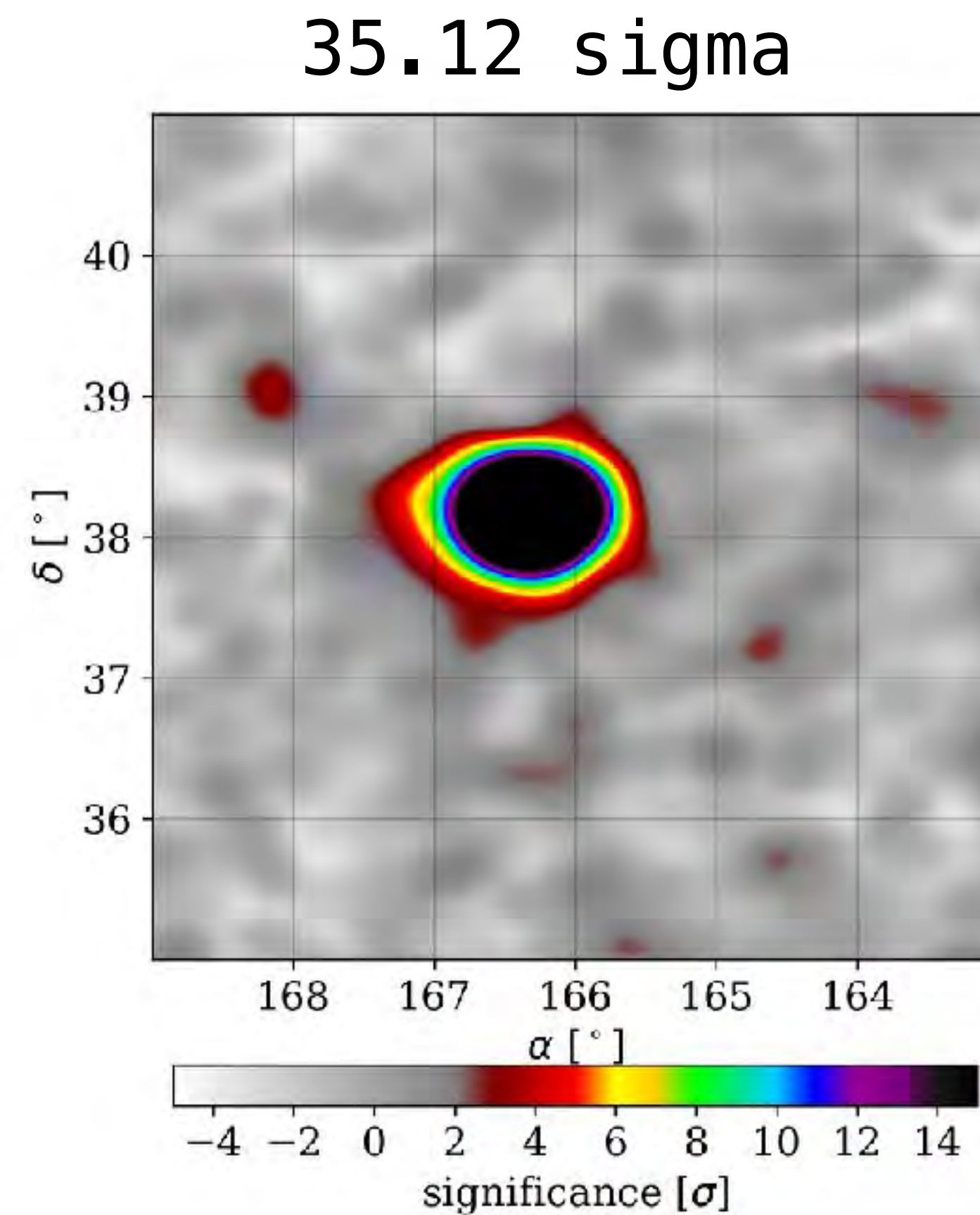
Pass 6

- Bin 4 and up
- ~12 % improvement

Mrk421 (flare) Pass6 Vs. Pass5 One Month



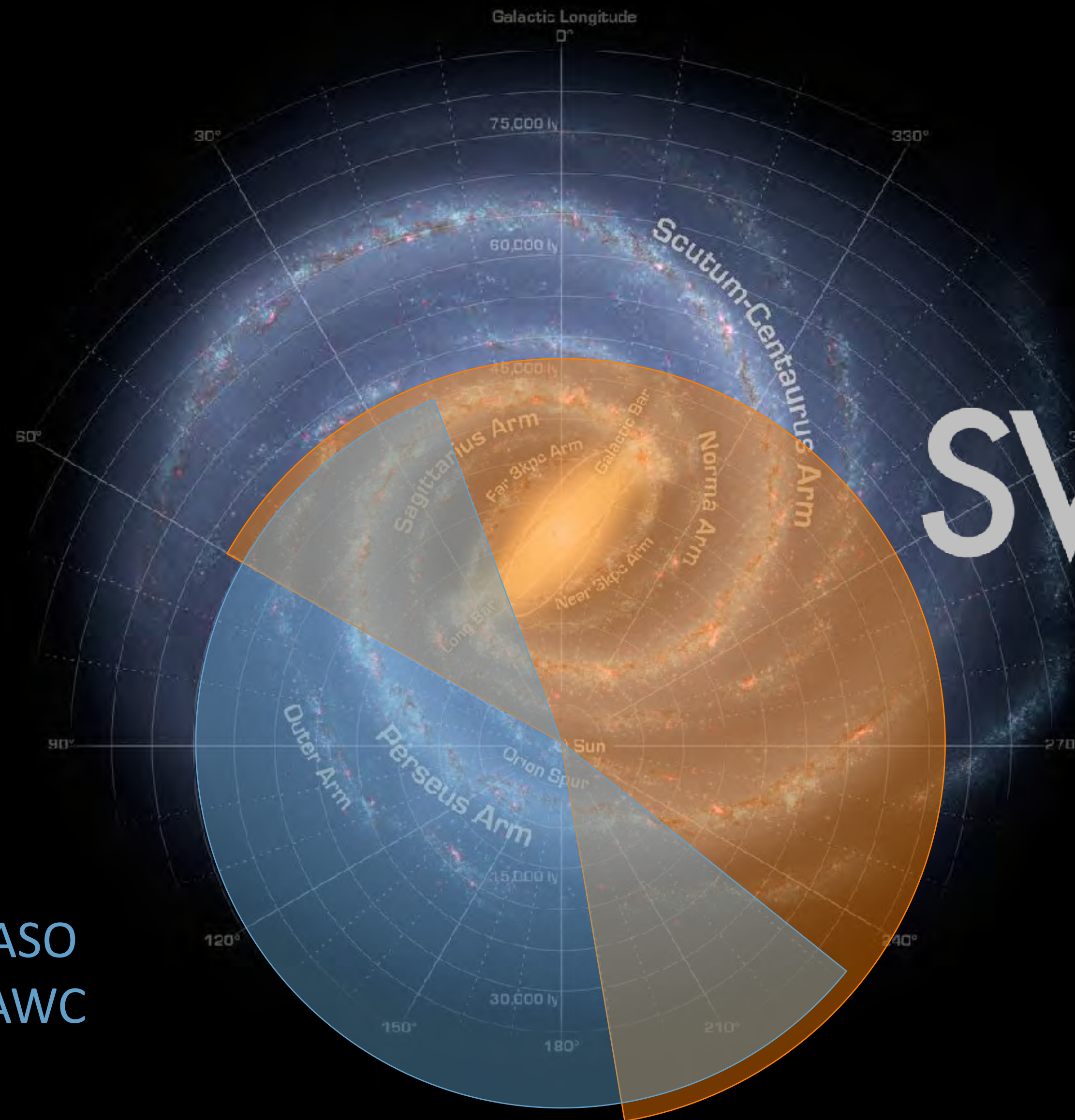
Pass 5



Pass 6

- Bin 4 and up
- ~18 % improvement

LHAASO
& HAWC



SWGO

Up to 45 degree zenith angle

THE FERMI BUBBLES

Image Credit: NASA

Visible to
SWGO
above 60°

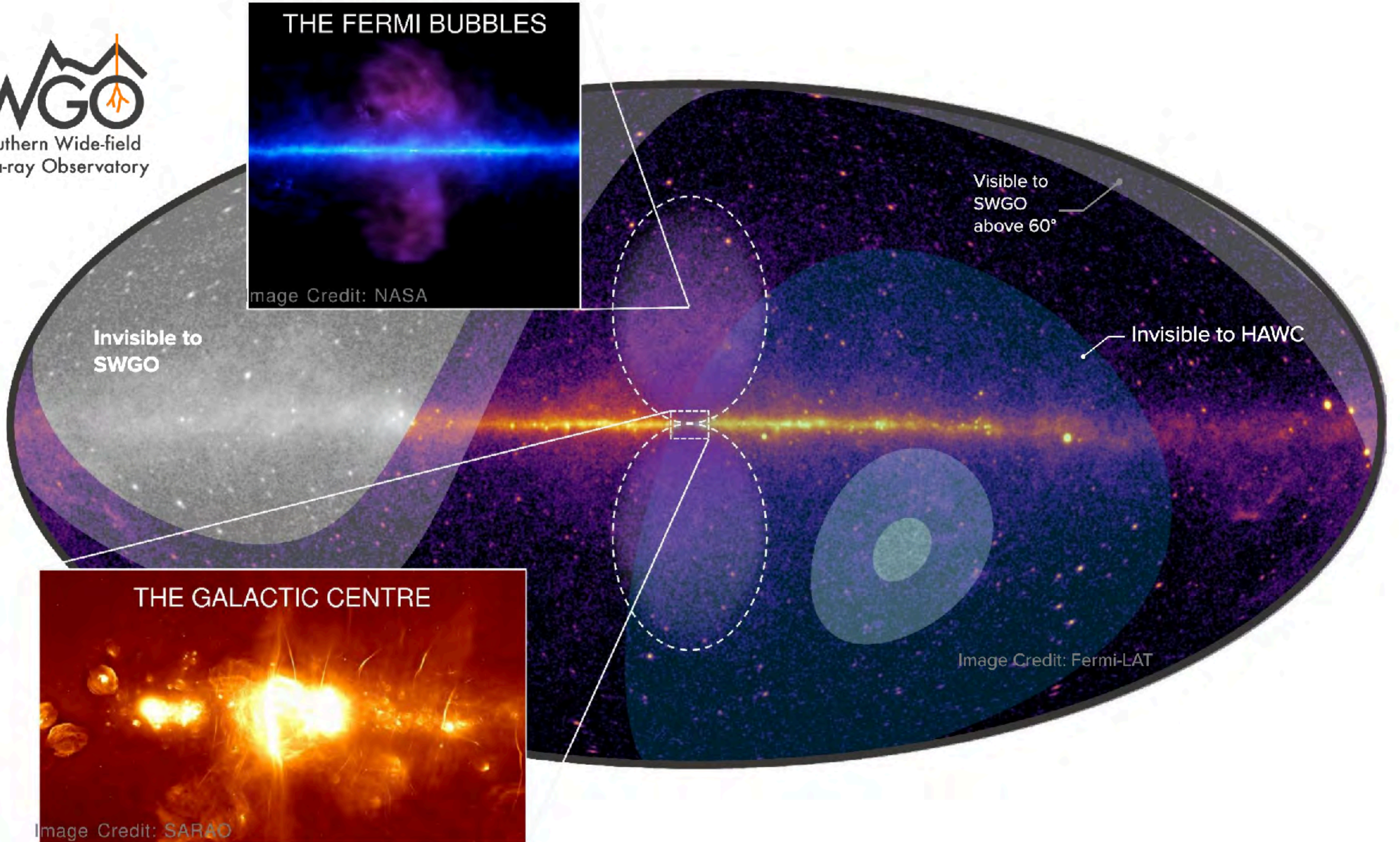
