The High Altitude Water Cherenkov (HAWC) TeV Gamma Ray Observatory at México,

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Departamento de Fisica, CUCEI

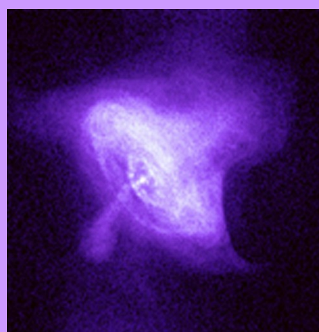
HAWC Member

WASDHA 2018, Moscow, Russia

Nature's Particle Accelerators are Gamma-Ray Sources

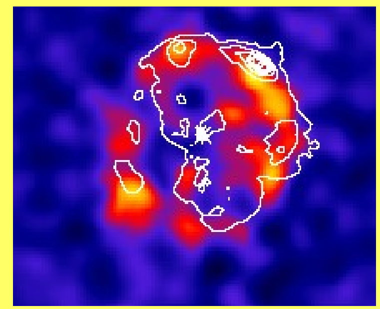
Galactic

Pulsars Wind Nebula

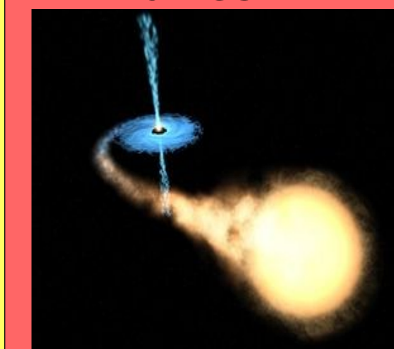


Pulsars

Supernova Remnant

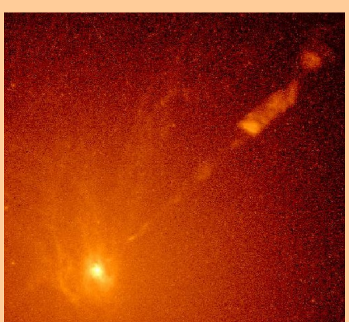


X-ray Binaries

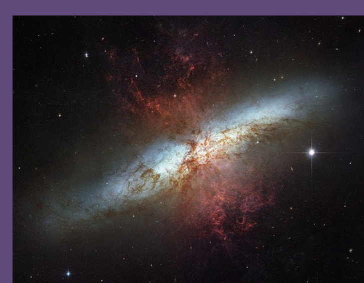


ExtraGalactic

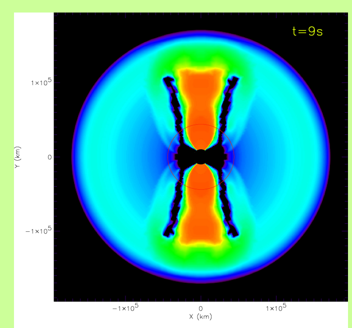
Active Galactic Nuclei



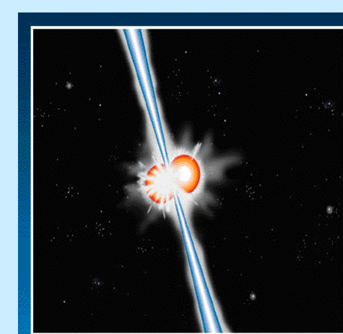
Starburst Galaxies

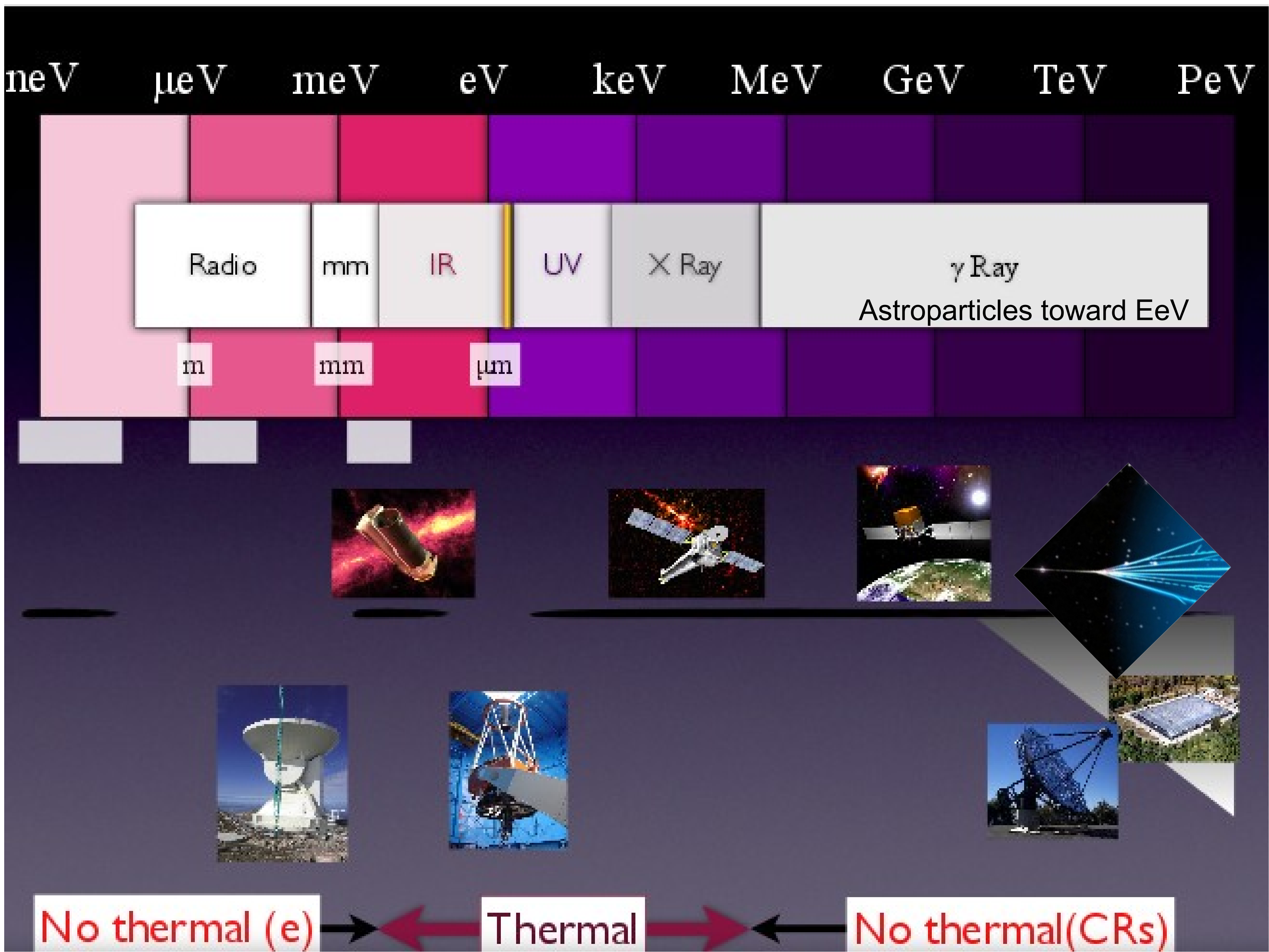


Long Gamma-Ray Burst



Short Gamma-Ray Burst

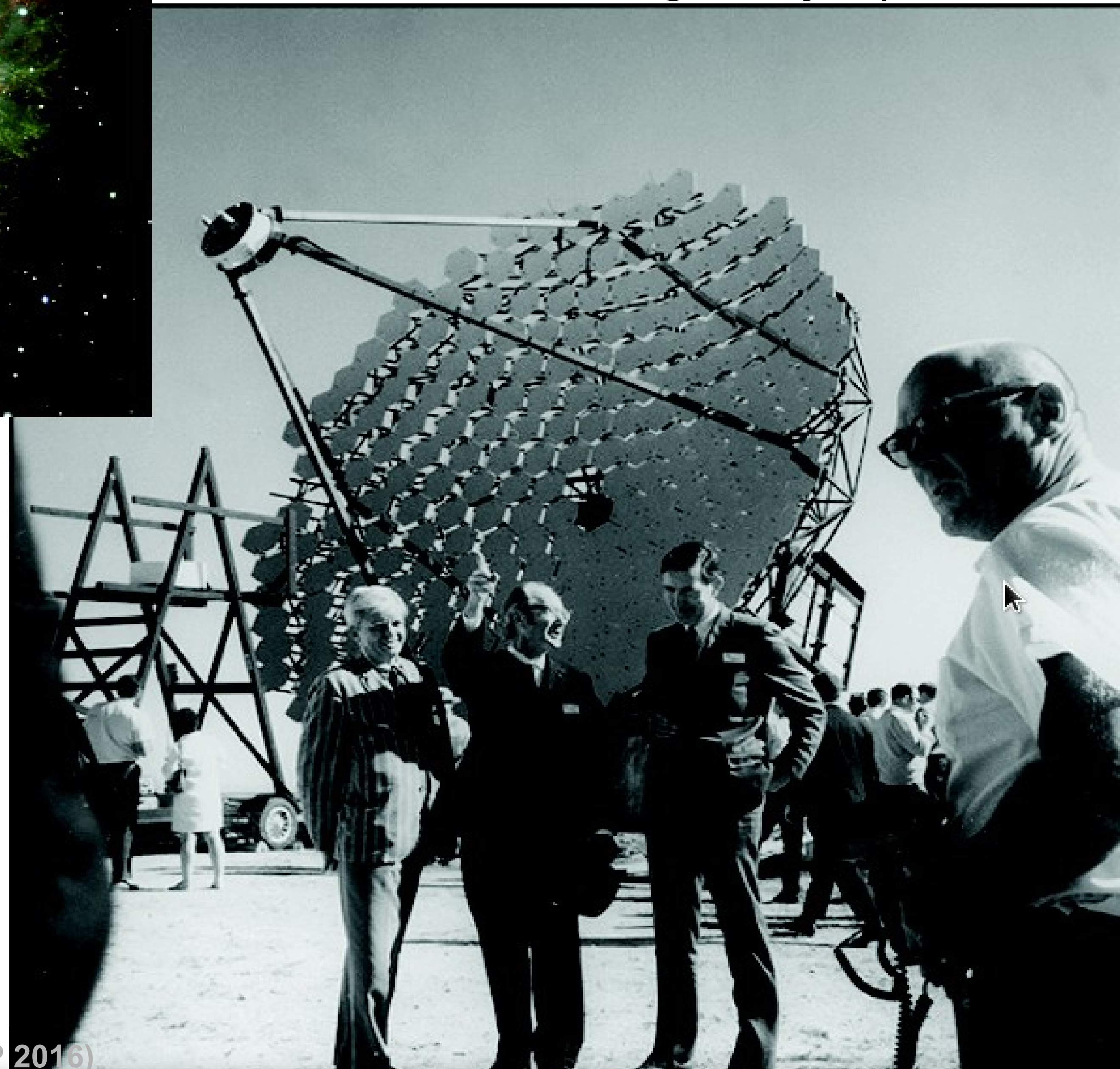




neV
μeV
meV
eV
keV
MeV
GeV
TeV
PeV
Radio
mm
IR
UV
X Ray
γ Ray
Astroparticles toward EeV
m
mm
μm
No thermal (e)
Thermal
No thermal(CRs)

The Birth of the VHE Gamma Ray Astrophysics

The first success full detection of the gamma-ray emission above 0.7 TeV from the Crab nebula in 1989 by the Whipple collaboration: 5 sigma in 50 hrs (159 pixel camera + Hillas image analysis)



A.E. Chudakov and G.T. Zatsepin (1961). Crimea Obs. (1961.1963)

The upper limit obtained by Chudakov was a proof of direct acceleration of electrons in the Crab Nebula (1961)

WATER VAVILOV-CHERENKOV EFFECT

First Large Water Cherenkov Detector
by Aleksandr Evgenievich Chudakov (1959-1960)

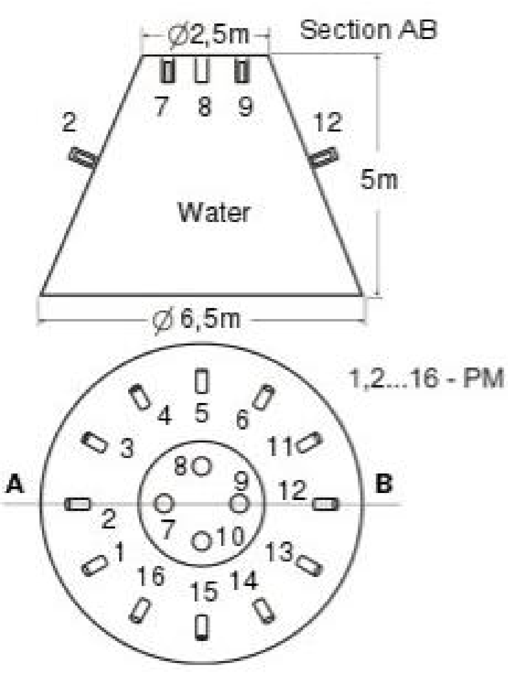


Fig. 4. The design of the Large Water Cherenkov Detector

This detector was constructed by Chudakov in 1959. This facility in the form of a truncated cone contained nearly 85 t of cleared water and 16 large PM tubes (the diameter of photo-cathode 15 cm). This detector was but a short episode in the Chudakov's activity, and, as usual, he did not published anything about it.

