Recent Results from the HAWC Gamma-ray Observatory

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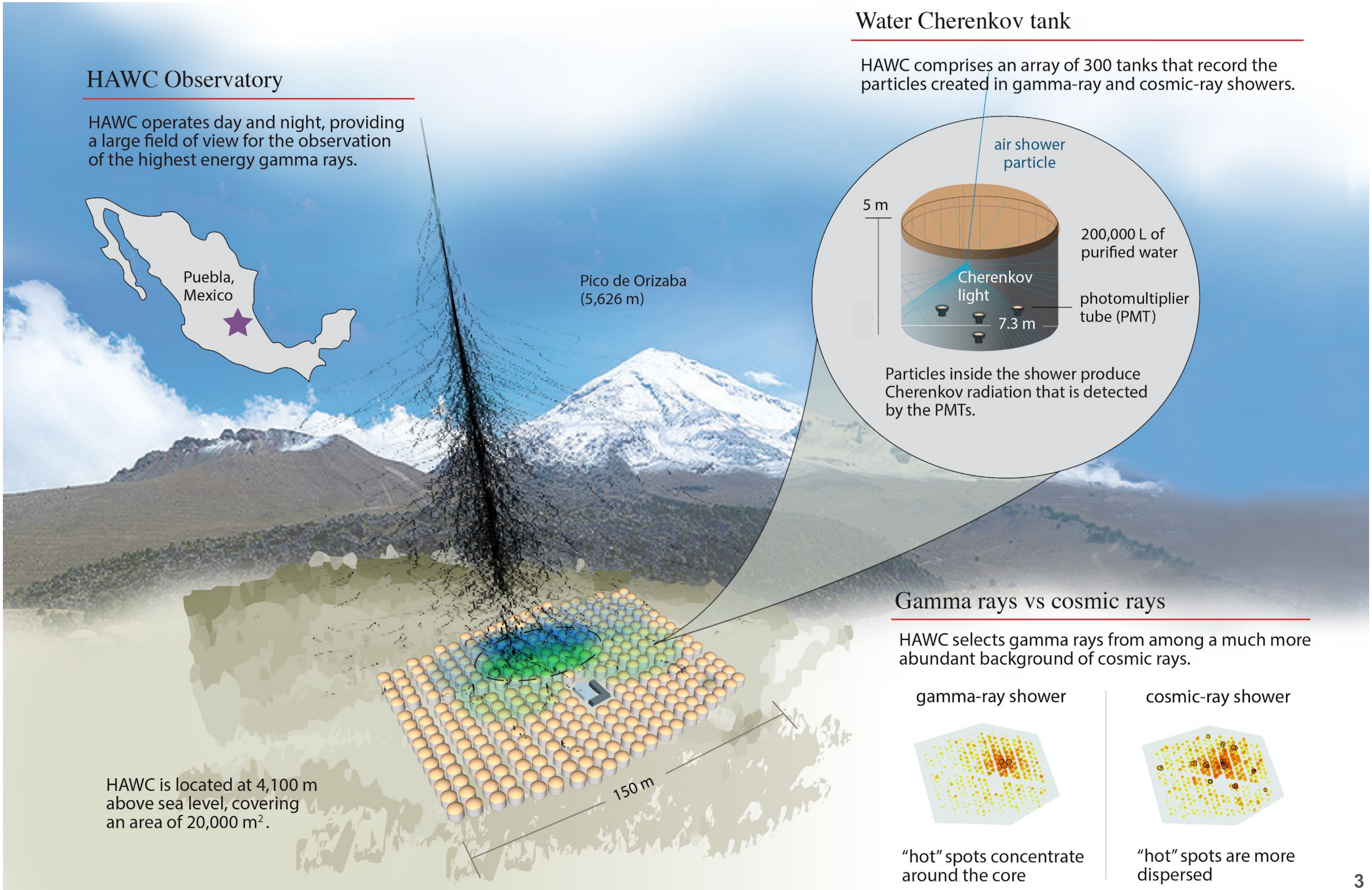
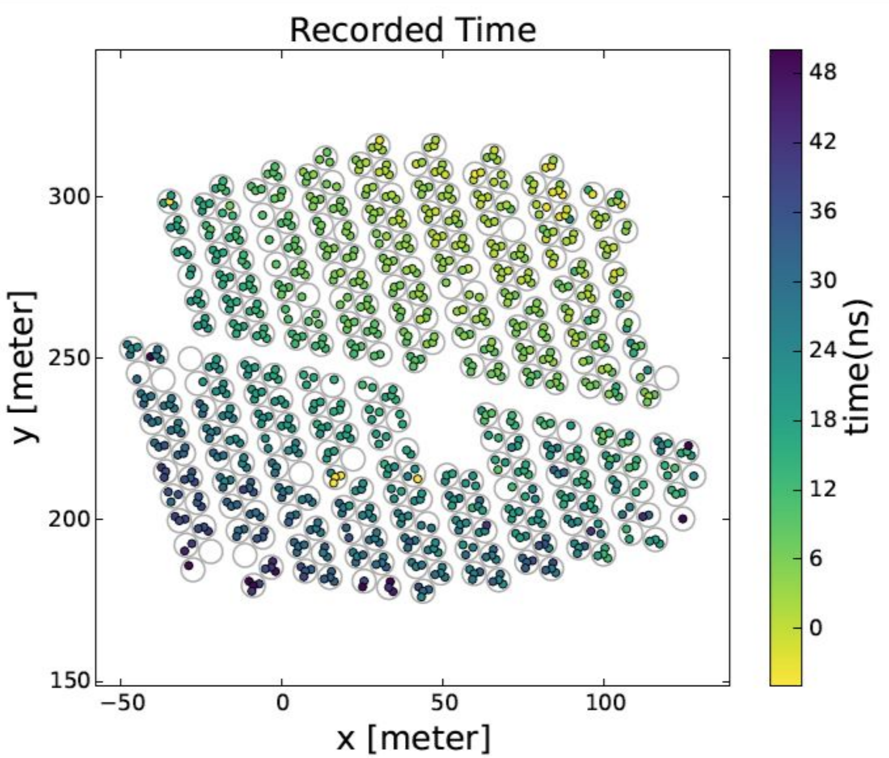
T-rex for scale
V2
V1

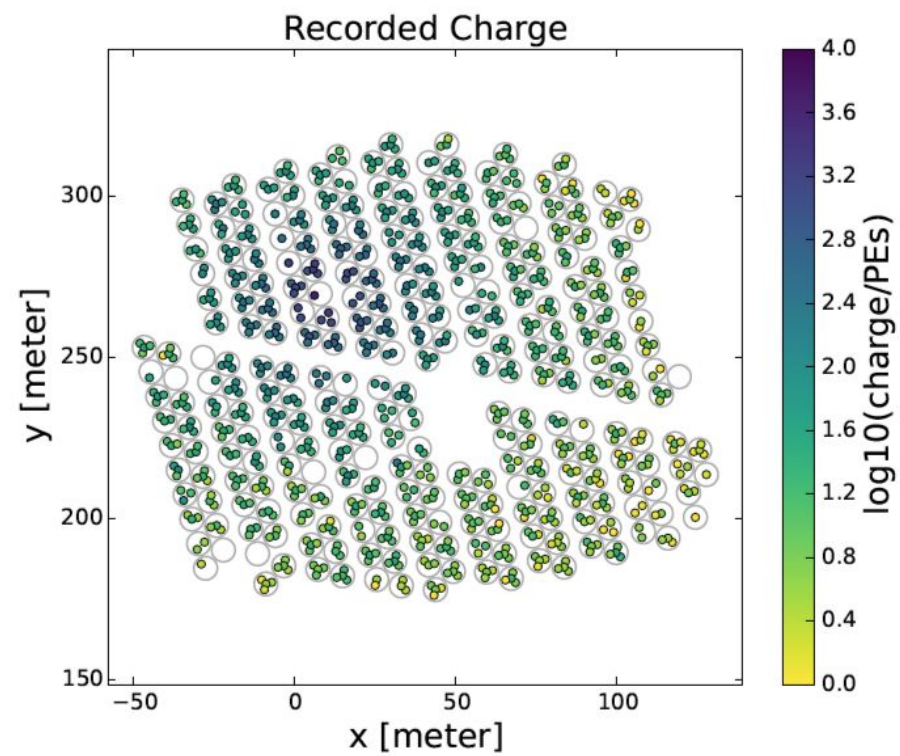
The HAWC Observatory



Observing Air Showers with Water Cherenkov Detectors

Abeysekara+ [The HAWC Collab] ApJ 843 39 (2017)
arXiv:1701.01778





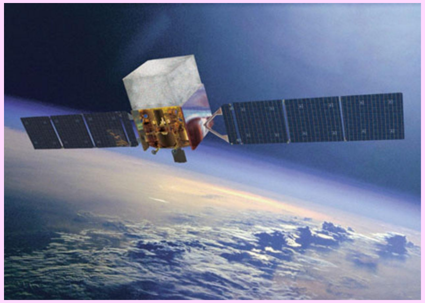
Timing of when each PMT was hit → direction