Invisible to HAWC

Invisible to
SWGO

THE GALACTIC CENTRE

Image Credit: Fermi-LAT

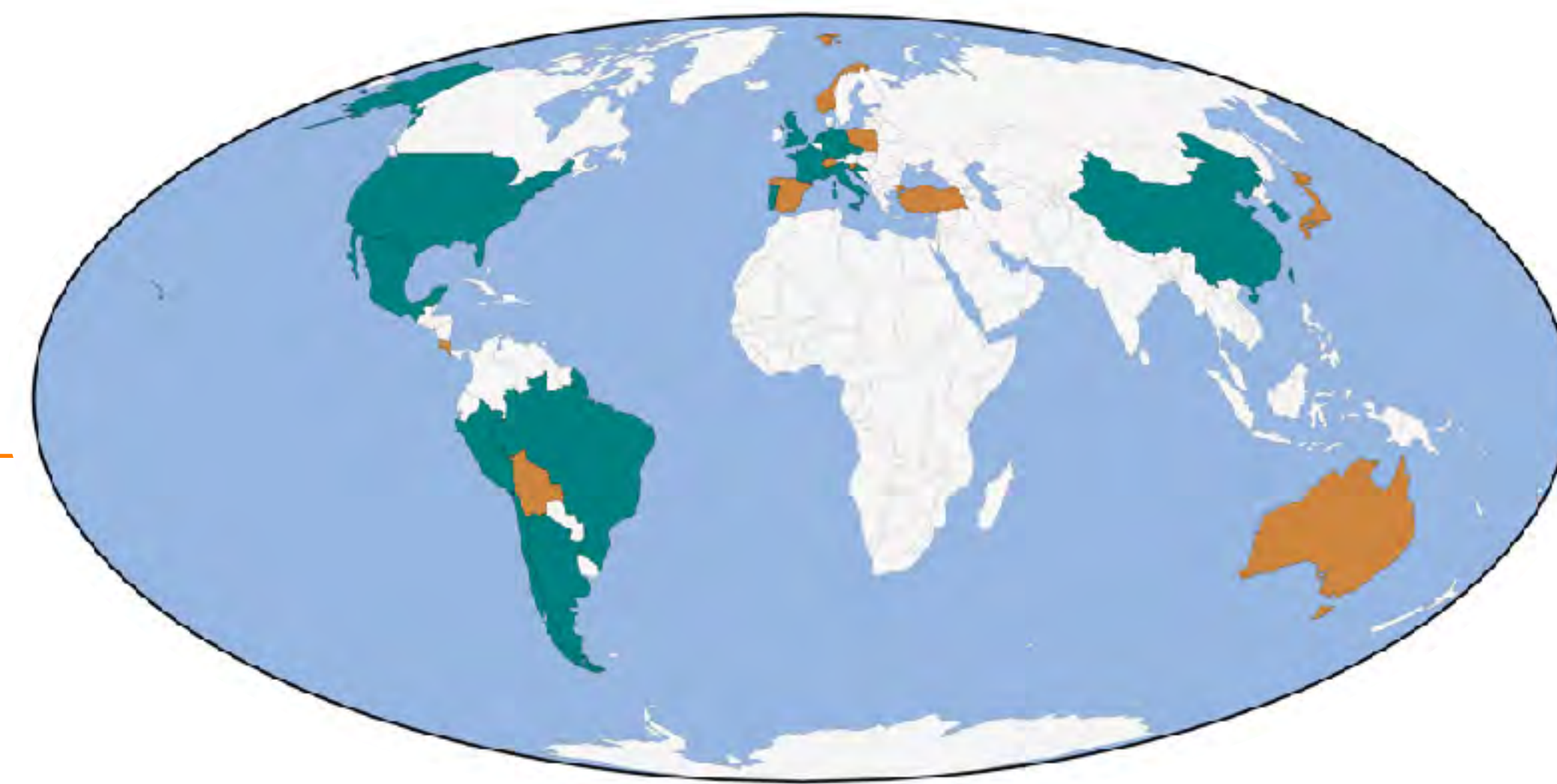
Image Credit: SARAO





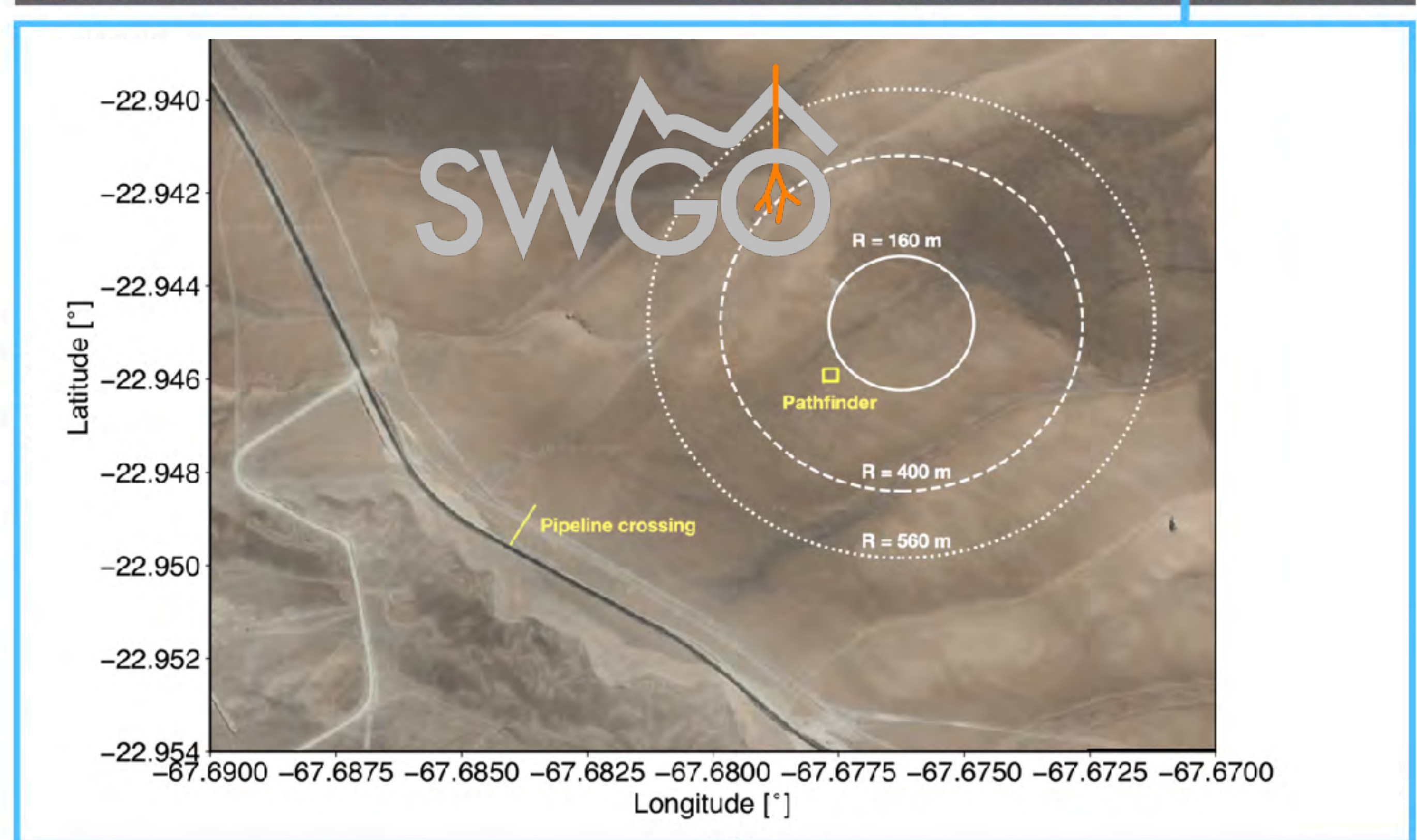
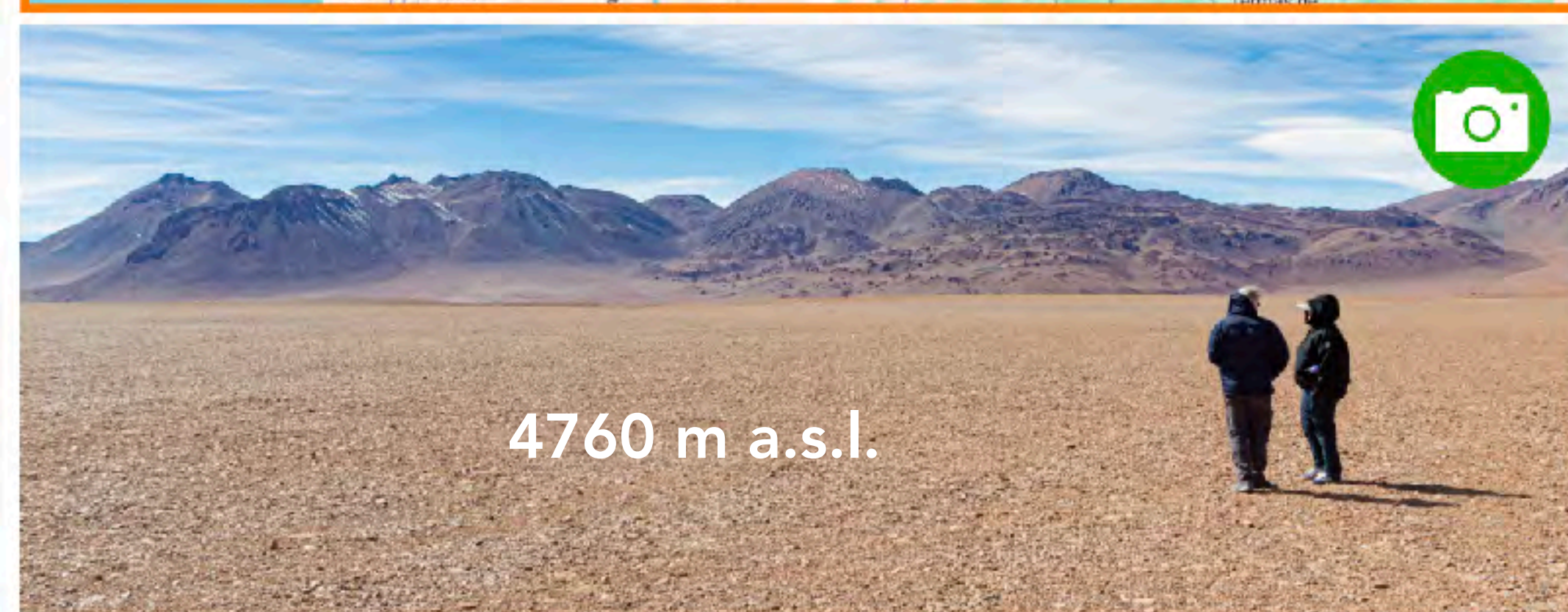
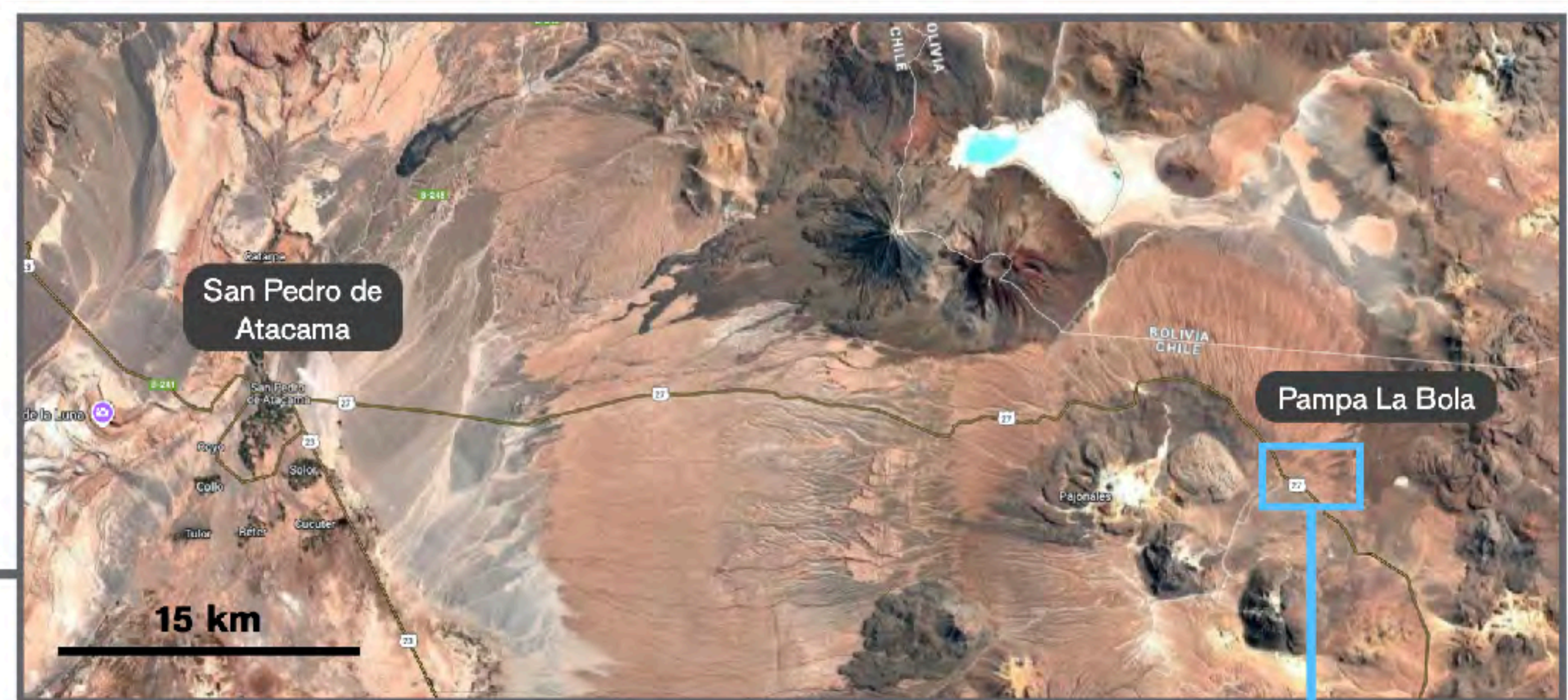
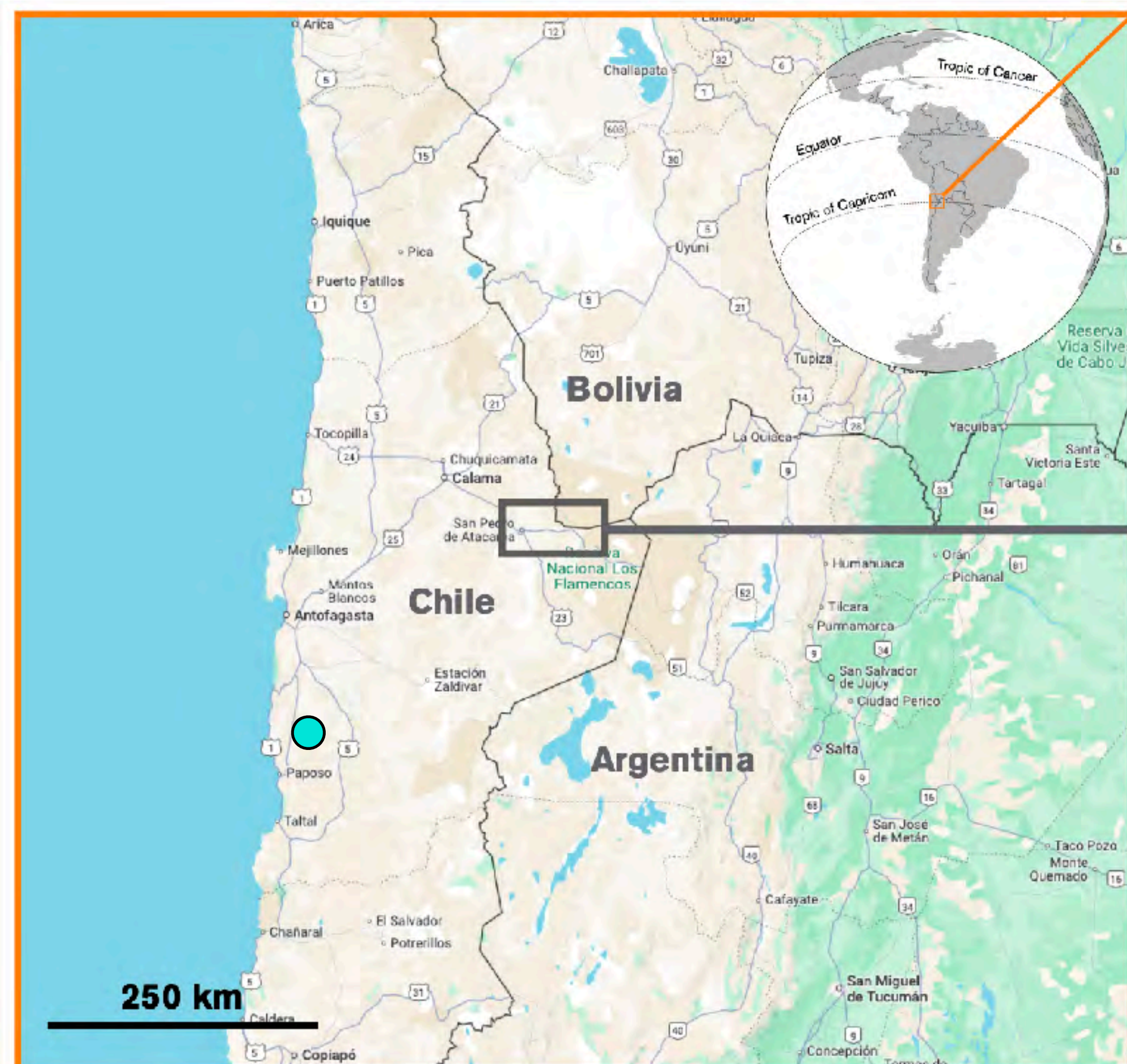
11th Collaboration Meeting -
Heidelberg, Germany, September 2024

