

Resultados del primer año del observatorio de rayos γ HAWC

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por la colaboración HAWC

Reunión Anual División de Partículas y Campos SMF
Puebla, 24 de mayo de 2016




The HAWC Collaboration

High Altitude Water Cherenkov
Gamma-Ray Observatory



<u>Mexico</u>		<u>United States</u>	
Instituto Nacional de Astrofísica, Óptica y Electrónica	INAOE	University of Maryland	UMD
Universidad Nacional Autónoma de México		Los Alamos National Laboratory	LANL
Instituto de Astronomía UNAM	IA-UNAM	Colorado State University	CSU
Instituto de Ciencias Nucleares UNAM	ICN-UNAM	George Mason University	GMU
Instituto de Física UNAM	IF-UNAM	Georgia Institute of Technology	GATECH
Instituto de Geofísica UNAM	IG-UNAM	Michigan State University	MSU
Benemérita Universidad Autónoma de Puebla	BUAP	Michigan Technological University	MTU
Centro de Investigación y Estudios Avanzados	CINVESTAV	Pennsylvania State University	PSU
Instituto Politécnico Nacional		NASA GSFC	
Centro de Investigación en Computo	CIC-IPN	University of California Santa Cruz	UCSC
Universidad Autónoma de Chiapas	UNACH	University of California Irvine	UCI
Universidad Autónoma del Estado de Hidalgo	UAEH	University of New Hampshire	UNH
Universidad de Guadalajara	UdG	University of New Mexico	UNM
Universidad Michoacana de San Nicolás de Hidalgo	UMSNH	University of Rochester	UR
Universidad Politécnica de Pachuca	UPP	University of Utah	UU
		University of Wisconsin	UW

MPI-HD & U. Costa Rica y Cracovia con miembros asociados



HAWC 300 Full operations

DATE: 03/20/2015
TIME: 12:26:30



Primer año de HAWC

- HAWC
- Mapa del cielo del primer año: detecciones
- Primer año: límites
- Mejoras a HAWC

Primer año de HAWC

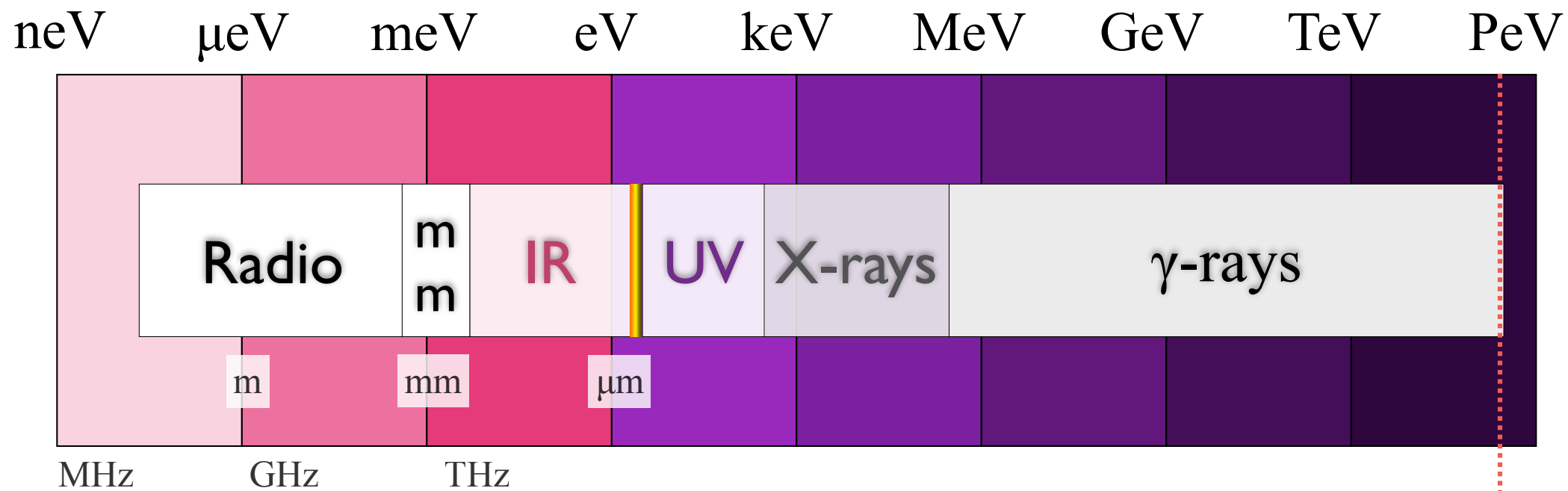
- HAWC



- Mapa del cielo del primer año: detecciones

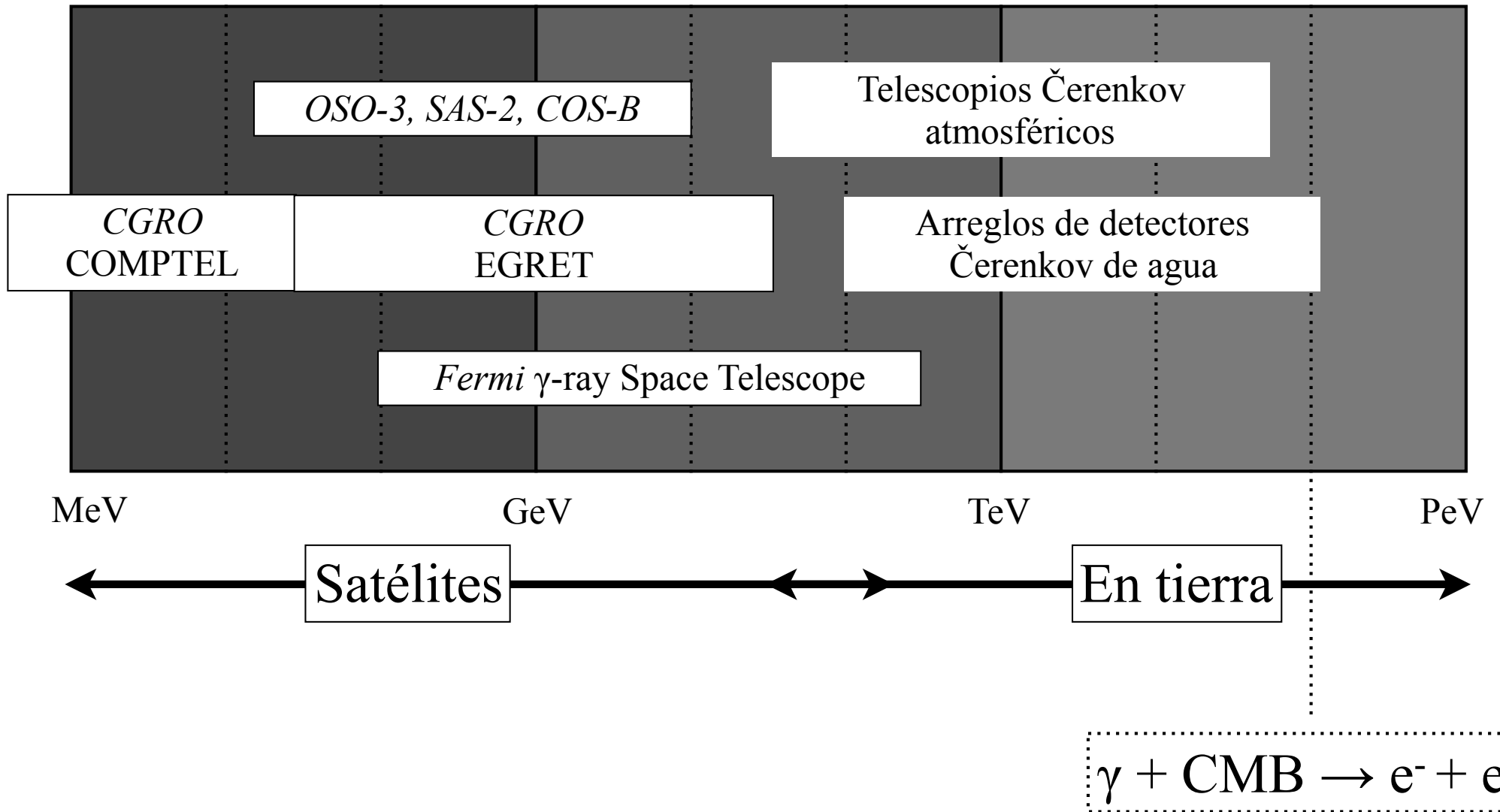
- Primer año: límites

- Mejoras a HAWC

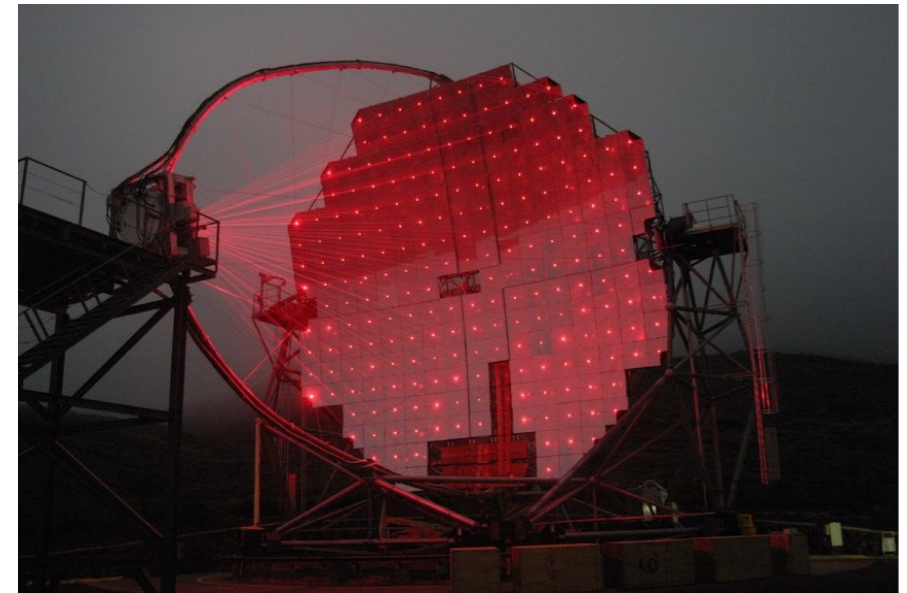
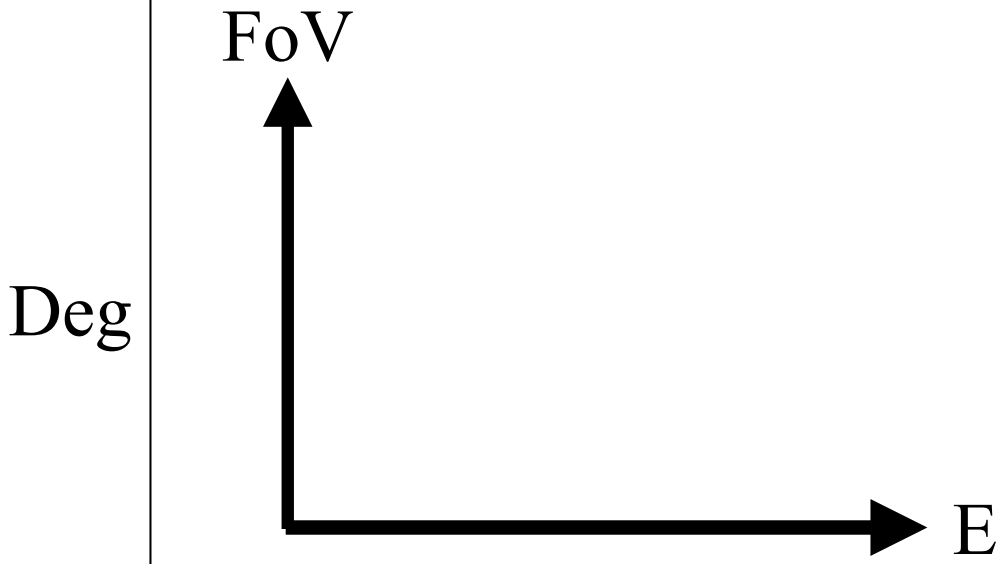
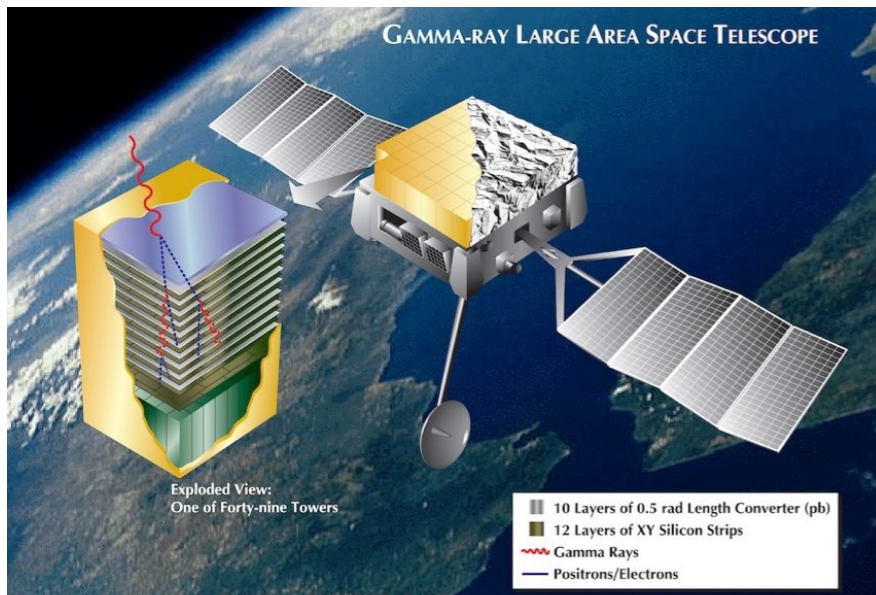


No térmico (e) \rightarrow **Térmico** \leftarrow No térmico (RCs)

La banda de rayos γ



Sr



GeV

TeV

Sr

Telescopios de producción de pares

0.1 - 100 GeV

En órbita: área efectiva limitada

Eliminación perfecta del ruido

Campo de visión amplio y largo ciclo de operación

Relevamiento & monitoreo del cielo

Eventos episódicos (AGN, GRB)

Emisión difusa extendida

Arreglos de detectores

100 GeV - 100 TeV

Gran área efectiva

Buena eliminación del ruido

Campo de visión amplio y largo ciclo de operación

Relevamiento & monitoreo parcial del cielo

Eventos episódicos (AGN, GRB)

Fuentes extendidas

Las mayores energías

Deg

FoV



Telescopios Čerenkov atmosféricos

50 GeV - 100 TeV

Gran área efectiva

Excelente eliminación del ruido

Pequeño campo de visión y bajo ciclo de operación - alta sensibilidad

Estudios detallados de fuentes conocidas

Relevamientos de regiones limitadas

Alta resolución espectral

GeV

TeV

Telescopios Čerenkov atmosféricos

Welcome to TeVCat!