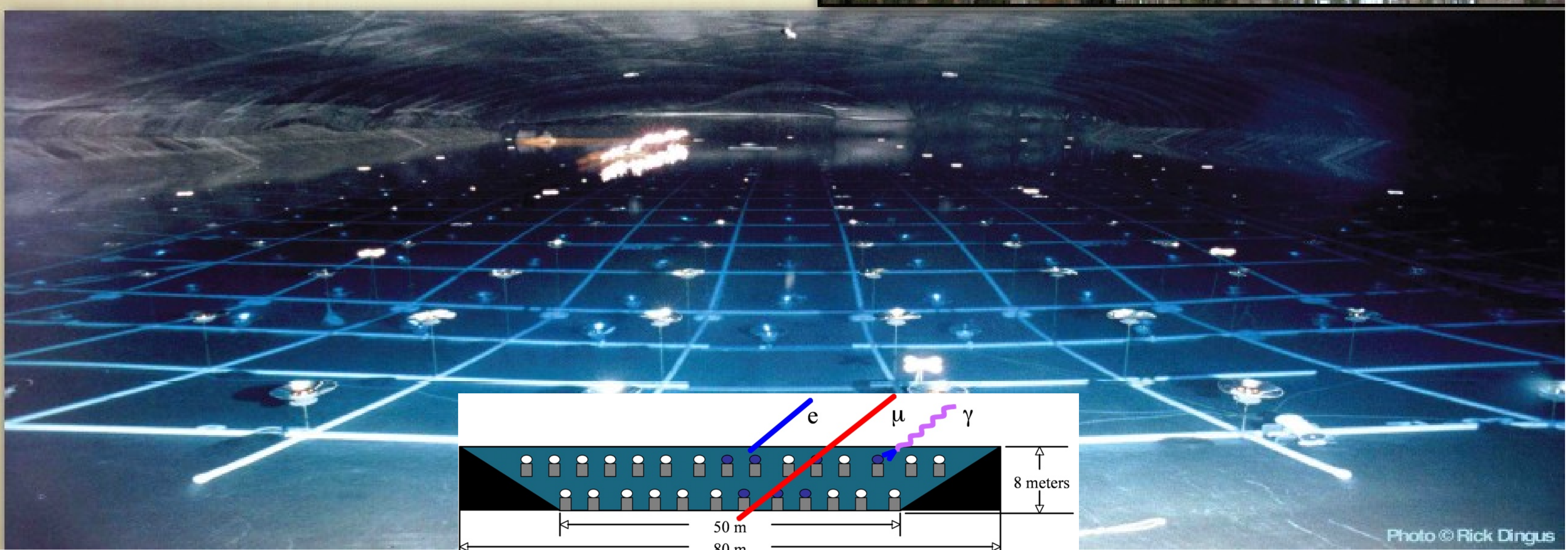
A.S Lidvansky

.... Father of the Gamma Ray Astrophysics

1 First generation of WCD

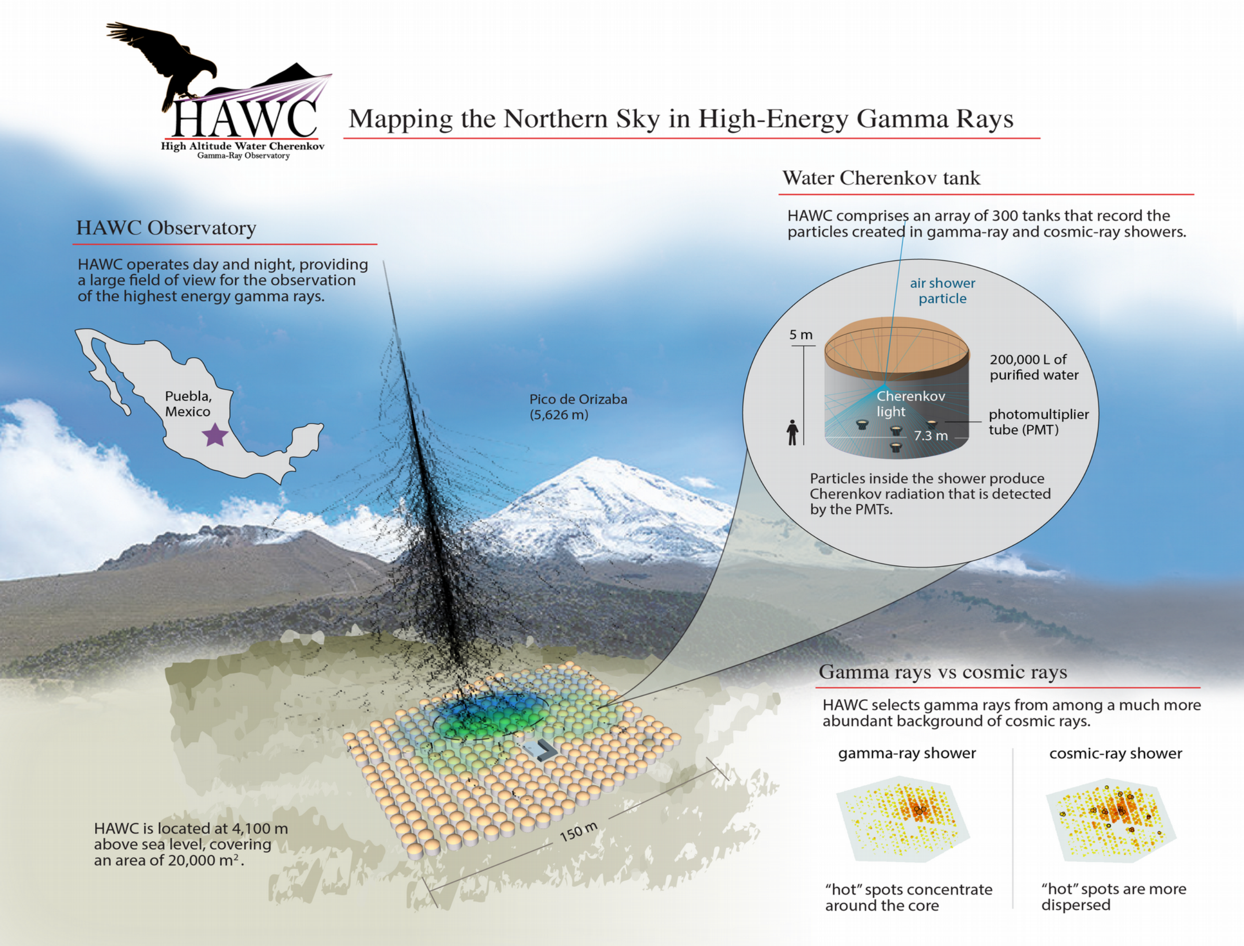
MILAGRO

- 2600m ASL (NM, USA)
- 2000-2008
- Water Cherenkov detector
- 898 PMTs
  - -450 top/273 bottom
  - -175 outriggers
- 40,000m² area
- 1700 Hz trigger rate
- 0.4°-0.9° resolution
- 2-40 TeV median energy



HAWC SITE

Latitude: 18°59.7’N
Longitude: 97°18.6’W



	Milagro	HAWC
Detector Area	3500 m^2 /2100 m^2	20,000 m^2
Time to 5σ on the Crab	120 days	5hrs
Median Energy	4 TeV	1 TeV
Angular Resolution	$0.40^\circ – 0.75^\circ$	$0.25^\circ – 0.50^\circ$
Energy Resolution at 5 TeV	140%	72%
Energy Resolution at 50 TeV	85%	35%
Hadron Rejection efficiency at 10 TeV	90%	>99.5%
Q for gamma/hadron rejection	1.6	5
Time to detect 5 Crab flare at 5σ	5 days	10 minutes
Eff. Area at 100 GeV	5 m^2	100 m^2
Eff. Area at 1 TeV	10^3 m^2	$20x10^3$ m^2
Eff Area at 10 TeV	$20x10^3$ m^2	$50x10^3$ m^2
Eff Area at 50 TeV	$70x10^3$ m^2	$70x10^3$ m^2
Volume of Universe where $3x10^{-6}$ erg/cm^2 GRB is detectable	7 Gpc^3	47 Gpc^3
Flux Sensitivity to a Crab-like source (1 year) (5σ detection)	625 mCrab	45 mCrab

The HAWC Collaboration

Mexico

Instituto Nacional de Astrofísica, Óptica y Electrónica
Universidad Nacional Autónoma de México
- Instituto de Astronomía UNAM
- Instituto de Ciencias Nucleares UNAM
- Instituto de Física UNAM
- Instituto de Geofísica UNAM

Benemérita Universidad Autónoma de Puebla
Instituto Politécnico Nacional
- Centro de Investigación y Estudios Avanzados
- Centro de Investigación en Cómputo - IPN

Universidad Autónoma de Chiapas
Universidad Autónoma del Estado de Hidalgo
Universidad de Guadalajara
Universidad Michoacana de San Nicolás de Hidalgo
Universidad Politécnica de Pachuca

United States

Los Alamos National Lab
University of Maryland
Georgia Institute of Technology
Michigan State University
Michigan Technological University
Pennsylvania State University
NASA GSFC
University of New Mexico
University of Rochester
University of Utah
University of Wisconsin

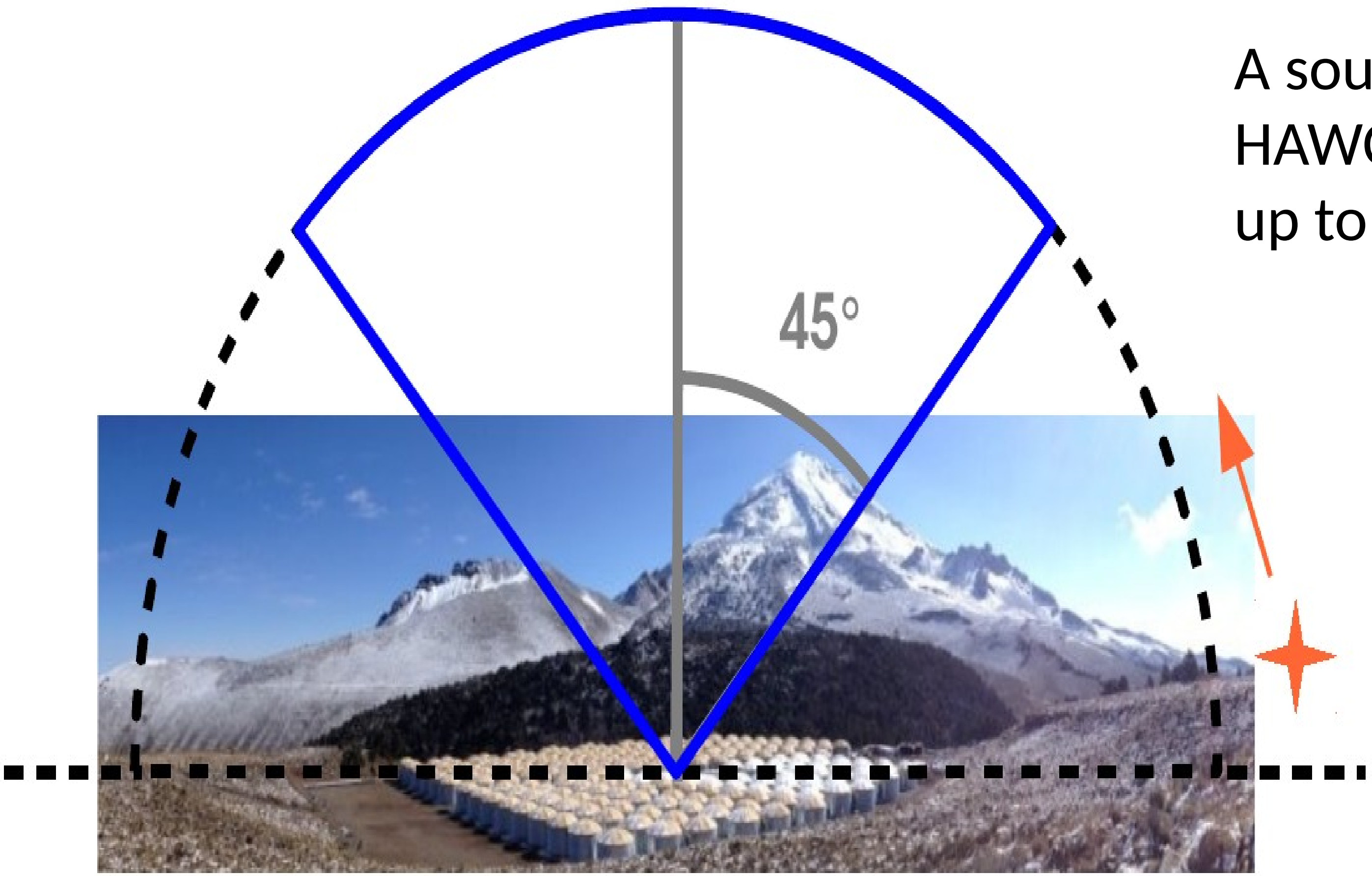
Europe

Max Planck Institute, Heidelberg
Univeristy of Costa Rica
Krakow Nuclear Institute, Poland


www.webcamsdemexico.com
inaoe

HAWC field of view

Field of view down to ~45° from zenith:
Scanning 2/3 of the sky each day through the rotation of the Earth



A source is visible for HAWC
up to **6 hours per day**

- **Photo Credit:: The HAWC Collaboration**

Differential Sensitivity

Differential Sensitivity per Quarter Decade of Energy

How to think about HAWC Sensitivity:

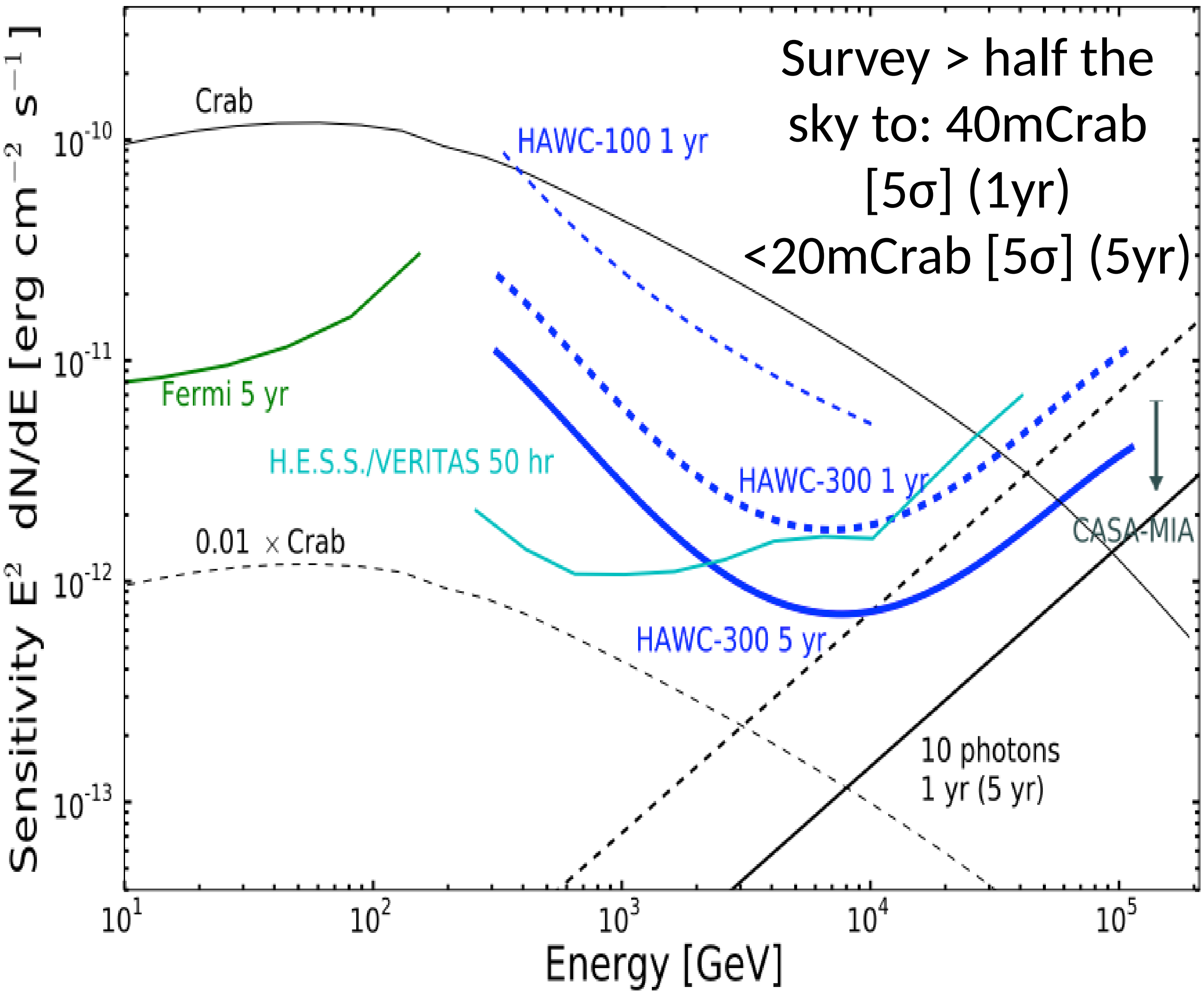
Instantaneous sensitivity about 15-20x less than IACTs:

- ~2-3x from Angular Resolution
- ~5x from energy threshold.

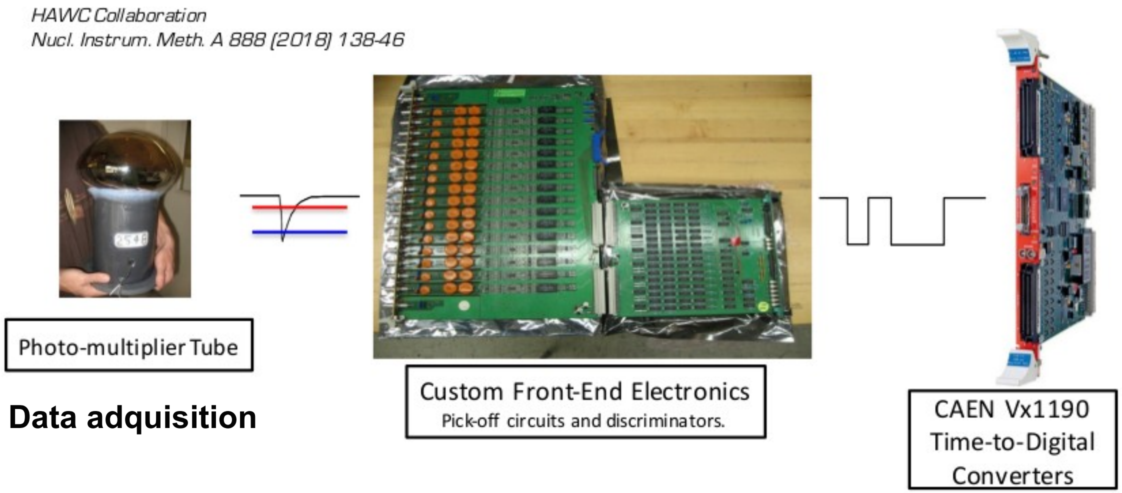
Exposure (sr yrs) is 2000-4000x higher.

