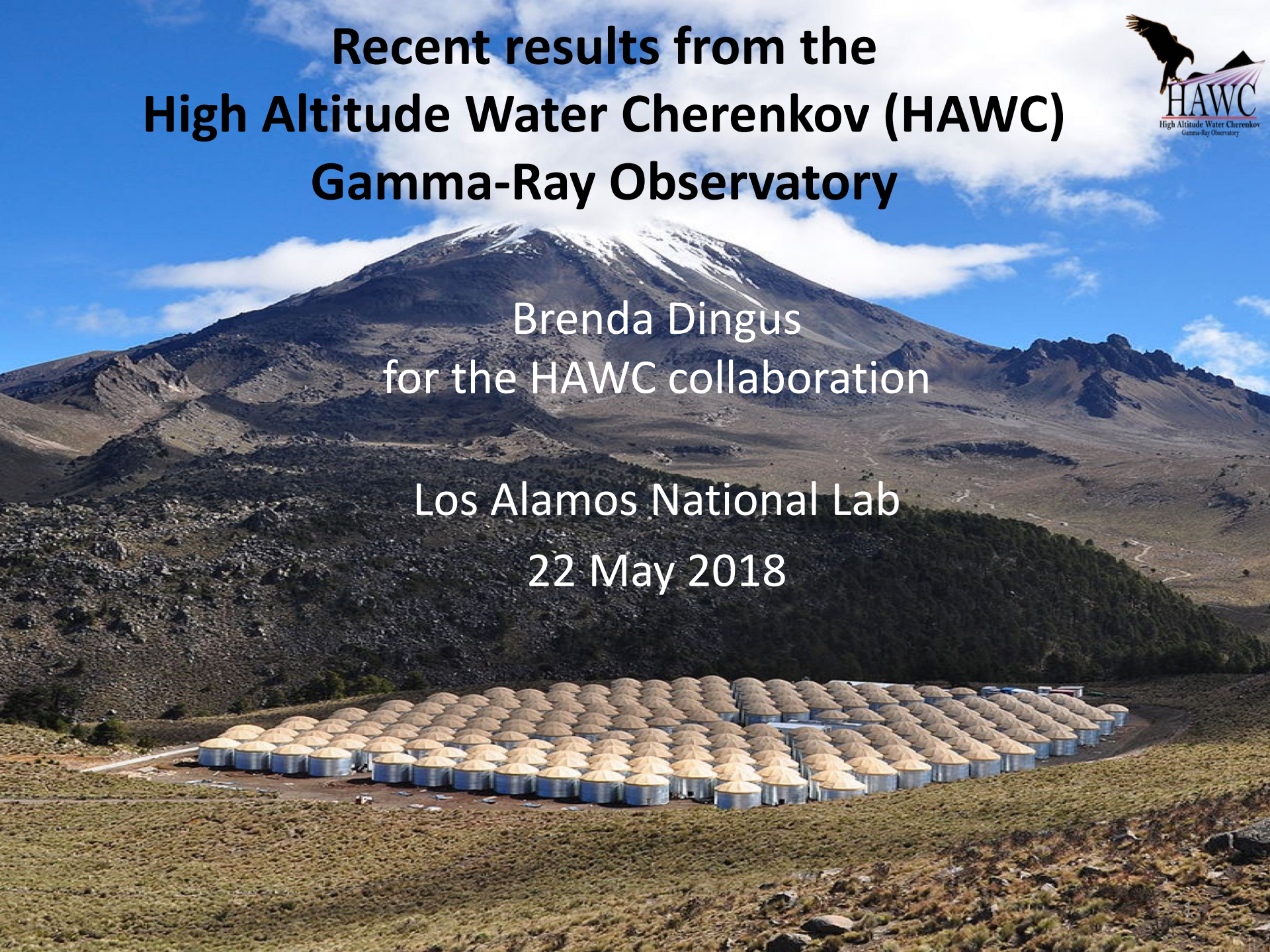
Recent results from the High Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory

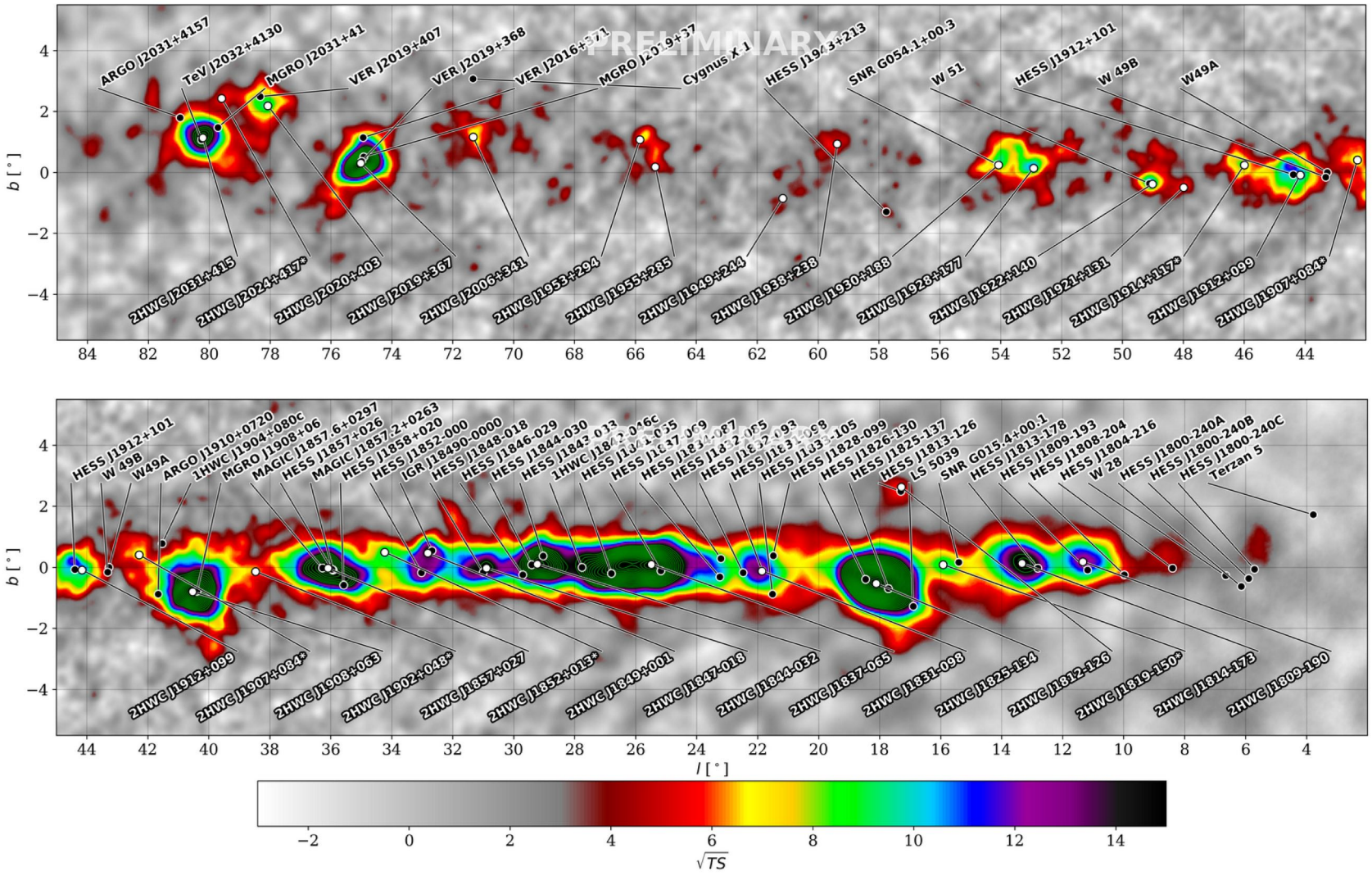
Brenda Dingus
for the HAWC collaboration

