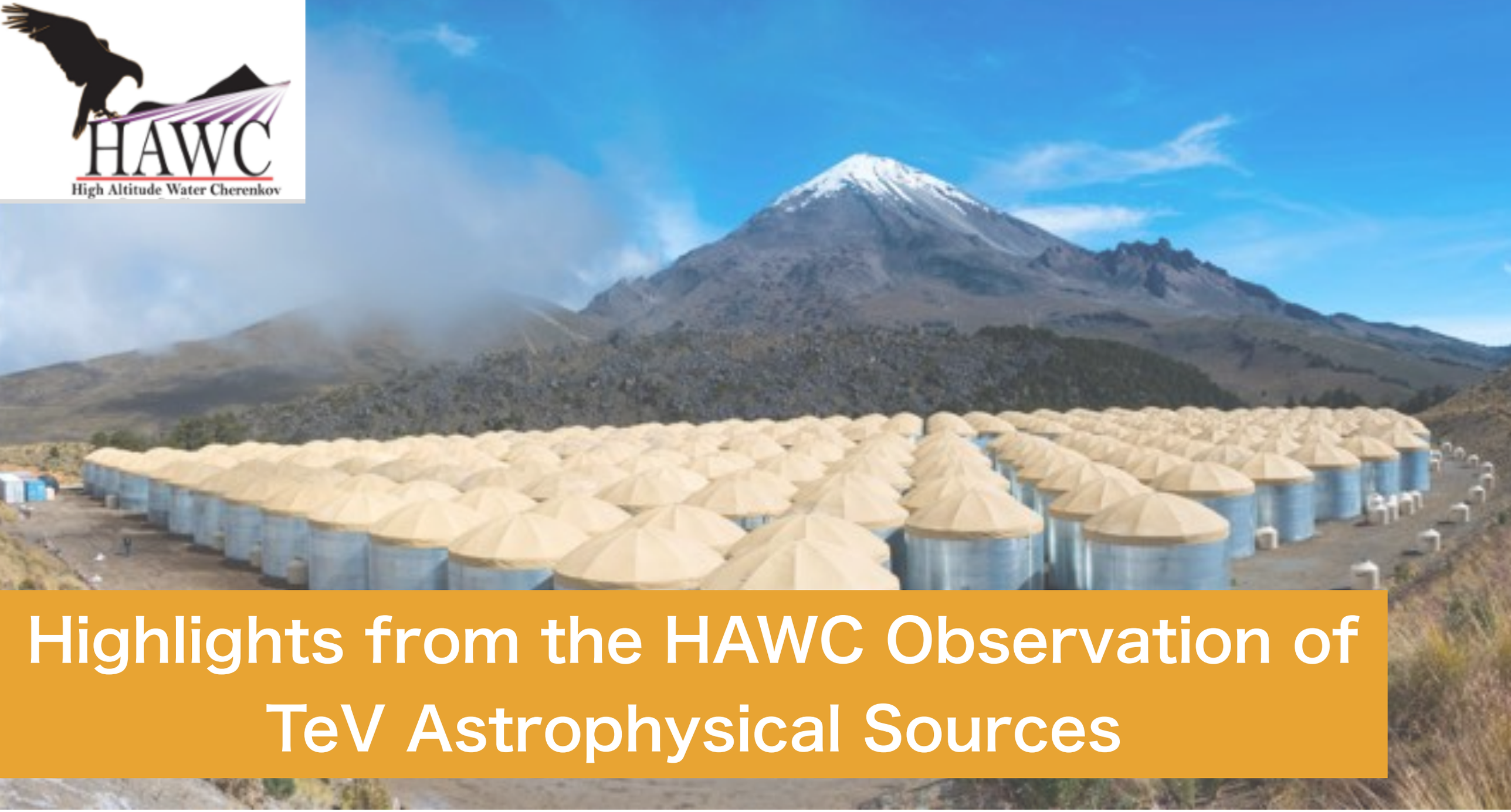


Highlights from the HAWC Observation of TeV Astrophysical Sources

Ke Fang
Einstein Fellow, Stanford University
HAWC Collaboration

TMEX, Vietnam, Jan 6, 2020

PS2, Jan 8: Indirect dark matter searches with HAWC

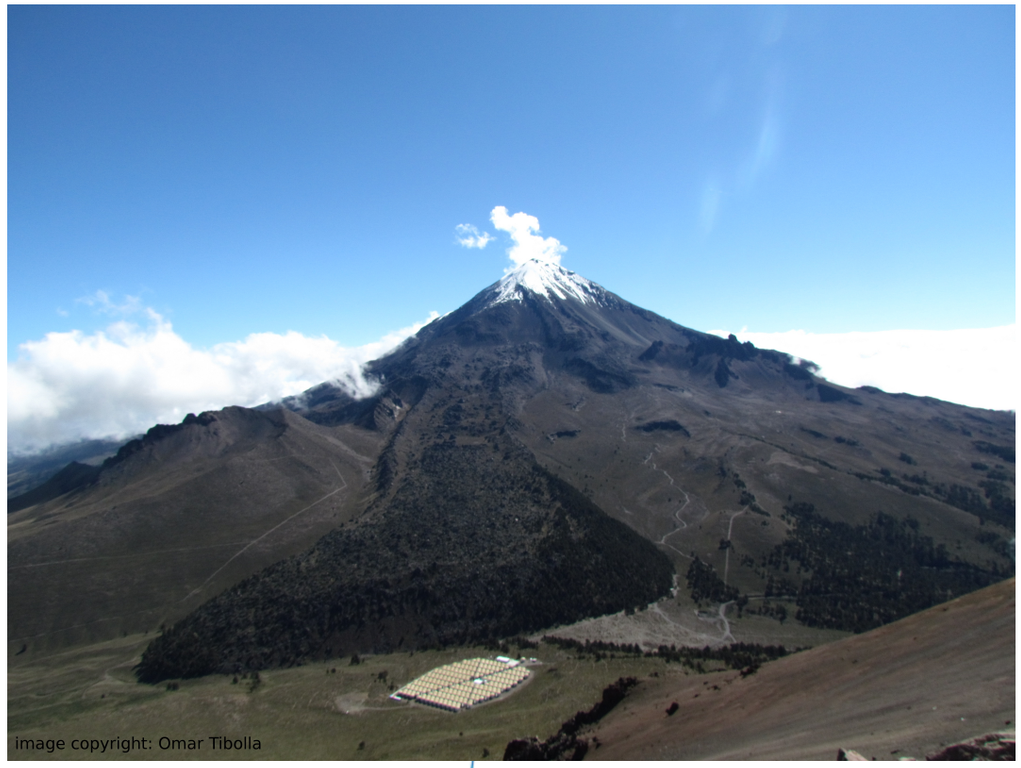
Highlights from the HAWC Observation of TeV Astrophysical Sources

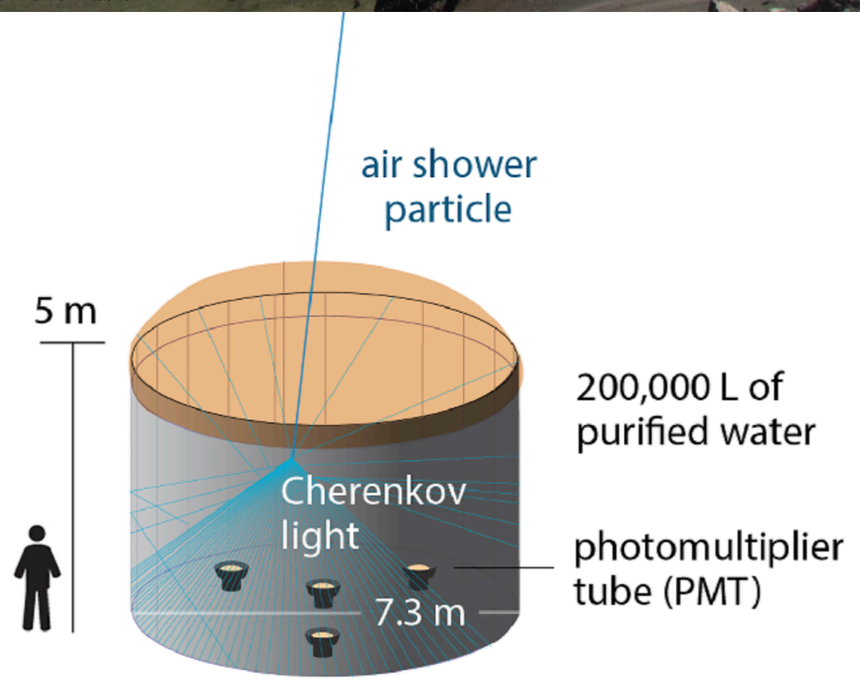
Ke Fang
Einstein Fellow, Stanford University
HAWC Collaboration

TMEX, Vietnam, Jan 6, 2020

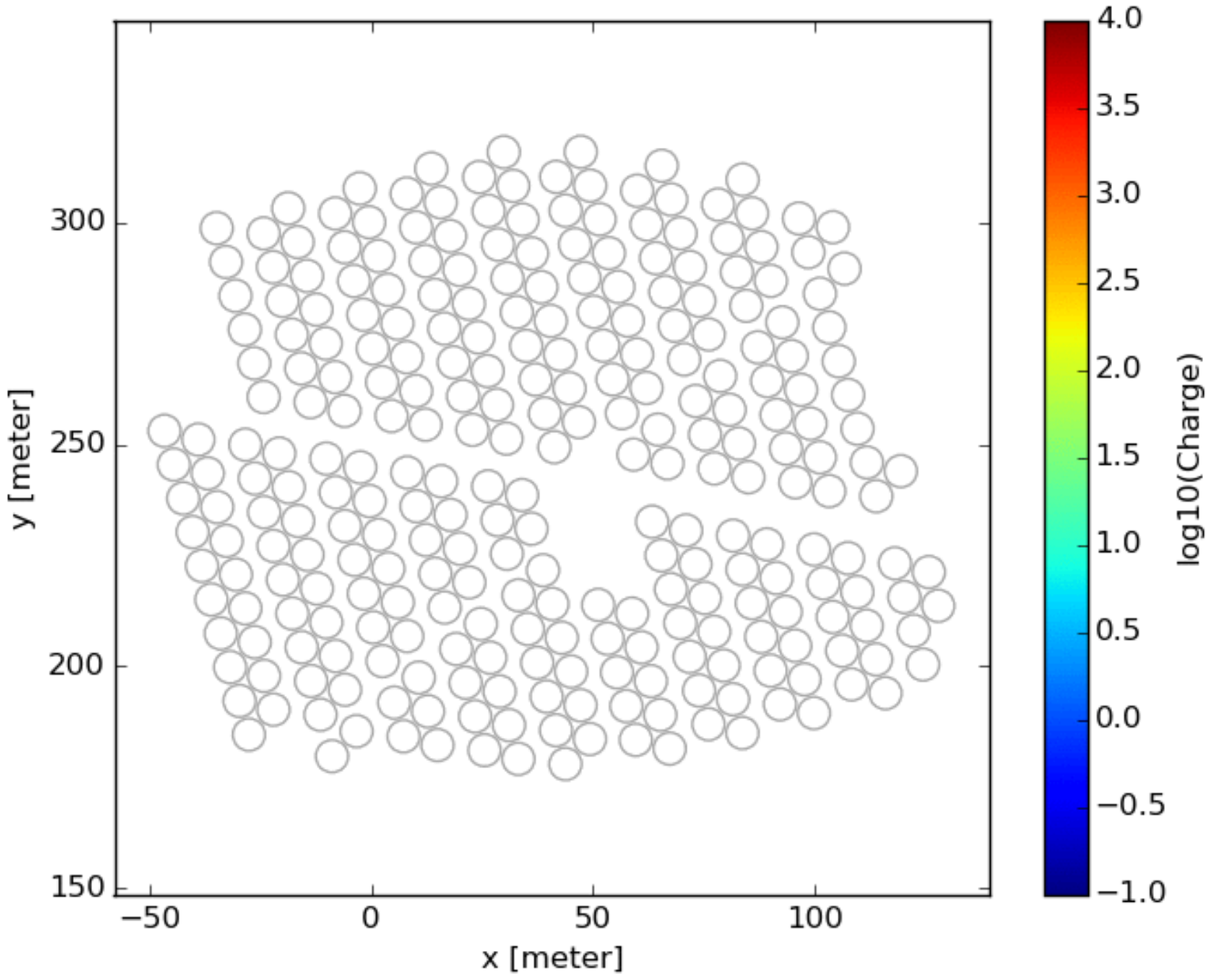
The High-Altitude Water Cherenkov Gamma-Ray Observatory