SWGGO Development



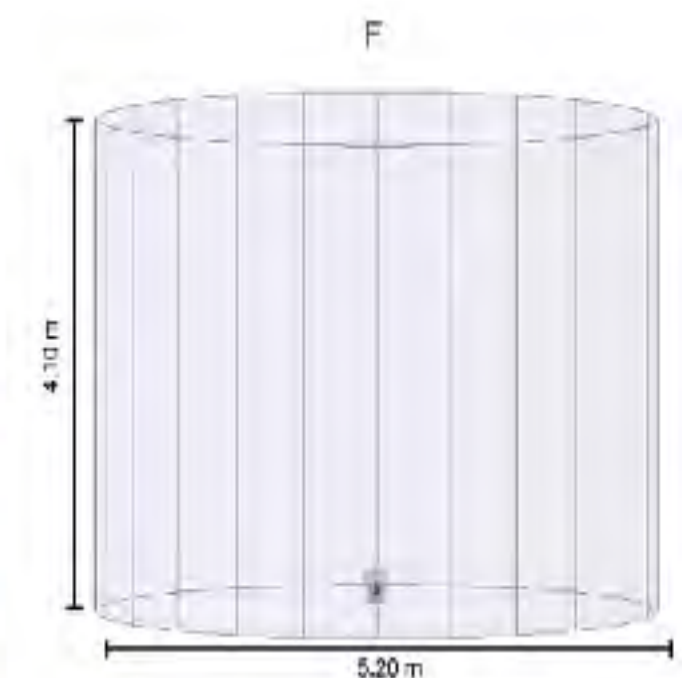
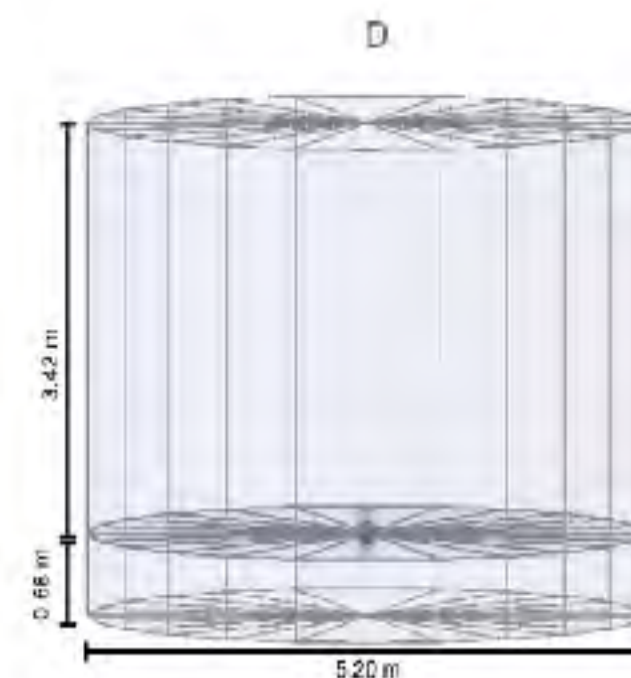
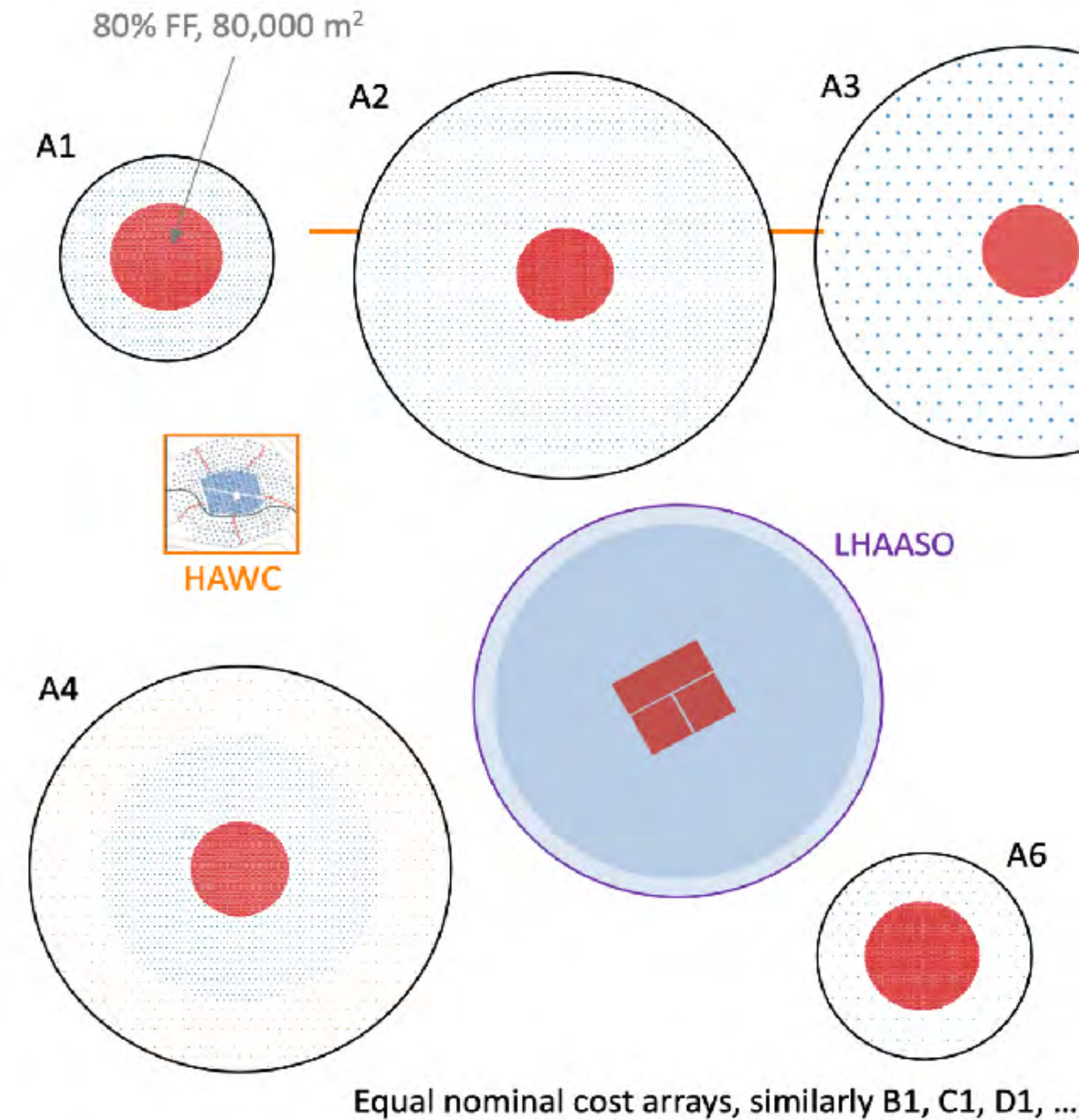
- ⦿ 2019: R&D phase starts
- ⦿ May 2020: Science Benchmarks defined
- ⦿ Feb 2022: Candidate Configs defined
- ⦿ May 2024: Inner Array Baseline
- ⦿ July 2024: Site Selection
- ⦿ June 2025: Science White Paper
- ⦿ Aug 2026: Outer Array Baseline
- ⦿ Design Report and on-site prototypes by early 2027 → entering a New Phase