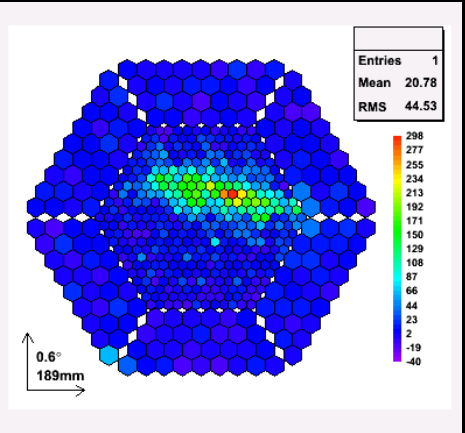
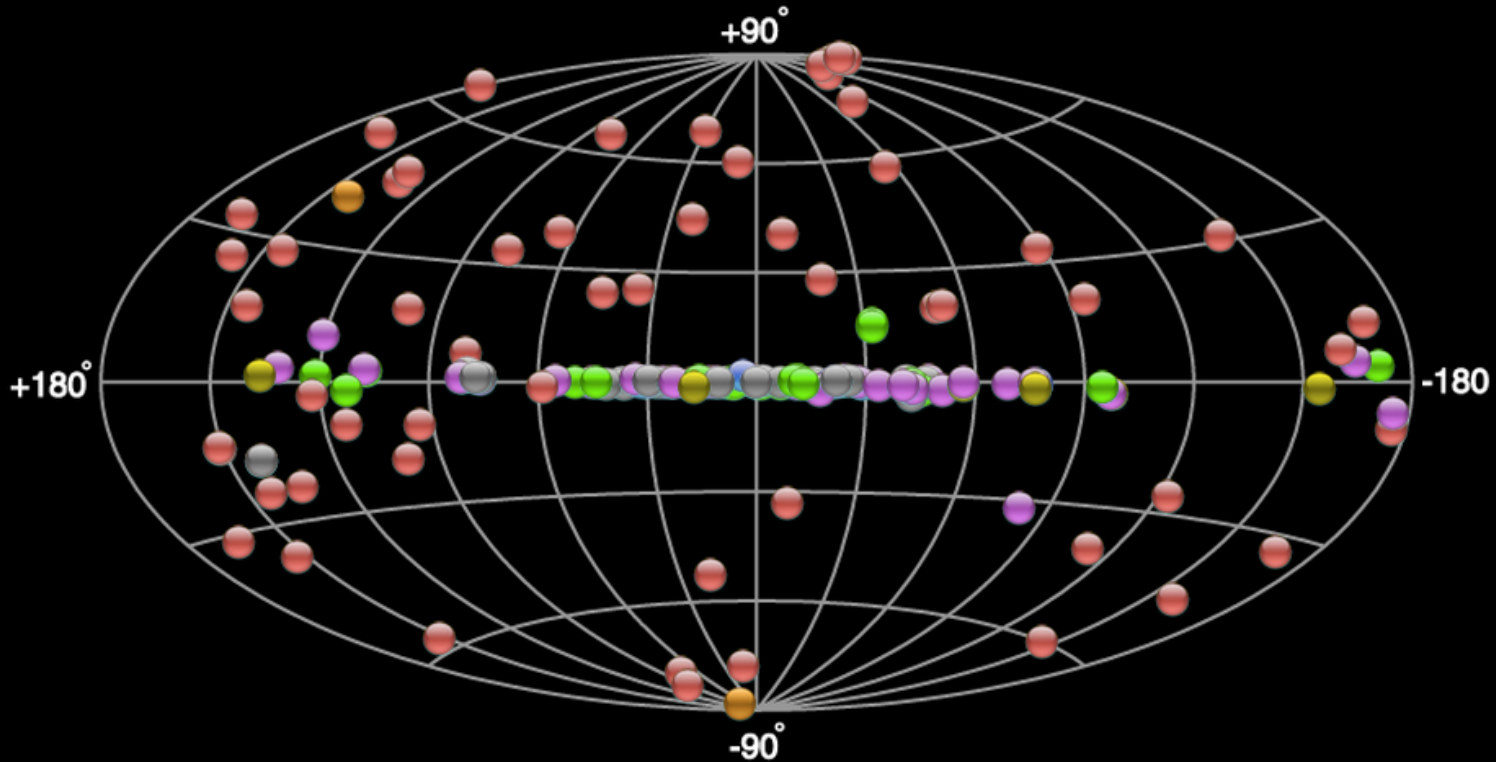


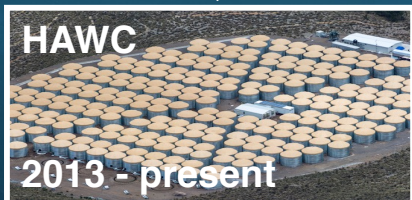
Table Cont... Map Cont... To... Lege...

- PWN
- Starburst
- HBL, IBL, FRI, Blazar, FSRQ, LBL, AGN (unknown type)
- Globular Cluster, Star Forming Region, uQuasar, Cat. Var., Massive Star Cluster, BIN, BL Lac (class unclear), WR
- Shell, SNR/Molec. Cloud, Composite SNR
- DARK, UNID, Other
- Binary, XRB, PSR, Gamma BIN

Export Black Export White



Arreglos de detectores - observatorios de rayos γ

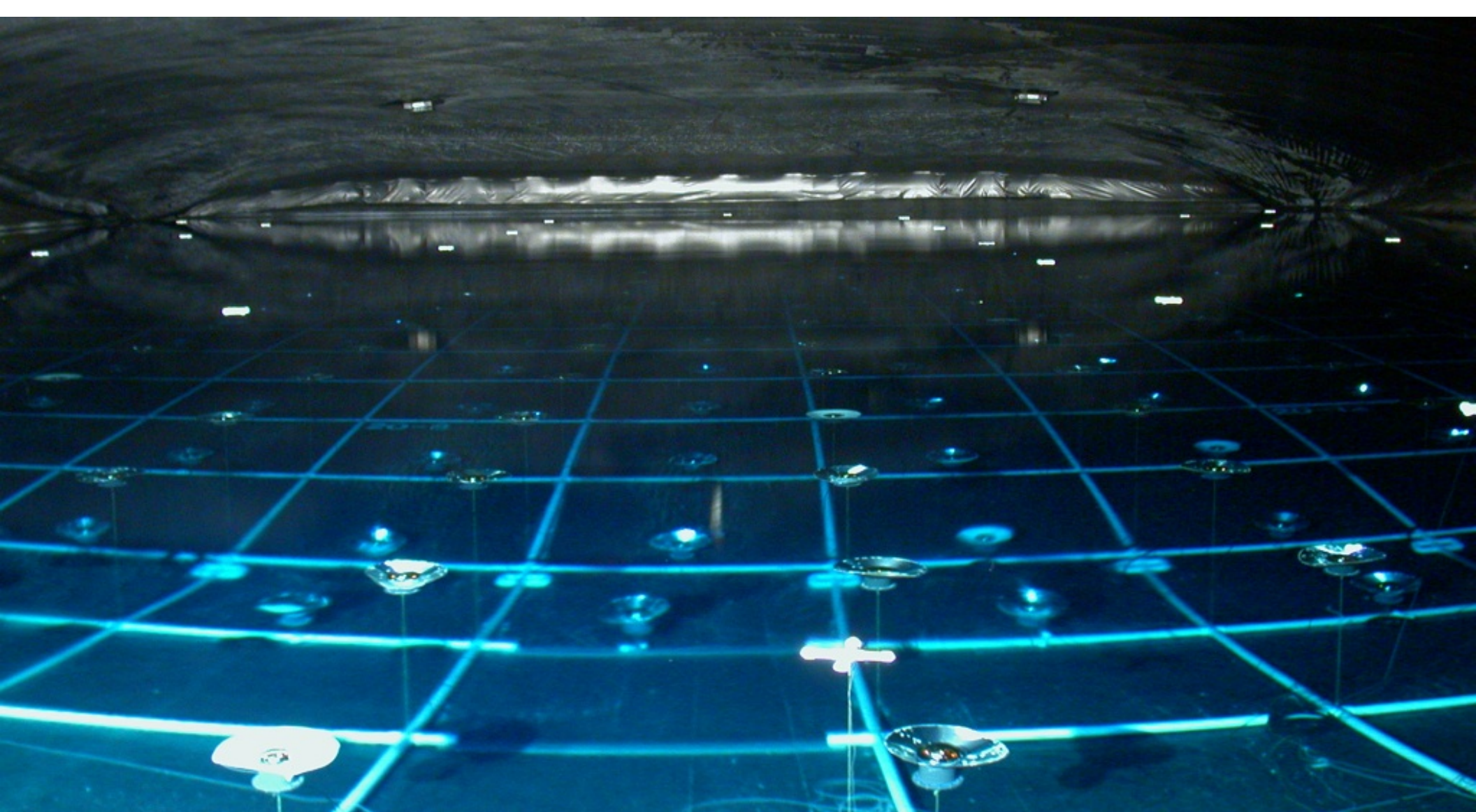


Ideales para monitoreo y mapeo de regiones amplias.

Realizan relevamientos no sesgados de porciones del cielo.

El observatorio Milagro

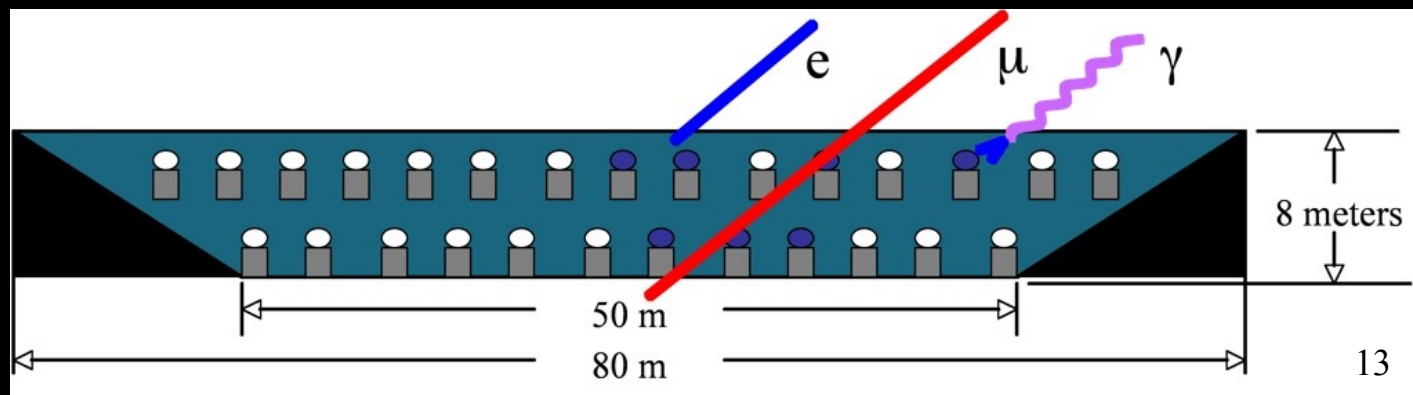
Primer observatorio de rayos γ Cherenkov de agua.
Ubicado en Nuevo México: altitud 2650m & latitud 36°N.
Mediana de energía = 40 TeV.
Operacional entre 1999 y 2008.



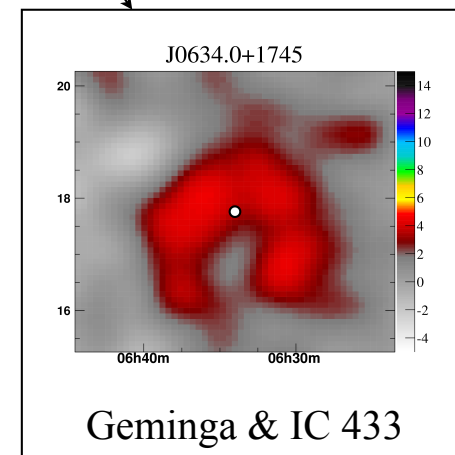
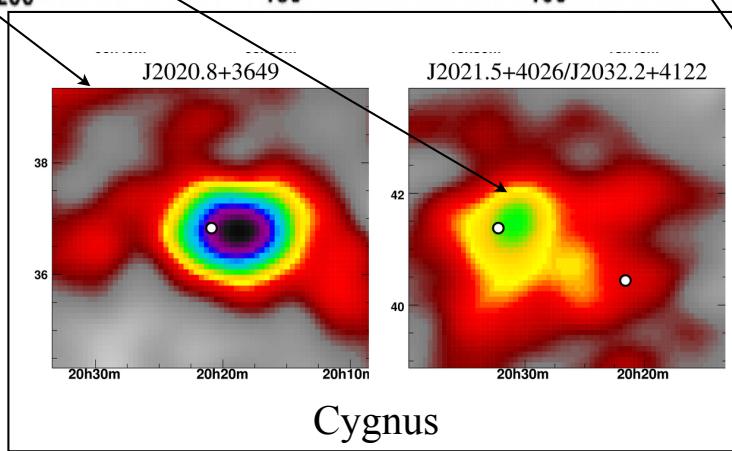
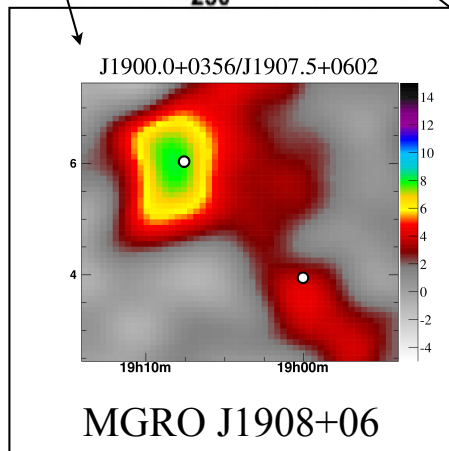
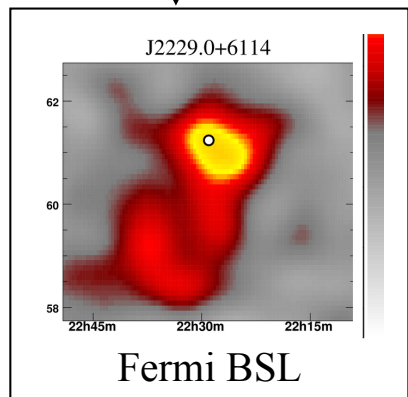
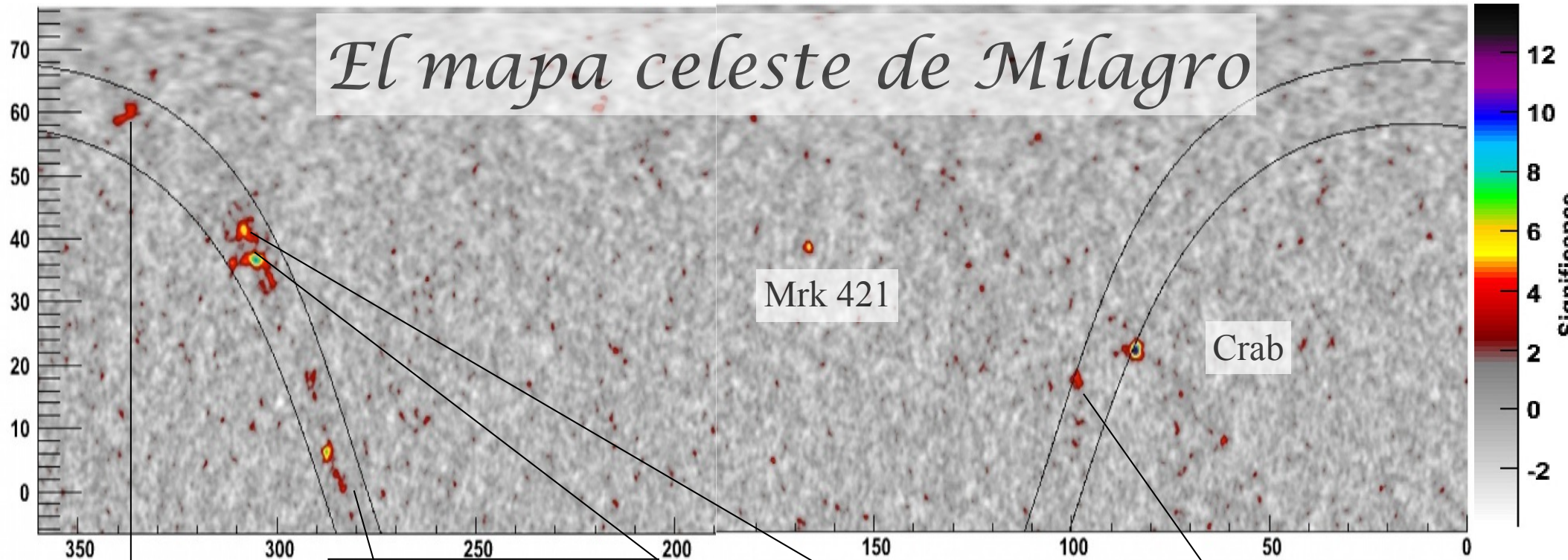
Plane of 2GeV Photons at 20°
Side View