~1500 hrs/src/yr

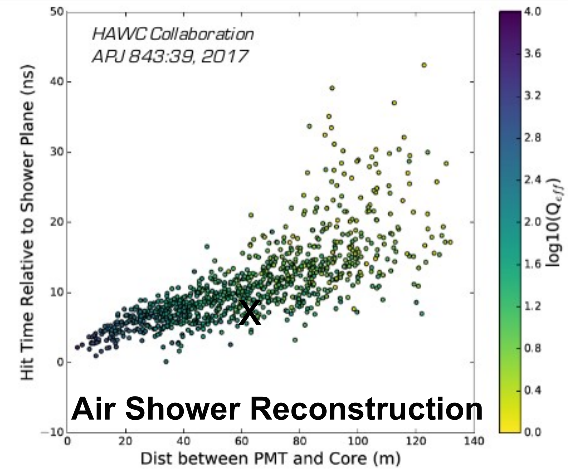
For hard or extended sources, HAWC improves relative to IACTs



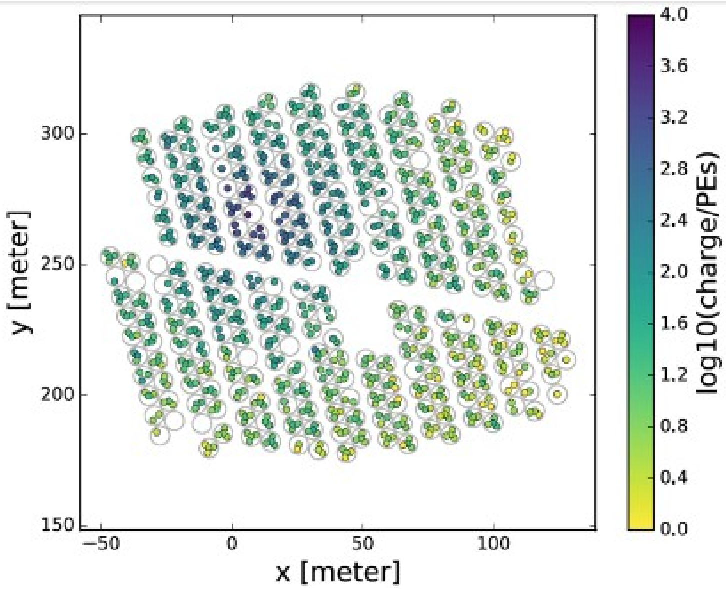
http://arxiv.org/abs/1306.5800 Astroparticle Physics 2013

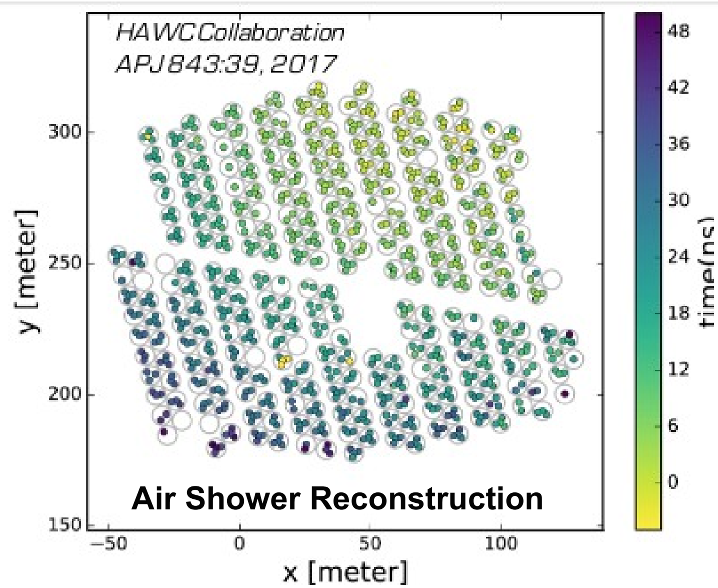


- The system is based on measuring the ToT (Time over Threshold)
- HAWC uses the TDCs as continuous recorders of edge timing: the experiment acquires and transmits all of the TDC-digitized edges to a computer farm
- The trigger happens at software level: a PMT multiplicity trigger



- Display of the arrival time distributions of a shower consistent with a gamma-ray from the Crab
- By precisely taking into account the shower curvature it is possible to get an angular resolution of up to 0.15°



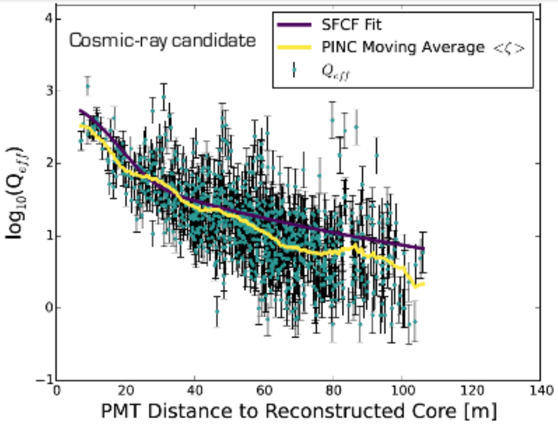


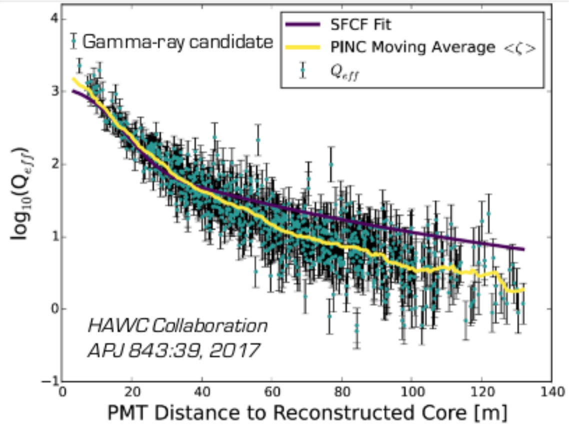
- ✓ Arrival Direction determined by relative timing (~1ns precision) of Cherekov Light Pulses observed in tanks
- ✓ Primary Energy determined by "size" of shower.
- ✓ Lateral distribution and curvature of shower front gives more information about energy
- ✓ Cosmic Ray Background rejection from clumpiness of shower 'footprint'

Step	Description	Hit selection
1	Calibration	
2	Hit selection	
3	Center of mass core reconstruction	Selected hits
4	SFCF core 1st pass	Selected hits
5	Direction 1st pass	Selected hits

Step	Description	Hit selection
6	SFCF 2nd pass	SH within 50 ns of 1st plane
7	Direction 2nd pass	SH within 50 ns of 1st plane
8	Compactness, $\mathcal{C}$	SH within 20 ns of 2nd plane
9	PINCness, $\mathcal{P}$	SH within 20 ns of 2nd plane

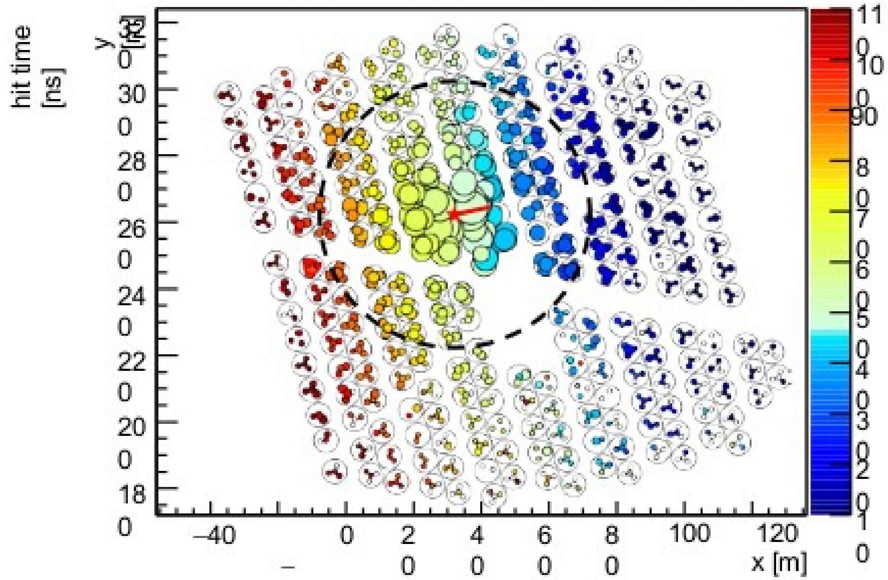
- **Credit: H. L. Vargas and W. Springer; The HAWC Collaboration**





"Smoothness" ➔ Photon

Likely Gamma-Ray Event



CxPE_{40}: Largest Q_{eff} outside a radius of 40 m from the shower core

N_{hit}: Number of PMT hits during the air shower

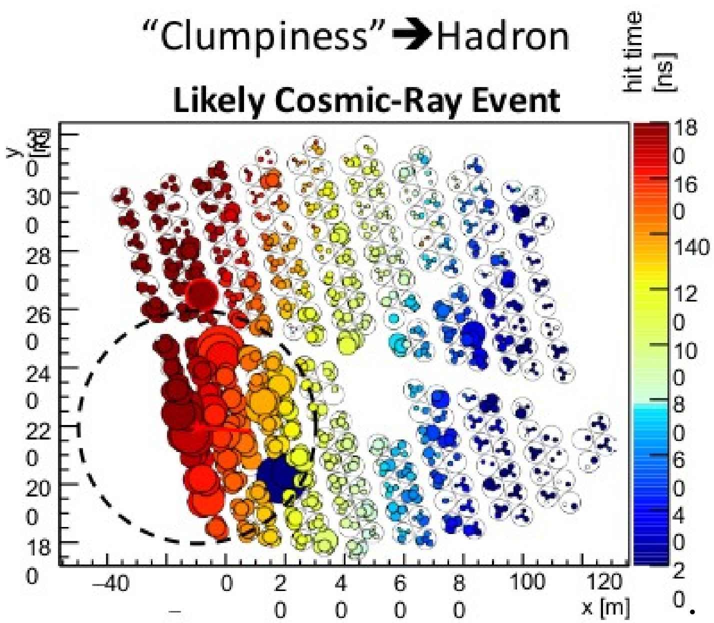
$$\mathcal{C} = \frac{N_{hit}}{CxPE_{40}}$$

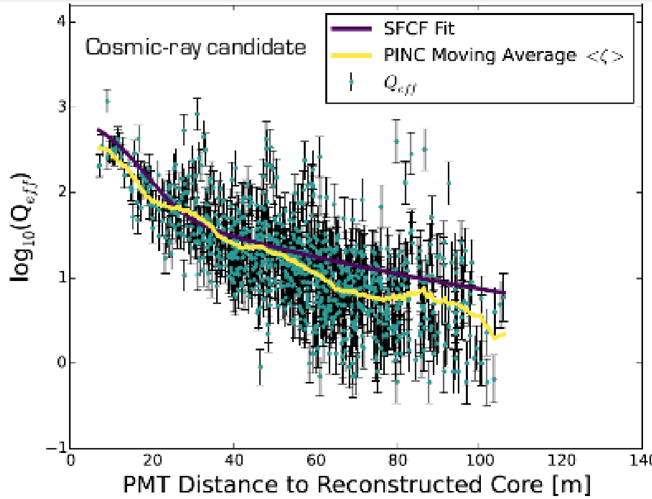
For hadronic showers $\mathcal{C}$ is small

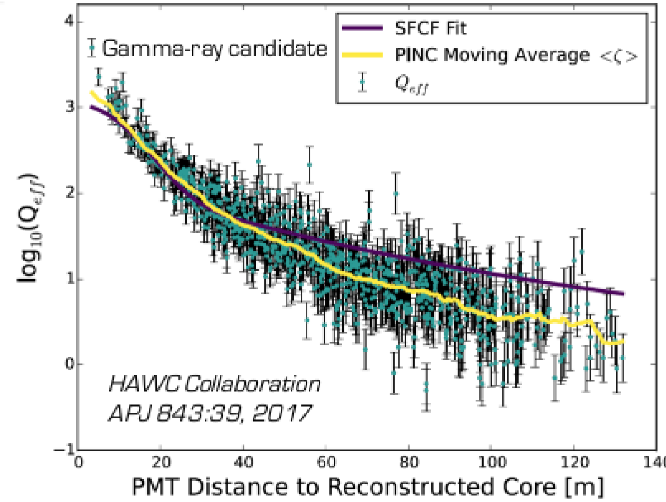
Gamma / Hadron Rejection

"Clumpiness" ➔ Hadron

Likely Cosmic-Ray Event







PINCness (**P**arameter for **I**dentifying **N**uclear **C**osmic rays)

$$\mathcal{P} = \frac{1}{N}\sum_{i=0}^{N}\frac{(\zeta_i - \langle\zeta_i\rangle)^2}{\sigma^2_{\zeta_i}}$$

$\zeta_i = \log_{10}(\mathrm{Q_{eff,i}})$

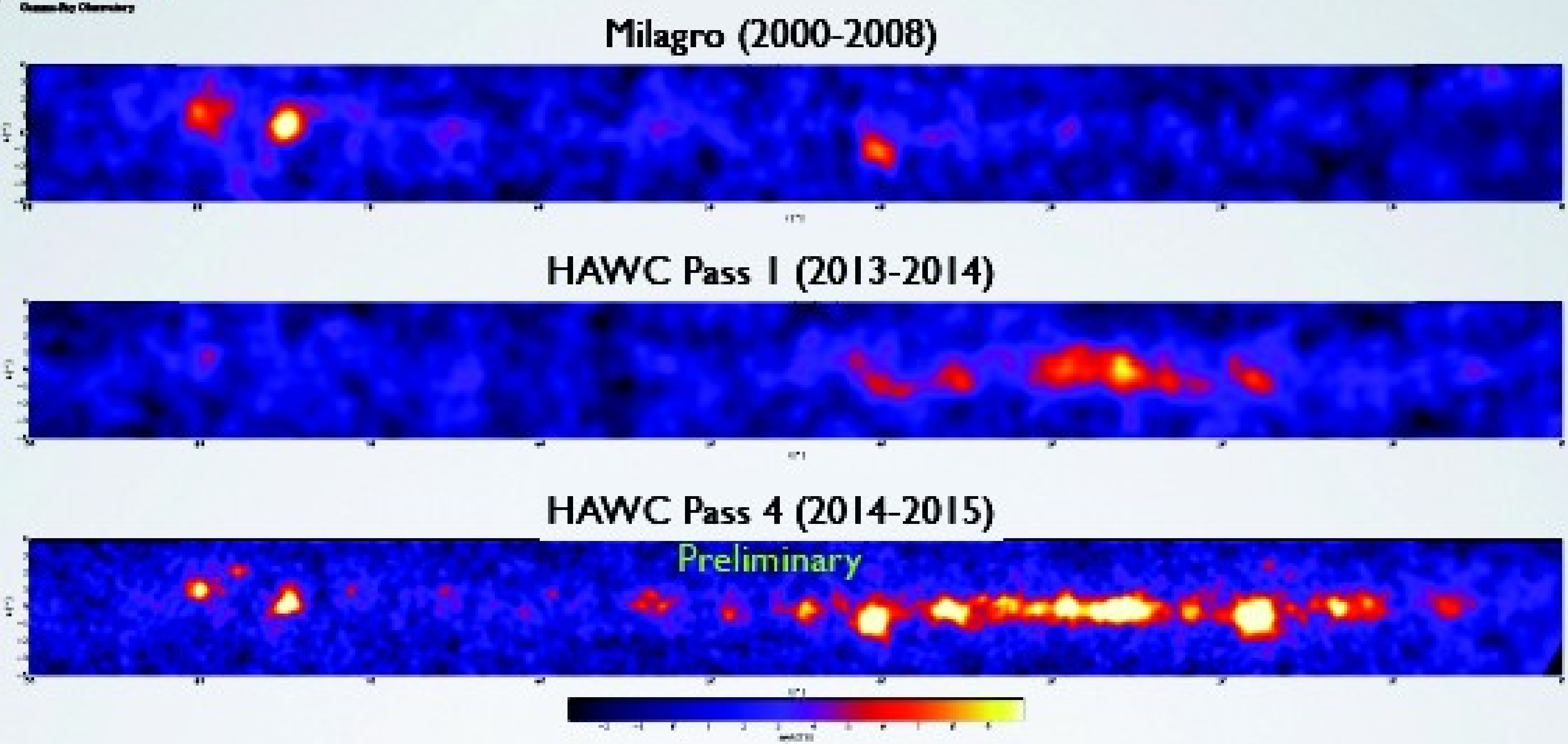
$\langle\zeta_i\rangle$: Average of all PMTs contained in an annulus of width 5m containing the hit

σ_{ζ_i} : Obtained from a sample of strong gamma-ray candidates from the Crab

For hadronic showers $\mathcal{P}$ is large

Credit: H. L. Vargas and W. Springer; The HAWC Collaboration

Galactic Plane



Milagro is located near Los Alamos, New Mexico

- different sensitivity by declination along Galactic plane.

