



PennState
Eberly College of Science



The High Altitude Water Cherenkov Observatory

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Professor of Physics, Astronomy and Astrophysics



Outline

Introduction & Motivation 1

The HAWC Observatory 2

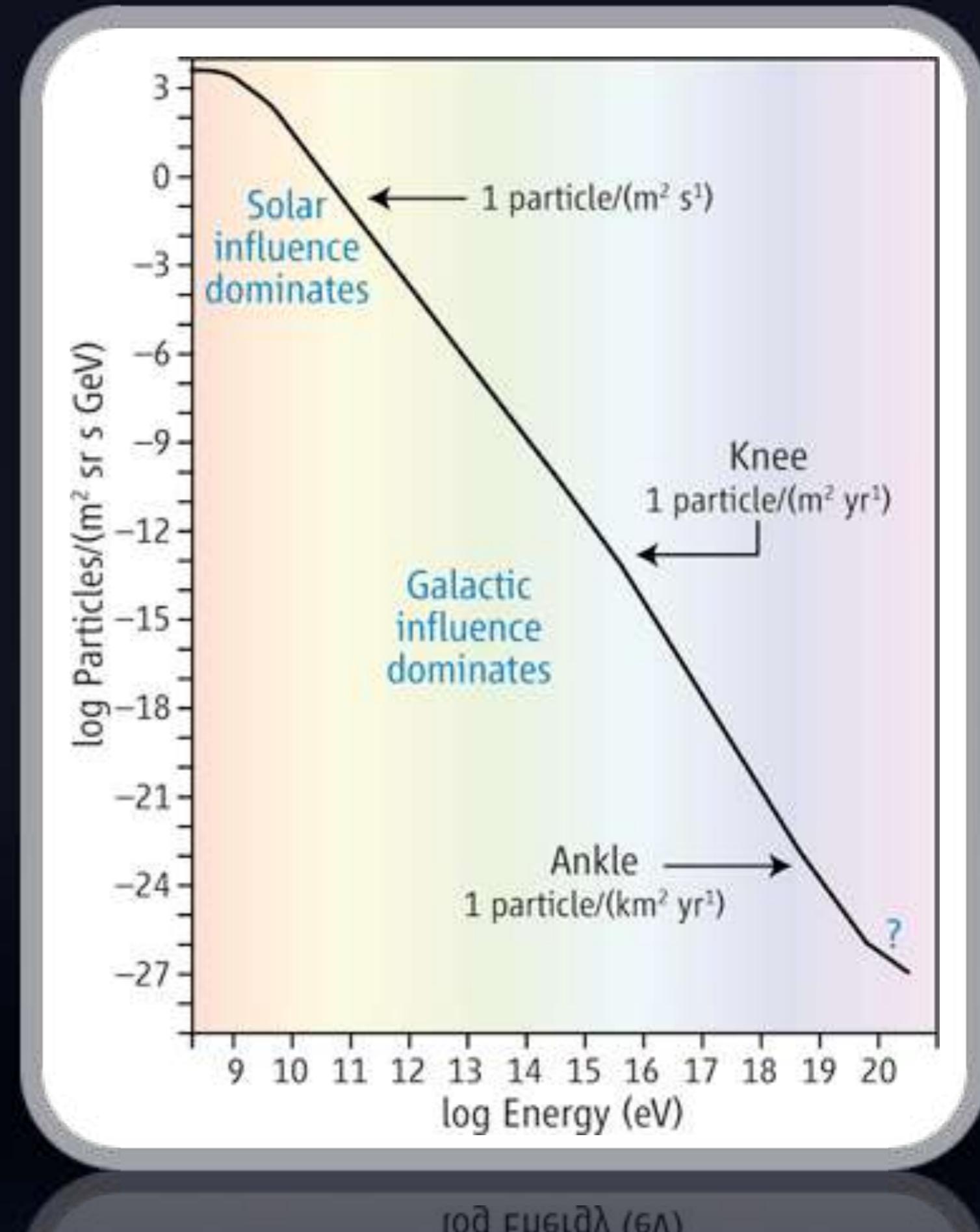
Recent results 3

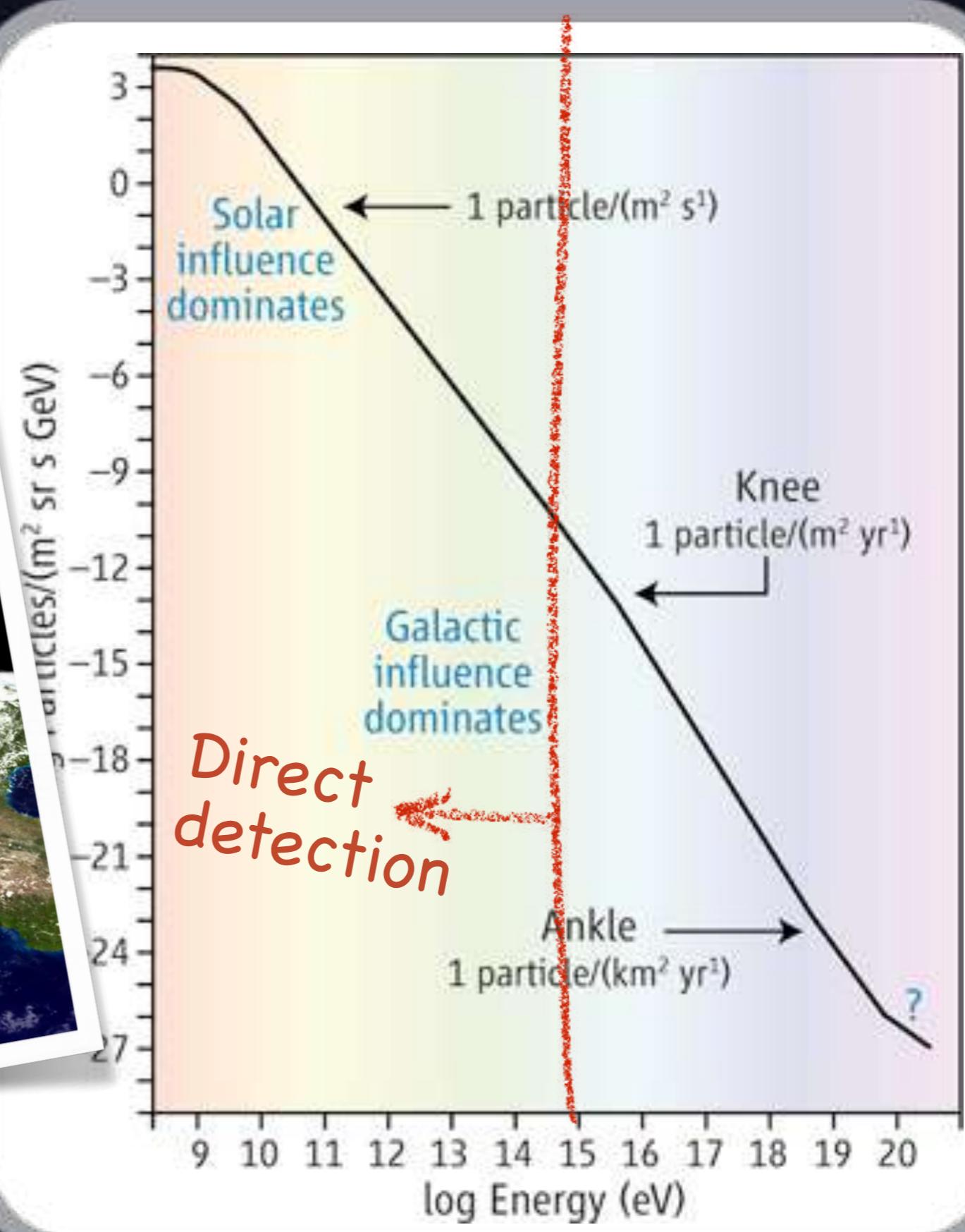
Outlook 4

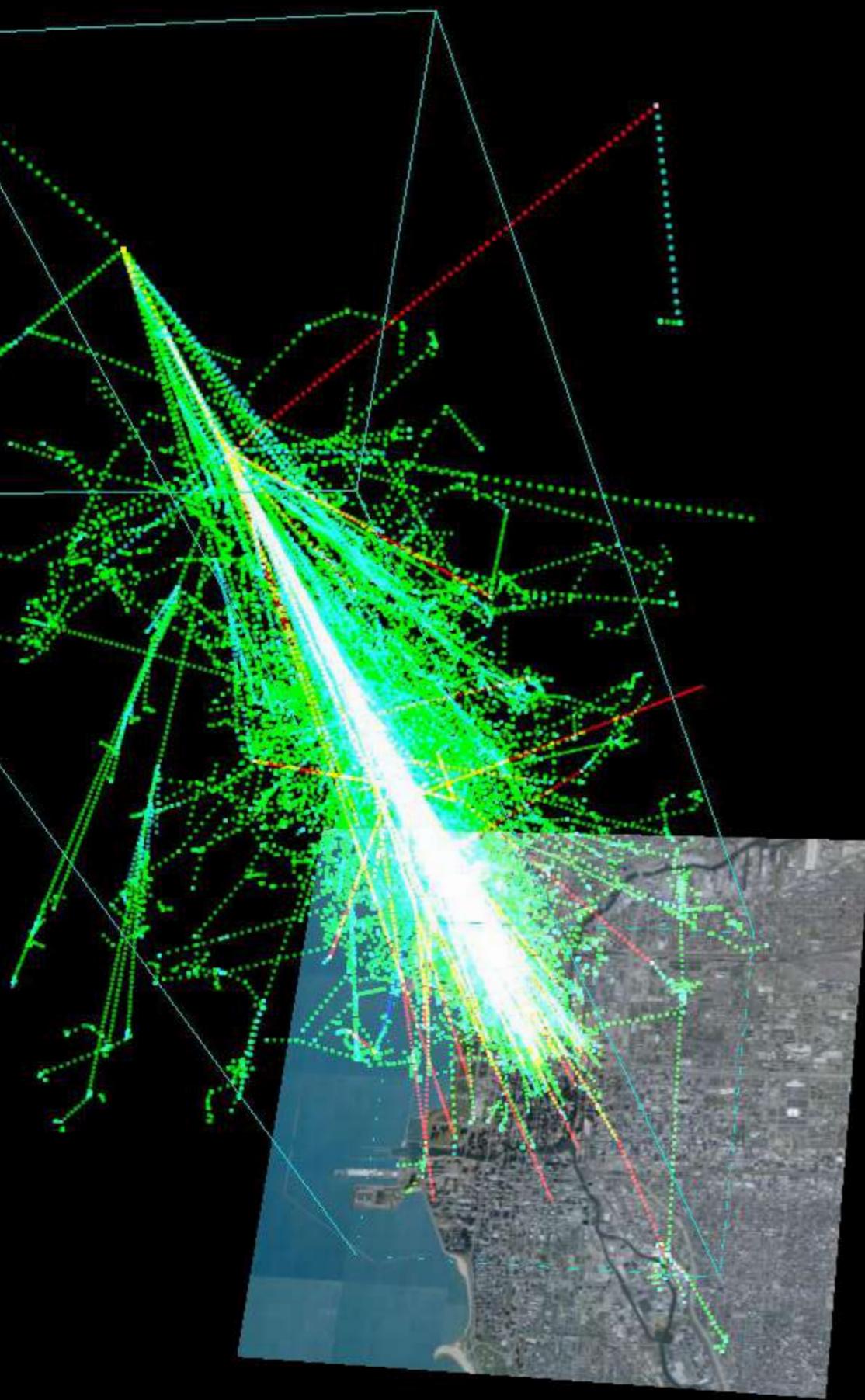


Cosmic Ray Flux

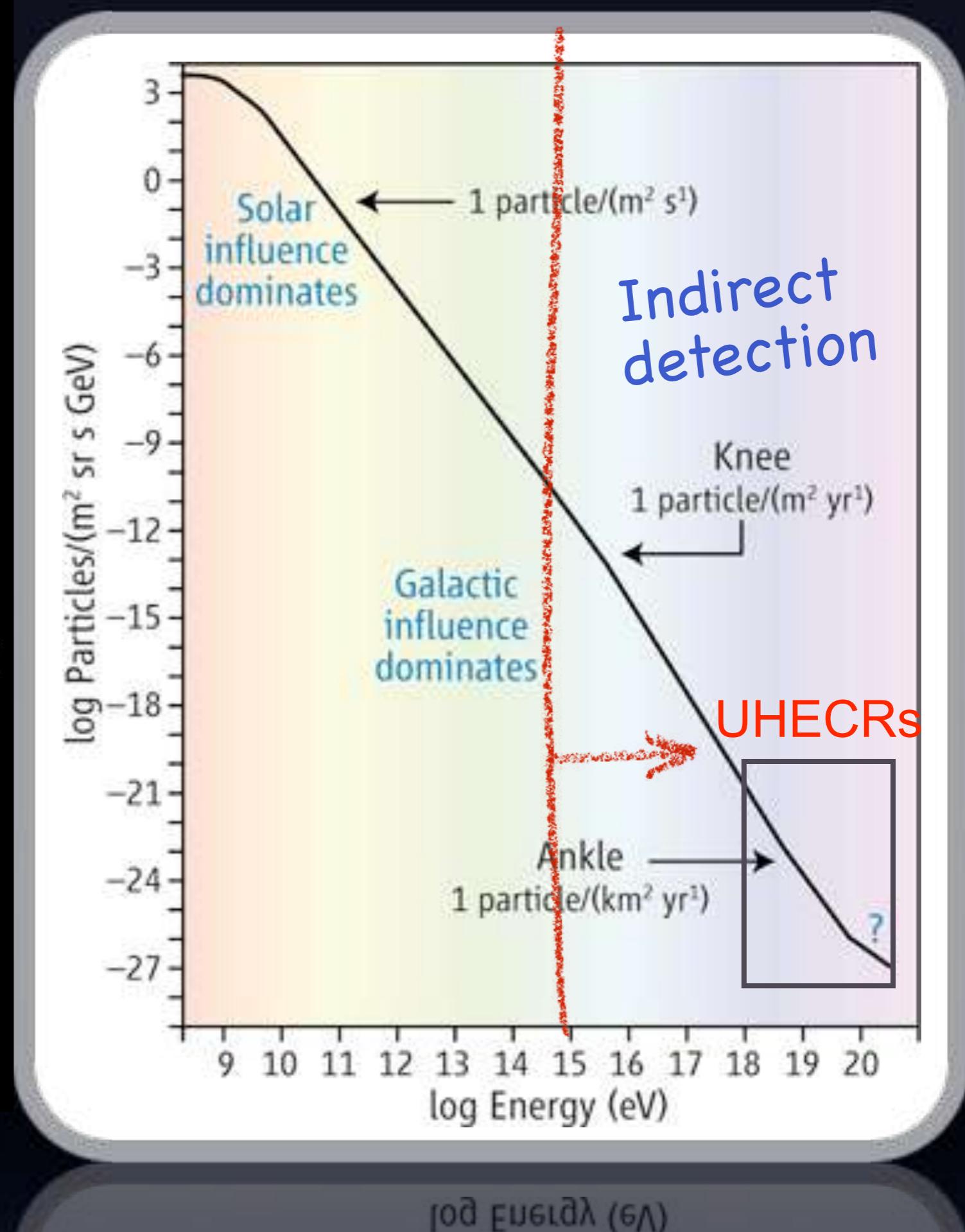
- At low E, solar **magnetic fields** strongly influence CR propagation
- At high E, the minimally deflected CRs are **far less intense** and thus much harder to detect.