Los Alamos National Lab

22 May 2018



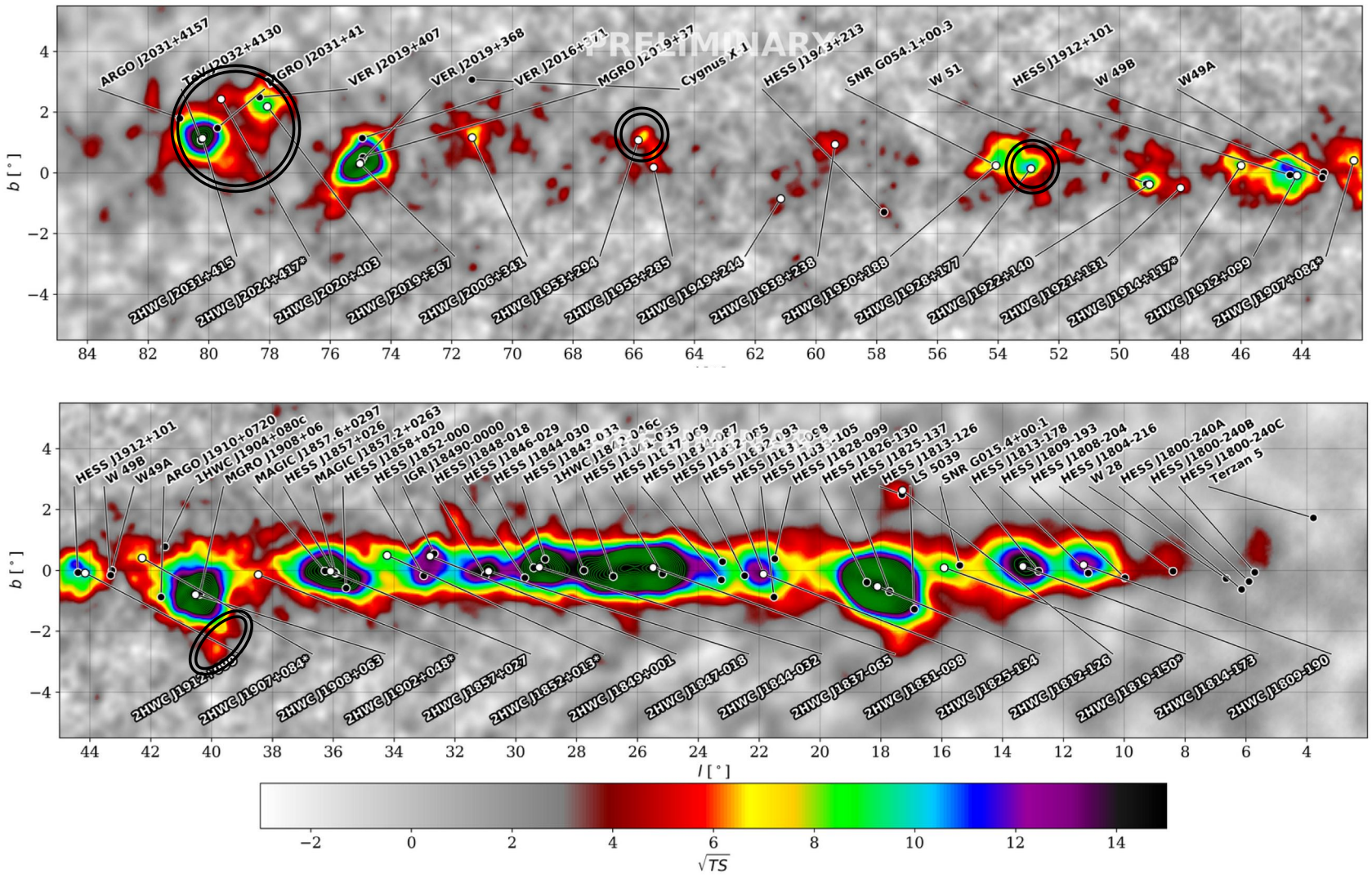
HAWC's Galactic Plane with 2.5 years of data



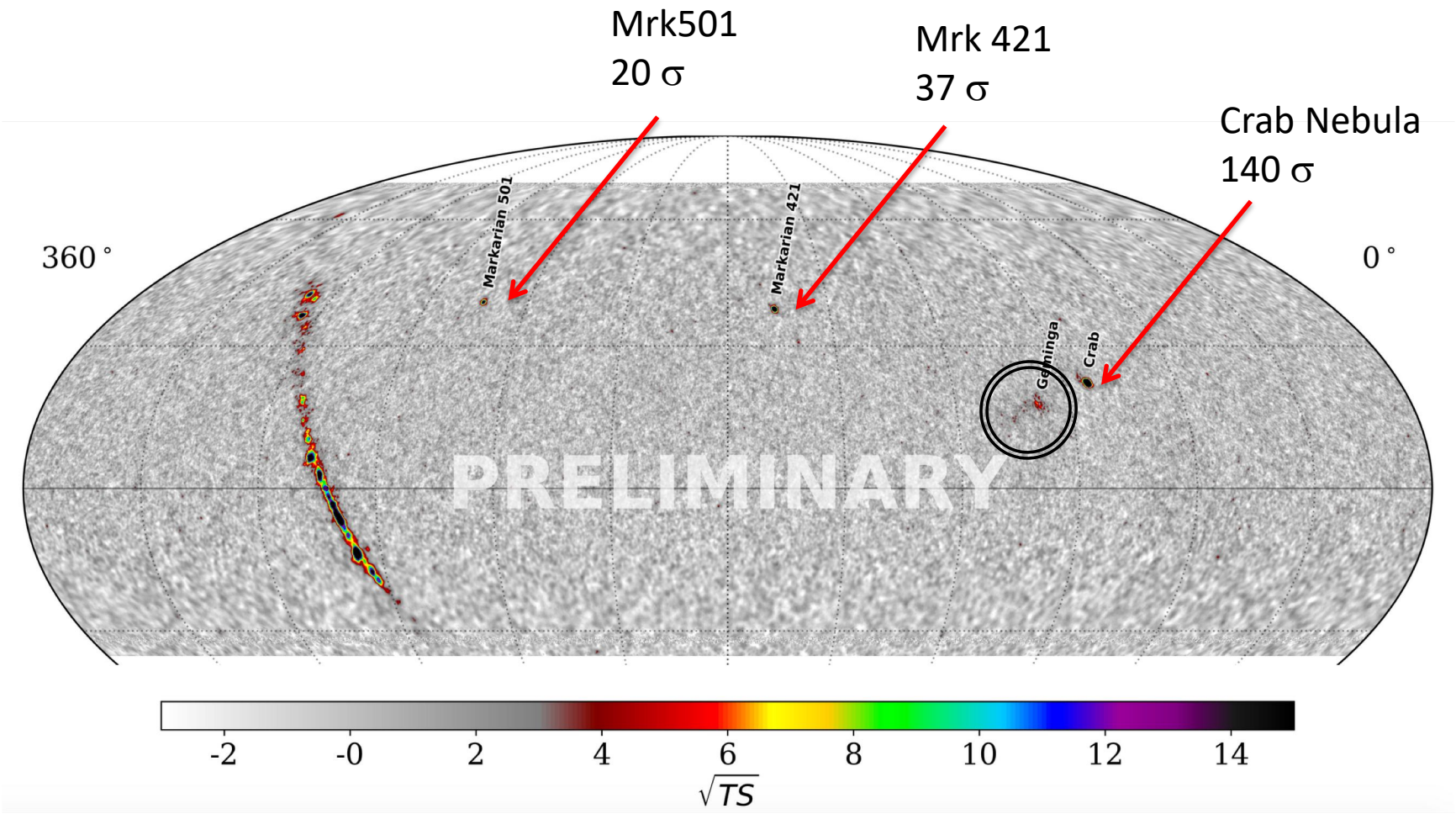
My Current Favorite HAWC Sources

1. **Geminga & Monogem:** HAWC disfavors these nearby pulsars as the sources of local e^+
2. **SS433:** Galactic microquasar is first detection of TeV resolved jets
3. **Cygnus Cocoon:** Stellar winds accelerating hadrons?
4. **DA495:** milliGauss Pulsar Wind Nebula discovered in radio with no known pulsations
5. **2HWC1928+178:** Coincident with Pulsar without x-ray nebula and with possible new x-ray binary

HAWC's Galactic Plane with 2.5 years of data

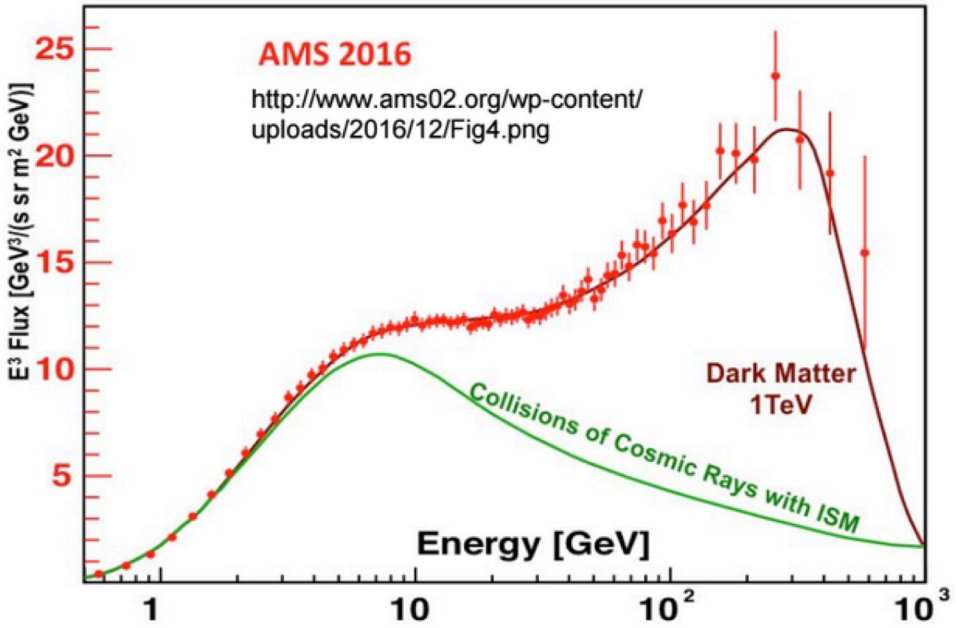


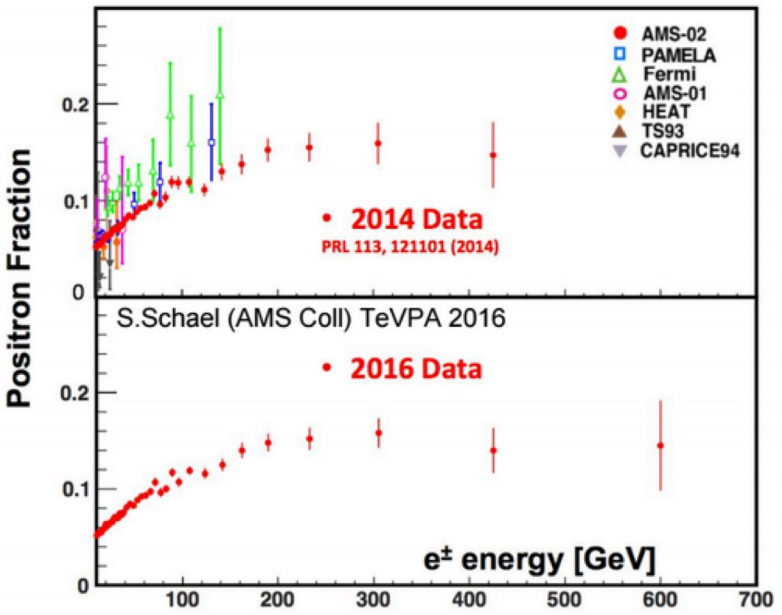
HAWC's 2.5 year Sky Map



2HWC catalog ApJ 2017, arXiv:1702.02992, was 507 days and contained 39 sources of which 10 were new