SWGGO R&D Phase Milestones		
✓	M1	R&D Phase Plan Established
✓	M2	Science Benchmarks Defined
✓	M3	Reference Configuration & Options Defined
✓	M4	Site Shortlist Complete
✓	M5	Candidate Configurations Defined
✓	M6	Performance of Candidate Configurations Evaluated
✓	M7	Preferred Site Identified
✓	M8	Design Finalised
	M9	Construction & Operation Proposal Complete



Design Optimization

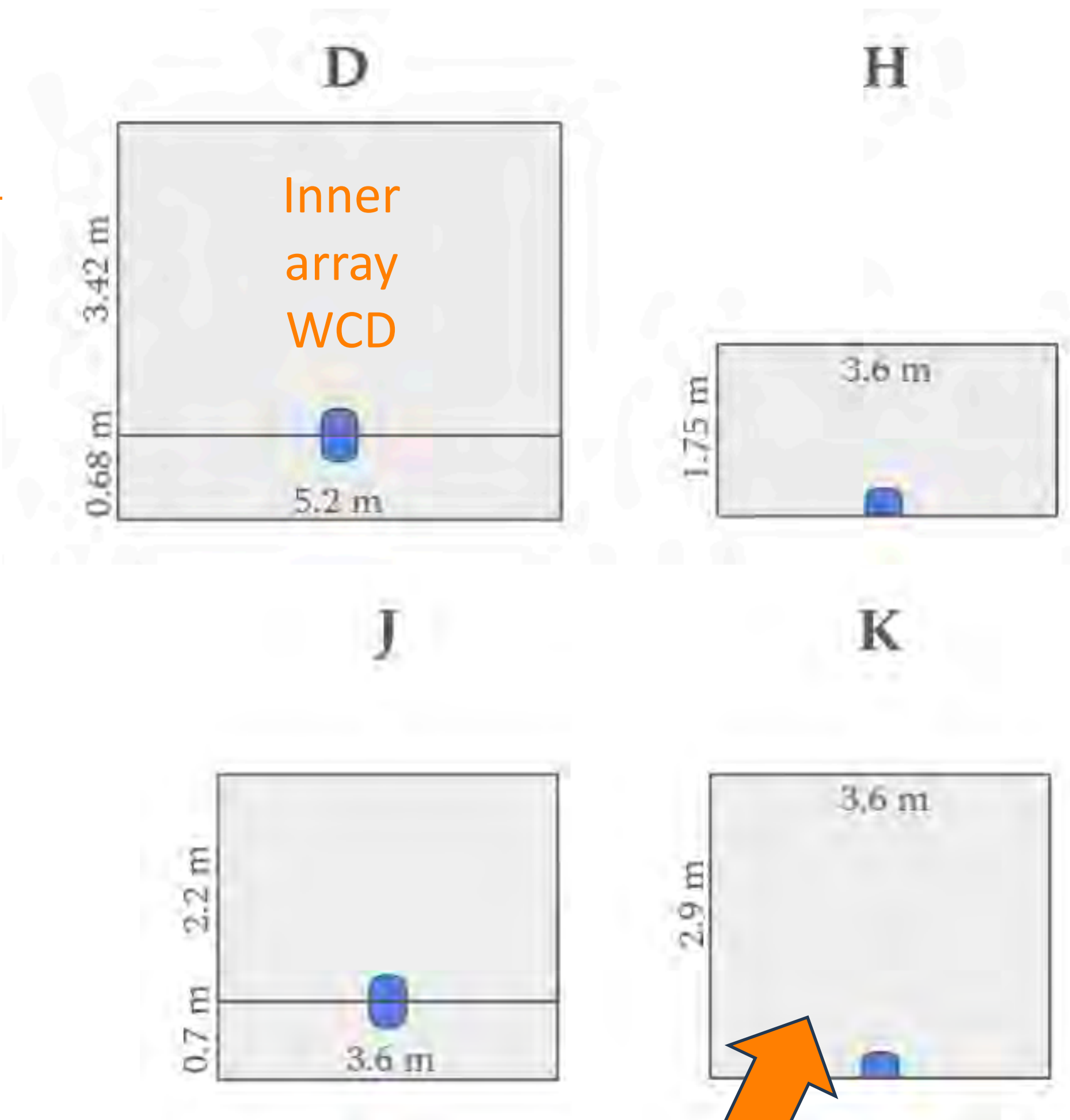
- Science performance based optimization in a wide phase space
- Step 1: Large scale simulations with
 - 6 detector unit options, single and double layer Cherenkov detectors
 - 7 layouts, with inner and outer array
 - Convergence on inner (>50% fill factor) array in 2024
 - ✓ 5.2 m dual layer tanks for best gamma/hadron separation
 - and on 1km² 3-zone array layout
- Step 2: recent effort to finalize the Baseline design



Design Optimisation

Step 2 WCD alternatives
1-4% FF simulations over 1 km²

- Science performance based optimization in a wide phase space
- Step 1: Large scale simulations with
 - 6 detector unit options, single and double layer Cherenkov detectors
 - 7 layouts, with inner and outer array
 - Convergence on inner (>50% fill factor) array in 2024
 - ✓ 5.2 m dual layer tanks for best gamma/hadron separation
 - and on 1km² 3-zone array layout
- Step 2: recent effort to finalize the Baseline design
 - simulating outer array WCD options at different FF

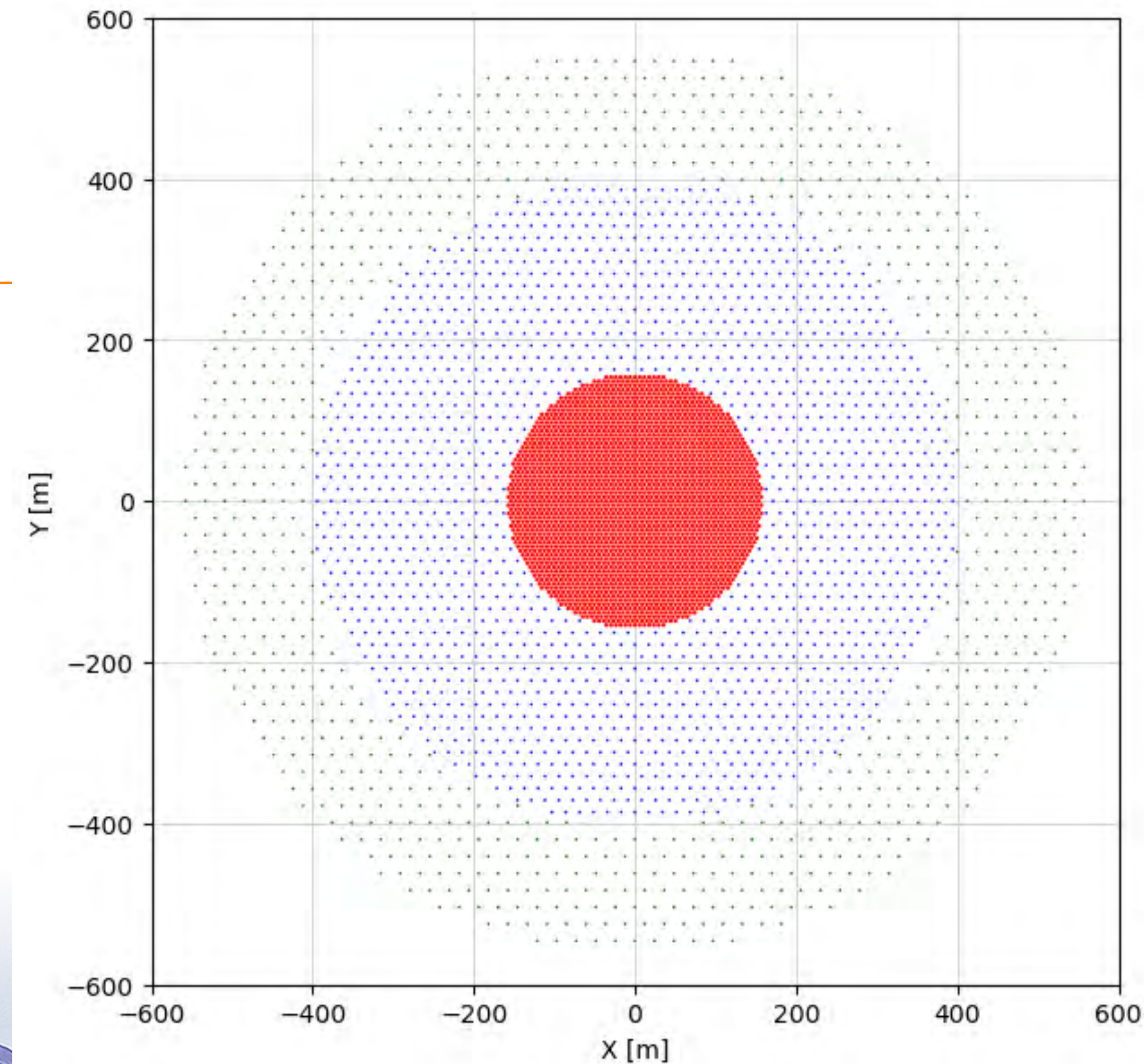


Best performance/cost
compromise for outer array

Baseline Array Layout

Three zones:

- Inner array:
 - FF=65%, R= 156 m, 2587 5.2 m tanks
 - Outer array:
 - FF= 4%, R= 400 m, 1656 3.6 m tanks
 - FF= 1.7%, R= 560 m, 804 3.6 m tanks
- (with modest 'mixed' zone outside inner array)