$1 \text{ EeV} \stackrel{\text{def}}{=} 10^{18} \text{ eV}$



18/11/2008

1659
1639
1629

Coihueco

Loma Amarilla

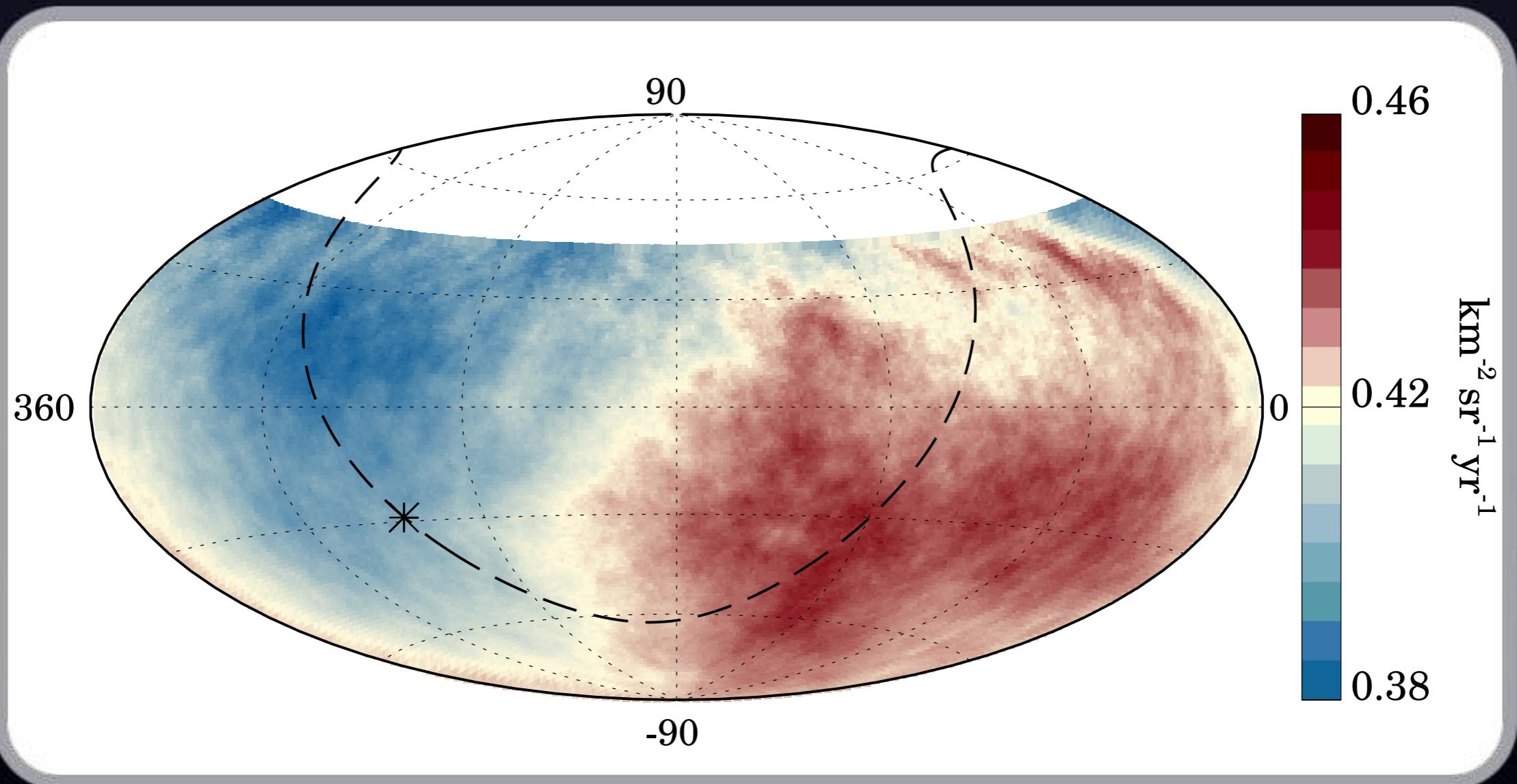
Los
Morados

Malargue

Los Leones

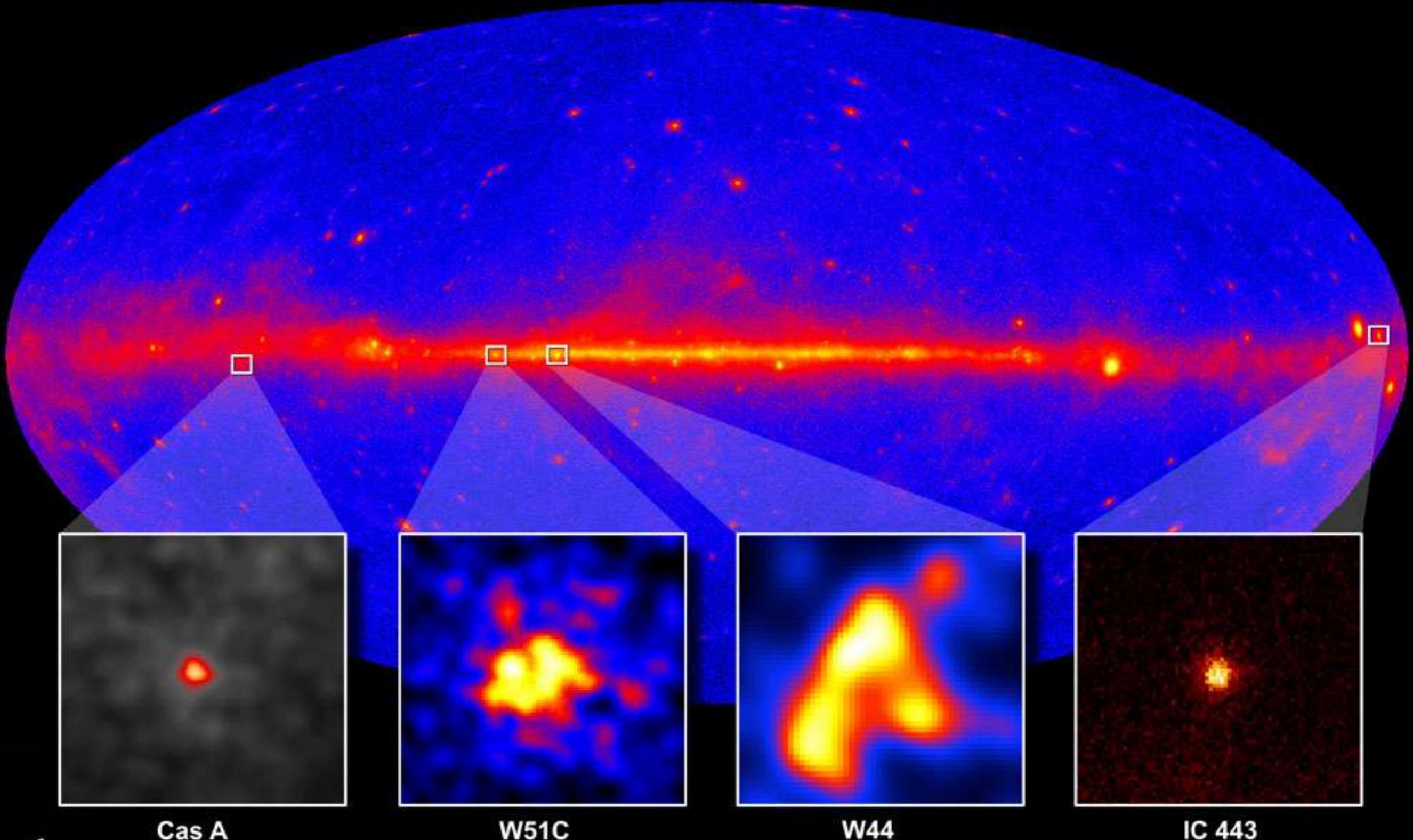
UHECR detection

$E > 8 \text{ EeV}$; 45° smoothing



UHECR sky map

NASA's Fermi telescope resolves supernova remnants at GeV energies



Cas A

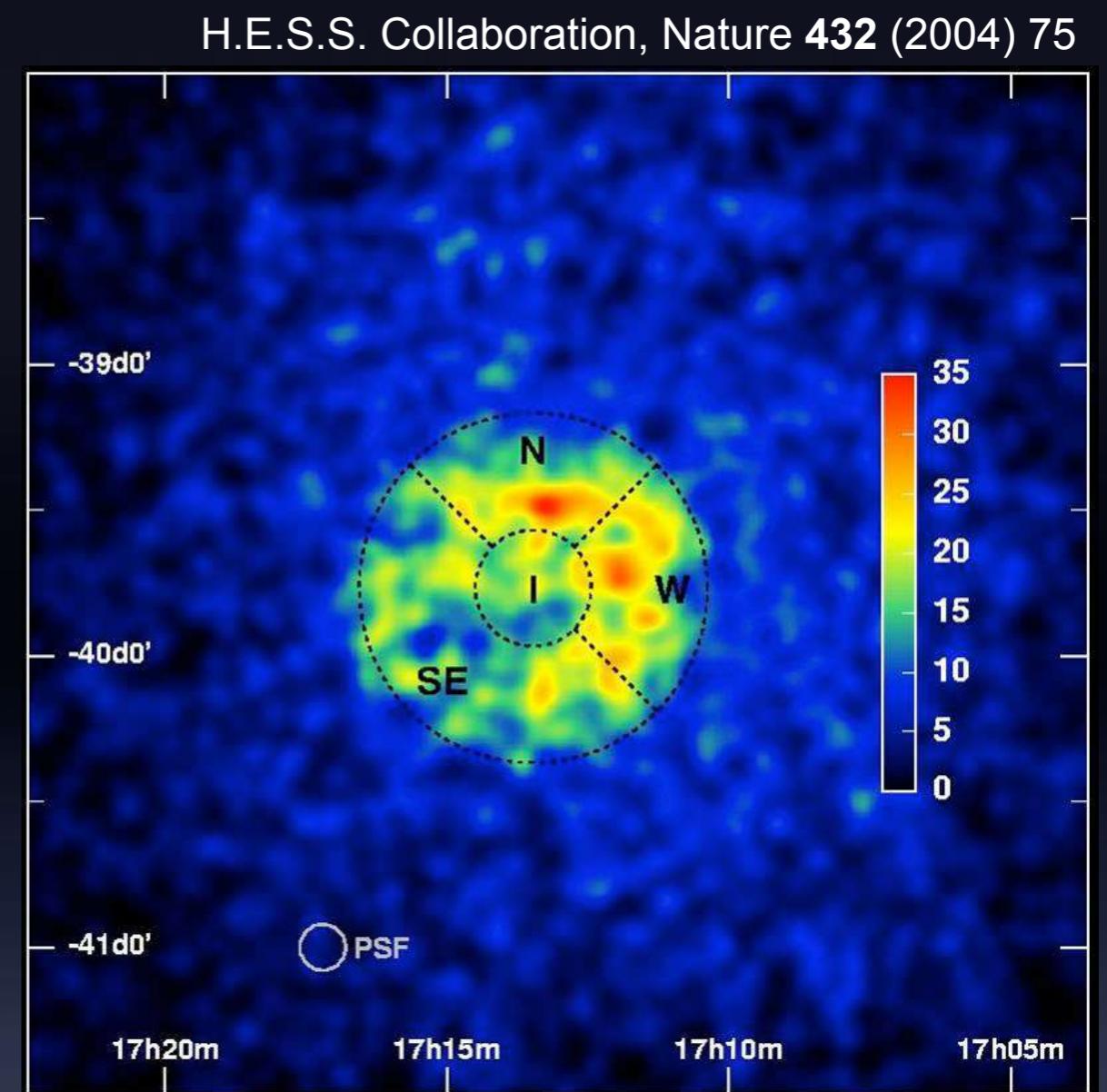
W51C

W44

IC 443

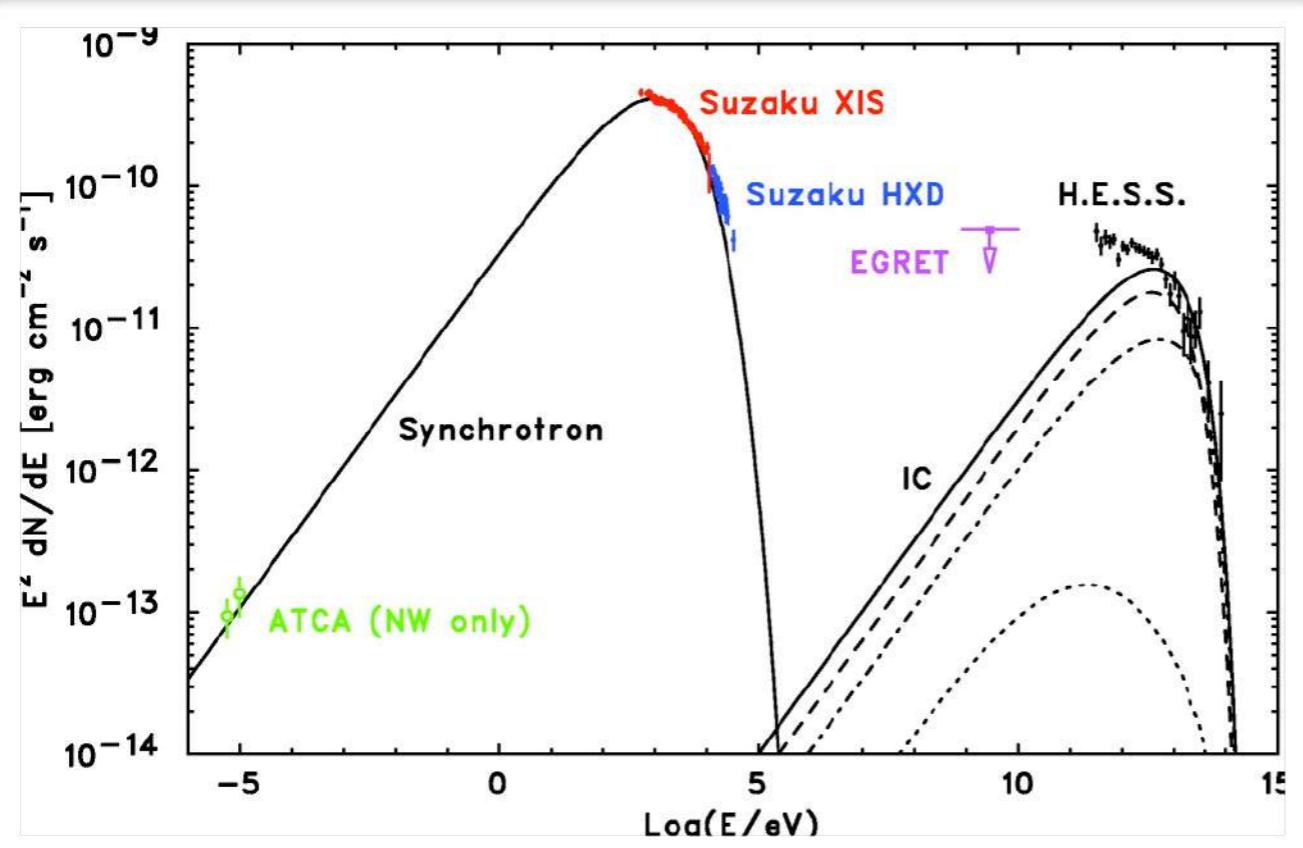
Supernova Remnants

- First resolved **TeV γ -ray** image of a Shell type SNR (Resolution ~ 10 arcmin)
- Acceleration source of cosmic rays, but is it evidence of protons?



Supernova Remnants

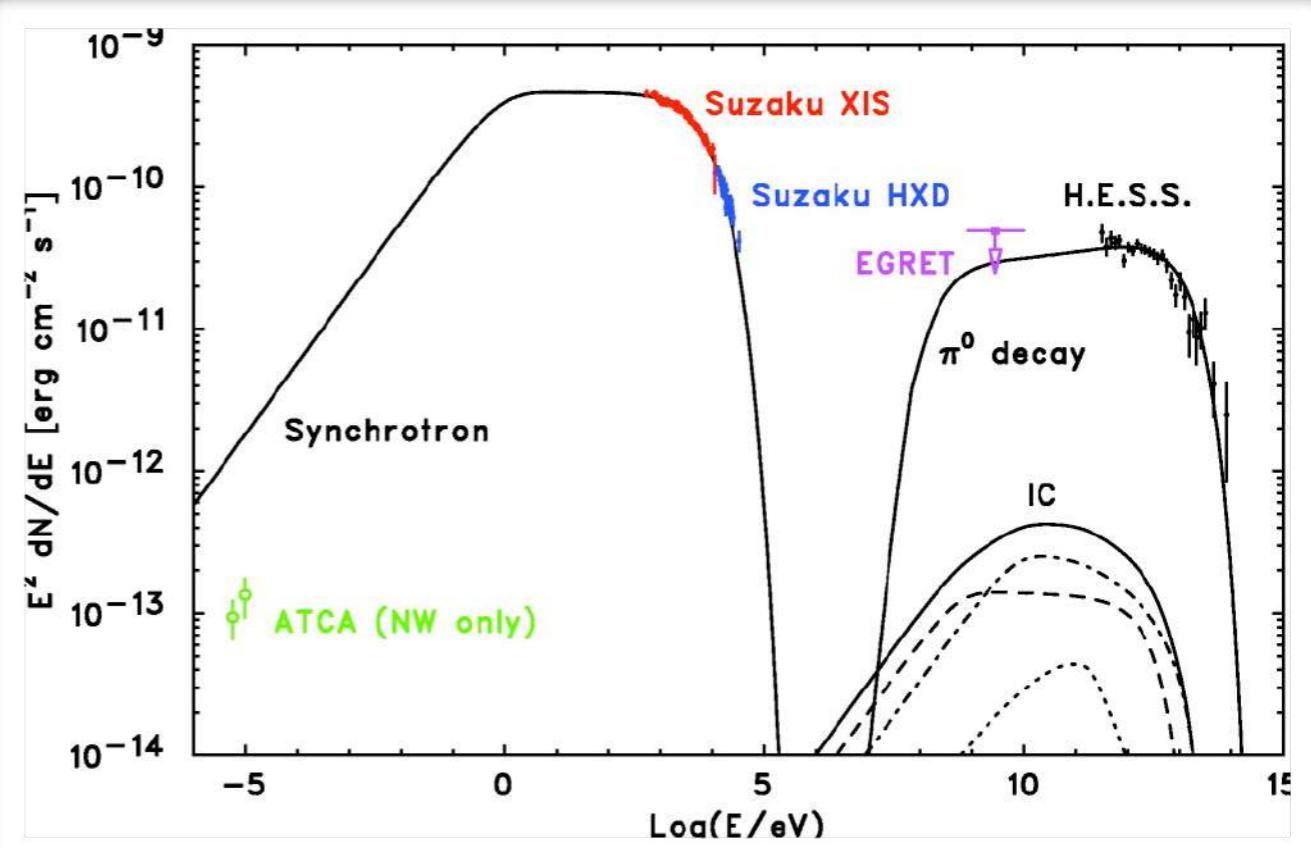
Tanaka et al., The Astrophysical Journal 685 (2008) 988



Leptonic

vs.

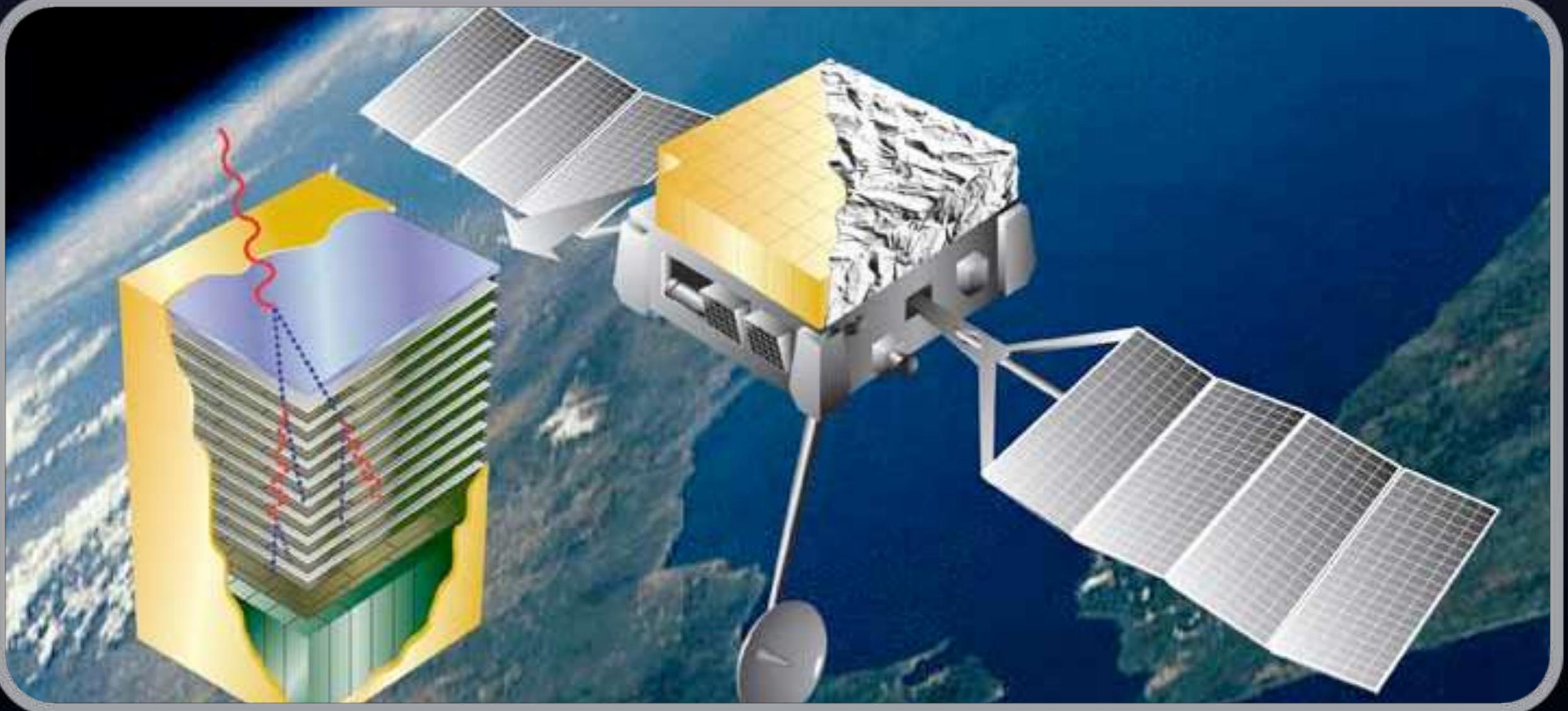
Hadronic



Scientific Motivation

- Constrain the **origin of cosmic rays** by measuring gamma-ray spectra to 100 TeV.
- Probe **particle acceleration** in astrophysical jets with **wide field of view, high duty factor** observations.
- Explore **new physics** with an **unbiased survey** of the **TeV sky**.

Experimental Techniques



- Space-based detectors
 - Low energy threshold
 - EGRET, Fermi-LAT

Experimental Techniques



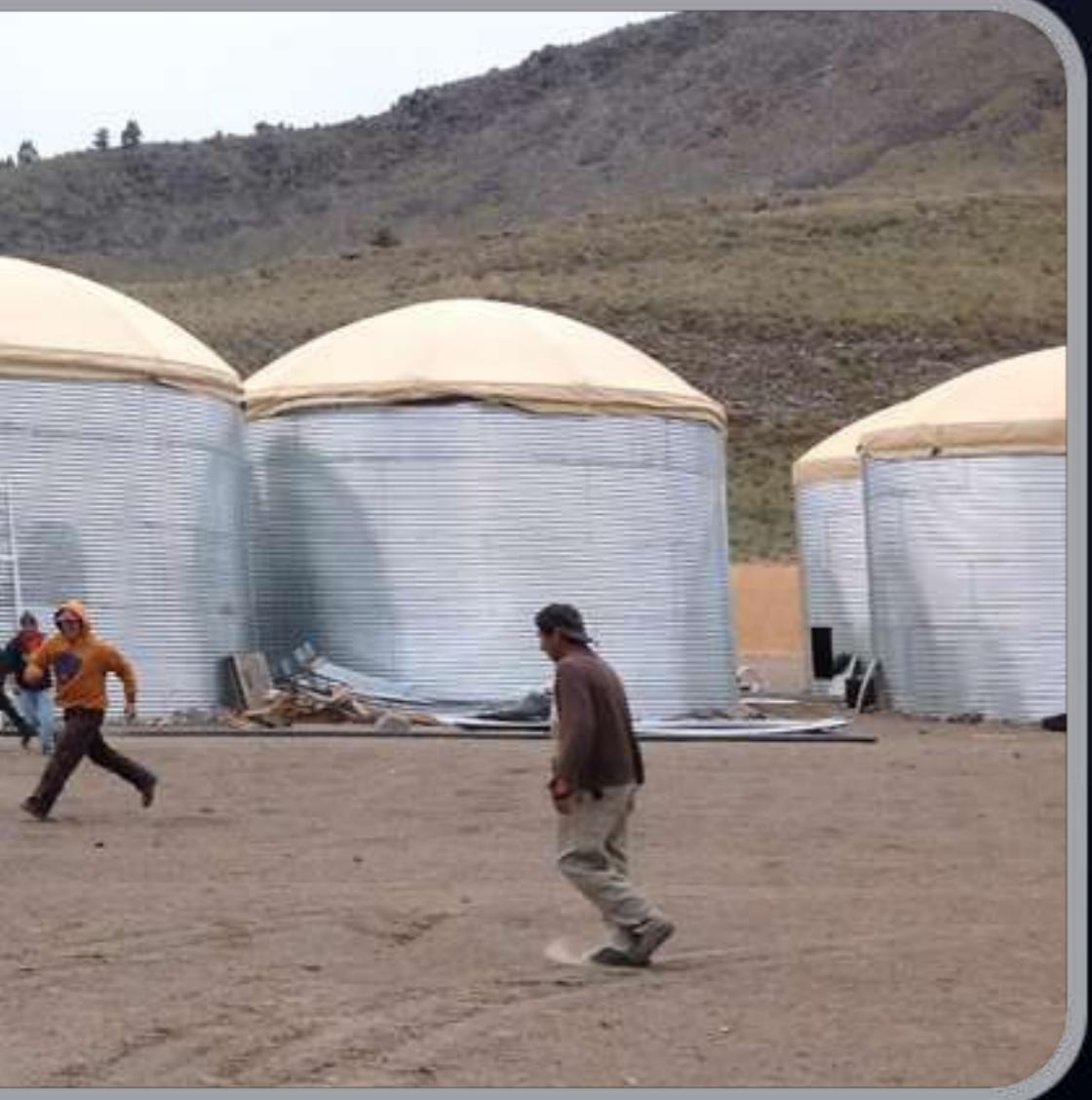
- Imaging Atmospheric Cherenkov Telescopes
 - High sensitivity
 - HESS, MAGIC, VERITAS

Experimental Techniques



- Ground array of air-shower particle detectors
- Large aperture + High duty cycle
- Milagro, Tibet, ARGO, HAWC

HAWC

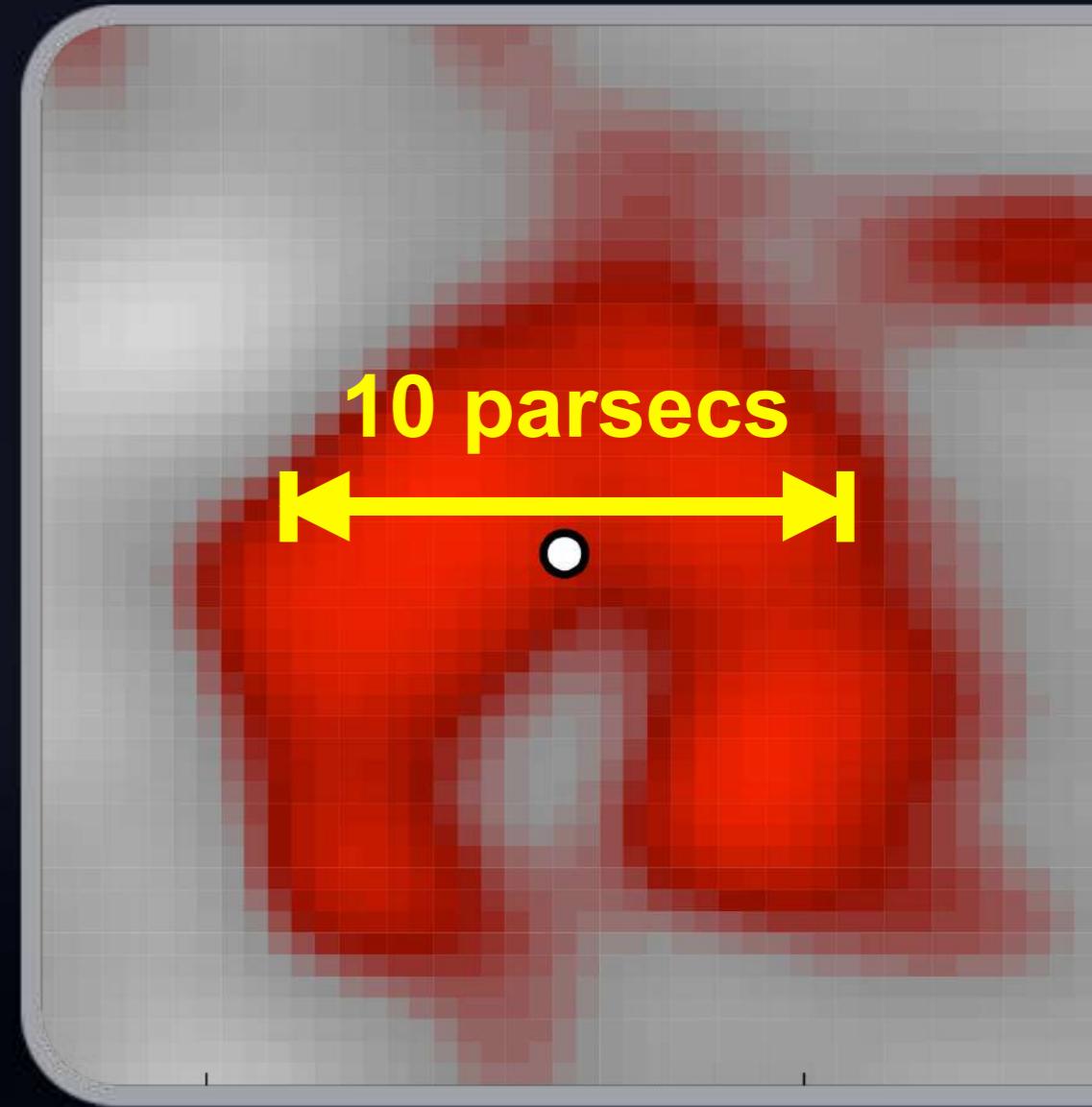


- 2nd generation water Cherenkov
- Wide instantaneous field of view (2 sr)
- High duty cycle (> 90%)
- Large area (22,000 m²)

