

The High-Energy Gamma-Ray Sky with HAWC

Hugo Ayala

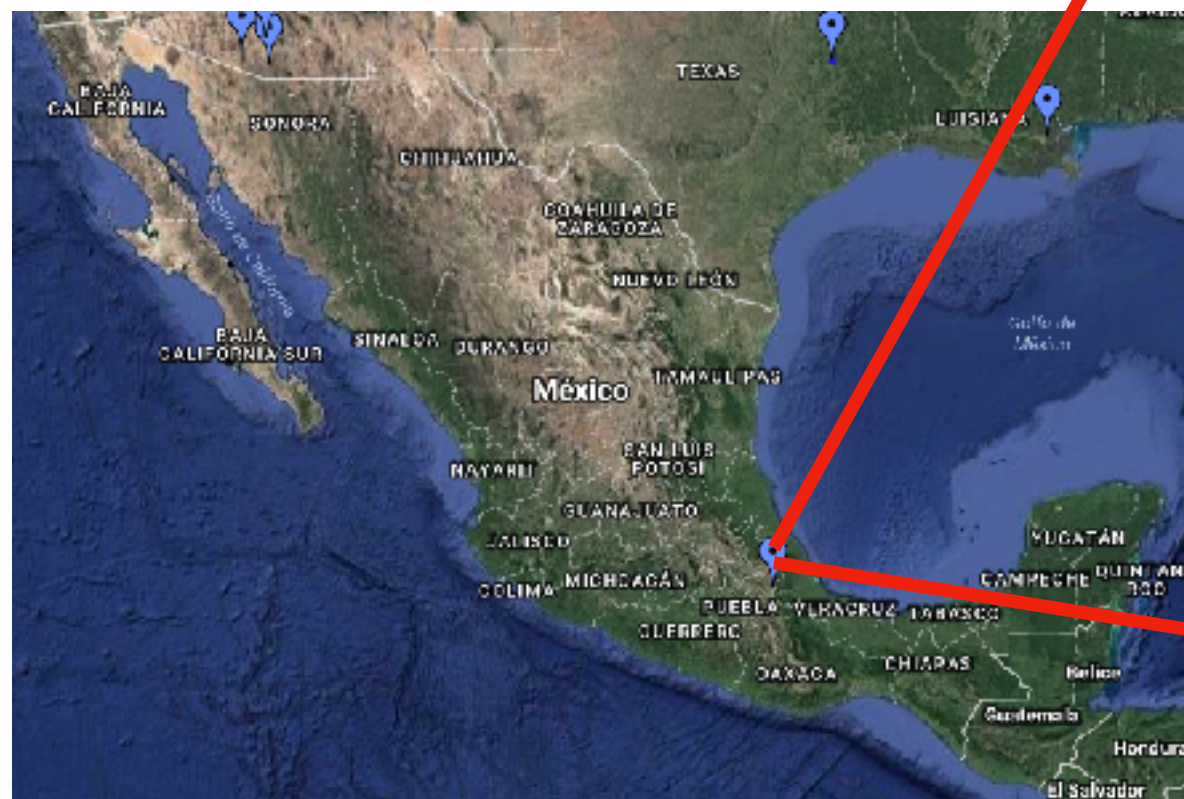


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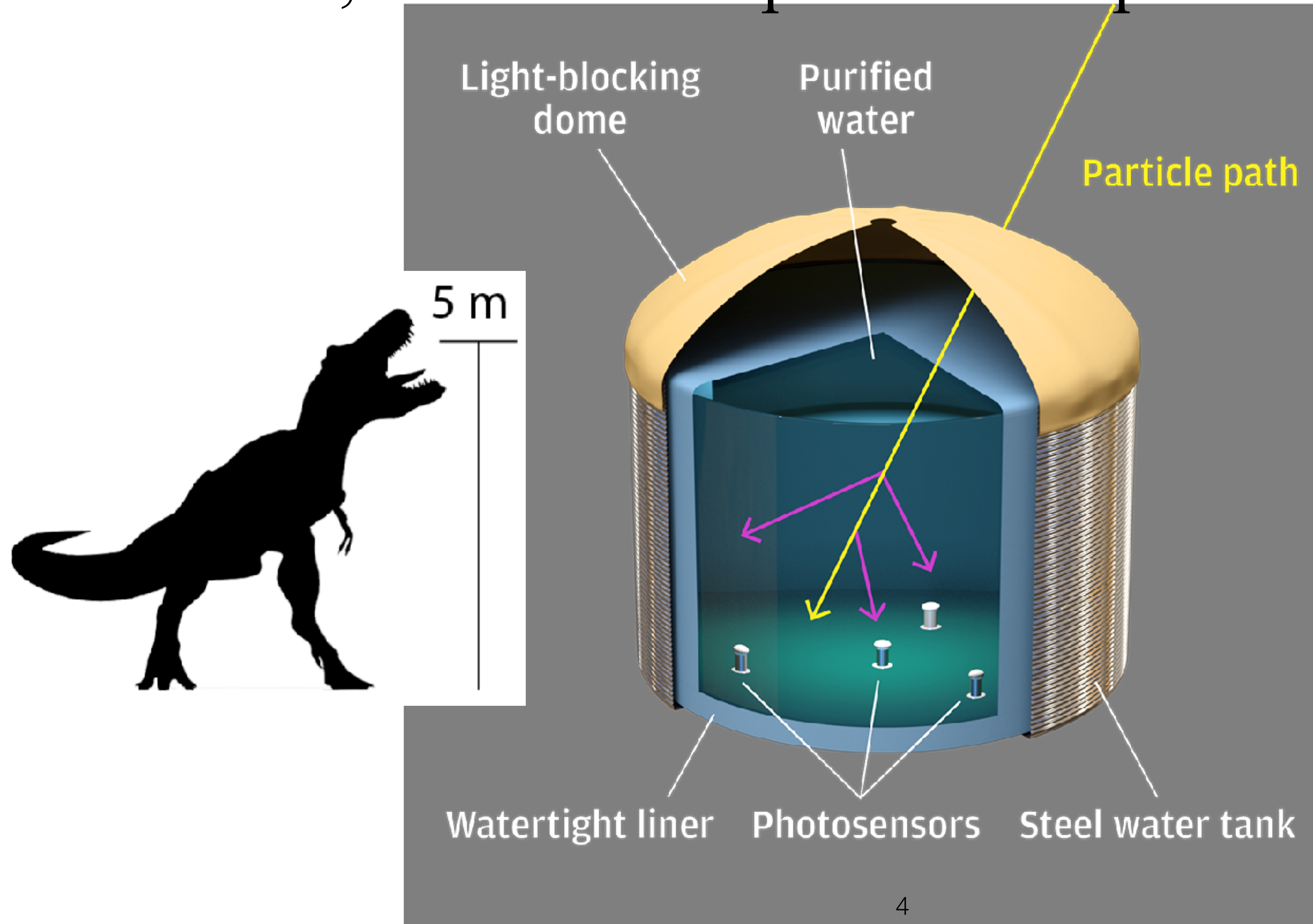
A collaboration between Mexico, USA, Germany, Poland, Costa Rica and Italy



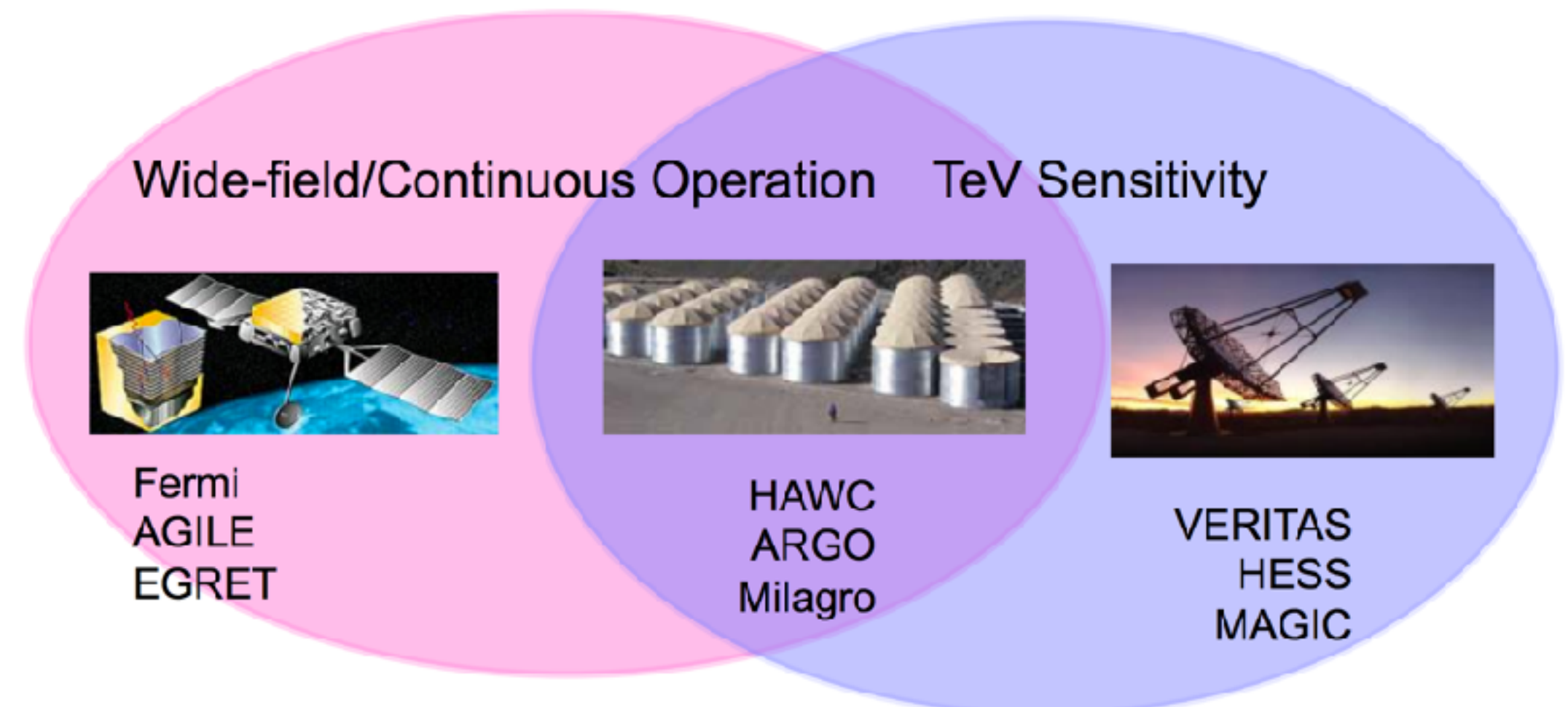
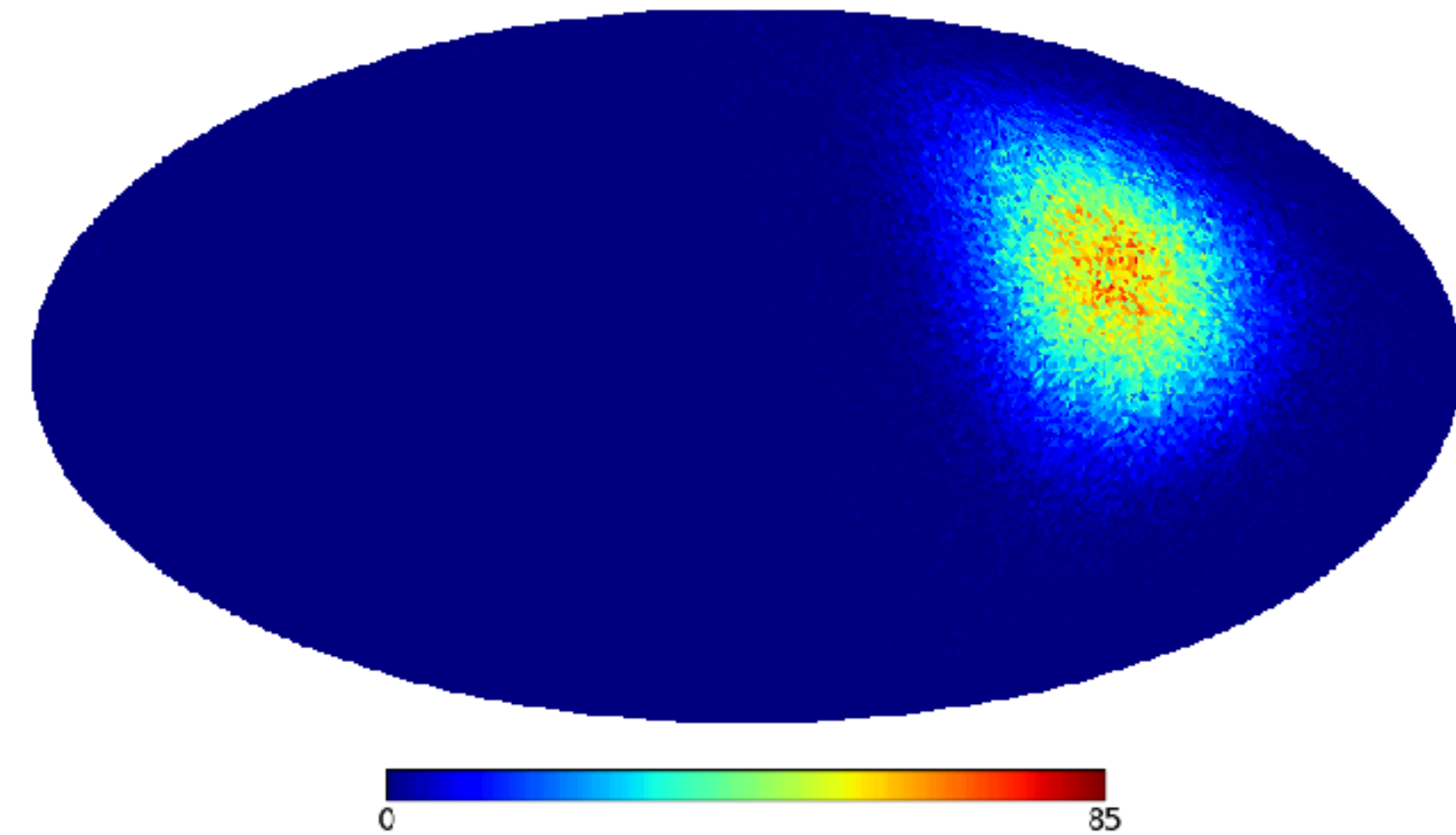
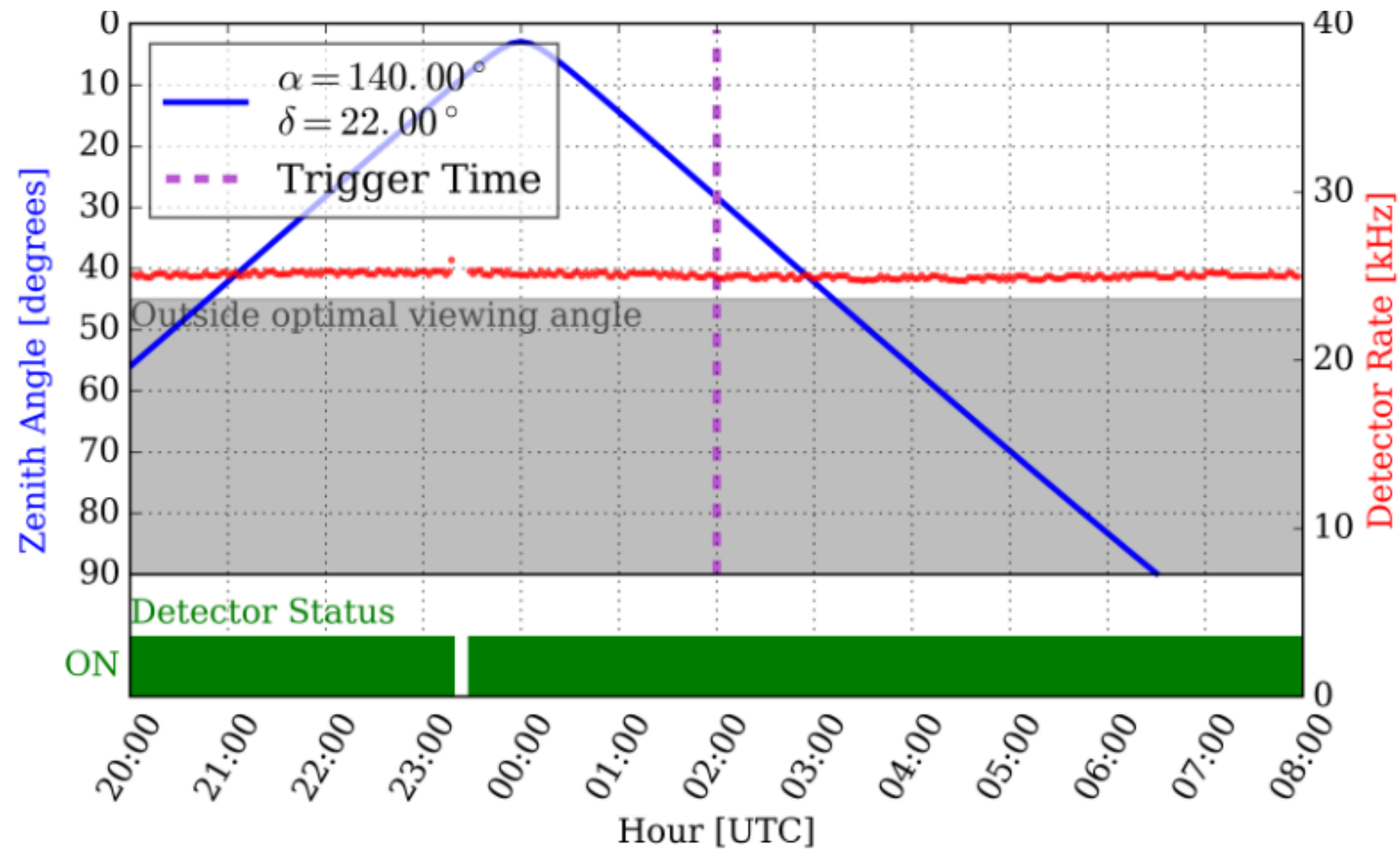
HAWC is located in central Mexico, near the Pico de Orizaba. Altitude 4100m a.s.l.