Local Cosmic Positrons

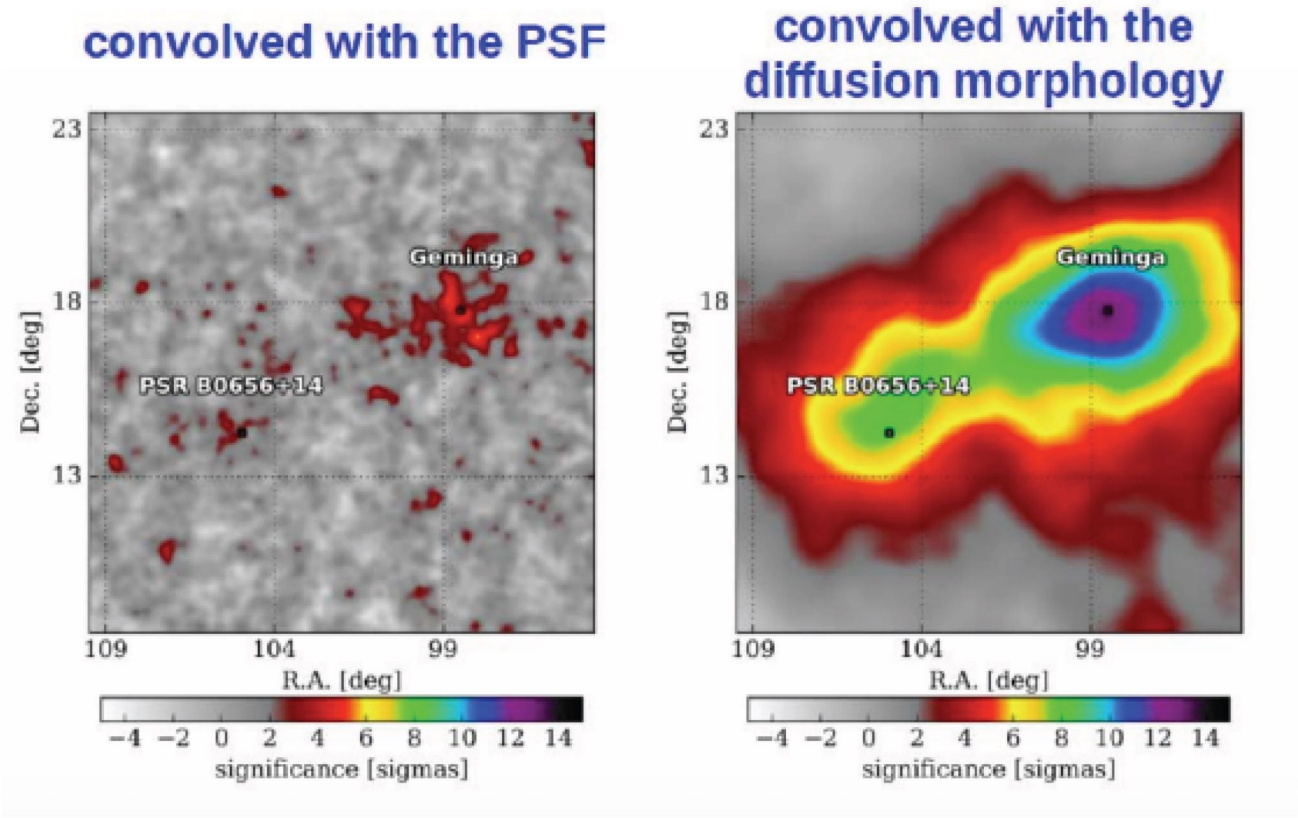




- **AMS-02 on board the International Space Station observes local cosmic rays since 2011**
  - **excellent charge resolution and particle species discrimination**
- **TeV e^-e^+ lose energy quickly and therefore must be produced locally (d < ~100 pc)**
  - ***secondaries* produced by cosmic ray interactions 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**

AMS Positrons from Pulsars?

- Postulated sources of AMS positron excess are nearby, old pulsars
- Geminga and Monogem are the best candidates
- HAWC detects both as very extended TeV gamma-ray sources