A second generation wide-field γ -ray detector

Main Features

- Most bright Galactic GeV sources
extend to TeV
- Best instrument for **hard spectrum** and **extended sources**



The HAWC Observatory



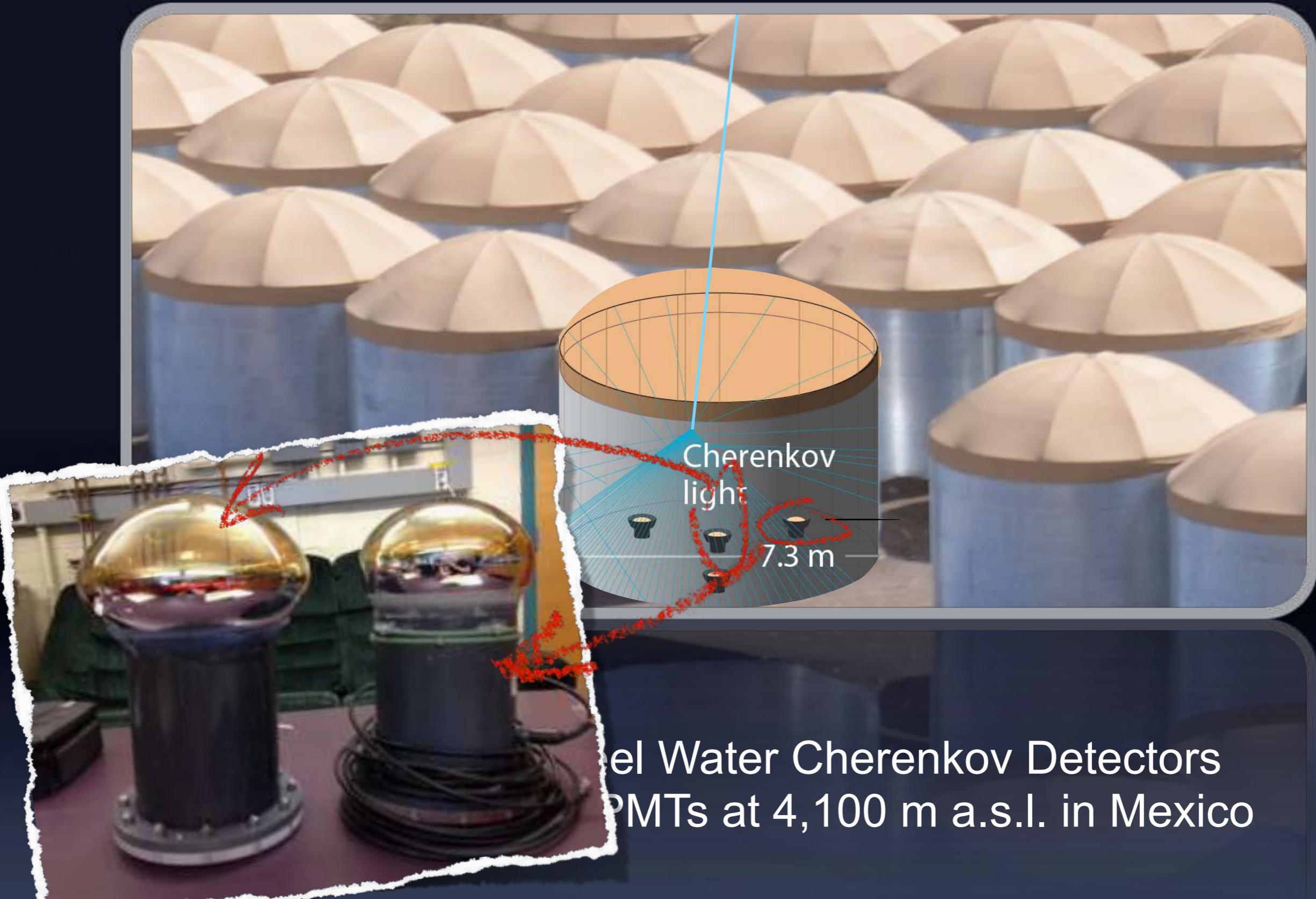
300 - 7 m x 5 m steel Water Cherenkov Detectors
(a.k.a. tanks) with 4 PMTs at 4,100 m a.s.l. in Mexico

Water Cherenkov Detectors

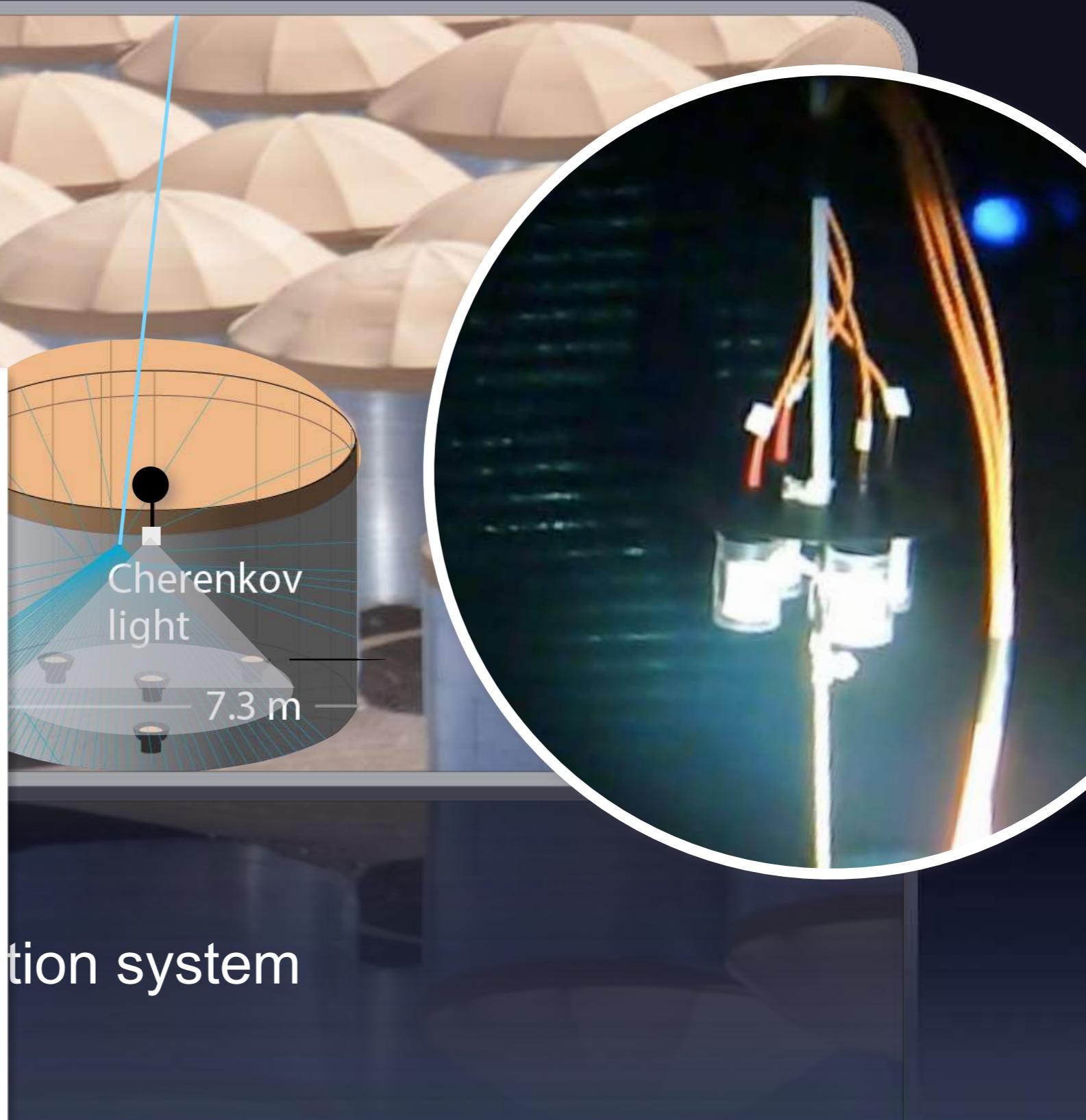


300 - 7 m x 5 m steel Water Cherenkov Detectors
(a.k.a. tanks) with 4 PMTs at 4,100 m a.s.l. in Mexico

Water Cherenkov Detectors



Water Cherenkov Detectors

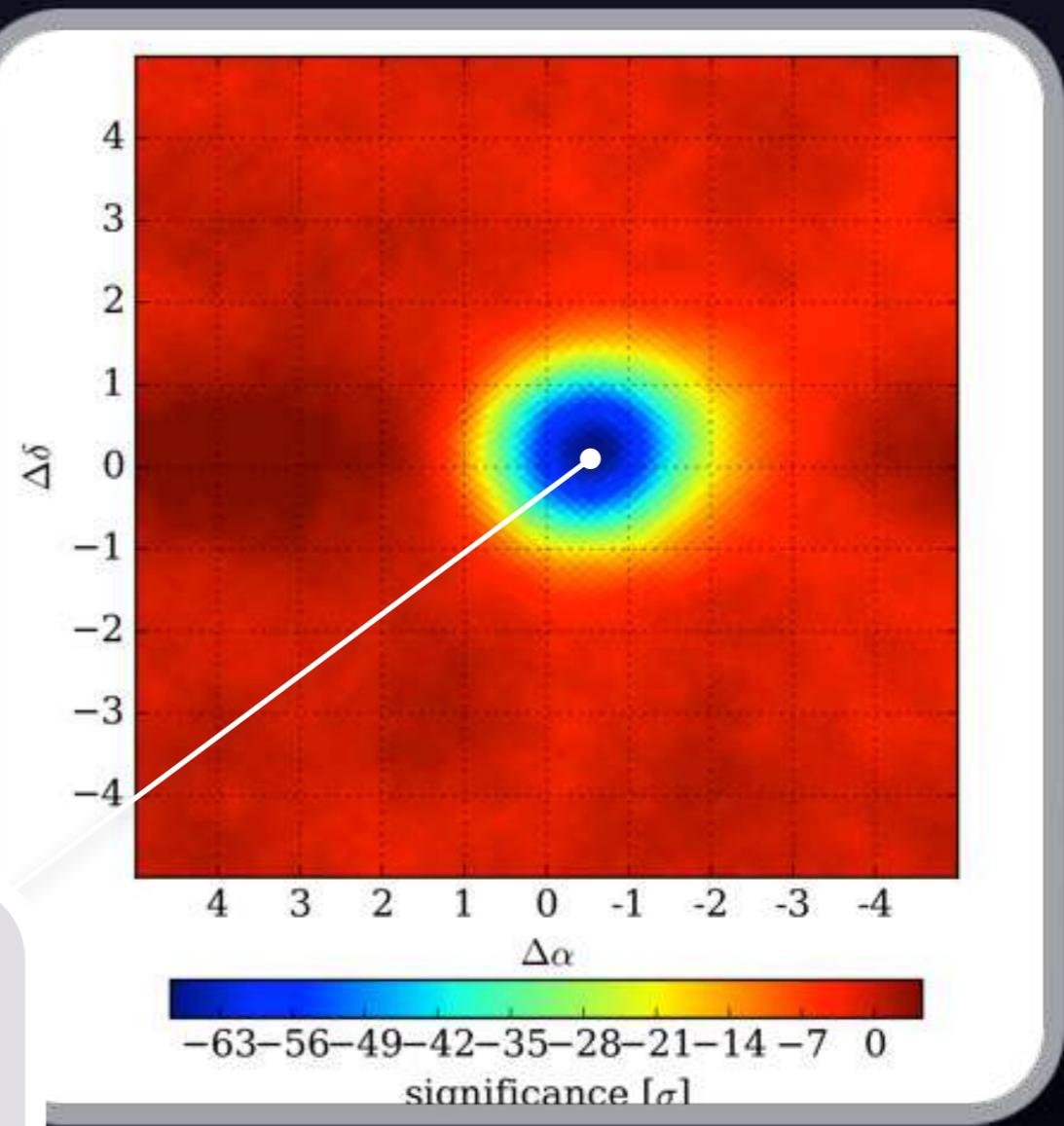


ation system

Water Cherenkov Detectors

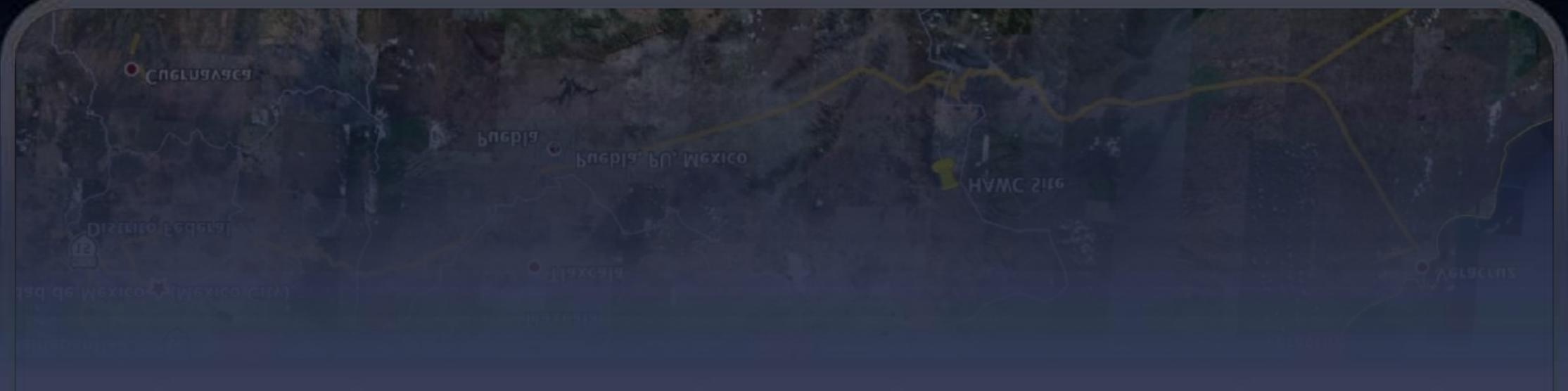
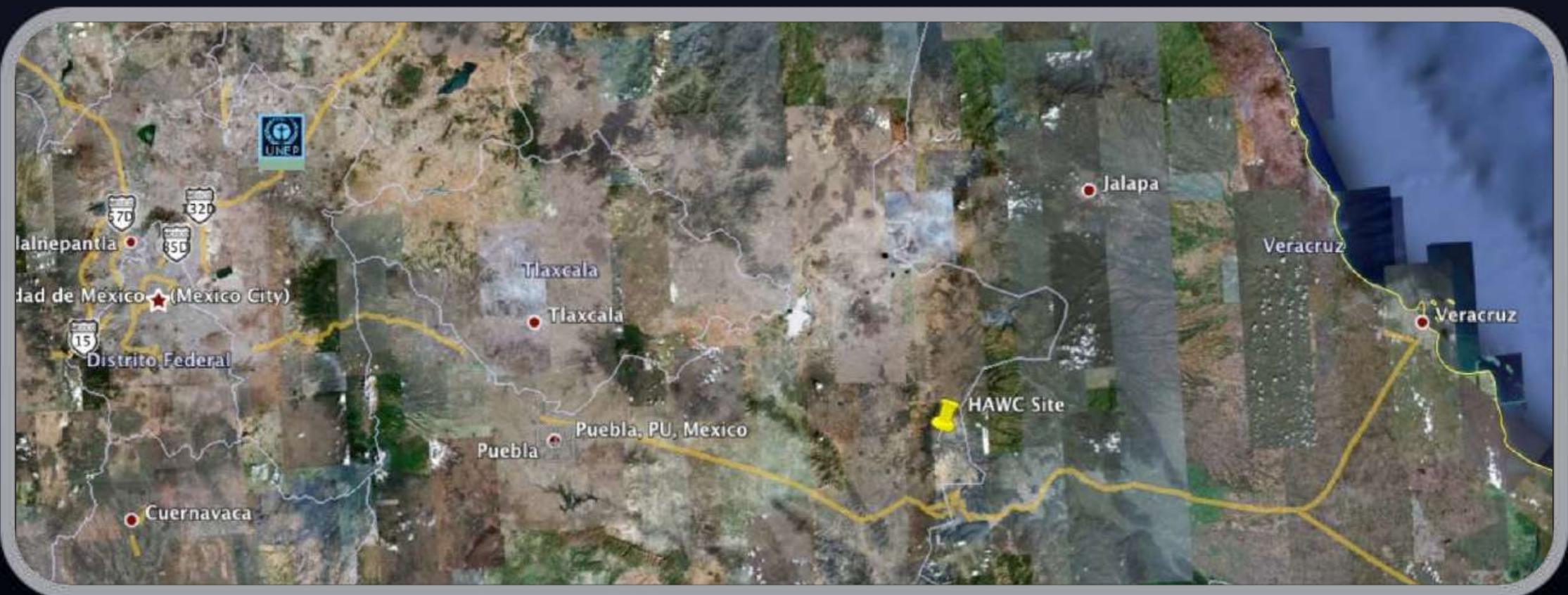
Effect of the laser calibration
on the observation of the
shadow of the Moon

- deflection matches 2 TeV median energy
- angular resolution < shadow width of 1.2°
- position verifies pointing



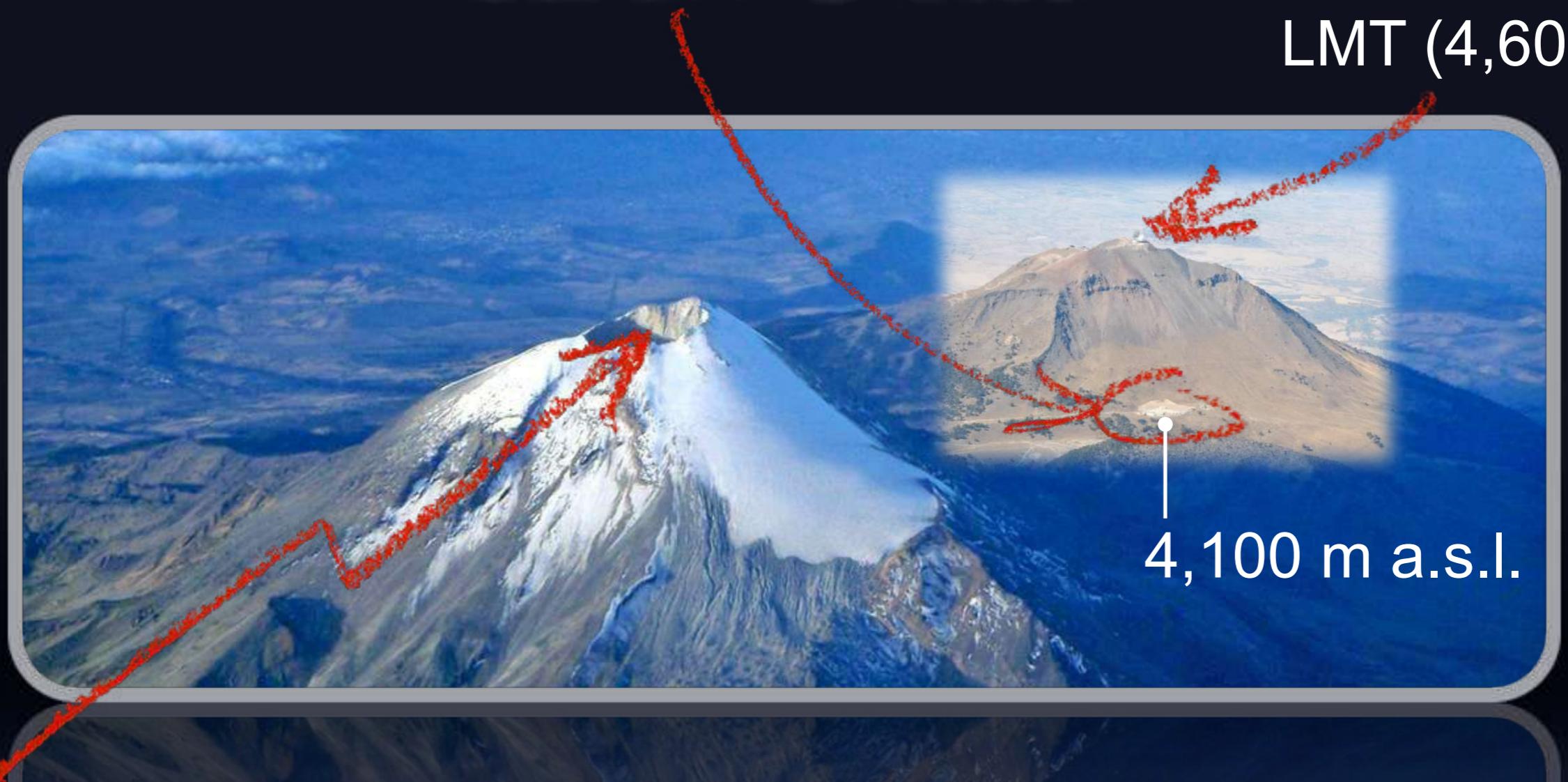
Dedicated laser calibration system

HAWC site



HAWC site

LMT (4,600 m)