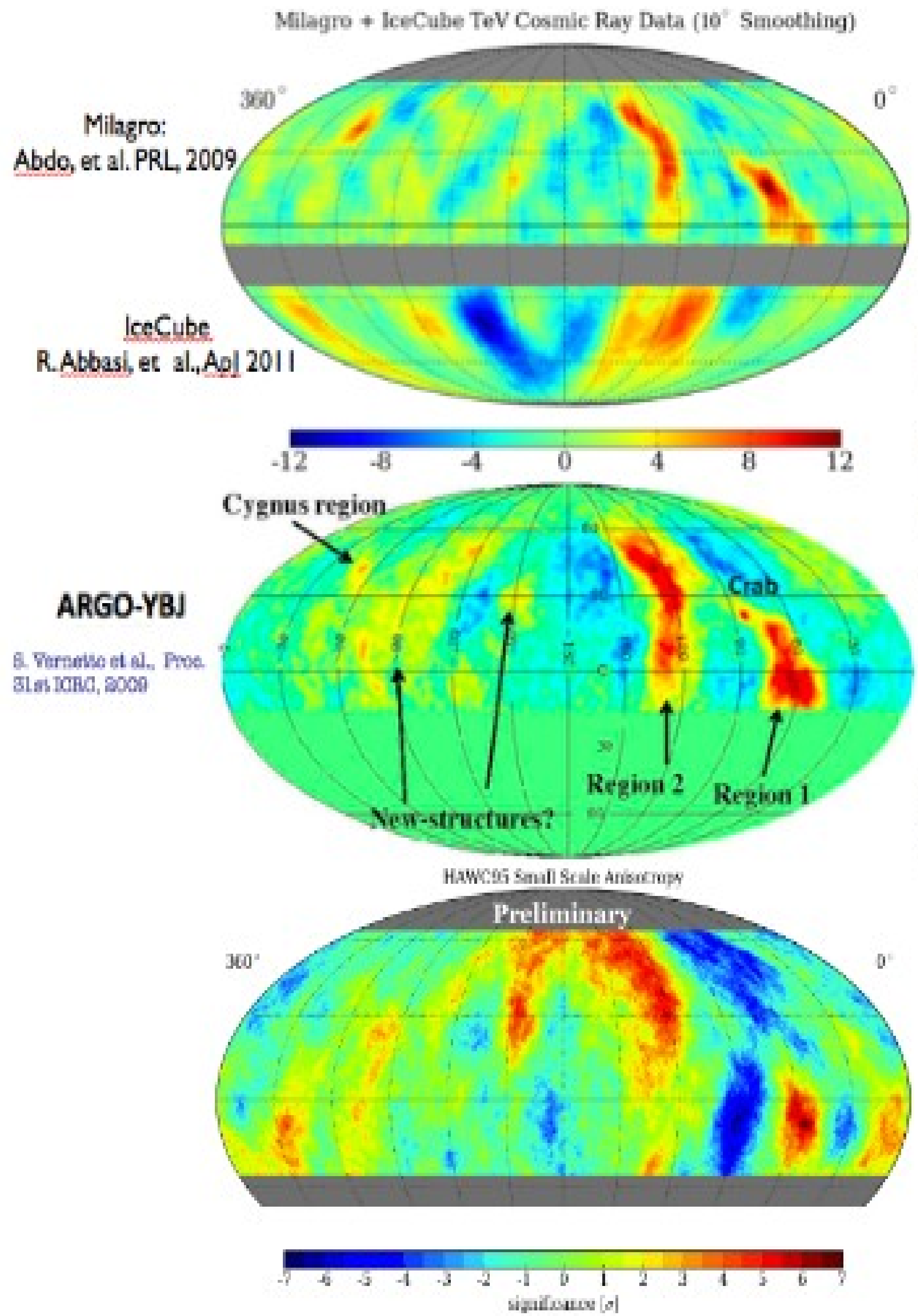
HAWC is ~15x more sensitivity with lower energy threshold, and more sensitive towards Galactic center.

- **Photo Credit:: The HAWC Collaboration**

- **August 1, 2014, 111 Detectors formal start operations (⅓ of full array)**

HAWC

Unexpected Anisotropy of 10 TeV Cosmic Rays; Gyroradius of 10TeV proton in 2μG field is 1000 AU



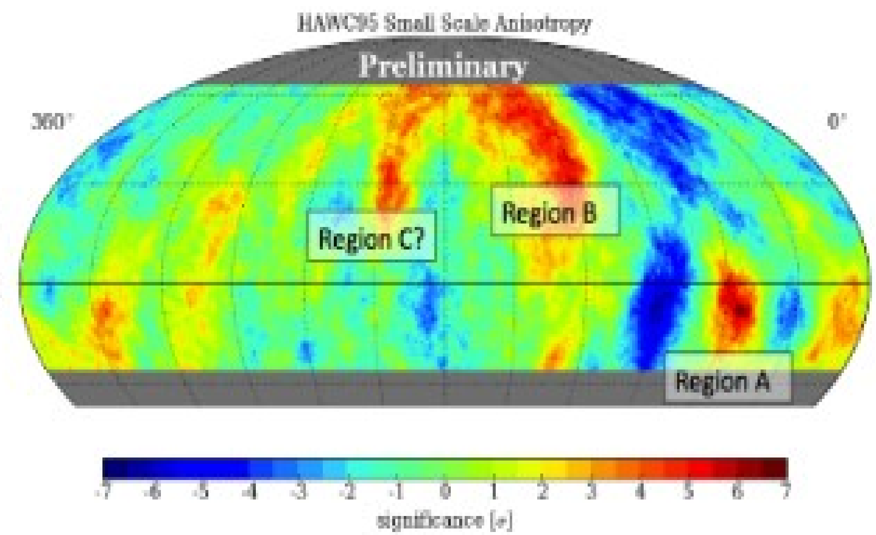
nCh ≥ 32

Direct integration

2hr ≥ dt ≥ 1hr

10° smoothing

Li/Ma signif.



Region A : 7.0 sigma
Region B: 5.5 sigma
Region C: 4.9 sigma

Pre-trial will be greater than 7 with another month of data.

Find post-trial with random data sets.

Abeysekara et al., HAWC Collaboration
The Astrophysical Journal, Volume 796, Issue 2, article id. 108, 11 pp. (2014)

- **Photo Credit: Michael Schnider (UCSC - HAWC)**

HAWC's 17 month Sky Map

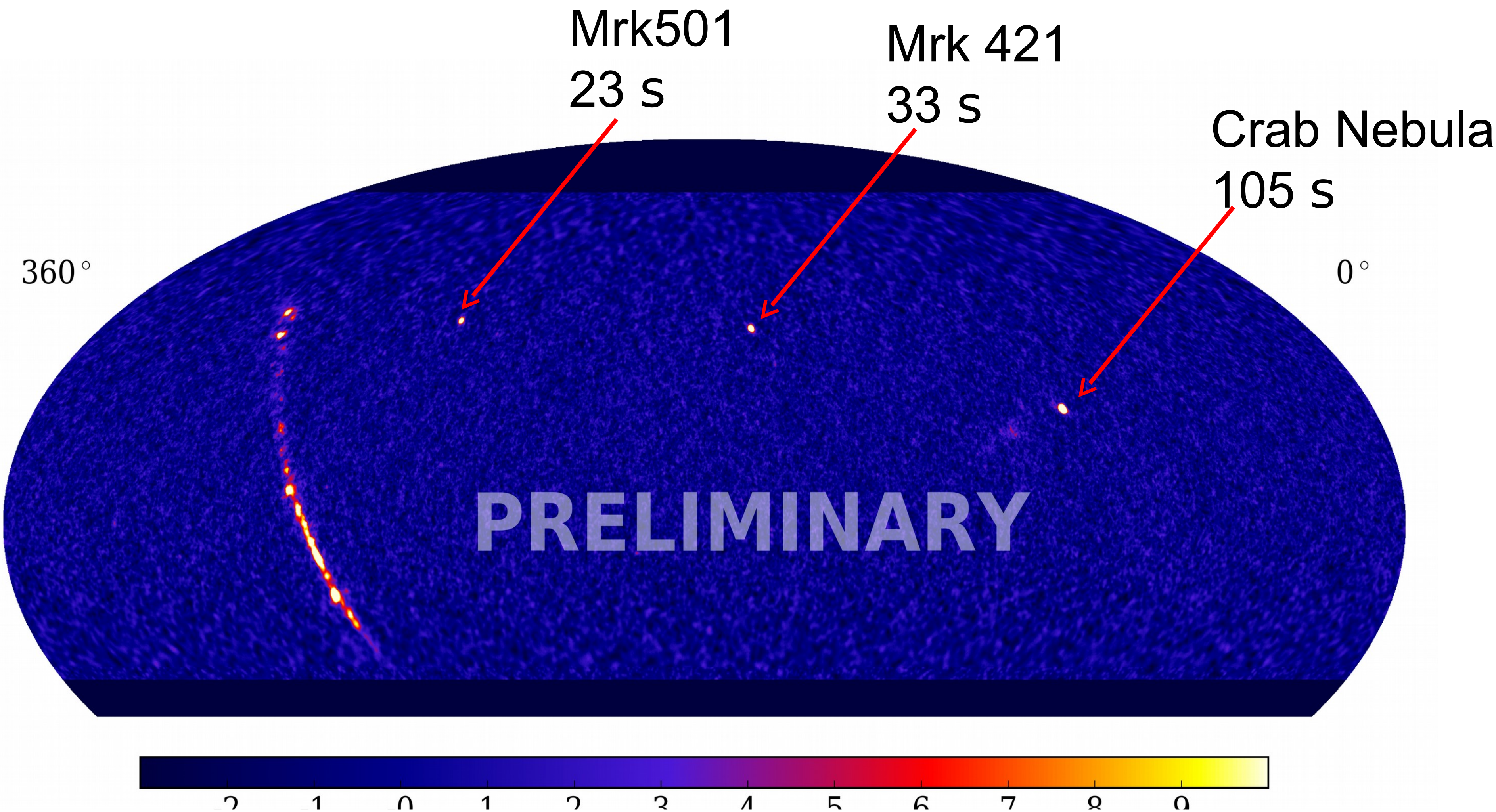
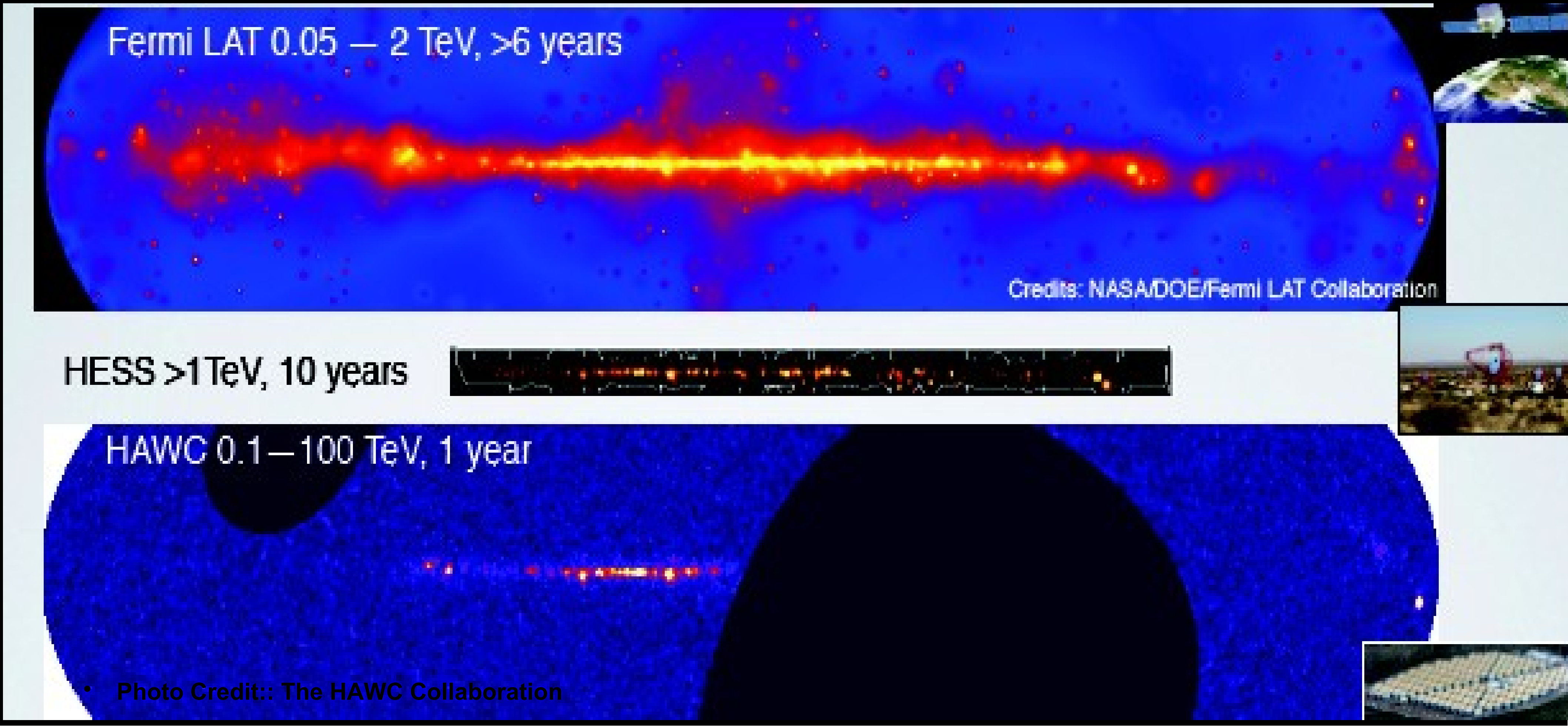


Photo Credit:: B. Dingus and The HAWC Collaboration

Milky Way at Gamma Rays: From Low (FERMI) to high energy (HESS+HAWC)