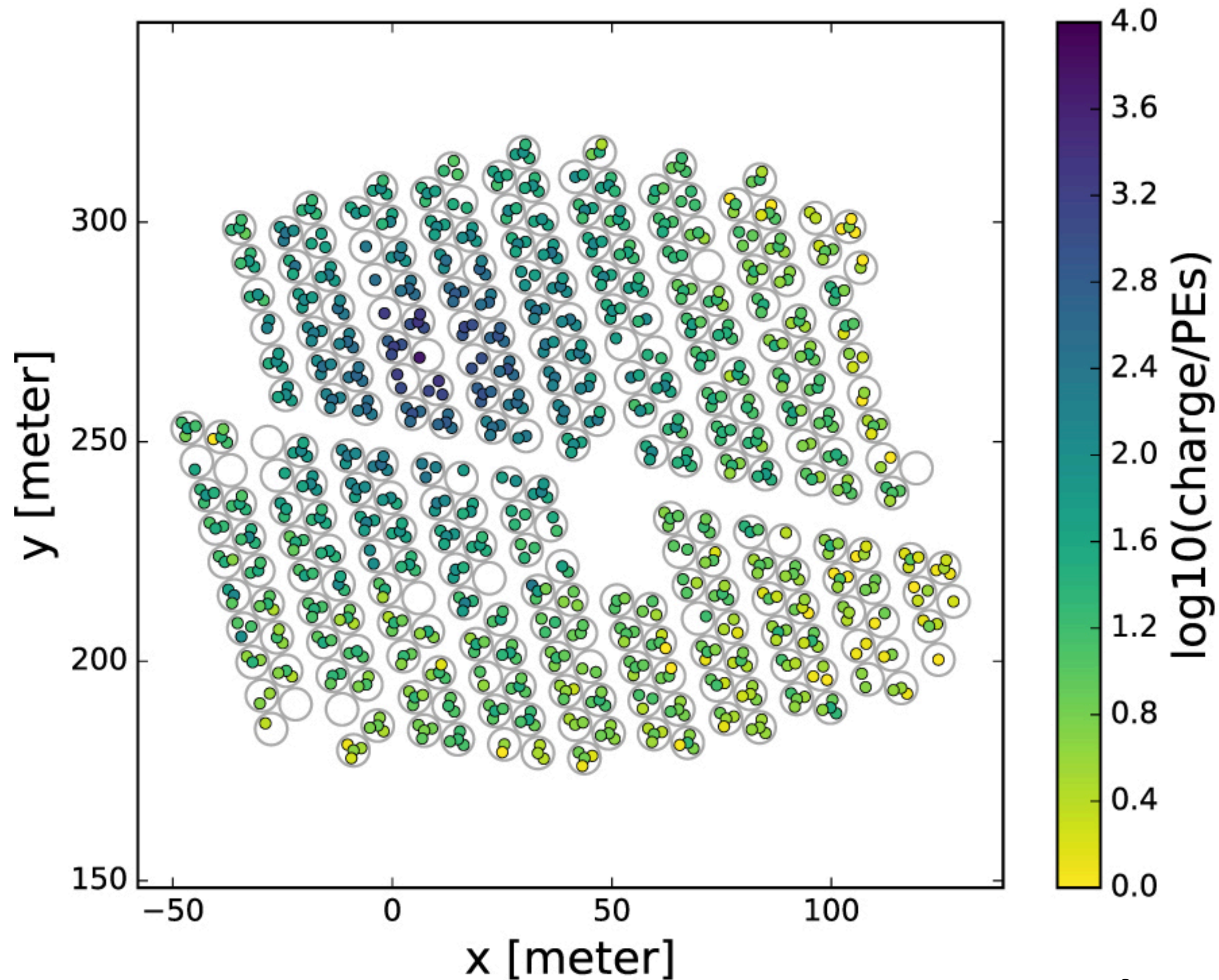
HAWC is composed of 300 water Cherenkov Detectors, each with 4 photomultiplier tubes



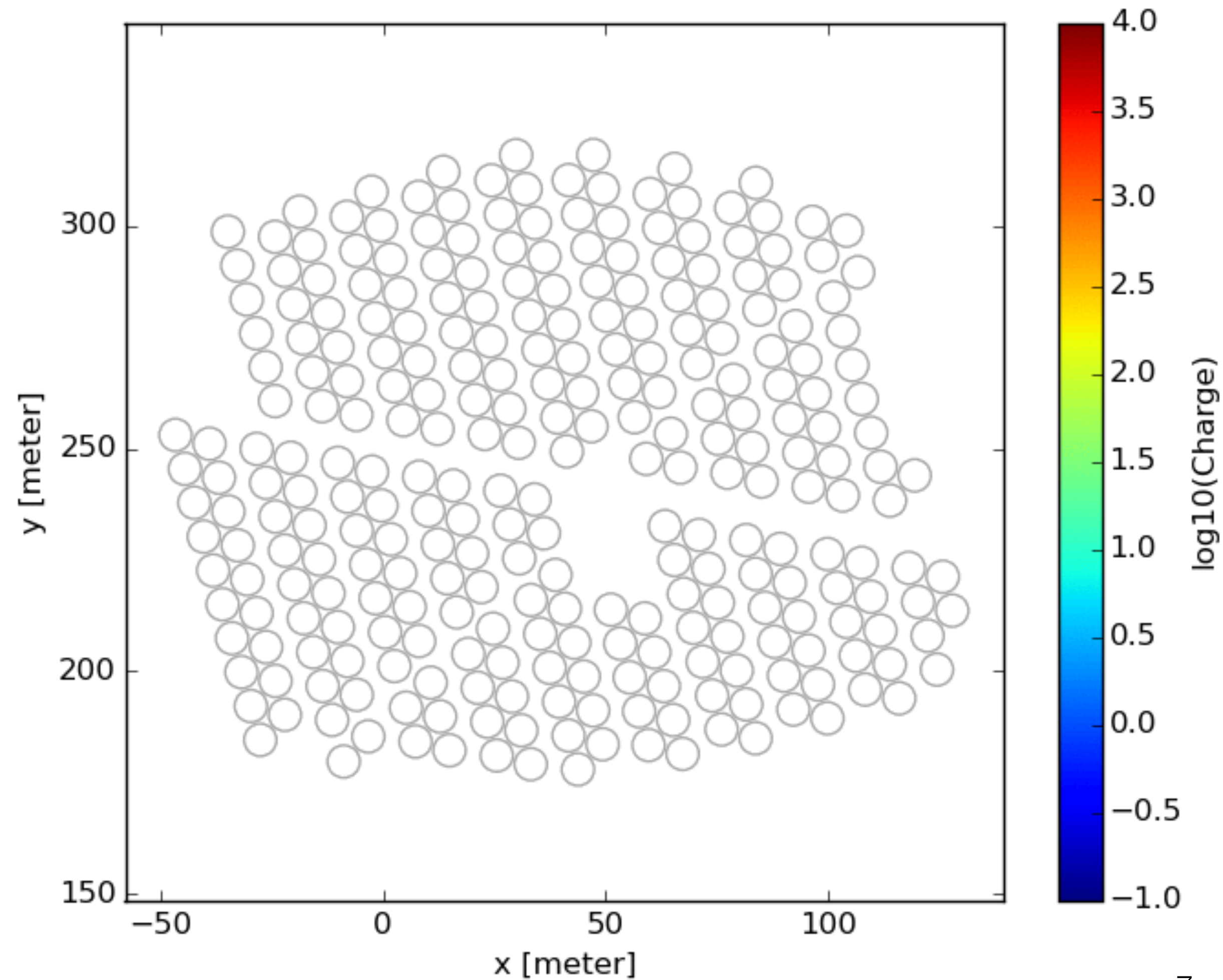
HAWC observes $\sim 2\text{sr}$ of the sky instantaneously. Covers 2/3rd of the sky daily.
 High duty cycle ($>90\%$)
 HAWC is sensitive to gamma rays with energy between $\sim 100\text{GeV}$ and 100TeV



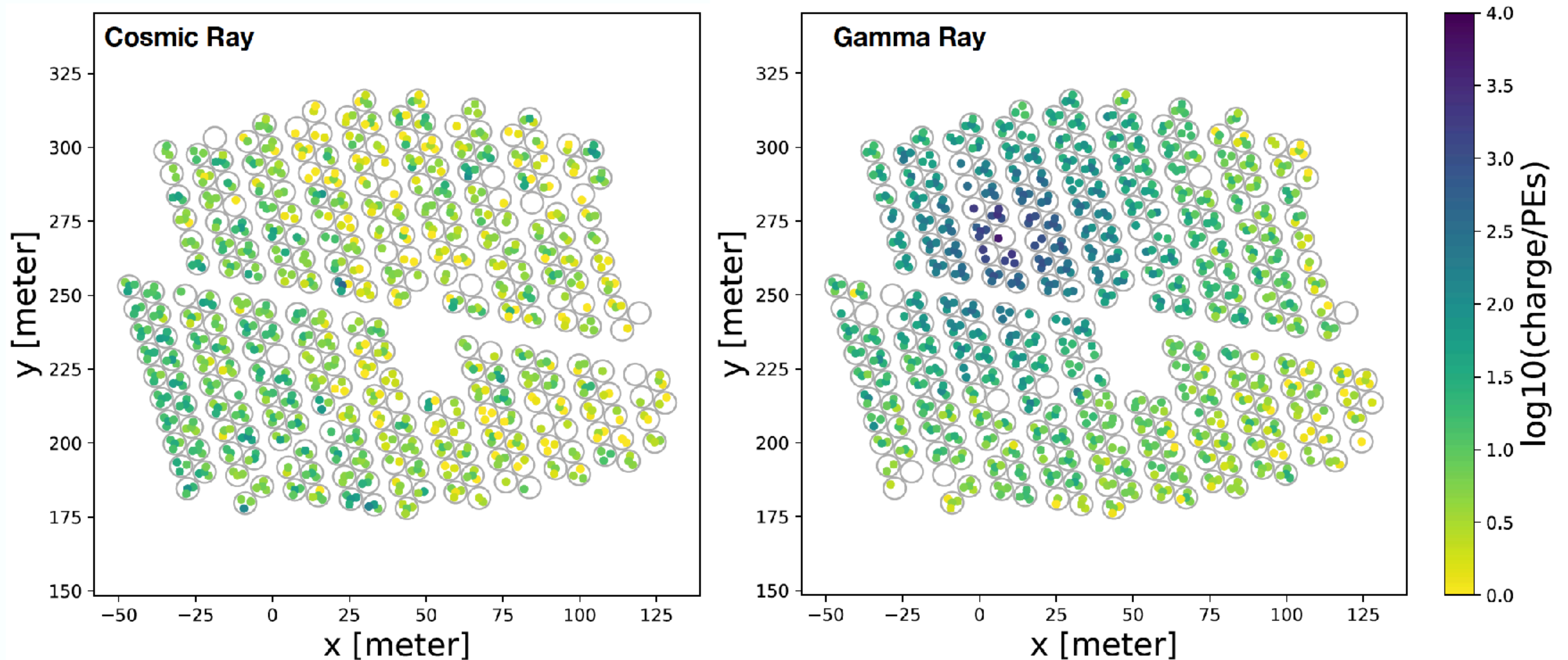
The core of the shower is found by using the deposited charge information in each tank



Use timing information of the profile of the shower to find direction of the primary gamma-ray

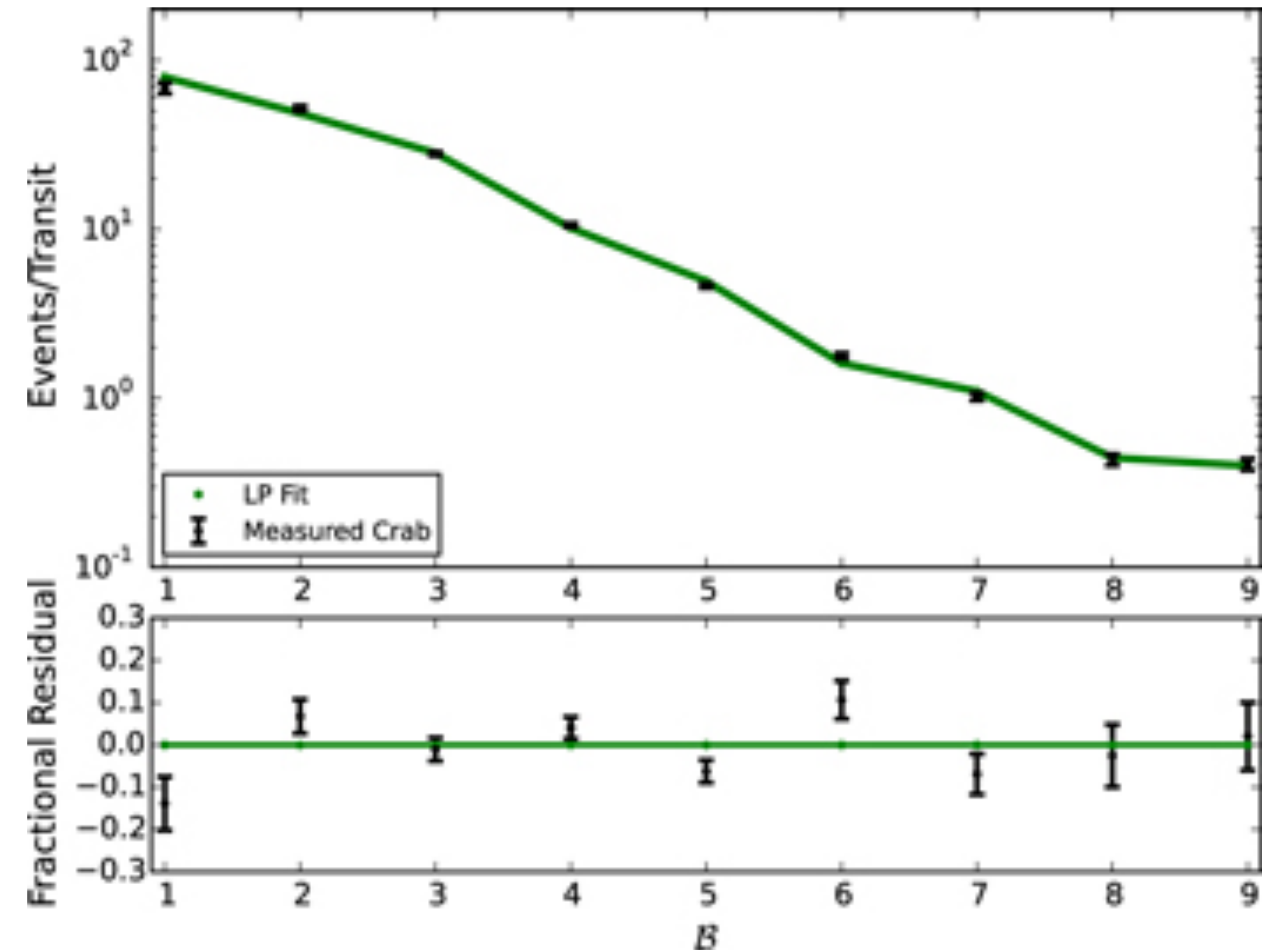
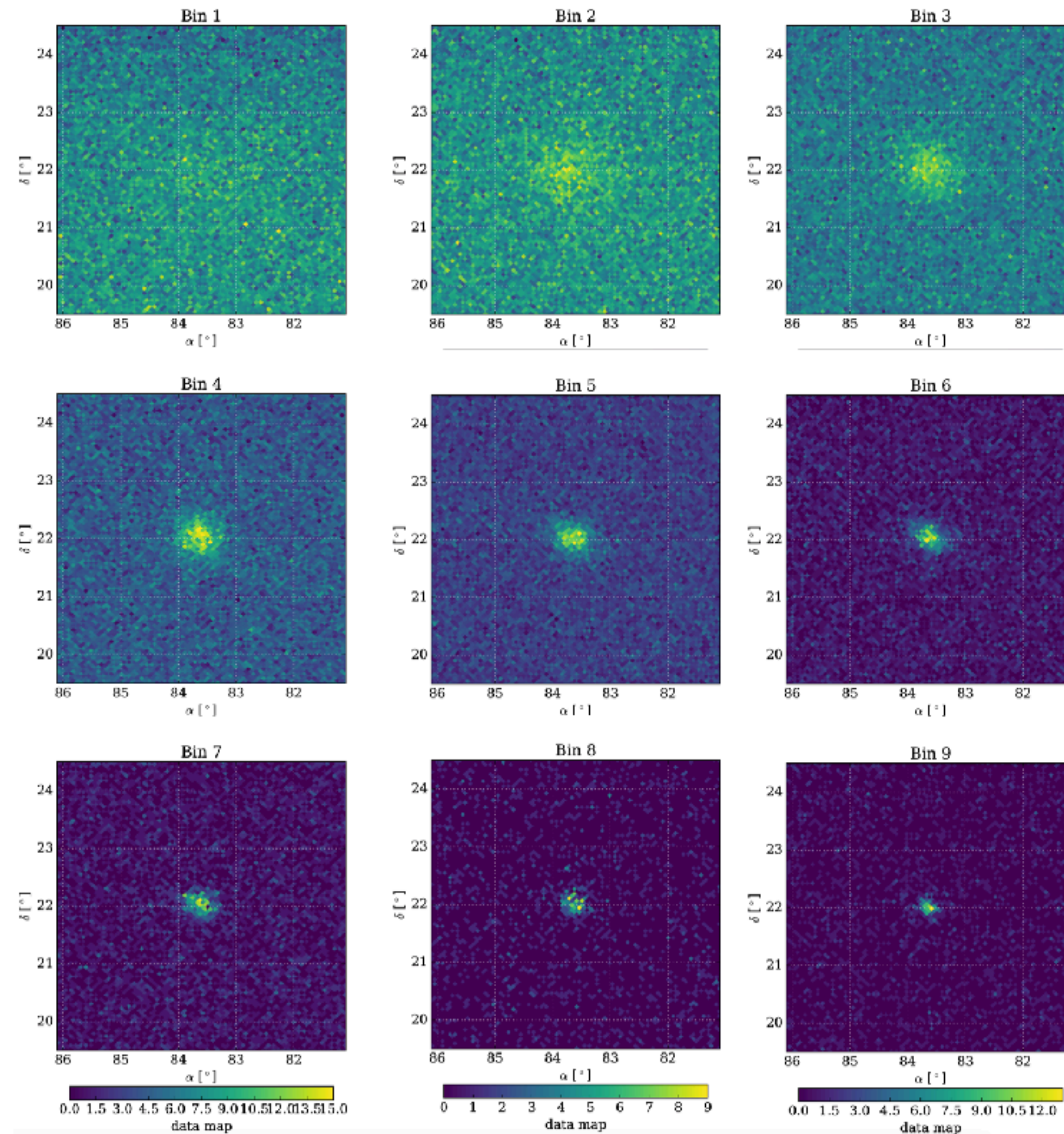


Gamma-like event is found by looking at the compactness and smoothness of the shower pattern on the array