Number of tanks	300 (4 PMTs/200,000 L of water in each)
Area	22,000 m^2
Location	Puebla, Mexico (19º North)
Altitude	4100 m
Duty Cycle	> 95%
Coverage	2/3 of sky per day
Sensitivity	300 GeV to > 100 TeV
Angular resolution	> 0.1 degrees

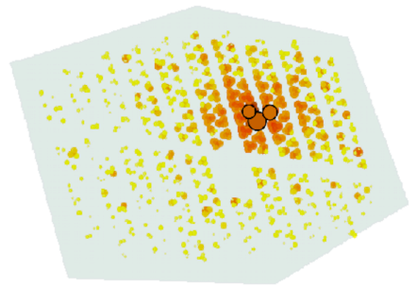




Event Reconstruction

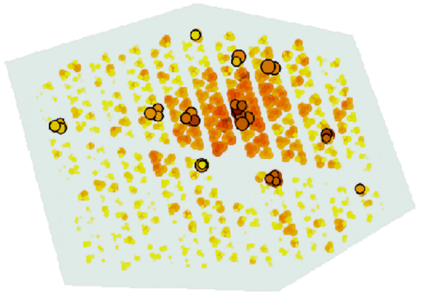


gamma-ray shower



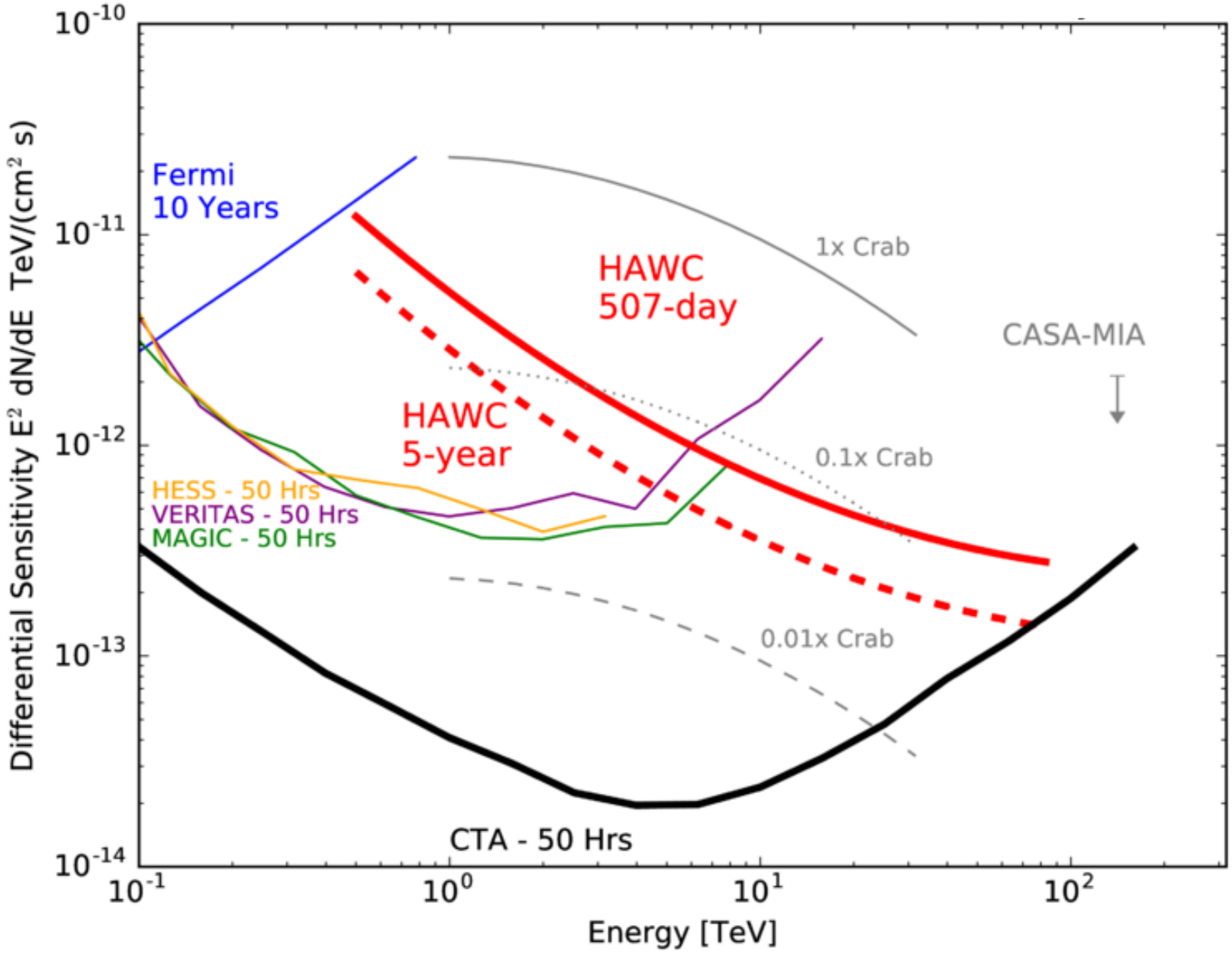
“hot” spots concentrate around the core

cosmic-ray shower



“hot” spots are more dispersed

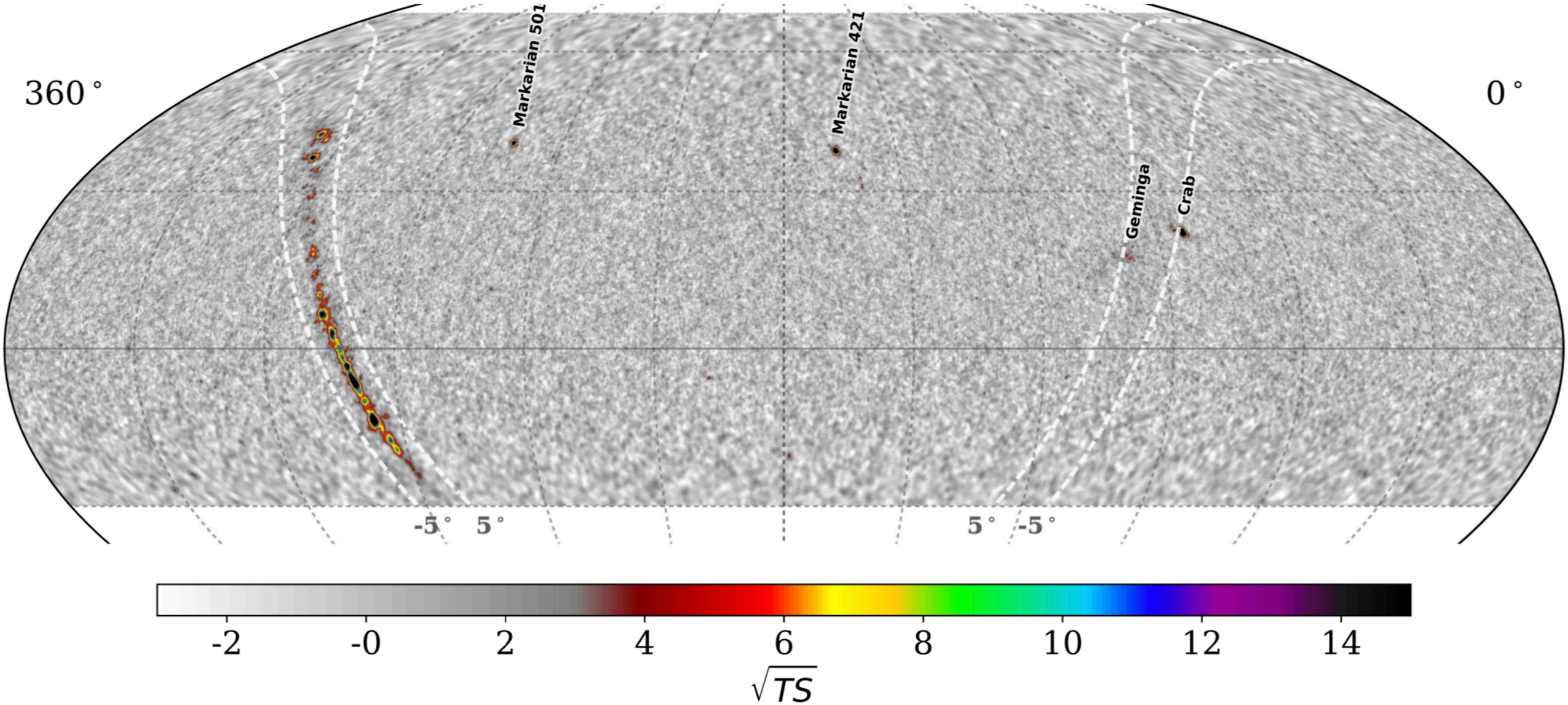
HAWC Sensitivity



HAWC offers both wide field-of-view and high sensitivity above 10 TeV.

Galactic Sources

The 2HWC Catalog based on 507 days of data



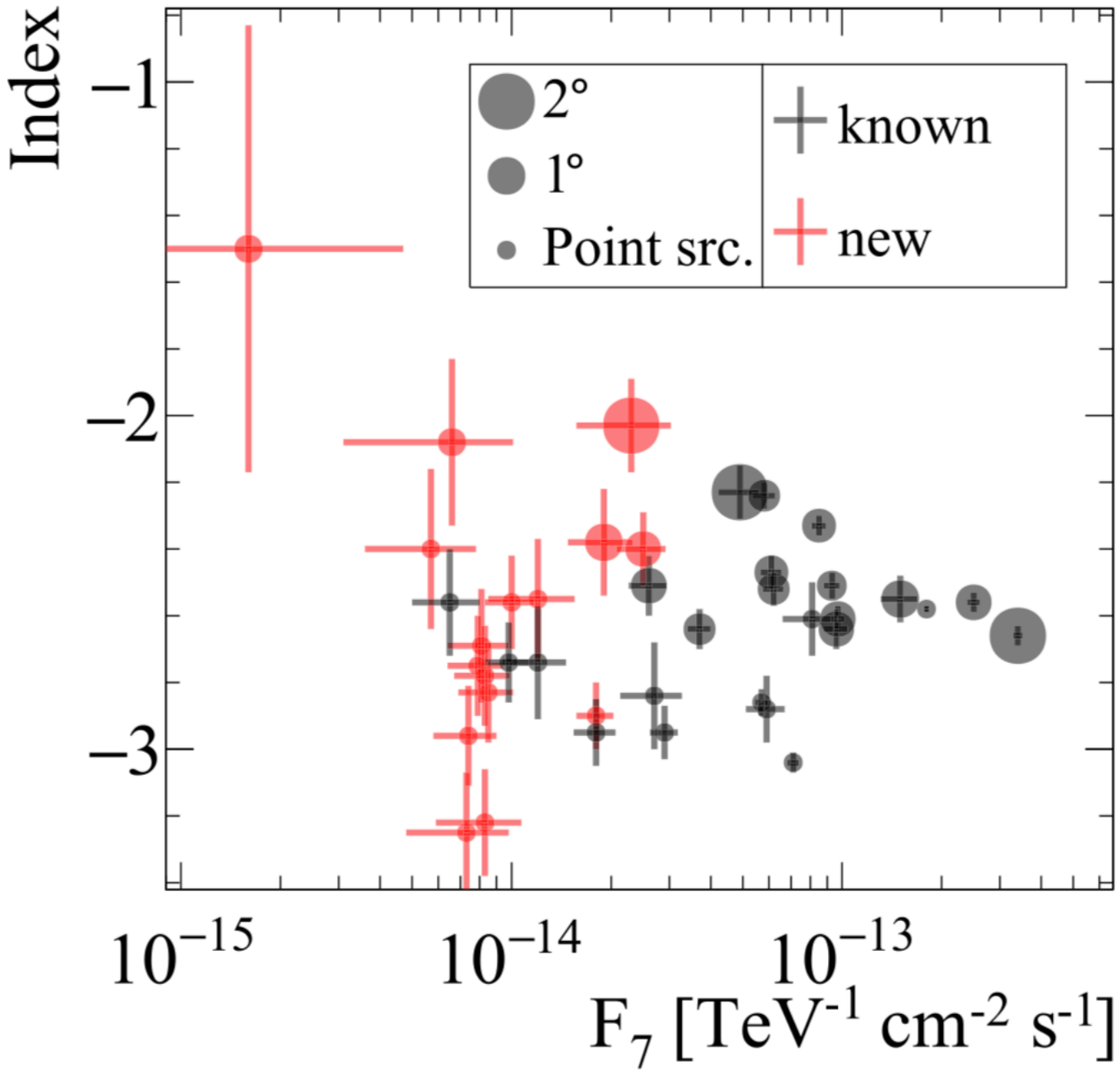
39 sources in total, 19 new

20 associated with previous detections

(10 PWN / SNR, 2 blazars, 8 unidentified)