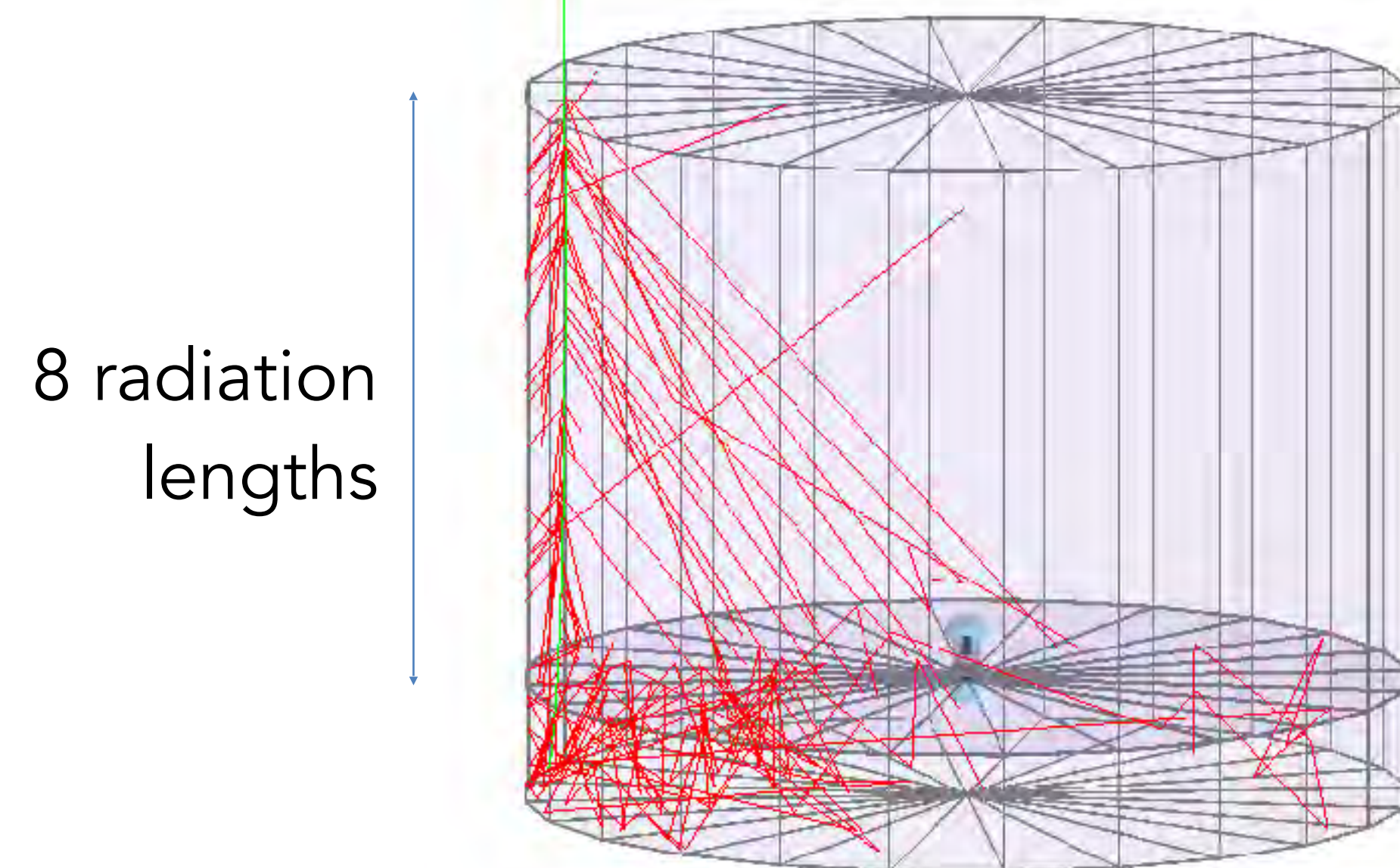
Inner Array WCD Baseline Design

- Steel tanks assembled on site
 - 5.2 m $\varnothing$, 4.0 m water depth
- Double-PMT unit in each detector
 - 10-inch PMTs (900 available)
- Signals collected at Field Nodes
 - Serve 55 WCDs each, 250 MS/s digitization



Inner Array WCD Baseline Design

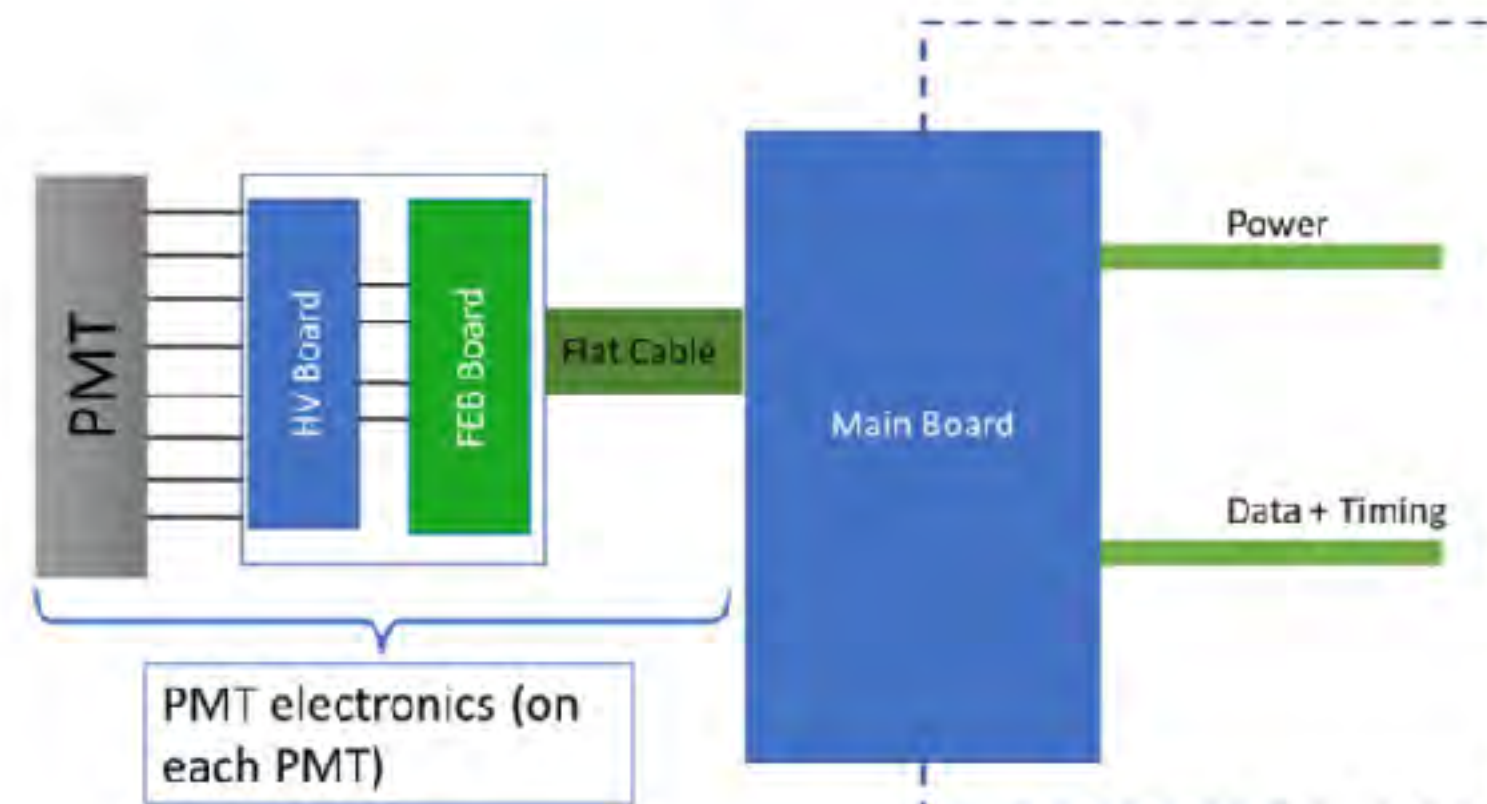
- Custom LDPE Bladders inside each steel tank
- Double-layered detectors
 - Separated by membrane
- Lower chamber is for background rejection → muon tagging
 - Reflective (Tykev) inner lining



Inflated with air to check for light leaks

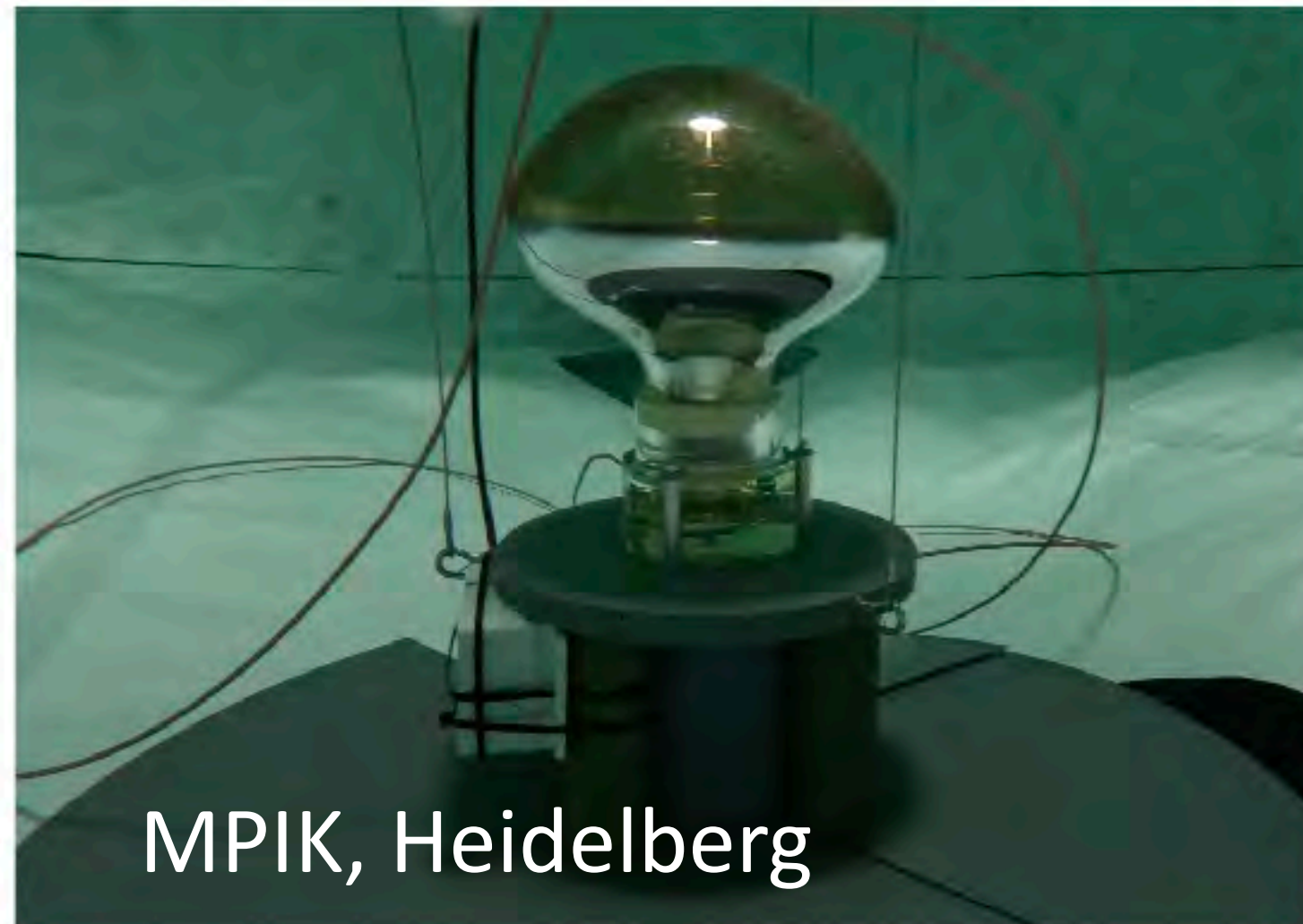
Outer Array WCD Baseline Design

- ◎ 3.6 m diameter, 2.9 m (water) depth
 - Improving Gamma/Hadron separation power with depth (more than) compensates for additional cost c.f. shallower tanks
 - Rotomolded tank with Auger heritage
- ◎ Single layer with multi-PMT sensor
 - 7x 3" PMTs with on-board digitization, development led by Napoli/INFN, heritage from neutrino projects