Charge of each PMT → energy

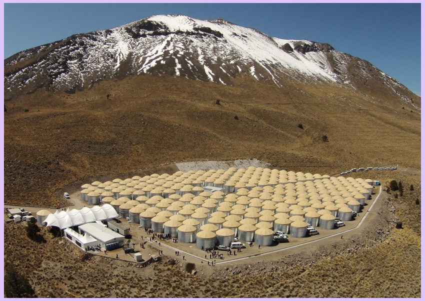
Wide Field of View TeV Observatory

Wide-field/Continuous Operation

TeV Sensitivity



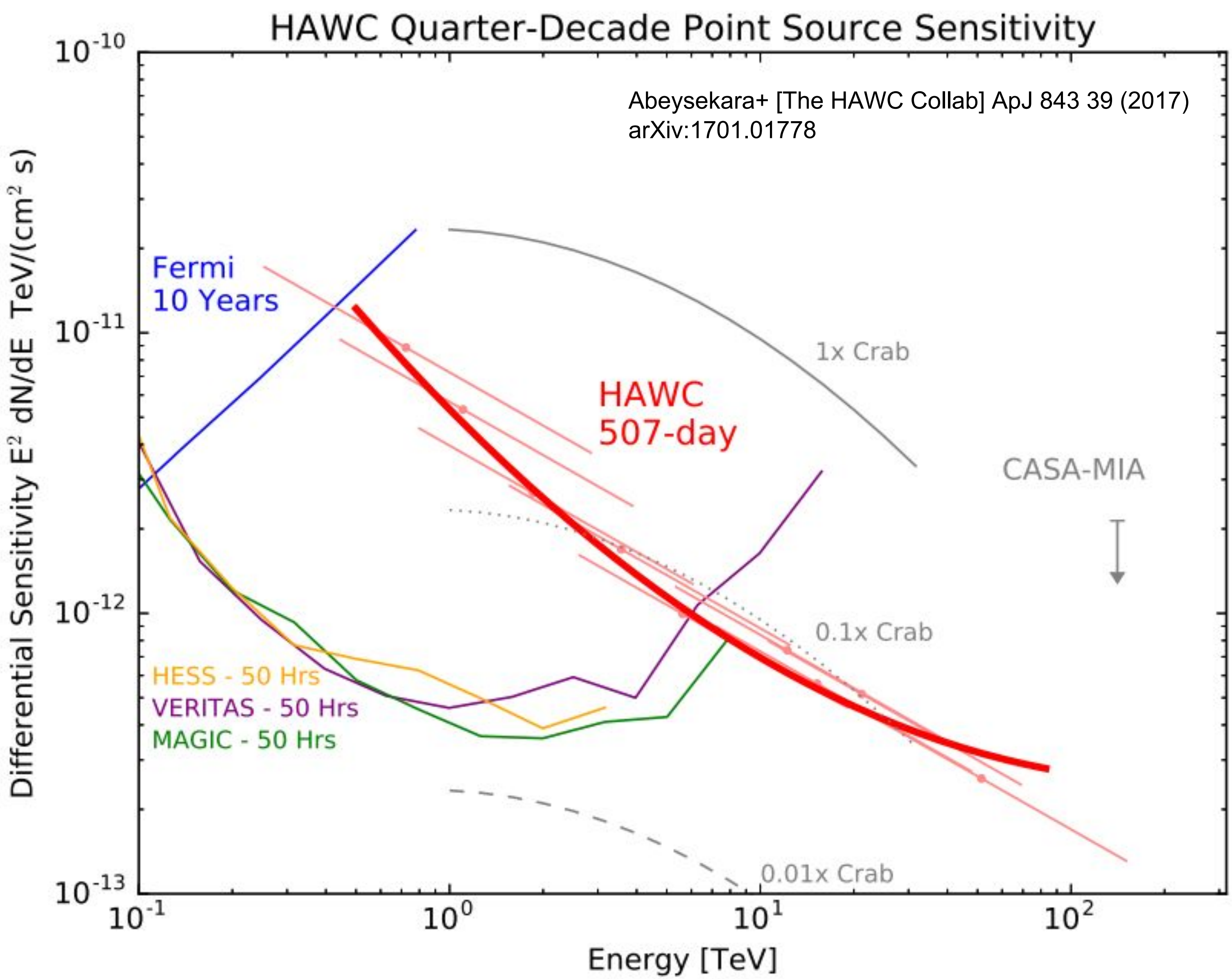
Fermi-LAT (GeV)



HAWC
ARGO-YBJ
LHASSO (future)

VERITAS, HESS,
MAGIC, FACT,
CTA (future)

The HAWC Observatory



HAWC Publications

Constraining the $\bar{p}/p$ Ratio in TeV Cosmic Rays with Observations of the Moon Shadow by HAWC
HAWC Collaboration: A.U. Abeysekara et al., submitted to Phys. Rev. D.

A Search for Dark Matter in the Galactic Halo with HAWC
HAWC Collaboration: A.U. Abeysekara et al., JCAP **02** (2018), 049.

Data Acquisition Architecture and Online Processing System for the HAWC gamma-ray observatory
HAWC Collaboration: A.U. Abeysekara et al., NIM A**888** (2018), 138-146.

Dark Matter Limits from Dwarf Spheroidal Galaxies with the HAWC Gamma-Ray Observatory
HAWC Collaboration: A. Albert et al., ApJ **853** (2018), 154.

Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth
HAWC Collaboration: A.U. Abeysekara et al., Science **6365** (2017), 911-914.

Multi-messenger Observations of a Binary Neutron Star Merger
LIGO Collaboration, Virgo Collaboration, HAWC Collaboration, et al., ApJ **848** (2017), L12.

All-particle cosmic ray energy spectrum measured by the HAWC experiment from 10 to 500 TeV
HAWC Collaboration: R. Alfaro et al., Phys. Rev. D **96** (2017), 122001.

The HAWC real-time flare monitor for rapid detection of transient events
HAWC Collaboration: A.U. Abeysekara et al., ApJ **843** (2017), 116.

Search for very-high-energy emission from Gamma-ray Bursts using the first 18 months of data from the HAWC Gamma-ray Observatory
HAWC Collaboration: R. Alfaro et al., ApJ **843** (2017), 88.