HAWC Collaboration, ApJ (2017)

Flux and Index of 2HWC Sources



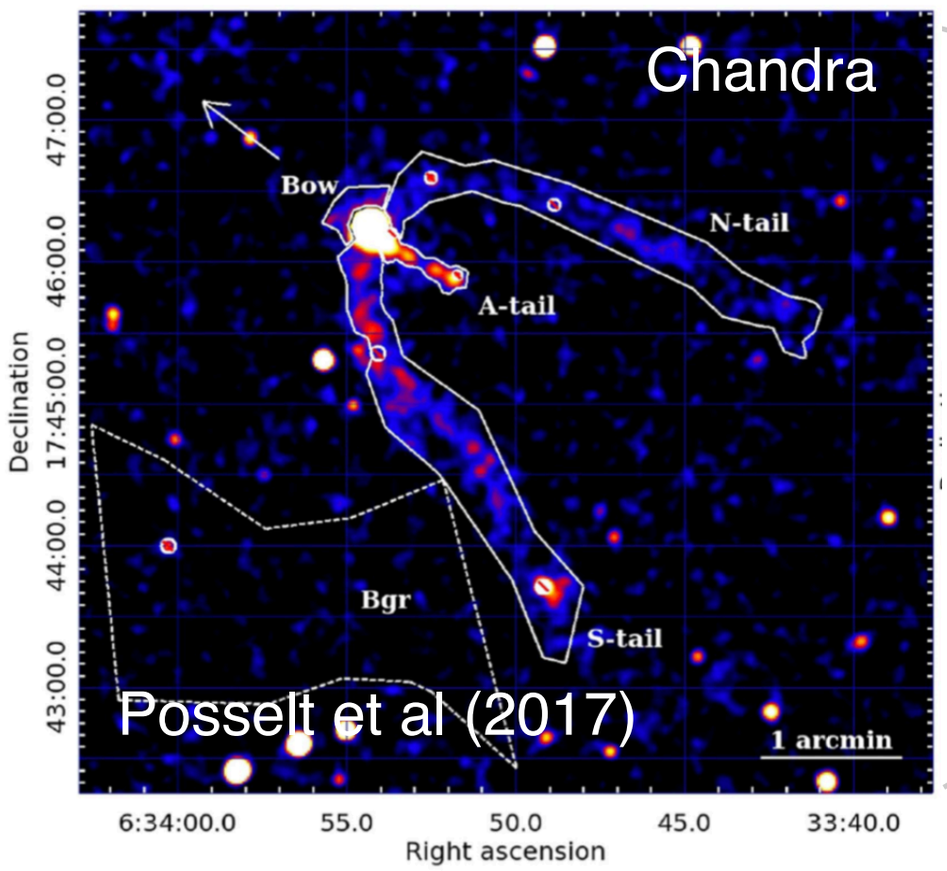
- https://data.hawc-observatory.org/datasets/2hwc-survey/index.php

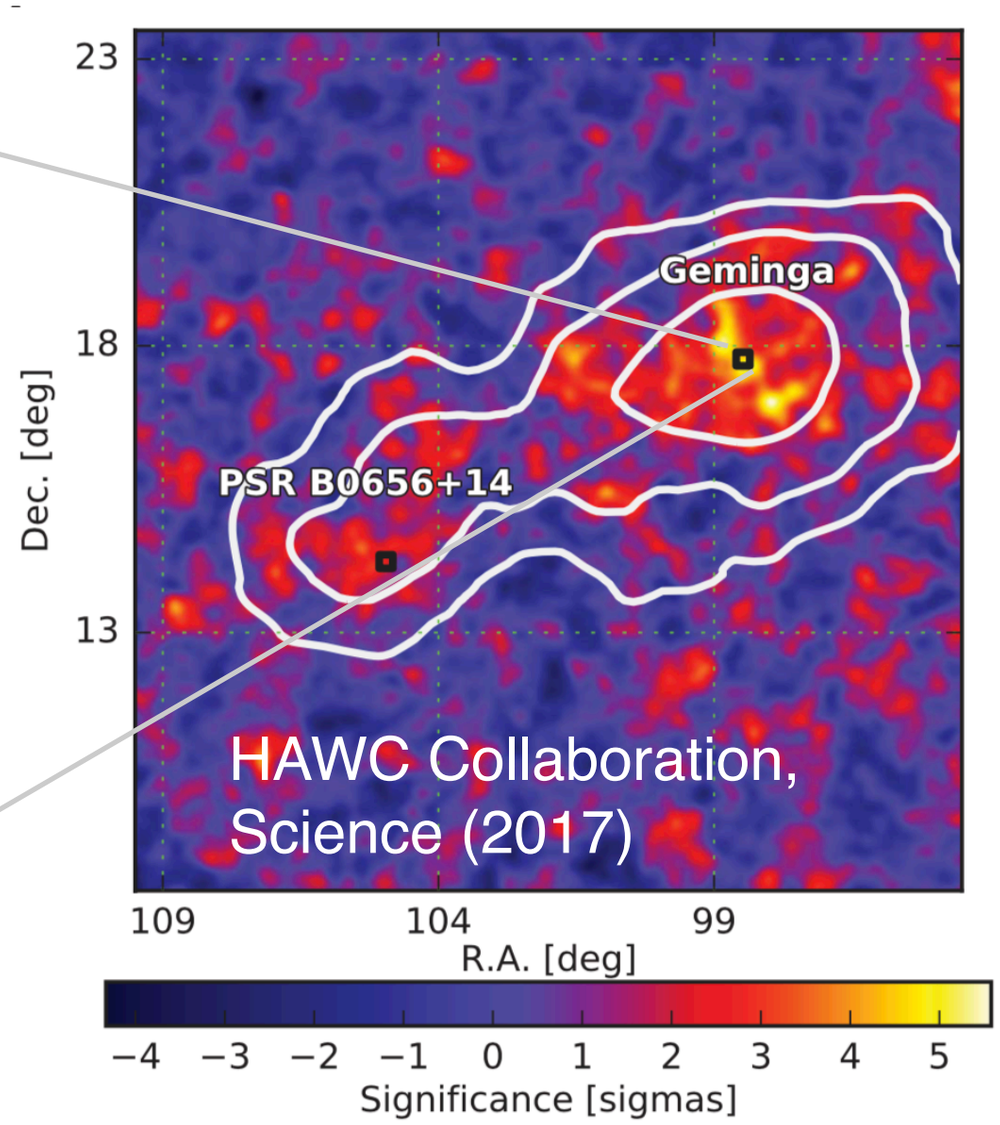
- Followed up by VERITAS, MAGIC & Fermi-LAT (Abeysekara+ 2018, Ahnen+ 2019). **Some confirmed** including DA 495

- **3HWC on the way**!

HAWC Collaboration, ApJ (2017)

Extended Gamma-ray Emission Around Geminga and PSR B0656+014

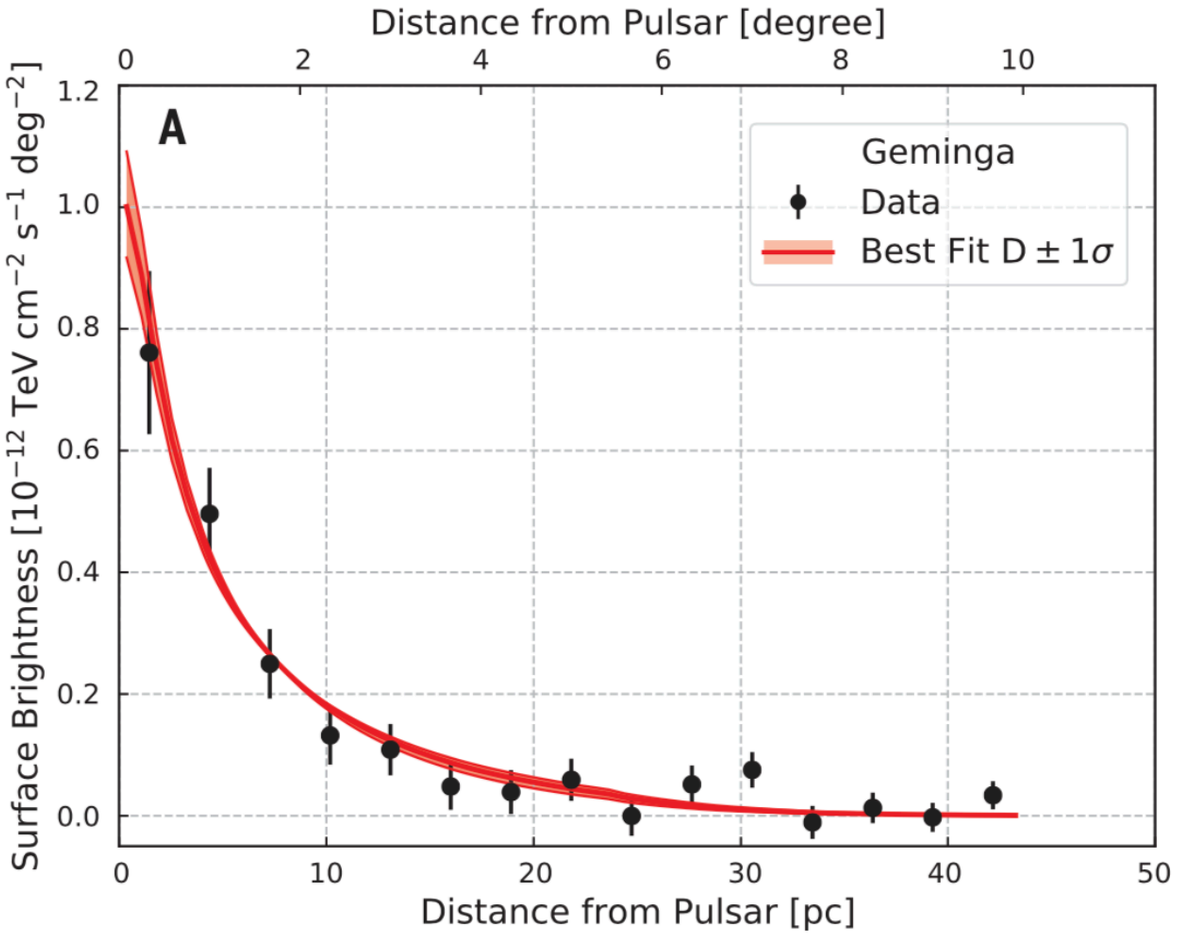




- Geminga pulsar: **middle-aged** (340 kyr), at 250 pc
- **Pulsar wind nebula** observed in X-ray has size **around 10 arcmin**
- **Extended TeV emission** observed by HAWC is **several degrees** across
- Implications for origin of positron flux