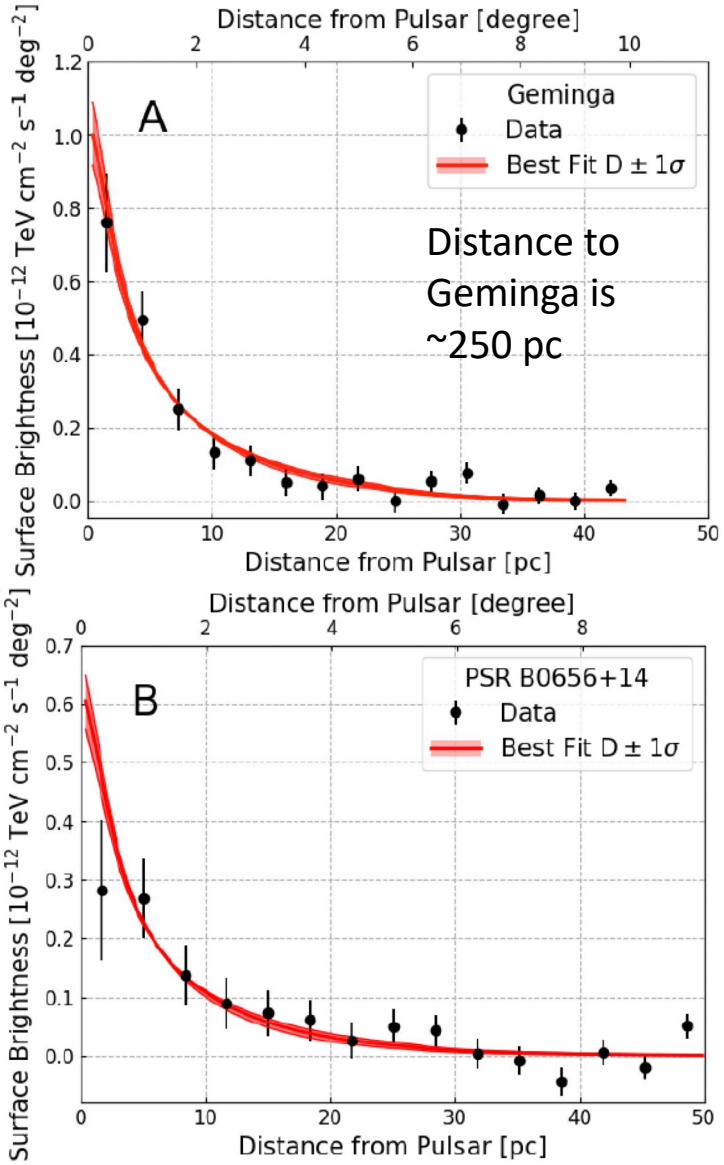
Science

17 November 2017

Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth

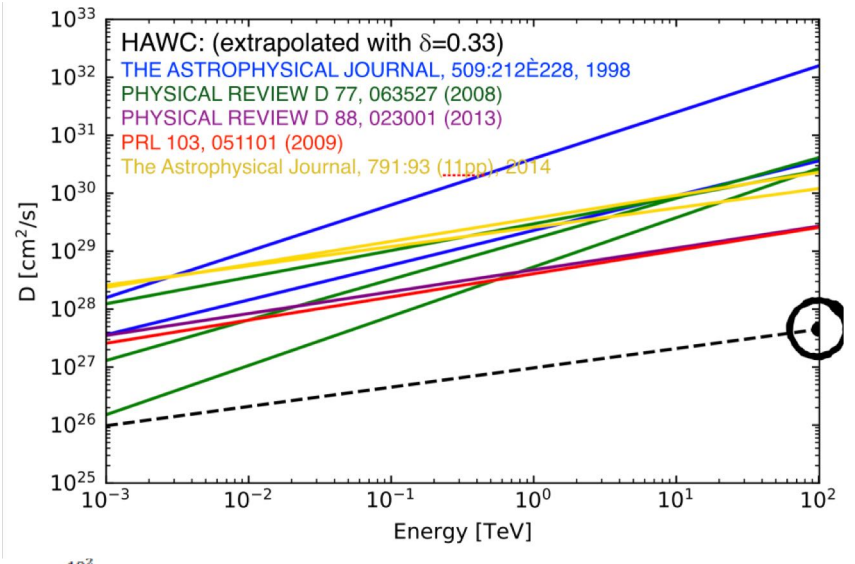
by the HAWC collaboration

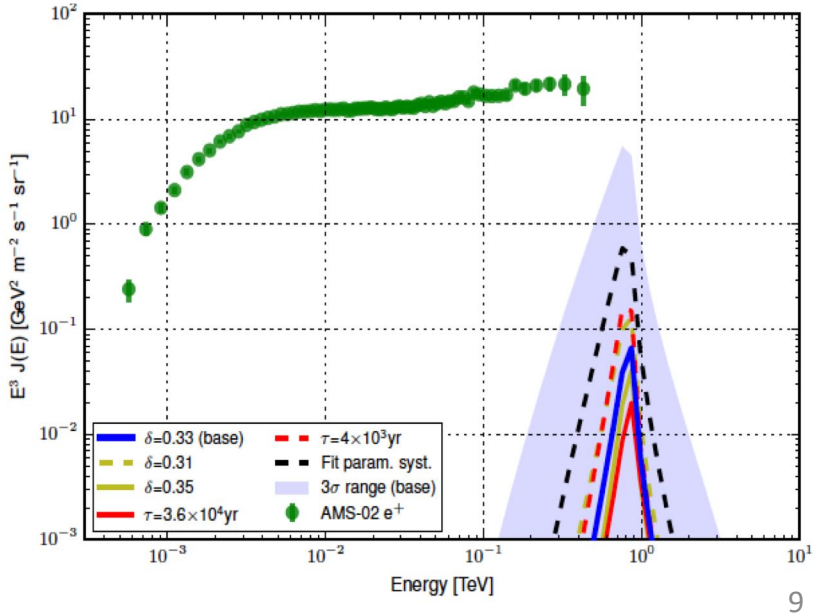
- HAWC observations prove that these sources are indeed accelerating electrons and positrons to multi-TeV energies.
- HAWC observations measure the total energy released in electrons and positrons which is much of their measured spin down energy.
- HAWC observations of the angular extent of these TeV nebula measures the diffusion coefficient of their propagation in the interstellar medium.



HAWC Diffusion vs. Cosmic Ray Secondary Derived Diffusion

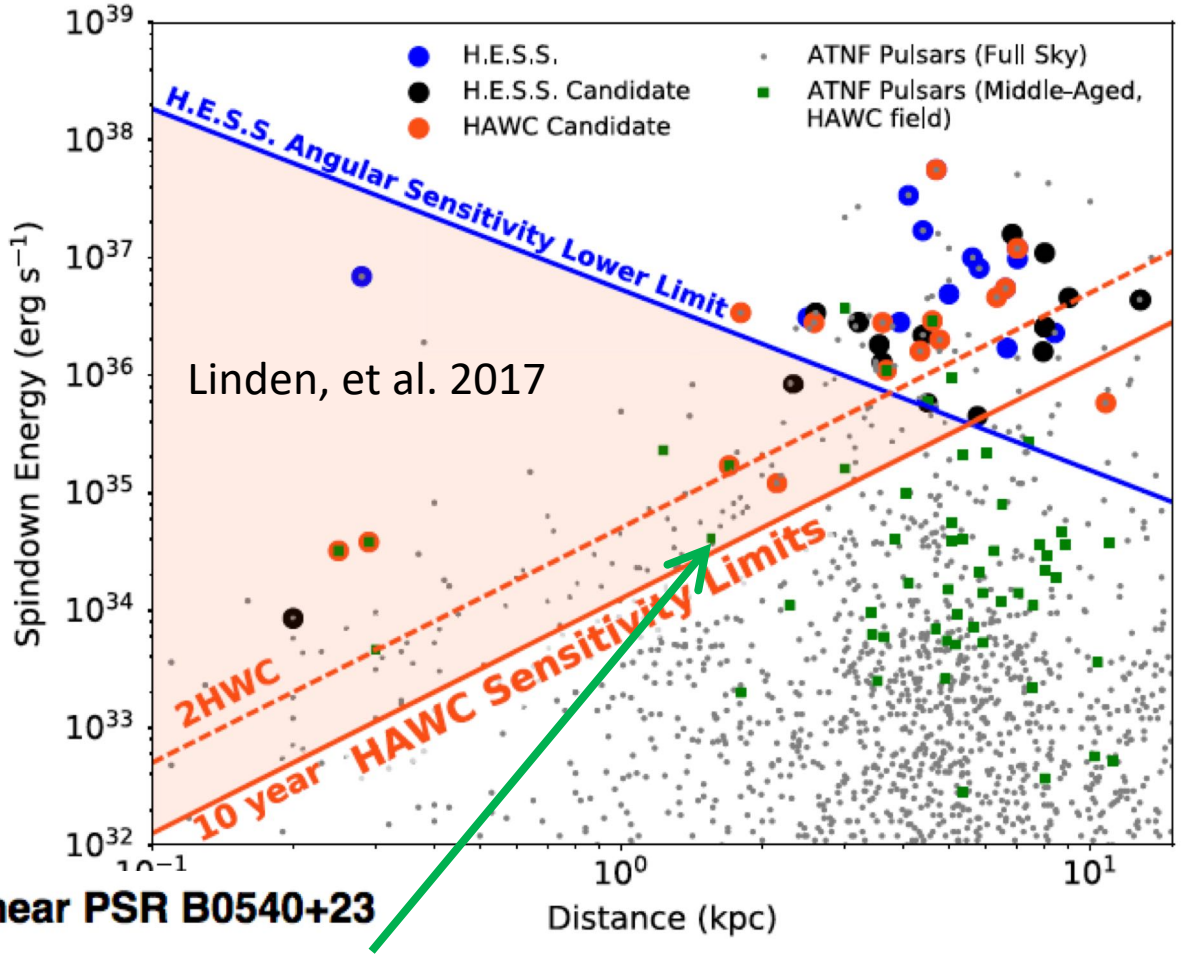
- Diffusion Coefficient, D, Measured by HAWC is much lower than that derived from cosmic ray secondaries
  - The ratio of Boron to Carbon is used to determine D averaged over the ~10 million year lifetime of cosmic rays. However, cosmic rays spend much of their lifetime in the halo of the galaxy where diffusion is probably faster.
- Assuming the HAWC measured D, the positrons from Geminga or Monogem contribute negligibly to the positron flux measured by satellite detectors like AMS-02.
- Hooper & Linden, 2017 argue that the highest energy electrons imply that D cannot be so low, except within ~10pc of the source.





Other Sources of the Positrons

- Annihilation or Decay of Dark matter into Standard Model Particles
- Other Nearby PWN (perhaps as yet undiscovered)
- Nearby Supernova Remnant Shocks
- Nearby X-ray Binaries
- New Theories about Secondaries Produced by Cosmic Ray Propagation

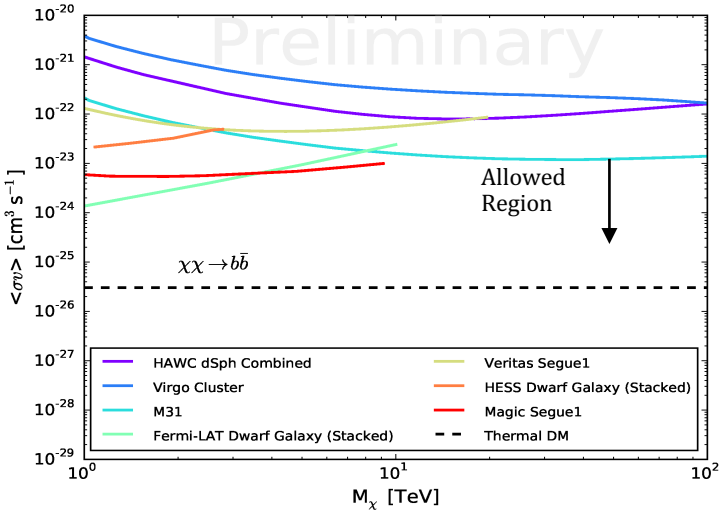


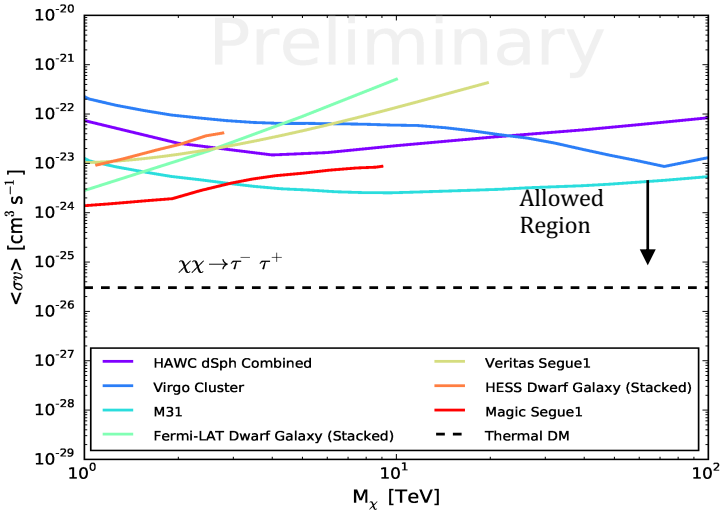
HAWC detection of TeV emission near PSR B0540+23

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)

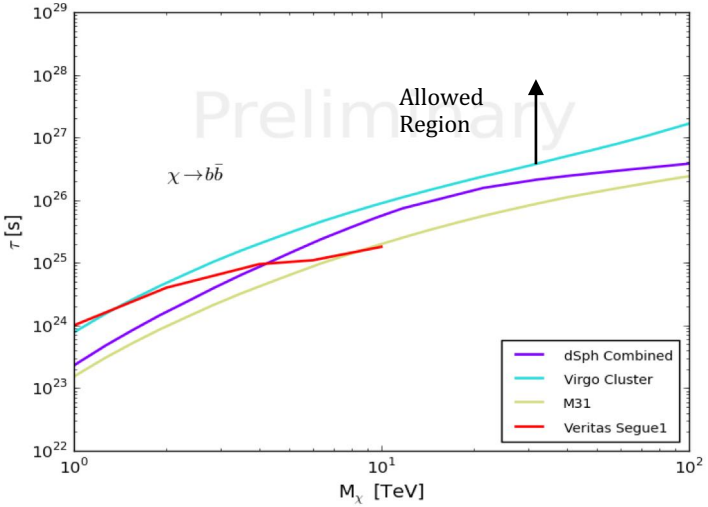
HAWC's DM Limits Are Better than other Gamma-Ray Observatories for masses > a few TeV (except HESS's Galactic Center observation which has uncertain DM density profile)