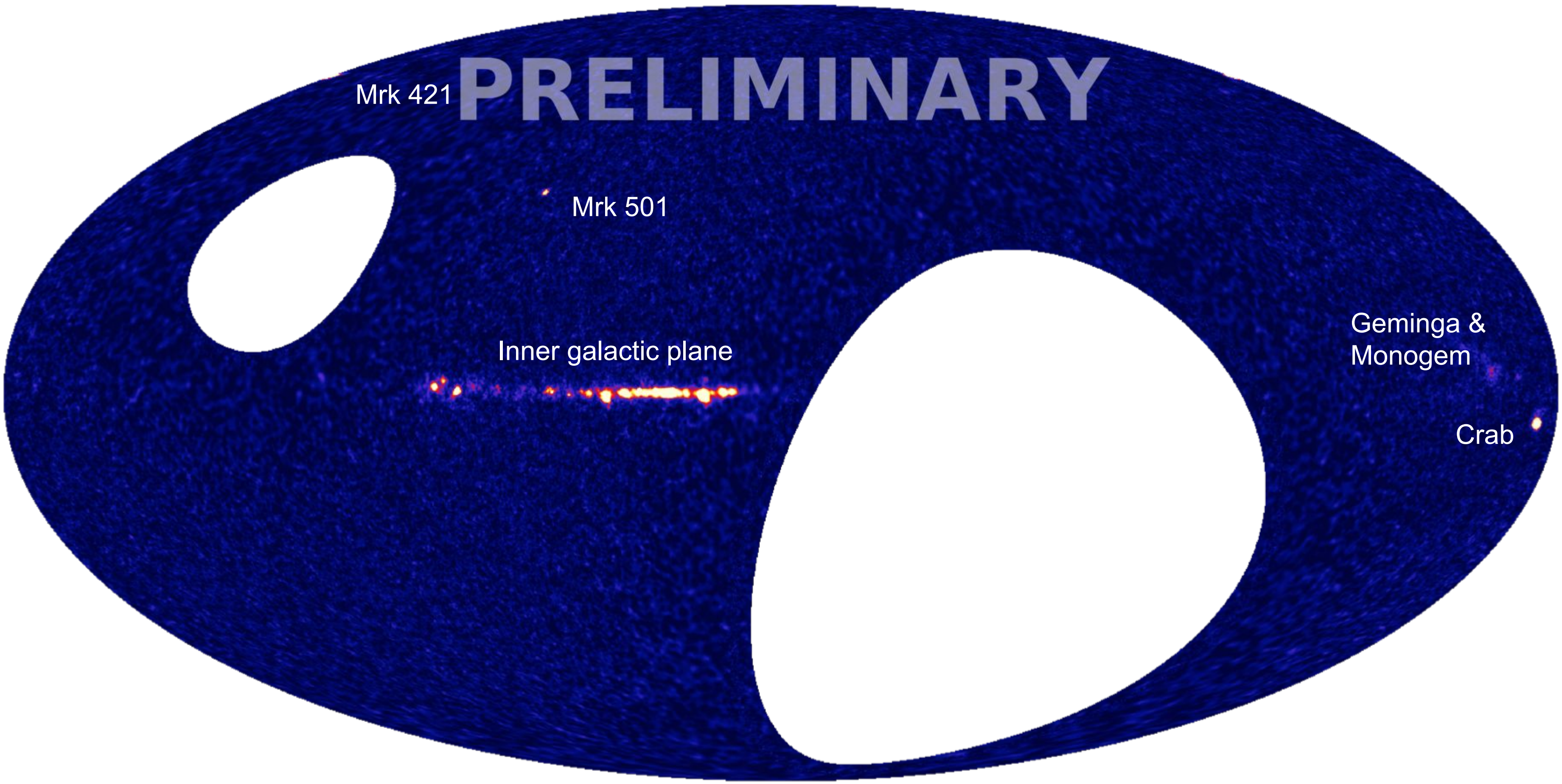
The 2HWC HAWC Observatory Gamma-Ray Catalog
HAWC Collaboration: A.U. Abeysekara et al., ApJ **843** (2017), 40.

Observation of the Crab Nebula with the HAWC Gamma-Ray Observatory
HAWC Collaboration: A.U. Abeysekara et al., ApJ **843** (2017), 39.

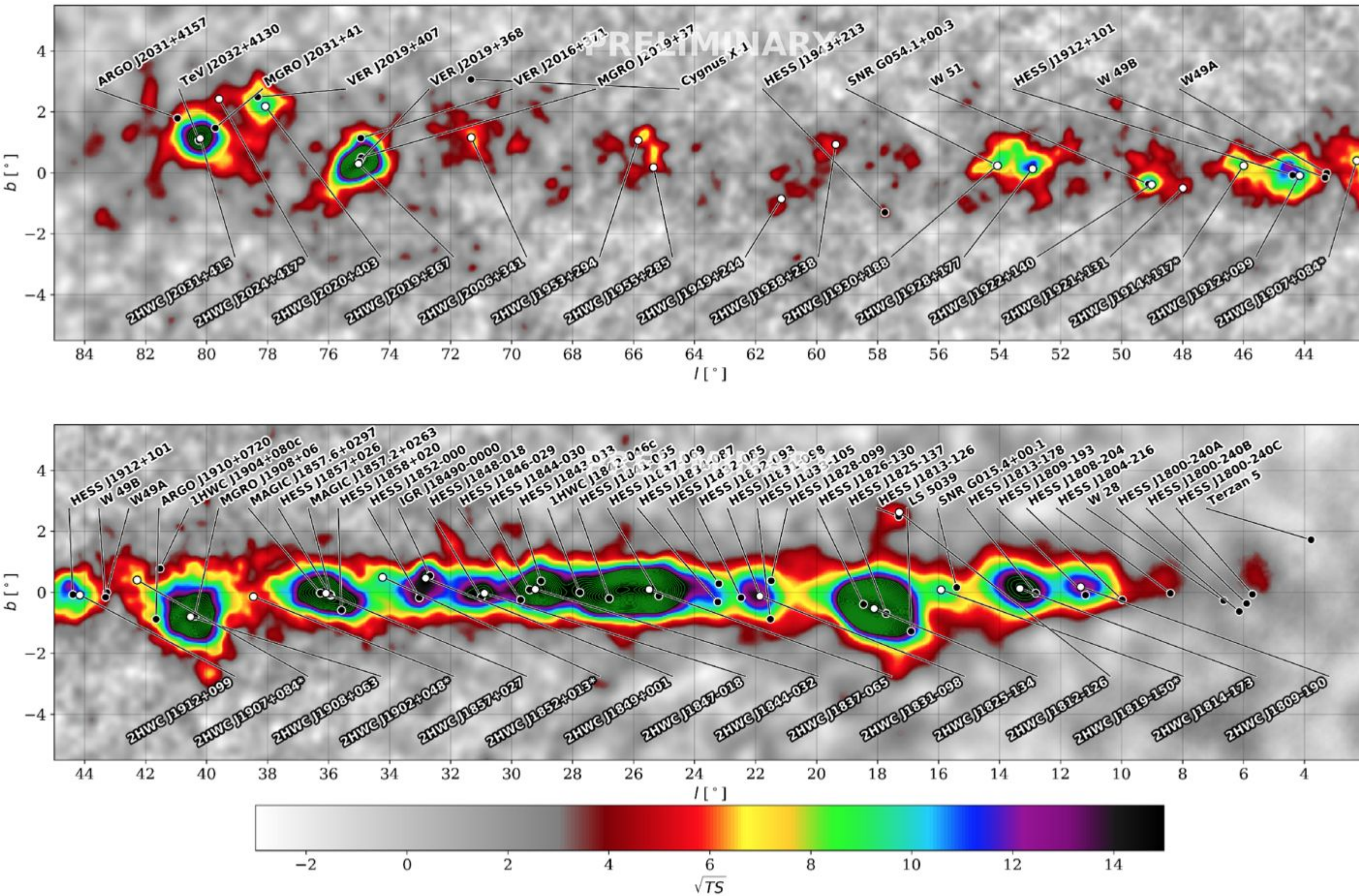
- **14 papers published in 2017 & 2018**
- **Too many results for just 20 min!**
- **Find all HAWC publications online https://www.hawc-observatory.org/publications/**

HAWC 3 year Sky Map

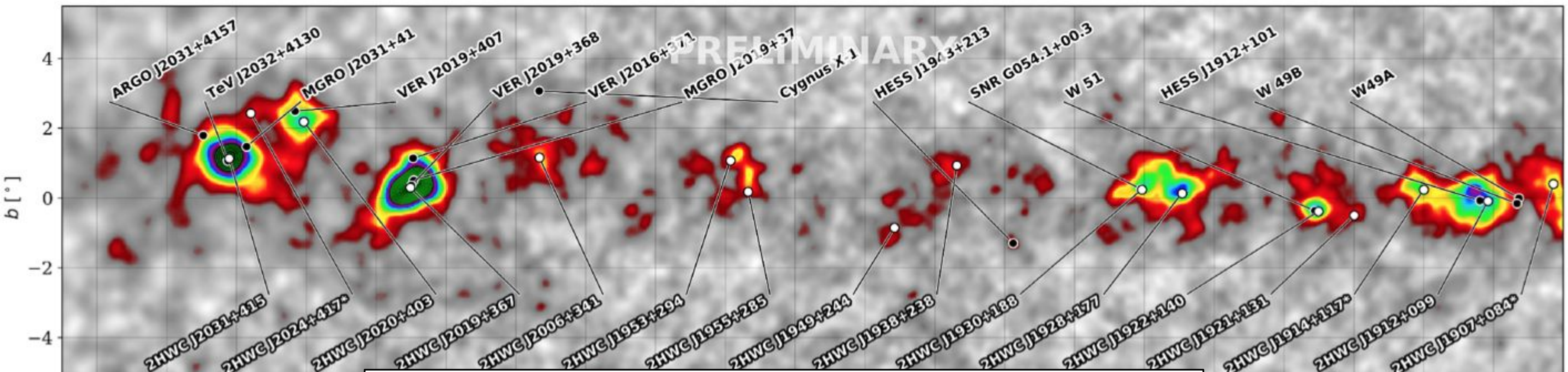
HAWC 3 year skymap -- 1017d livetime: 2014-11 to 2017-12