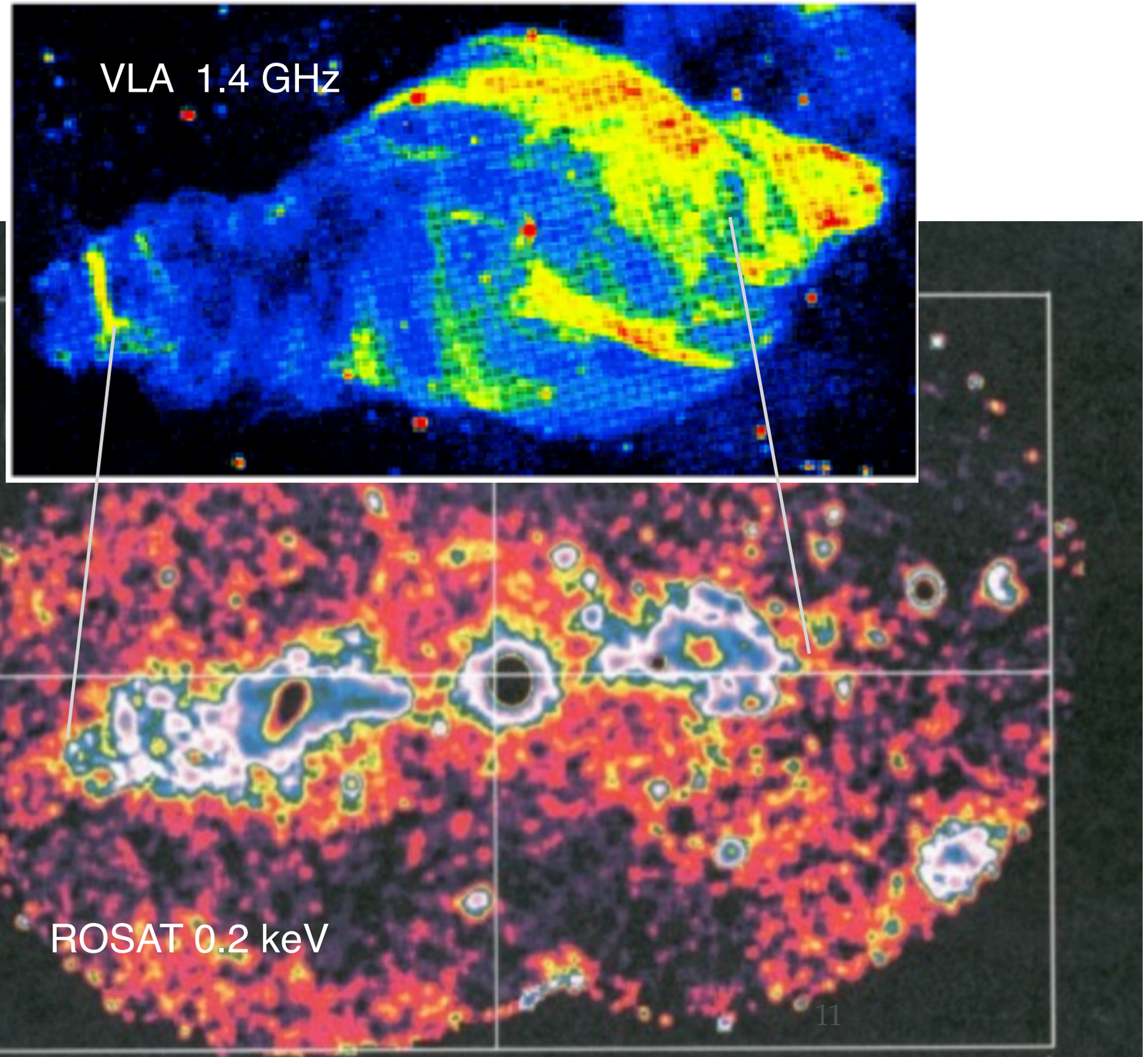
Geminga and the “TeV Halos”

- Derived diffusion coefficient is **100x smaller than previously considered**
- Similar extended emission found surrounding PSR 0656+14, xHWC J0543+233
- “**TeV halos**”: a universal feature? Way to find pulsars invisible to radio/GeV surveys?
- **Origin of extended TeV emission**: smaller coherence length? Anisotropic diffusion?



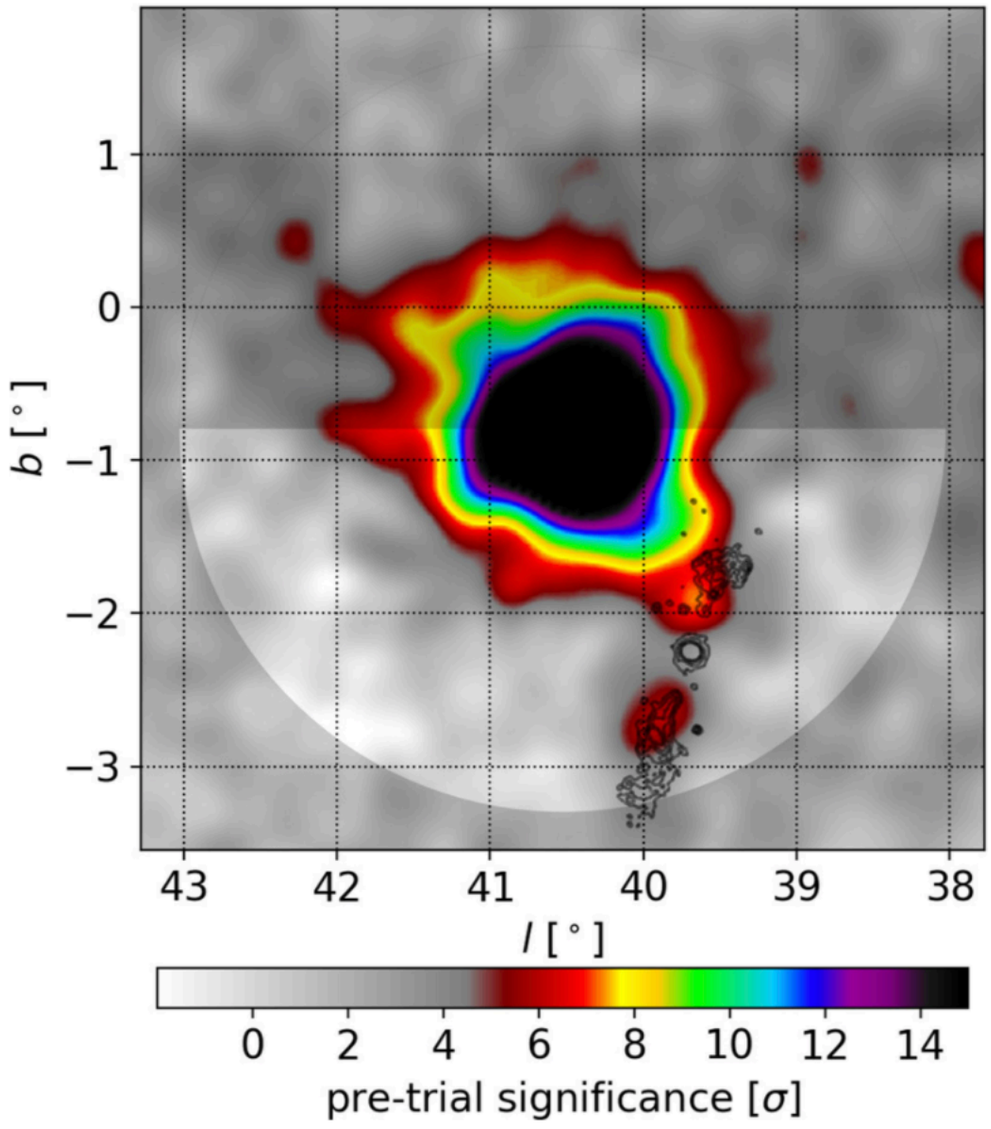
HAWC Collaboration, Science (2017)

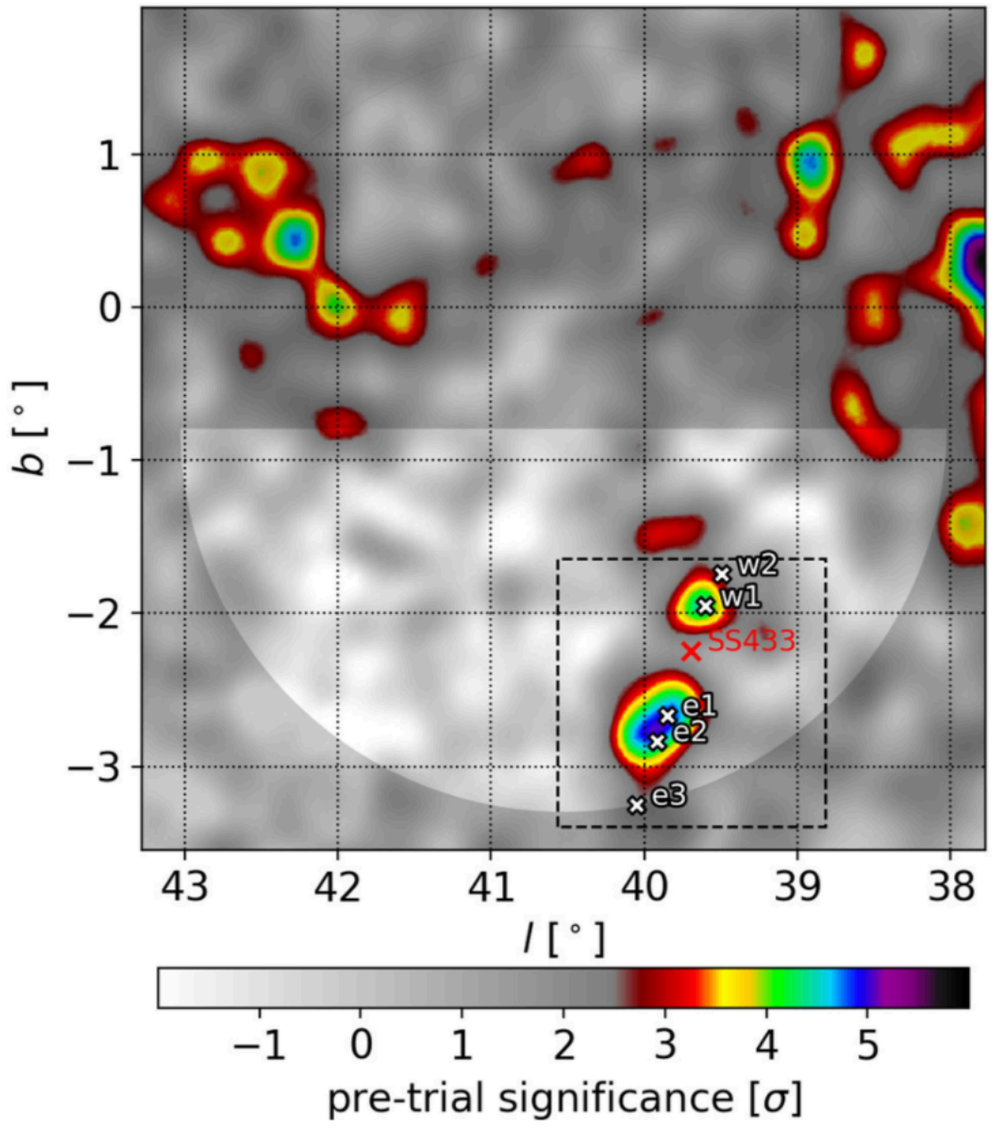
The SS 433 / W50 Complex



- **Microquasar inside a SNR** w. Jet speed ~ 0.26 c, Jet luminosity ~ 10^39 erg/s
- Up to 50 keV X-rays observed, suggesting existence of **multi-hundred TeV electrons**