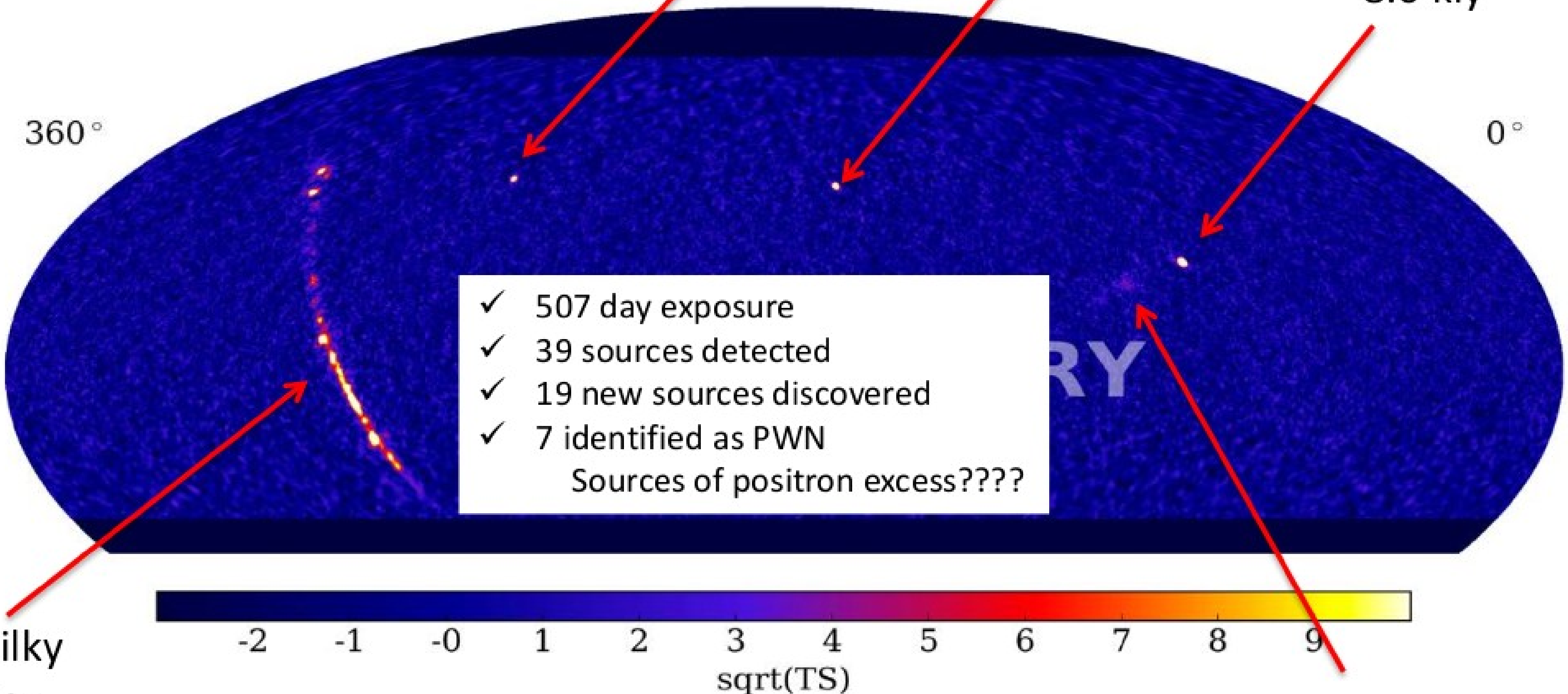
Actual view of the Galaxy at these energies (2015)



- Photo Credit:: The HAWC Collaboration

2HWC catalog

http://iopscience.iop.org/article/10.3847/1538-4357/aa7556/meta



- ✓ 507 day exposure
- ✓ 39 sources detected
- ✓ 19 new sources discovered
- ✓ 7 identified as PWN

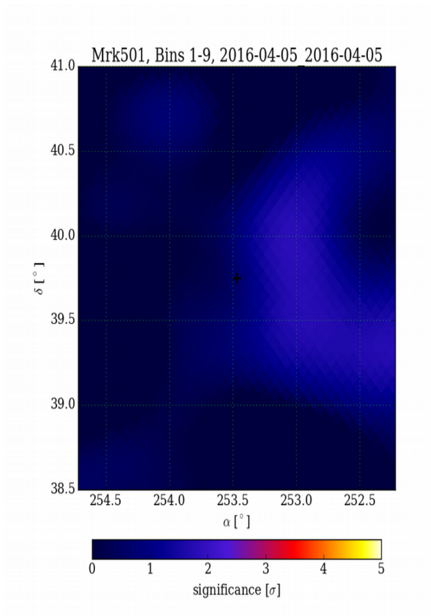
  Sources of positron excess????

- **Credit: Wayne Springerand The HAWC Collaboration**

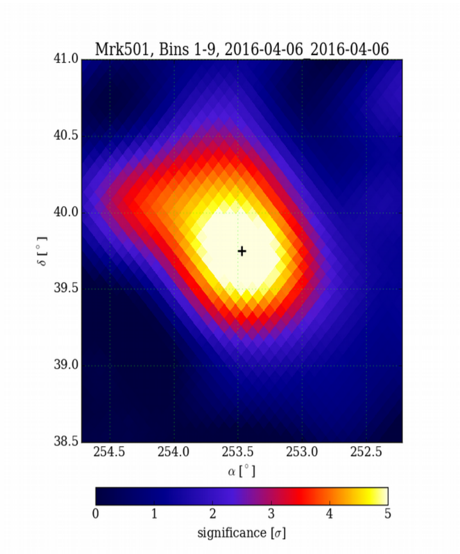
HAWC detection of increased TeV flux state for Markarian 501

ATel #8922; *Andrés Sandoval (IF-UNAM), Robert Lauer (UNM), Joshua Wood (UMD) on behalf of the HAWC collaboration*
on 7 Apr 2016; 23:38 UT

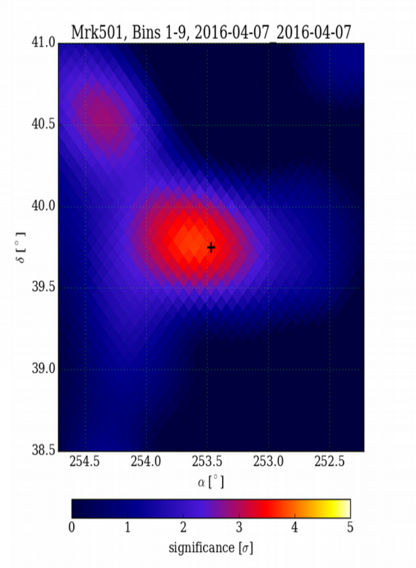
Astronomer’s Telegram to immediately alert community of activity.



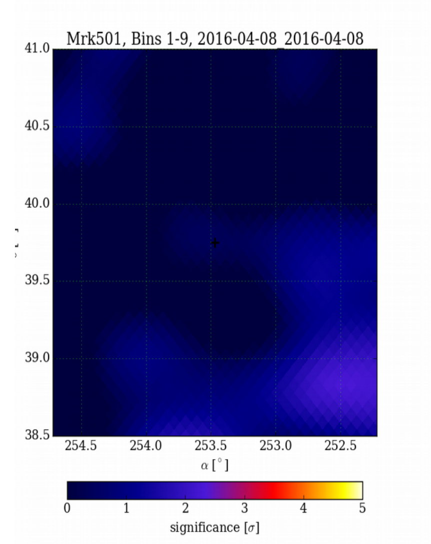
April 5, 2016



April 6, 2016



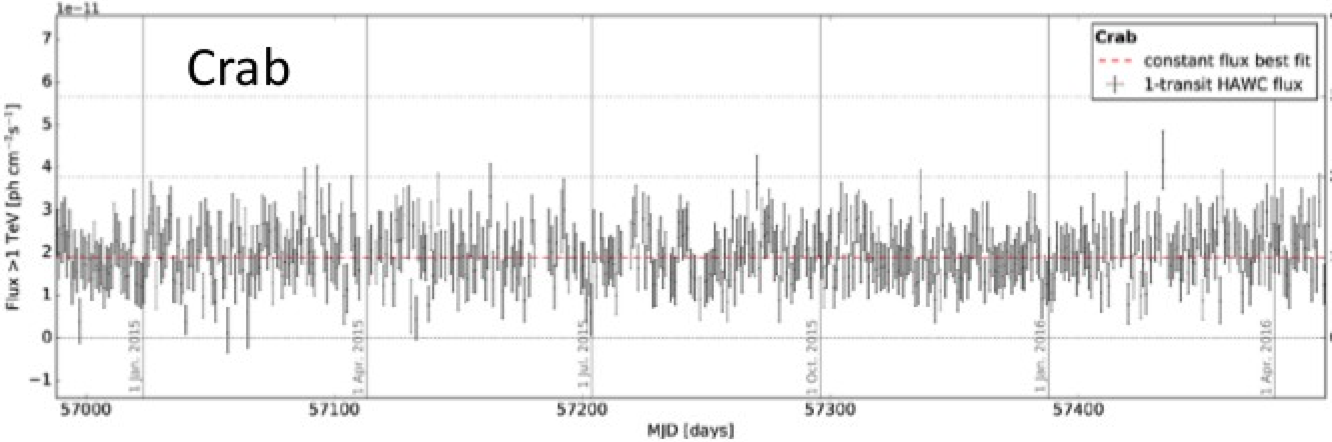
April 7, 2016

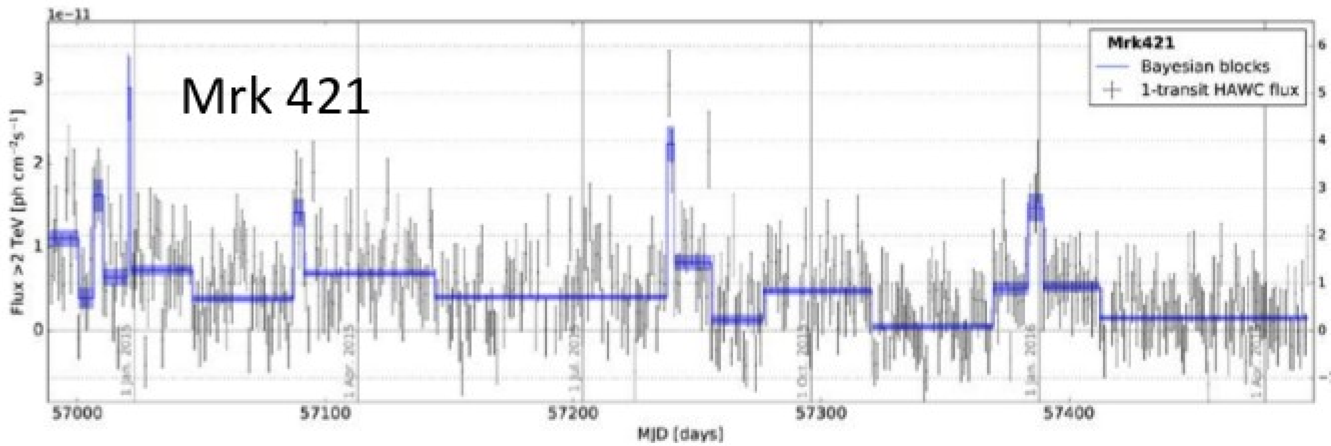


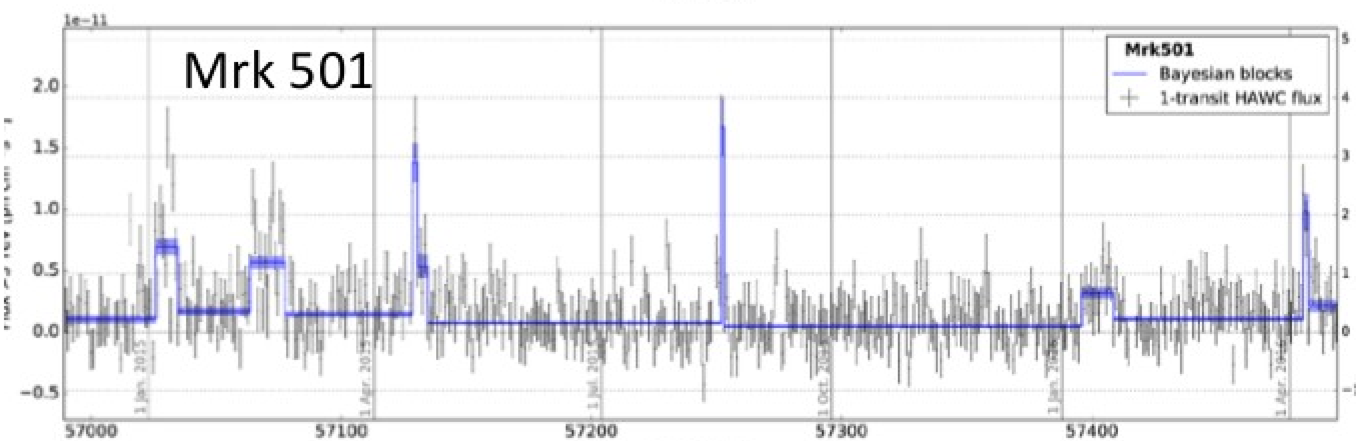
April 8, 2016

Monitoring all gamma-ray sources visible to HAWC every day.

Credit:: The HAWC Collaboration



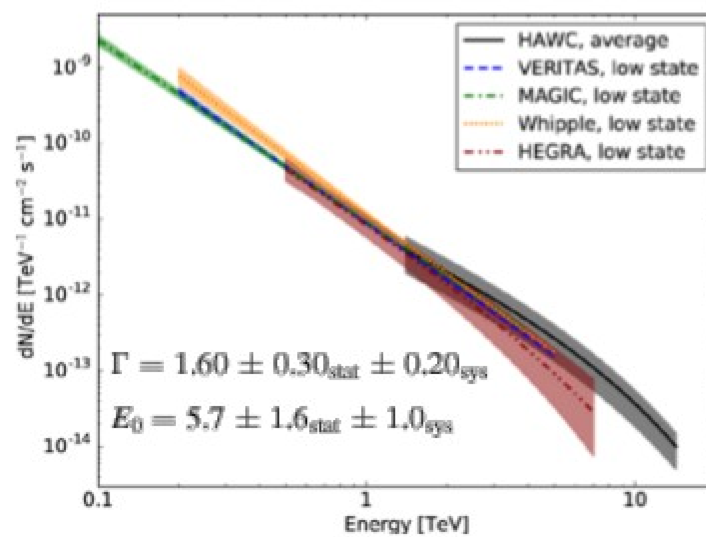




Daily Monitoring of TeV Gamma-Ray Emission from Mrk 421, Mrk 501, and the Crab Nebula with HAWC

Abeysekara *et al* [HAWC] ApJ **841** (2017) 100

- **17 months**
- **Daily monitoring**
- **0.5 TeV – 100 TeV**



HAWC spectral fit result for Mrk 501 (black

http://iopscience.iop.org/article/10.3847/1538-4357/aa729e/meta

- **Credit: Wayne Springerand The HAWC Collaboration**

Journal Articles

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.

All-particle cosmic ray energy spectrum measured by the HAWC experiment from 10 to 500 TeV
HAWC Collaboration: A. Albert et al., accepted for publication in Phys. Rev. D.

Dark Matter Limits from Dwarf Spheroidal Galaxies with the HAWC Gamma-Ray Observatory
HAWC Collaboration: A. Albert et al.

The HAWC real-time flare monitor for rapid detection of transient events
HAWC Collaboration: A. Albert 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.

Search for Very High Energy Gamma Rays from the Northern Fermi Bubble Region with HAWC
HAWC Collaboration: A.U. Abeysekara et al., ApJ **842** (2017), 85.

Daily monitoring of TeV gamma-ray emission from Mrk 421, Mrk 501, and the Crab Nebula with HAWC
HAWC Collaboration: A.U. Abeysekara et al., ApJ **841** (2017), 100.

Multiwavelength follow-up of a rare IceCube neutrino multiplet
HAWC, IceCube, Fermi-LAT Collaboration: M.G. Aartsen et al., submitted to A&A.

Primordial Black Holes: Observational Characteristics of the Final Evaporation
T.N. Ukwatta, D.R. Stump, J.T. Linnemann, J.H. MacGibbon, S.S. Marinelli, T. Yapici, and K. Tollefson, Astropart. Phys. **80** (2016), 90-114.

Search for TeV Emission from Point-like Sources in the Galactic Plane with a Partial Configuration of the HAWC Observatory
HAWC Collaboration: A.U. Abeysekara et al., Astrophys. J. **817** (2016), 3.

Experimental Constraints on γ-ray Pulsar Gap Models and the Pulsar GeV to Pulsar Wind Nebula TeV Connection
A.U. Abeysekara and J.T. Linnemann, Astrophys. J **804** (2015), 25.