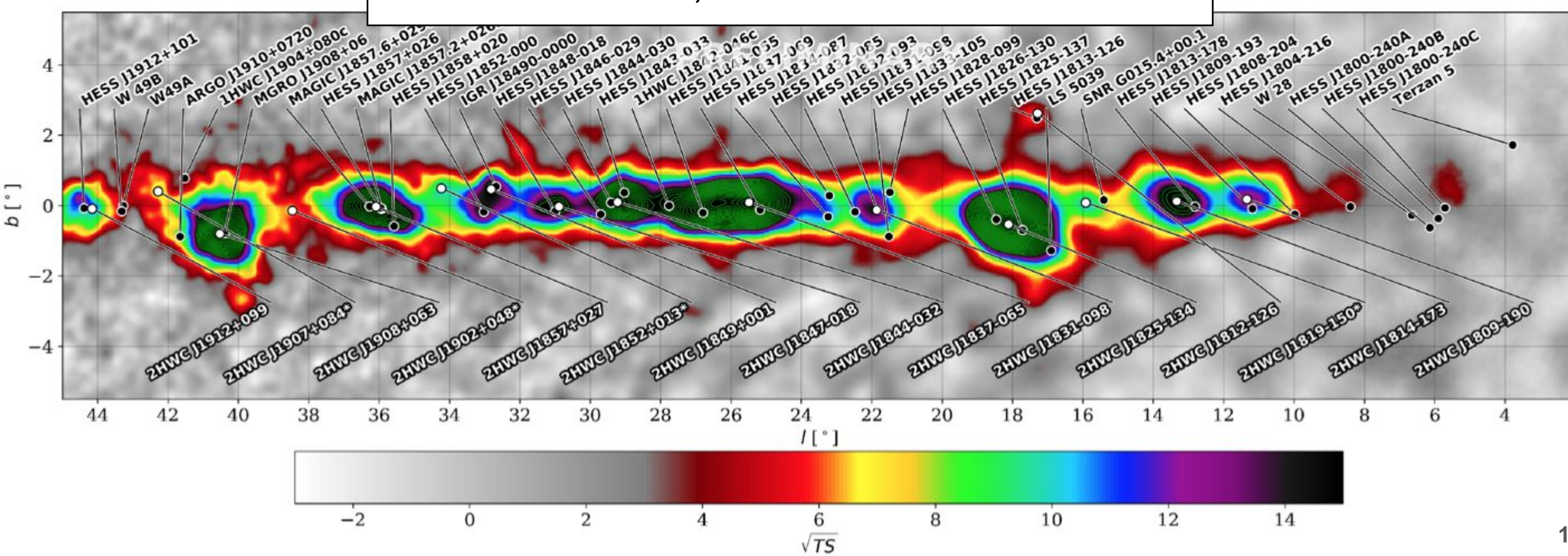
HAWC 3 year Sky Map
Inner Galactic Plane



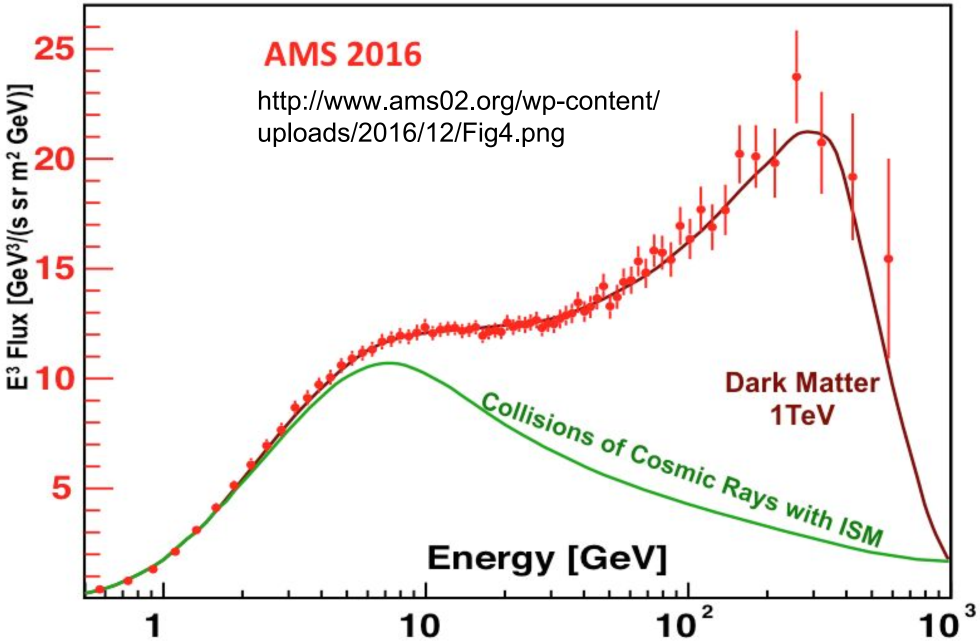
HAWC 3 year Sky Map
Inner Galactic Plane