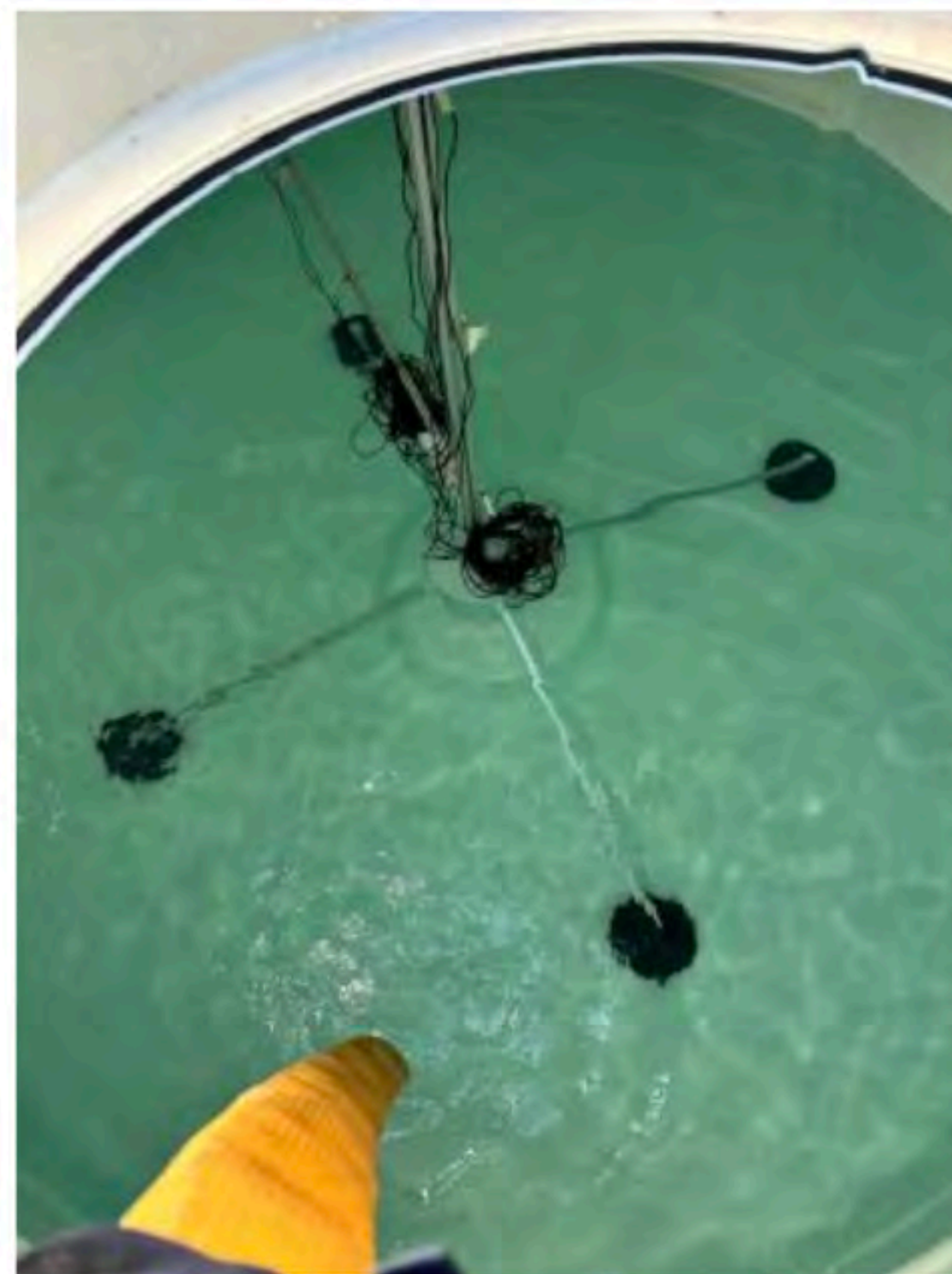
Prototyping work

- ◎ Low Altitude Test Sites:
 - Rio, Heidelberg, Milano, Temple Uni. USA
- ◎ Plus HAWC and Atacama