GPS Timing and Control System of the HAWC Detector
A.U. Abeysekara, T. Ukwatta, D. Edmunds, J. Linnemann, A. Imran, G. Kunde, and I. Wisher.

Search for Gamma Rays from the Unusually Bright GRB 130427A with the HAWC Gamma-Ray Observatory
HAWC Collaboration: A.U. Abeysekara et al., Astrophys. J. **800** (2015), 78.

Milagro Limits and HAWC Sensitivity for the Rate-Density of Evaporating Primordial Black Holes
Milagro Collaboration (A.A. Abdo et al.) and HAWC Collaboration (A.U. Abeysekara et al.) Astropart. Phys. **64** (2015), 4-12.

VAMOS: A Pathfinder for the HAWC Gamma-Ray Observatory
HAWC Collaboration: A.U. Abeysekara et al., Astropart. Phys. **62** (2015), 125-133.

Observation of Small-Scale Anisotropy in the Arrival Direction Distribution of TeV Cosmic Rays with HAWC
HAWC Collaboration: A.U. Abeysekara et al., Astrophys. J. **796** (2014), 108.

The Sensitivity of HAWC to High-Mass Dark Matter Annihilations
HAWC Collaboration: A. U. Abeysekara et al., Phys. Rev. D **90** (2014), 122002.

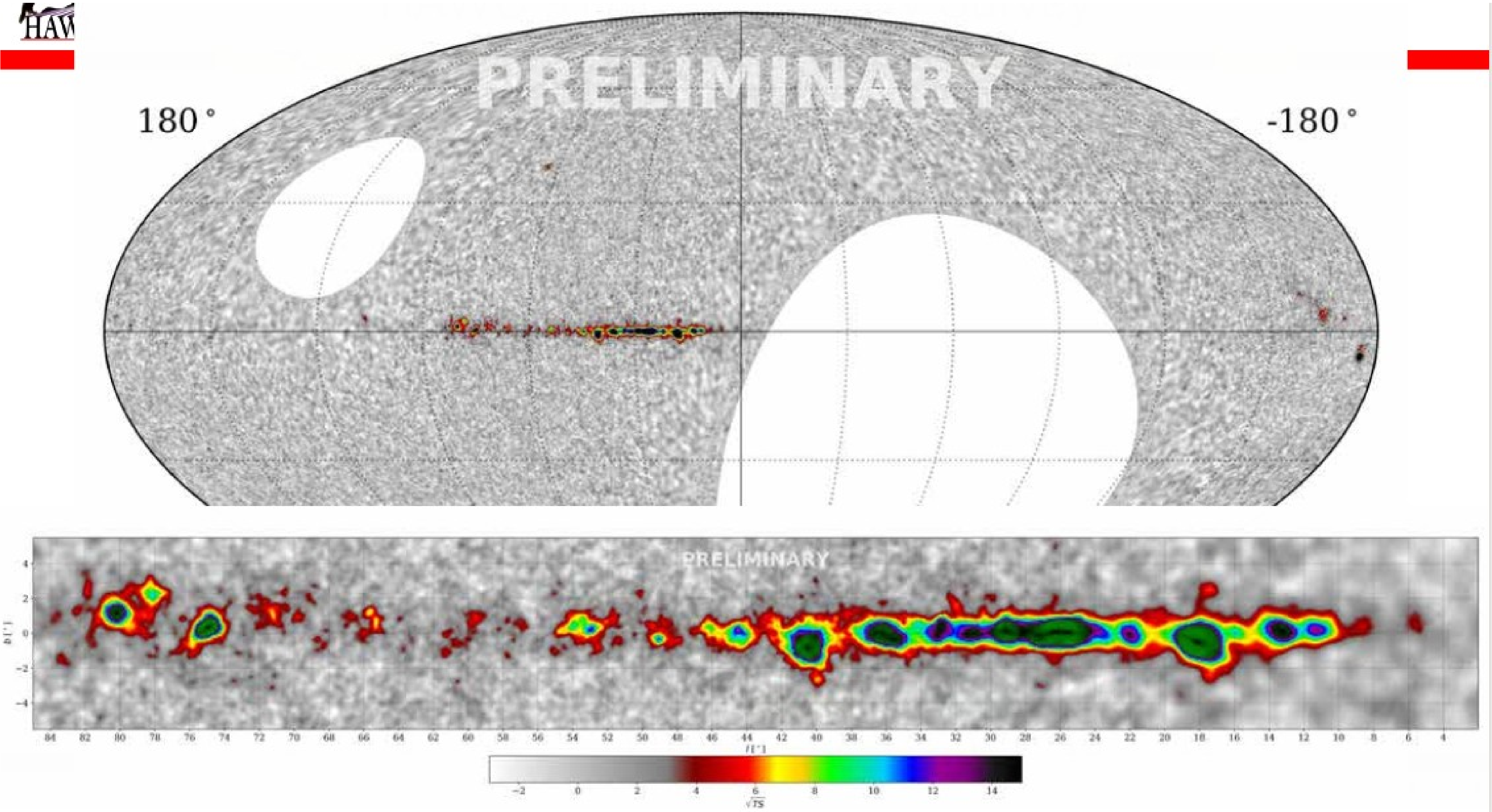
Prospects for the Detection of GRBs with HAWC
I. Taboada, R.C. Gilmore, NIM A **742** (2014), 276-277.

Sensitivity of the High Altitude Water Cherenkov Detector to Sources of Multi-TeV Gamma Rays
HAWC Collaboration: A. U. Abeysekara et al., Astropart. Phys. **50-52** (2013), 26-32.

On the Sensitivity of the HAWC Observatory to Gamma-Ray Bursts
HAWC Collaboration: A. U. Abeysekara et al., Astropart. Phys. **35** (2012) 641-650.

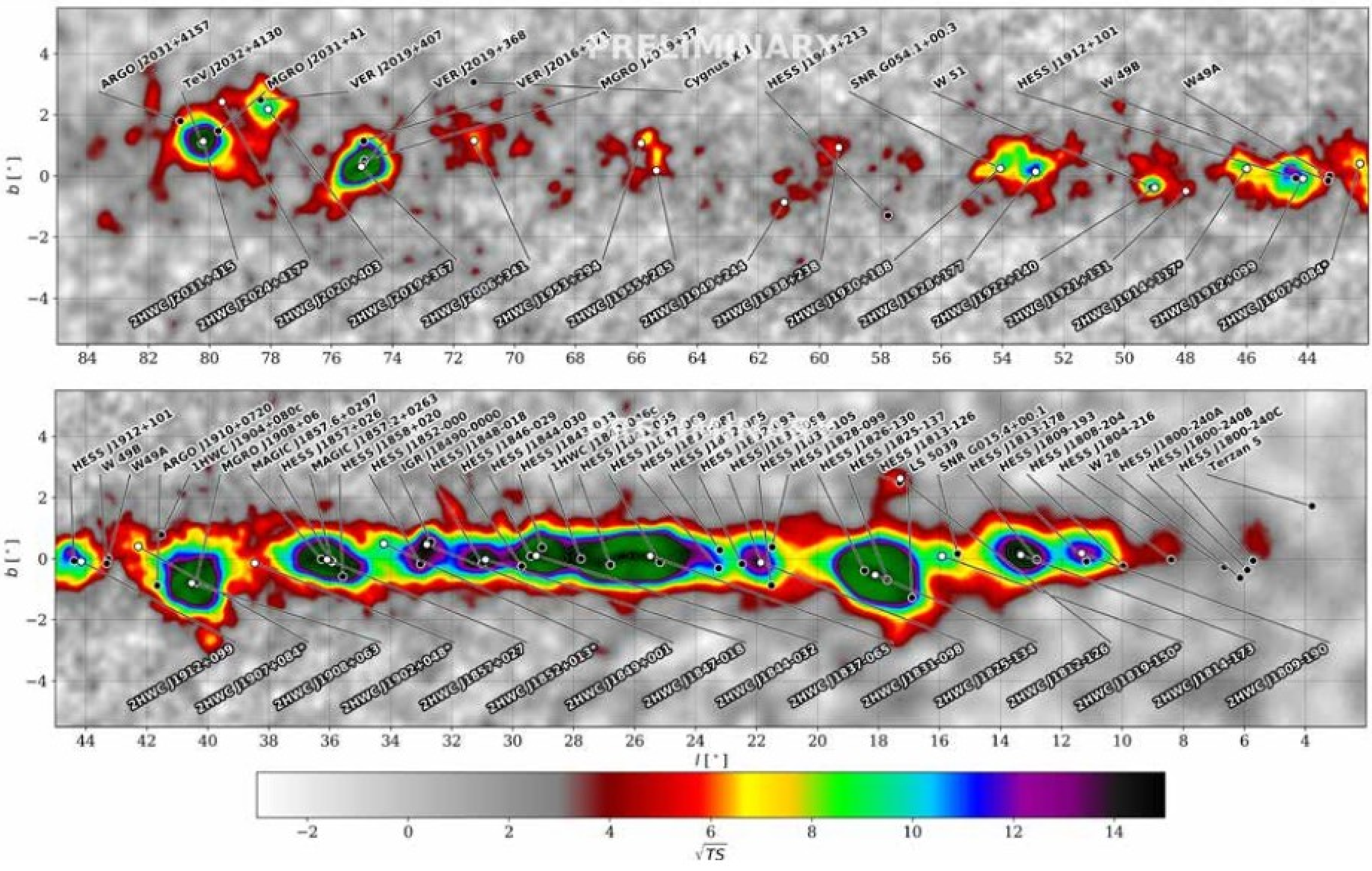
- **Credit: Wayne Springerand The HAWC Collaboration**

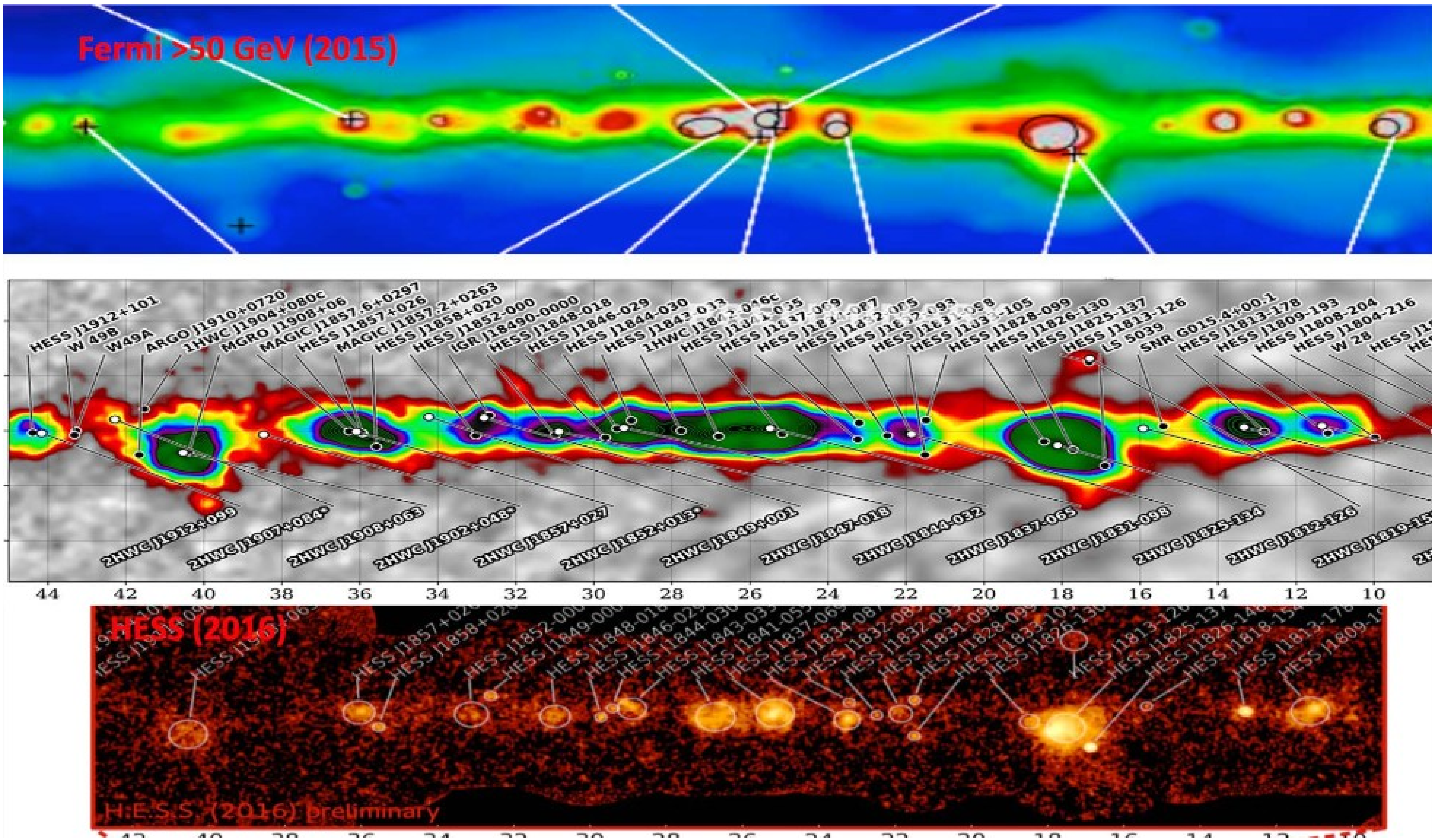
HAWC Sky Map 1017 Days of Data



- **Credit: The HAWC Collaboration**

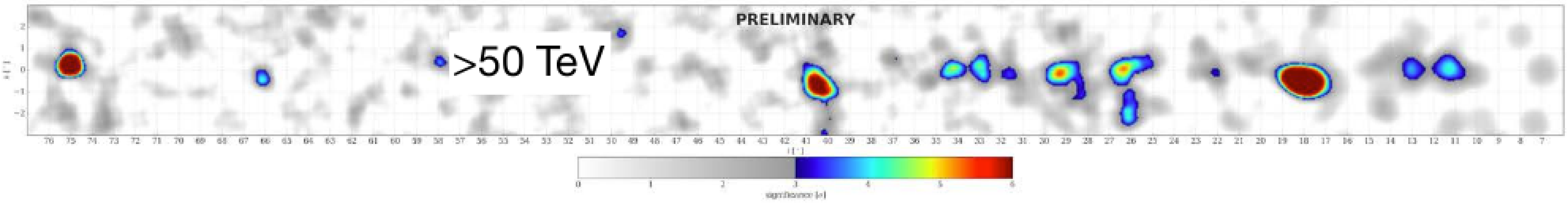
1017 Days of Data



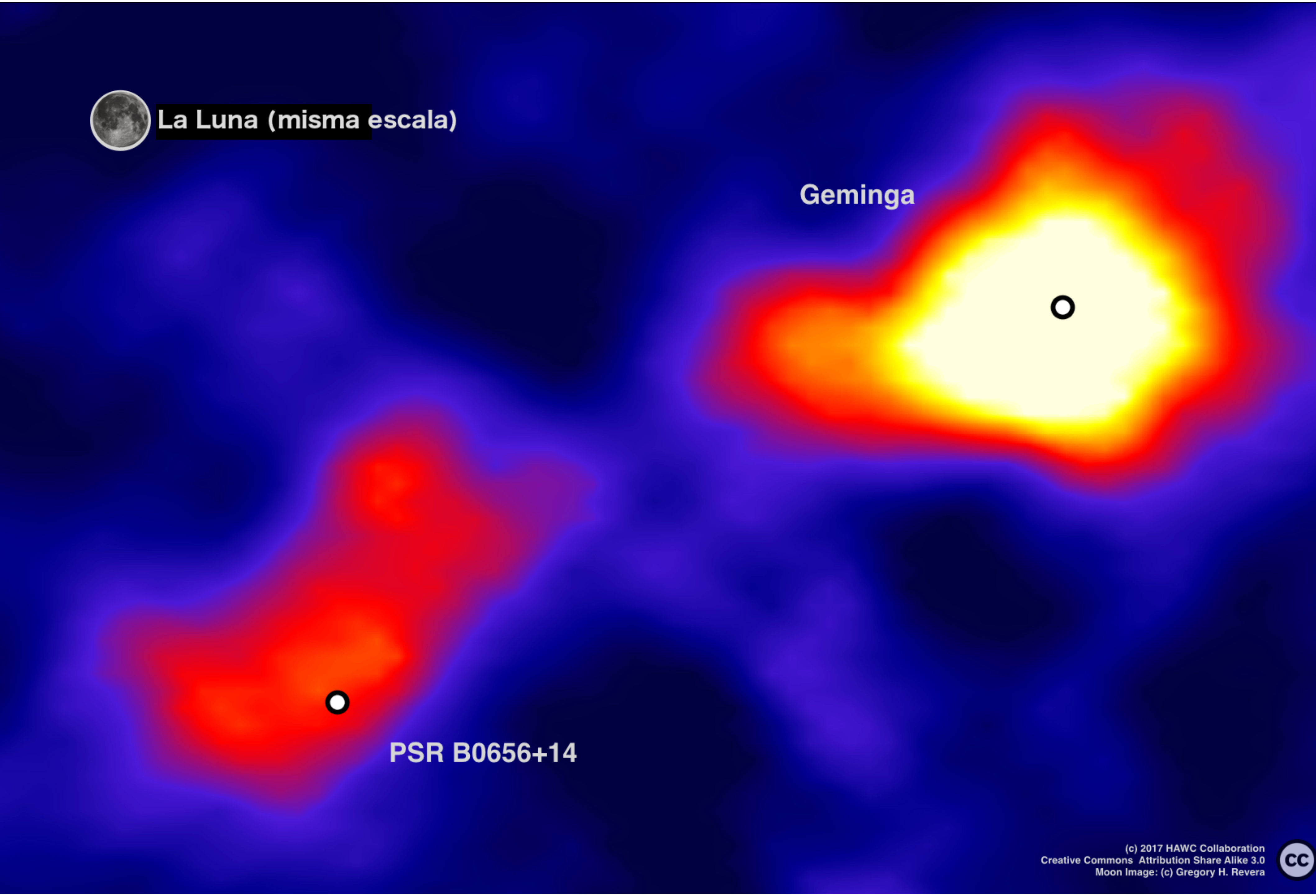


- **Credit: Jordan Goodman and the HAWC Collaboration**

- By measuring spectra out beyond 30 TeV we can look for hadronic accelerators
- HAWC has produced the first map showing sources above 50 TeV
- Once we measure the spectra we can determine their origin