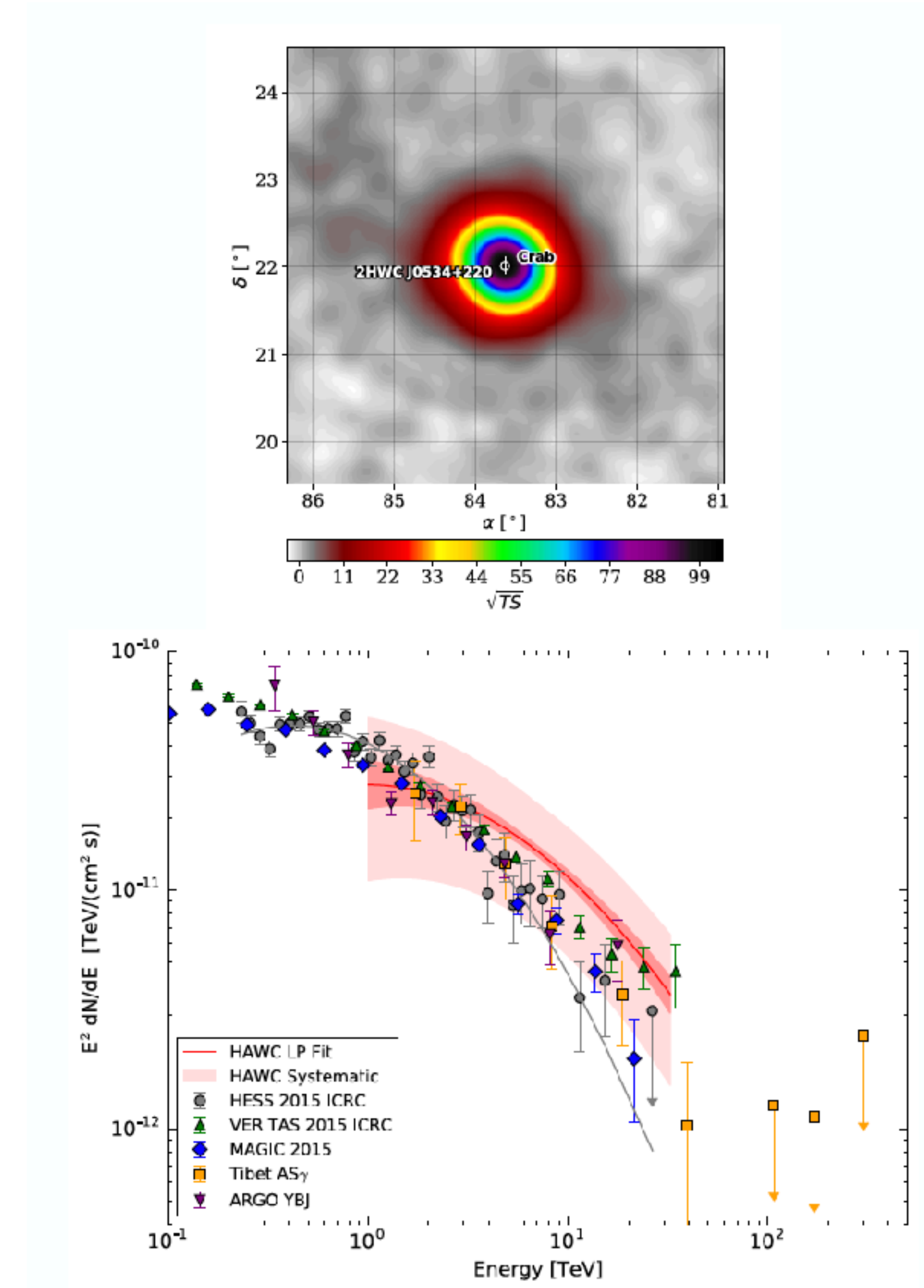
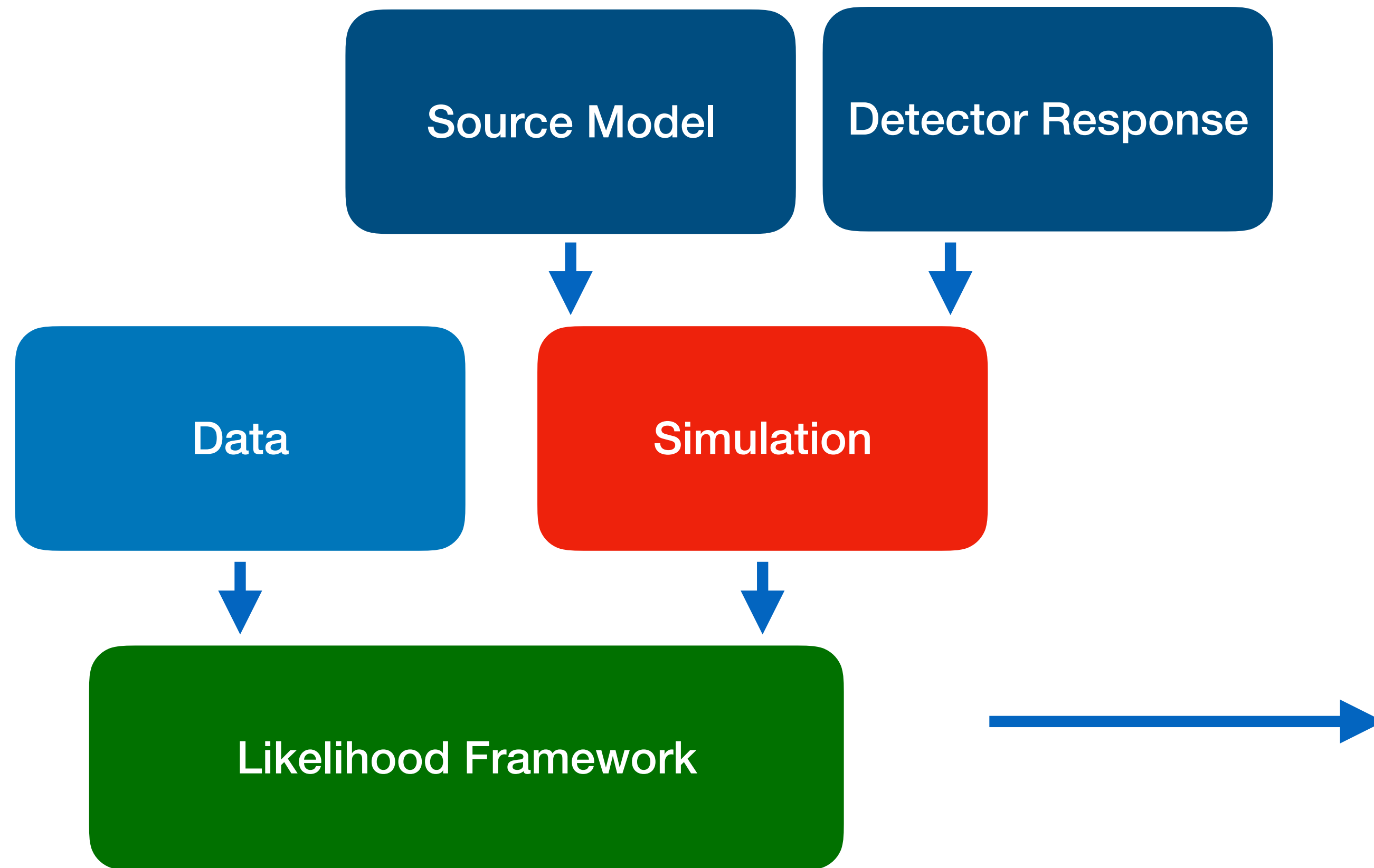


Data analysis: data set divide in 9 size bins.
 Size is defined as the fraction of active PMTs that participated in the reconstruction.
 Proxy for energy. Below are the number of events around the Crab Nebula.

Excess events from the Crab



Sources are found by using a likelihood procedure.
Likelihood is also used to find spectral parameters of the source.

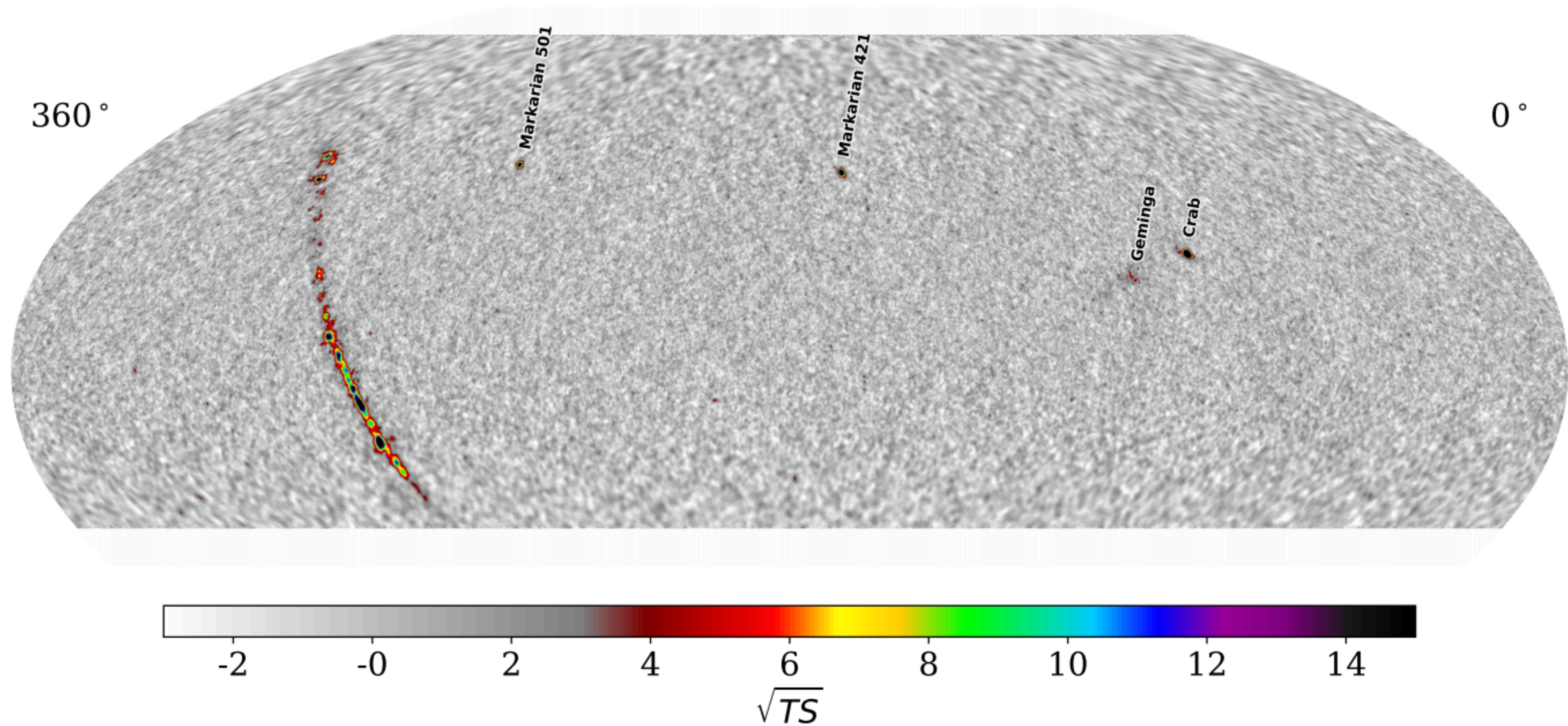


A. U. Abeysekara *et al* 2017 *ApJ* **843** 39

A. U. Abeysekara *et al* 2017 *ApJ* **843** 40

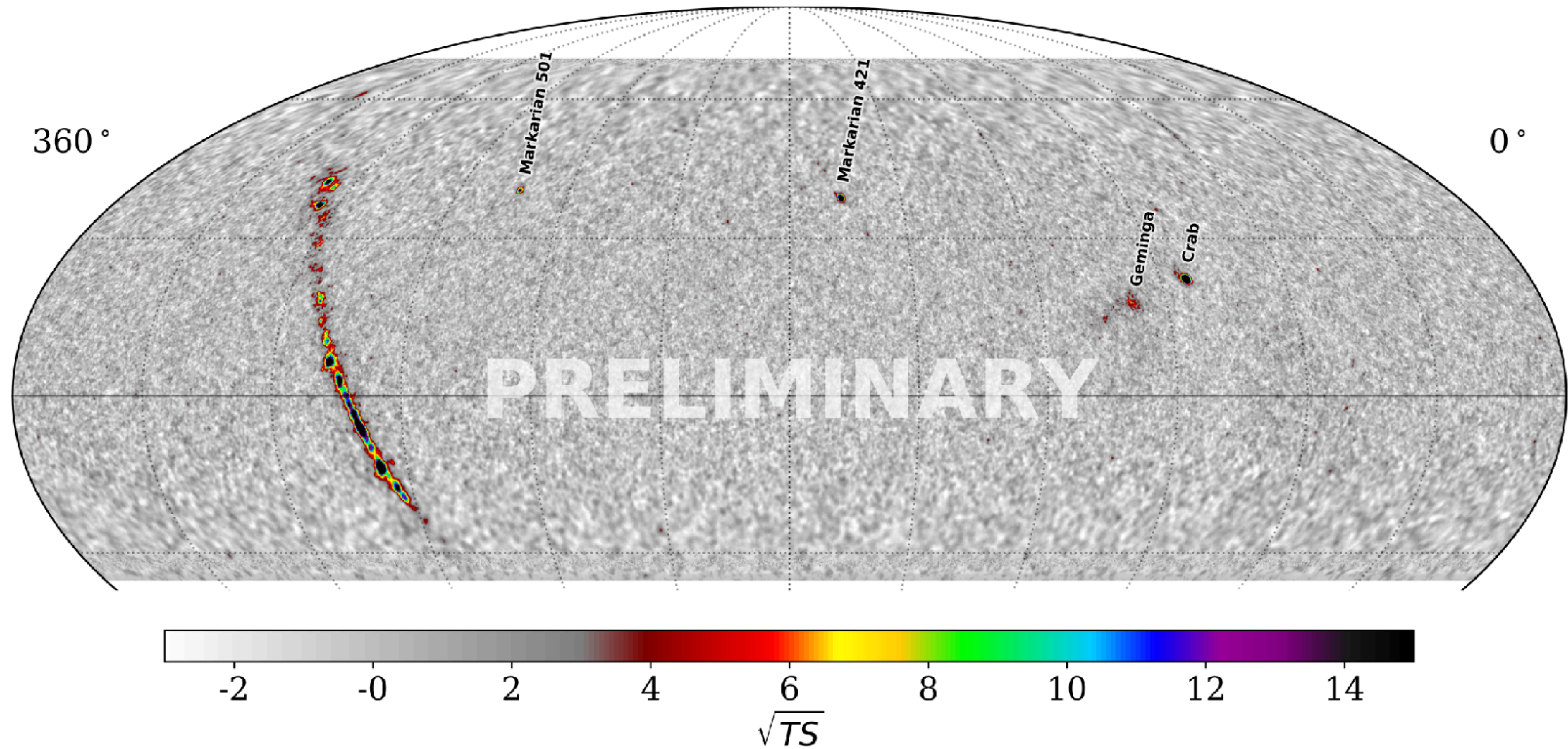
HAWC SkyMap: 1017 days of data.

2HWC catalog (***ApJ** 843, 40 (2017)*) was 507 days, with 39 sources of which 10 were new.