Test Installation above SWGO

5000 m a.s.l. – test impact of freezing++



First step on-site: the Pathfinder

To validate technologies & procedures planned for the **full-scale array**

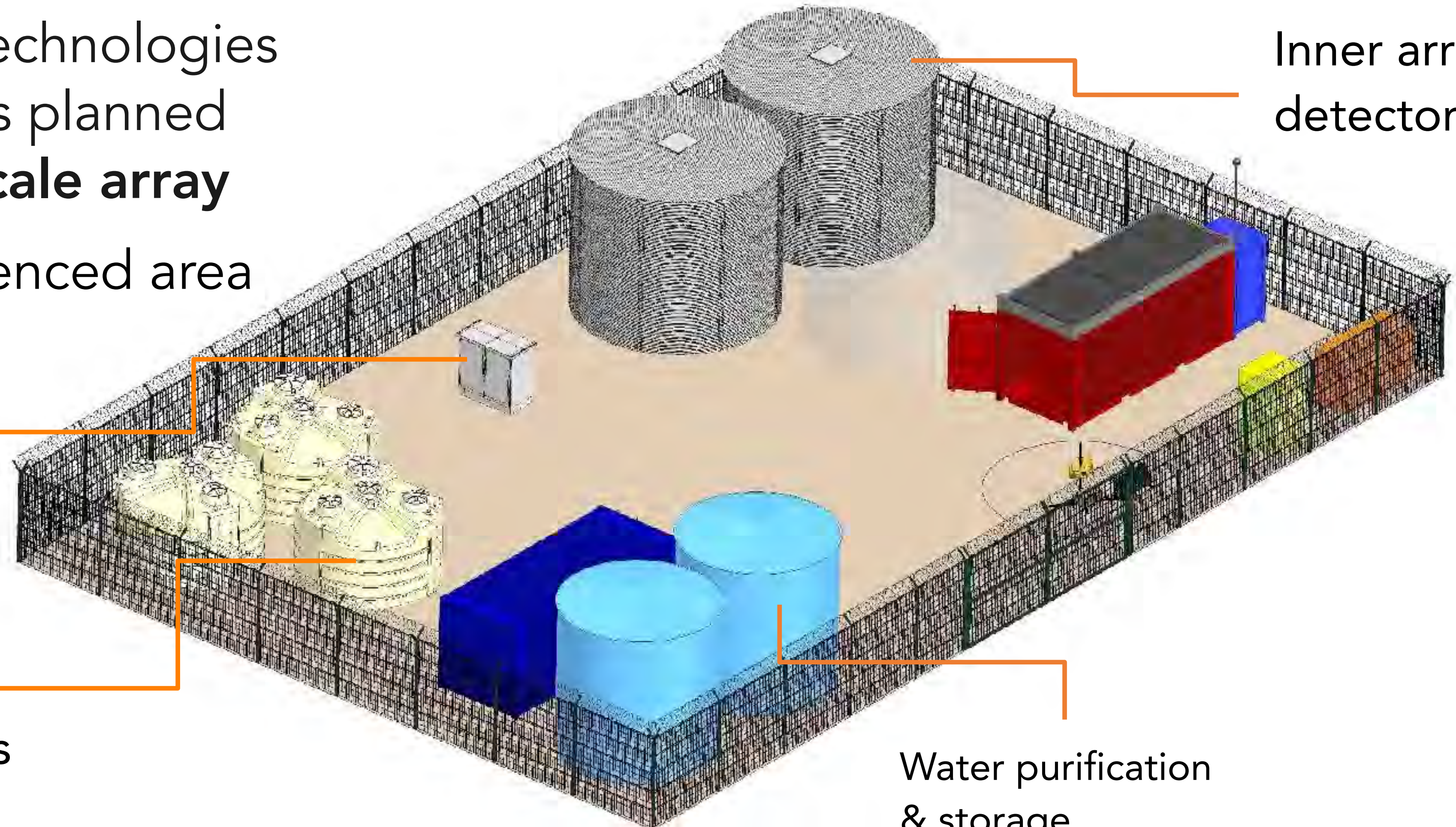
- 30x30m fenced area

Field node

Inner array detector units

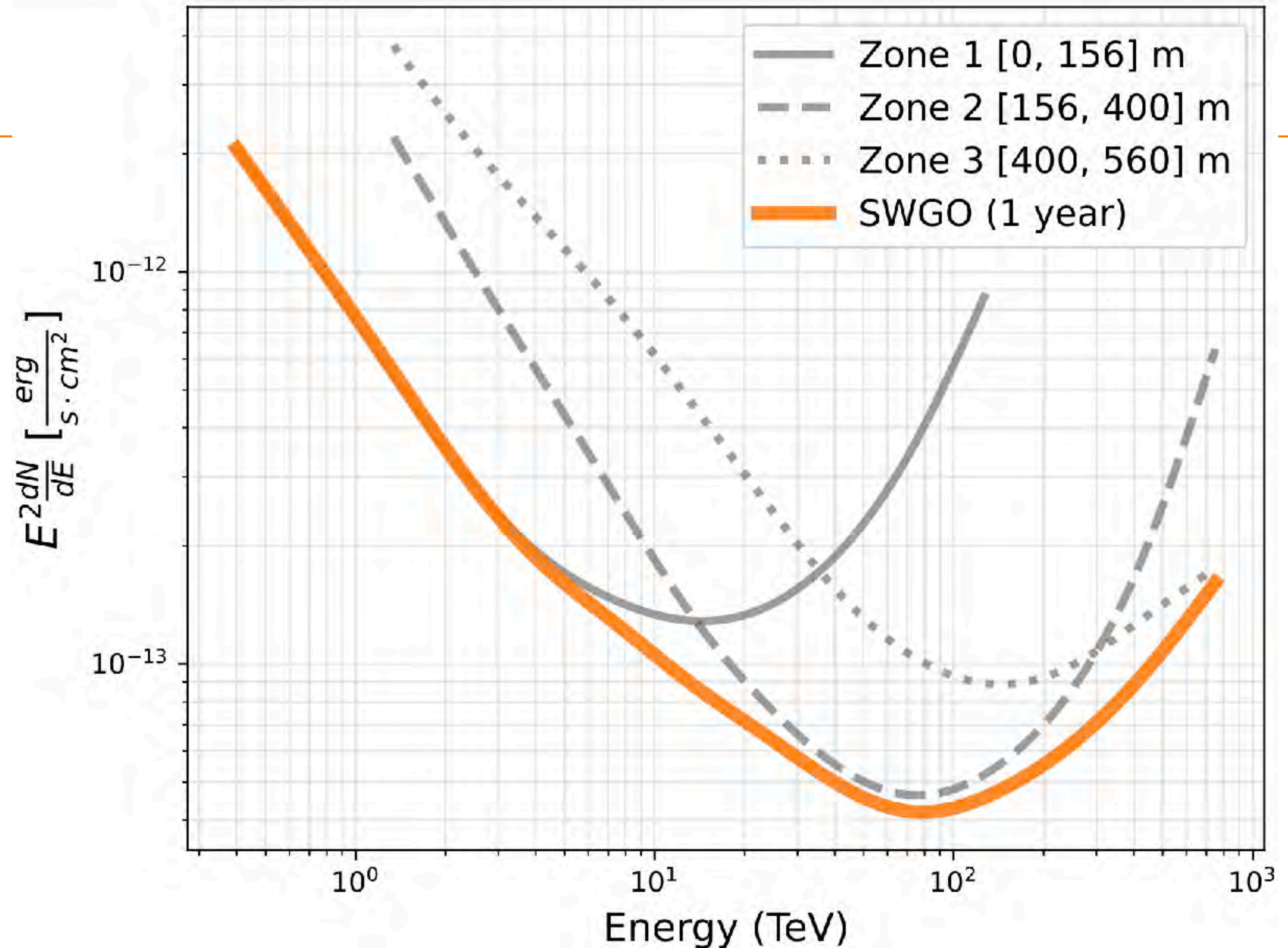
Outer array detector units

Water purification & storage



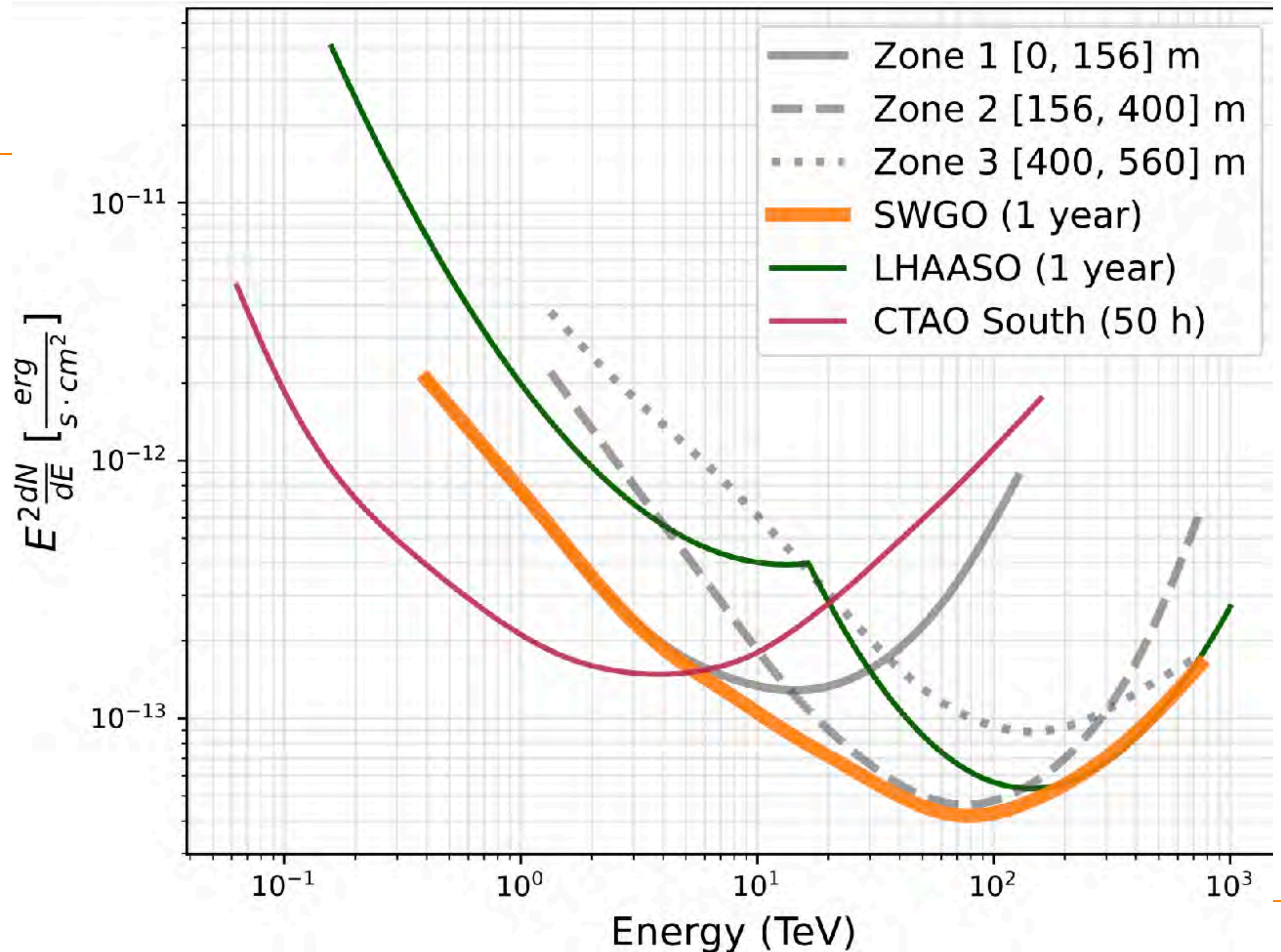
Sensitivity

- With newly established outer array baseline can put together the array sensitivity curve

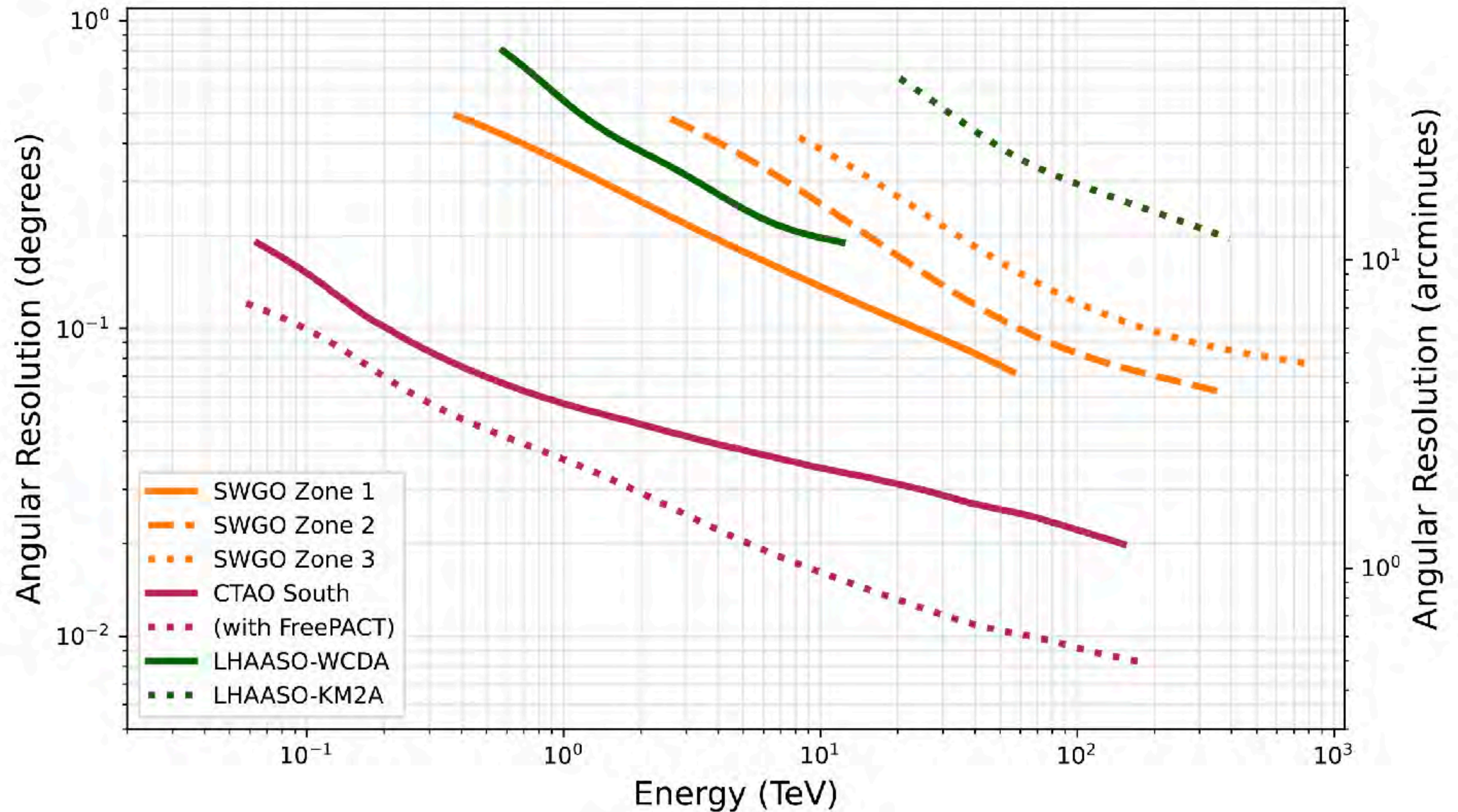


Sensitivity

- Comparison to LHAASO and CTAO-South



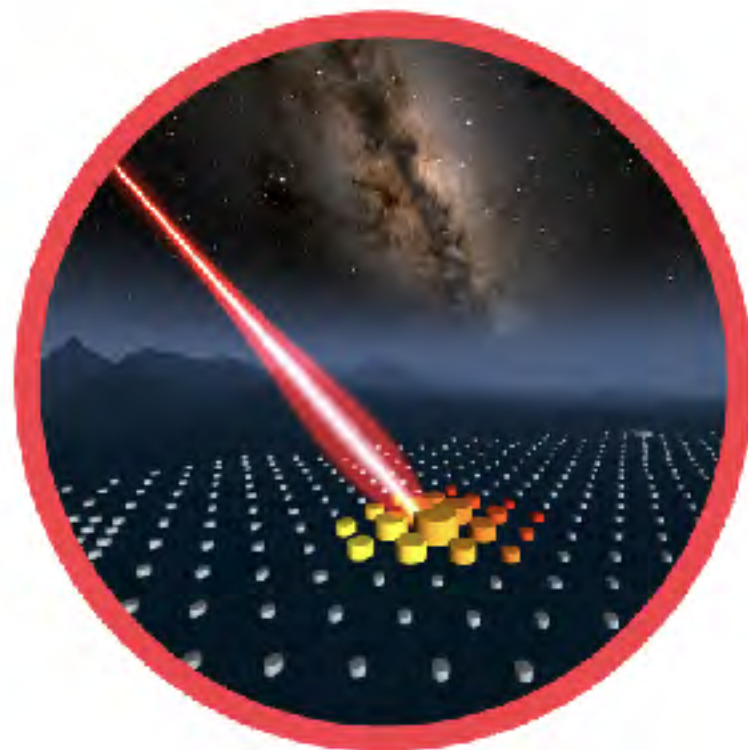
Angular Resolution



Multi-messenger astronomy with SWGO

Cosmic Rays

- ⊙ Composition and hadronic interaction models
- ⊙ Nearby extragalactic accelerators (GZK)