Pico de Orizaba (18,500 ft)

Deployment



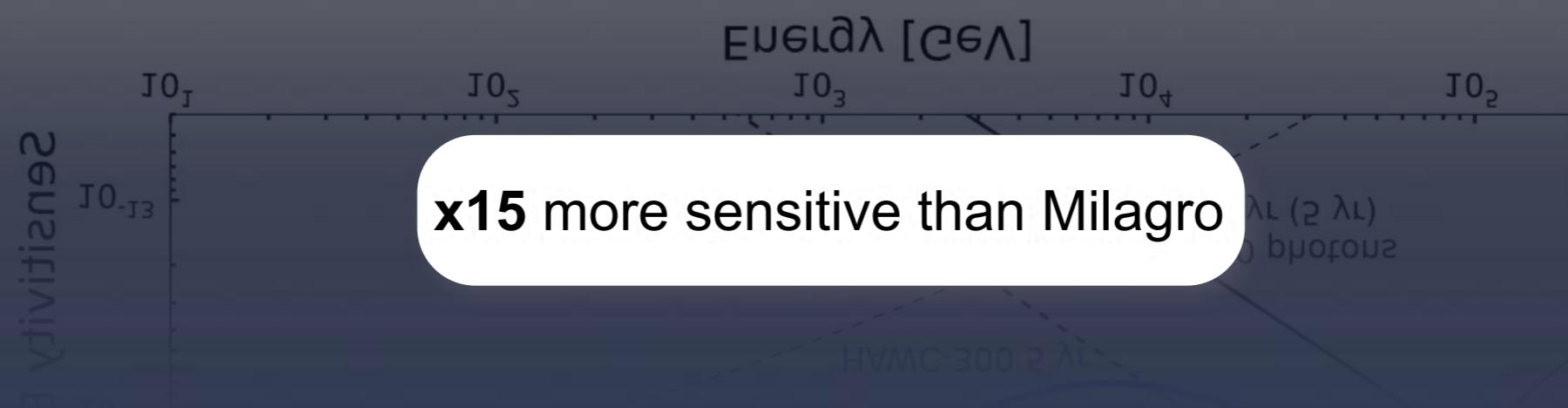
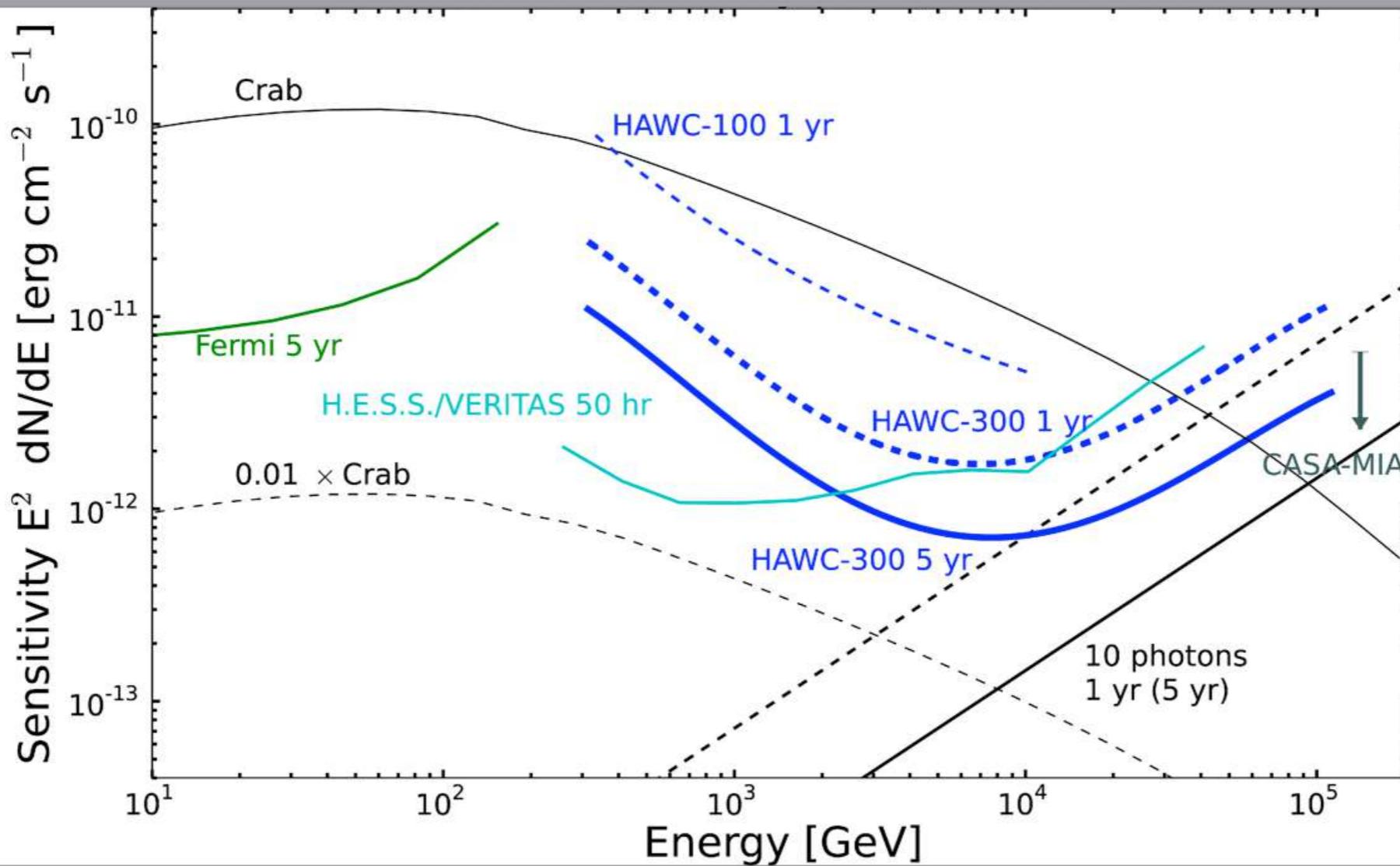
From 2011 to 2015

Deployment

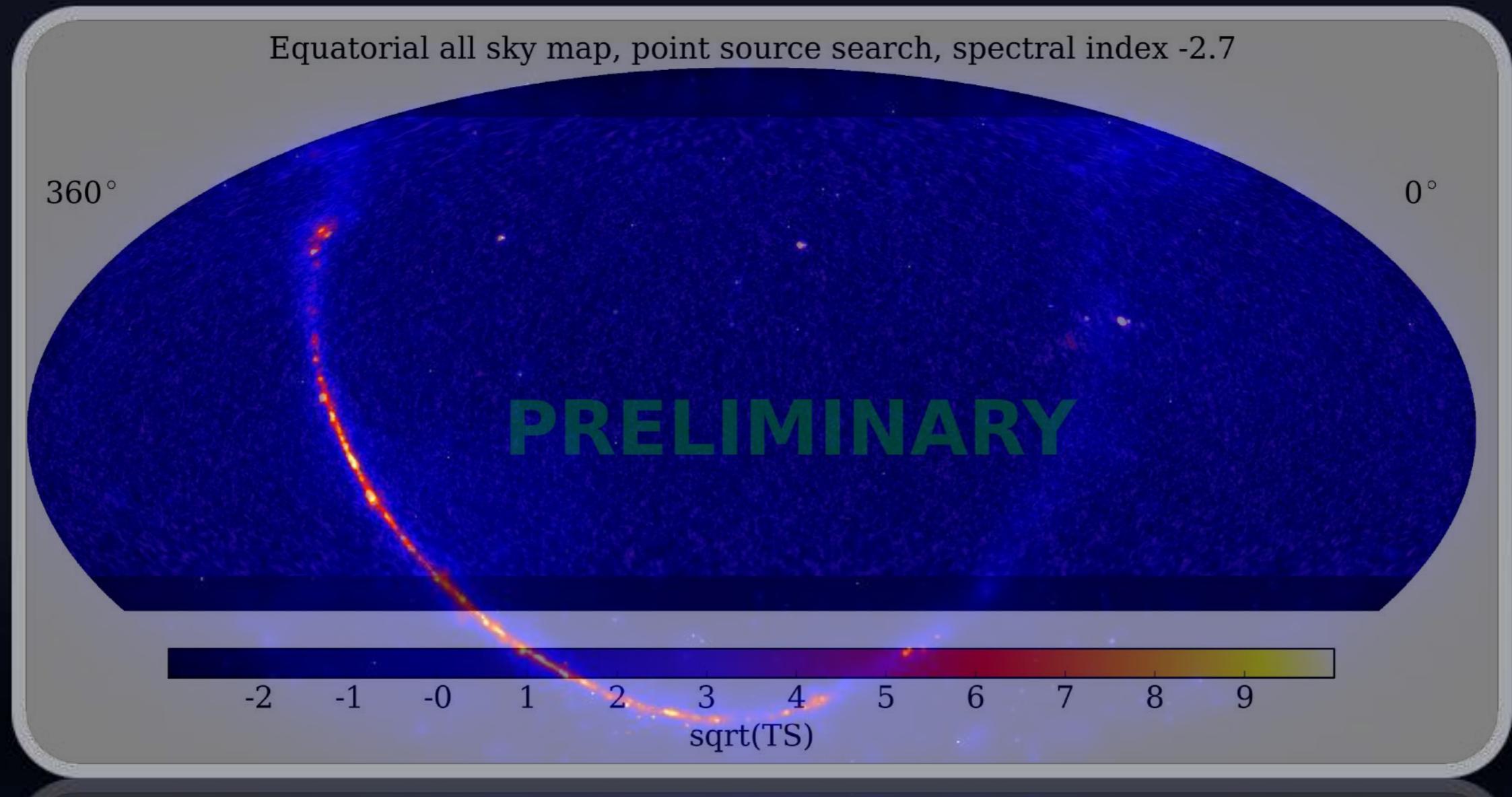


From 2011 to 2015

Design improvements



Design improvements



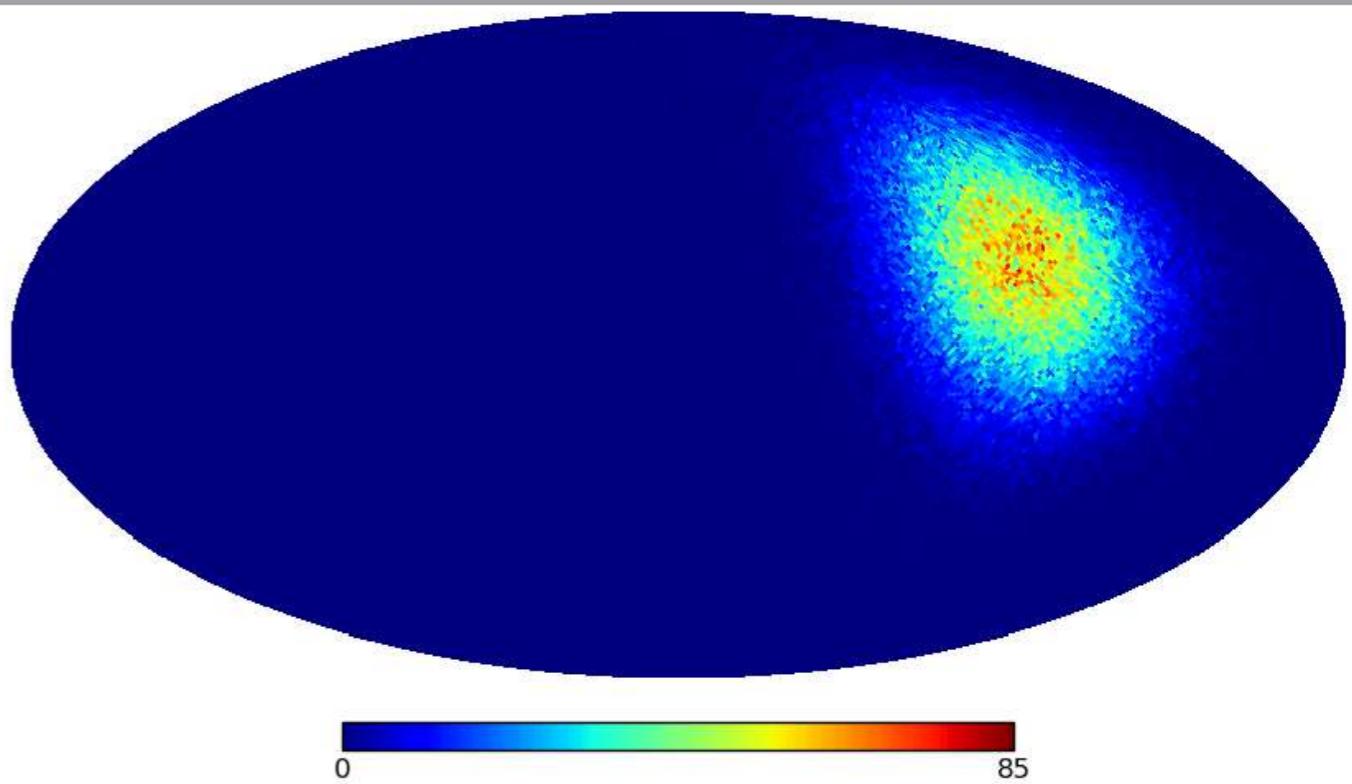
Fermi-LAT sky smoothed map
 $E > 50$ GeV (Pass 8 - 6 years of data)
(courtesy of M. Ajello)

Preliminary HAWC smoothed map
 $E > 500$ GeV (~ 1 year of data)
Full array

Take-away points

half-way point...

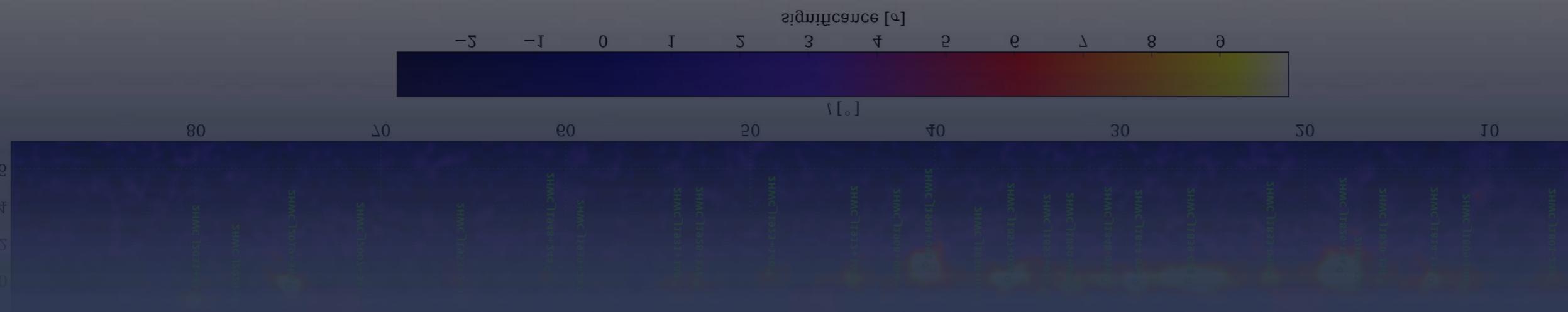
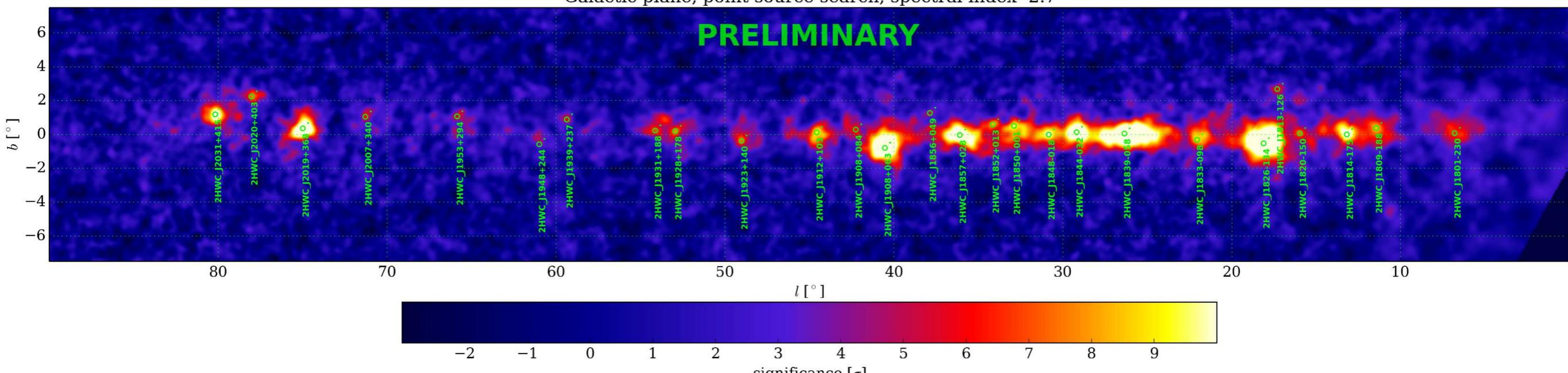
- Continuous operation
- Large instantaneous field of view



first HAWC catalog

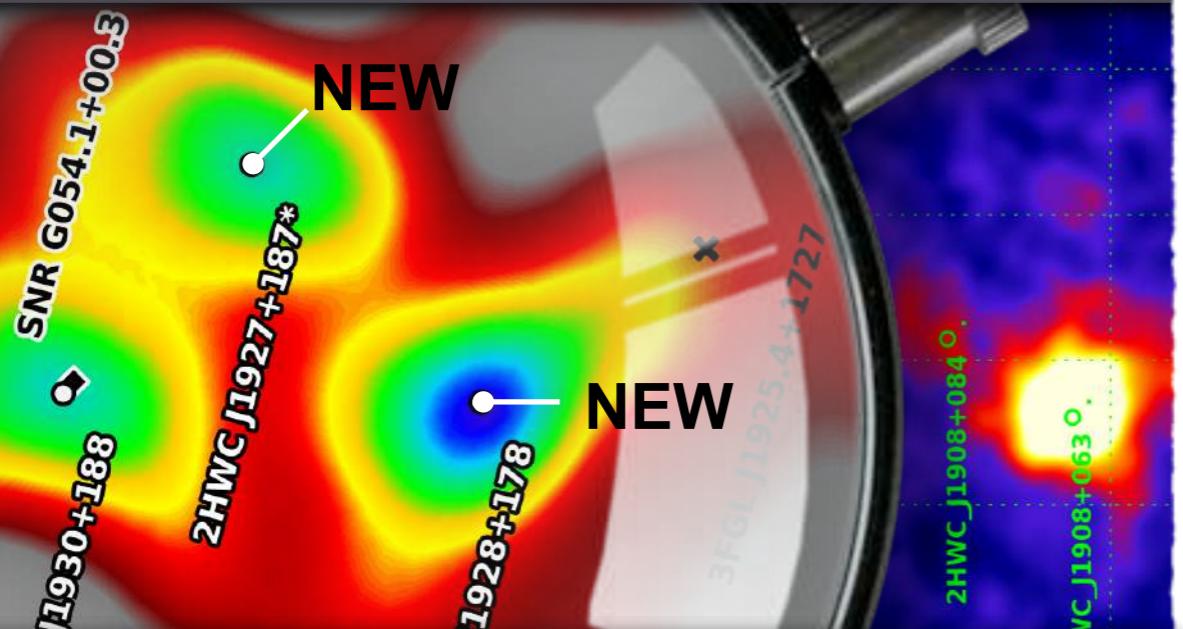
Galactic plane, point source search, spectral index -2.7

PRELIMINARY



2HWC J1930+188

- coincident with VER J1930+188
- SNR G54.1+00.3 — PSR J1930+1852
- TeV emission was reported to be point-like and likely from PWN
- nearby molecular CO cloud



2HWC J1928+178

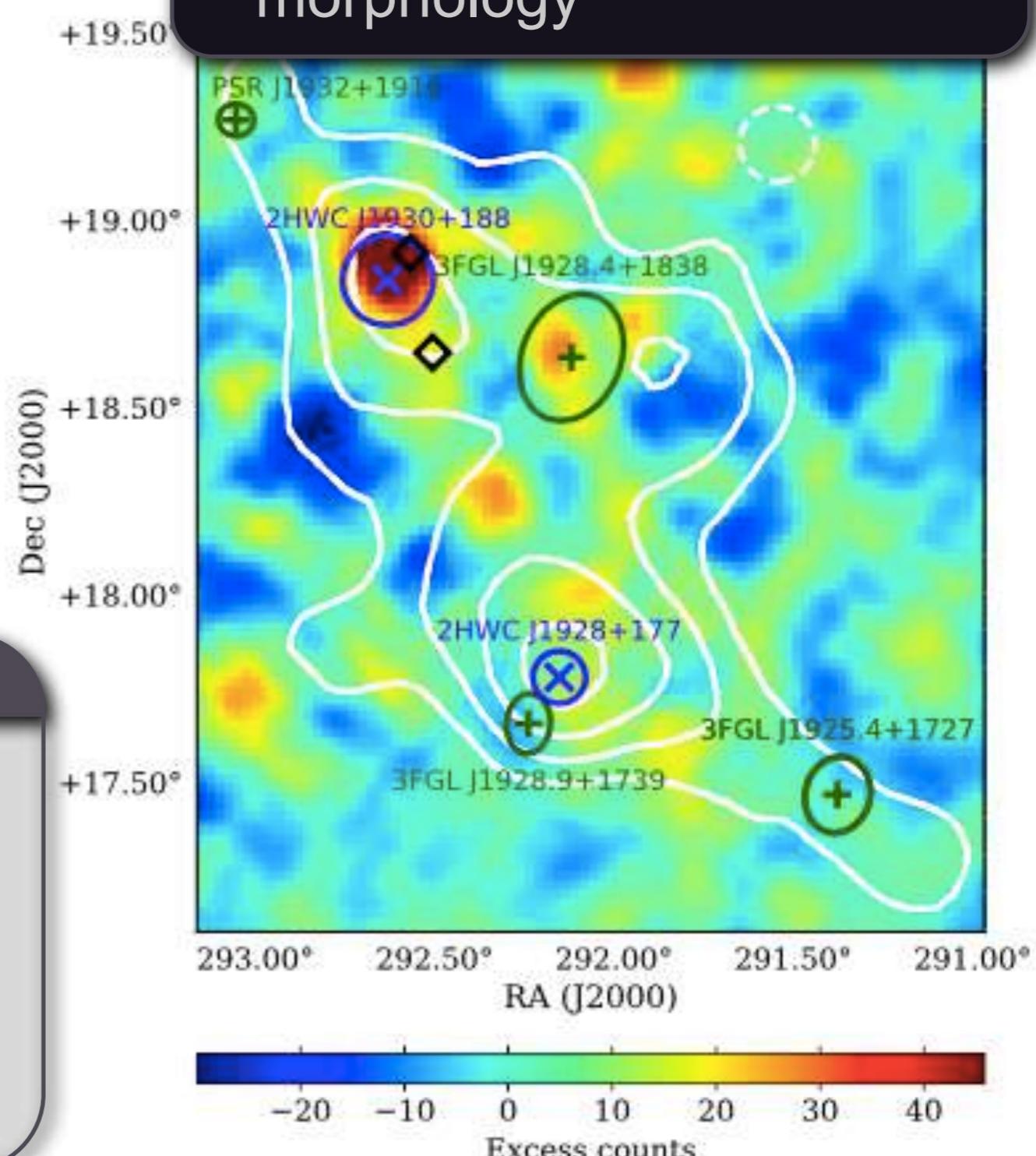
- coincident with PSR J1928+1746
- tail towards unidentified source