Detection of SS 433 Jets in 1,017-day Data



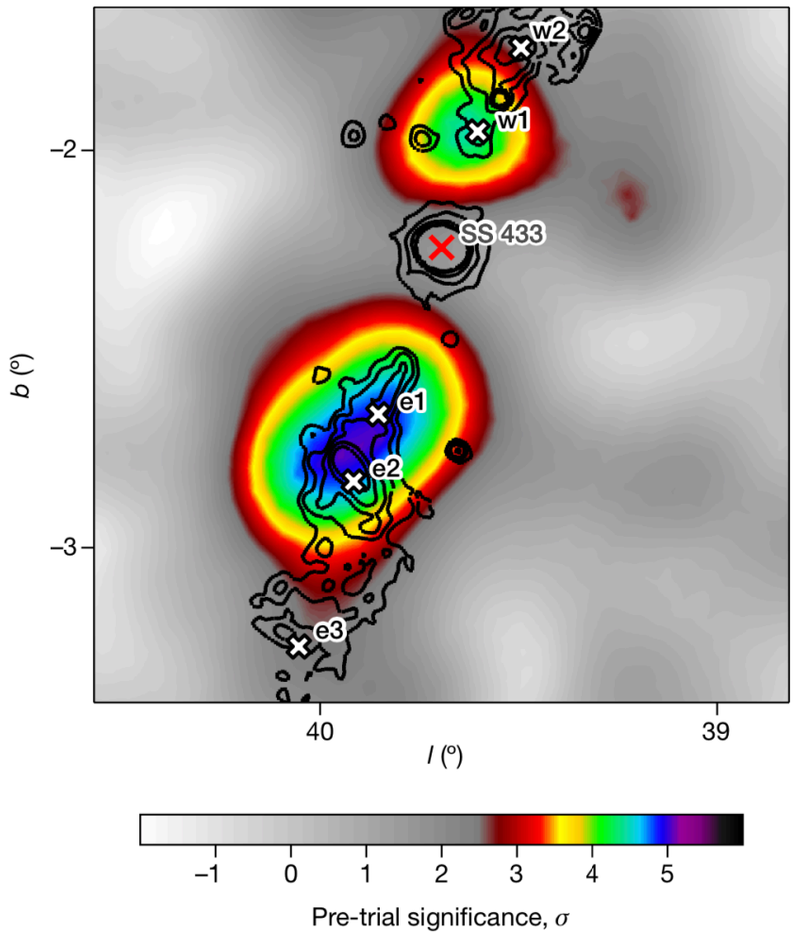


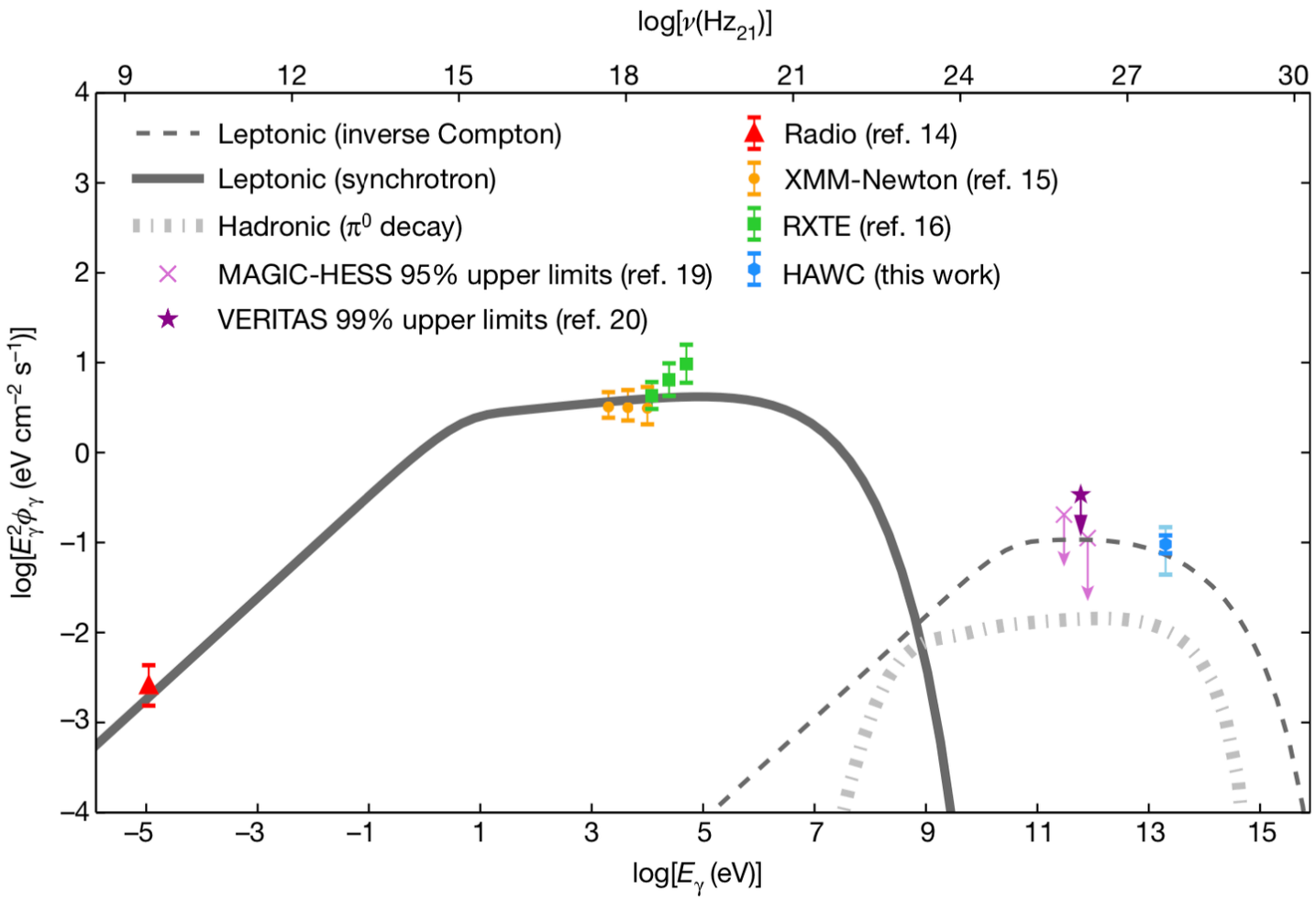
Gamma-rays with energies of **at least 25 TeV** are measured from the lobes of SS 433.

HAWC Collaboration, Nature (2018)

Particle Acceleration in Microquasar Jets

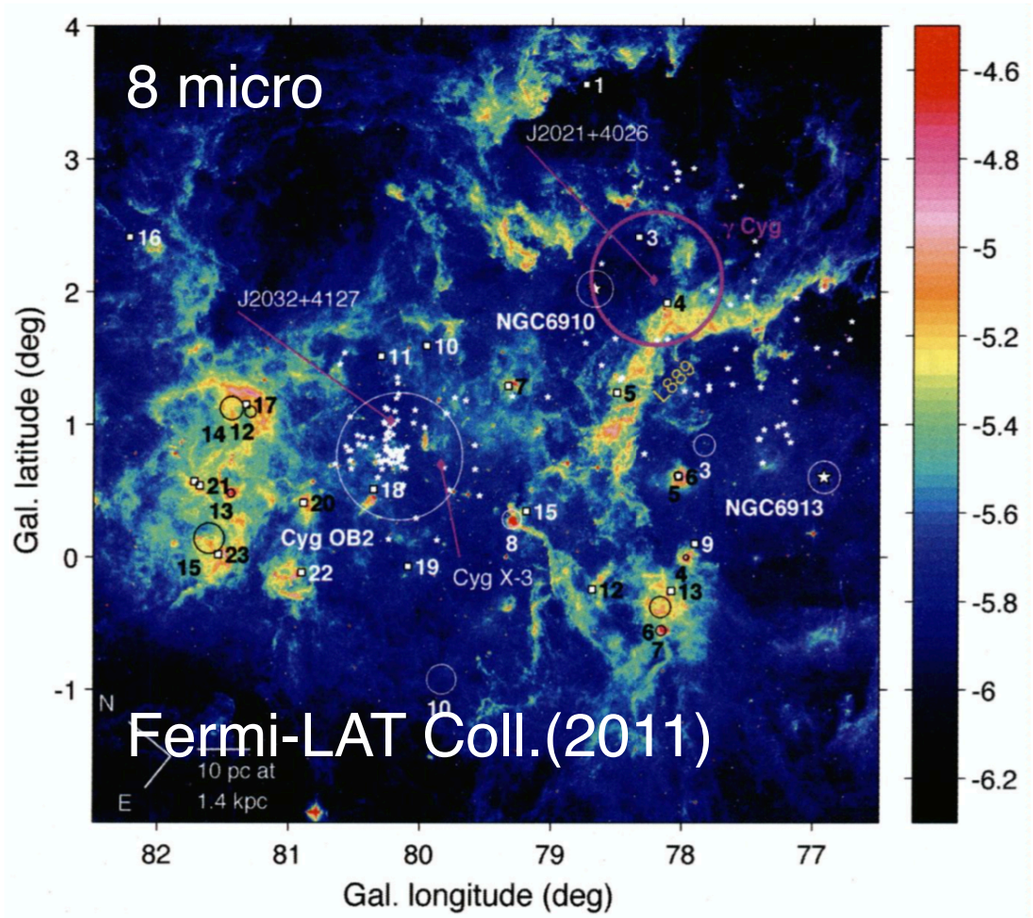
HAWC Collaboration, Nature (2018)

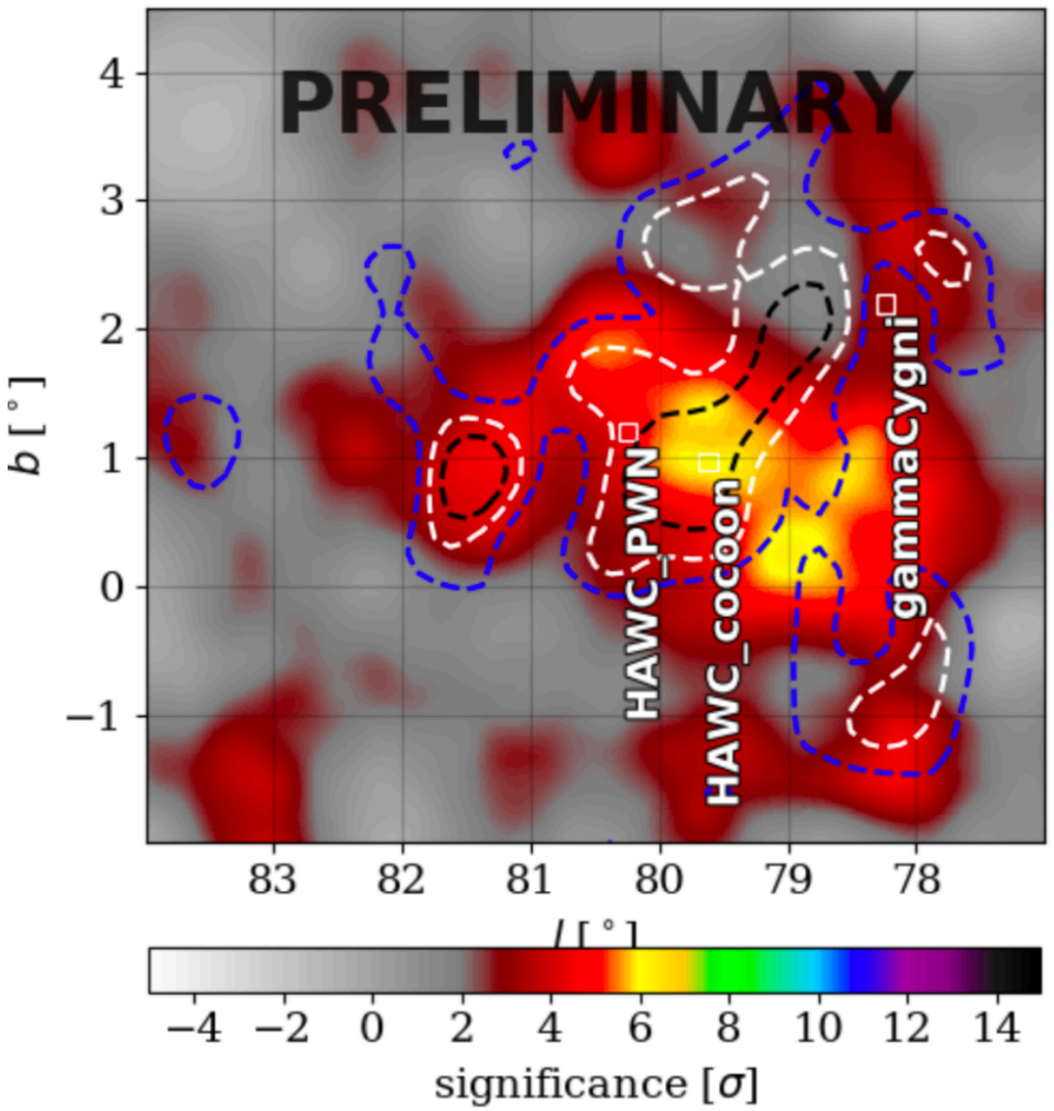




- Emission sites far from central binary suggests **local particle acceleration**
- Gamma-ray flux & observed jet power **disfavor proton scenario**
- Multi-wavelength observation can be explained by **a single electron population with maximum energy over 100 TeV**