Again notice the detailed structure of the showerfront in the pond, and the very deep penetration. The refraction of this showerfront is delayed until very deep in the pond due to the penetration of the energetic gamma photons.

Red - electrons and positrons
Green - secondary gammas
Blue - Cherenkov Photons



El mapa celeste de Milagro



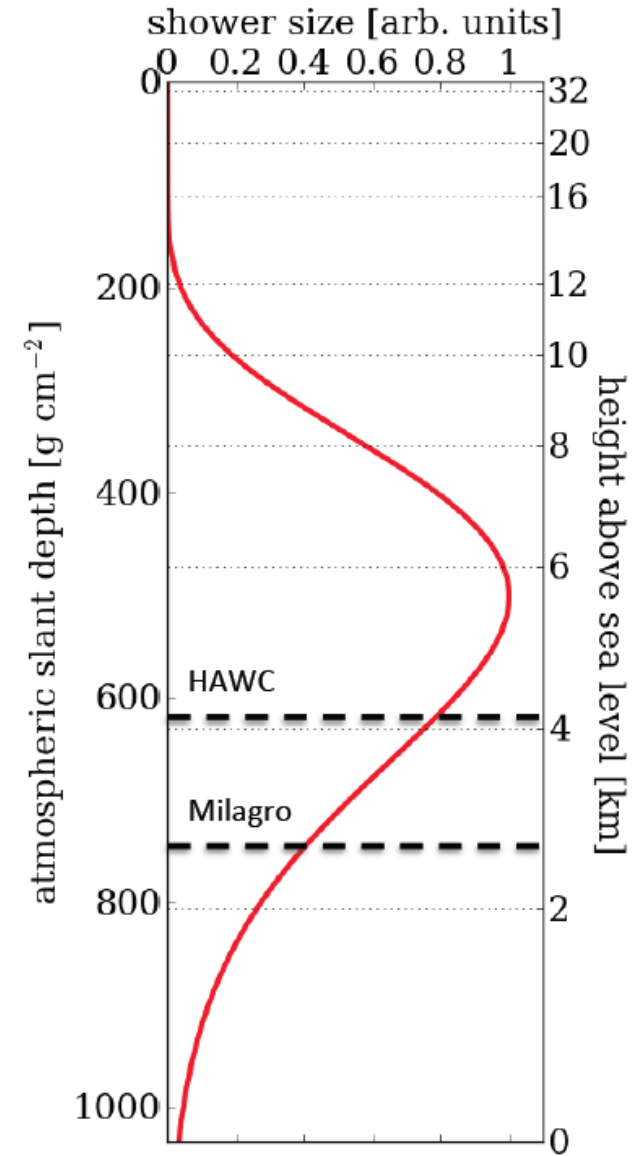
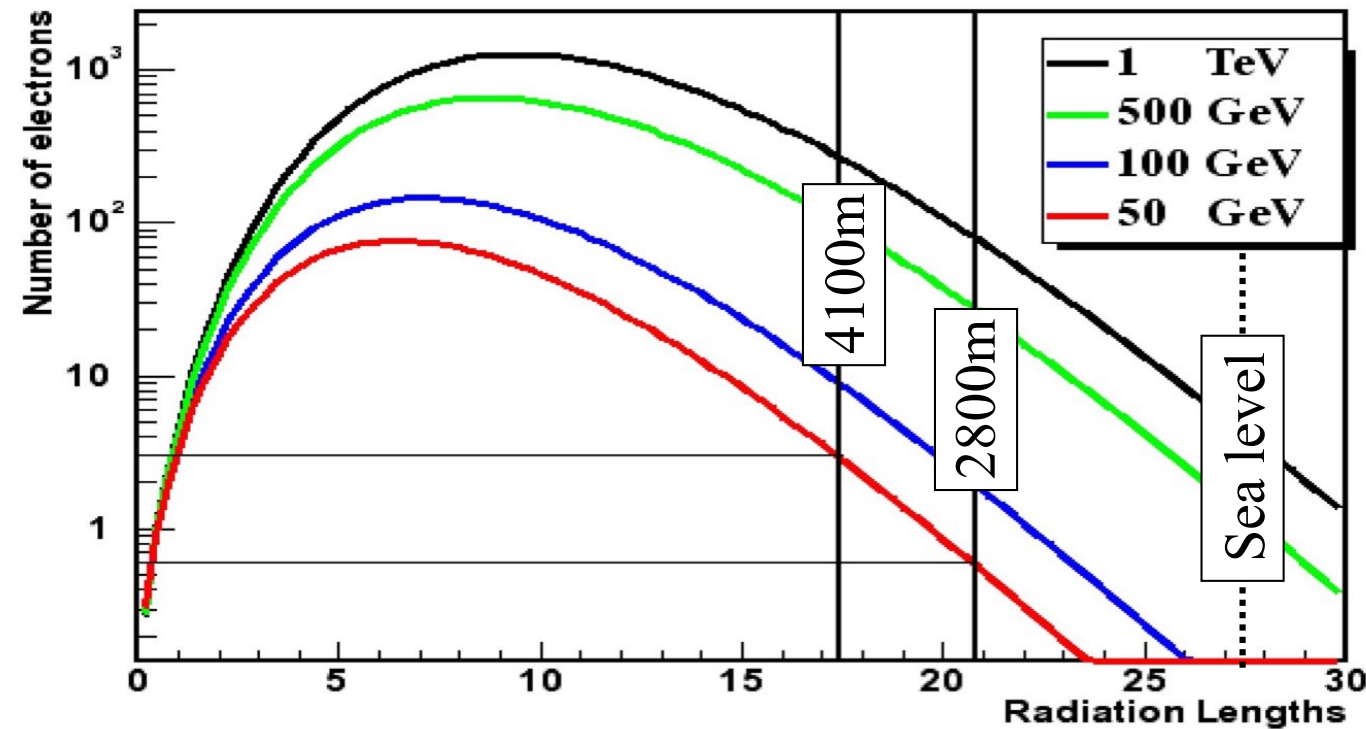
GeV PSR => TeV PWNe

High Altitude Water Cherenkov observatory

- Detector Cherenkov de agua construido con la experiencia de MILAGRO.
- Ubicado por encima de 4000 metros [Sierra Negra 4100m y 19°N]
- Diseño optimizado:
 - 4 × área de muestreo (22,000 m²),
 - 10 × área de detección de muones (22,000 m²),
 - aislamiento óptico de detectores individuales,
 - ➔ 15 × sensibilidad de MILAGRO.
- Rango de energía: 0.1 - 100 TeV :: detector de rayos cósmicos.
- Campo de visión: 1/6 del cielo instantáneo => 2/3 del cielo en un día sideral.



La atmósfera es la parte superior del detector



Sensitividad & campo de visión

Instrumento de tránsito

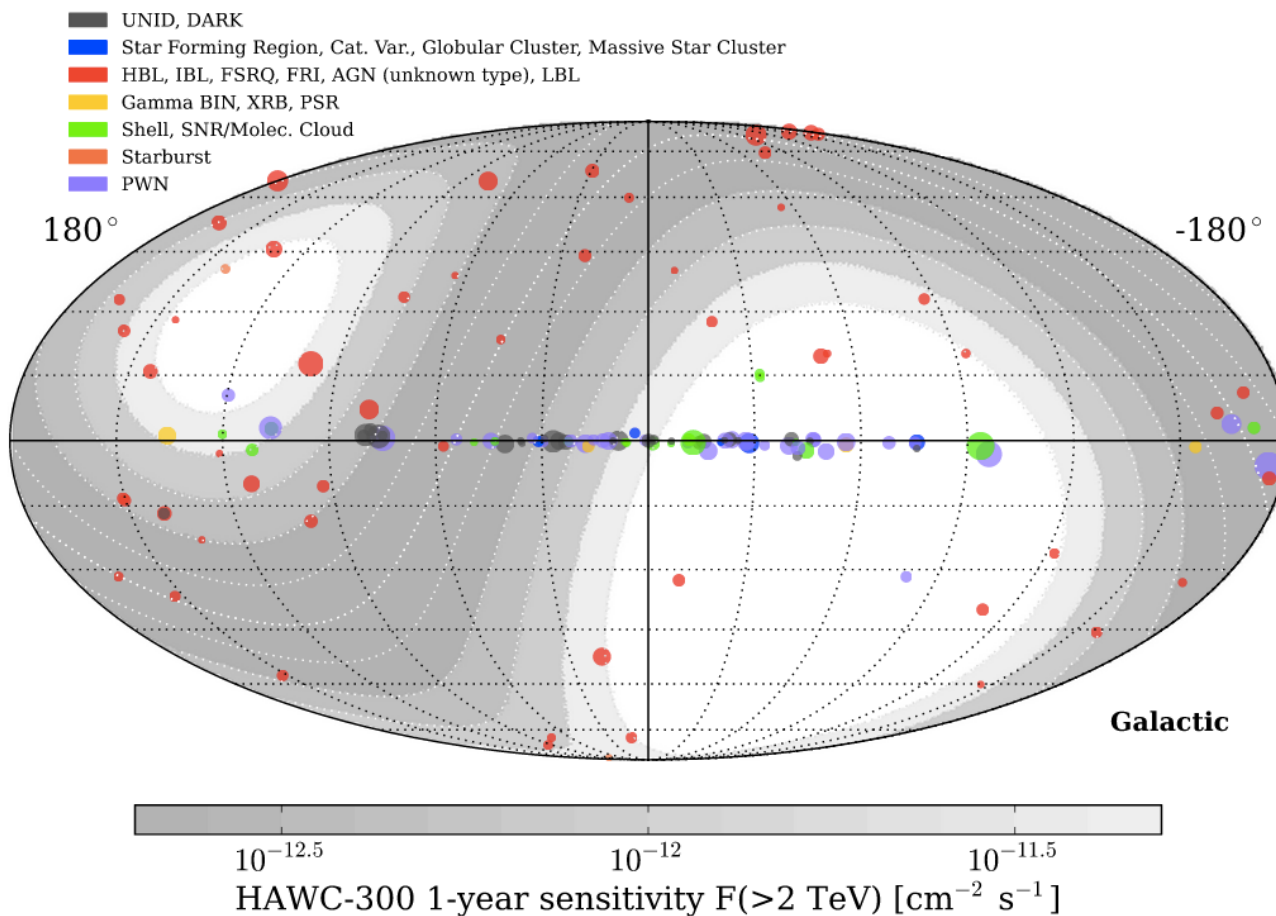
FOV = 1.8 Sr

HAWC deberá muestrear
2/3 de la esfera celeste cada
día a una profundidad de 1
Crab @ 5σ :

➔ eventos episódicos

➔ fuentes difusas extendidas

➔ 60 mCrab / sqrt(año)



3/2/2006
2003 2015

N

Observatorio de Rayos Gama HAWC

Image © 2015 DigitalGlobe

Google earth

2003

Fecha de las Imágenes: 3/2/2006 lat. 18.994865° long. -97.307674° elev. 4097 m alt. ojo 4.51 km

1/23/2011

N

Observatorio de Rayos Gama HAWC

Image © 2015 DigitalGlobe

Google earth

2003

Fecha de las imágenes: 1/23/2011 lat. 18.994865° long. -97.307674° elev. 4097 m alt. ojo 4.51 km

5/21/2011

Observatorio de Rayos Gama HAWC

Image © 2015 DigitalGlobe

Google earth

2003

Fecha de las imágenes: 5/21/2011 lat. 18.994865° long. -97.307674° elev. 4097 m alt. ojo 4.51 km

10/10/2012
2003 2015

Observatorio de Rayos Gama HAWC

Image © 2015 DigitalGlobe

Google earth

2003

Fecha de las Imágenes: 10/10/2012 lat. 18.994865° long. -97.307674° elev. 4097 m alt. ojo 4.51 km

3/1/2014
2003 2015

N

Observatorio de Rayos Gama HAWC

Image © 2015 DigitalGlobe

Google earth

2003

Fecha de las Imágenes: 3/1/2014 lat. 18.994865° long. -97.307674° elev. 4097 m alt. ojo 4.51 km