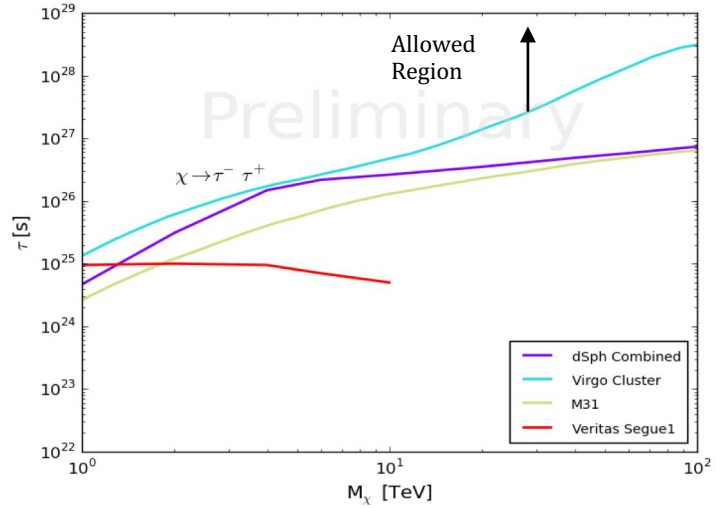
Annihilation





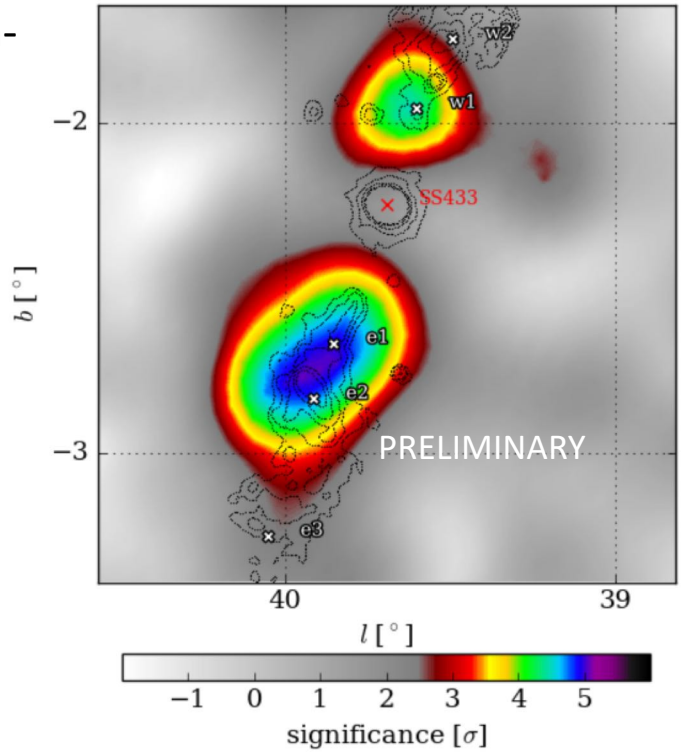
Decay





SS433: Galactic Black Hole in a Binary inside a Supernova Remnant

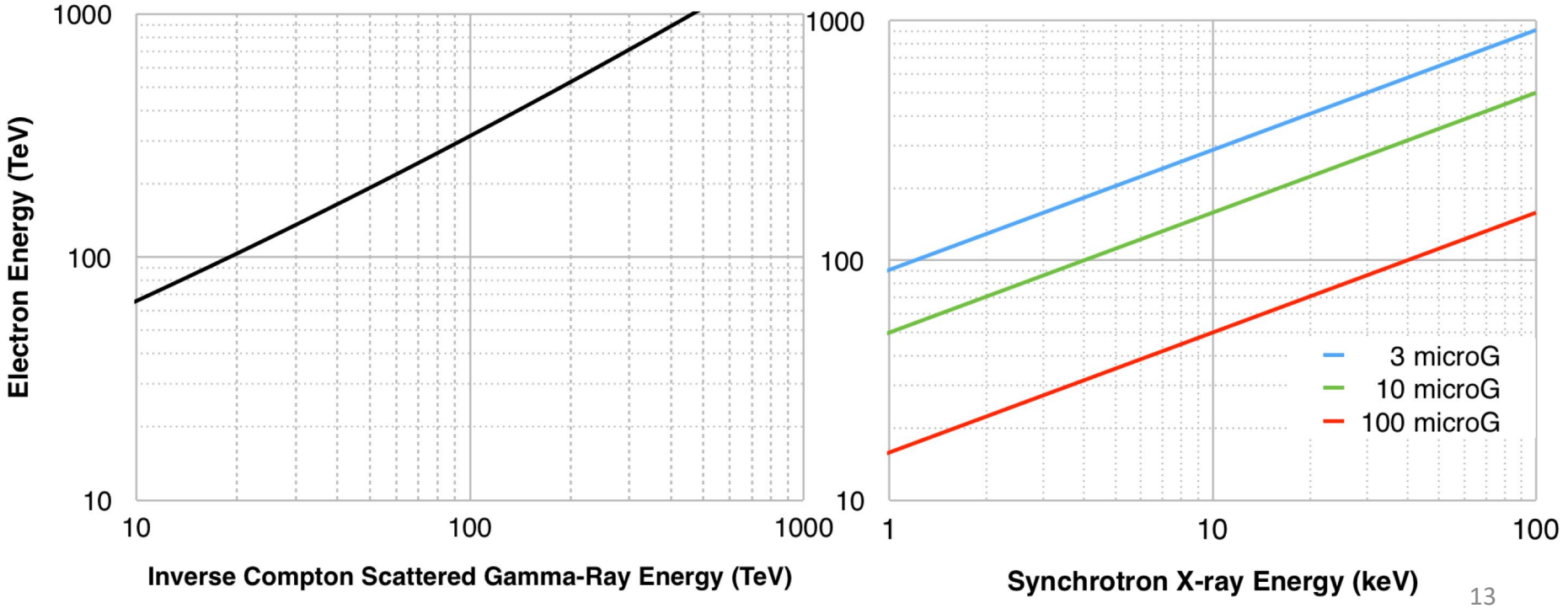
- Jets are postulated to accelerate particles in many gamma-ray sources and probably in the UHECR sources
  - Acceleration could be due to shocks when the jet slows due to interaction with the external medium or due to magnetic reconnection within the intense fields of the jet
- HAWC observation of SS433 is the first direct proof of particle acceleration to > 100TeV 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
  - Electrons radiate synchrotron x-rays and magnetic field is then given by the electron energy determined by HAWC
  - Acceleration does not happen at the black hole because the cooling time of the electrons is too short to make the observed gamma-rays



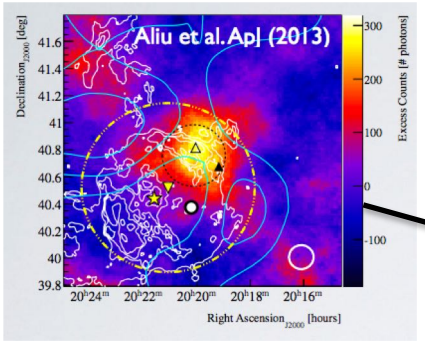
HAWC significance with the overlay of x-ray contours. The HAWC detection is correlated with the jet lobes and not the black hole.

Electrons emit TeV gamma-rays and keV x-rays

- Multi-TeV gamma rays are produced by inverse Compton scattering of the CMB so the electron energy is known. Other photon fields are negligible due to Klein-Nishina cross-section.
- X-ray synchrotron energy depends on the magnetic field & particle energy.
- Therefore, using the TeV determined electron energy, the magnetic field is constrained.