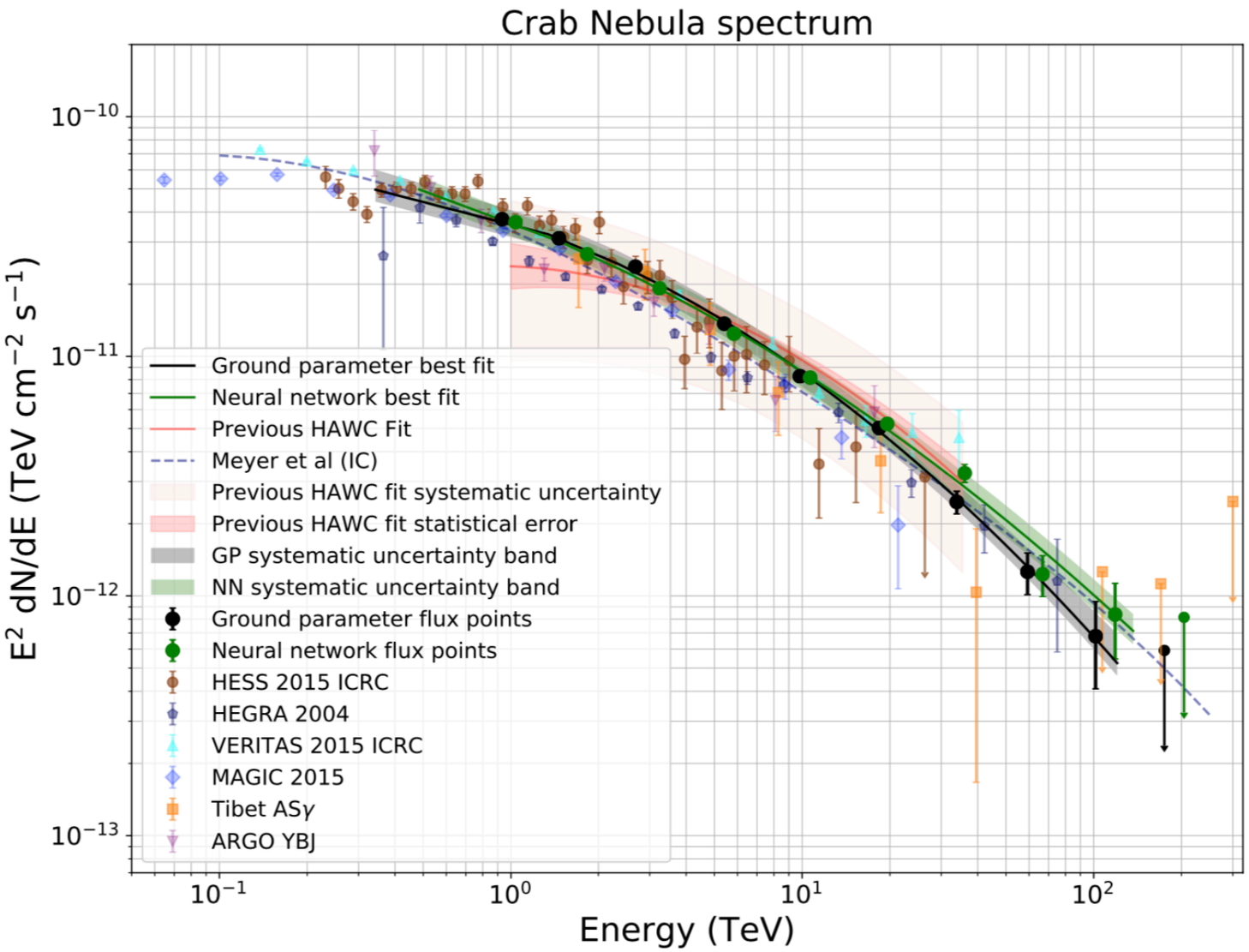
Cygnus Cocoon





- **Star-forming region of Cygnus X**: young stellar clusters, bright HI, HII emission, high gas density
- GeV gamma-rays likely come from **freshly accelerated cosmic rays**
- **Detected by HAWC at >14 sigma**

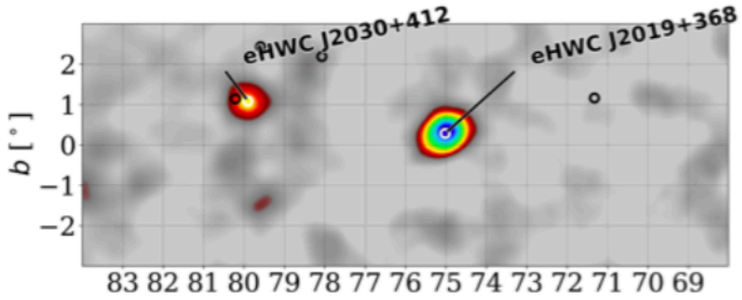
Crab Nebula at the Highest-energies

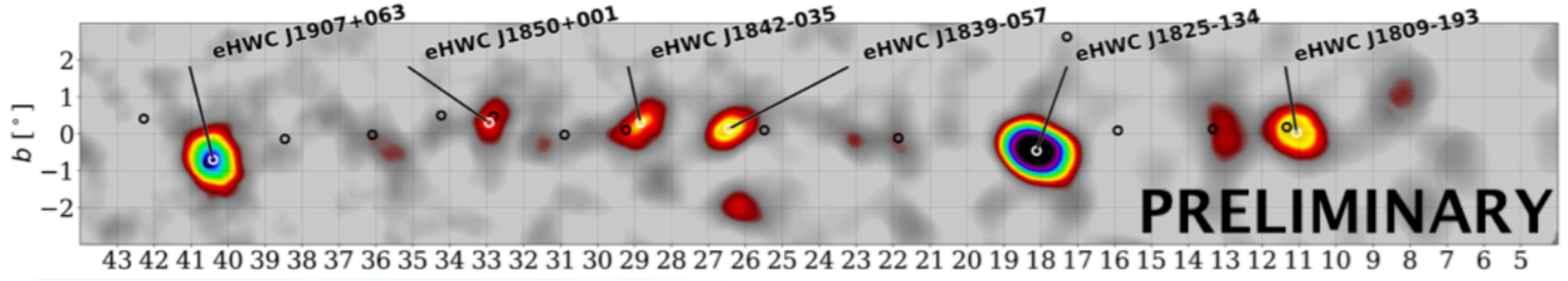


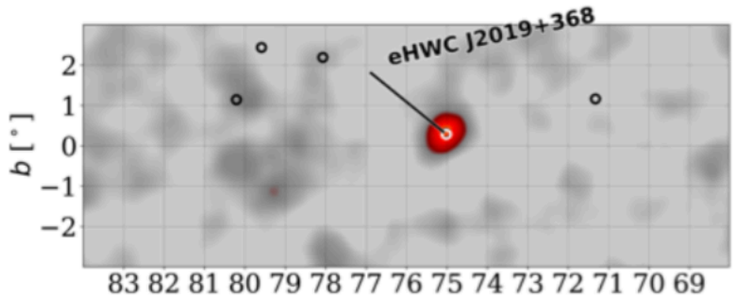
New energy-estimation method yields improved energy resolution that allows accurate **measurement of gamma-ray energies well beyond 100 TeV**.

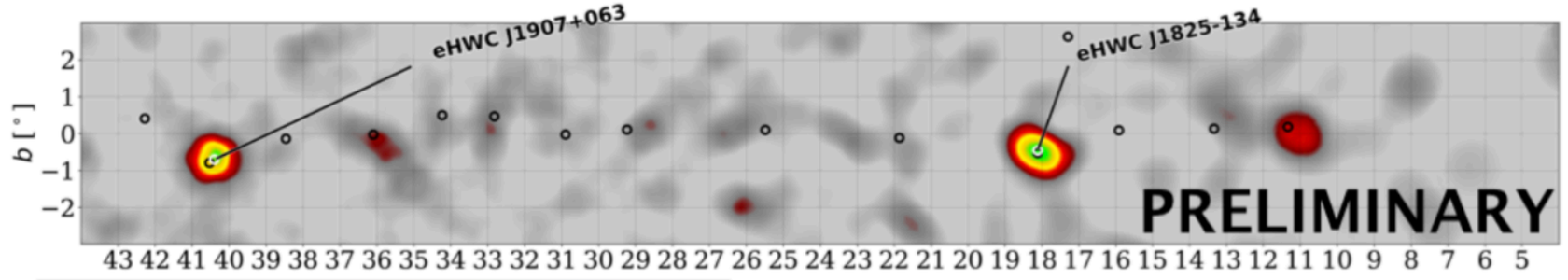
HAWC Collaboration, ApJ (2019)

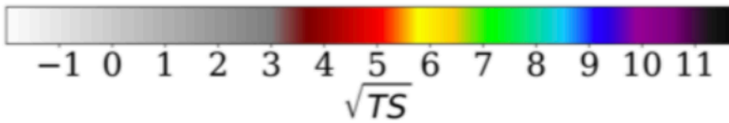
Catalog of Gamma-ray Sources above 56 and 100 TeV

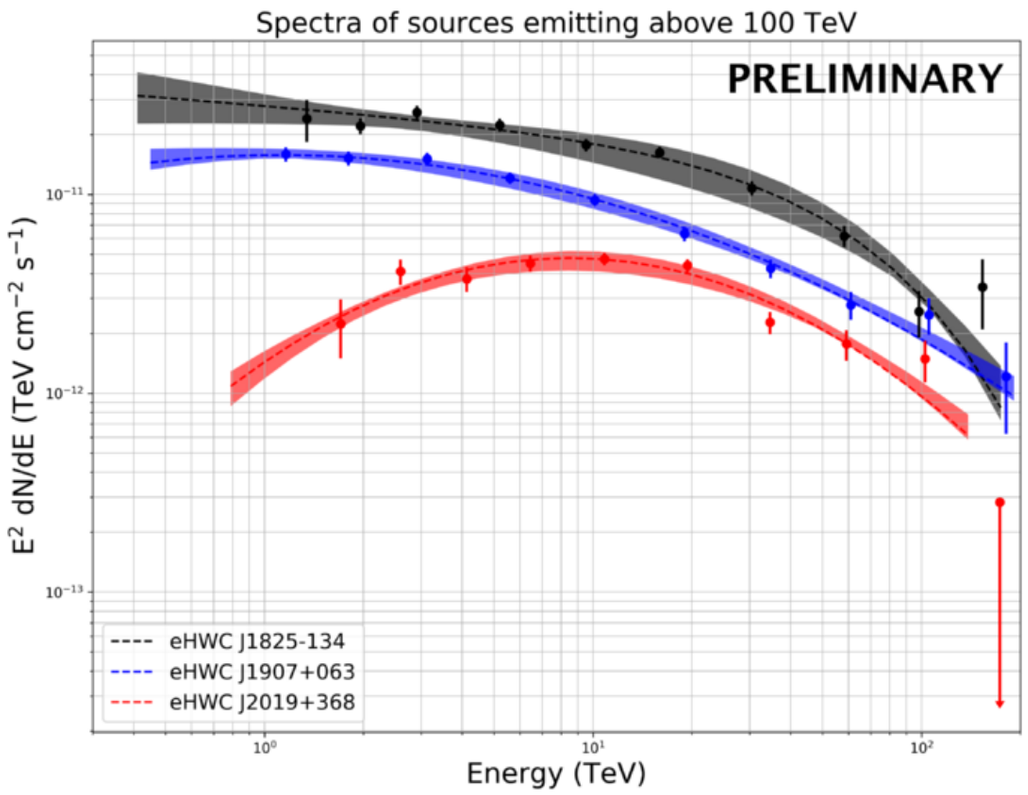












- **Highest-energy** source catalog
- All source in the Galactic plane remain **extended** above 56 TeV
- **Different spectra** found from the three sources above 100 TeV