12/31/2014

Observatorio de Rayos Gama HAWC

Image © 2015 DigitalGlobe

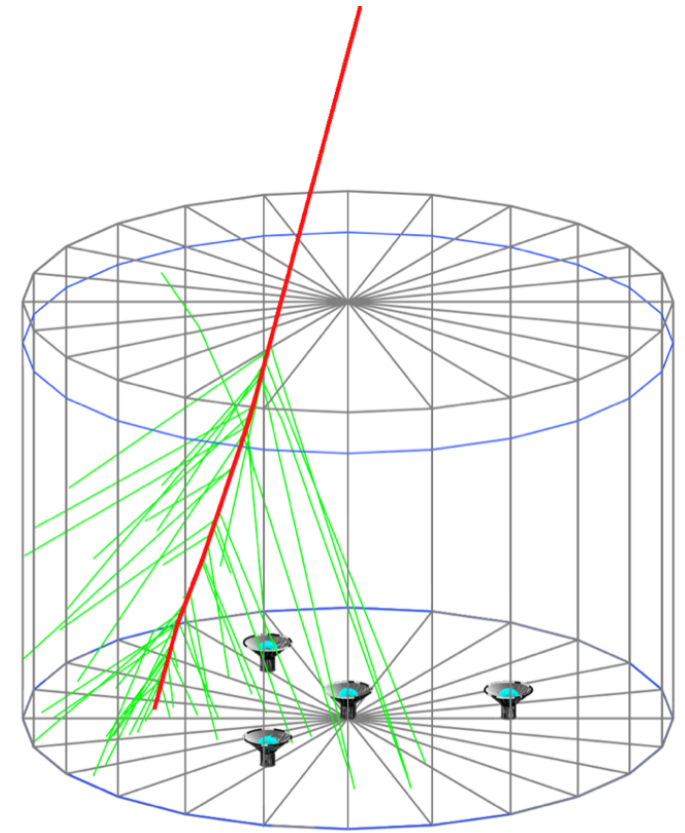
Google earth

2003

Fecha de las Imágenes: 12/31/2014 lat. 18.994865° long. -97.307674° elev. 4097 m alt. ojo 4.51 km

Detectores Cherenkov de agua

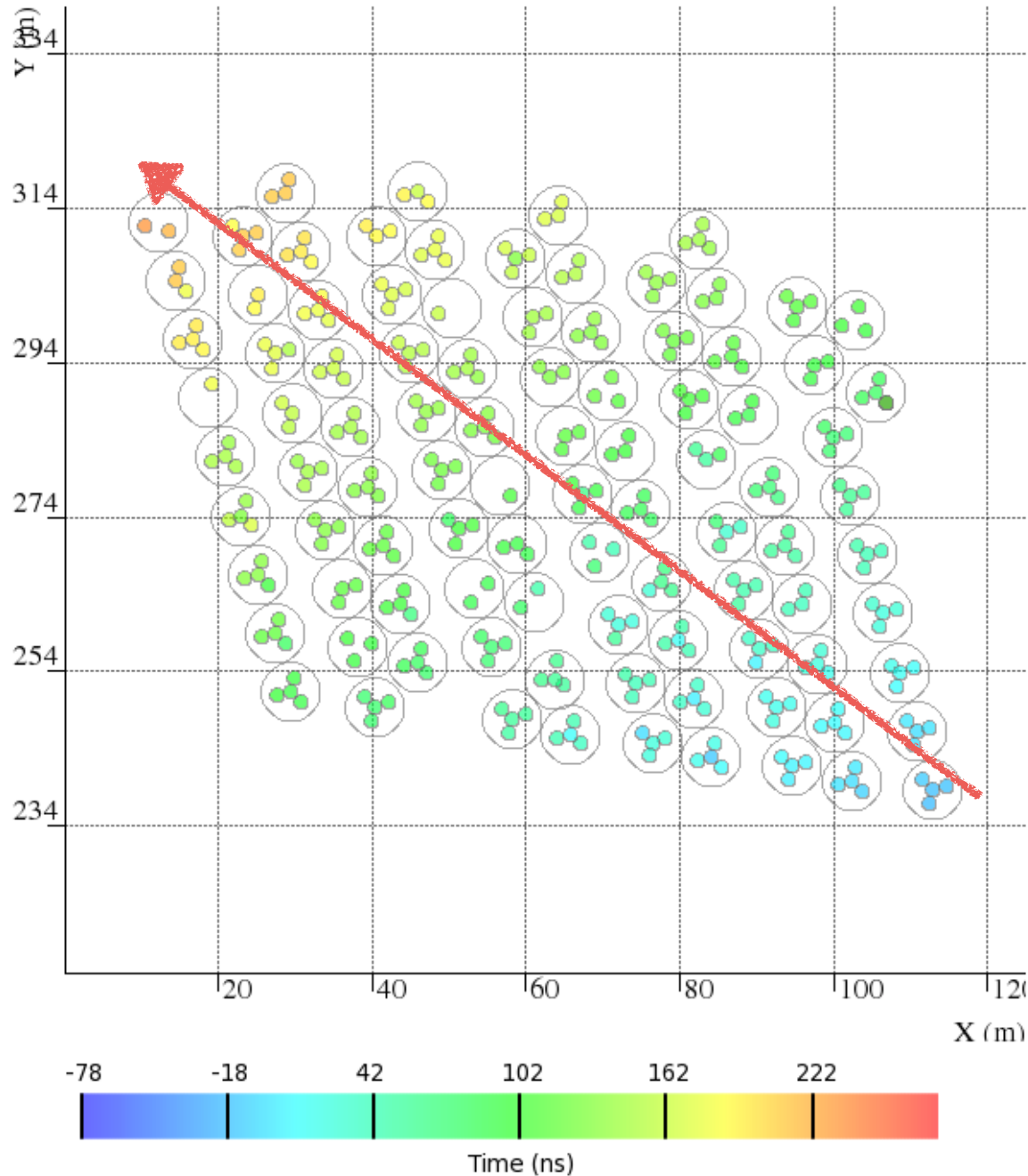
- Cada WCD tiene 180,000 litros de agua.
- Agua tratada: máxima transparencia.
- Cada WCD tiene 3(8") + 1(10") PMT: respuesta rápida y alta QE a la luz Cherenkov (azul a UV).
- Fibras ópticas para calibración.
- Cada WCD conectado a counting house.



Timing

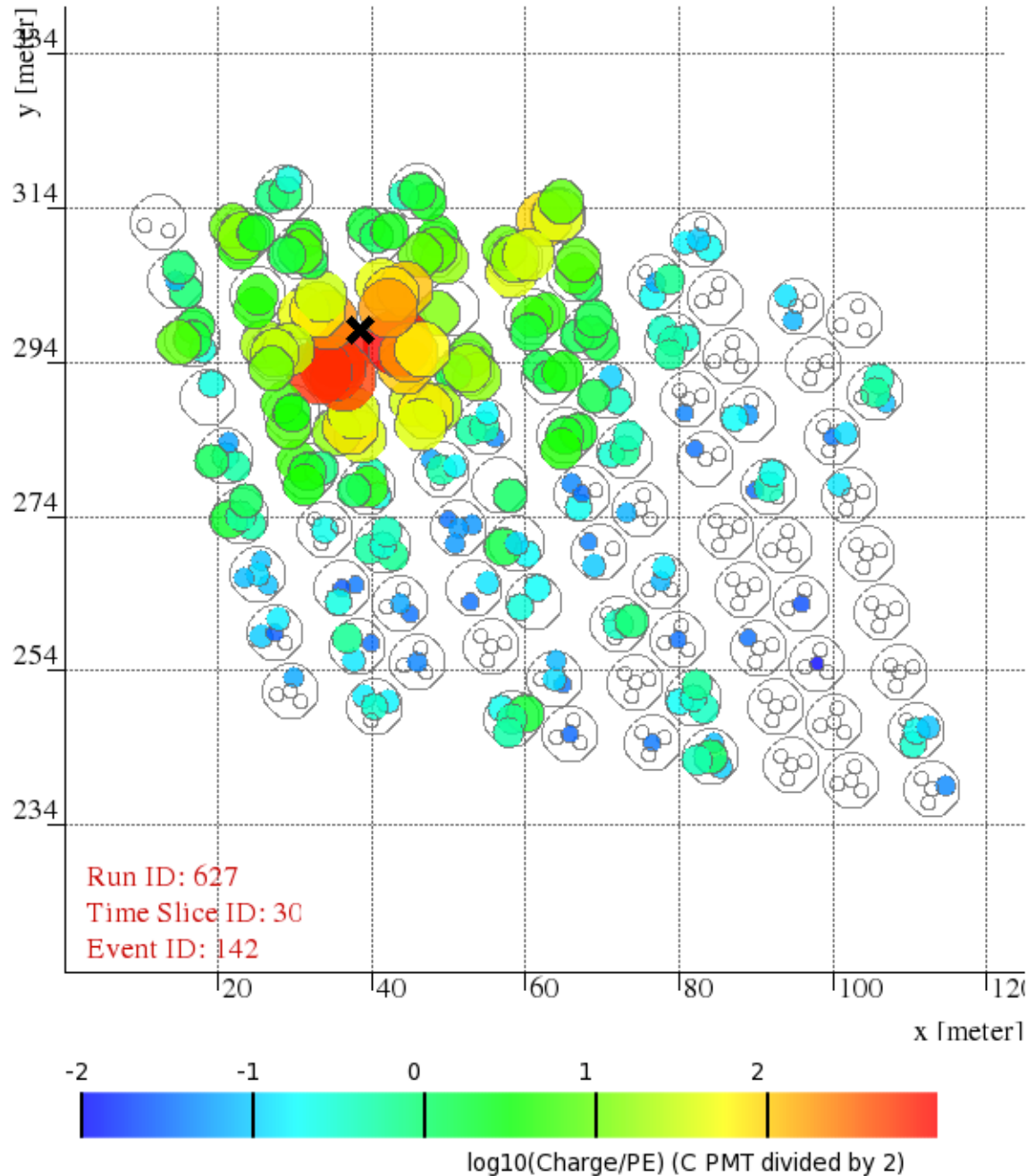
El espacio entre tanques equivale a 25 - 50 ns-luz.

Se ajustan los tiempos de llegada a un frente curvo de partículas \Rightarrow residuos por debajo de 1ns.



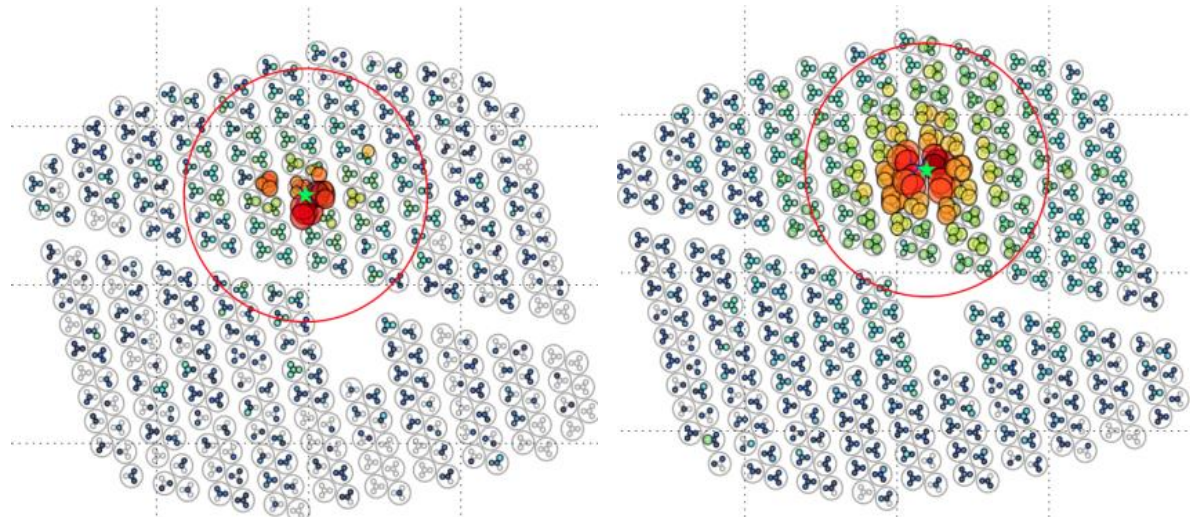
Intensidad

- Registro de pulsos individuales en PMTs:
 - Estimación de energía.
 - discriminación γ /hadrón.
- Ubicación del centro de la cascada y modelaje del depósito de energía de acuerdo a modelos estándar (NKG) y simulaciones de la respuesta de HAWC.