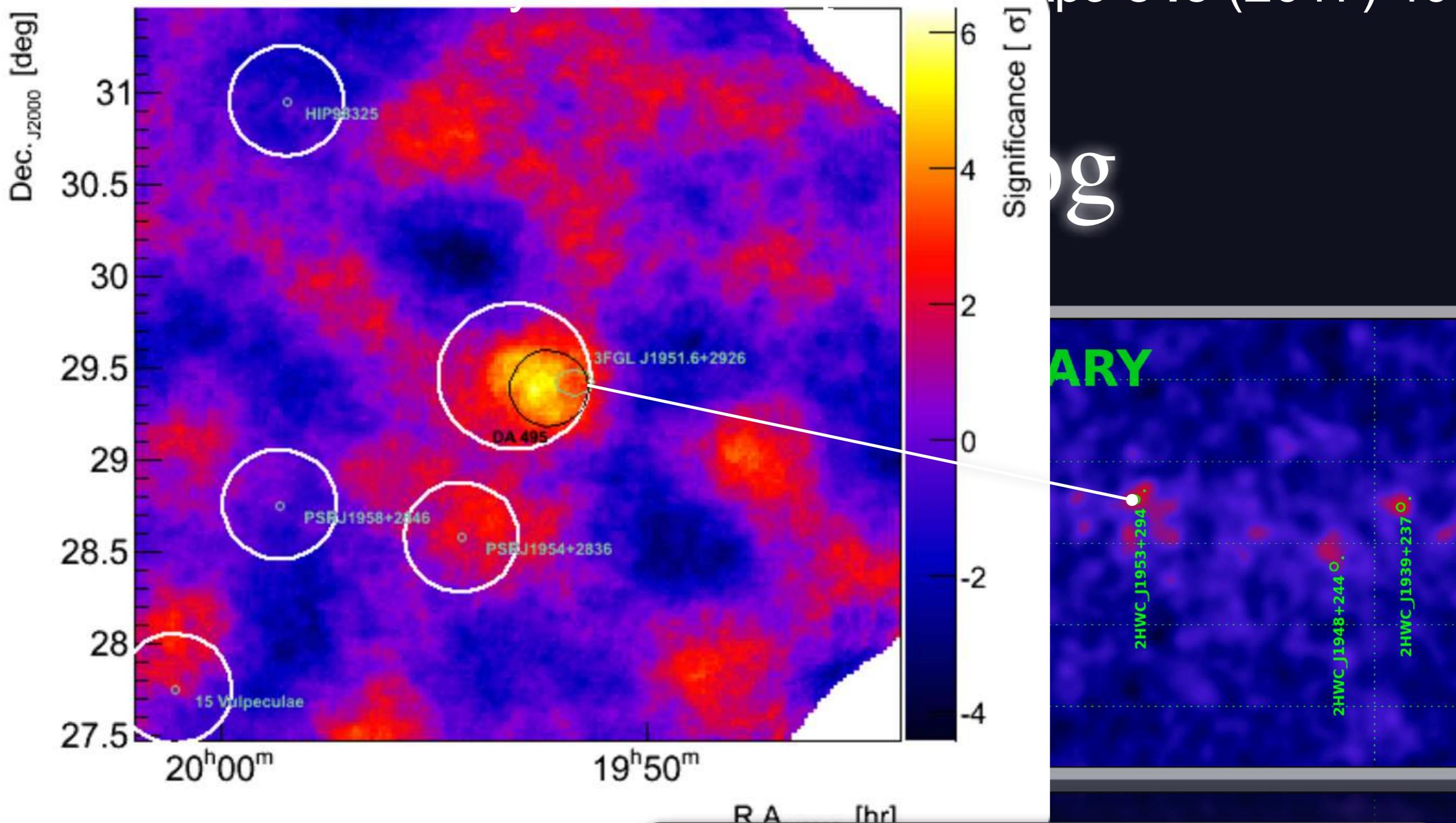
3FGL J1925.4+1727

- VERITAS pt-src upper limit ~1.4% of Crab

2HWC J1927+187*

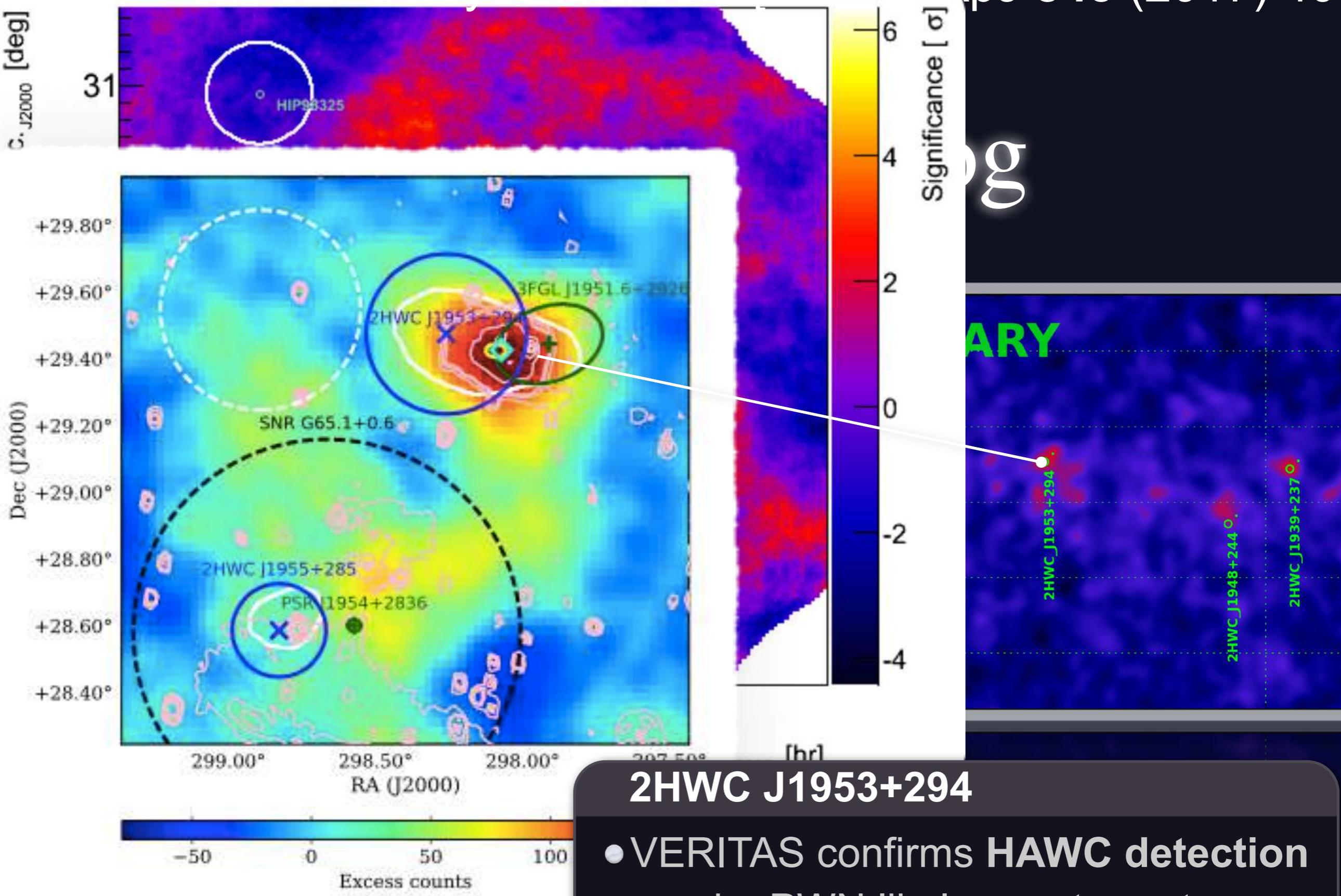
- associated with 2HWC J1930+188?
- ongoing analysis on spatial morphology

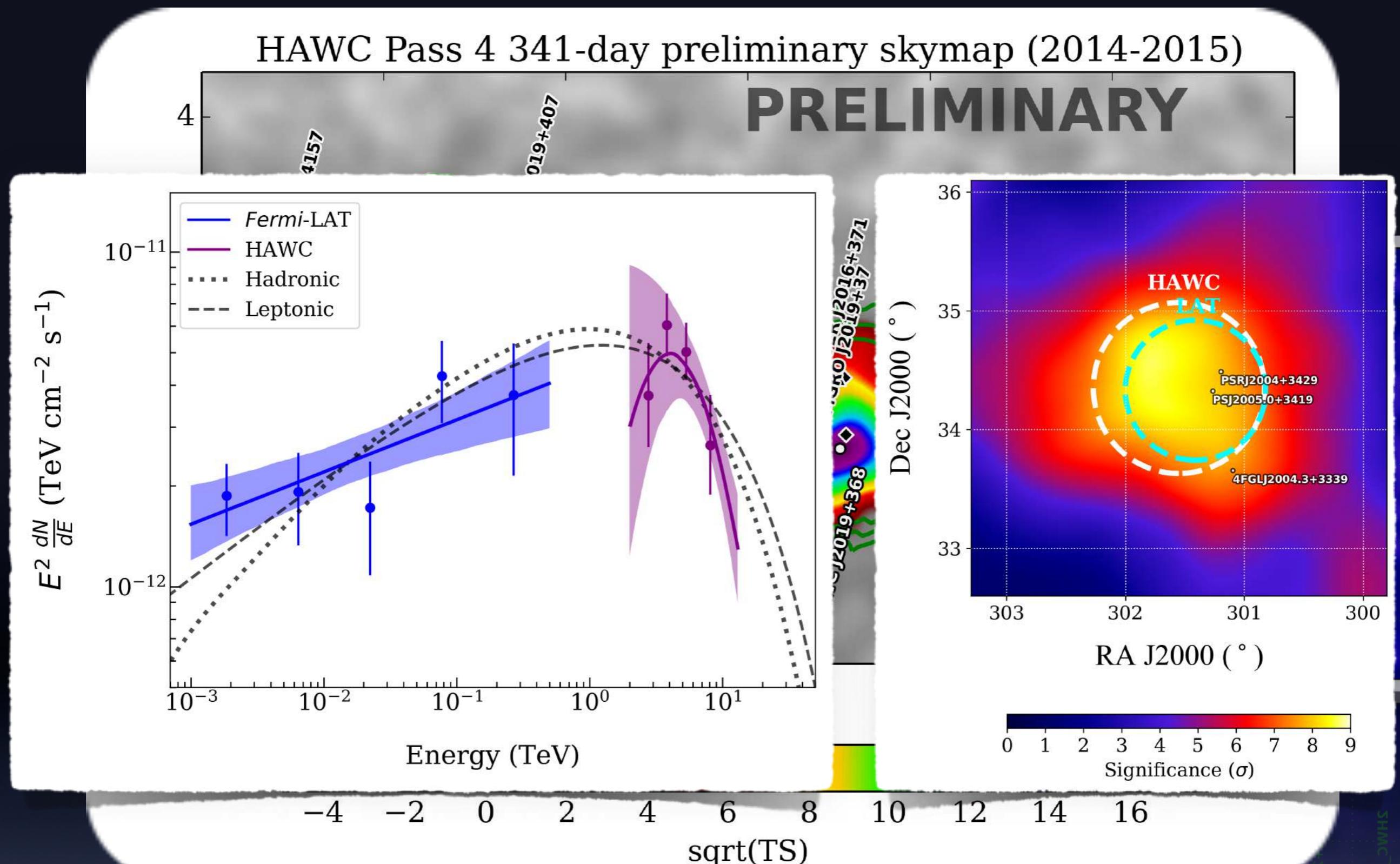




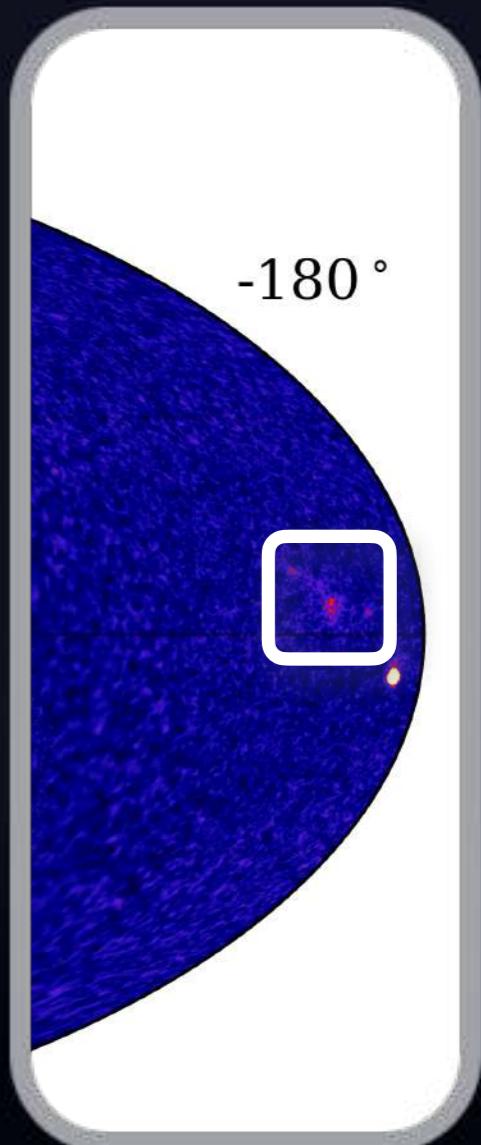
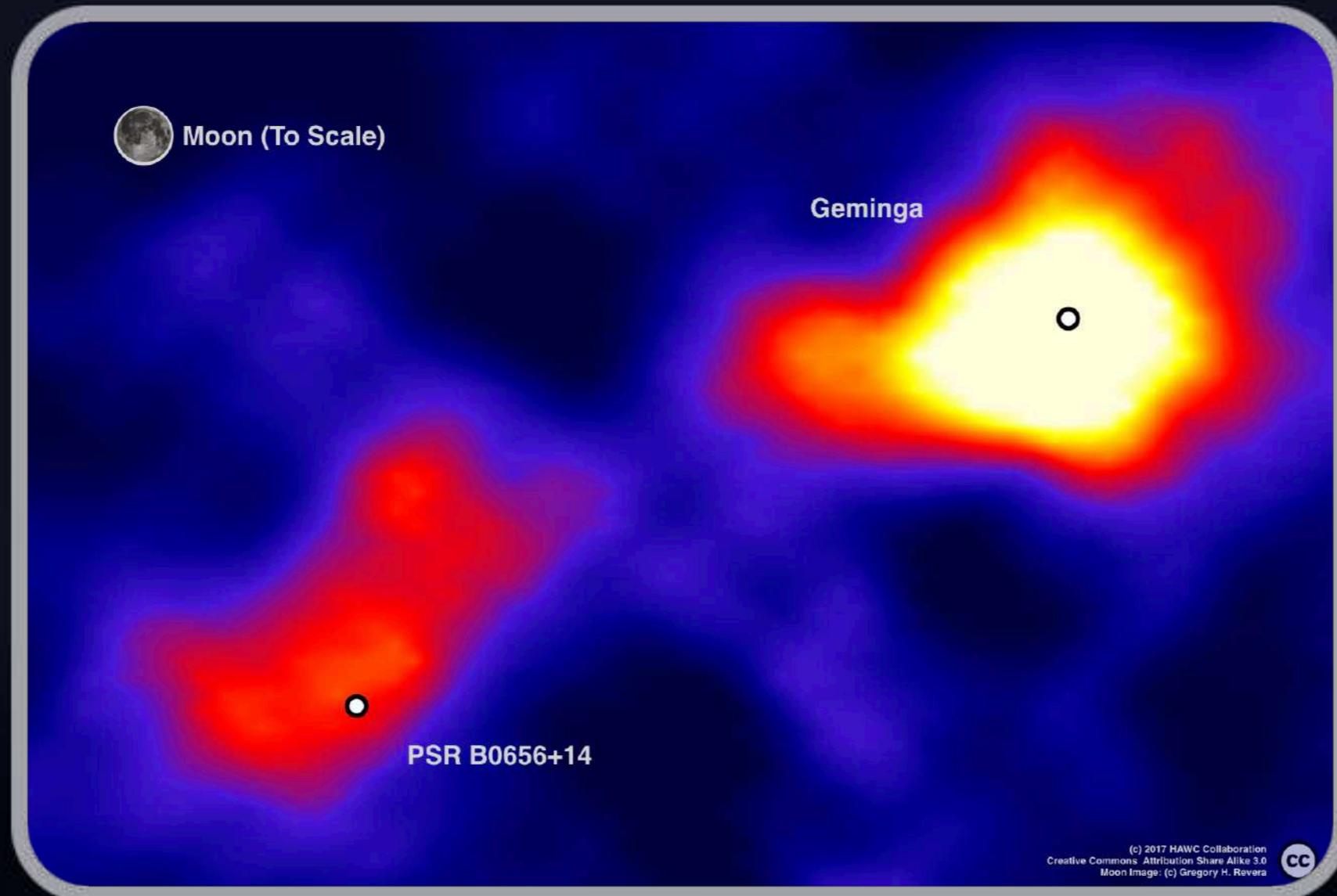
2HWC J1953+294