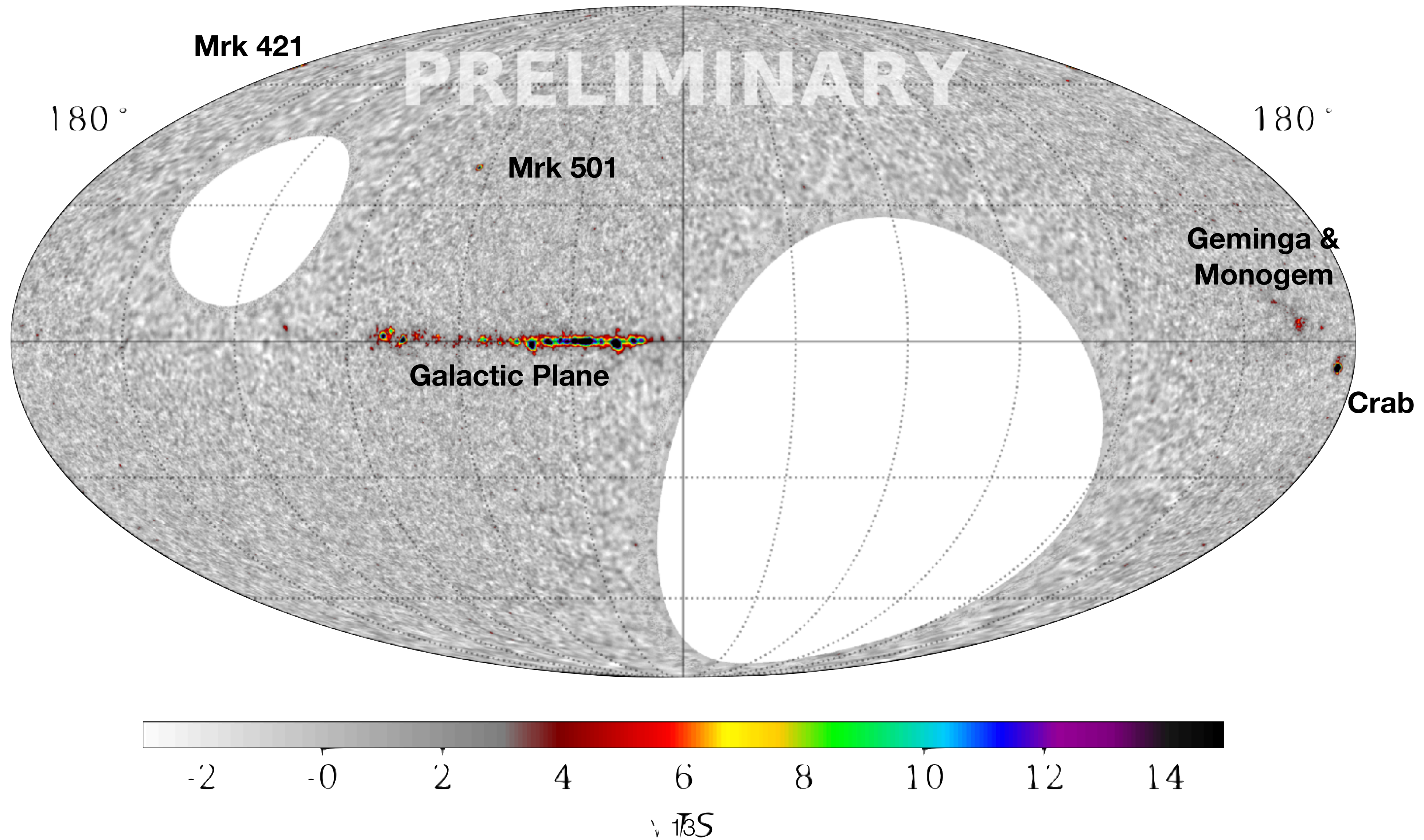
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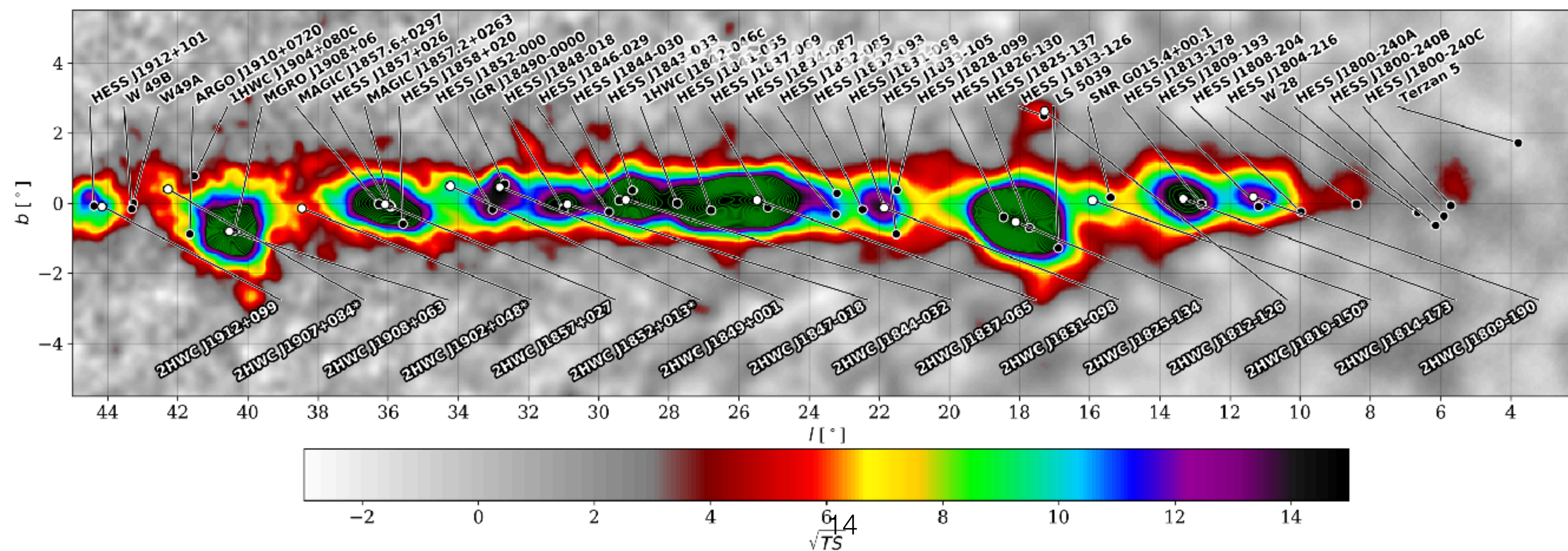
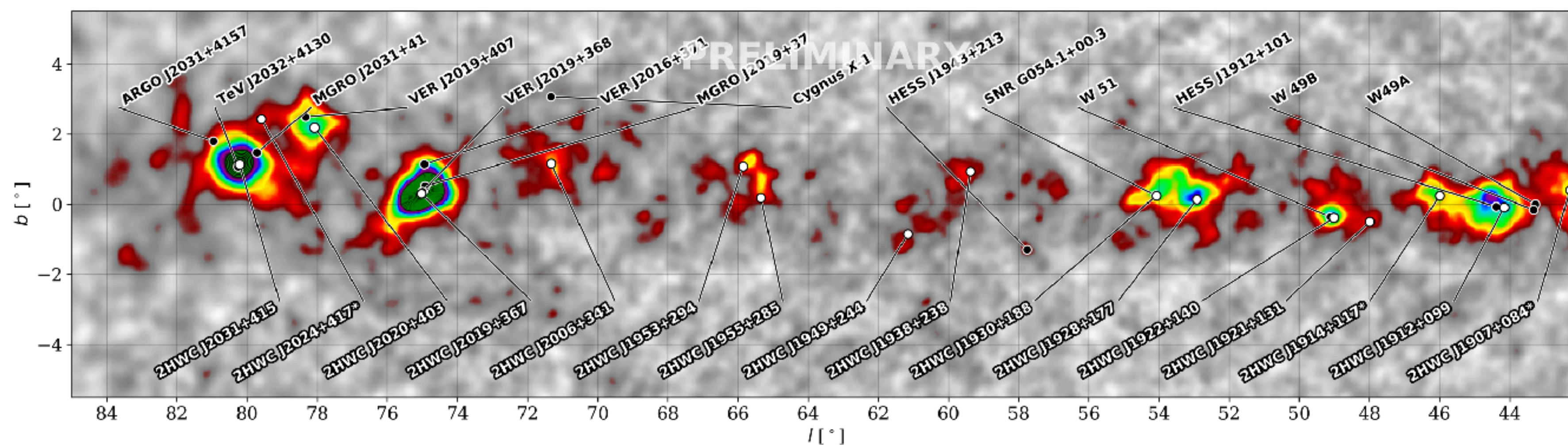
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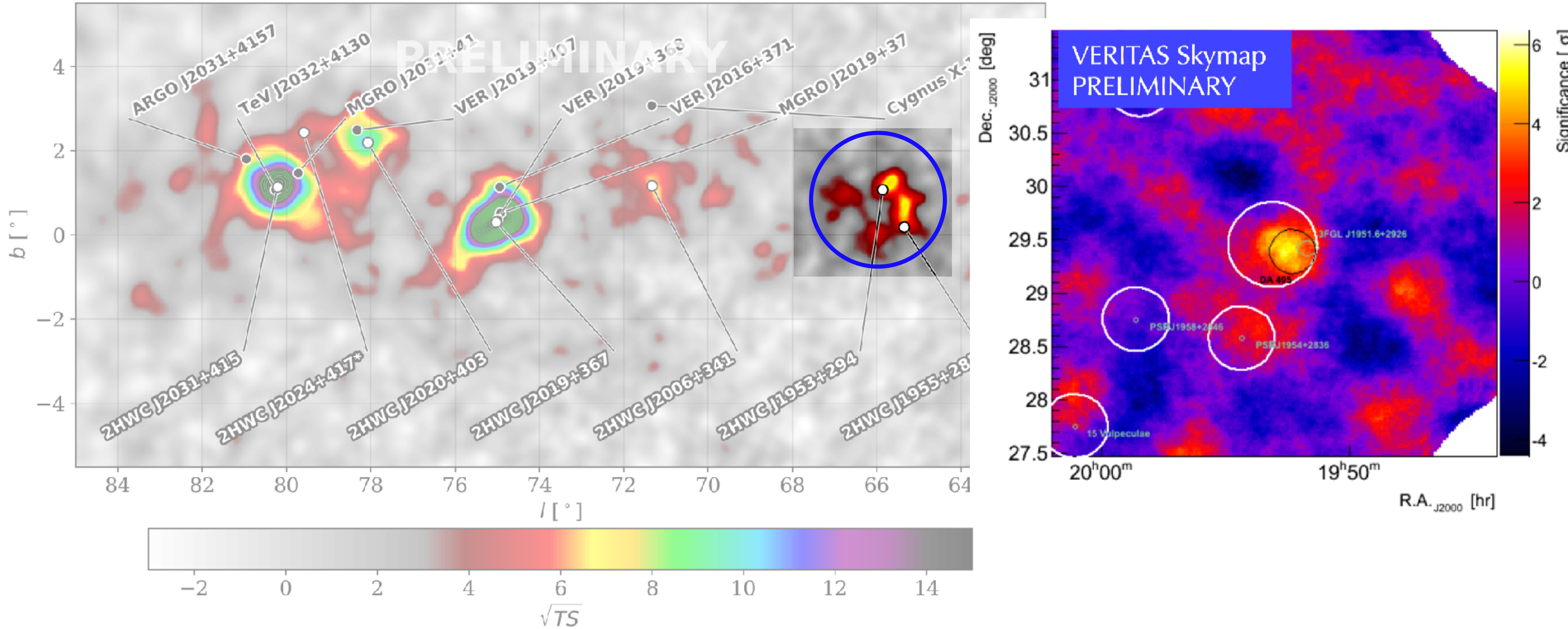
HAWC SkyMap: 1017 days of data.

2HWC catalog (*ApJ* 843, 40 (2017)) sources marked with white circles.

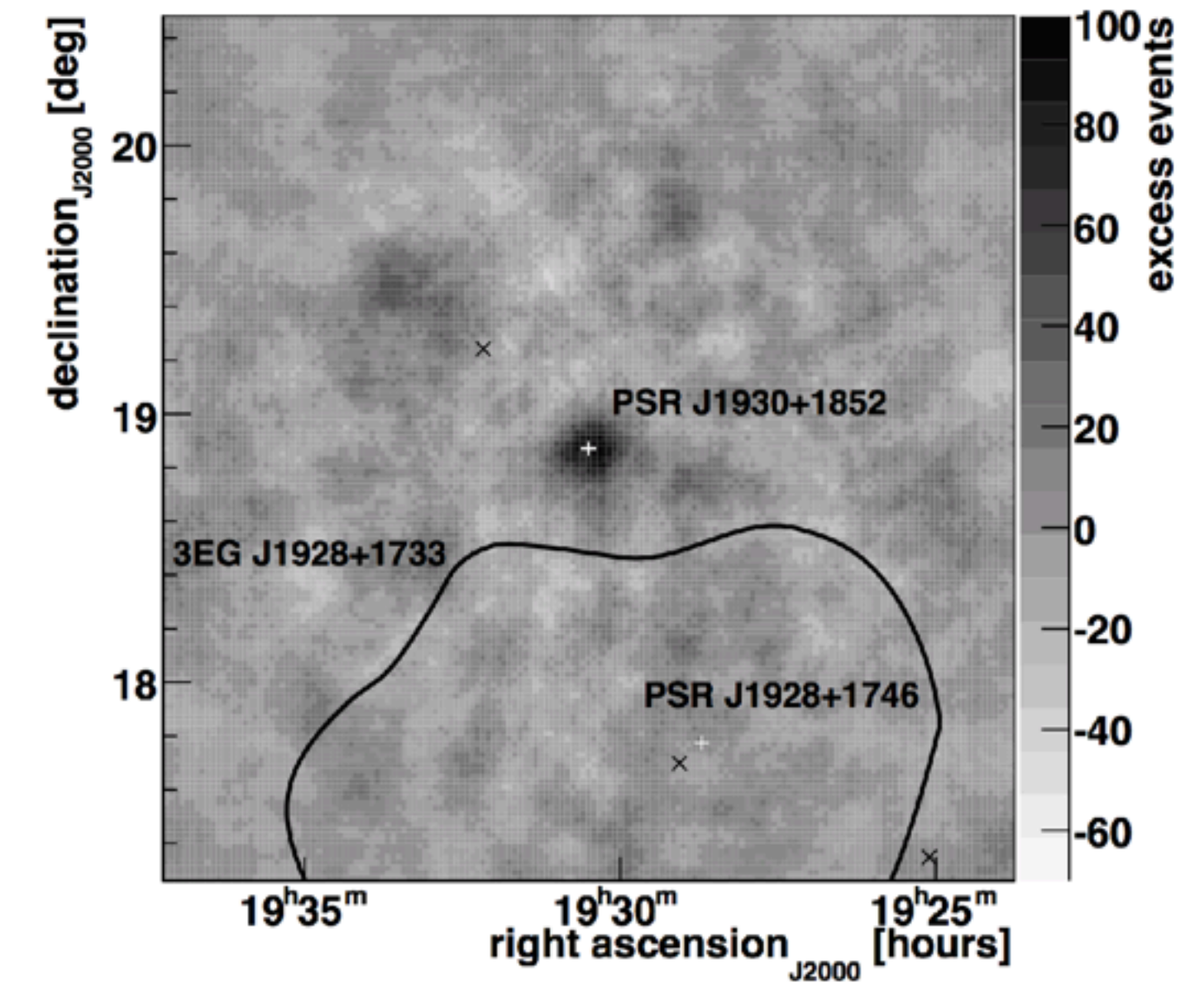
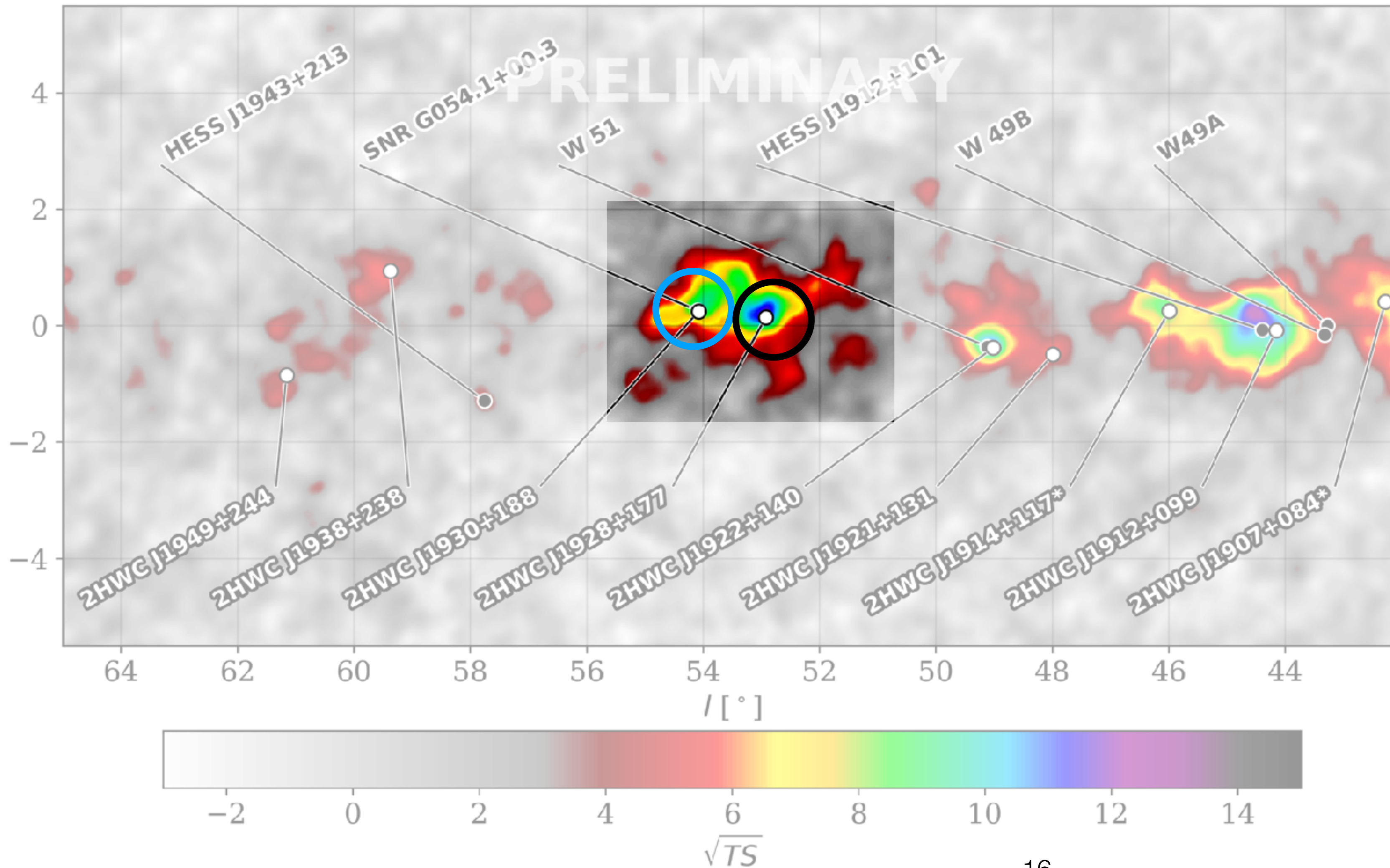
Other catalogs marked with black circles.



2HWC J1953+294 is a new TeV source. Archival study from VERITAS confirmed it. Joint collaboration paper in progress. See arXiv: 1708.05744