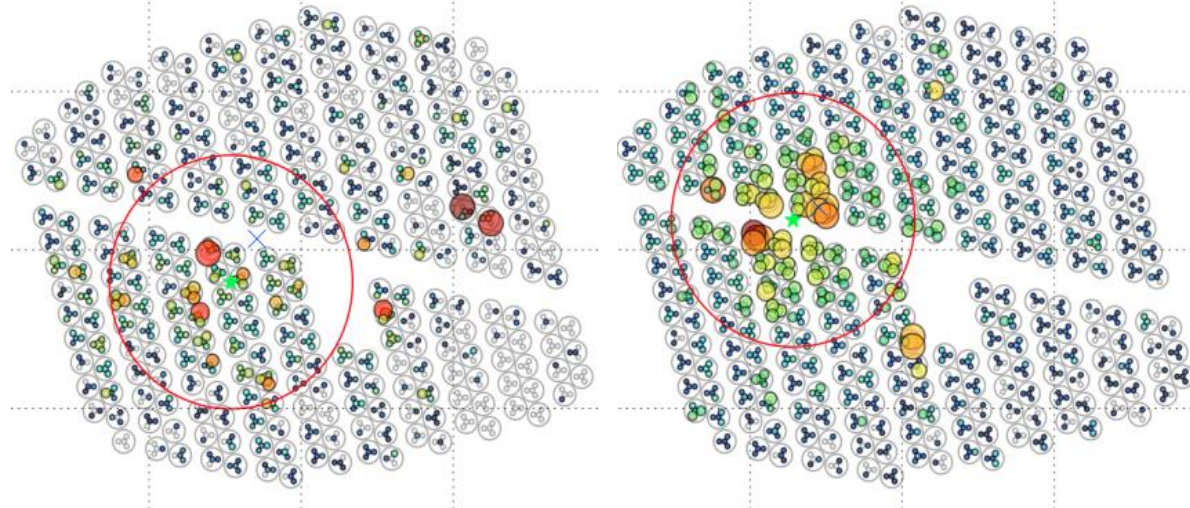


Discriminación γ / hadrón

γ



Hadrón

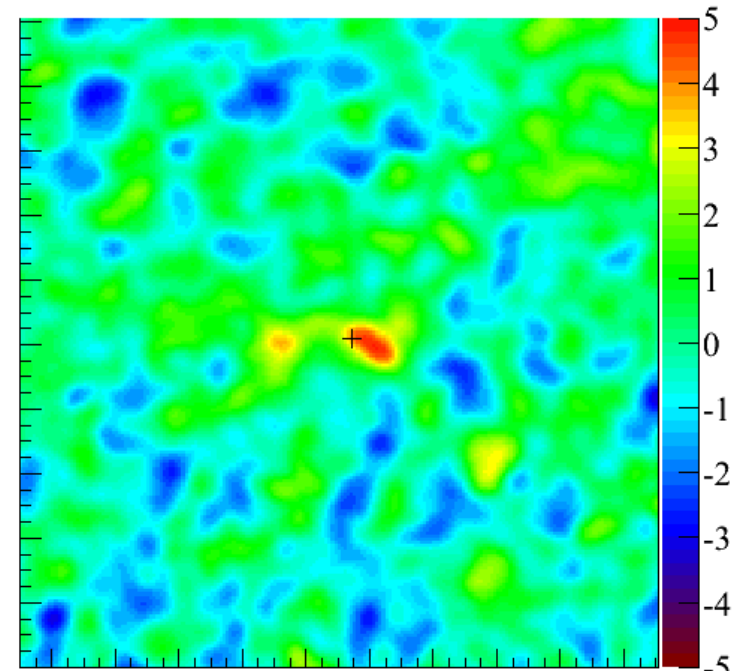
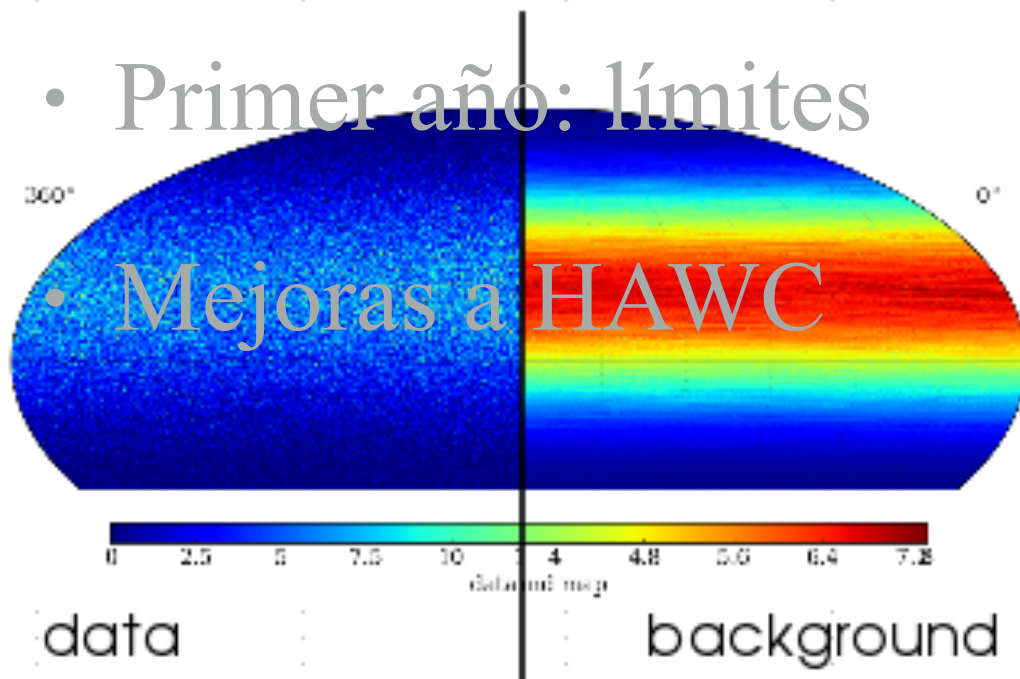