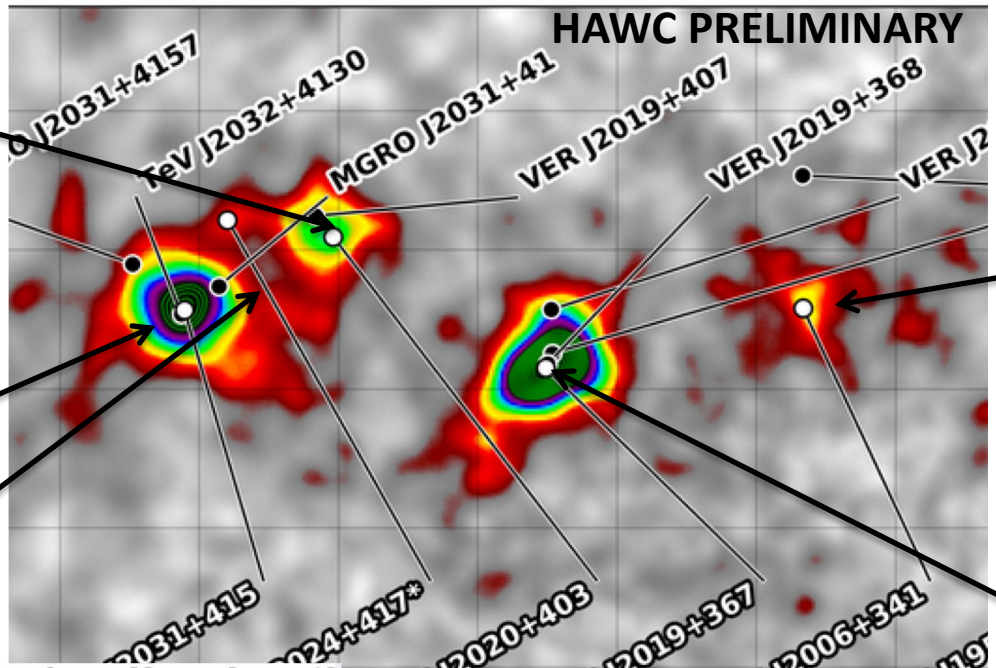
Complex Cygnus Region



VERITAS source

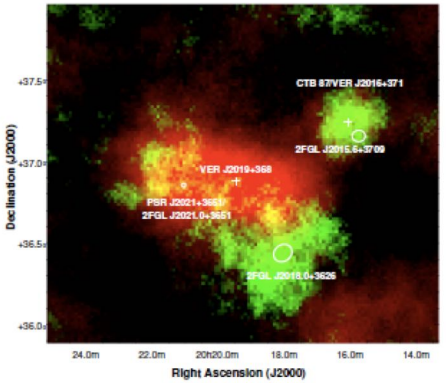
HEGRA Source
PWN in x-ray binary

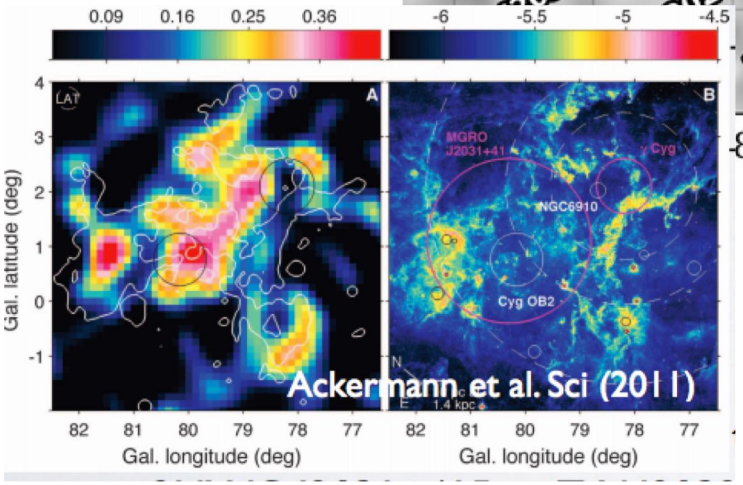
Fermi's
Cygnus Cocoon



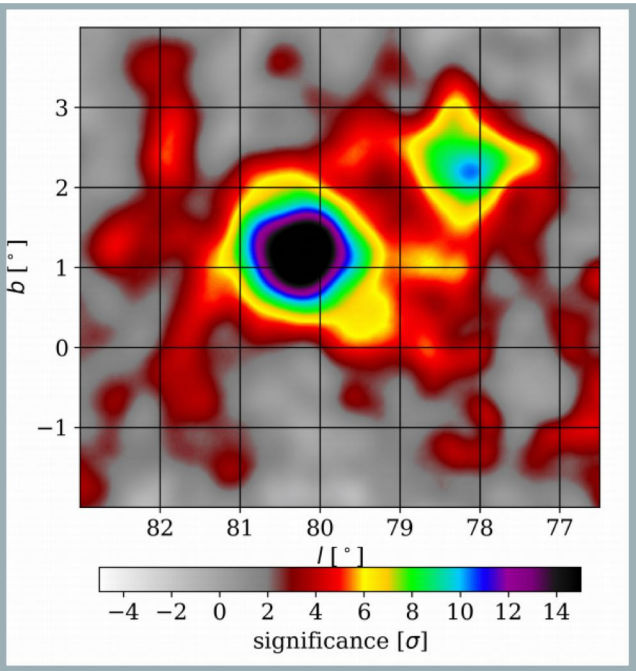
New TeV Source

Multiple VERITAS
sources

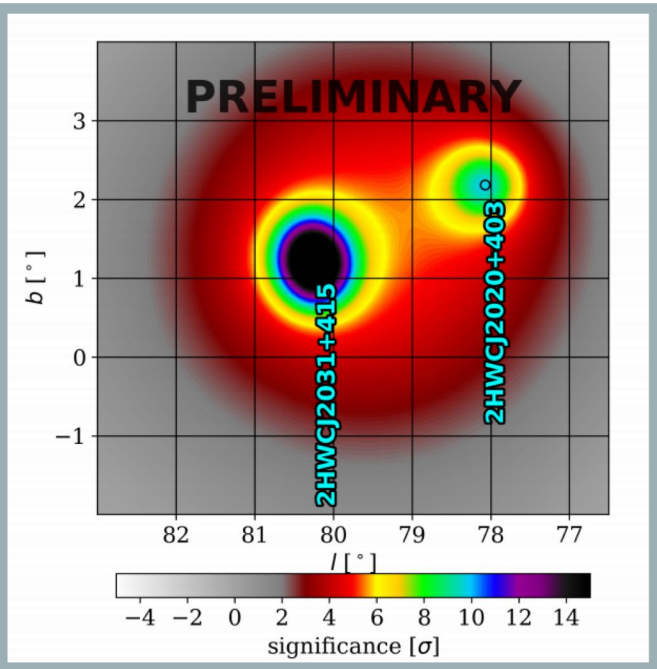




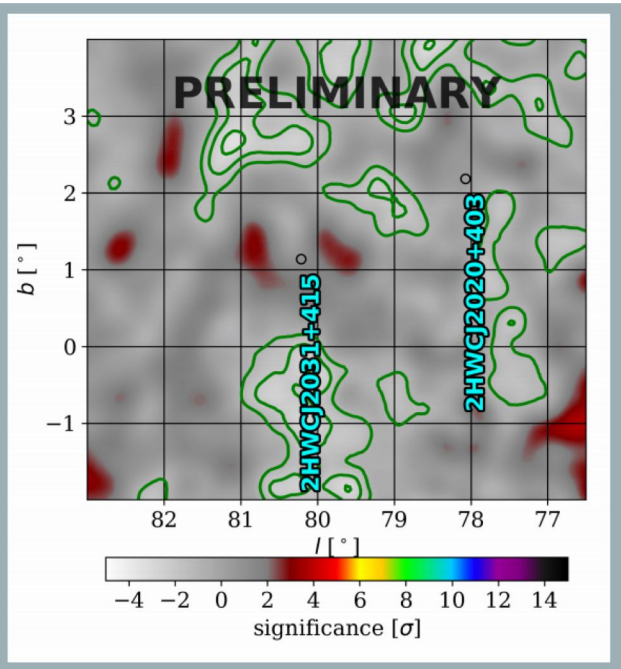
Cygnus Cocoon:
HAWC model with 2 sources + cocoon