- VERITAS confirms HAWC detection
- nearby PWN likely counterpart



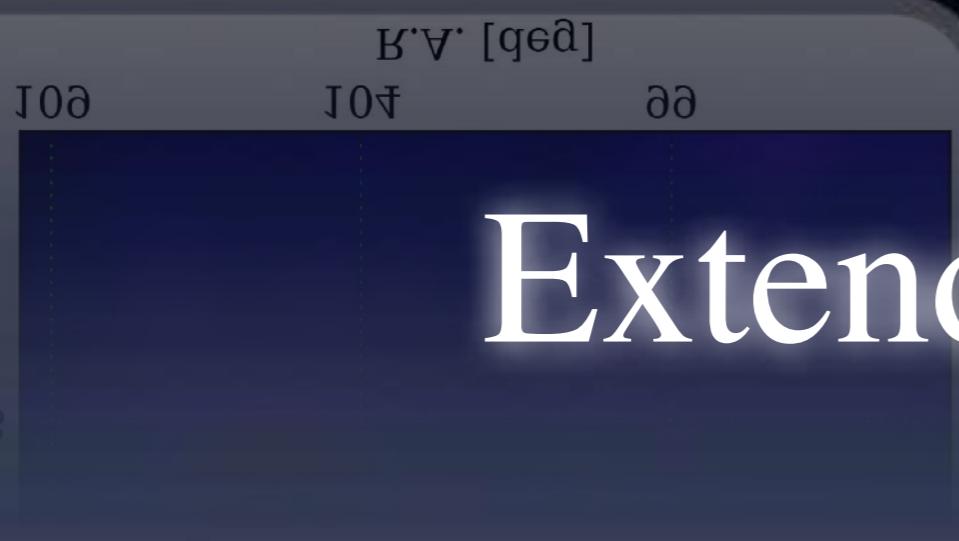
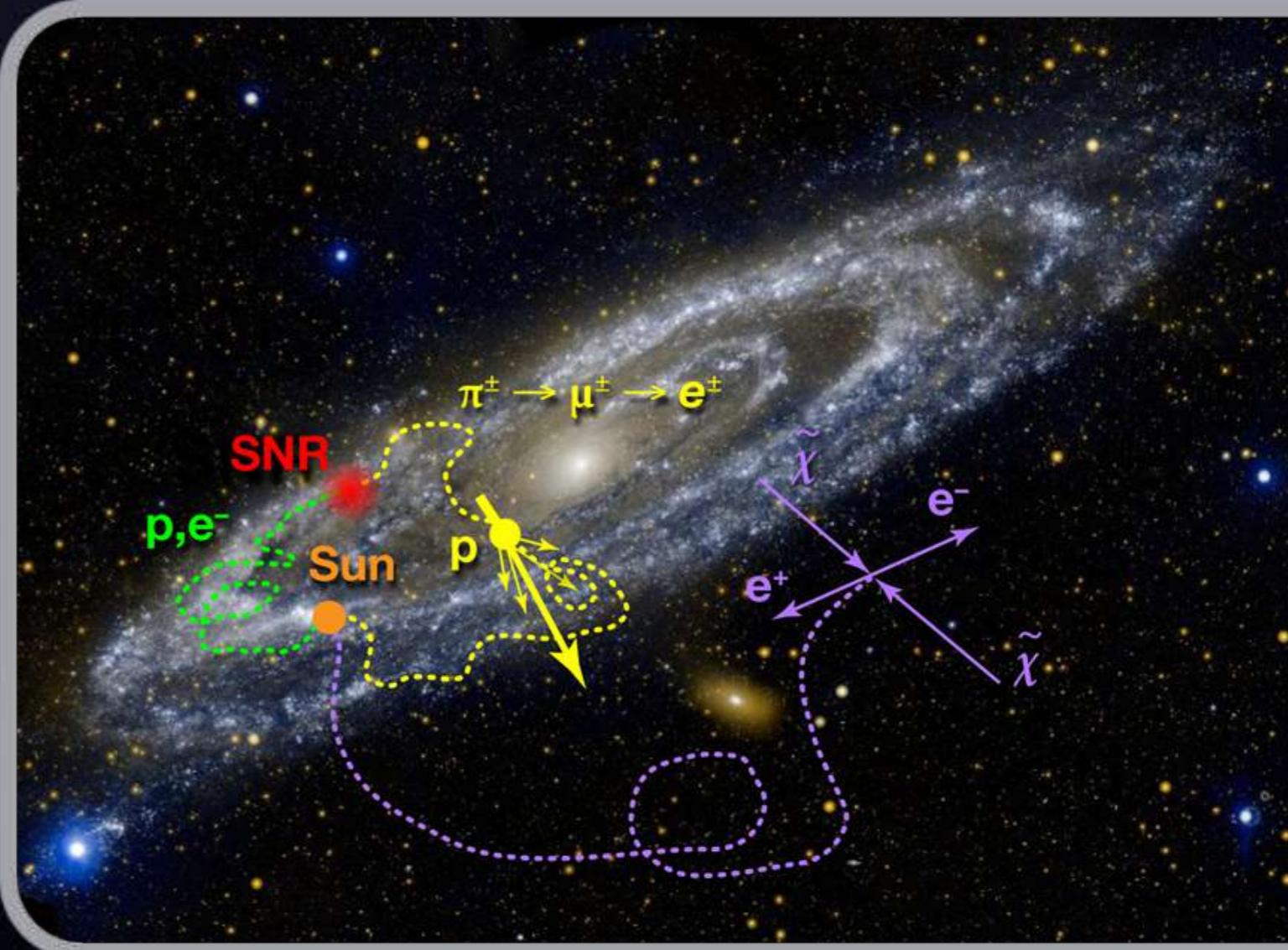
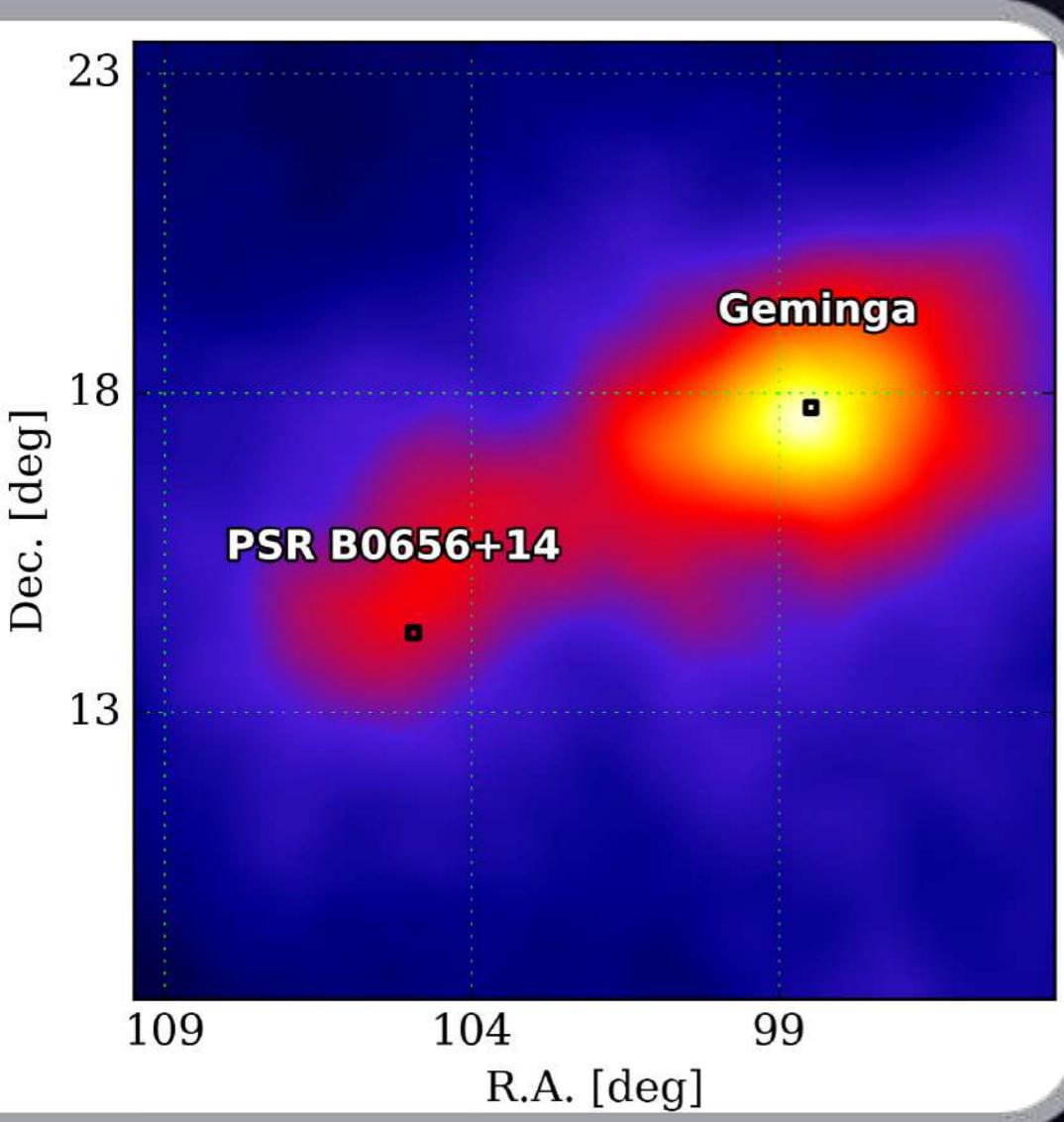


Geminga

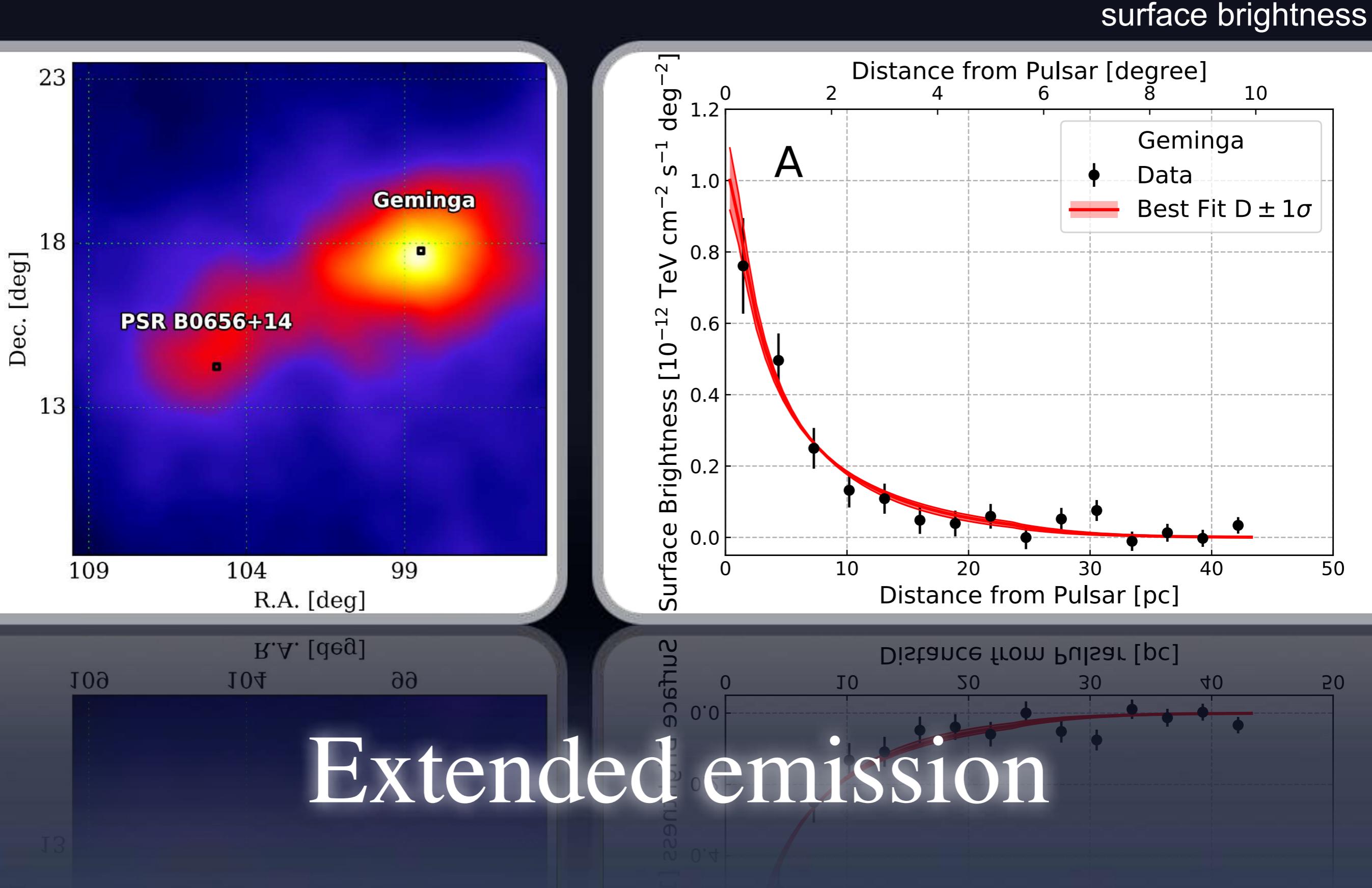


Multi-TeV sky

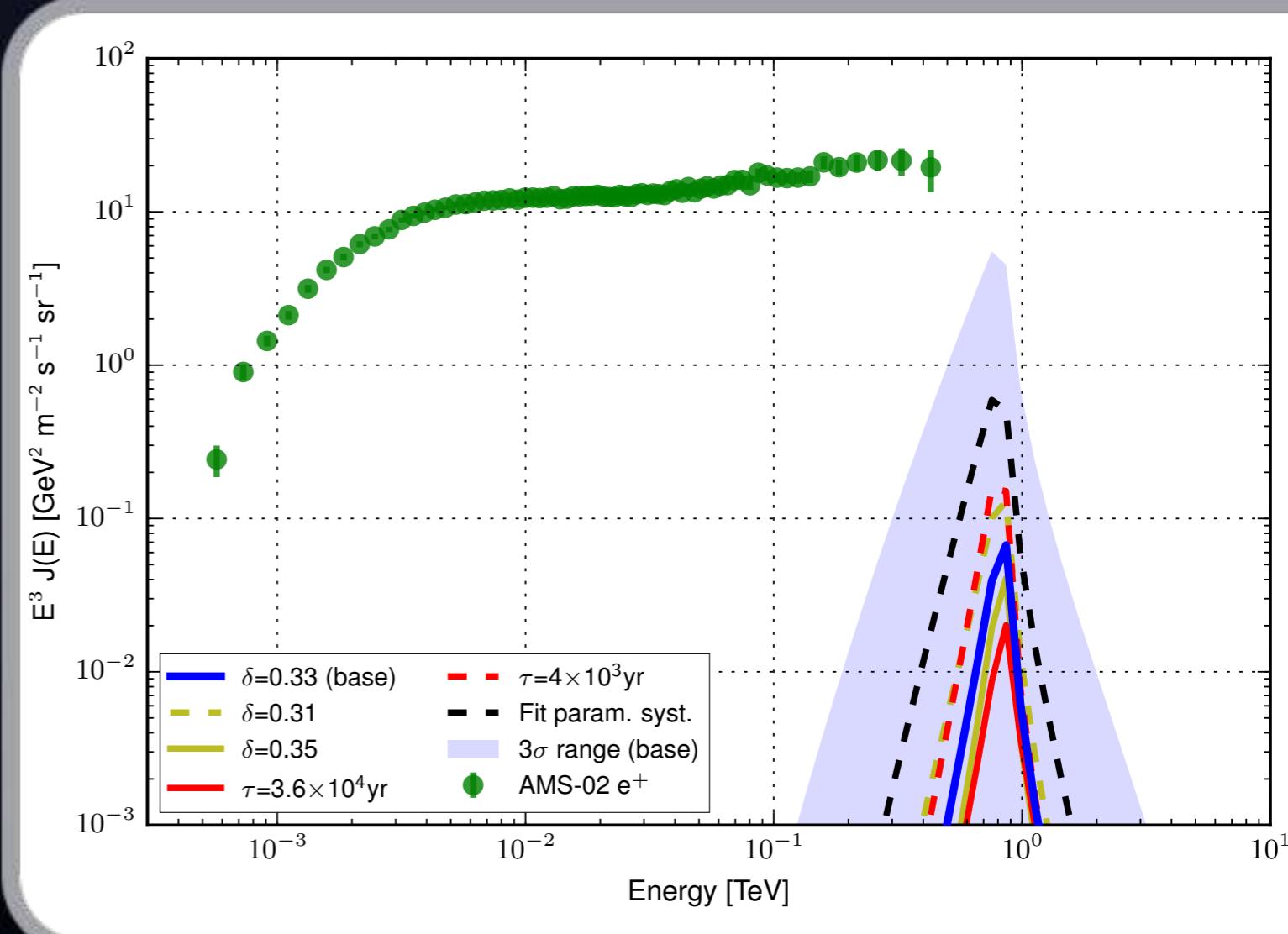
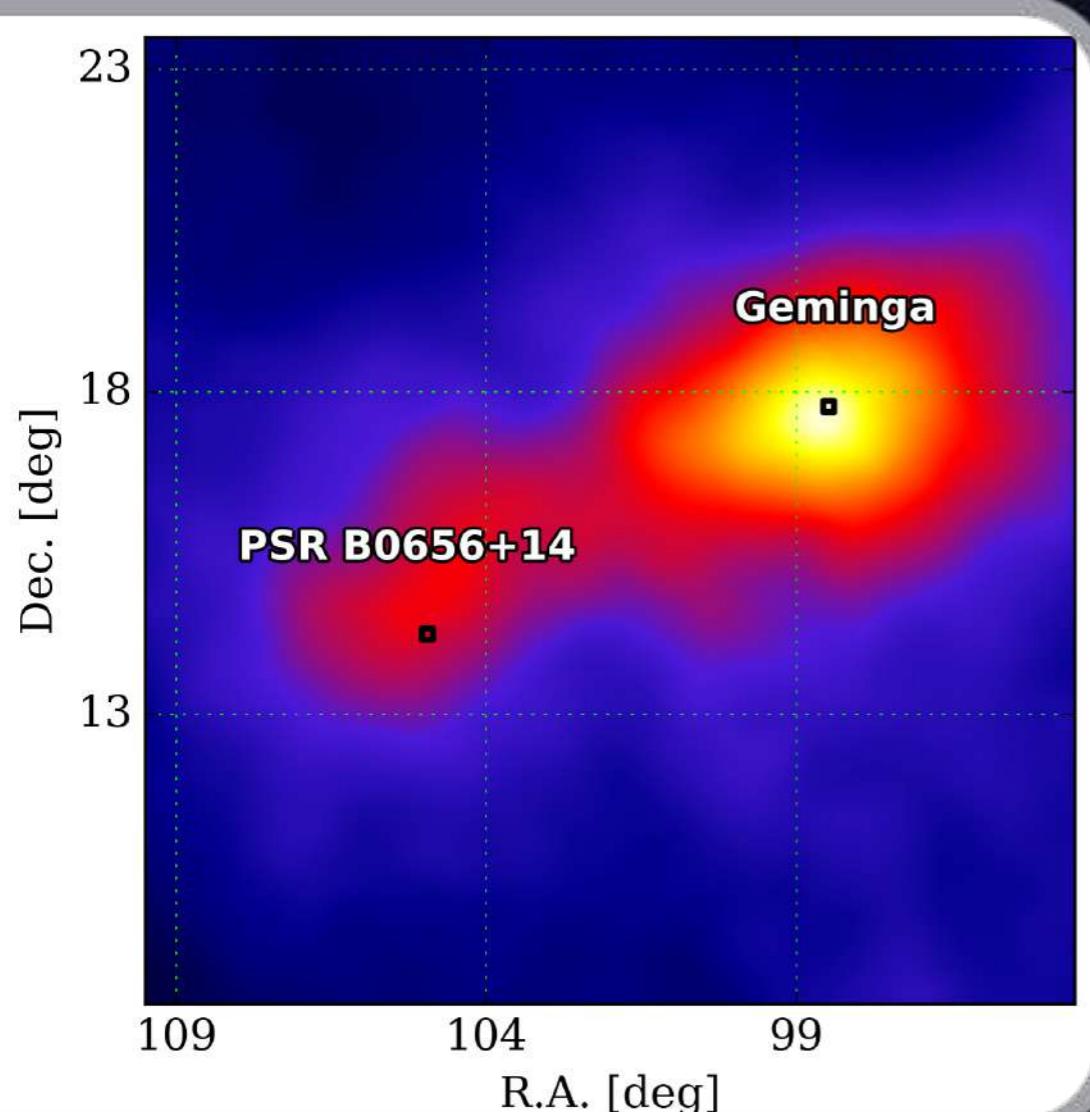
Positron excess from nearby pulsars?



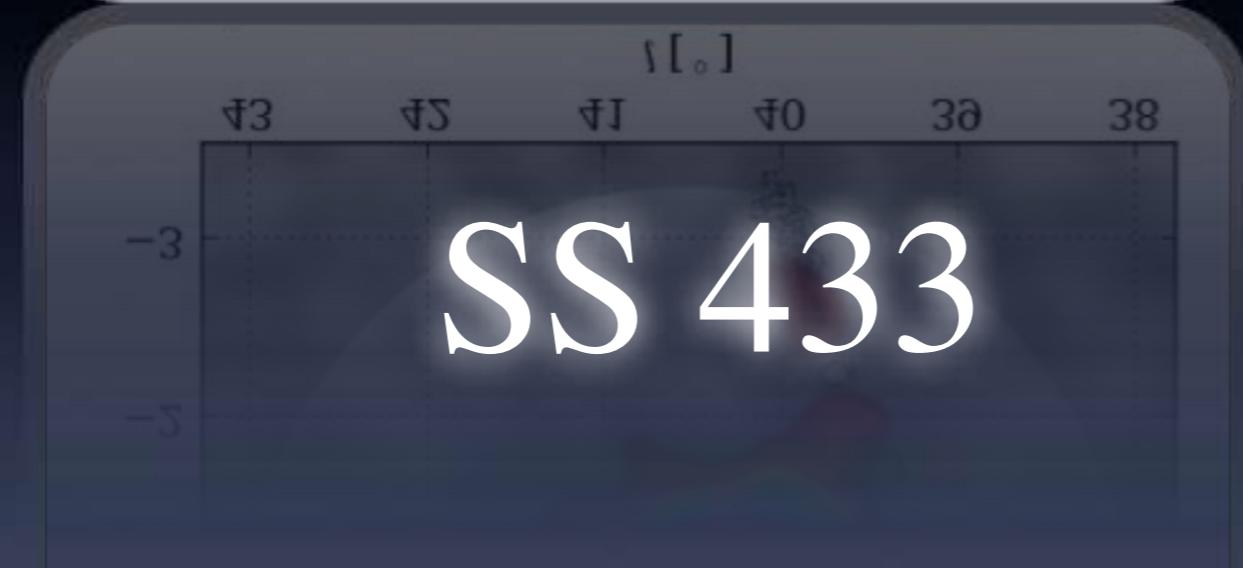
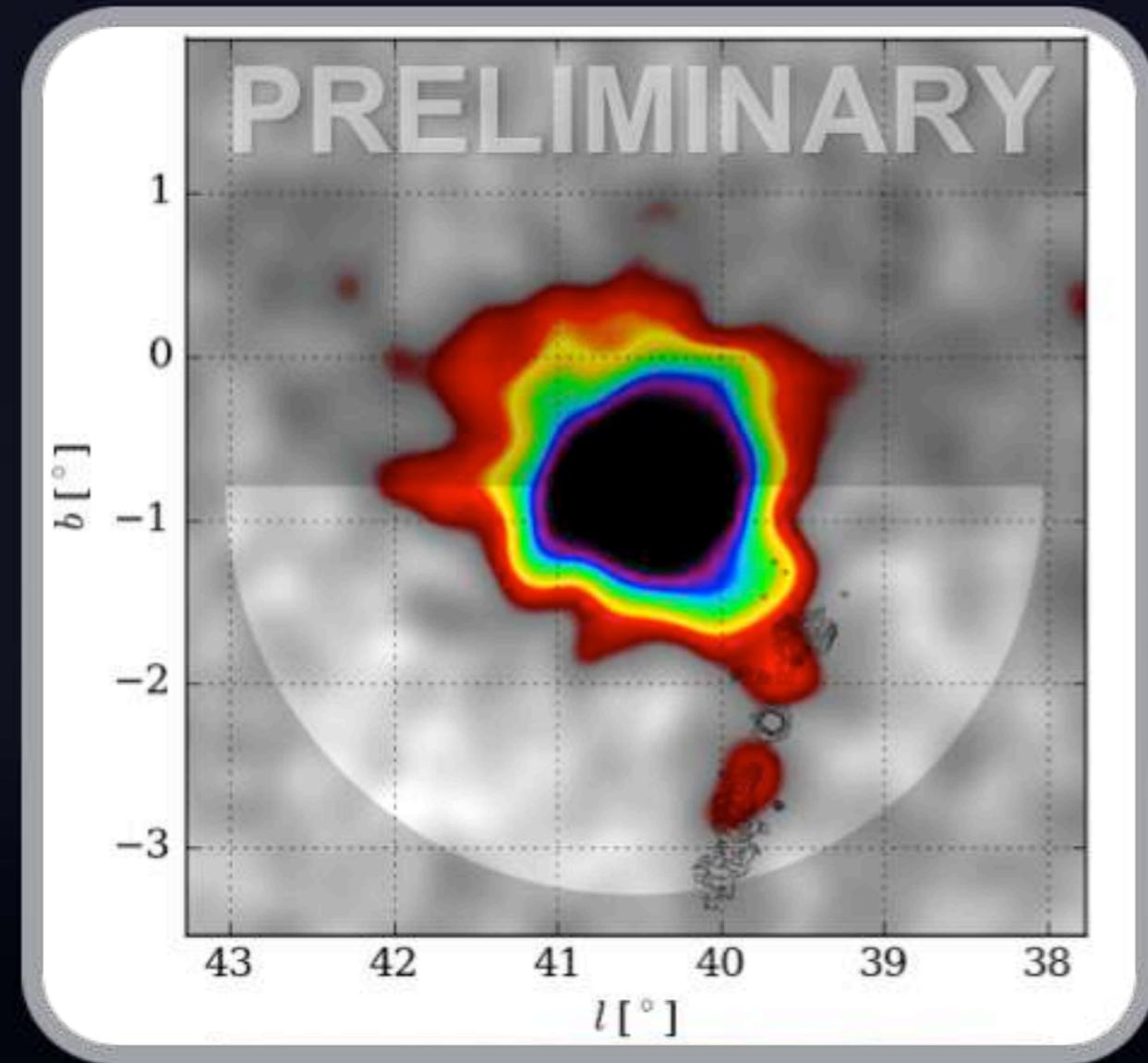
Extended emission