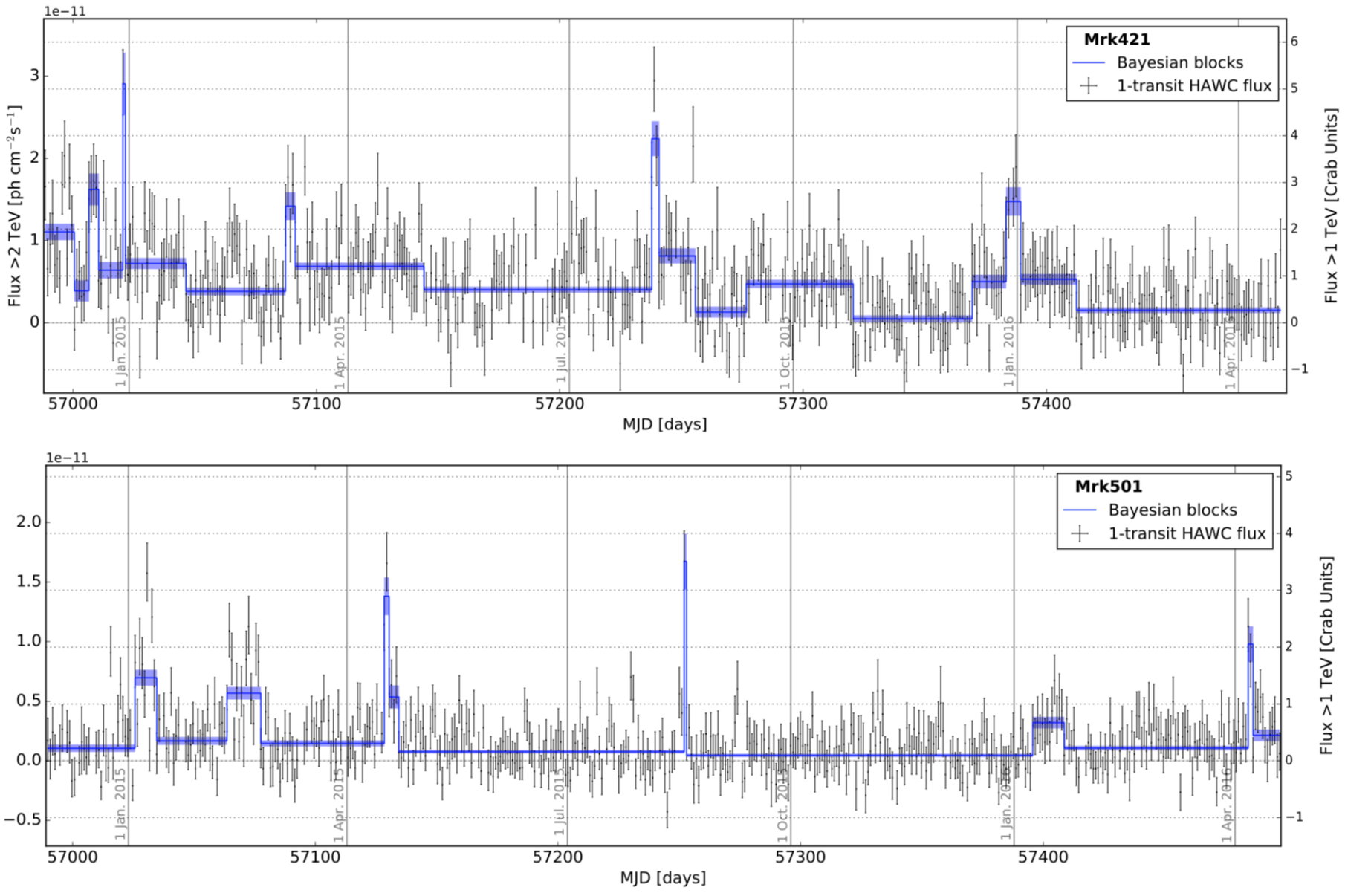
HAWC Collaboration, accepted to PRL

Survey of TeV Emission from Galactic Supernova Remnants

SNR name	RA	Dec	TeV association	Isolated	HAWC detected
SNR006.4-00.1	270.36°	−23.44°	HESS J1801-233 [8]	no	—
SNR008.7-00.1	271.36°	−21.59°	HESS J1804-216 [9]	no	—
SNR020.0-00.2	277.11°	−11.50°	—	no	—
SNR023.3-00.3	278.57°	−8.75°	HESS J1834-087 [9, 10]	no	—
SNR024.7+00.6	278.60°	−7.17°	—	no	—
SNR034.7-00.4	284.05°	1.34°	—	no	—
SNR043.3-00.2	287.75°	9.09°	HESS J1911+090 [11, 12]	no	—
SNR045.7-00.4	288.94°	11.08°	—	no	—
SNR049.2-00.7	290.81°	14.14°	W51 C [13]	no	yes
SNR074.0-08.5	312.77°	30.90°	—	yes	no
SNR078.2+02.1	305.26°	40.41°	γCygni [14]	no*	yes
SNR089.0+04.7	311.15°	50.42°	—	yes	no
SNR109.1-01.0	345.41°	58.83°	—	yes	no
SNR111.7-02.1	350.85°	58.83°	Cassiopeia A [15]	yes	no
SNR180.0-01.7	84.55°	27.86°	—	yes	no
SNR189.1+03.0	94.28°	22.57°	IC 443 [16, 17]	yes	yes
SNR205.5+00.5	98.91°	5.87°	—	no*	no

Extragalactic Sources

Daily Monitoring of Mrk 421 and 501



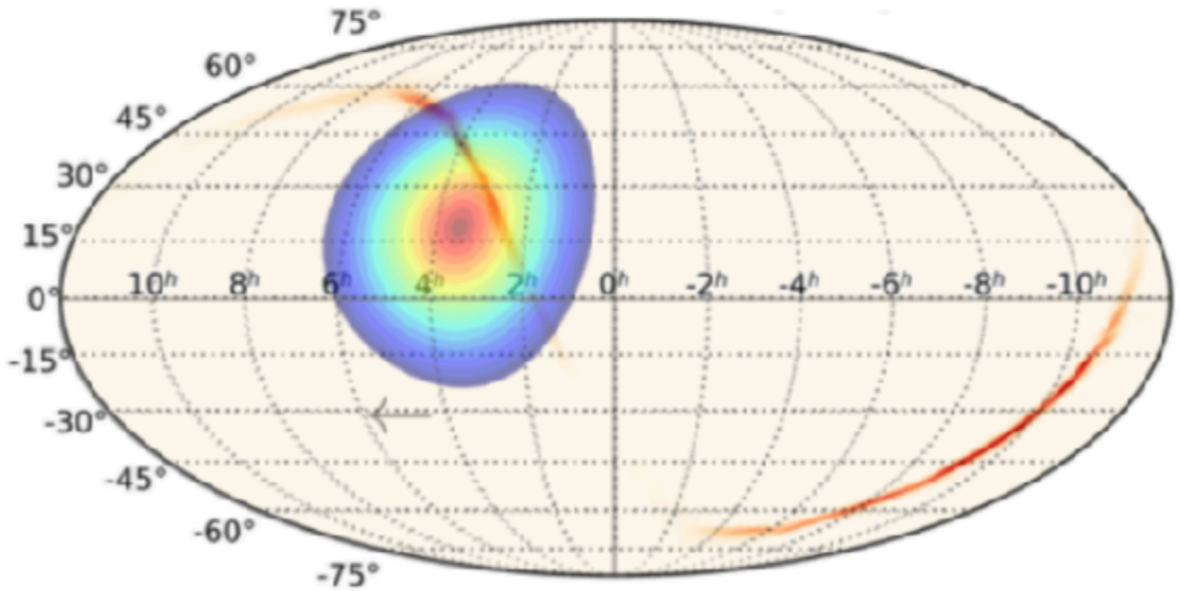
HAWC Collaboration, ApJ (2017)

HAWC also monitors TeV emission from radio galaxies and other extragalactic sources