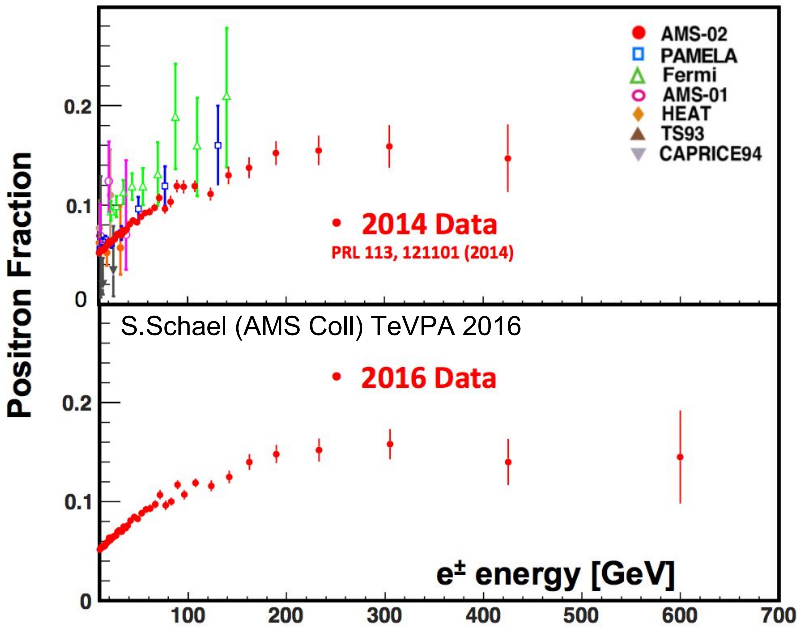


2HWC catalog (ApJ 2017) was 507 days and found 39 sources, 19 of which were new



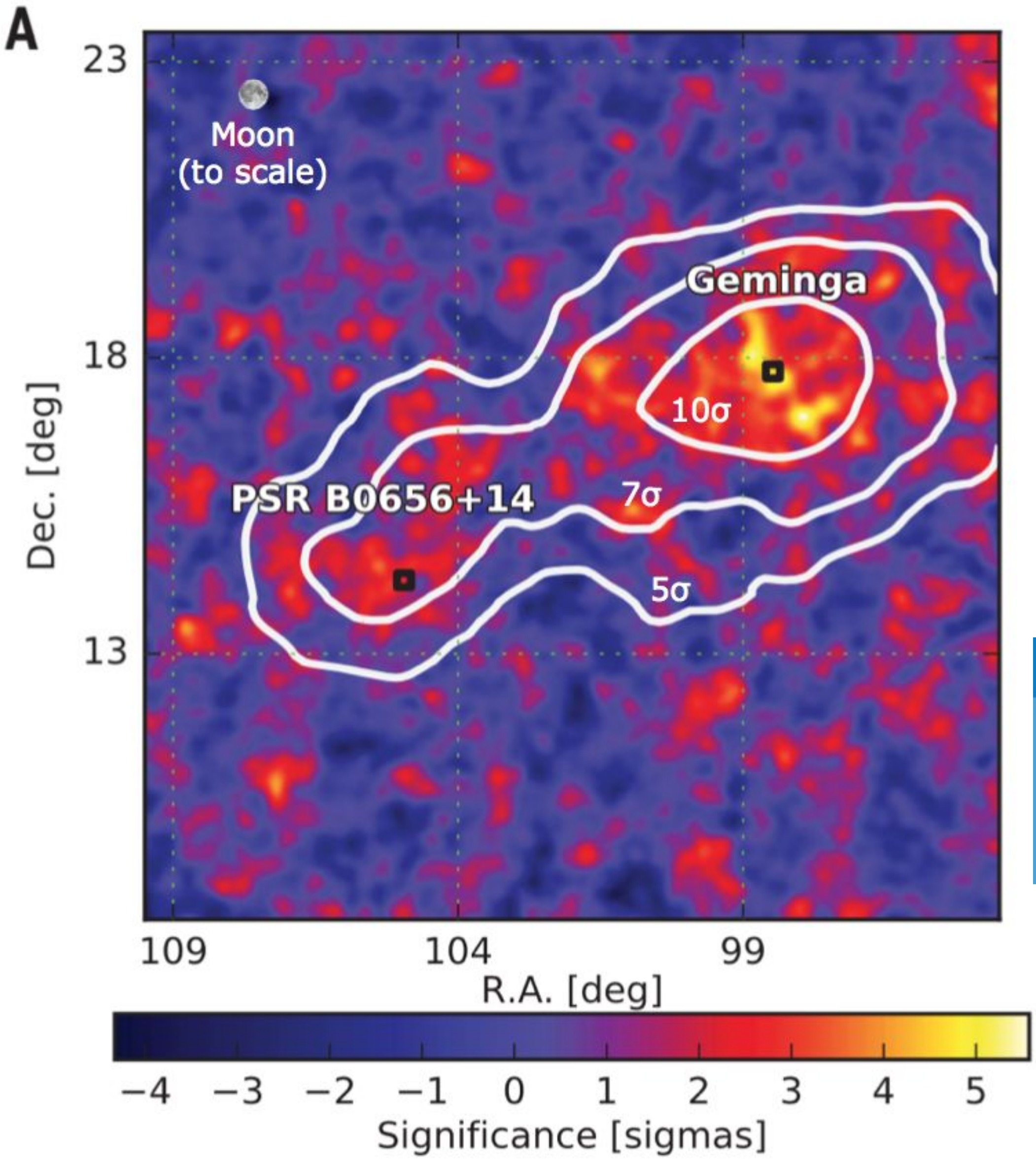
Local Positron Fraction Mystery





- AMS-02 on board the International Space Station observes local cosmic rays since 2011
  - excellent charge resolution and particle species discrimination
- TeV e^-e^+ lose energy quickly and therefore must be produced locally (d < ~100 pc)
  - *secondaries* produced by cosmic ray interactions with ISM (spallation)
  - *primaries* produced by local source
    - local cosmic accelerator (e.g. Geminga)? local dark matter interactions?
- Larger positron flux observed above ~10 GeV than expected from secondaries
  - First observed by Pamela in 2009, since confirmed by Fermi LAT and AMS-02
  - Are they from a local cosmic accelerator or dark matter?
    - If they are from dark matter, other annihilation products should be produced

Geminga and Monogem

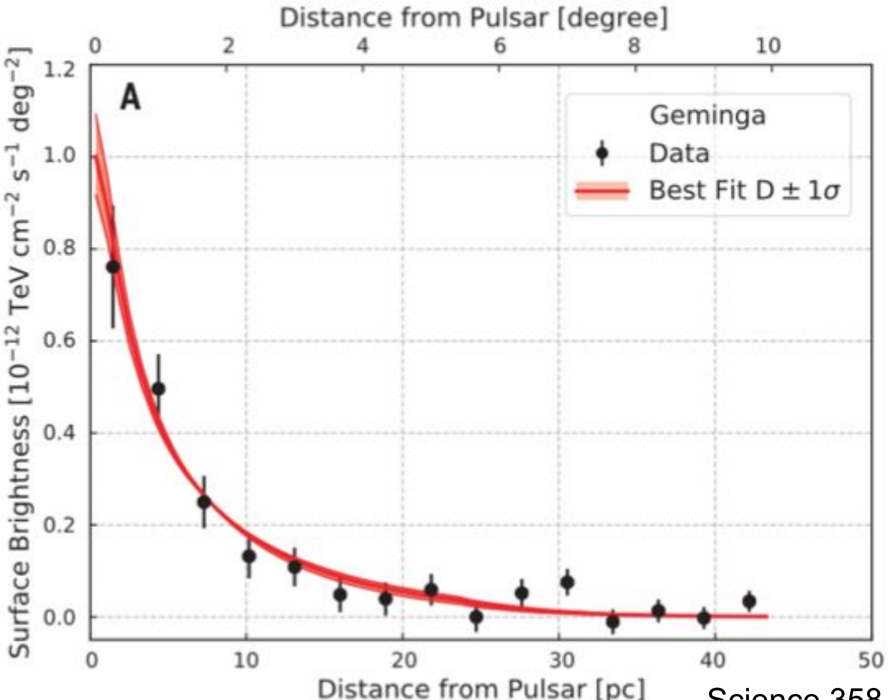


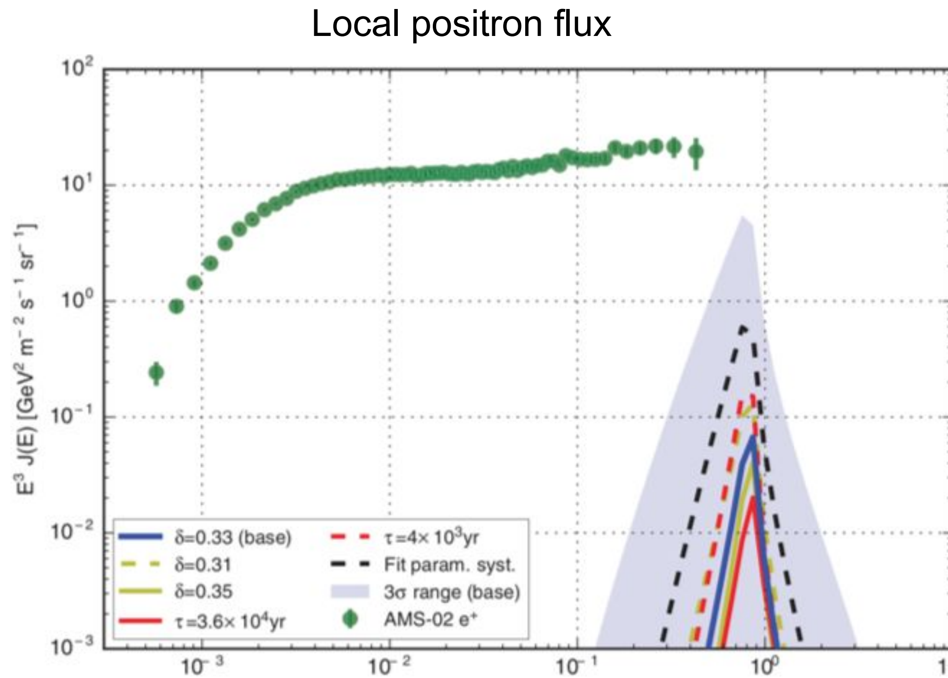
- **HAWC observes extended emission from both the Geminga and Monogem (PSR B0656+14) pulsars**
- **These are both nearby, middle-aged pulsars that could be producing the observed local positrons**