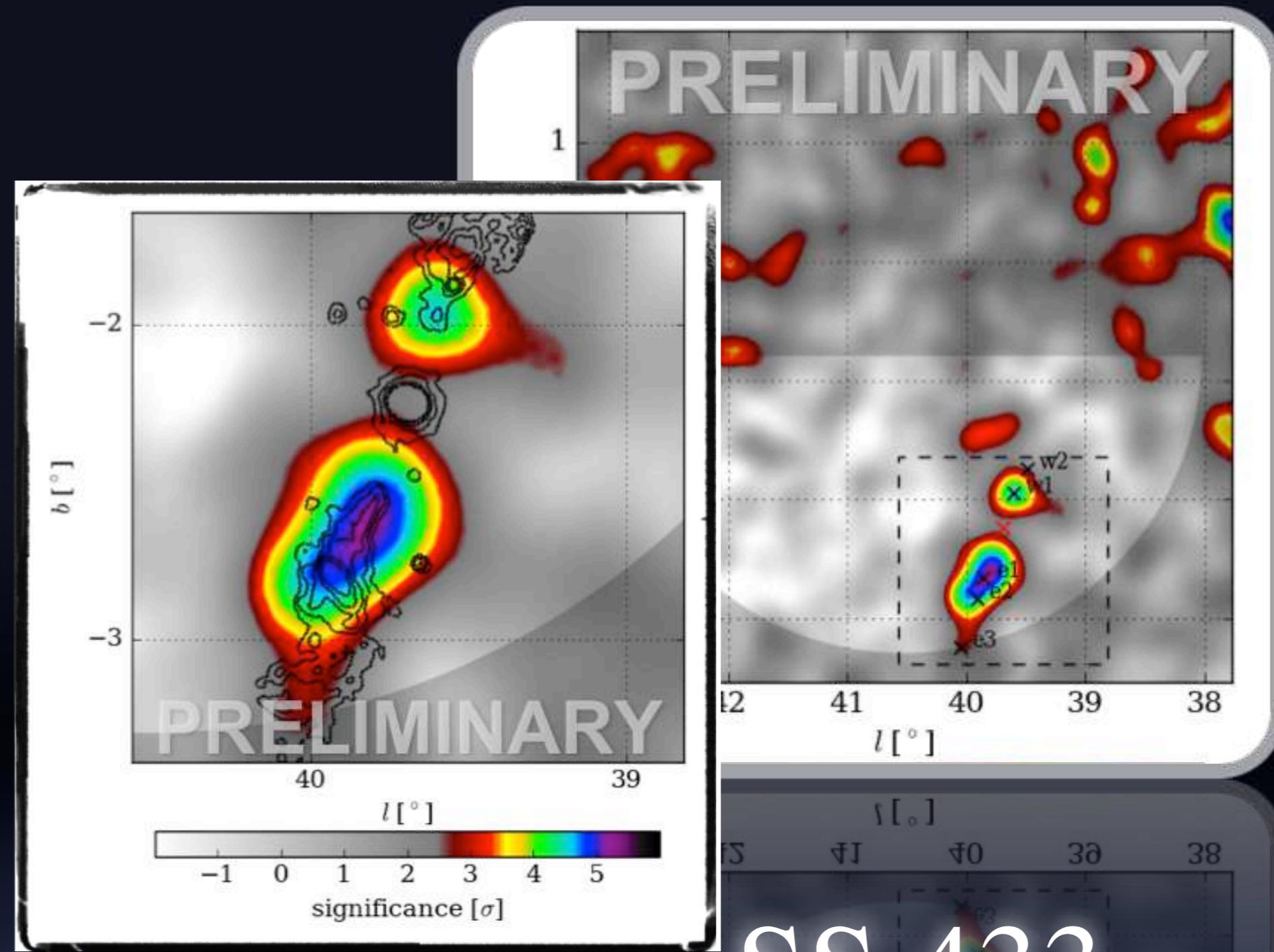
Estimated positron energy flux at Earth



VHE emission from the jets of a microquasar

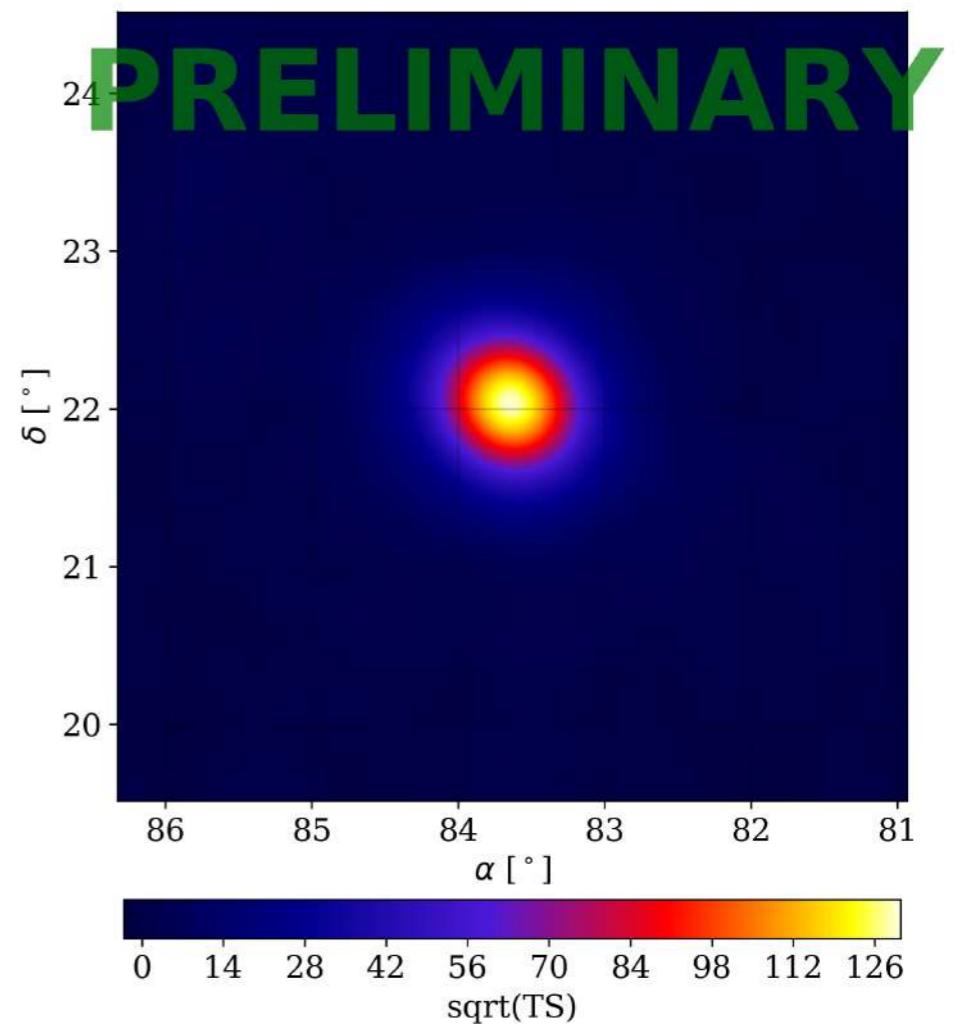
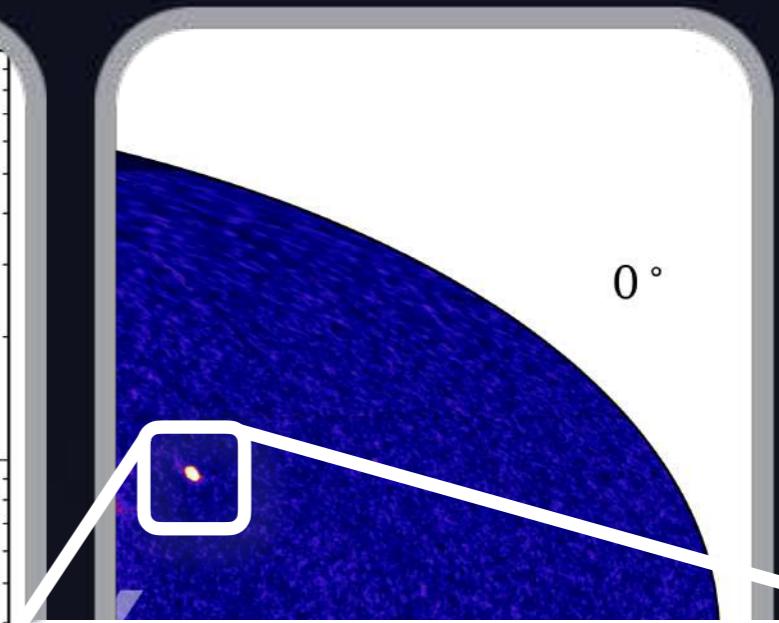
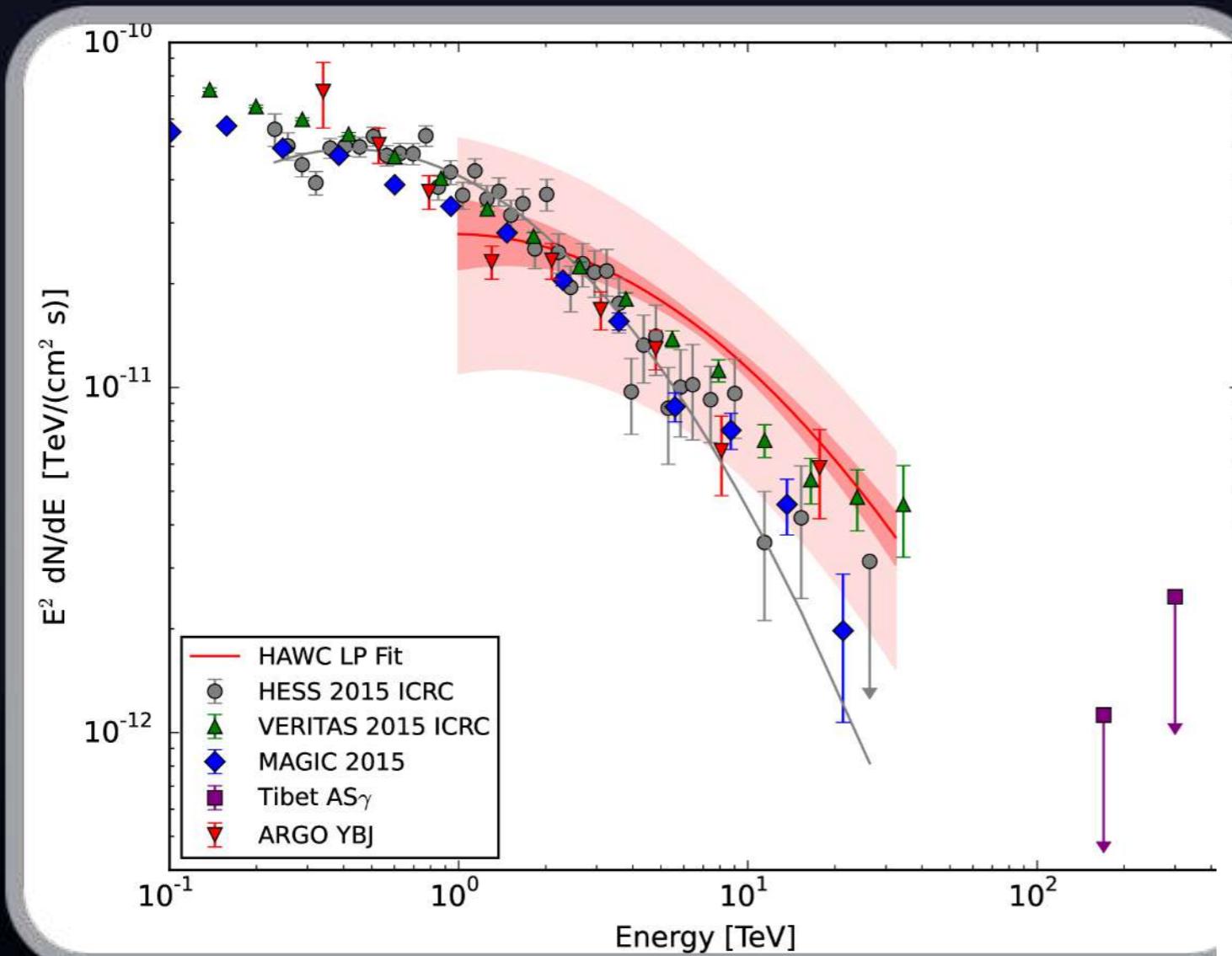


VHE emission from the jets of a microquasar

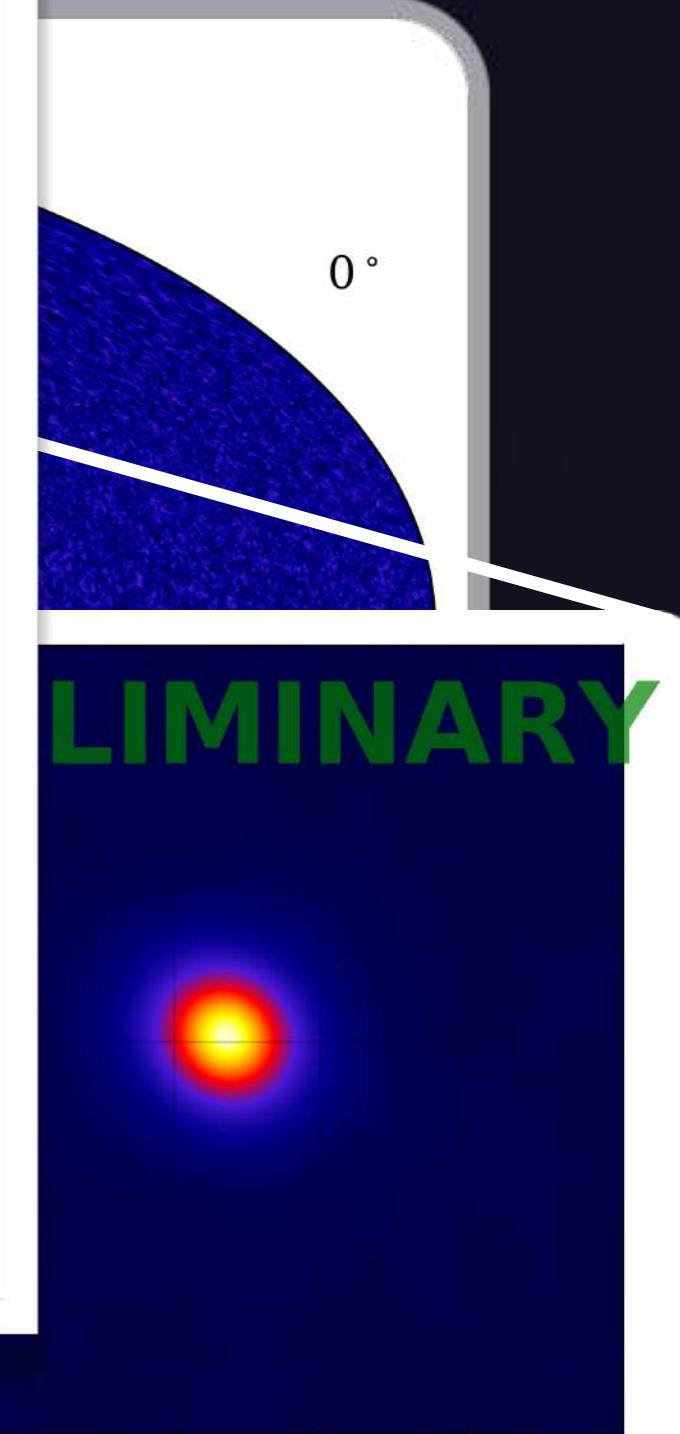
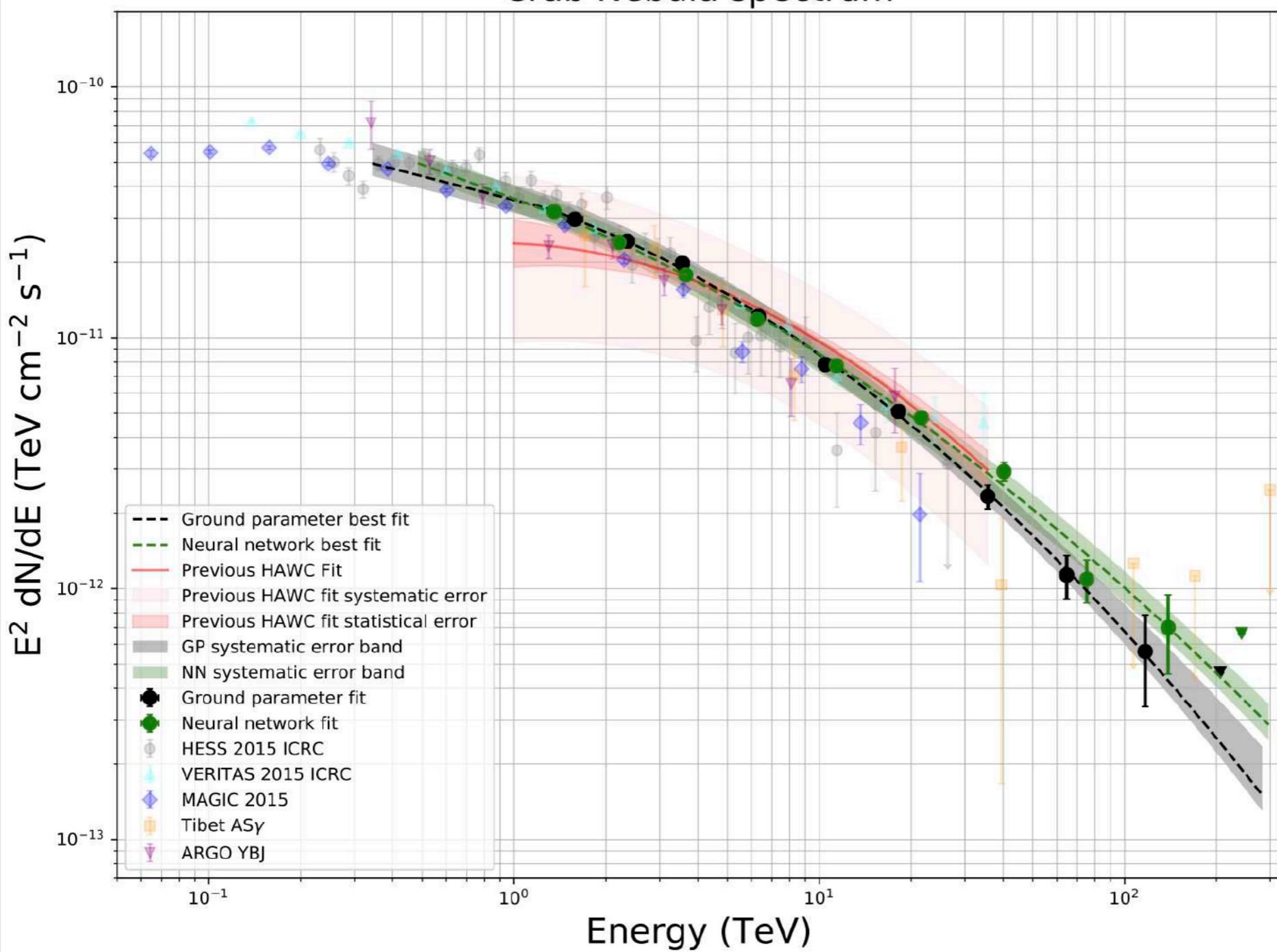


SS 433

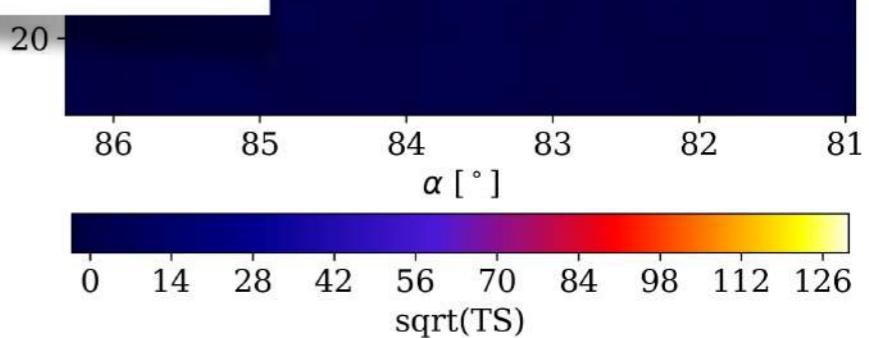
The Crab



Crab Nebula spectrum



Multi-TeV



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Multiple Galactic Sources with Emission Above 56 TeV Detected by HAWC, a.k.a. Kelly's thesis

A. U. Abeysekara *et al.* (HAWC Collaboration)
Phys. Rev. Lett. **124**, 021102 – Published 15 January 2020



Physics See Synopsis: [A Catalog of High-Energy Gamma-Ray Sources](#)

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ABSTRACT

We present the first catalog of gamma-ray sources emitting above 56 and 100 TeV with data from the High Altitude Water Cherenkov Observatory, a wide field-of-view observatory capable of detecting gamma rays up to a few hundred TeV. Nine sources are observed above 56 TeV, all of which are likely galactic in origin. Three sources continue emitting past 100 TeV, making this the highest-energy gamma-ray source catalog to date. We report the integral flux of each of these objects. We also report spectra for three highest-energy sources and discuss the possibility that they are PeVatrons.