Data Map

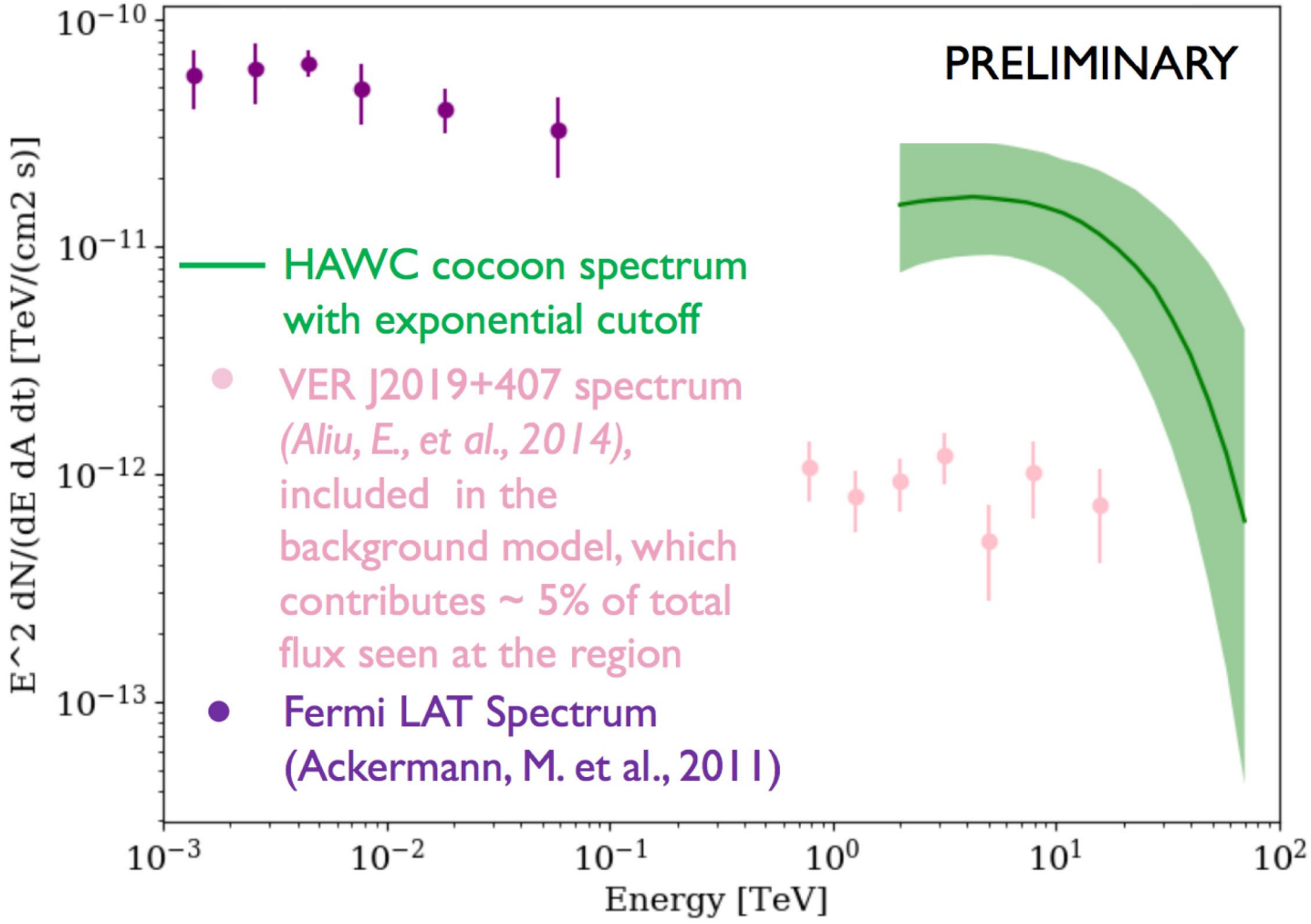


Model Map

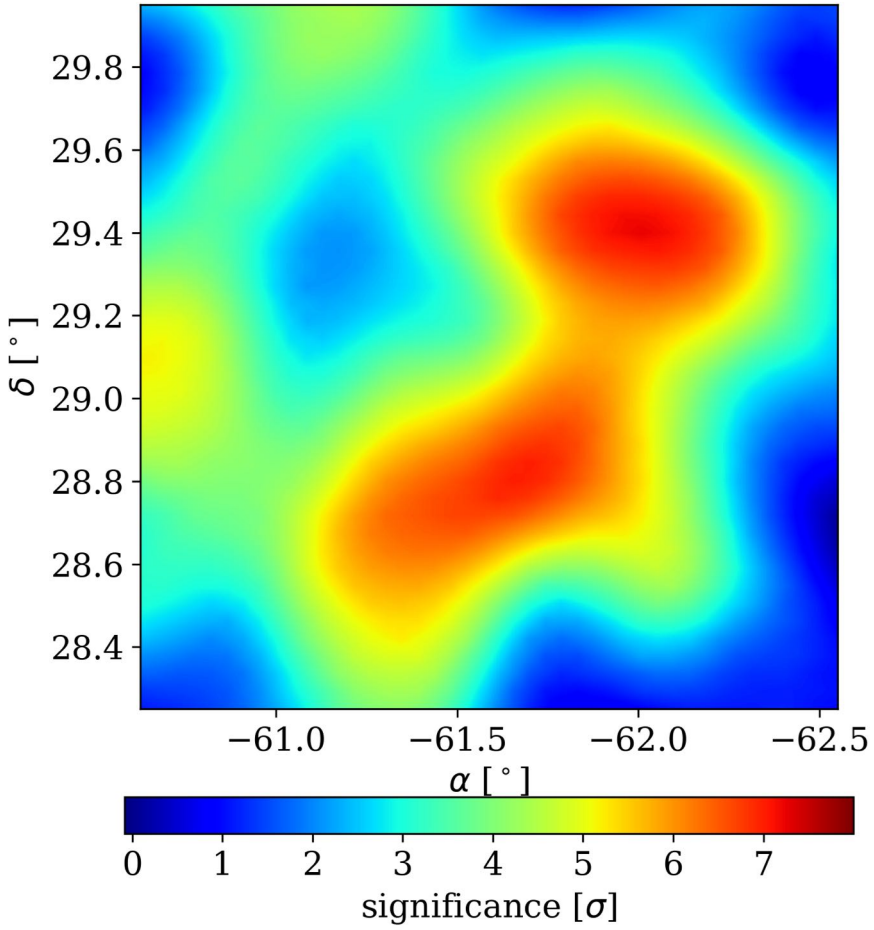


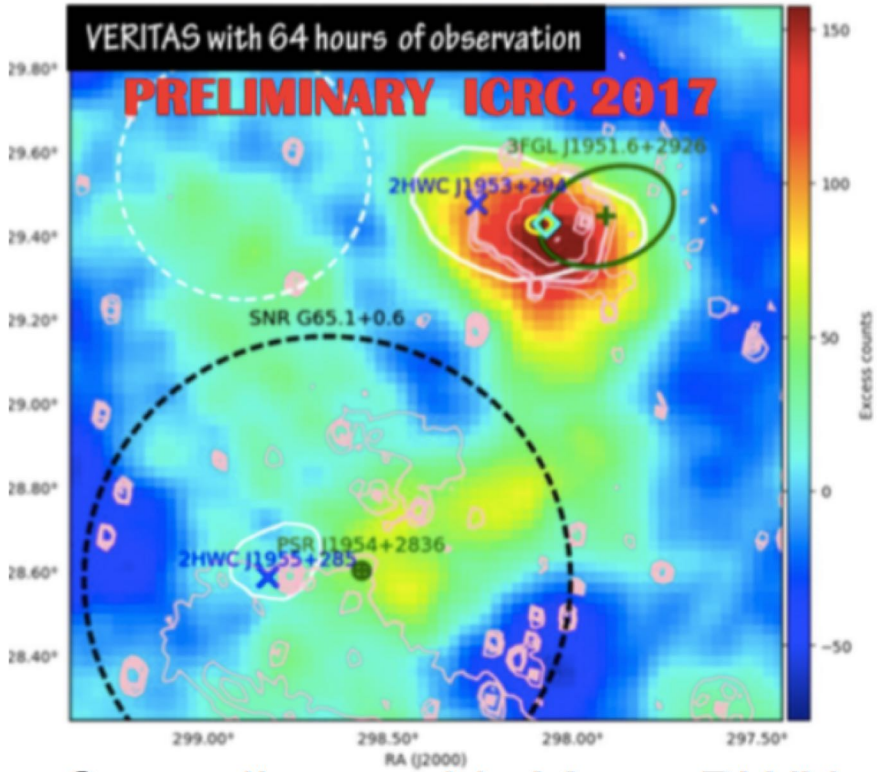
Residual Map
(with -1, -2, -3, -4 contours)