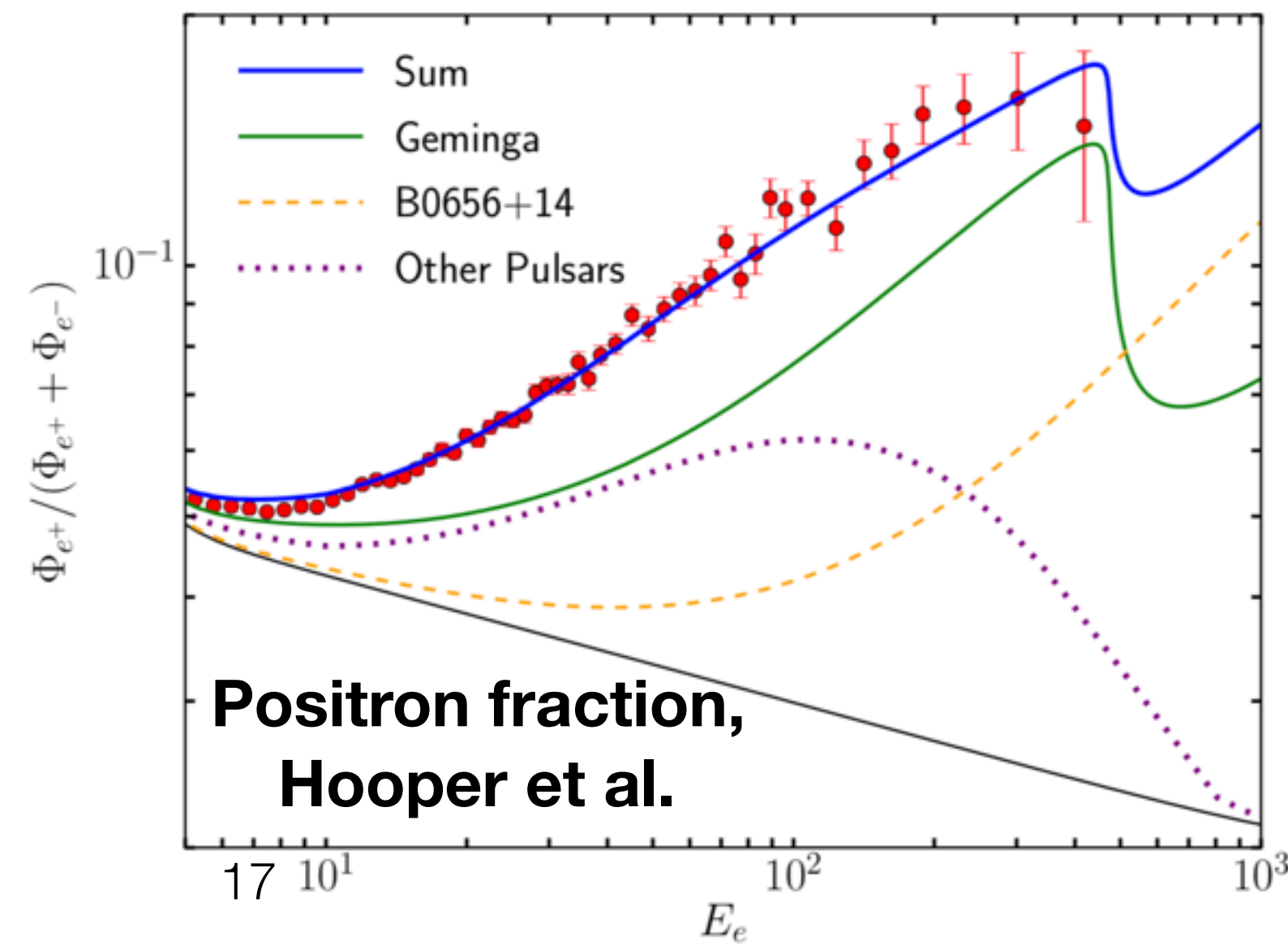
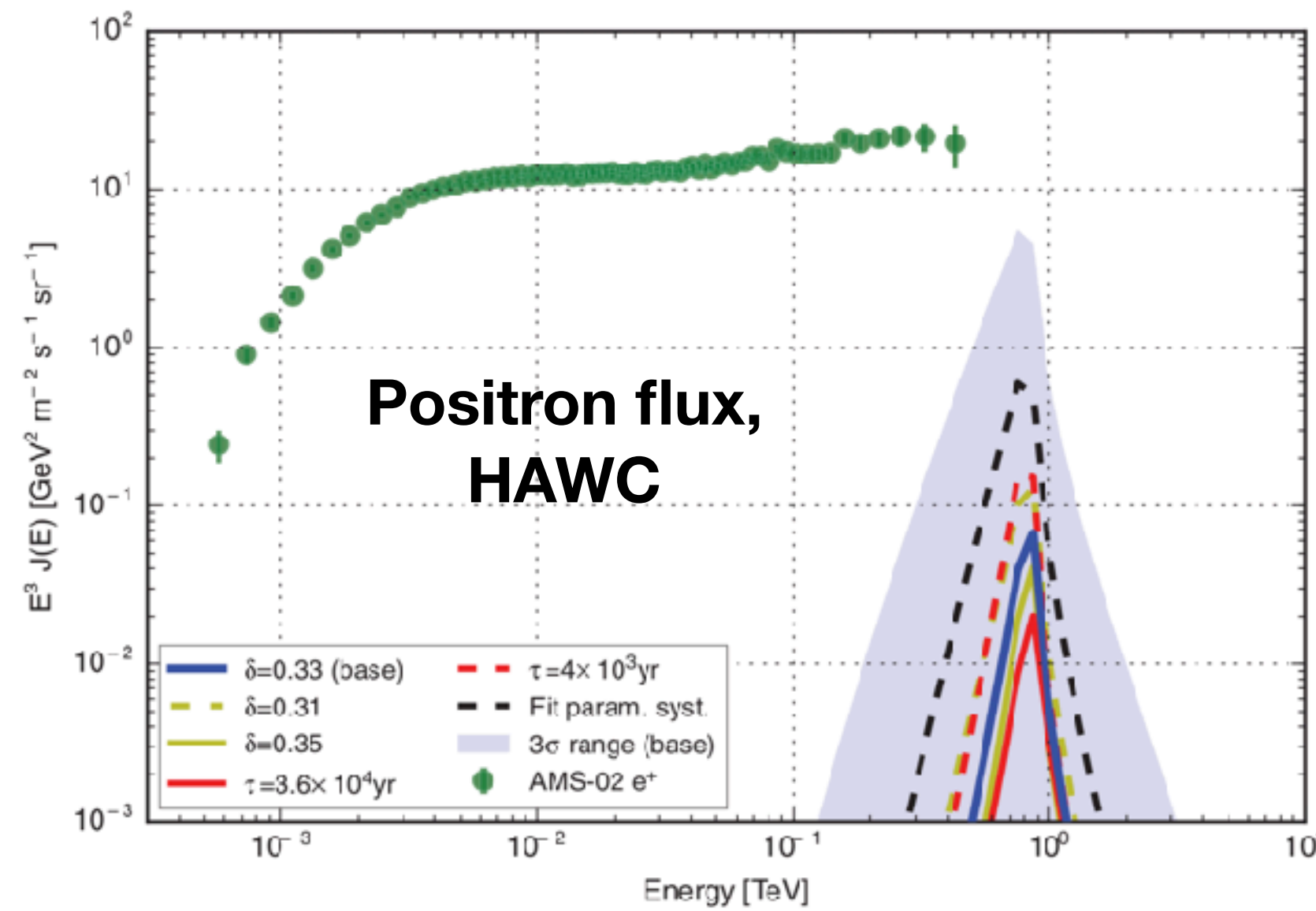
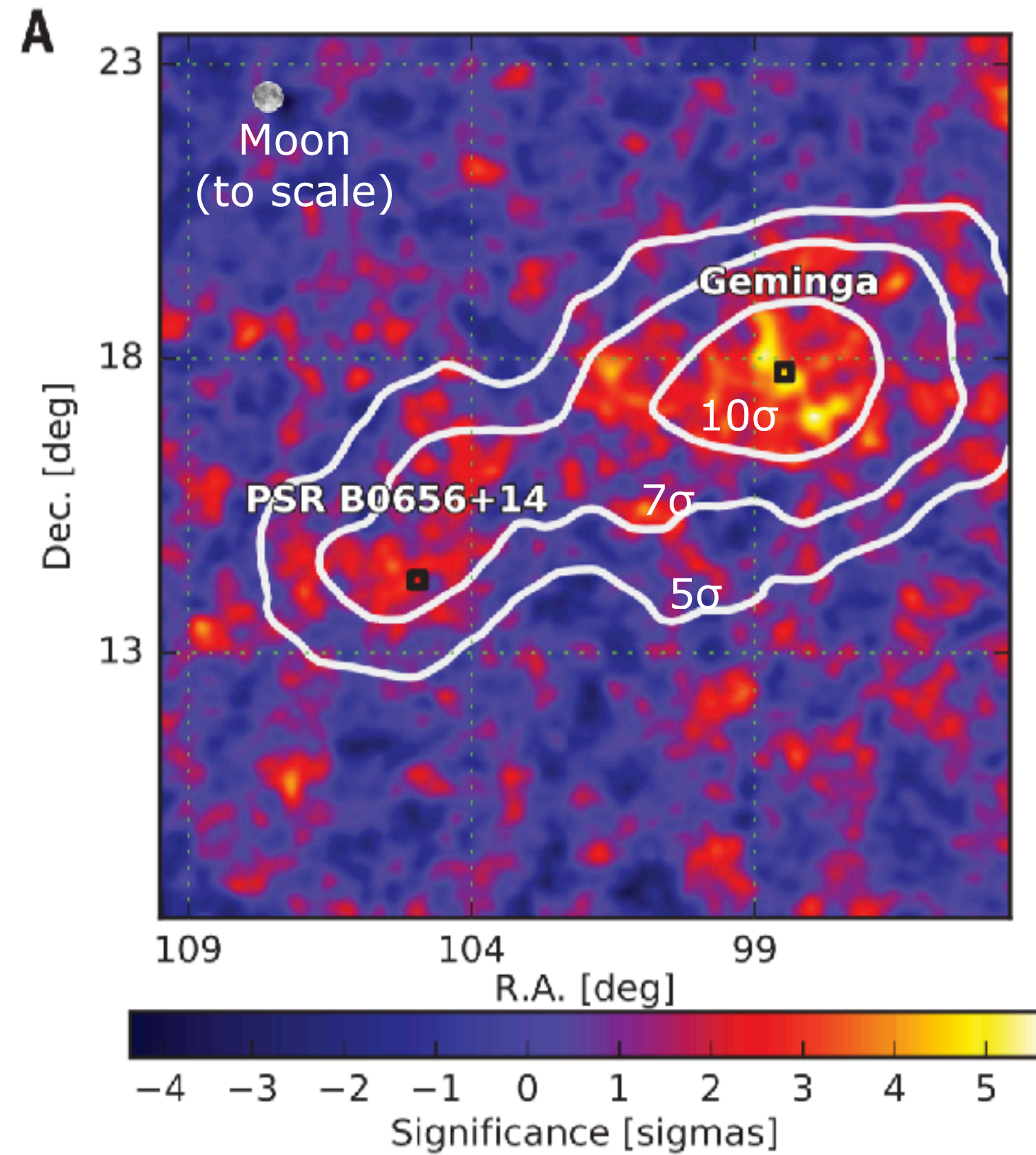
New source: 2HWC J1928+177. Associated with energetic PSR J1928+1746 and possible extended source. Not seen by VERITAS.
 2HWC J1930+188 corresponds to SNR G054.1+00.3 found by VERITAS



VERITAS, Acciari, et al. 2010

TeV Halos: Observations from Geminga-Monogem presented in Science, 2017.

Positron excess interpretation differs between HAWC and Hooper et al.

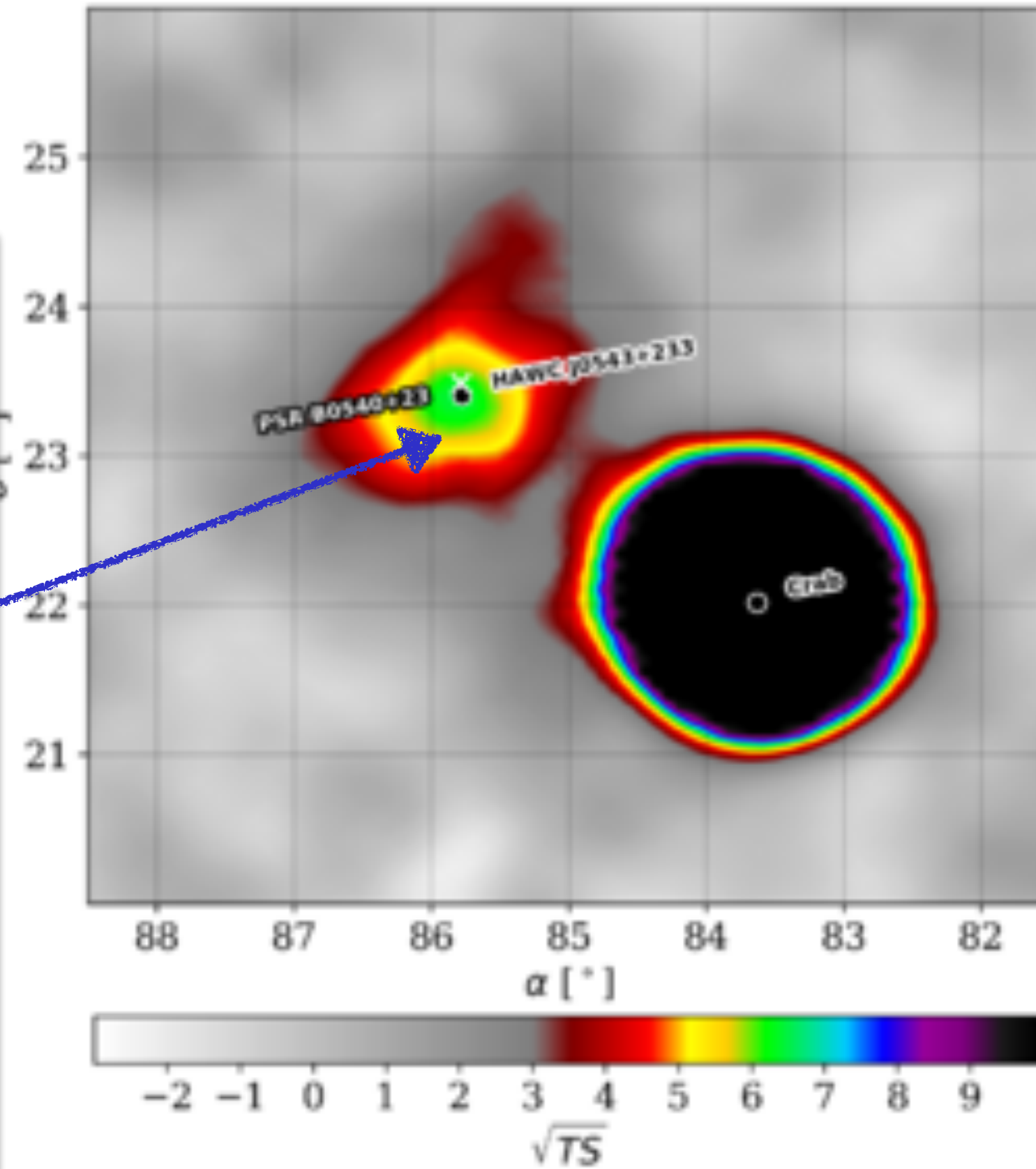
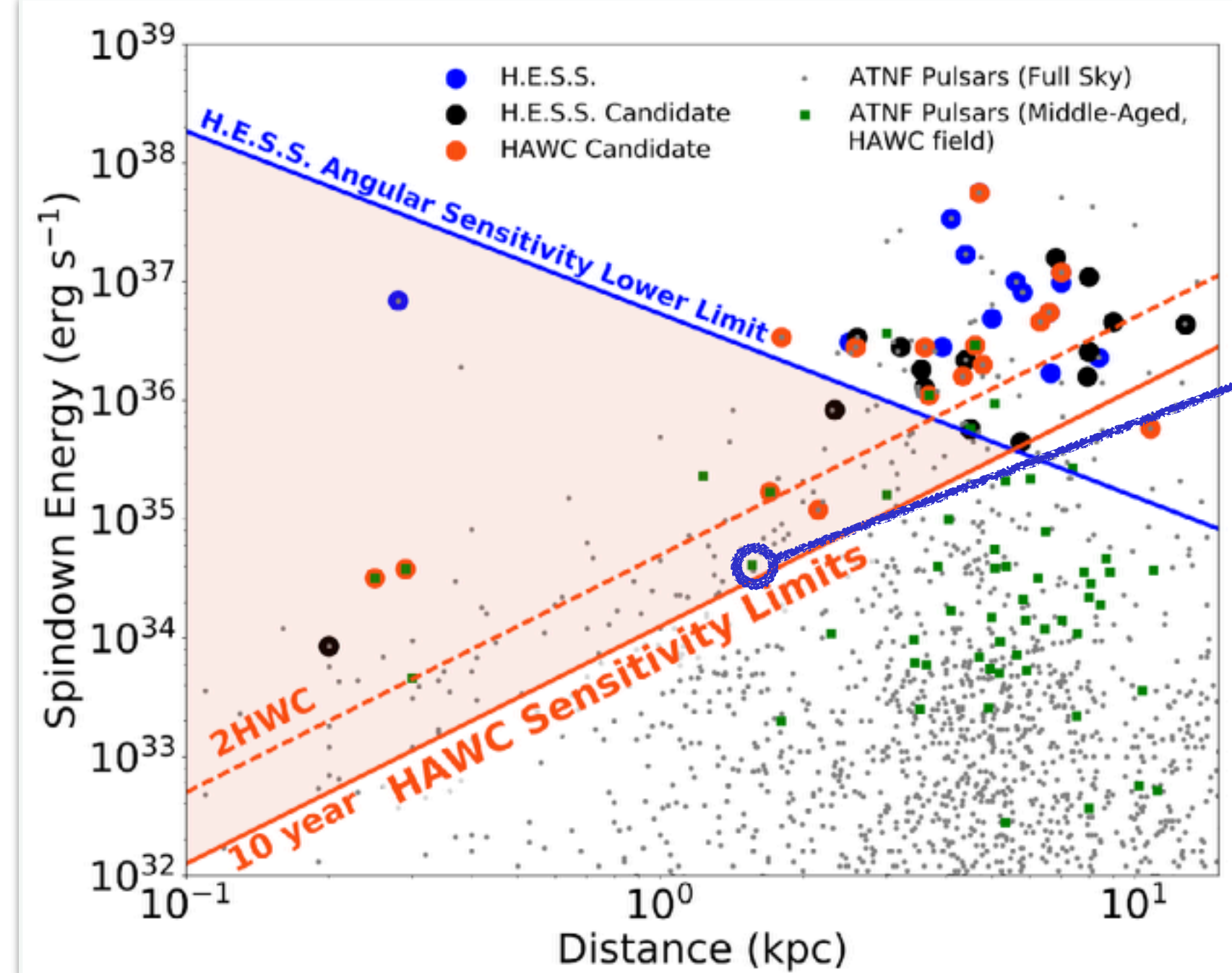


- HAWC assumes a uniform value for the diffusion constant
- Hooper et al, PRD 96, 2017 assumes a variable diffusion constant

	Geminga	Monogem
\dot{E} [erg/s]	3.2×10^{34}	3.8×10^{34}
Age [yr]	3.42×10^5	1.1×10^5
Dist. [pc]	250	288

Expected more Geminga-like pulsars as predicted by Linden et al, PRD 2017.
 Detection of HAWC J0543+233 associated with PSR B0540.

Linden et al., PRD 96, 103016 (2017)



HAWC detection of TeV emission near PSR B0540+23

ATel #10941; *Colas Riviere (University of Maryland), Henrike Fleischhack (Michigan Technological University), Andres Sandoval (Universidad Nacional Autonoma de Mexico) on behalf of the HAWC collaboration*
 on 9 Nov 2017; 23:11 UT
 Credential Certification: Colas Riviere (riviere@umd.edu)

Subjects: Gamma Ray, TeV, VHE, Pulsar

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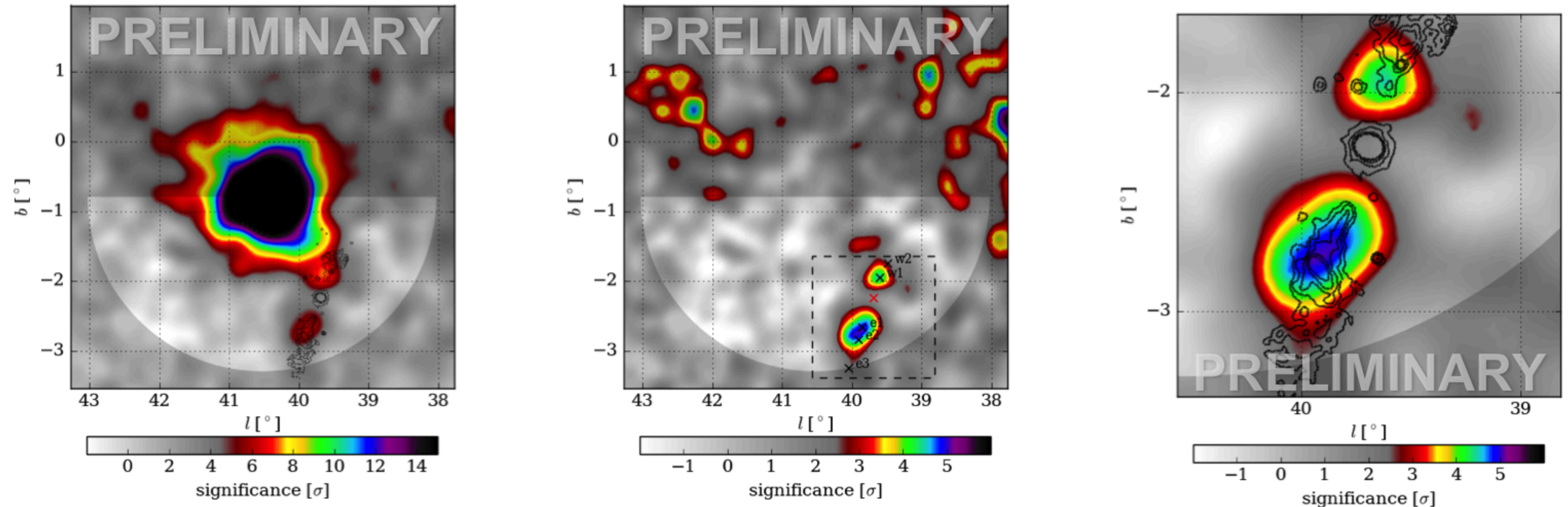
The High Altitude Water Cherenkov (HAWC) collaboration reports the discovery of a new TeV gamma-ray source HAWC J0543+233. It was discovered in a search for extended sources of radius 0.5° in a dataset of 911 days (ranging from November 2014 to August 2017) with a test statistic value of 36 (6σ pre-trials), following the method presented in [Abeysekara et al. 2017, ApJ, 843, 40](#). The measured J2000.0 equatorial position is RA=85.78°, Dec=23.40° with a statistical uncertainty of 0.2°. HAWC J0543+233 was close to passing the selection criteria of the 2HWC catalog ([Abeysekara et al. 2017, ApJ, 843, 40](#), see [HAWC J0543+233 in 2HWC map](#)), which it now fulfills with the additional data.

HAWC J0543+233 is positionally coincident with the pulsar PSR B0540+23 (\dot{E} = 4.1e+34 erg s⁻¹, dist = 1.56 kpc, age = 253 kyr). It is the third low \dot{E} dot, middle-aged pulsar announced to be detected with a TeV halo, along with Geminga and B0656+14. It was predicted to be one of the next such detection by HAWC by [Linden et al., 2017, arXiv:1703.09704](#).