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

Science 358 (2017) no.6365, 911-914

Electron/Positron Diffusion Coefficient

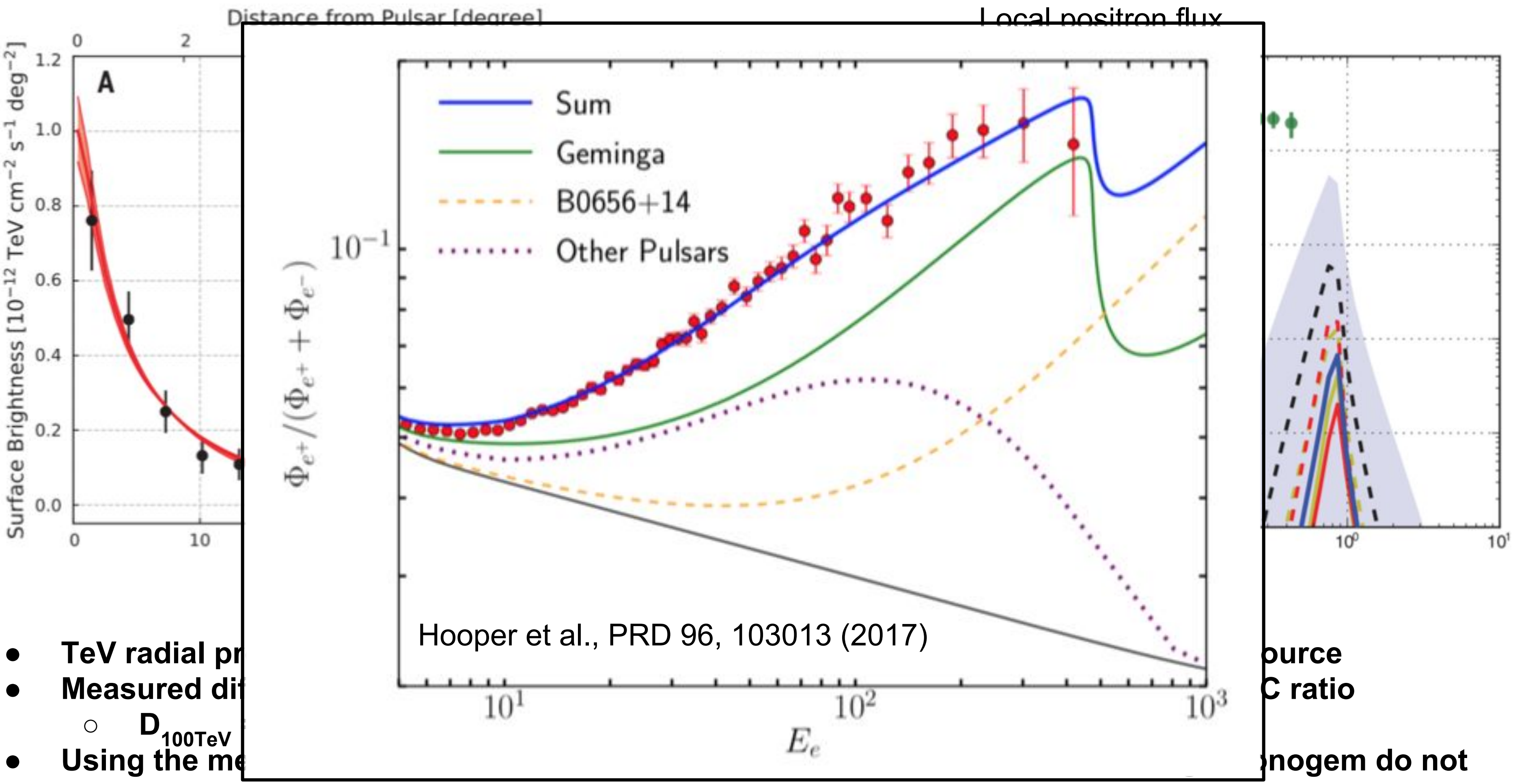




Science 358 (2017) no.6365, 911-914

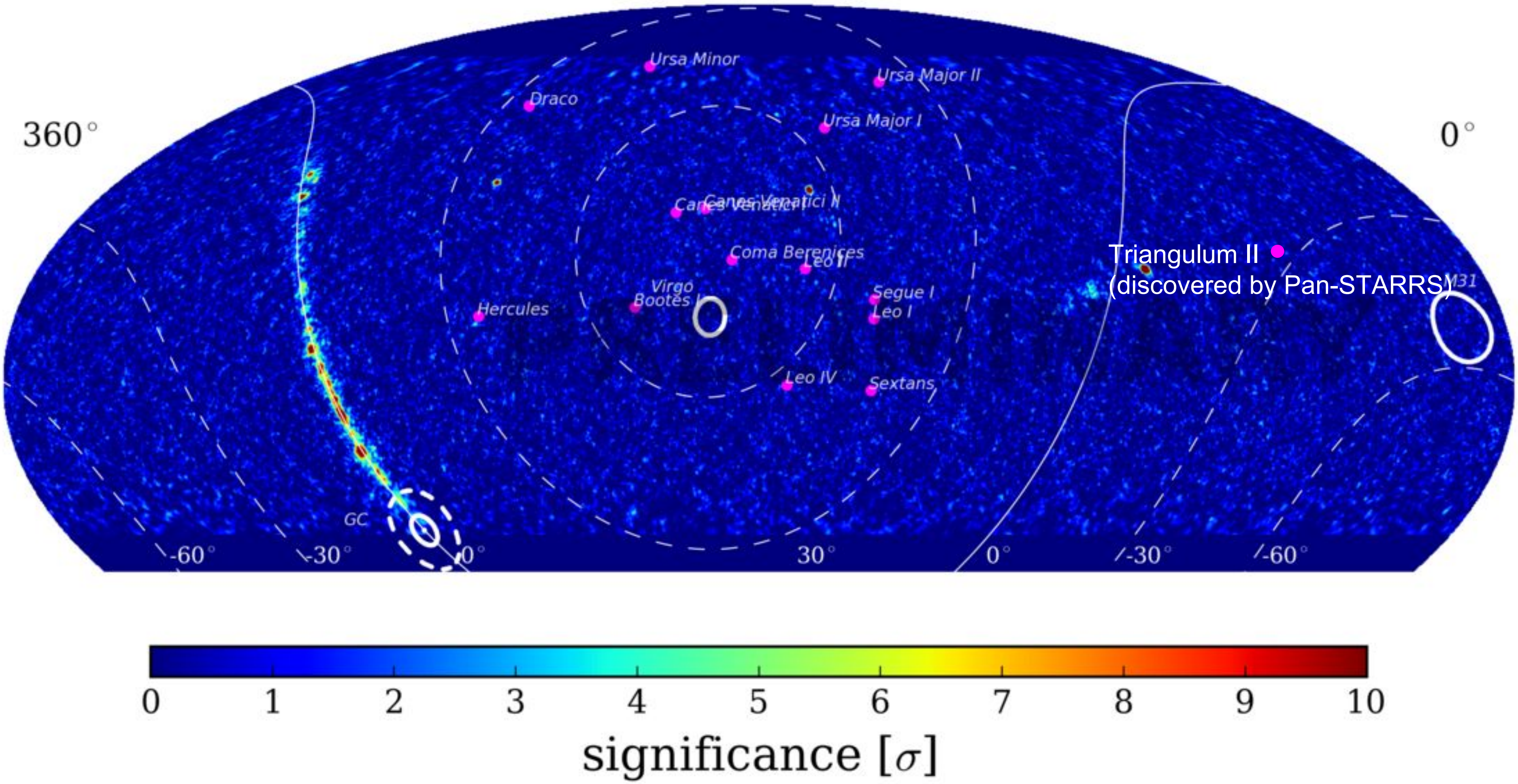
- **TeV radial profile → direct measurement of electron/positron diffusion around the source**
- **Measured diffusion is ~100 times smaller than the ISM diffusion derived from the B/C ratio**
  - **D_{100TeV} = 4.5±1.2x10^{27} cm^2/s**
- **Using the measured diffusion coefficient, e$^+$/e$^-$ cannot reach Earth and Geminga/Monogem do not explain the positron excess**

Electron/Positron Diffusion Coefficient



- **TeV radial pr** ... **ource**
- **Measured di** ... **C ratio**
  - **D$_{100TeV}$**
- **Using the me** ... **nogem do not explain the positron excess**
- **But, if you use a variable diffusion coefficient, the positrons can reach earth and explain the positron excess**
  - **D. Hooper et al., PRD 96, 103013 (2017); K. Fang et al., arXiv:1803.02640; S. Profumo et al., arXiv:1803.09731**