- **Credit: Jordan Goodman and the HAWC Collaboration**


La Luna (misma escala)
Geminga
PSR B0656+14
(c) 2017 HAWC Collaboration
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Moon Image: (c) Gregory H. Revera
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REPORT

PARTICLE ASTROPHYSICS

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

A. U. Abeysekara,[1] A. Albert,[2] R. Alfaro,[3] C. Alvarez,[4] J. D. Álvarez,[5] R. Arceo,[4] J. C. Arteaga-Velázquez,[5] D. Avila Rojas,[3] H. A. Ayala Solares,[6] A. S. Barber,[1] N. Bautista-Elivar,[7] A. Becerril,[3] E. Belmont-Moreno,[3] S. Y. BenZvi,[8] D. Berley,[9] A. Bernal,[10] J. Braun,[11] C. Brisbois,[6] K. S. Caballero-Mora,[4] T. Capistrán,[12] A. Carramiñana,[12] S. Casanova,[13,14] M. Castillo,[5] U. Cotti,[5] J. Cotzomi,[15] S. Coutiño de León,[12] C. De León,[15] E. De la Fuente,[16] B. L. Dingus,[2] M. A. DuVernois,[11] J. C. Díaz-Vélez,[16] R. W. Ellsworth,[17] K. Engel,[9] O. Enríquez-Rivera,[18] D. W. Fiorino,[9] N. Fraija,[10] J. A. García-González,[3] F. Garfias,[10] M. Gerhardt,[6] A. González Muñoz,[3] M. M. González,[10] J. A. Goodman,[9] Z. Hampel-Arias,[11] J. P. Harding,[2] S. Hernández,[3] A. Hernández-Almada,[3] J. Hinton,[14] B. Hona,[6] C. M. Hui,[19] P. Hüntemeyer,[6] A. Iriarte,[10] A. Jardin-Blicq,[14] V. Joshi,[14] S. Kaufmann,[4] D. Kieda,[1] A. Lara,[18] R. J. Lauer,[20] W.H. Lee,[10] D. Lennarz,[21] H. León Vargas,[3] J. T. Linnemann,[22] A. L. Longinotti,[12] G. Luis Raya,[7] R. Luna-García,[23] R. López-Coto,[14]* K. Malone,[24] S. S. Marinelli,[22] O. Martinez,[15] I. Martinez-Castellanos,[9] J. Martínez-Castro,[23] H. Martínez-Huerta,[25] J. A. Matthews,[20] P. Miranda-Romagnoli,[26] E. Moreno,[14] M. Mostafá,[24] L. Nellen,[27] M. Newbold,[1] M. U. Nisa,[8] R. Noriega-Papaqui,[26] R. Pelayo,[23] J. Pretz,[24] E. G. Pérez-Pérez,[7] Z. Ren,[20] C. D. Rho,[8] C. Rivière,[9] D. Rosa-González,[12] M. Rosenberg,[24] E. Ruiz-Velasco,[3] H. Salazar,[15] F. Salesa Greus,[13]* A. Sandoval,[3] M. Schneider,[28] H. Schoorlemmer,[14] G. Sinnis,[2] A. J. Smith,[9] R. W. Springer,[1] P. Surajbali,[14] I. Taboada,[21] O. Tibolla,[4] K. Tollefson,[22] I. Torres,[12] T. N. Ukwatta,[2] G. Vianello,[29] T. Weisgarber,[11] S. Westerhoff,[11] I. G. Wisher,[11] J. Wood,[11] T. Yapici,[22] G. Yodh,[30] P. W. Younk,[2] A. Zepeda,[25,4] H. Zhou,[2]* F. Guo,[2] J. Hahn,[14] H. Li,[2] H. Zhang[2]

The unexpectedly high flux of cosmic ray positrons detected at Earth may originate from nearby astrophysical sources, dark matter, or unknown processes of cosmic-ray secondary production. We report the detection, using the High-Altitude Water Cherenkov Observatory (HAWC), of extended tera–electron volt gamma-ray emission coincident with the locations of two nearby middle-aged pulsars (Geminga and PSR B0656+14). The HAWC observations demonstrate that these pulsars are indeed local sources of accelerated leptons, but the measured tera–electron volt emission profile constrains the diffusion of particles away from these sources to be much slower than previously assumed. We demonstrate that the leptons emitted by these objects are therefore unlikely to be the origin of the excess positrons, which may have a more exotic origin.

Cosmic rays are high-energy particles from space that have been known for more than a century. The origin of high-energy cosmic rays and how they are accelerated remains unclear. Most cosmic rays are protons or atomic nuclei, but positrons and electrons also are a small fraction of the total cosmic-ray flux. Positrons are especially puzzling because the PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) detector observed an unexpected excess of positrons at energies >10 GeV, compared with the predicted flux that originates from interactions of cosmic-ray protons propagating through the Galaxy (*1*). Confirmation of these results has come from the Fermi Large Area Telescope (*2*) and AMS [Alpha Magnetic Spectrometer (*3*)] experiments; the latter also showed that the excess signal extends to hundreds of giga-electron volts.

Energy losses experienced in interstellar magnetic and radiation fields by the highest-energy positrons require that their sources lie within a few hundred parsecs from Earth (*4*). Nearby potential cosmic ray accelerators—for example, pulsar wind nebulae (PWNe)—have been proposed as the sources of these extra positrons (*5*, *6*). A PWN consists of a rapidly spinning neutron star (pulsar) that produces a wind of electrons and positrons that are further accelerated by the surrounding shock with the interstellar medium (ISM). There are a handful of known pulsars that are both close enough to be candidate sources and sufficiently old for the highest-energy positrons to have had time to arrive at Earth (*7*, *8*). Nearby dark matter particle interactions could also produce positrons (*9*). Both PWNe and dark matter sources should also produce gamma rays that could potentially be observed coming from the sources, unlike positrons (whose paths are deflected by magnetic fields).

Recently, the High-Altitude Water Cherenkov Observatory (HAWC) collaboration reported the detection of tera–electron volt gamma rays around two nearby pulsars, which are among those proposed to produce the local positrons (*10*). HAWC is a wide-field-of-view, continuously operating detector of extensive air showers initiated by gamma rays and cosmic rays interacting in the atmosphere (*11*). The angular resolution improves from 1.0° to 0.2° with the size of the air shower. HAWC is the most sensitive survey detector above 10 TeV and is well suited to detecting nearby sources, which would have a greater angular extent. Operation of the full detector began in March 2015, and the data set presented here includes 507 days, as described in (*11*).

Tera–electron volt gamma-ray emissions from the pulsars Geminga and PSR B0656+14 were found in a search for extended sources that was performed for the HAWC catalog, in which these two pulsars have the designations 2HWC J0635+180 and 2HWC J0700+143 (*10*). By fitting to a diffusion model (*12*), the two sources were detected with a significance at the pulsar location of 13.1 and 8.1 standard deviations (σ), respectively (Fig. 1A). The tera–electron volt emission region

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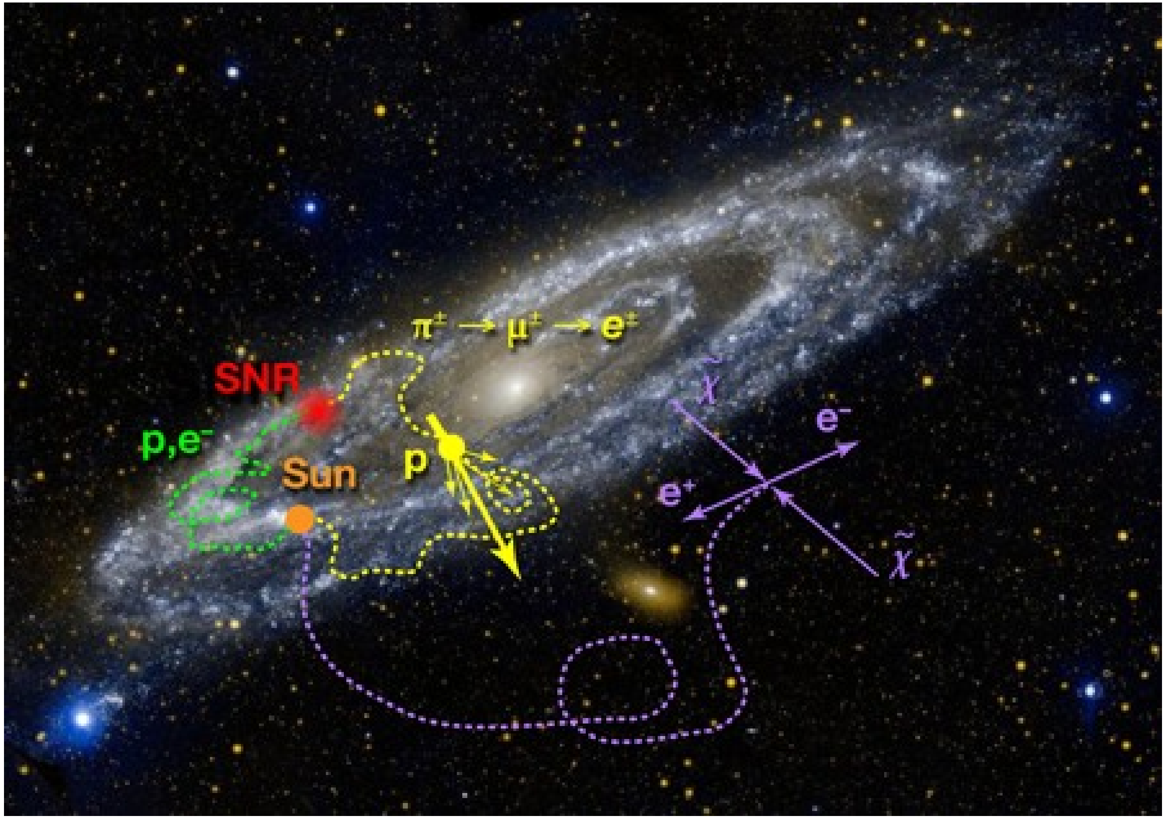
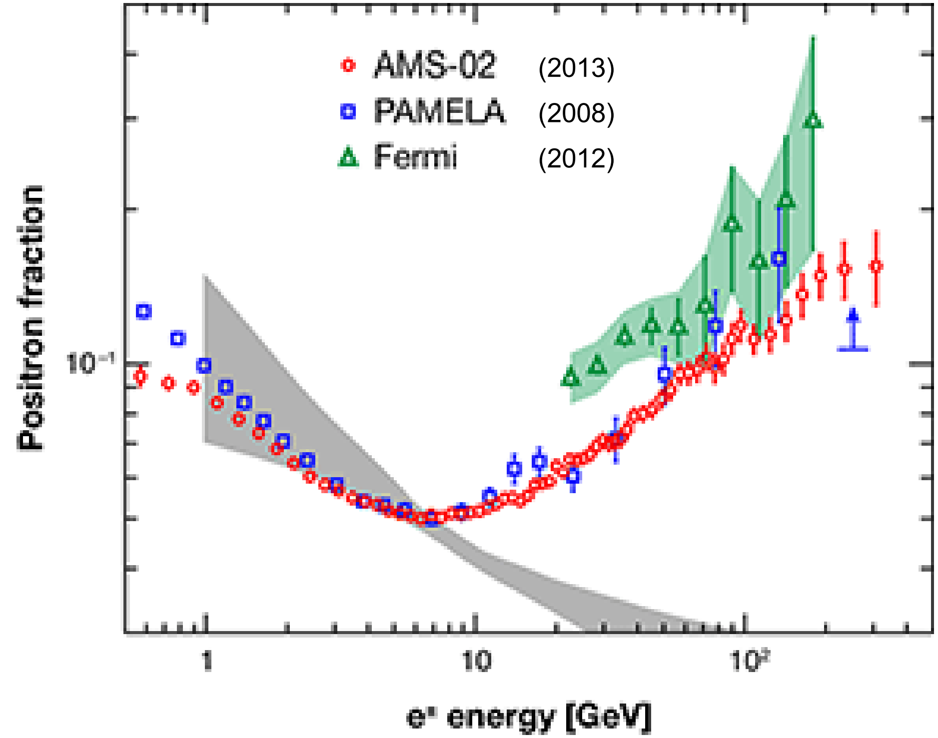


Flujo de particulas de alta energia cerca de la tierra (rayos cosmicos). Verde: Primarias que vienen de fuentes originales de rayos cosmicos (RSN,PWN). Amarillo: Particulas secundarias que se producen cuando las primarias interactuan con el ISM produciendo piones y muons, estos ultmos decayendo en positrones y electrones. Morado: Electrones y positrones formados por la aniquilacion de materia obscura (WIMP).