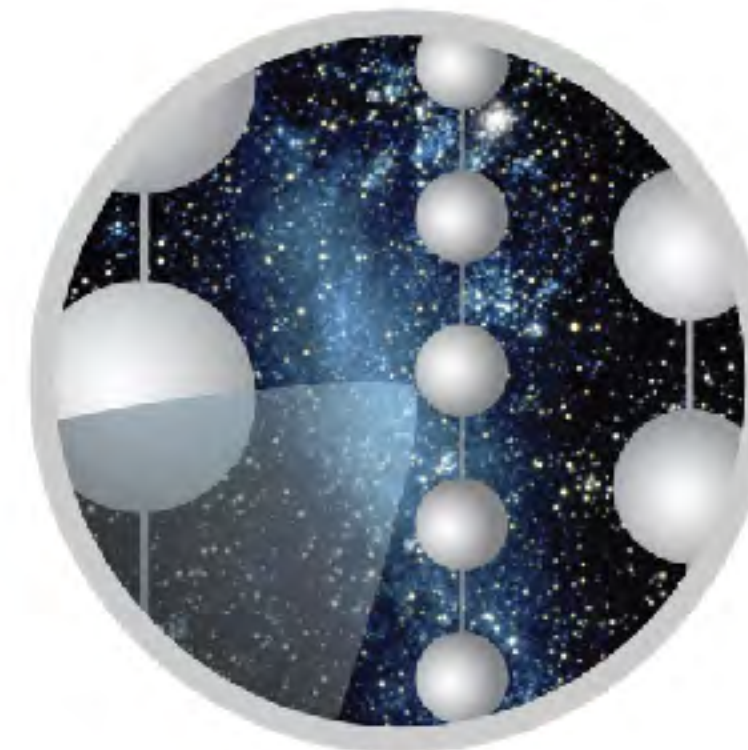
Gravitational Waves

- ⊙ Compact object mergers in the local universe ($z < 0.1$) → gamma-ray bursts



Neutrinos

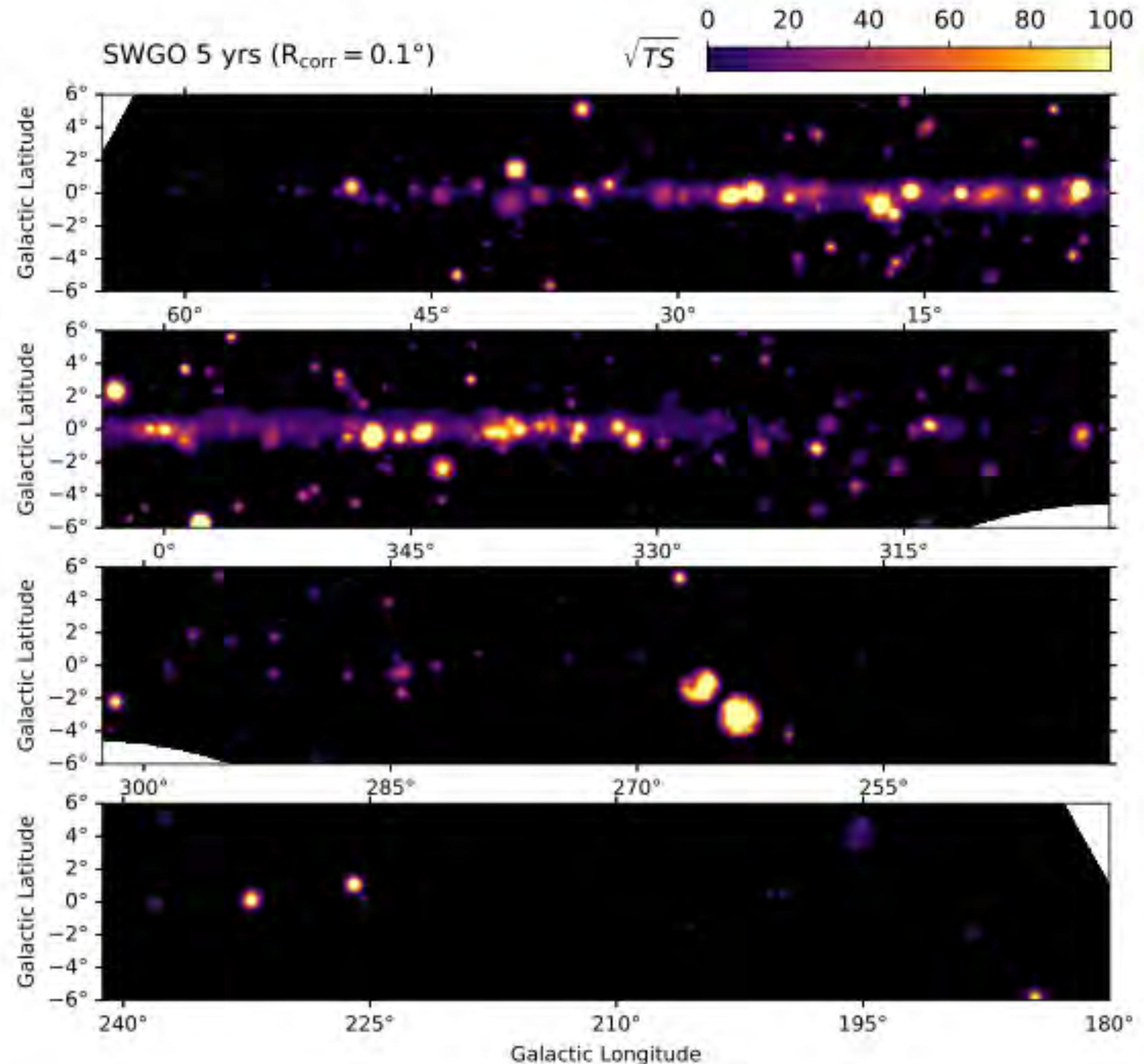
- ⊙ Diffuse Galactic emission
- ⊙ PeV+ hadron accelerators



Our Galaxy

- Simulated Galactic Plane Observation with SWGO
 - Use CTAC pop. Model
 - ✓ 499 CTA dets
 - ✓ 461 detections in SWGO FoV
 - ✓ SWGO 5 years: 487
 - Very similar source statistics
 - ✓ Strong complementarity in terms of E-range and source scale
 - ✓ CTAO resolution critical – SWGO will extend spectra

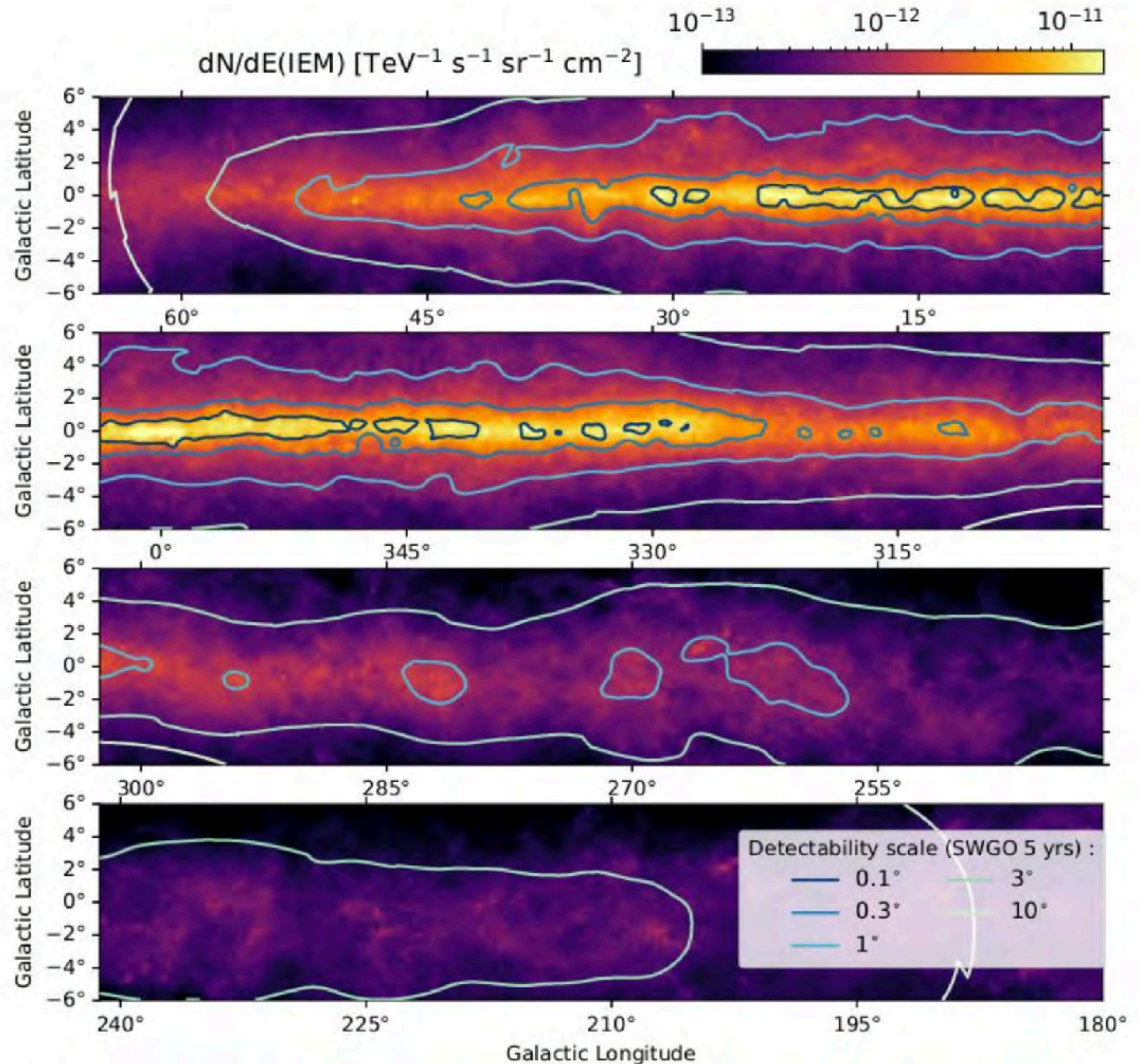
Massive stellar clusters, microquasars,
PWN, SNR +++



Diffuse Emission

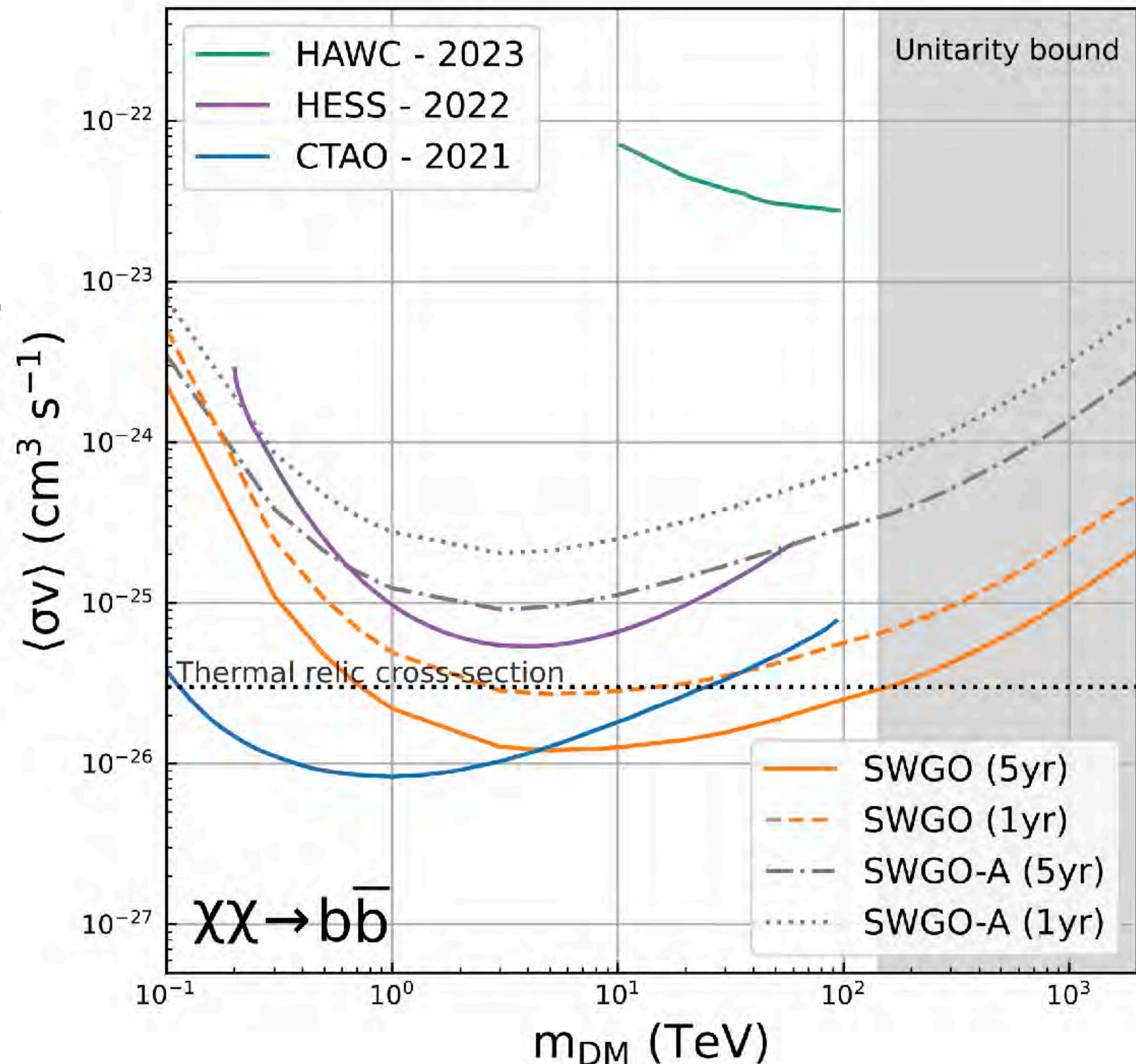
- ◎ Strongly complementary to neutrino diffuse measurement
 - And northern coverage from LHAASO and HAWC
- ◎ Can measure flux of well localised features
 - e.g. Bania Clump → CR density spot checks

(and of course source/diffuse intermediate cases like Cygnus Bubble, Westerlund 1 outflow, +++)



Dark Matter

- WIMPs as a Thermal Relic of the Big Bang
 - Still a strong DM candidate
 - cf recent LZ event !
- Indirect detection with gammas reaching critical sensitivity for Gal. Centre
 - SWGO advantages: wide field, BG systematics, higher energies
 - Again CTAO+SWGO extremely powerful
 - ✓ joint study in prep.



In to a new phase...

- ◎ Beyond the pathfinder:

- Engineering array ~30 tanks – operating by early 2029
- 800 radio antennae array (SWGGO-TURBO)
- and now...

- ◎ Good news from Brazil

- \$10M allocated for rotomolded tank production in Brazilian industry
 - ✓ Allows a large fraction of the outer array tanks to be built during 2029-2030
- NB a large number of PMTs (3" and 10") already available for construction

- ◎ Recent APPEC recommendation:

- "APPEC strongly supports the construction of the Southern Wide-field Gamma-ray Observatory (SWGGO) on a sustainable path"

Summary

- ◎ SWGO brings the successful wide-field gamma-ray approach to a new hemisphere – the first major instrument of this type in the south
 - Targeting inner galaxy, galactic centre, dark matter, GRBs, PeV sources, +++
 - Strongly complementary to neighboring CTAO South
 - See science case white paper for details: <https://arxiv.org/abs/2506.01786>
- ◎ Now approaching construction
 - Pathfinder at Pampa La Bola about to be established
 - Outer array construction will start in 2029 – Brazilian contribution confirmed