Primer año de HAWC

- HAWC
- Mapa del cielo del primer año: detecciones

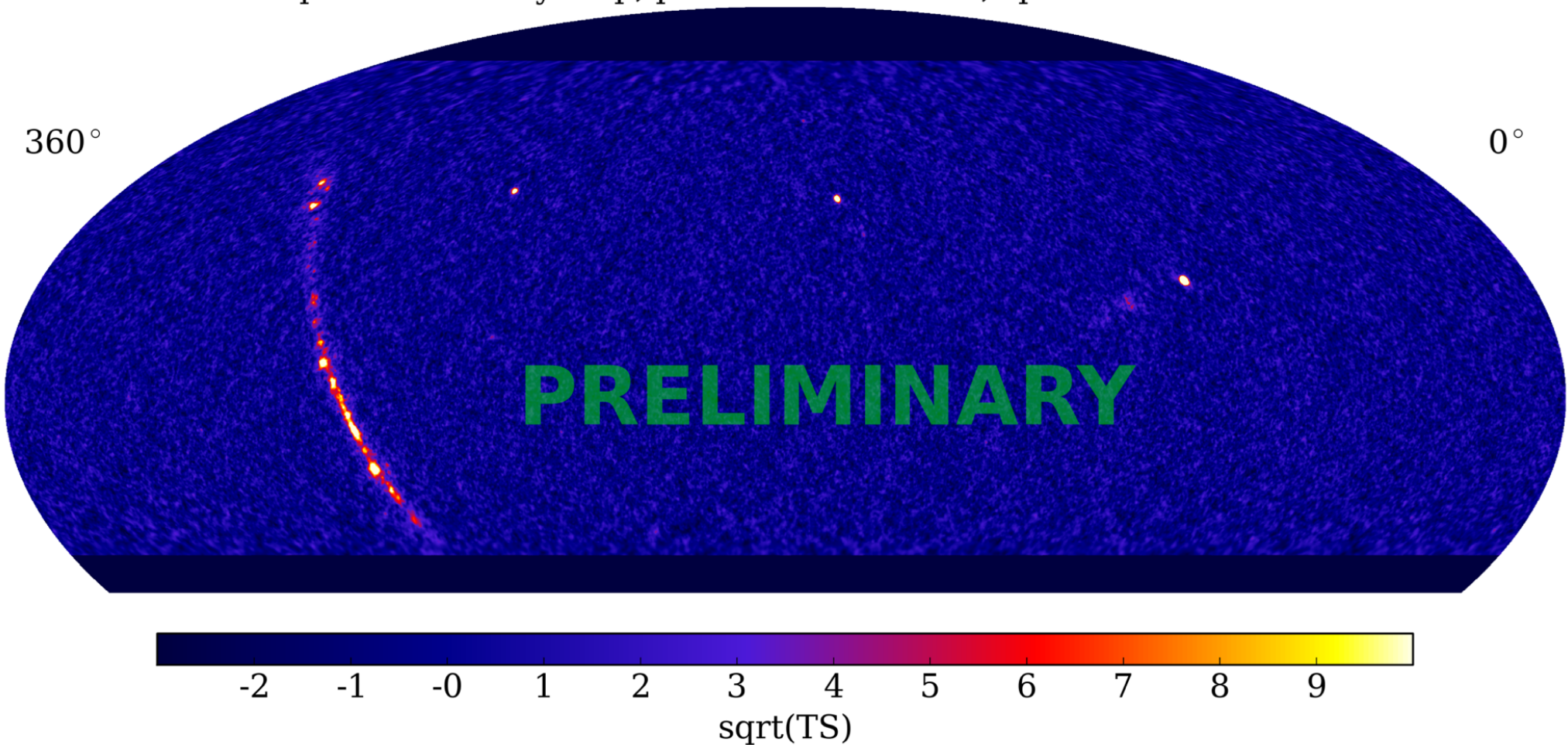
- Primer año: límites

- Mejoras a HAWC



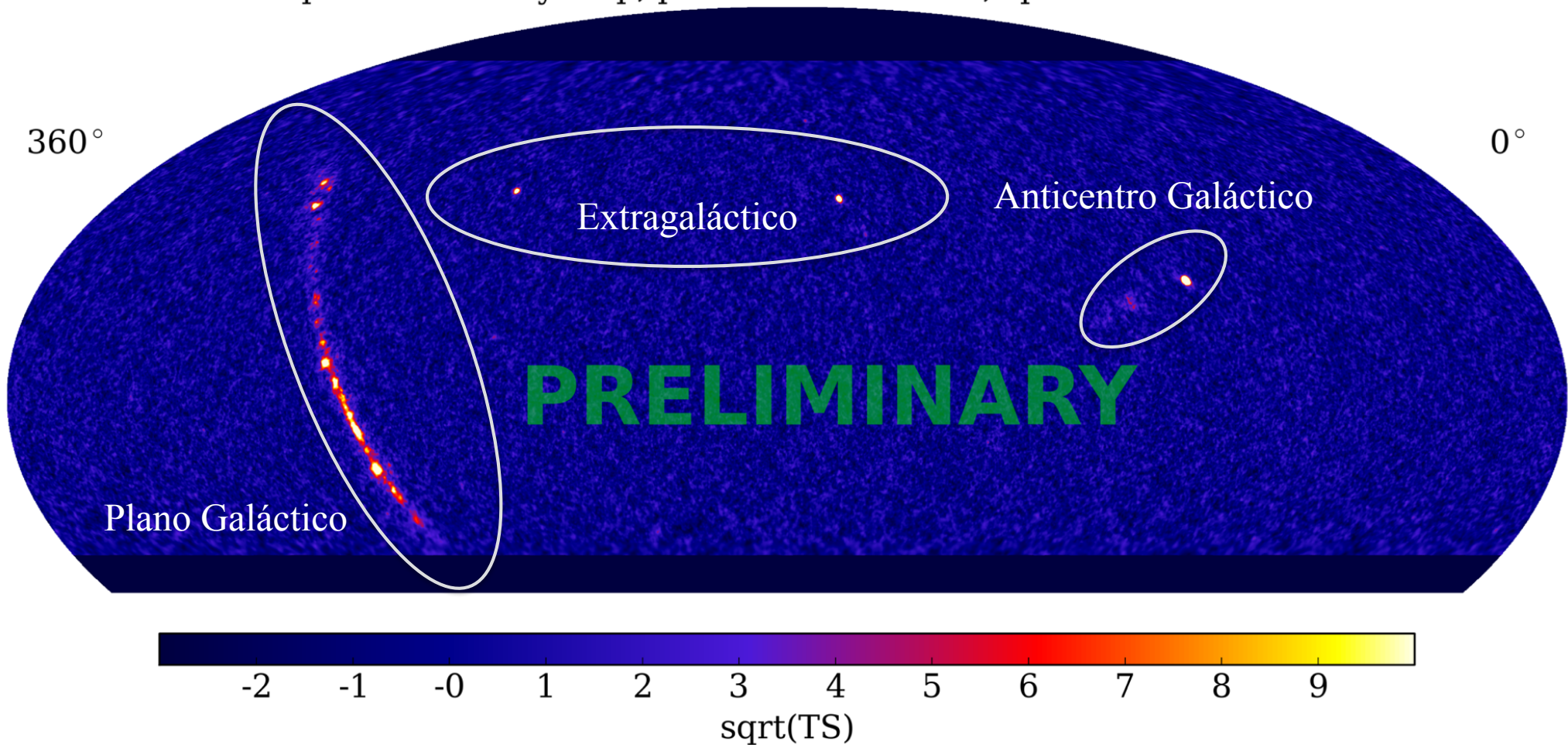
Primer año de HAWC

Equatorial all sky map, point source search, spectral index -2.7



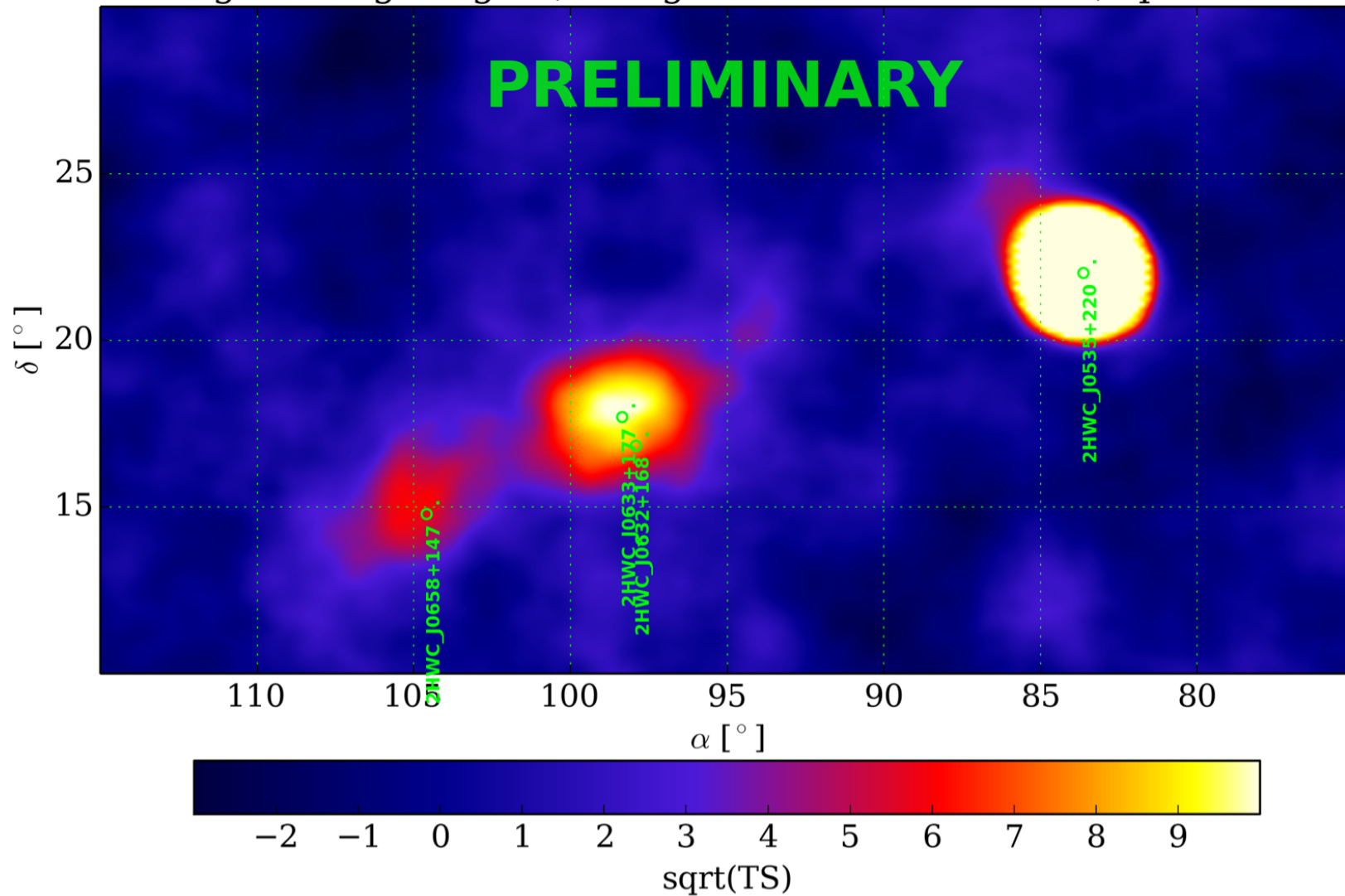
Primer año de HAWC

Equatorial all sky map, point source search, spectral index -2.7

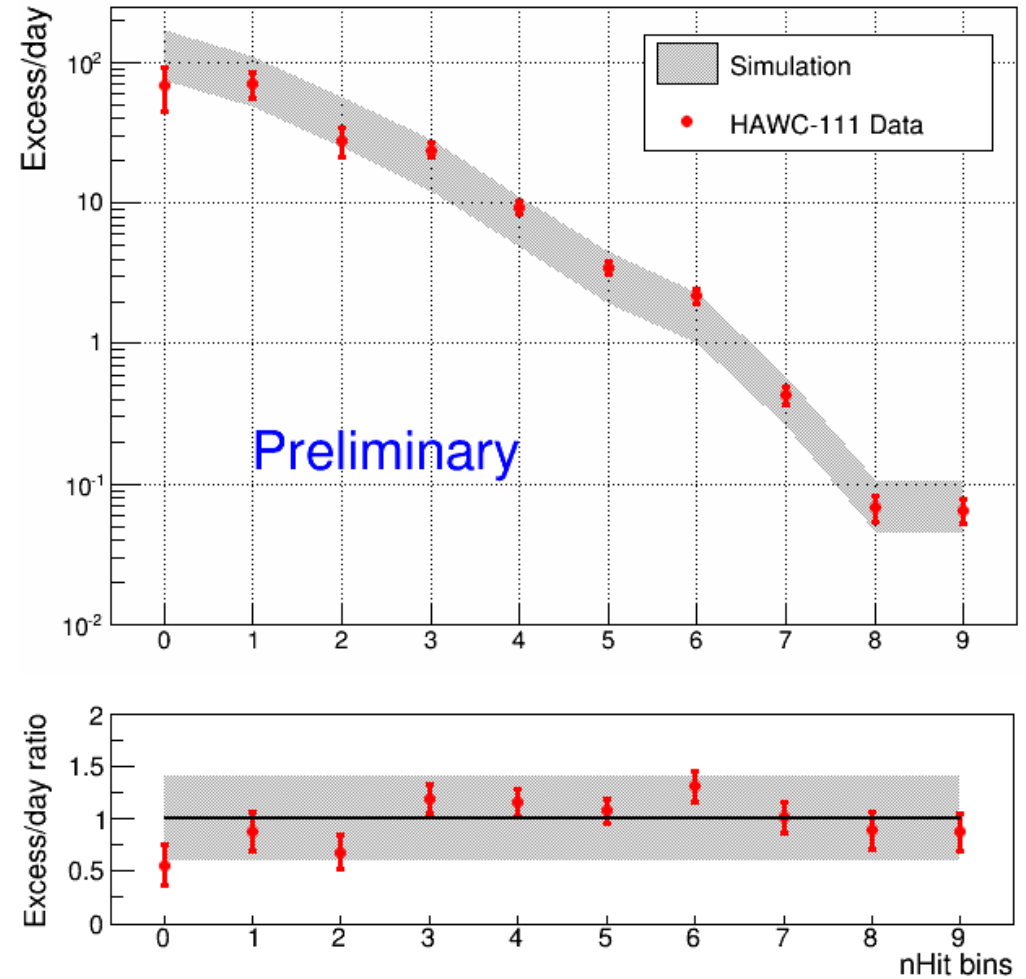
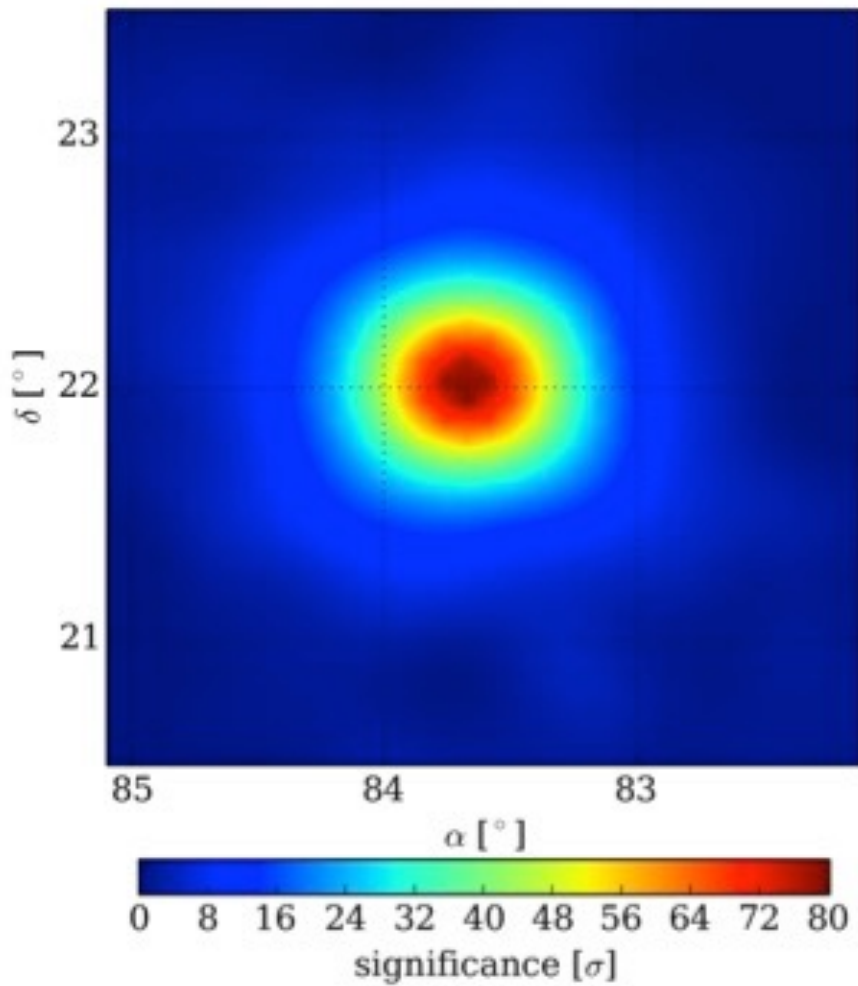


Anticentro Galáctico

Crab/Geminga/Gamigo region, 2 degrees extended search, spectral index -2.0

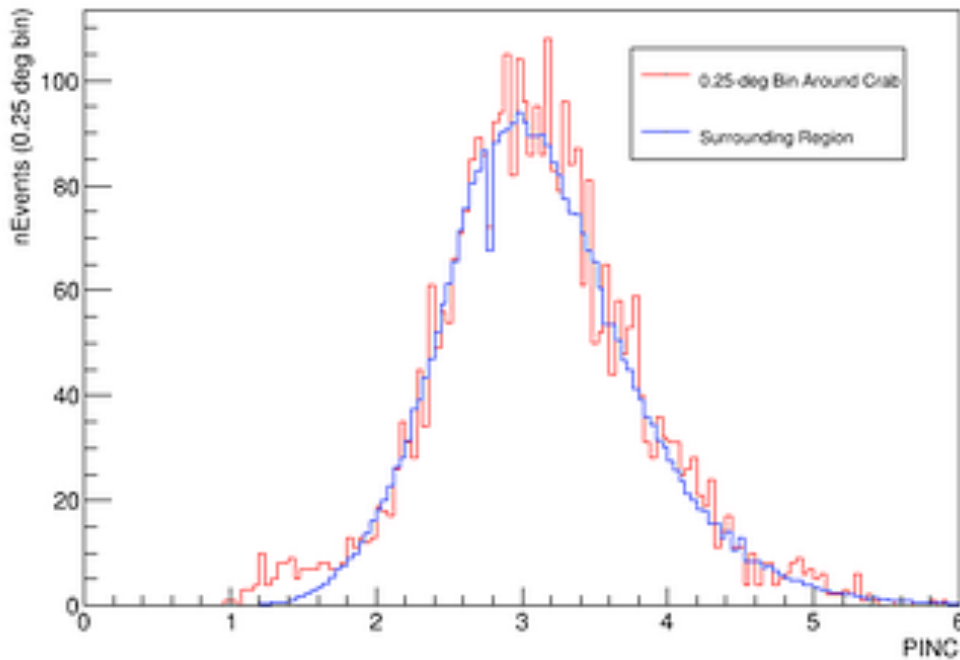


El Cangrejo

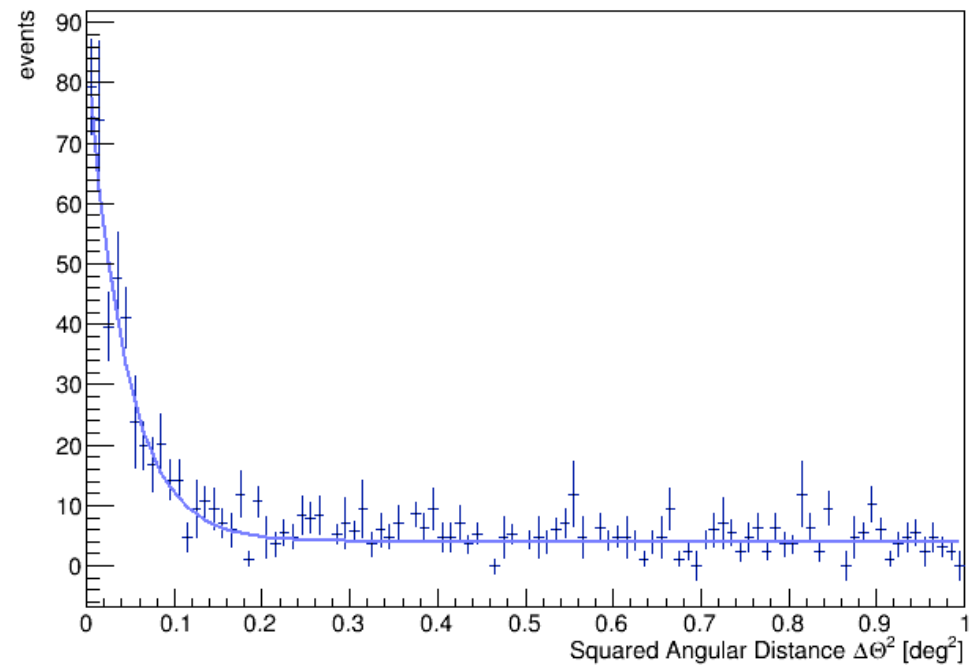


Análisis “Pass 4”

>85% PMTs Hit

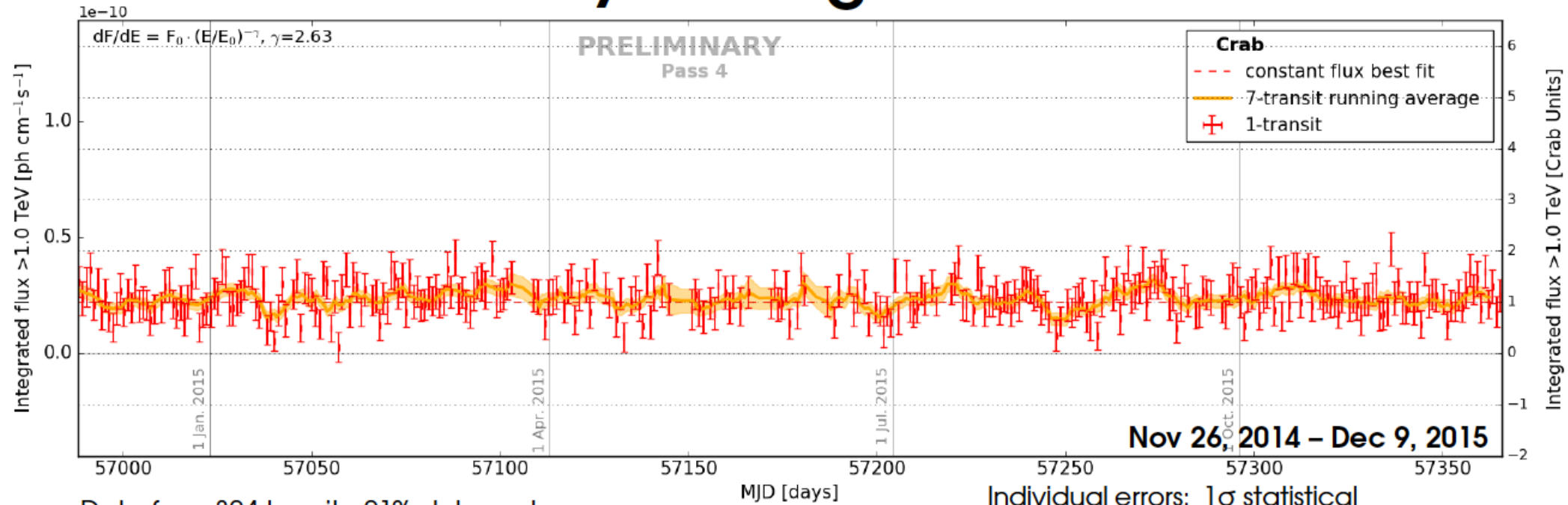


PING : Parameter for Identification
of Nuclear Cosmic Rays
Reject > 99.9% hadronic background
while retaining >50% of γ -rays



Angular resolution for large
events $\sim 0.15^\circ$
68% containment = 0.24°
Achieving proposed resolution

Crab Nebula: Daily Flux Light Curve



Data from 324 transits, 21% duty cycle

Individual errors: 1σ statistical
Overall scaling: 20% systematic uncertainty

A likelihood test shows that the **data is consistent with a constant flux.**

The Crab Nebula has shown flares at lower (\sim MeV) gamma-ray energies, but none such flare was observed by Fermi-LAT during the period shown here.