Multi-messenger Astrophysics

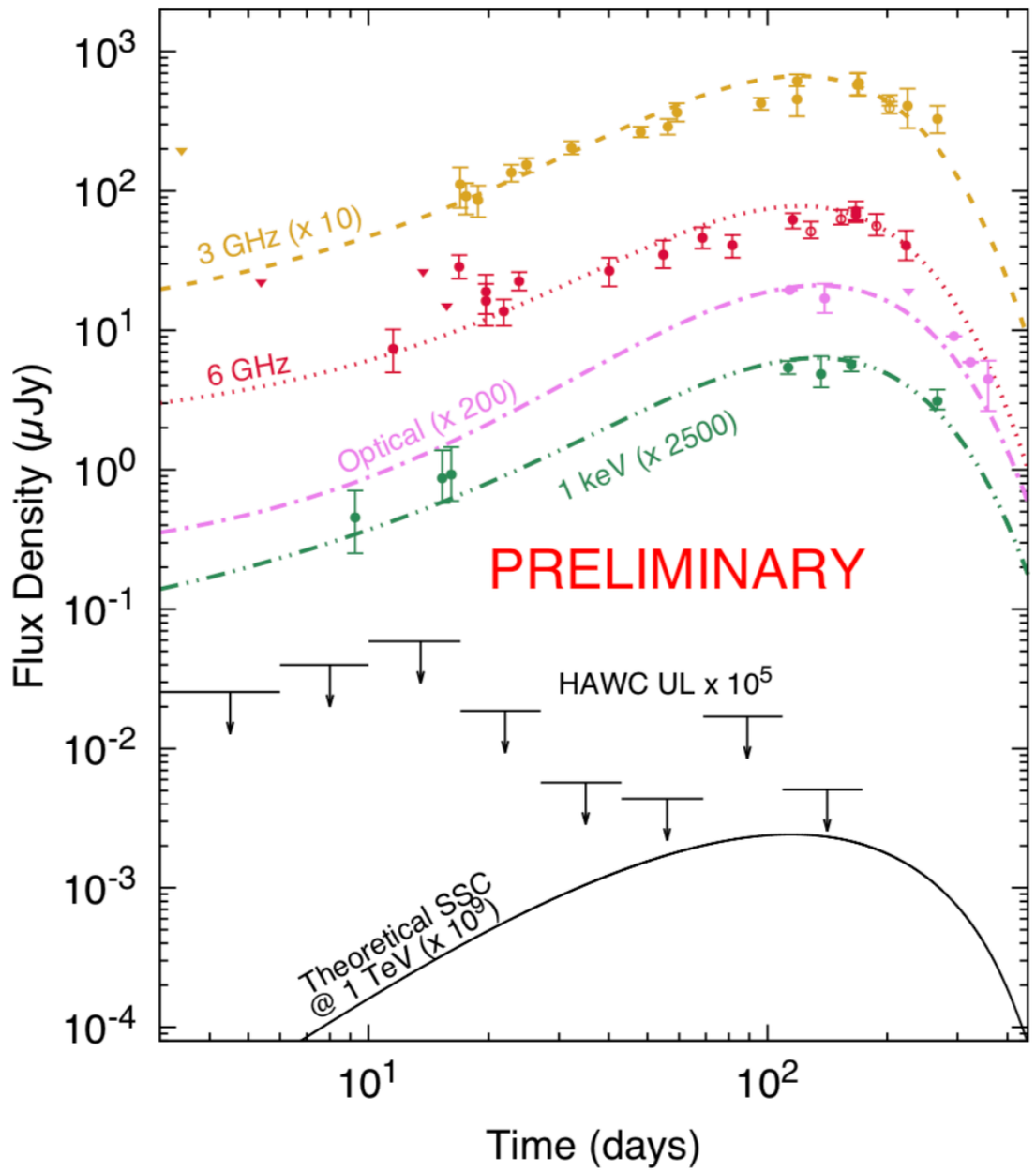
Follow-ups of Gravitational Wave Events

GW151226

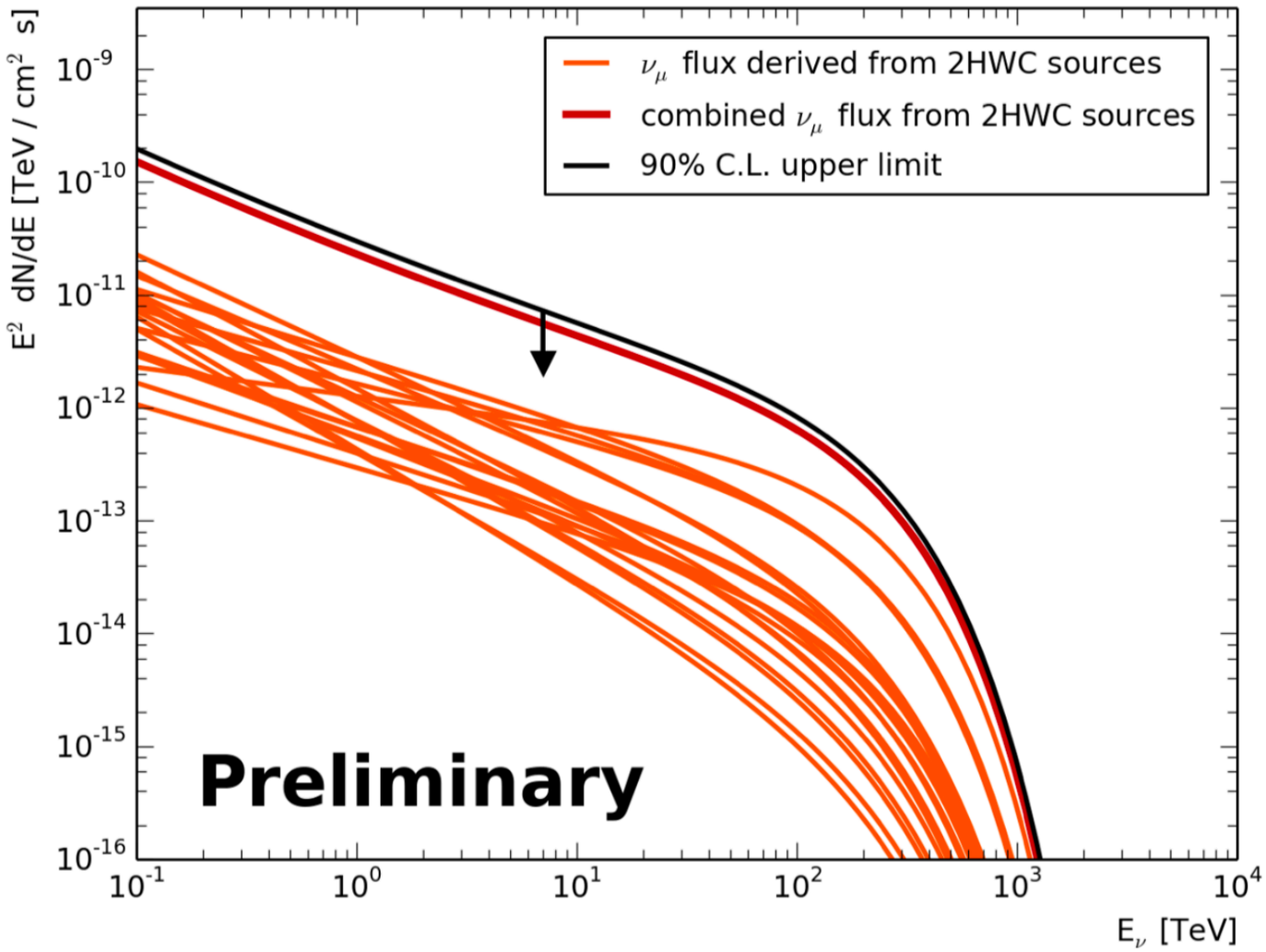


HAWC's wide field-of-view is ideal for transient follow-ups.

GW170817



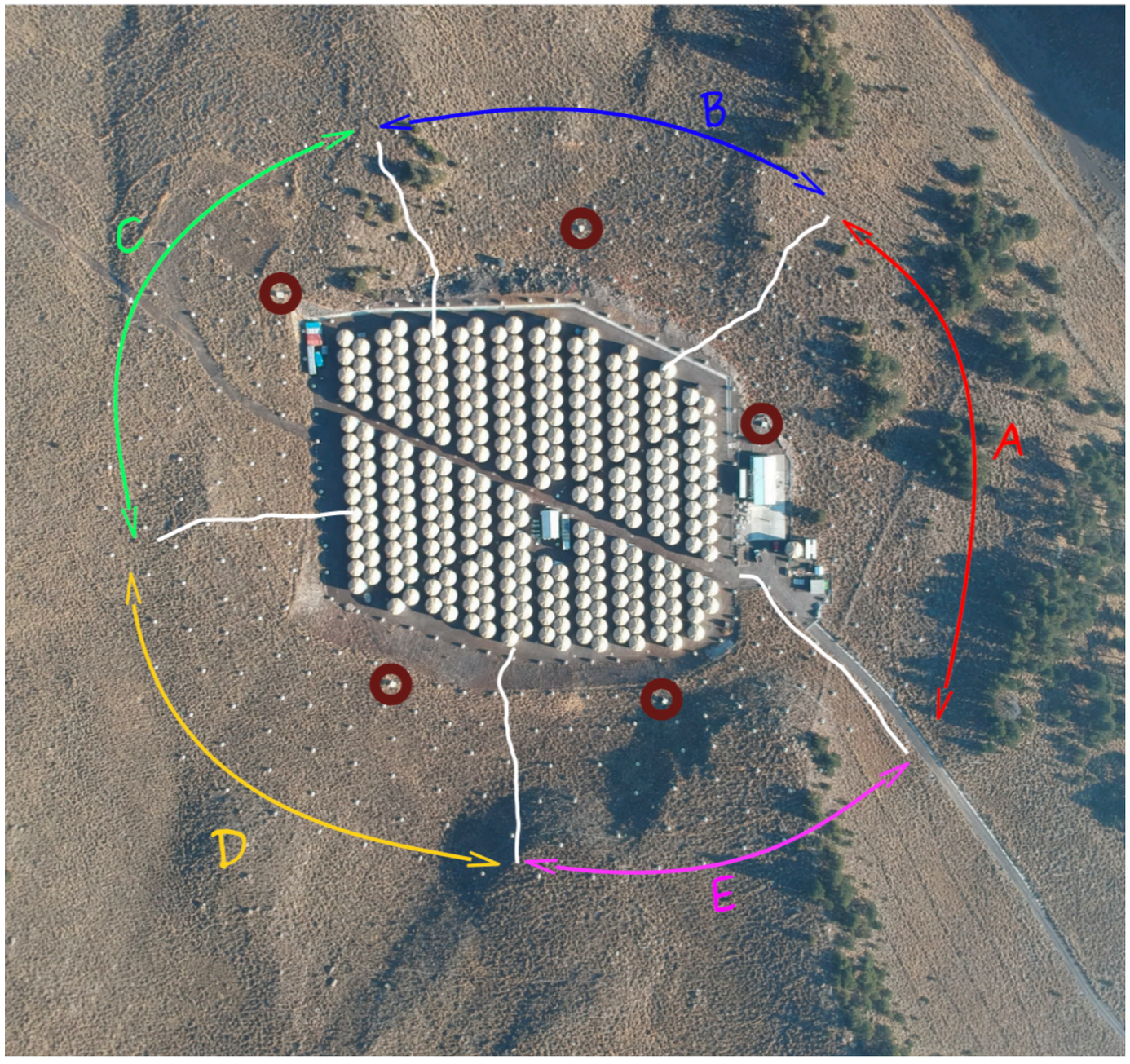
Searches for Galactic Neutrino Sources



No significant excess found in IceCube data from HAWC sources in the Galactic plane, tightly constraining the contribution from hadronic interactions to high-energy emission.

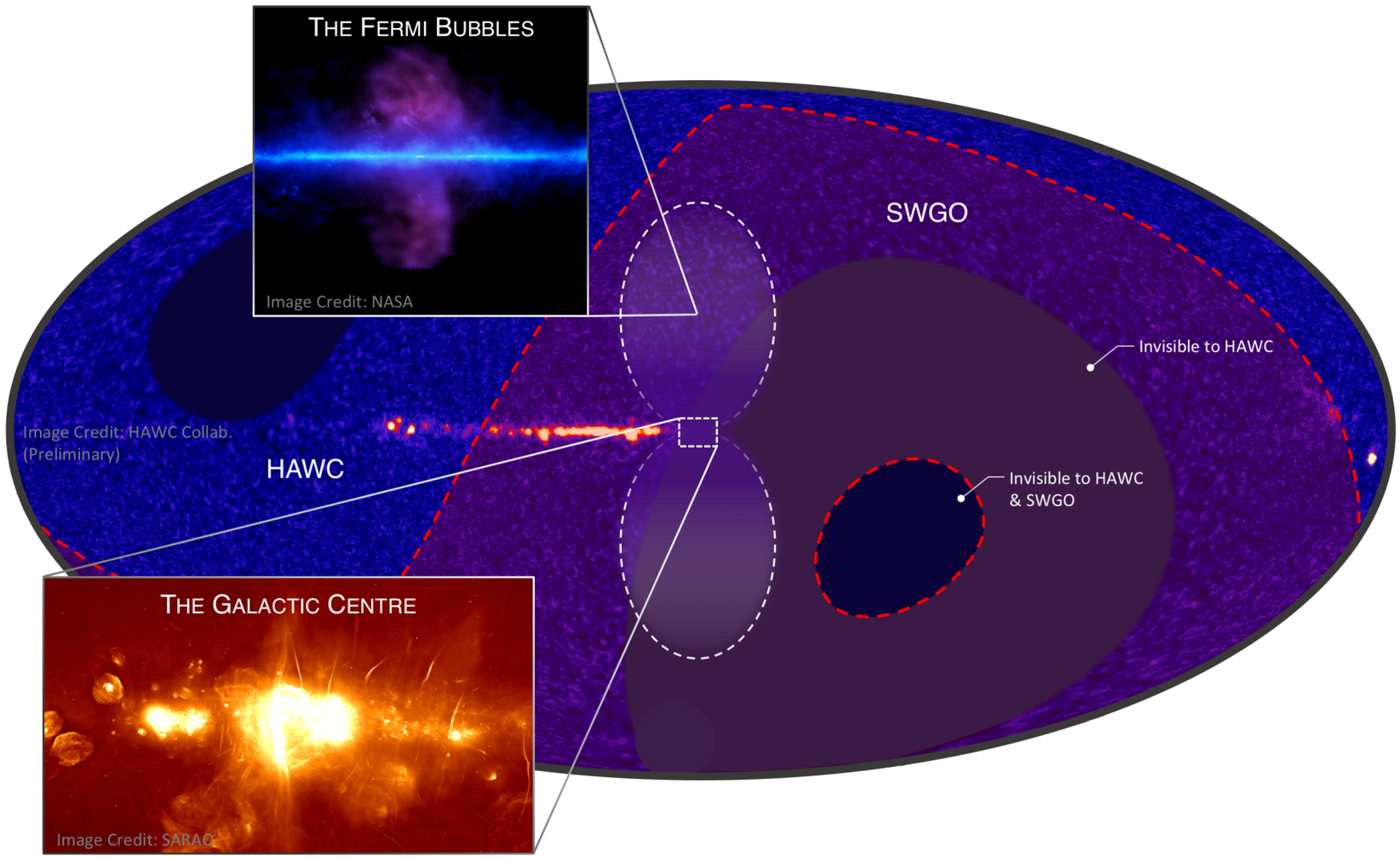
Upgrades and Future Experiment

The Outrigger Array



- 345 cylindrical tanks, 1.55 m in diameter, 1.65 m in height. Each with one PMT
- Divided into 5 sections for trigger and readout
- **Will better constrain the core location** and improve event reconstruction
- Fully deployed. **Started taking data since Aug 2018**
- Combined reconstruction of outrigger array with main array being implemented

Southern Wide-field-of-view Gamma-Observatory



- Proposed HAWC-like experiment in the **Southern Hemisphere**
- **Measurement of Galactic Center,** full sky coverage for transients
- Based primarily on **water Cherenkov detector** units
- Sites in South America being considered
- Astro 2020 white paper

Conclusion

- HAWC is surveying TeV sources with **large sky coverage and high sensitivity**
- A variety of source classes have been explored, **improving our understanding of pulsars and black hole jets**
- **Outriggers** have started taking data and will improve detector sensitivity above 10 TeV