Using a simple source model consisting of a disk of radius 0.5°, the measured spectral index is -2.3 ± 0.2 and the differential flux at 7 TeV is $(7.9 \pm 2.3) \times 10^{-15}$ TeV⁻¹ cm⁻² s⁻¹. The errors are statistical only. Further morphological and spectral analysis as well as studies of the systematic uncertainty are ongoing.

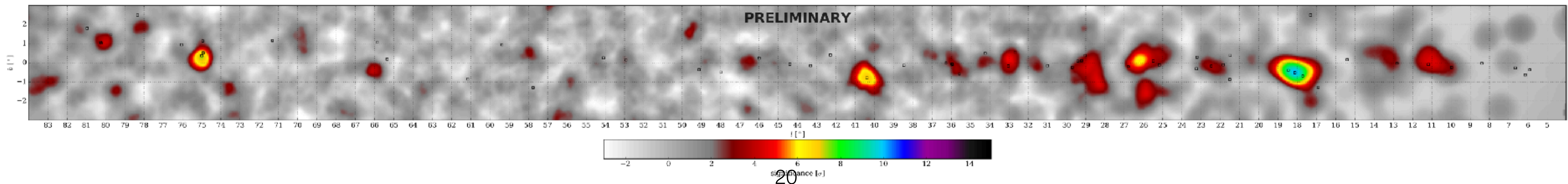
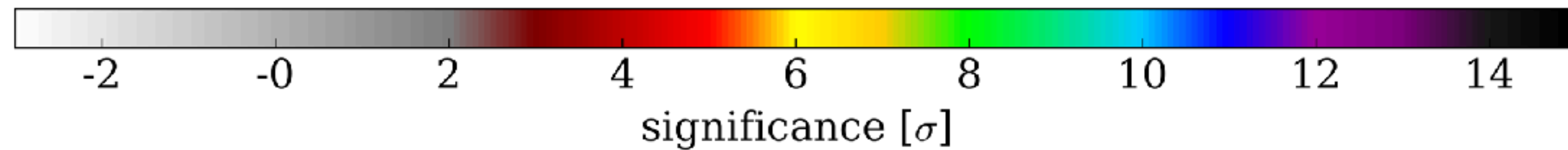
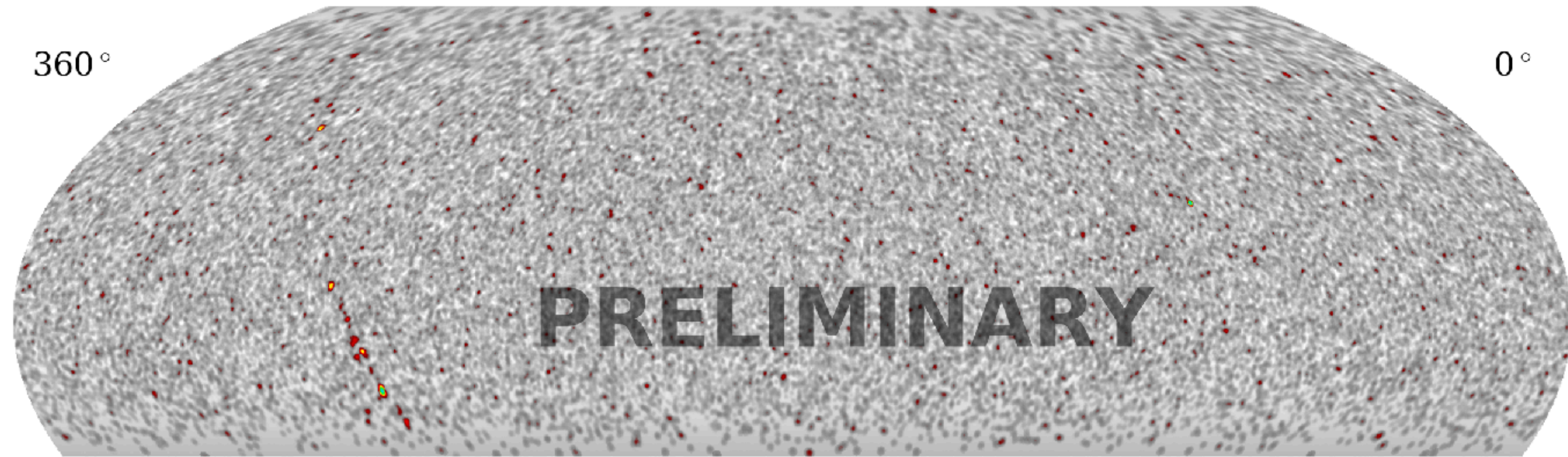
Observations from the galactic microquasar SS 433 below
MGRO1908.

HAWC observes TeV emission coincident with the lobes of the jets.

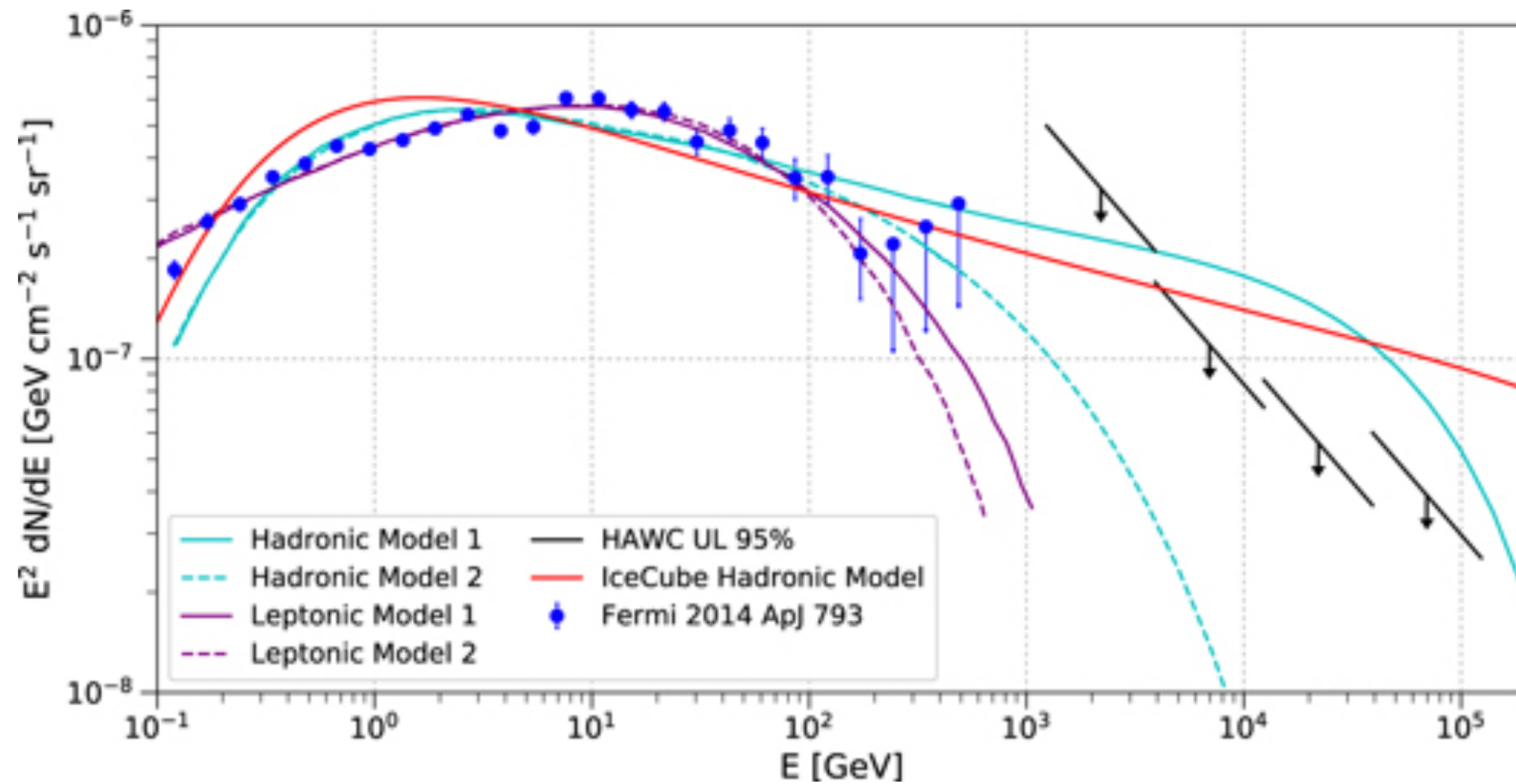


Publication was just accepted in Nature. Be alert for when it gets published.
If going to TeVPA, look for Chang Rho

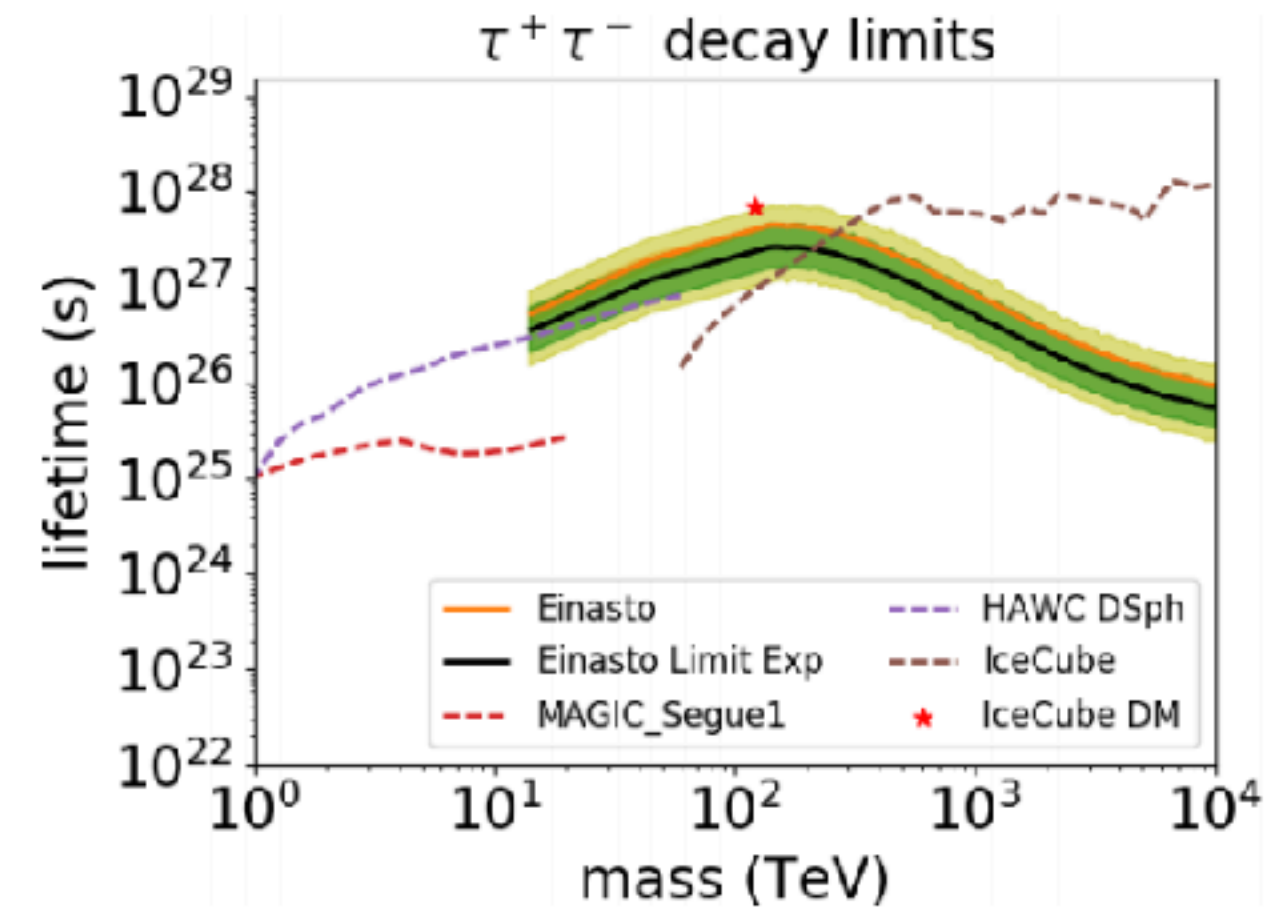
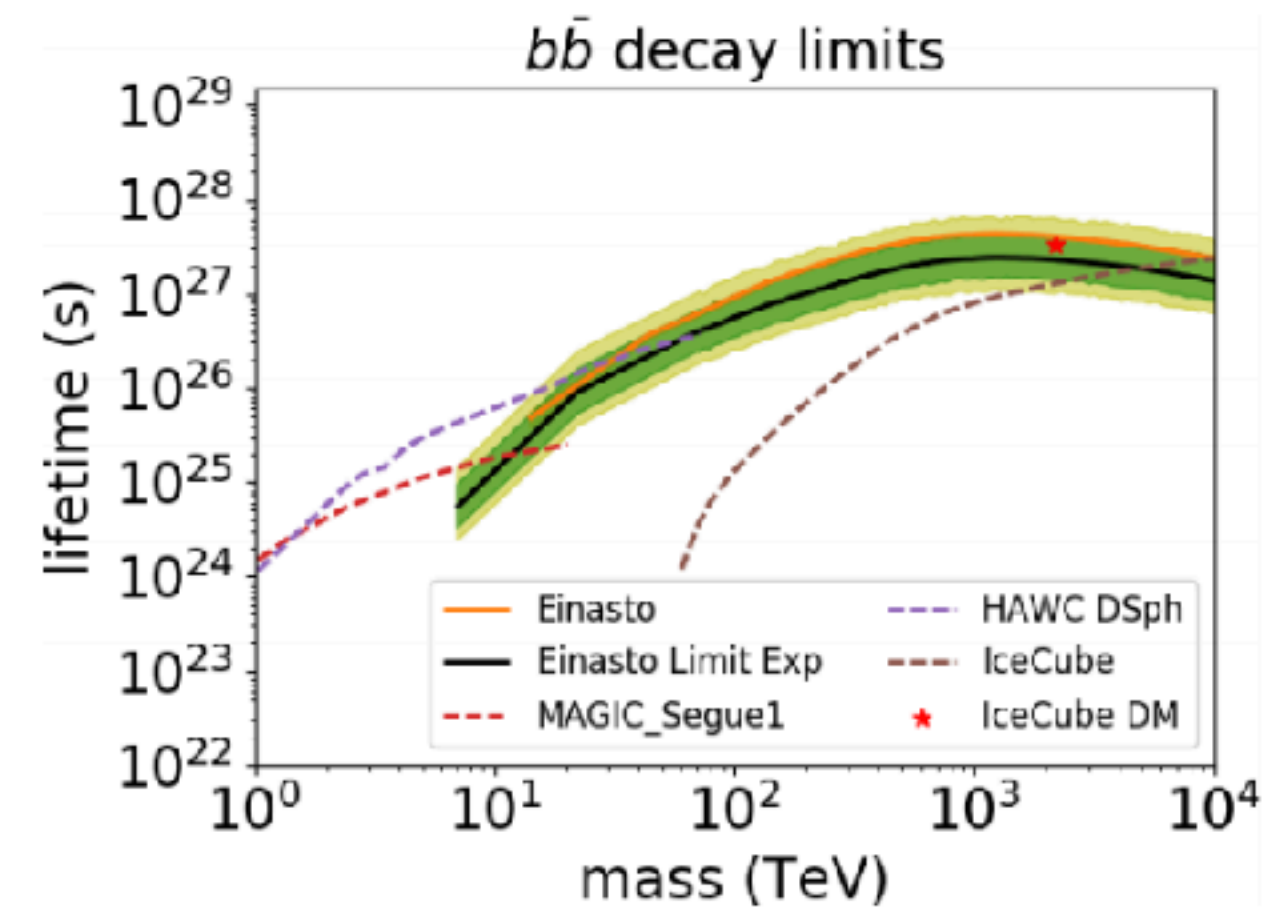
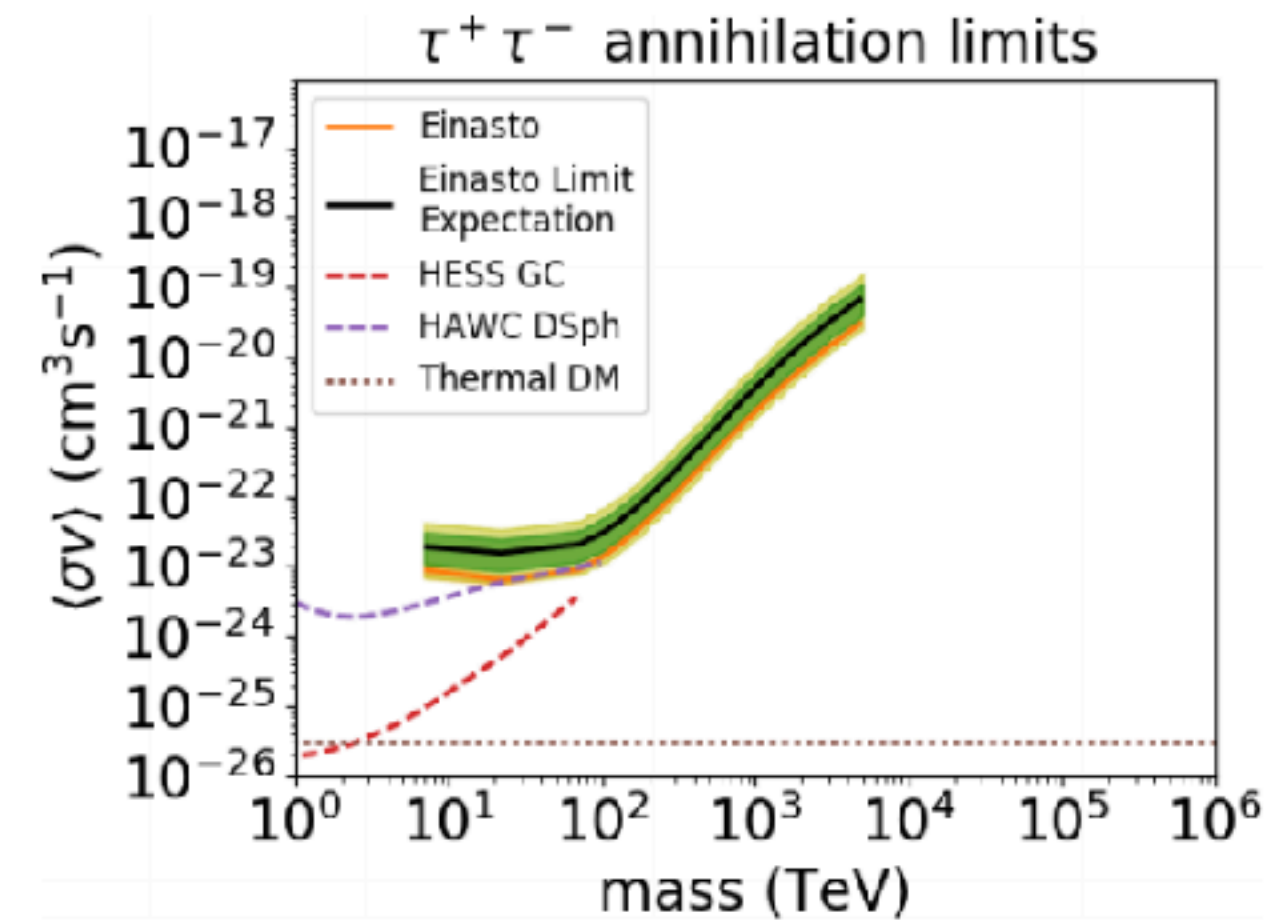
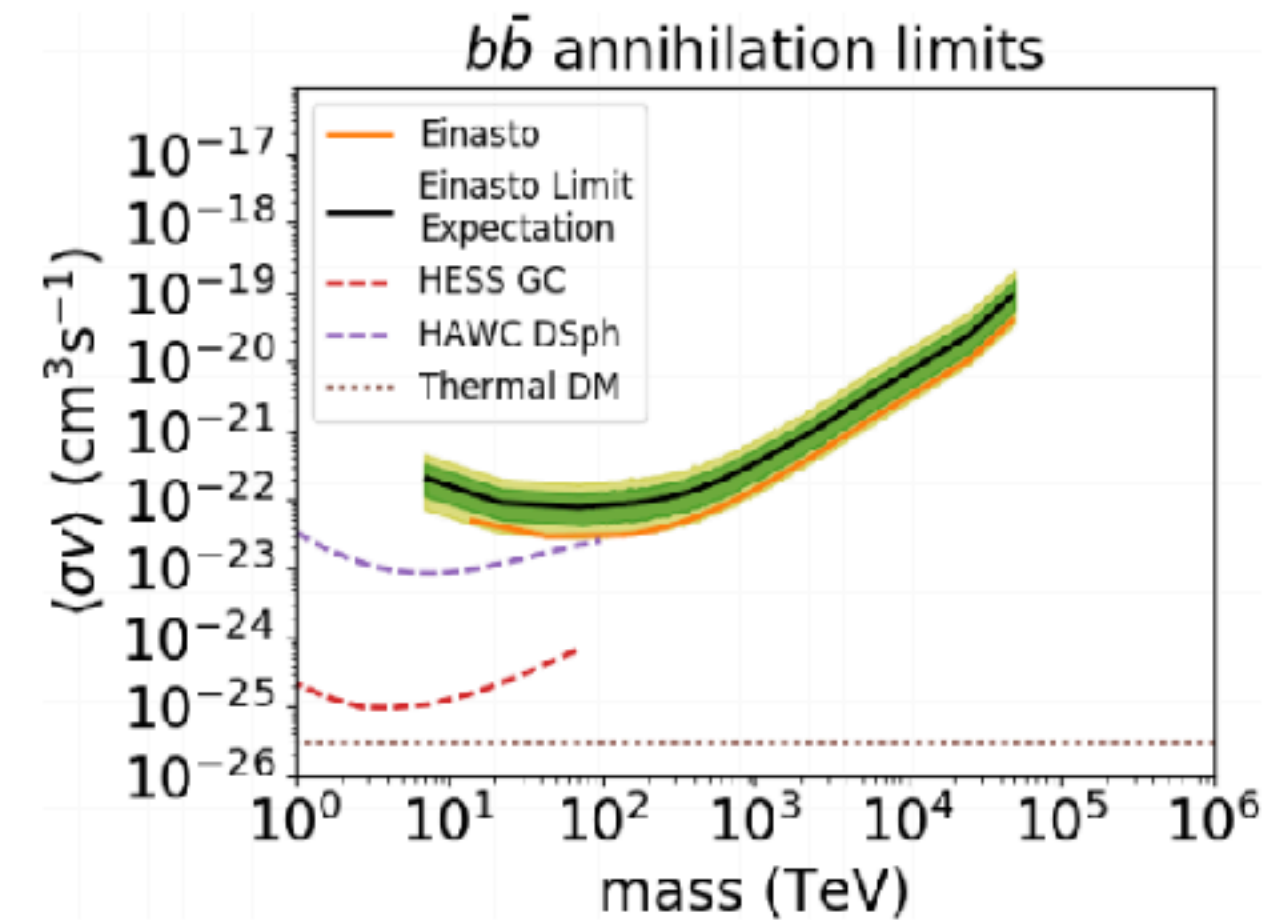
Searches for hadronic accelerators: high-energy maps above 56 TeV. Livetime is 911.3 days. Using new energy estimator under development. If you go to TeVPA, look for Kelly Malone.