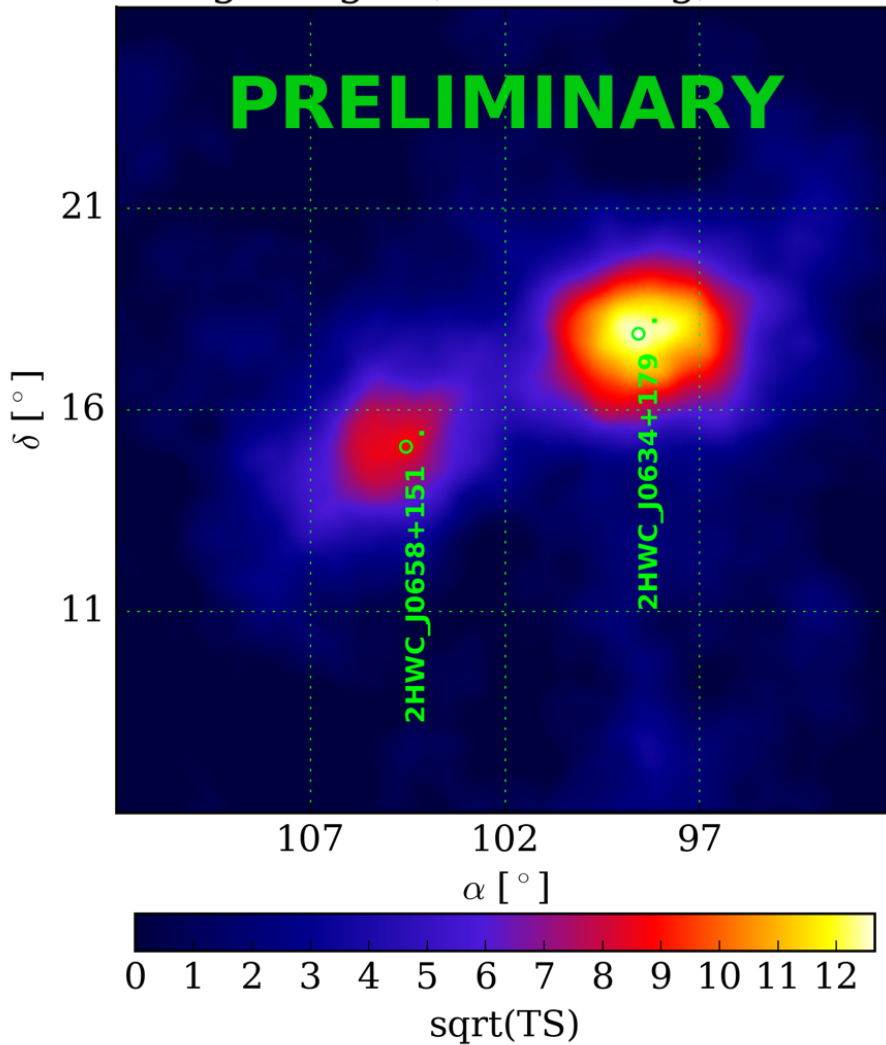
Robert Lauer (rlauer@phys.unm.edu)

APS Meeting, April 18, 2016

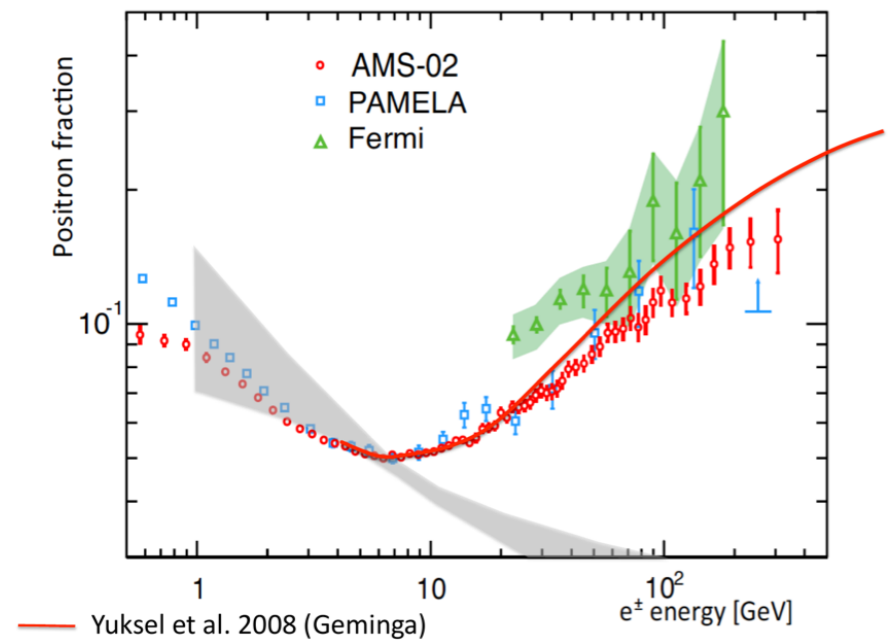
8

Geminga y compañía

Geminga Region, Disk 2 deg, index -2.2.



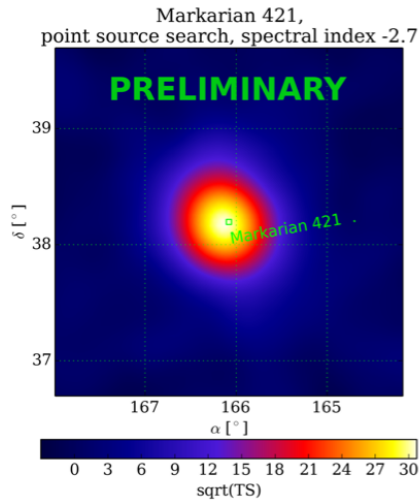
- Ambas fuentes cercanas asociadas a un pulsar.
- Conexión con exceso de positrones?



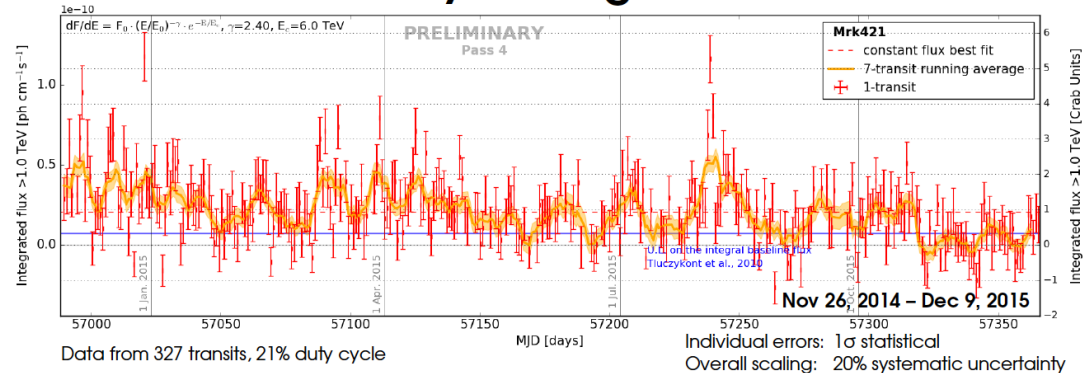
Extragaláctico

Mrk 421

Blazar más brillante del cielo en TeV.
Primera fuente extragaláctica descubierta en TeV.
Detectada marginalmente por MILAGRO
 $z = 0.030$



Markarian 421: Daily Flux Light Curve

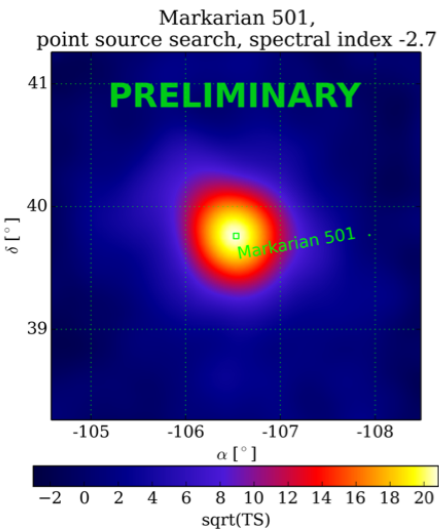


Likelihood variability: **Inconsistent with constant flux, p-value < 10⁻¹⁰**

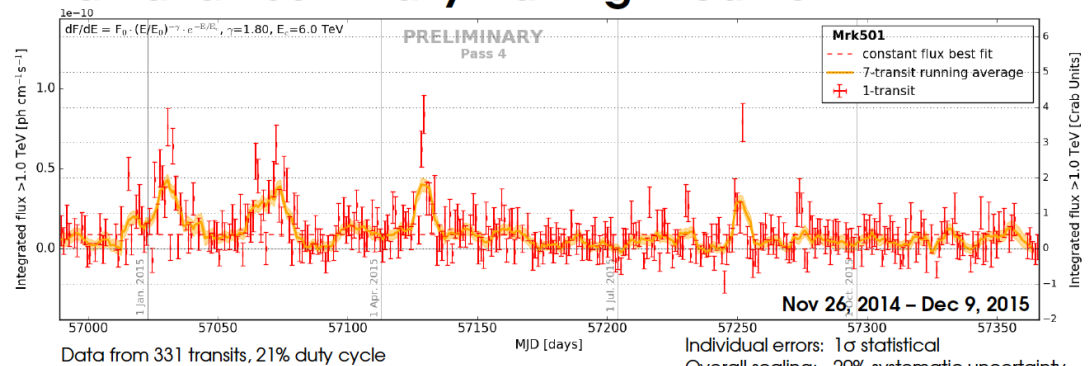
High States: - A large number of high flux states until spring 2015, resulting in a high **average flux about equal to the Crab flux**
- **7 transits show a flux > 4 σ_{flux} above the average** (constant flux fit)

Mrk 501

BL Lac cercano.
Emisión en TeV altamente variable con escalas temporales cortas.
Evidencia en MILAGRO
 $z = 0.033$



Markarian 501: Daily Flux Light Curve



Likelihood variability: **Inconsistent with constant flux, p-value < 10⁻¹⁰**

High States: **5 transits show a flux 4 σ_{flux} above the average** (constant flux fit)

Outside
GCN
IAUCs

Other
ATel on [Twitter](#) and [Facebook](#)
[ATELstream](#)
[ATel Community Site](#)
MacOS: [Dashboard Widget](#)

24 May 2016; 06:47 UT

[[Previous](#) | [Next](#) | [ADS](#)]

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

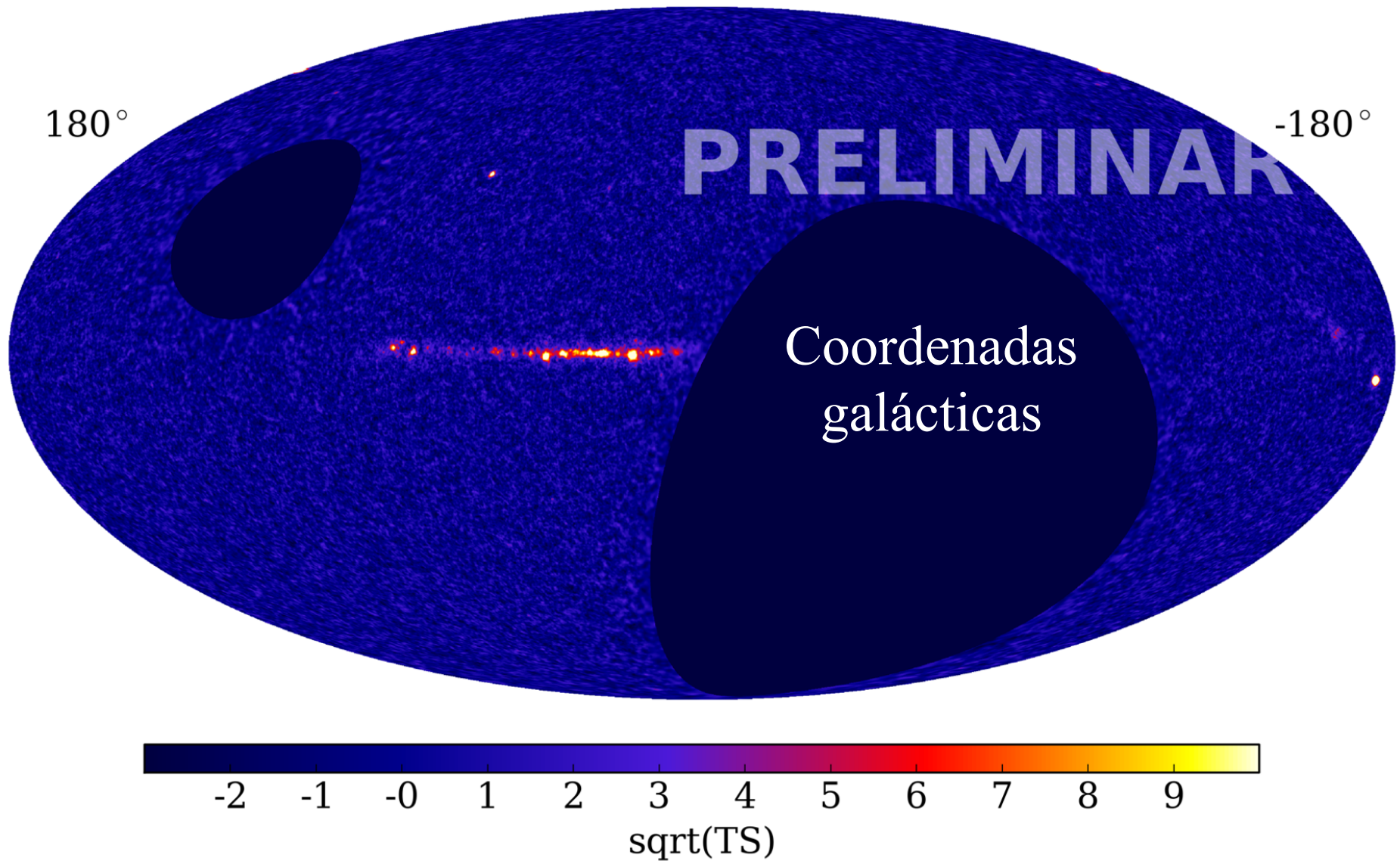
Credential Certification: C. Michelle Hui (c.m.hui@nasa.gov)