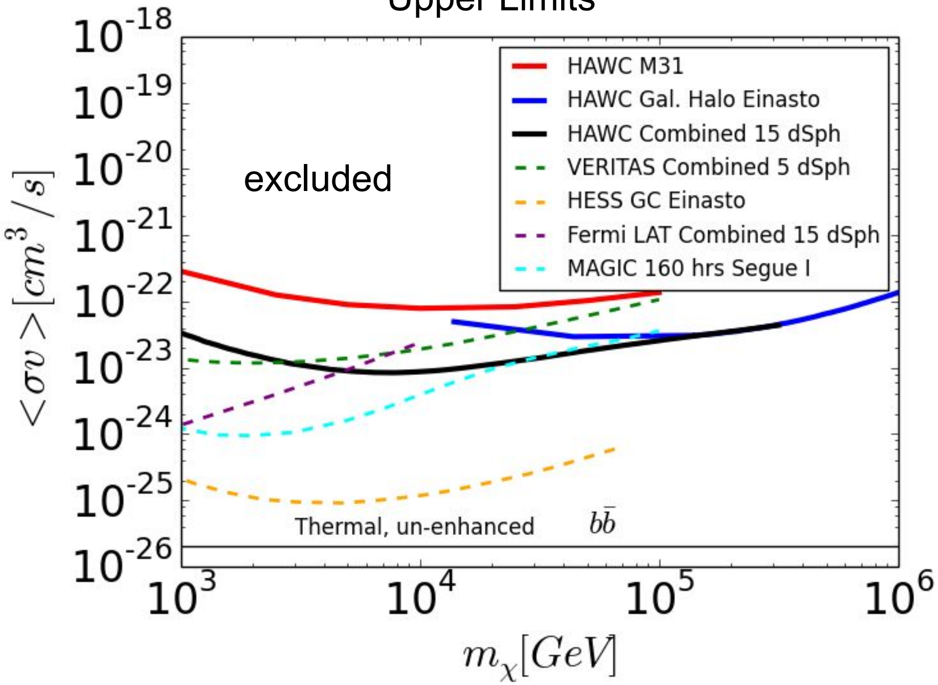
HAWC Dark Matter Targets



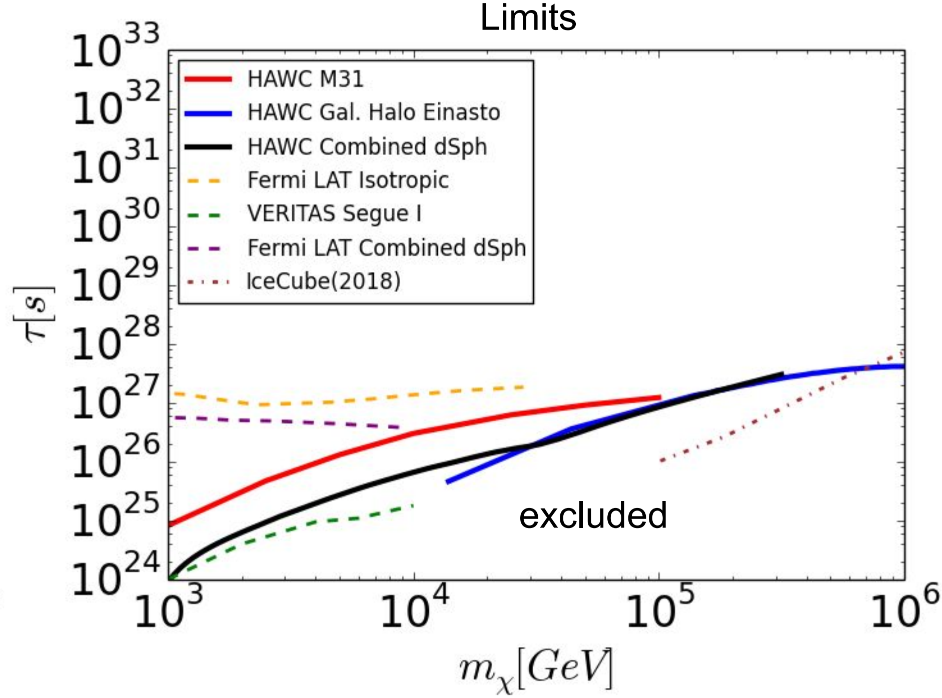
- **HAWC has a wide field of view making it sensitive to extended objects**
- **HAWC surveys ⅔ of the sky every day, including several DM targets**