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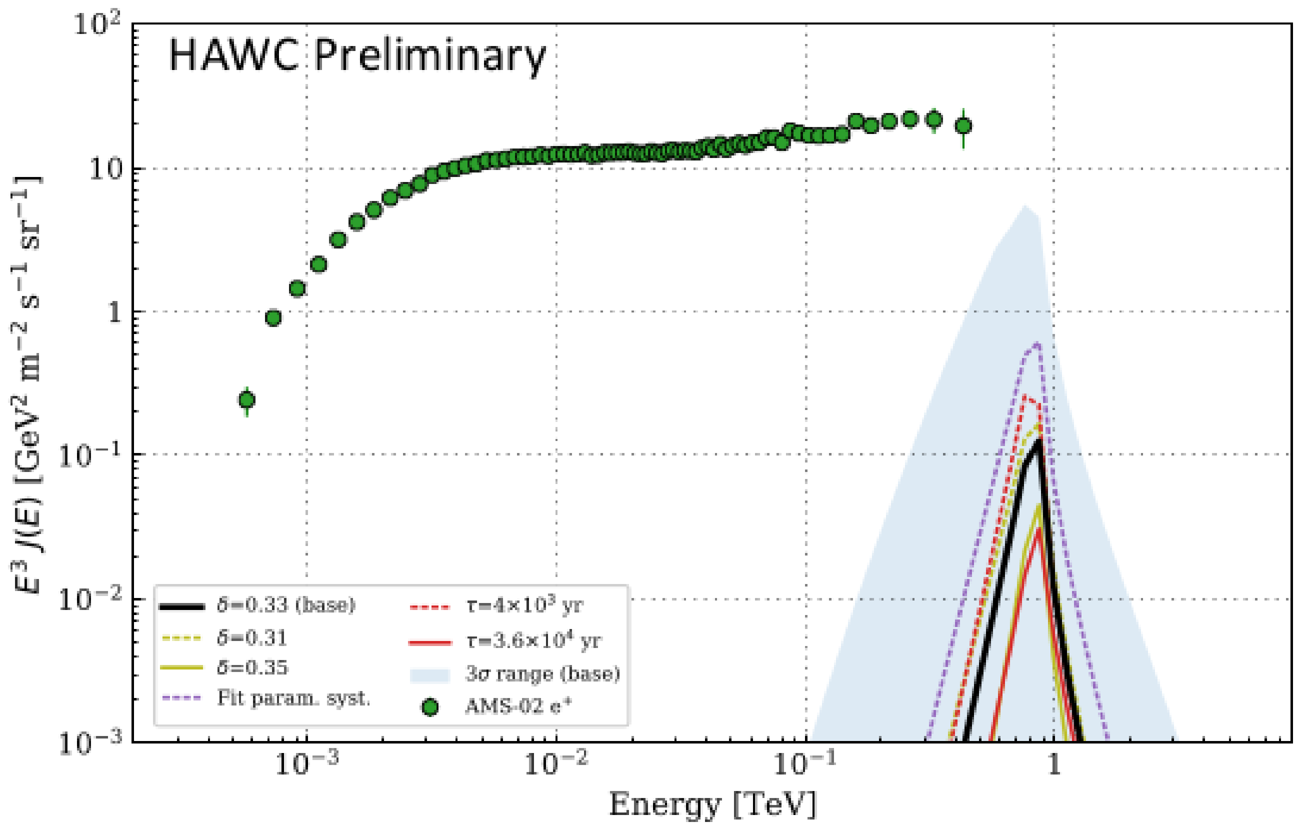
25 billones de eventos
6.8 millones son e y e*
400,000 e+ 0.5-350 GeVs

PaMeLa a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

The measured gamma ray emission is produced by the leptons diffusing into the ISM and IC scattering from the CMB

Using the properties measured by HAWC of these sources, we can infer the propagation of the $e^{\pm}$ to Earth

Contribution of Geminga, the other source is negligible



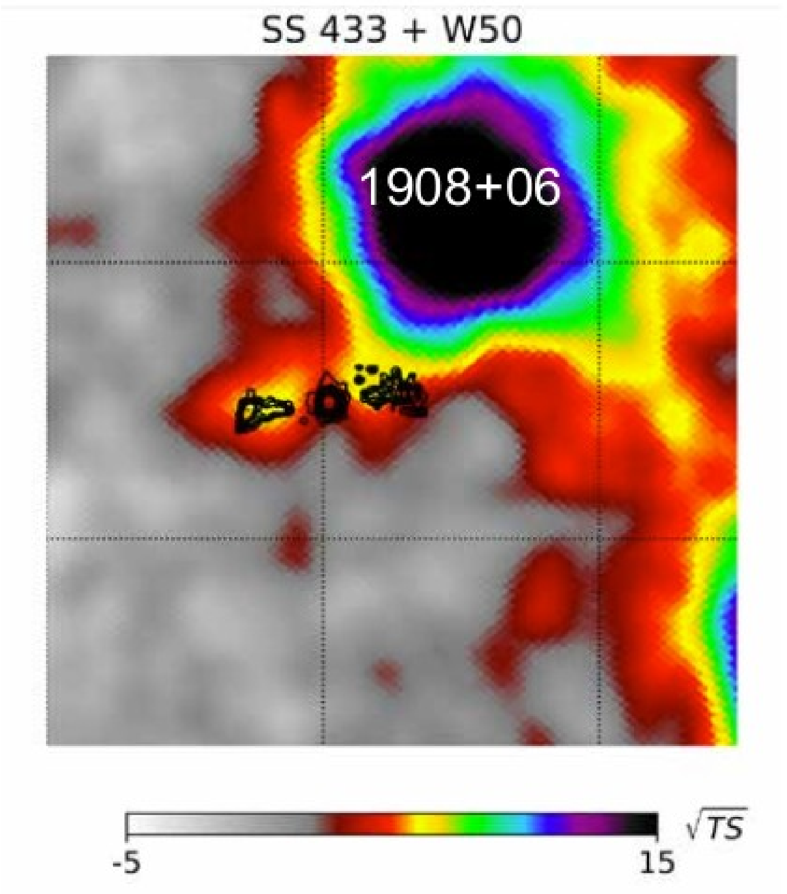
The measured positron flux cannot be explained by the contributions from Geminga and 2HWC J0700+143

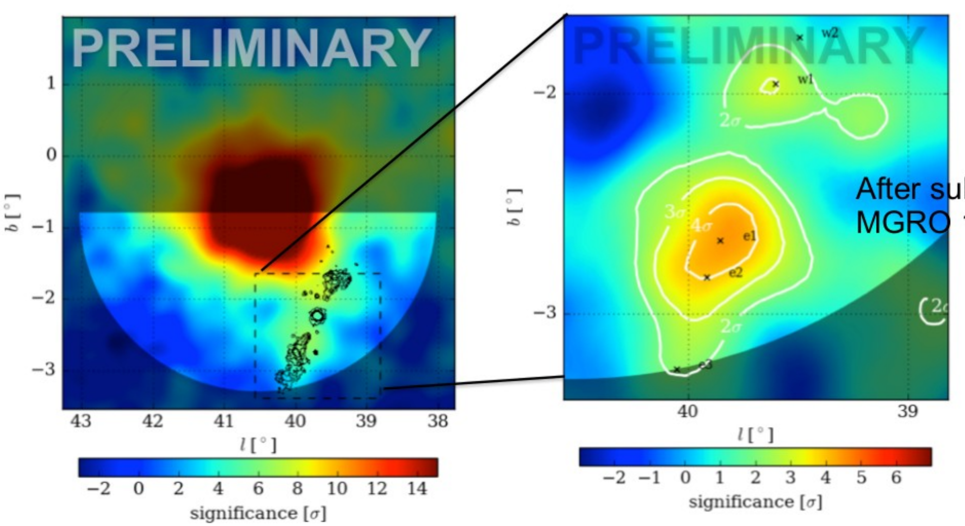
Nearby Pulsar Wind Nebulae do not explain AMS positron observations

- **Credit: The HAWC Collaboration**

Detection of μ-quasar SS433

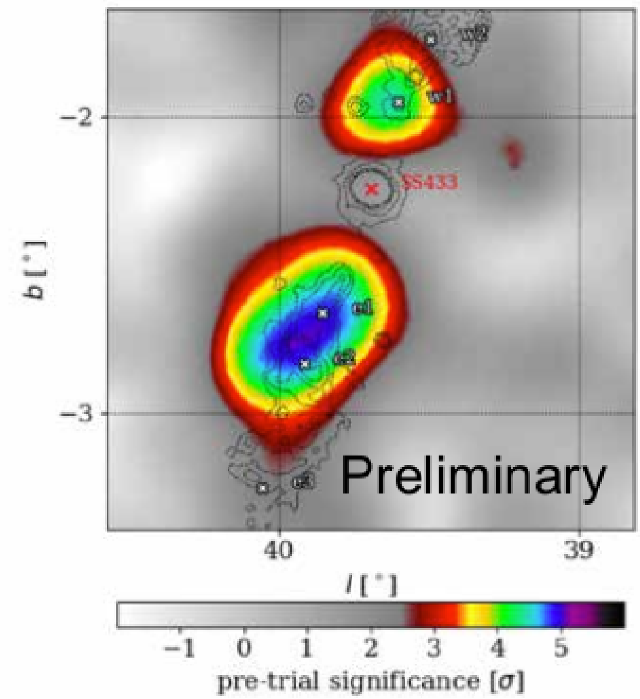
- SS433 - x-ray binary with black hole
- Imaged jets ~ perpendicular to line of sight & containing hadrons
- Until now, no jets have been imaged at TeV energies.
- SS 433 has long been a suspected VHE gamma-ray source.
- The observation of TeV lobes provides new information about SS 433, including its luminosity and magnetic field.





Credit: Jordan Goodman and the HAWC Collaboration

- 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



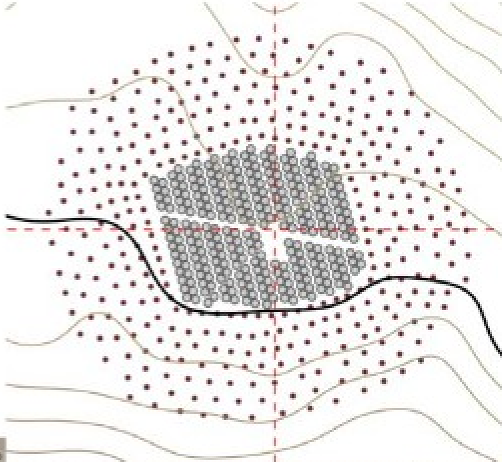
HAWC significance with the overlay of x-ray contours showing the jet lobes and not the black hole.

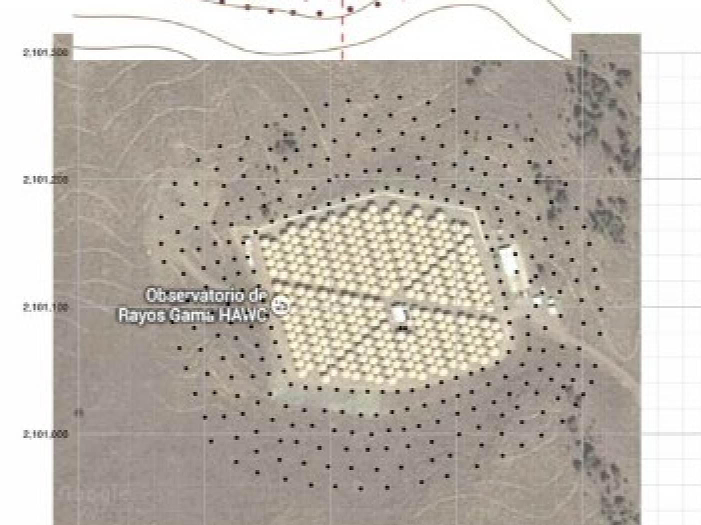
Possible Detection of μ-quasar SS433

- We used a diffusion model to fit the extended MGRO J1908+06. We have also tested the Gaussian model and the powerlaw model and their effects on the fitted lobes have been included in the systematics (< 20%).
- For the spectral model, simple power law was used.
- Modeling can indicate whether the gammas are likely of hadronic or leptonic origin and where the acceleration occurs
- (Paper in progress)

- **Credit: Jordan Goodman and the HAWC Collaboration**

Outriggers

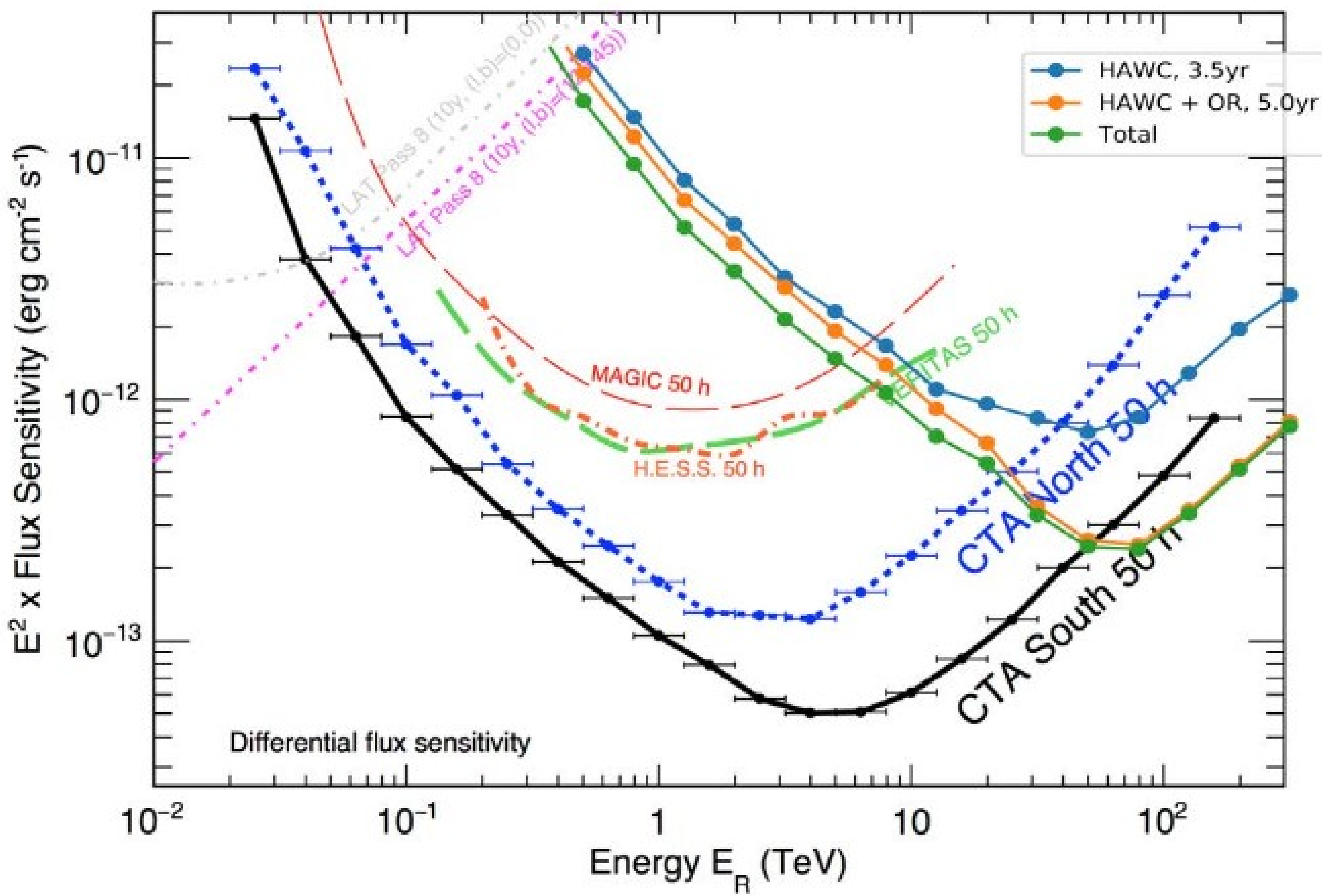




- HAWC Sparse Outrigger Array being deployed now:
  Enhanced Sensitivity above 10 TeV
  - Accurately determine core position for showers off the main tank array.
  - Increase effective area above 10 TeV by ~4x
- Funded by LANL/MPIK (Heidelberg)/Mexico.
- 2500 liter tanks: 1/80th size of HAWC tanks.

- **Credit: Jordan Goodman and the HAWC Collaboration**

HAWC with Outriggers



• **Credit: Jordan Goodman and the HAWC Collaboration**

HA WC is a very sucefull experiment, surveying the TeV sky with a wide-field of view, discovering new classes of sources, viewing the highest energy sky (e.g. > 50 TeV sky), and playing an important role in Multi-messenger astrophysics

With the upgrade (outriggers), lots more to come!…...

The High Altitude Water Cherenkov (HAWC) TeV Gamma Ray Observatory at México,

Eduardo de la Fuente Acosta (Ph. D)
edfuente@gmail.com

THANK YOU!

Universidad de Guadalajara, México
Departamento de Fisica, CUCEI

HAWC Member

WASDHA 2018, Moscow, Russia