Searches for extended, diffuse emission have led to upper limits for the flux of the Fermi Bubbles and limits on dark matter annihilation cross-section and decay lifetime

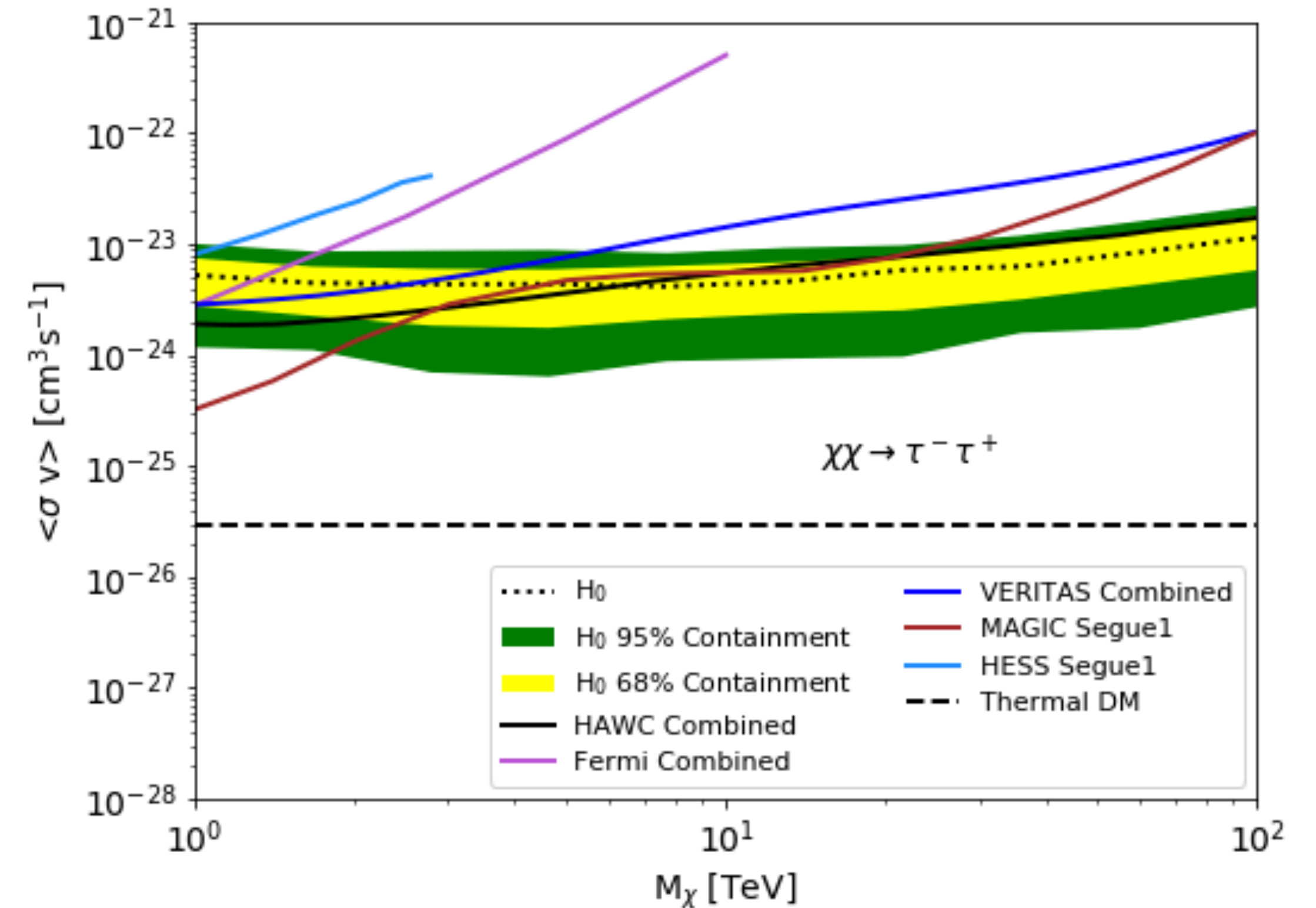
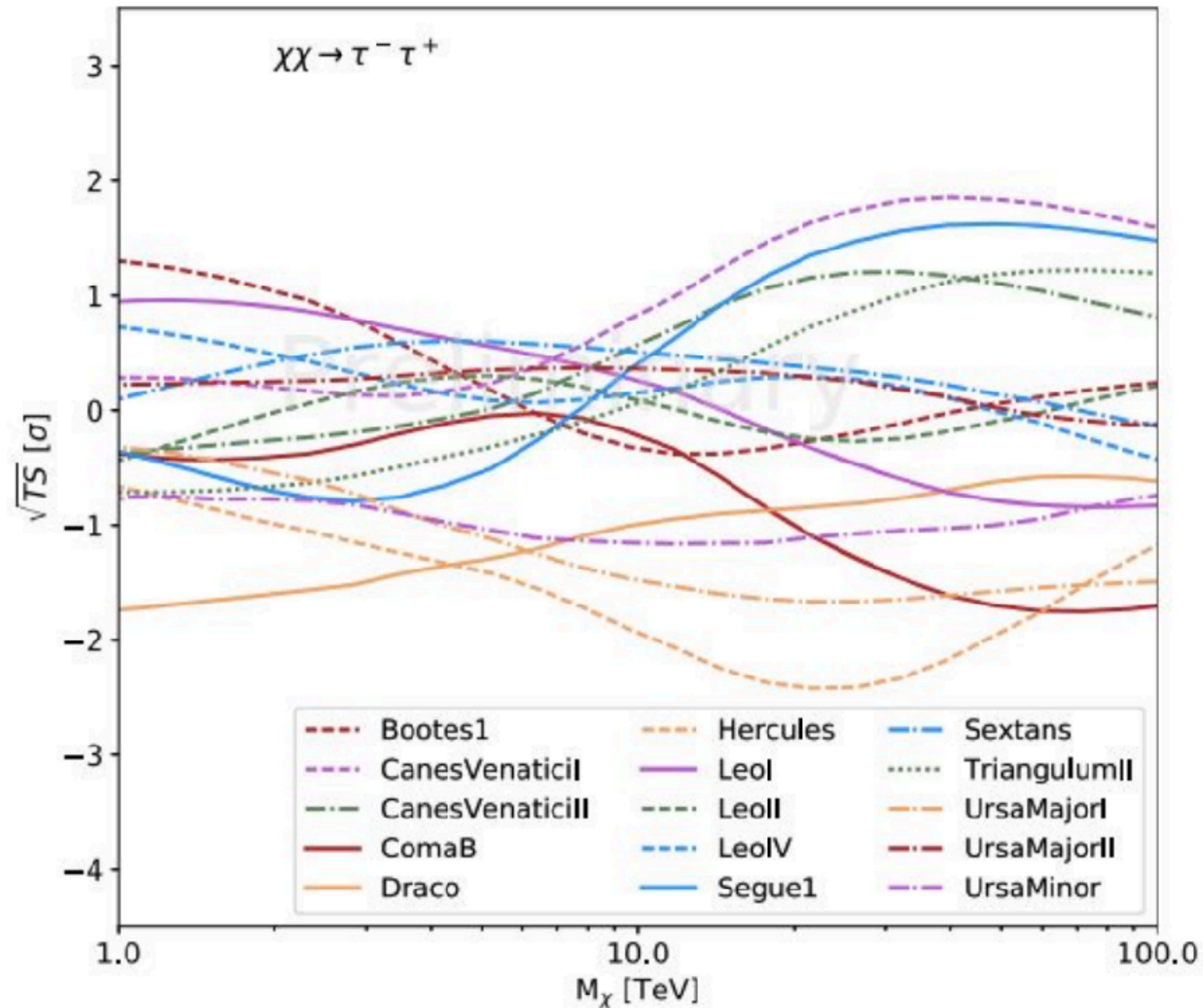


Abeysekara et al. ApJ 2017



A.U. Abeysekara et al JCAP02(2018)049

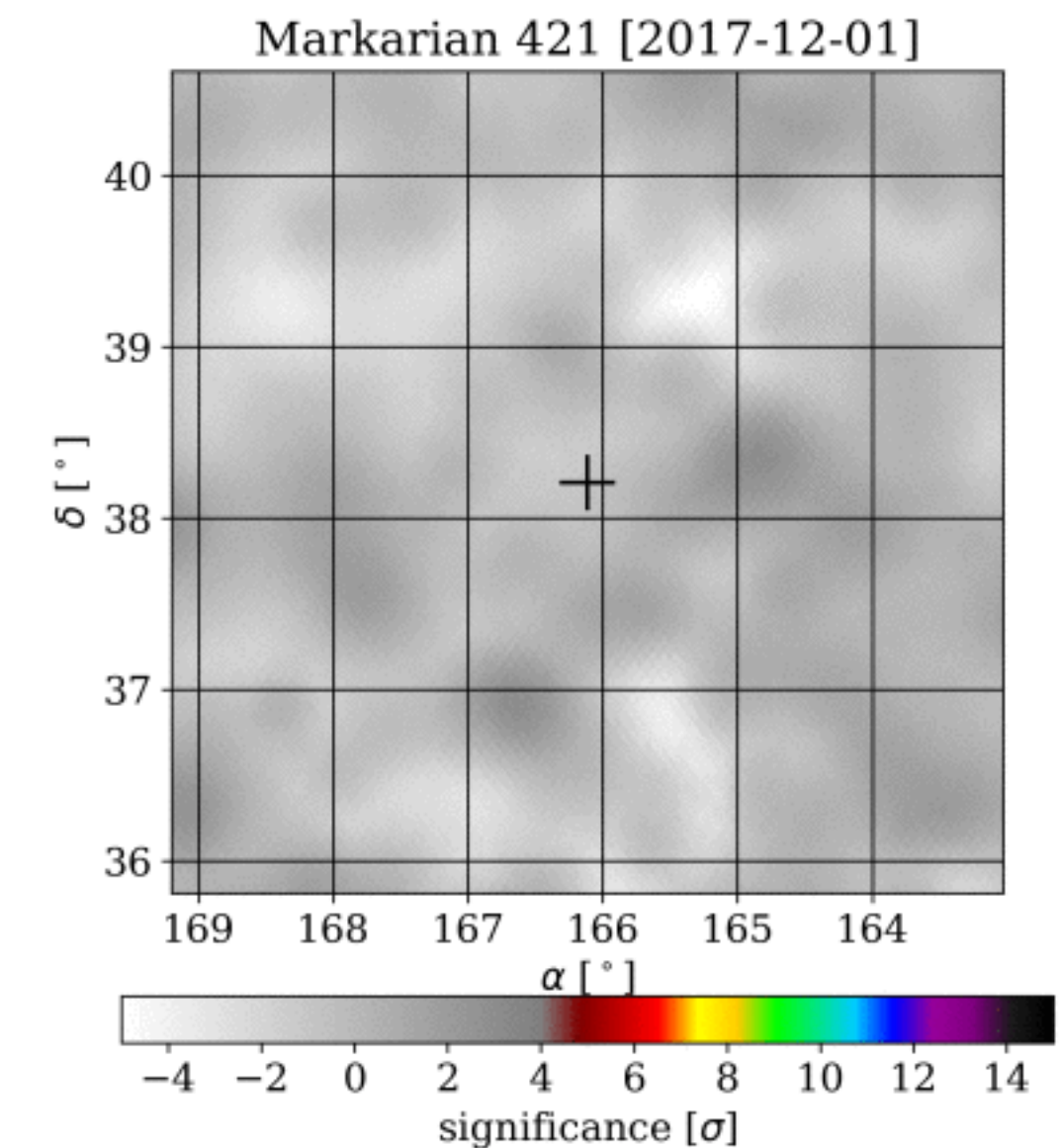
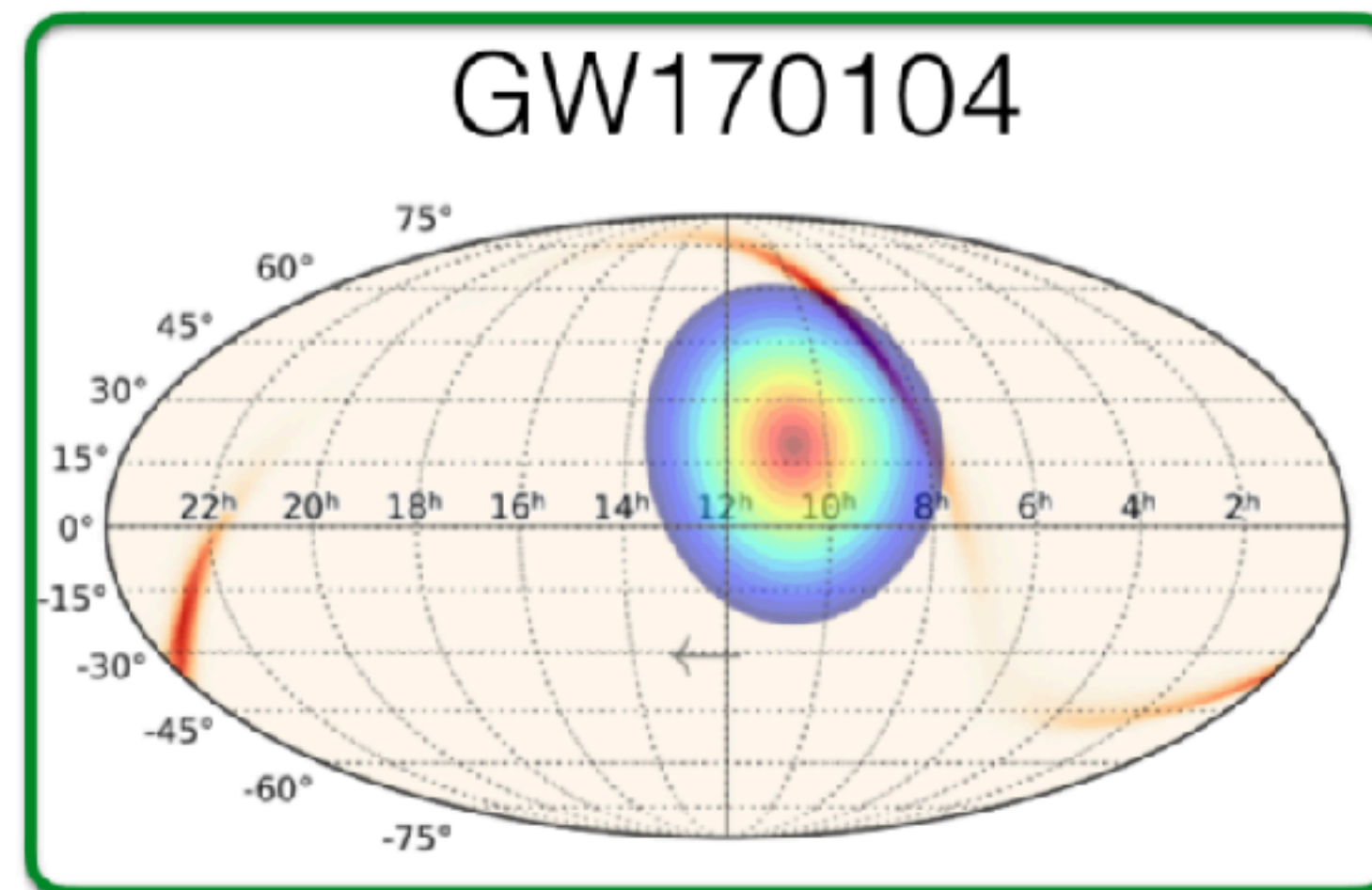
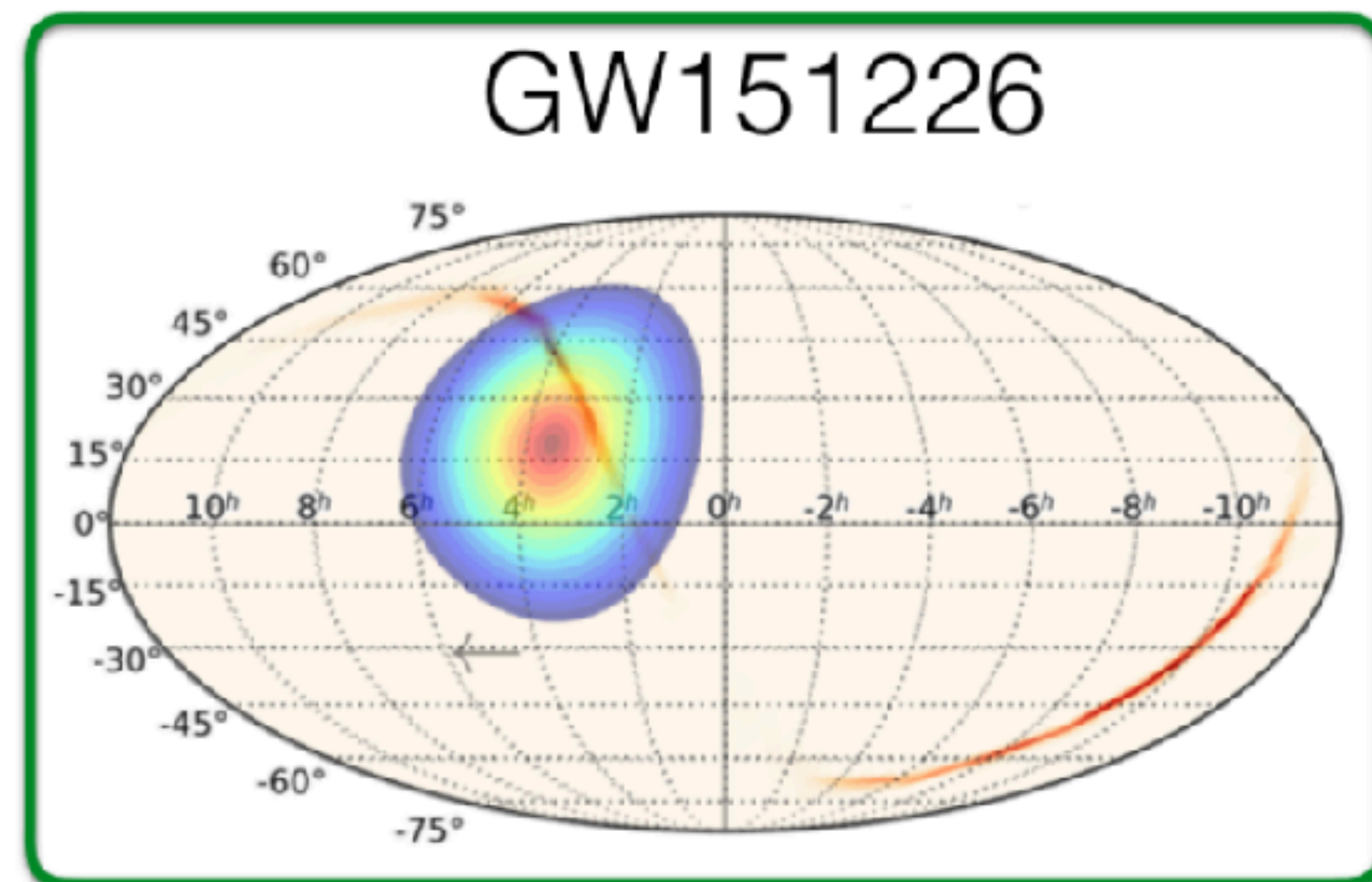
Other dark matter searches presented in Albert et al ApJ. 853 (2018) for dSph dwarf galaxies