Dark Matter Limits -- $\tau^+\tau^-$

DM Annihilation Cross Section Upper Limits

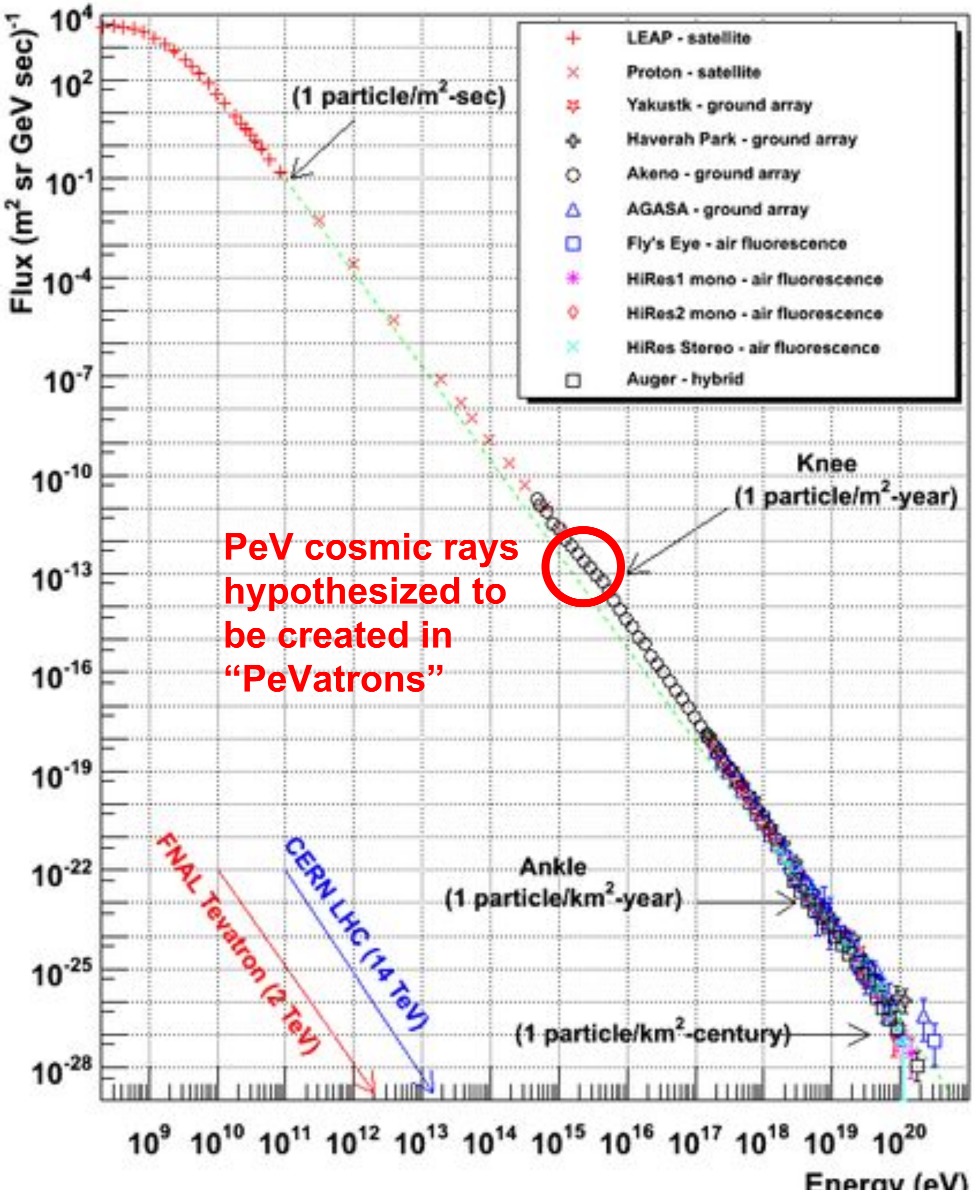


DM Decay Lifetime Lower Limits



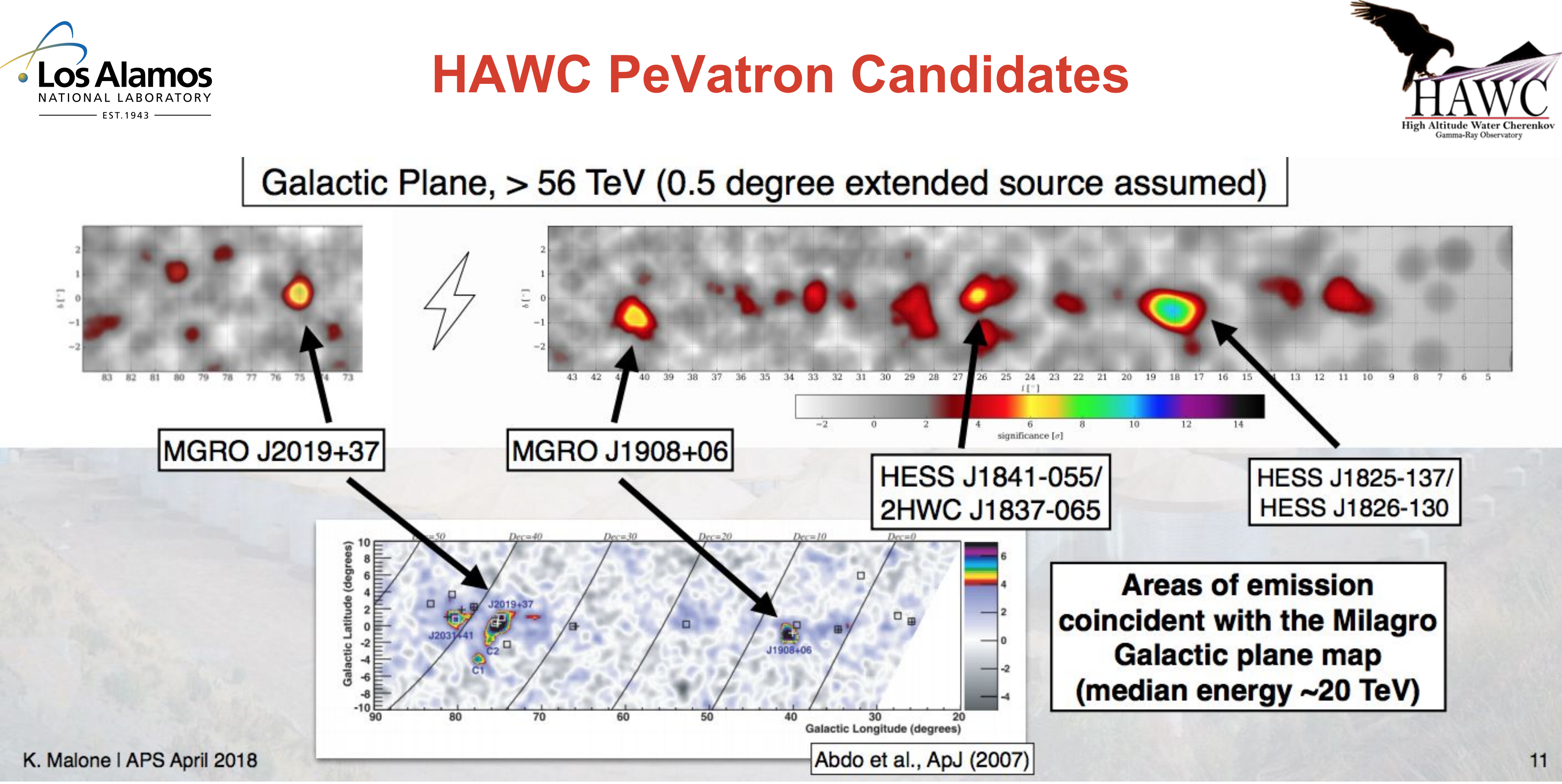
- **No gamma-ray excess detected in any target**
- **Limits set on DM annihilation cross section and decay lifetime**

What are the sources of high-energy cosmic rays?



http://www.physics.utah.edu/~whanlon/spectrum.html

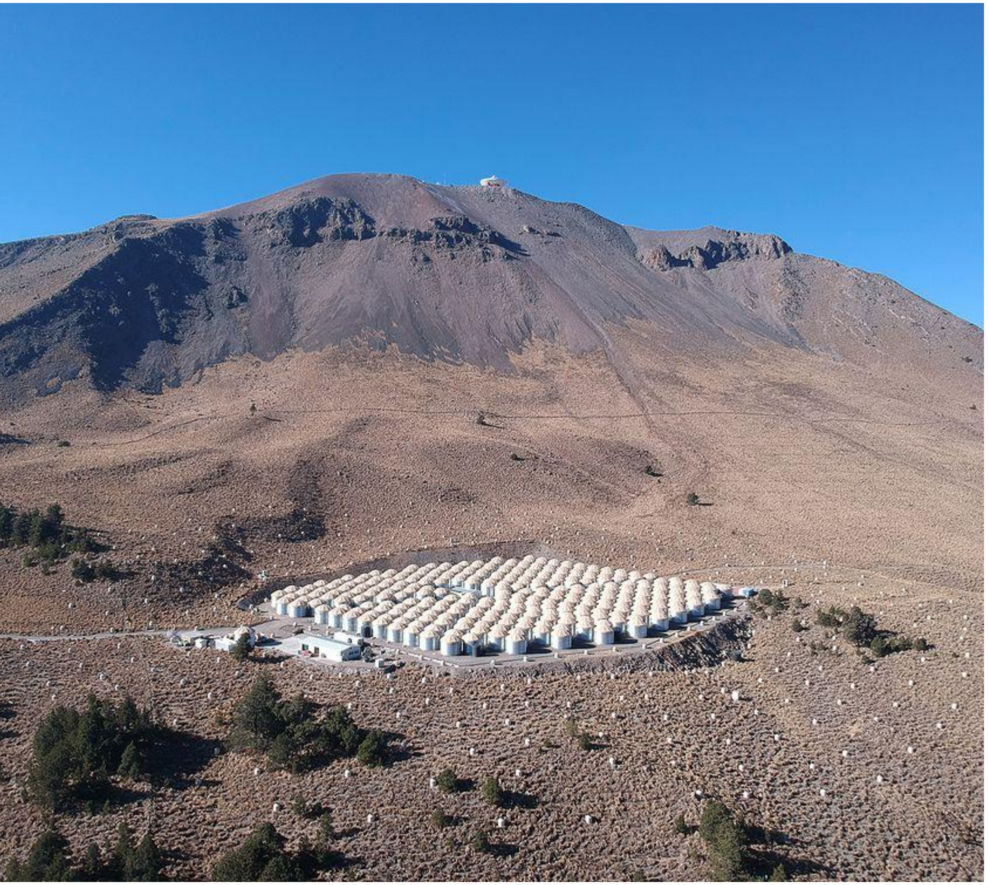
- Cosmic rays below the "knee" are hypothesized to be from the Milky Way Galaxy, while higher energy cosmic rays are hypothesized to be extragalactic
- We know some sources of cosmic rays, but the highest energy Galactic sources (PeVatrons) are still not well characterized
  - PeVatrons make 10's to 100's of TeV gamma rays
  - H.E.S.S. observations of the Galactic Center suggest it is a PeVatron (Nature 2016)
  - Are other Galactic sources PeVatron candidates?

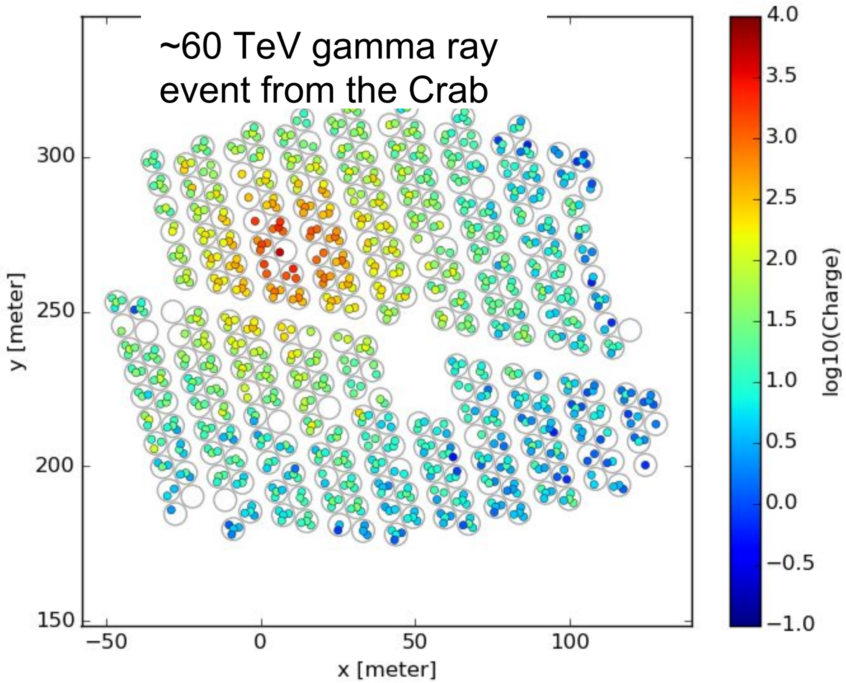


- **HAWC is observing the highest energy photons ever detected (>50 TeV)**

- **Preliminary analysis has found high-energy (>56 TeV) sources**
  - **PeVatron candidates**
  - **High-energy sources are coincident with pulsars**
  - **Spectral fits are forthcoming, which will help determine emission mechanisms and if they are PeVatrons**

Upgrade to HAWC Array





- **Upgrade to HAWC array is underway**
  - **add larger, sparse array of small tanks**
- **Provide better measure of high energy showers**
  - **expect gain in sensitivity > 10 TeV of about 3-4**

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Summary

HAWC High Altitude Water Cherenkov Gamma-Ray Observatory

- The full HAWC Observatory has been observing the TeV gamma-ray sky since March 2015
  - Wide field of view, works day and night
- 2 year catalog discovered 10 new sources
- Observations from Geminga and Monogem pulsars constrain origin of local positrons
- HAWC sets competitive limits on dark matter annihilation and decay
- HAWC is observing the highest energy photons ever detected
  - Have found a new PeVatron candidate
  - Outrigger array will extend our high energy reach