Cocoon Spectrum Breaks



2HWC 1953+294 = DA495?
VERITAS Confirms HAWC detection

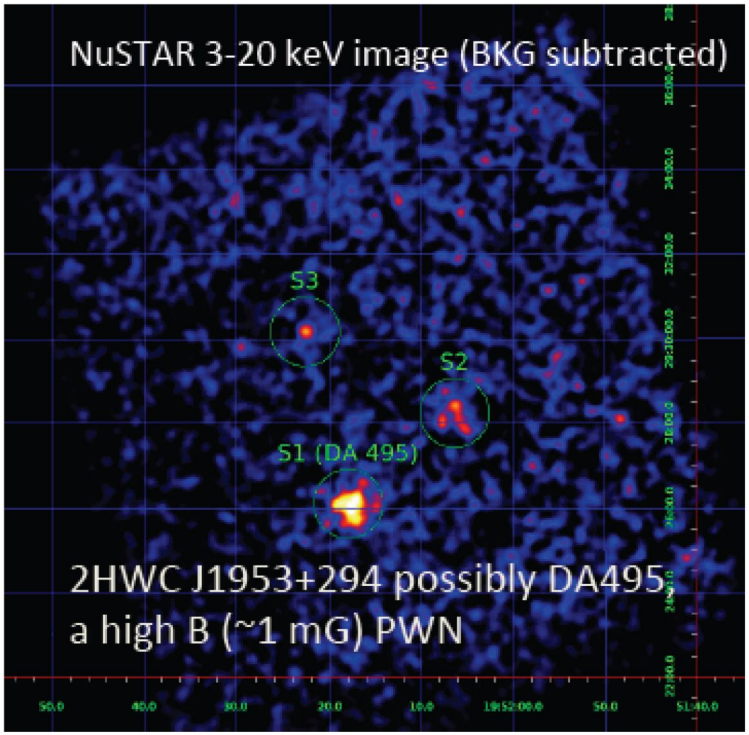


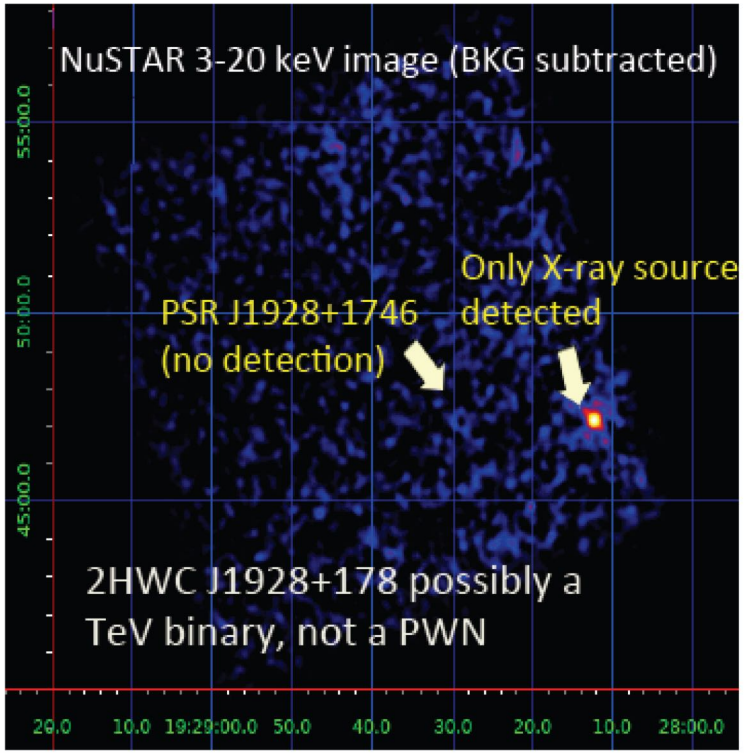


Cyan diamond is X-ray PWN

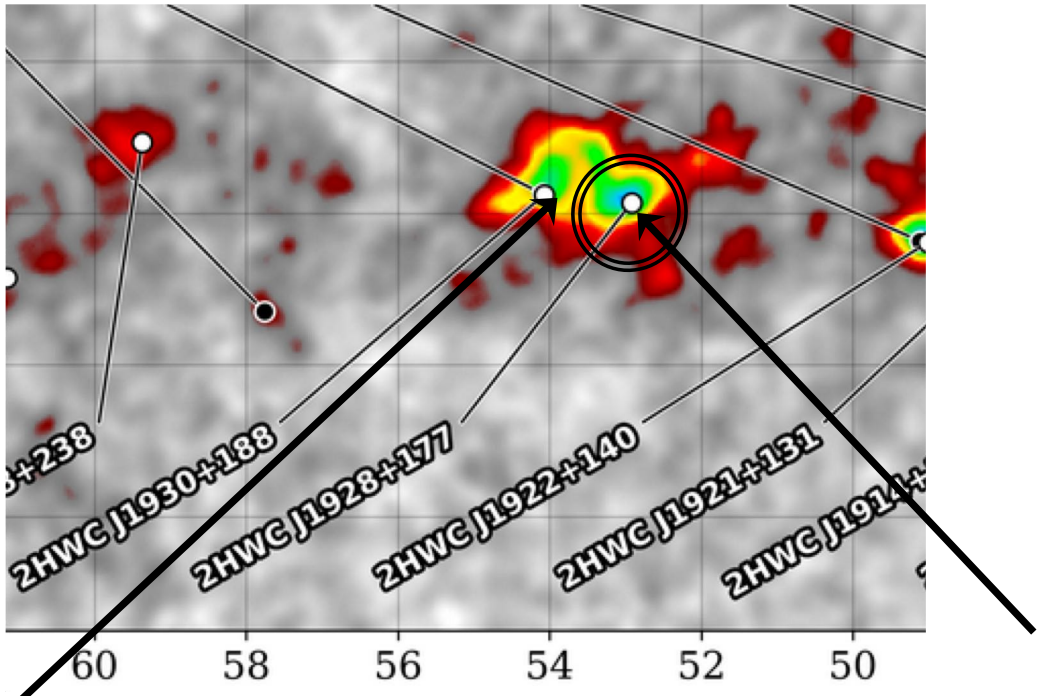
NuSTAR-VERITAS-HAWC Legacy Project

- First 2 NuSTAR observations are very interesting.
  - DA495: A high B field Pulsar Wind Nebula with no pulsar detected
  - A potential TeV binary of which there are only 6 known
- Joint project involves Columbia scientists on VERITAS (Brian Humensky and Reshmi Mukherjee) and on NuSTAR (Kaya Mori and Chuck Hailey)





2HWC1928+177: A new x-ray binary?

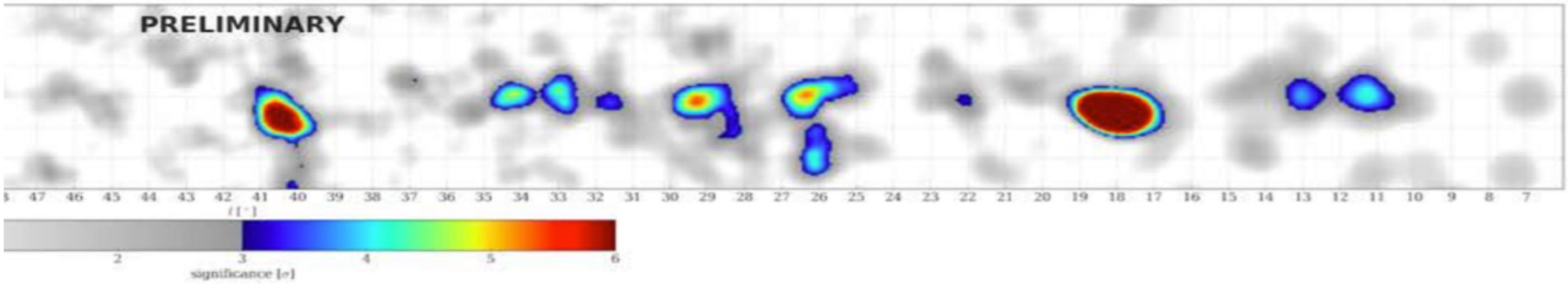


Supernova remnant with very energetic pulsar

Pulsar ~ 8kpc away, but no PWN detected by NuSTAR

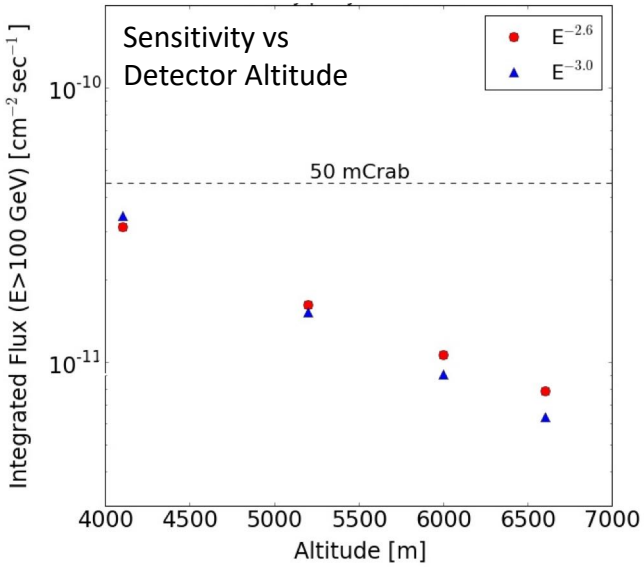
Conclusion

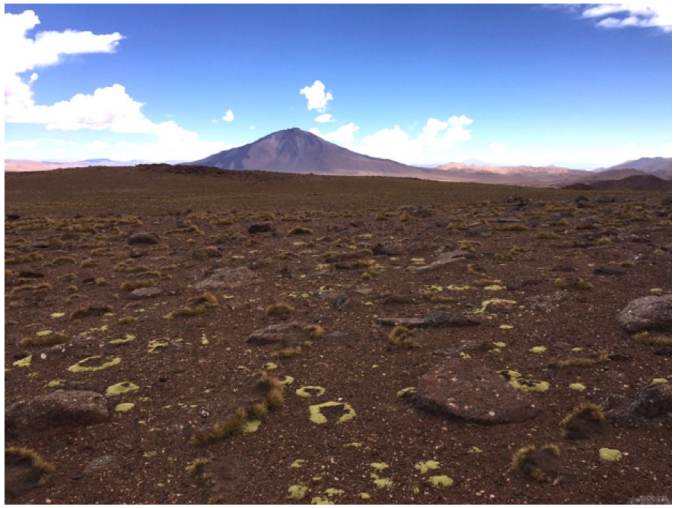
- HAWC is surveying the TeV sky.
- HAWC is detecting interesting new sources.
- HAWC extends energy range on known sources.
  - Outrigger array upgrade nearly complete which increases HAWC's effective area x 3-4 for gamma-rays > ~20 TeV
  - Already detecting multiple sources > 50 TeV



Beyond HAWC

- Higher Altitude than HAWC increases low energy sensitivity and larger than HAWC detector also increases high energy sensitivity
- Developing international collaboration for a southern hemisphere, HAWC-like observatory
- Interested US, European, Mexican, and South American collaborators have had several meetings
  - Visited potential sites in Argentina and Chile
  - Formed Southern Gamma-Ray Survey Observatory (SGSO) Alliance
  - Preparing White Paper for Astronomy and Astrophysics Decadal Survey 2020
- Science Objectives are many
  - Discovering rare transient events requires full sky coverage (e.g. Gamma Ray Bursts & Gravitational Wave Sources)
  - Galactic Center Region
  - TeV Source finder for CTA south





SGSO Alliance (Please Join!)

https://www.sgso-alliance.org/SGSOWiki/doku.php

- Current Focus is writing of white paper on science objectives
- Next face-to-face meeting In Heidelberg Oct 2018

The Southern Gamma-ray Survey Observatory Alliance

The SGSO Alliance mission statement

The Southern Gamma-ray Survey Observatory Alliance is a collection of scientists interested in the science and engineering of an extensive air shower detector located at a high-altitude site in the mountains of South America. SGSO will be sensitive to astrophysical gamma rays and cosmic rays in the energy range between 100 GeV and 100 TeV. The purpose of the alliance is the advancement of such a detector.

The member scientists intend to elucidate the expected scientific discoveries of SGSO and the design parameters required to obtain these discoveries; to prototype and test various elements of the detectors; to explore and prototype several detector designs options; to evaluate the suitability of possible sites; to simulate and optimize the sensitivity of different detector designs; and to investigate and make measurements at potential sites. We will work together to communicate our findings among ourselves and the international scientific community.

The alliance will work toward the completion of whitepapers on the scientific capabilities of the detector, pursue funding and promote SGSO for long term planning within the astrophysics community.

Members of SGSO are entitled to access shared documents and participate in workshops and scientific meetings. Membership is informal and carries no obligation or commitment.

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