Issue

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DOI: <https://doi.org/10.1103/PhysRevLett.124.021102>



PHYSICAL
REVIEW
LETTERS

γ -ray sky above 56 TeV

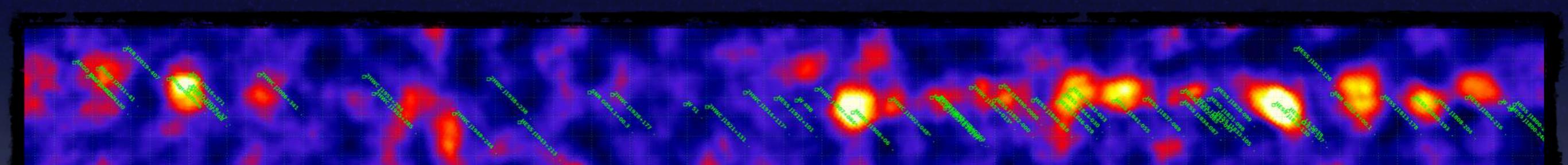
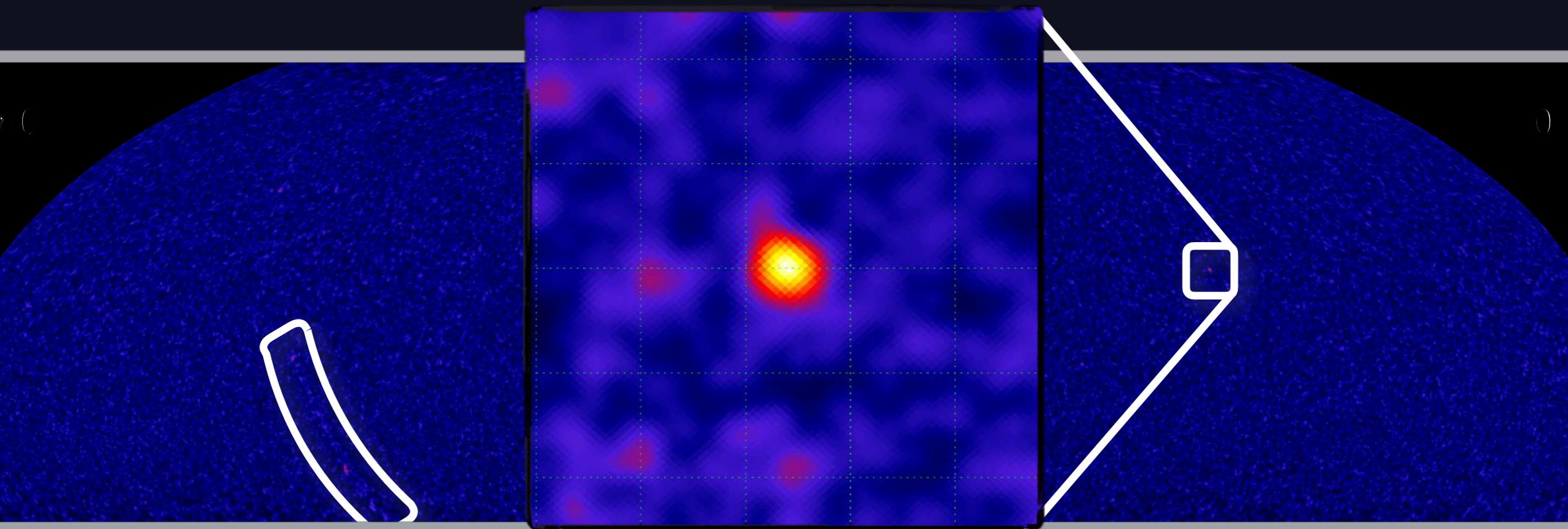
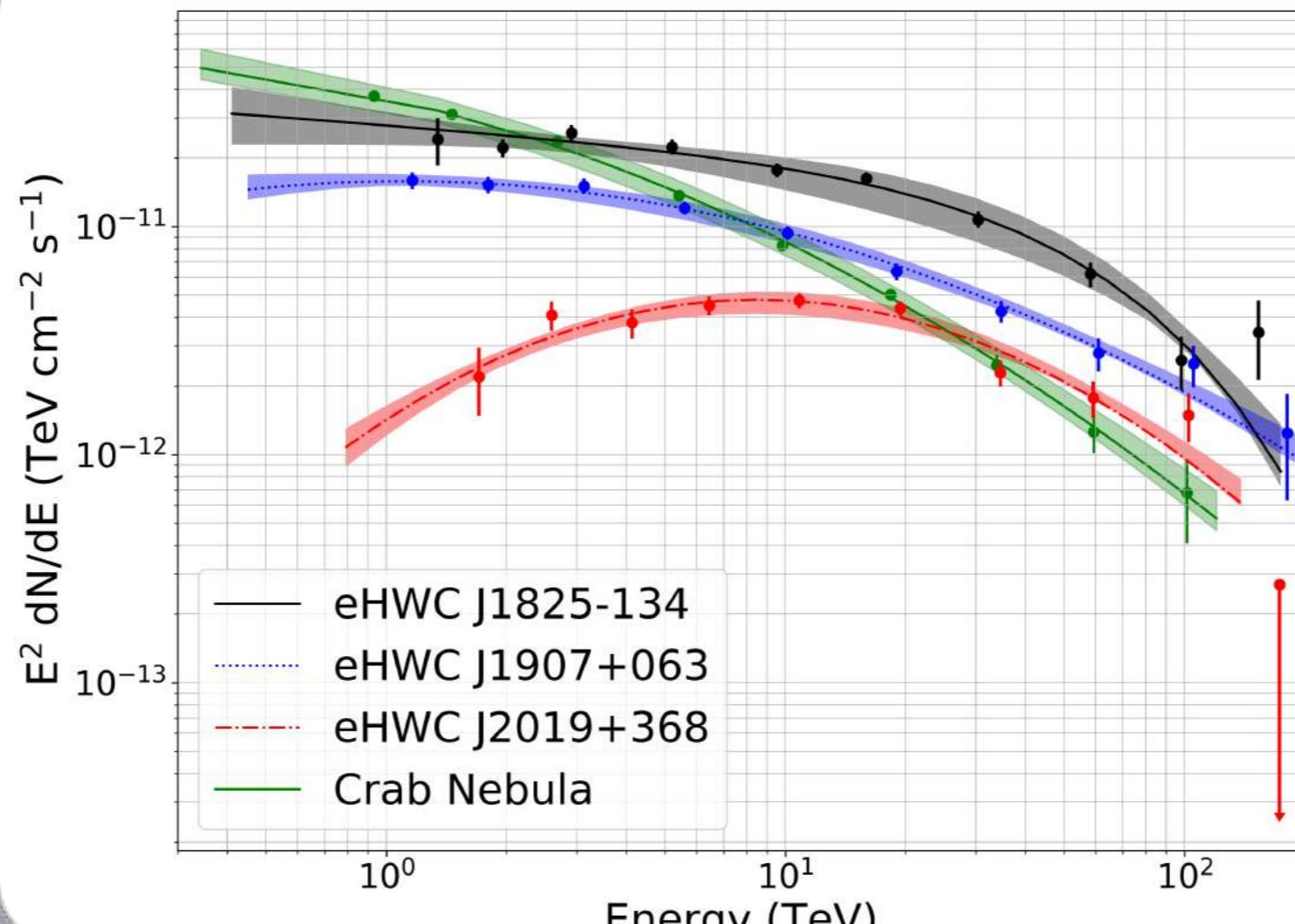
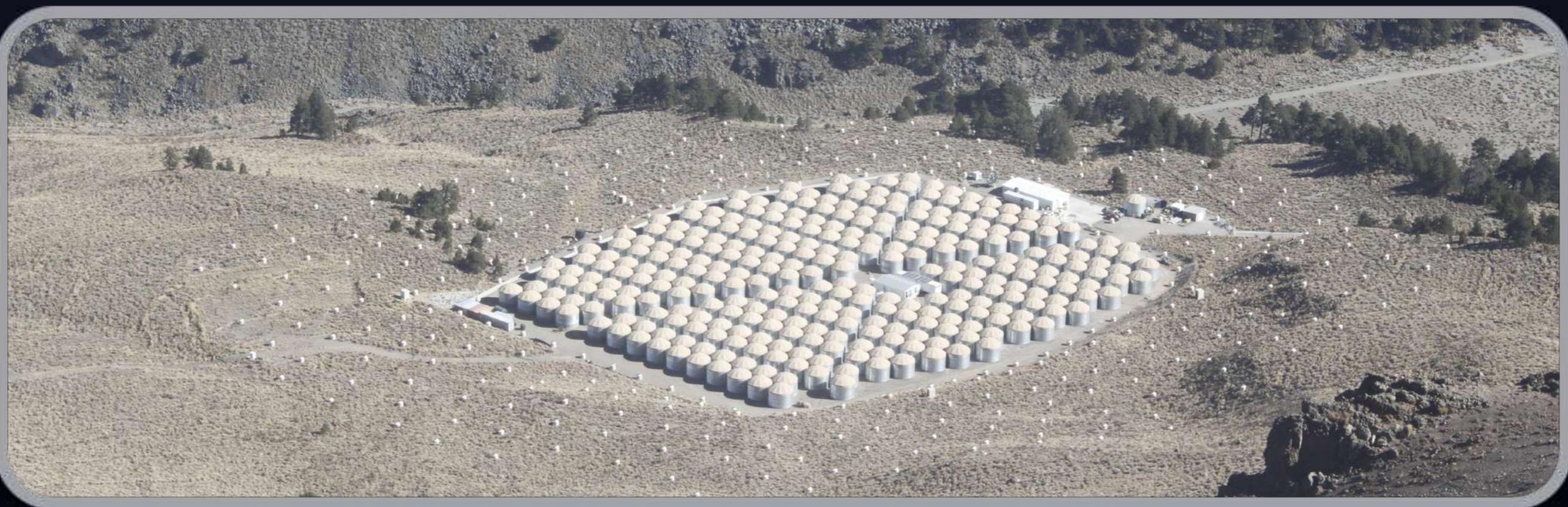


FIG. 3 of the PRL

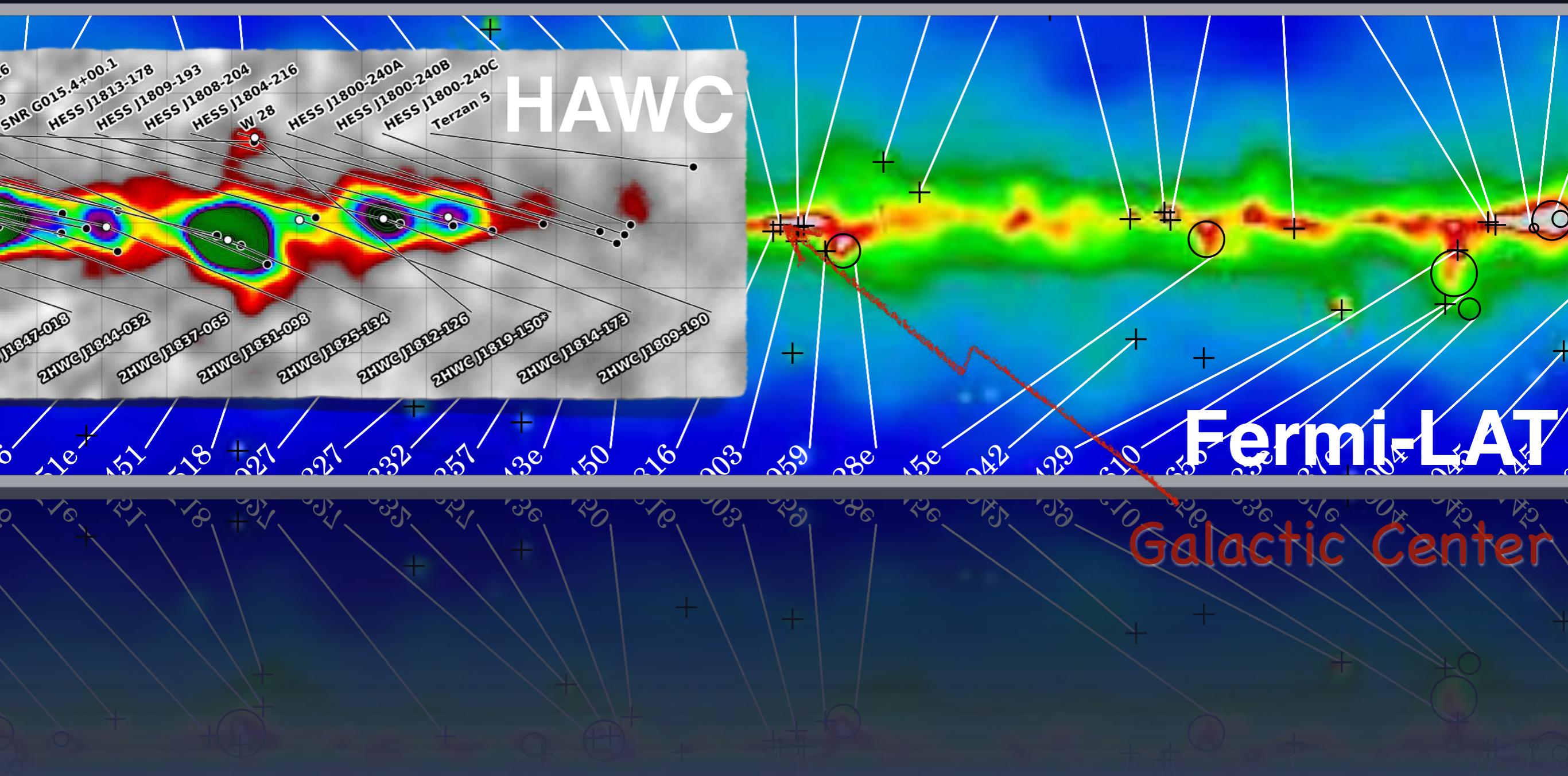


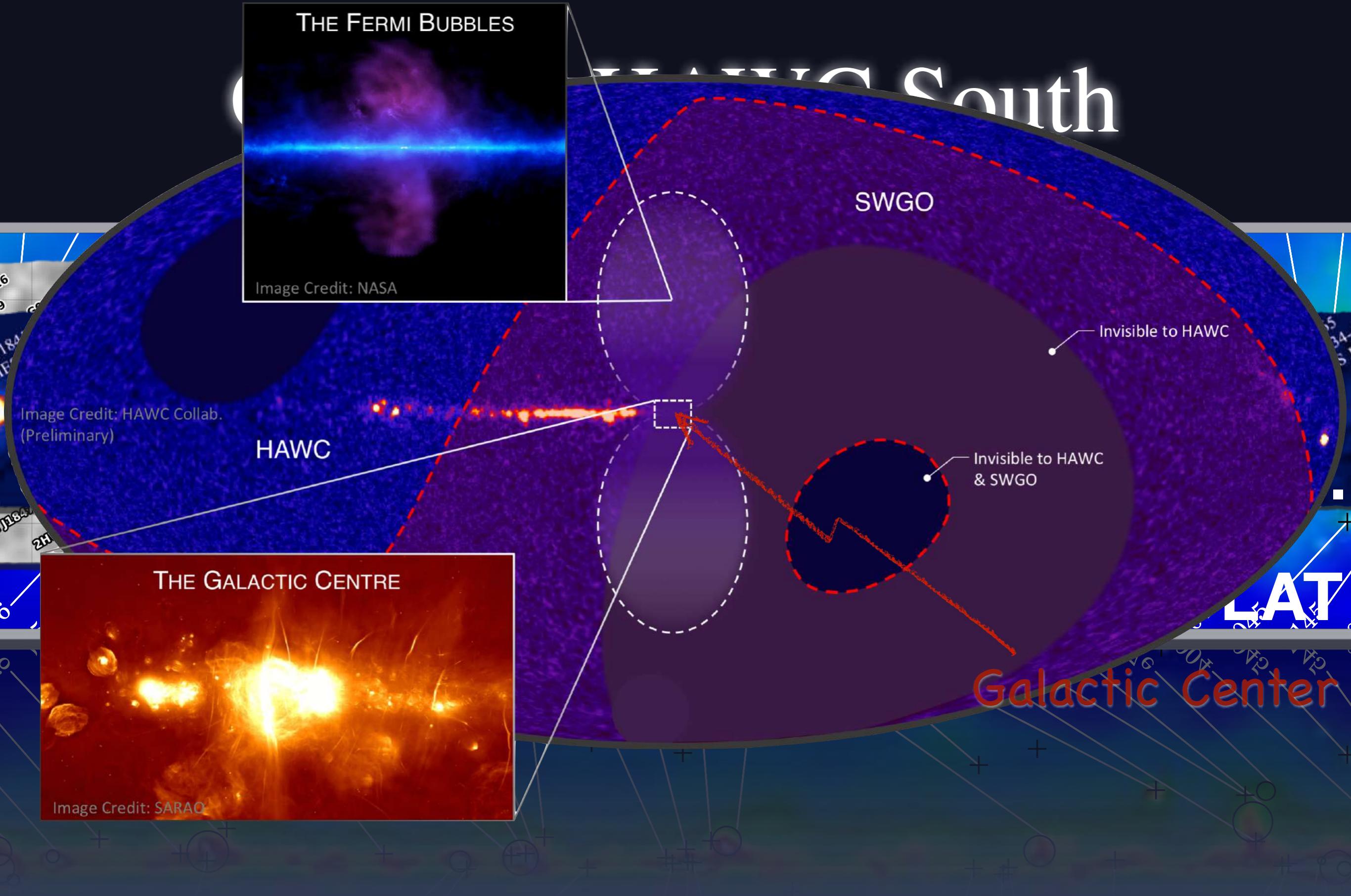
The highest energy sources

Outlook: Outriggers



Outlook: HAWC South





Conclusions

Main results

- Extended regions, transient events, highest energies

Other results

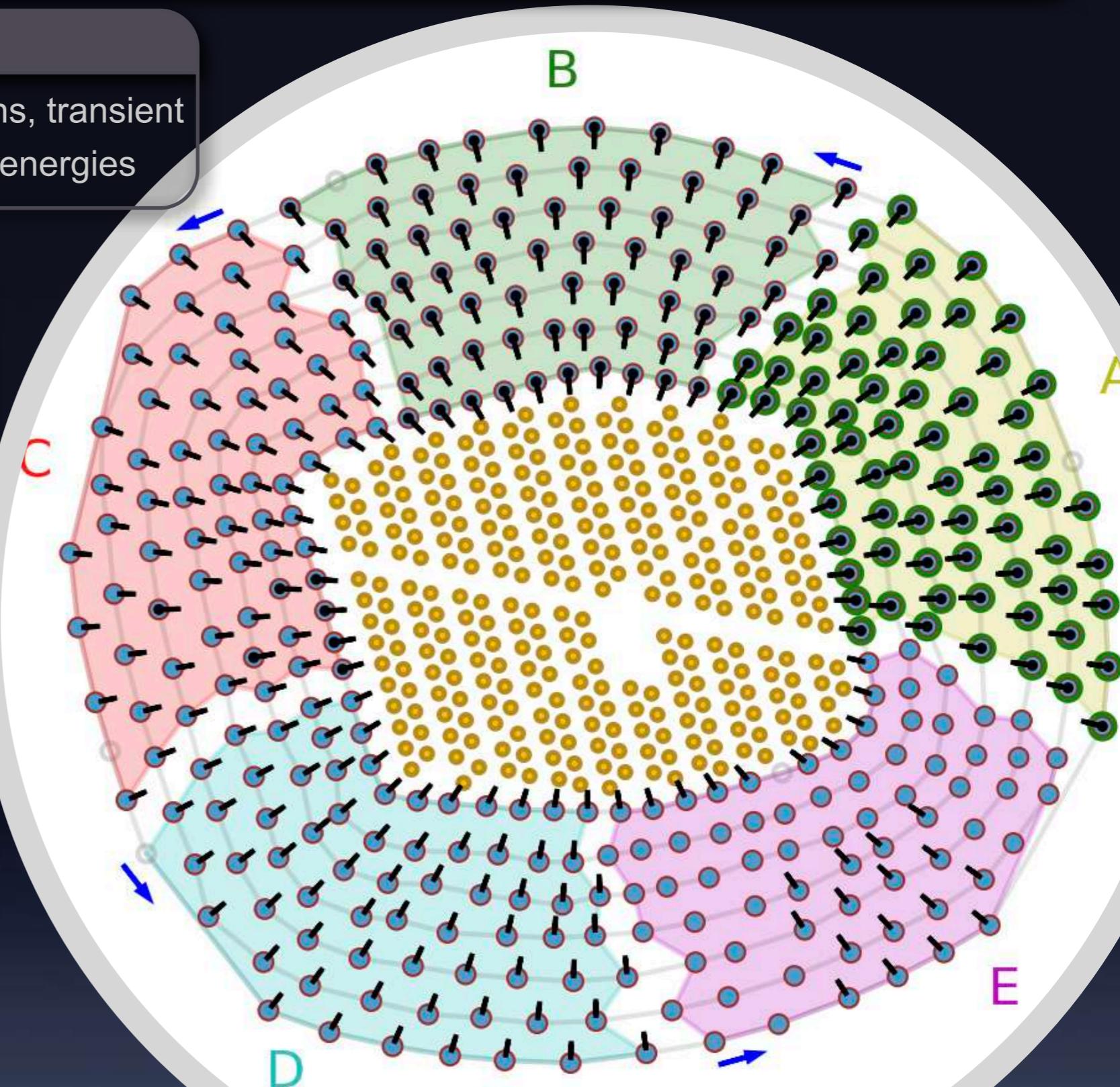
- Dark matter, extended regions, diffuse emission, cosmic rays, ...
- EBL, solar physics, ...

Multi-messenger physics

- MoUs with IceCube, IACTs, etc
- AMON
- HAWC alerts

Outlook

- Array of Outriggers
- Southern Observatory



Thank you very much

The HAWC Collaboration



Recent HAWC publications

- “HAWC J2227+610 and Its Association with G106.3+2.7, a New Potential Galactic PeVatron,” *The Astrophysical Journal Letters* 896 (2020) L29
- “Multiple Galactic Sources with Emission Above 56 TeV Detected by HAWC,” *Physical Review Letters* 124 (2020) 021102
- “Measurement of the Crab Nebula Spectrum Past 100 TeV with HAWC,” *The Astrophysical Journal* 881 (2019) 134
- “Searching for dark matter sub-structure with HAWC,” *Journal of Cosmology and Astroparticle Physics* 07 (2019) 022
- “MAGIC and Fermi-LAT gamma-ray results on unassociated HAWC sources,” *Monthly Notices of the Royal Astronomical Society* 485, 356 (2019)
- “All-sky Measurement of the Anisotropy of Cosmic Rays at 10 TeV and Mapping of the Local Interstellar Magnetic Field,” *The Astrophysical Journal* 871, 96 (2019)
- “Very-high-energy particle acceleration powered by the jets of the microquasar SS 433,” *Nature* 562, 82-85 (2018)

Thank you very much

The HAWC Collaboration in the covid-19 times...

@harm, hard for us English speake...