HAWC monitors the sky for transient phenomena.

HAWC can follow-up events and send alerts

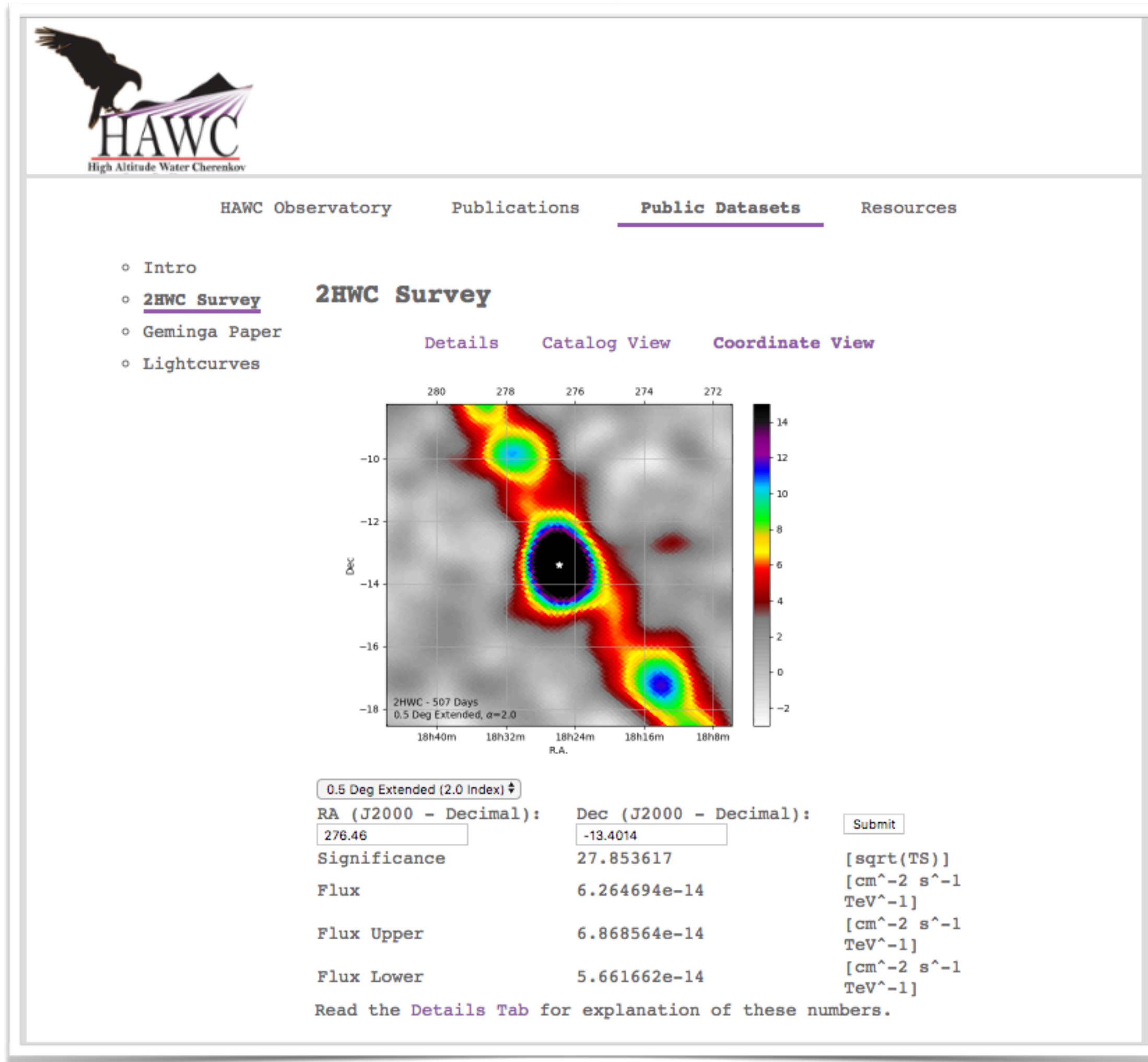
- Gravitational Wave events (LIGO-Virgo, et al. ApJ 2017)



- Monitoring AGN flares: Atel #8922, #9137, #9936, #9946, #11077, #11194.
- Daily Monitoring (ApJ 841, 100(2017))

Public data can be found in data.hawc-observatory.org

2HWC survey is available online. Public can use it for analyses, see for example Hooper and Linden 2018, arXiv: 1803:0408



Millisecond Pulsars, TeV Halos, and Implications For The Galactic Center Gamma-Ray Excess

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Abstract. Observations by HAWC indicate that many young pulsars (including Geminga and Monogem) are surrounded by spatially extended, multi-TeV emitting regions. It is not currently known, however, whether TeV emission is also produced by recycled, millisecond pulsars (MSPs). In this study, we perform a stacked analysis of 24 MSPs within HAWC's field-of-view, finding between 2.6 – 3.2σ evidence that these sources are, in fact, surrounded by TeV halos. The efficiency with which these MSPs produce TeV halos is similar to that exhibited by young pulsars. This result suggests that several dozen MSPs will ultimately be detectable by HAWC, including many "invisible" pulsars without radio beams oriented in our direction. The TeV halos of unresolved MSPs could also dominate the TeV-scale diffuse emission observed at high galactic latitudes. We also discuss the possibility that TeV and radio observations could be used to constrain the population of MSPs that is present in the inner Milky Way, thereby providing us with a new way to test the hypothesis that MSPs are responsible for the Galactic Center GeV excess.

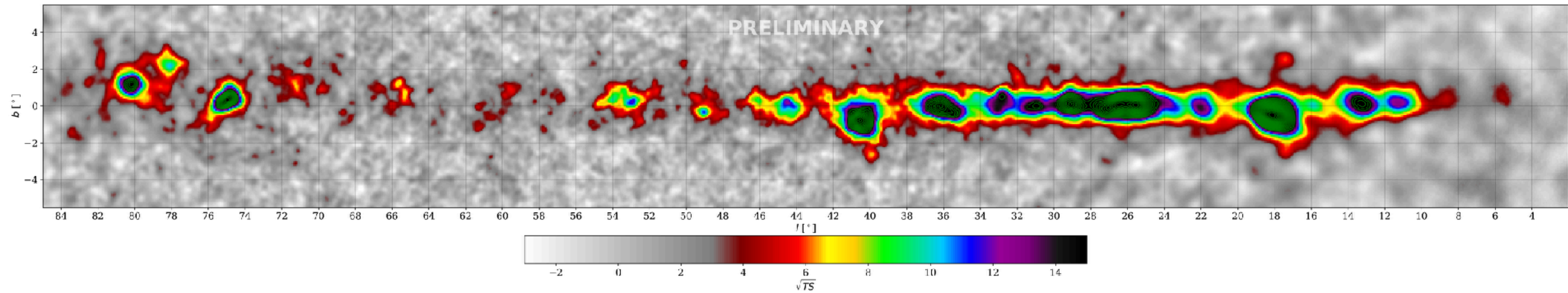
HAWC is surveying the high-energy gamma-ray sky

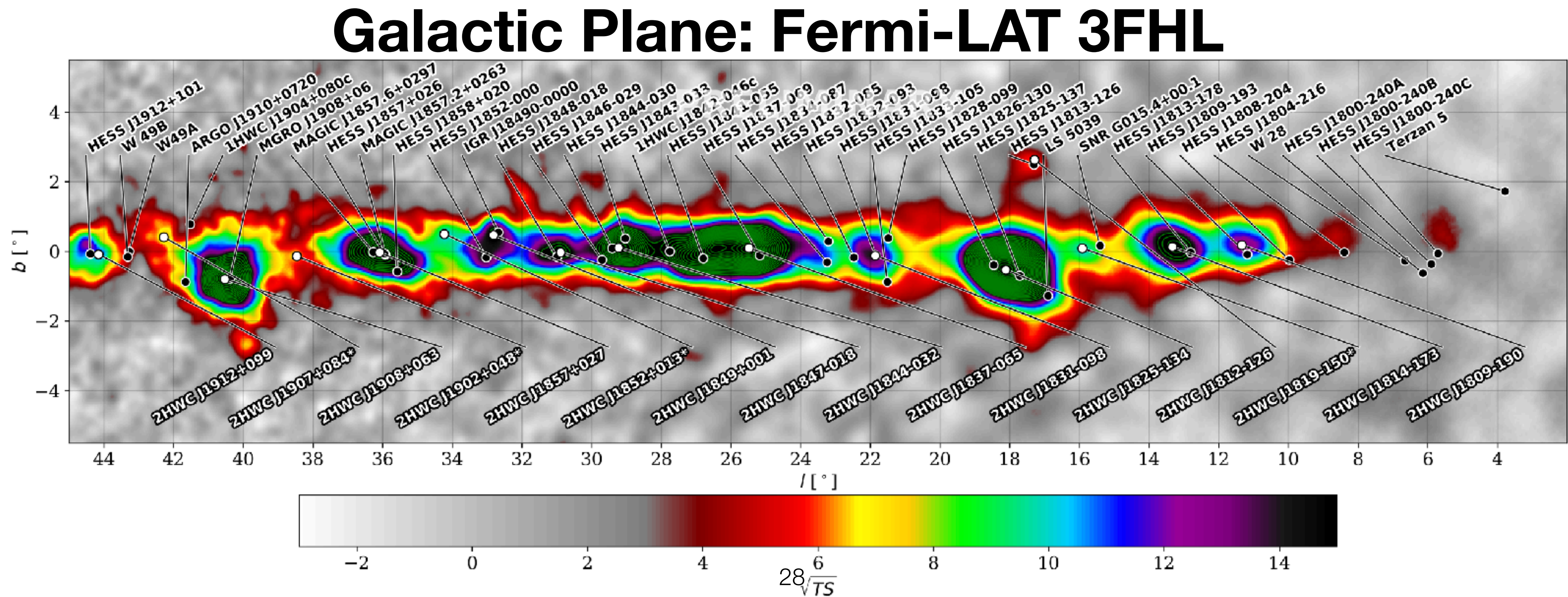
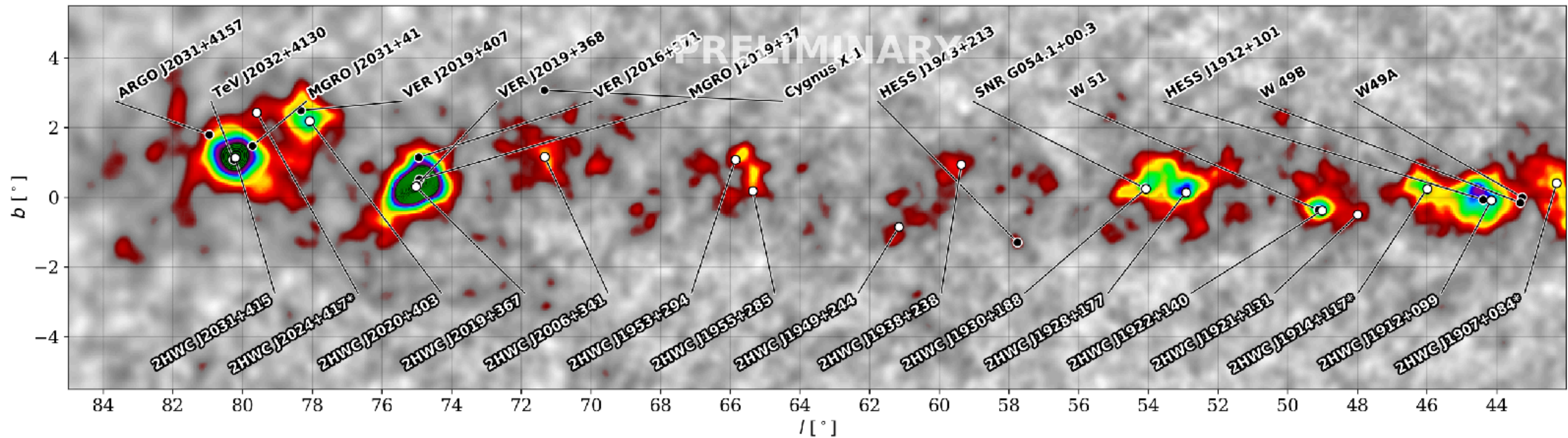
- **Discovery new type of TeV sources: TeV Halos**
- **Observation of TeV lobes from SS 433.**
- **Observation of high-energy gamma rays $>56\text{TeV}$**
- **Contribution to Multimessenger Astrophysics: follow-ups and issuing alerts**

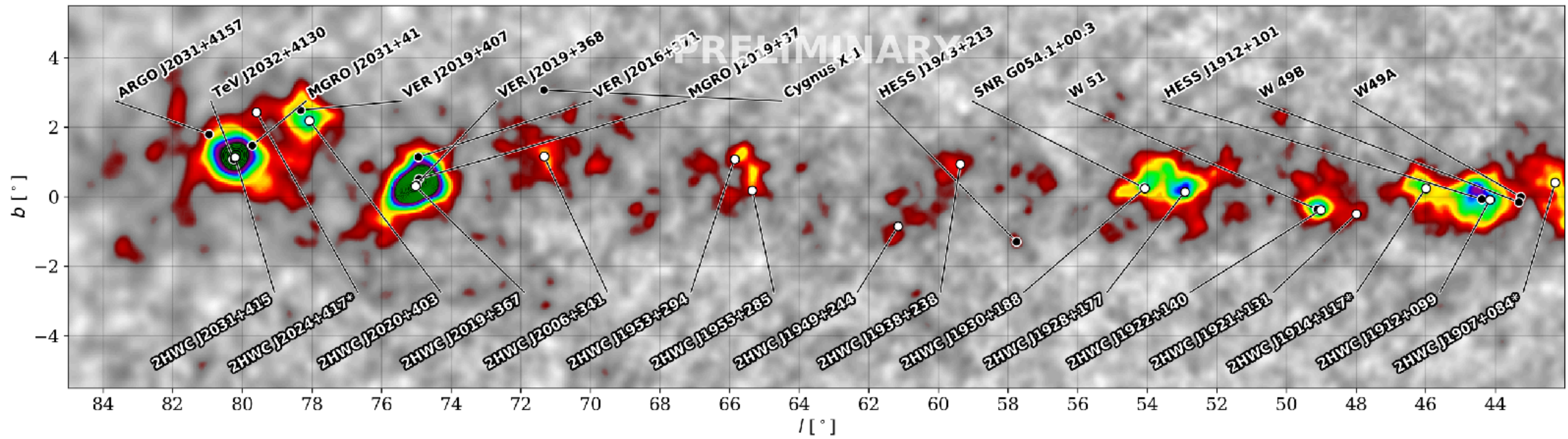
Back-up

HAWC SkyMap: 1017 days of data.

2HWC catalog (ApJ 2017) was 507 days, with 39 sources of which 10 were new.







Galactic Plane: H.E.S.S. Galactic Plane Survey