Subjects: Gamma Ray, TeV, VHE, Request for Observations, AGN, Blazar

[Tweet](#) [Recommend](#) 11

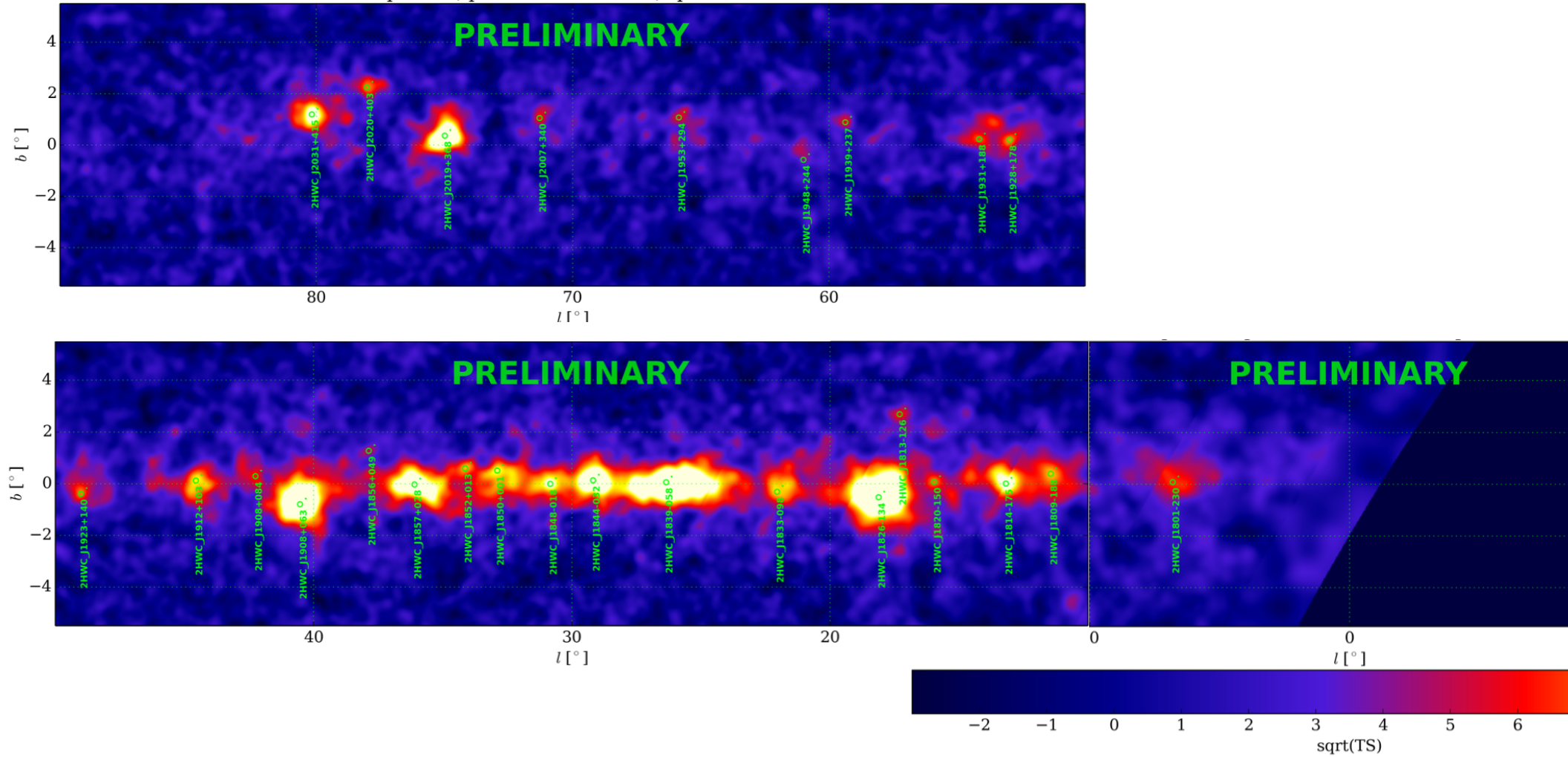
The HAWC Observatory measured an increased gamma-ray flux from the direction of the BL Lac Markarian 501 ($z=0.033$) at the level of $(4.88 \pm 1.05) \times 10^{-11}$ photons $\text{cm}^{-2} \text{s}^{-1}$ above 1 TeV when averaged during the 6 hour transit over HAWC on April 6, 2016 (MJD 57484.31 - 57484.56) which is 2.2 times the average Crab flux observed by HAWC. For the following transit on April 7, 2016 (MJD 57485.30 - 57485.55), a decreased but still above-average flux of $(2.78 \pm 0.09) \times 10^{-11}$ photons $\text{cm}^{-2} \text{s}^{-1}$ was observed, 1.3 times the Crab flux seen by HAWC. The flux on April 6 lies 4 sigma above the average flux of 0.89×10^{-11} photons $\text{cm}^{-2} \text{s}^{-1}$ that was measured for this source by HAWC during the previous year. The flux level on April 7 is 2 sigma above this average and seems to indicate a declining but on-going high flux state. All flux values are obtained from a maximum likelihood fit under the assumption of a fixed spectral shape with power law index of 1.8 and exponential cut-off at 6 TeV. These spectral parameters are the best fit results for HAWC data from Markarian 501 collected between November 2014 and December 2015. HAWC is a TeV gamma ray water Cherenkov array located in the state of Puebla, Mexico that monitors 2/3 of the sky every day with an instantaneous field of view of ~ 2 sr. The HAWC contact people for this analysis are Robert Lauer (University of New Mexico, rjlauer@unm.edu) and Michelle Hui (Marshall Space Flight Center, c.m.hui@nasa.gov).

Primer año de HAWC



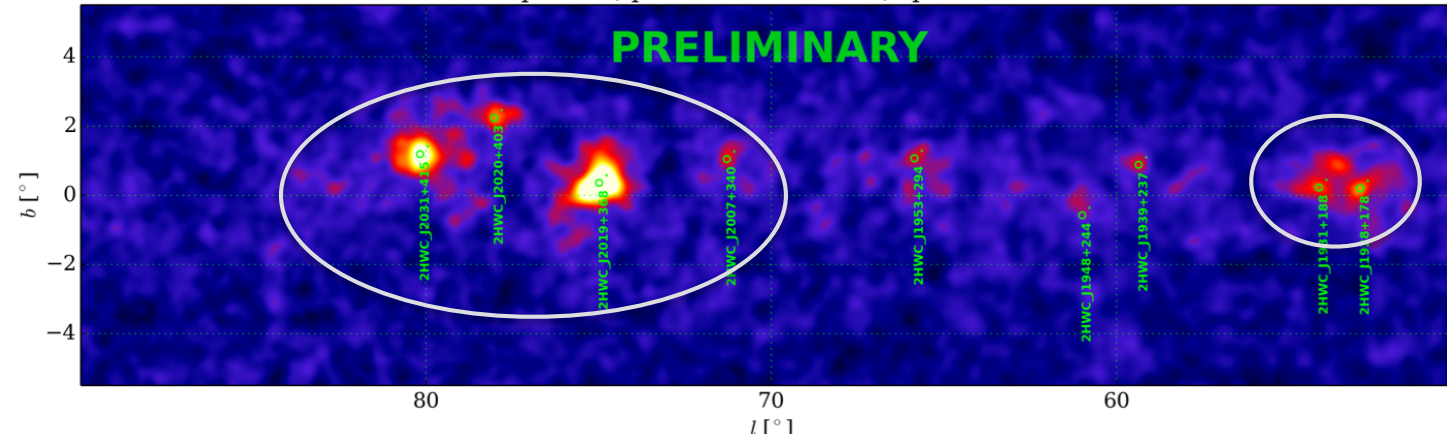
En el Plano Galáctico

Galactic plane 2, point source search, spectral index -2.7

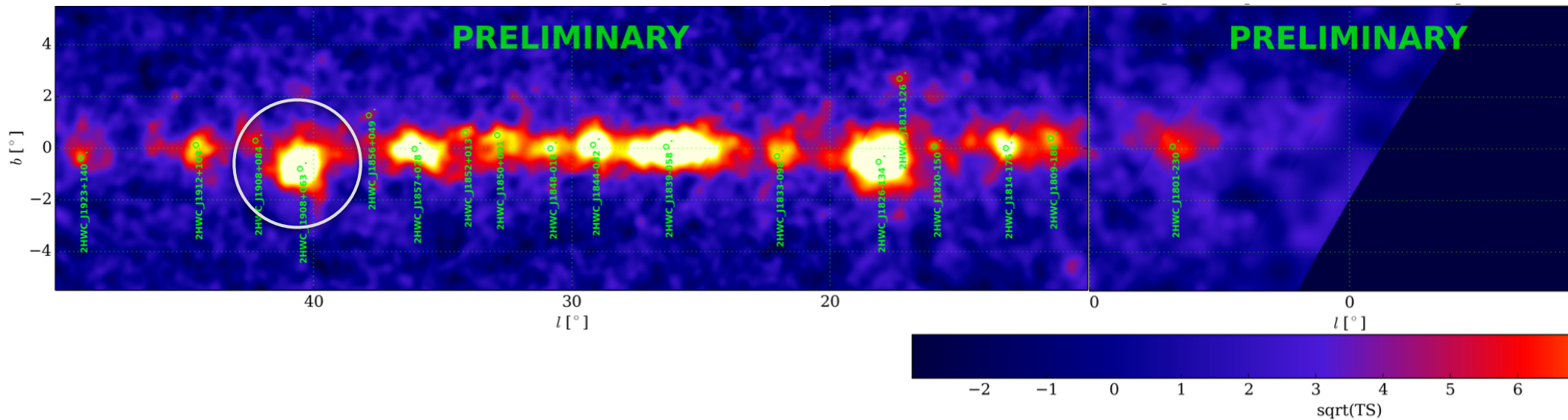


En el Plano Galáctico

Galactic plane 2, point source search, spectral index -2.7



Alrededor de 40
fuentes en el
Plano Galáctico:
25% son nuevas



En el Plano Galáctico

Galactic plane 2, point source search, spectral index -2.7

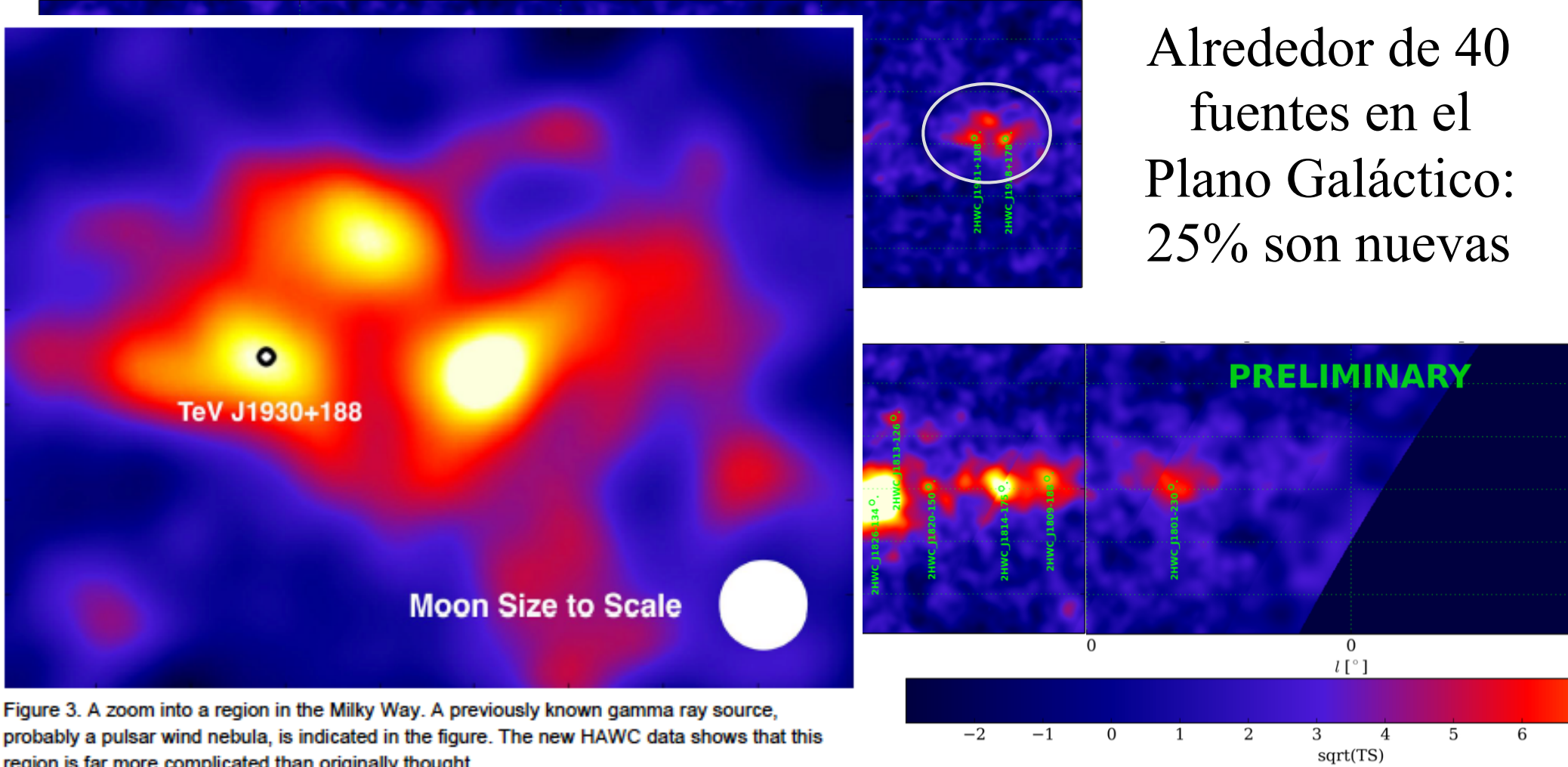


Figure 3. A zoom into a region in the Milky Way. A previously known gamma ray source, probably a pulsar wind nebula, is indicated in the figure. The new HAWC data shows that this region is far more complicated than originally thought.

Primer año de HAWC

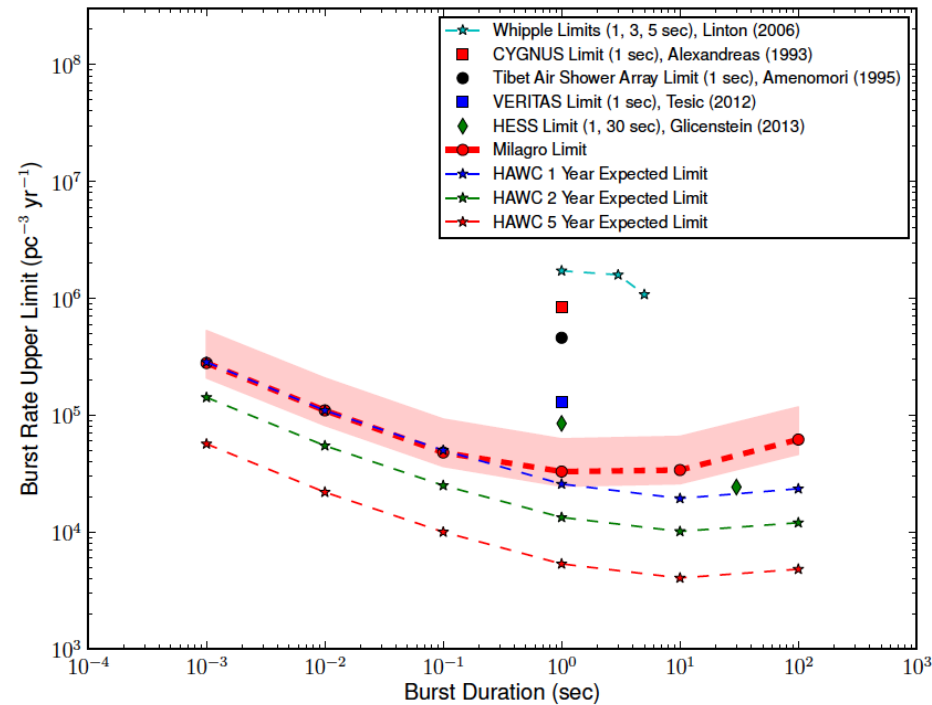
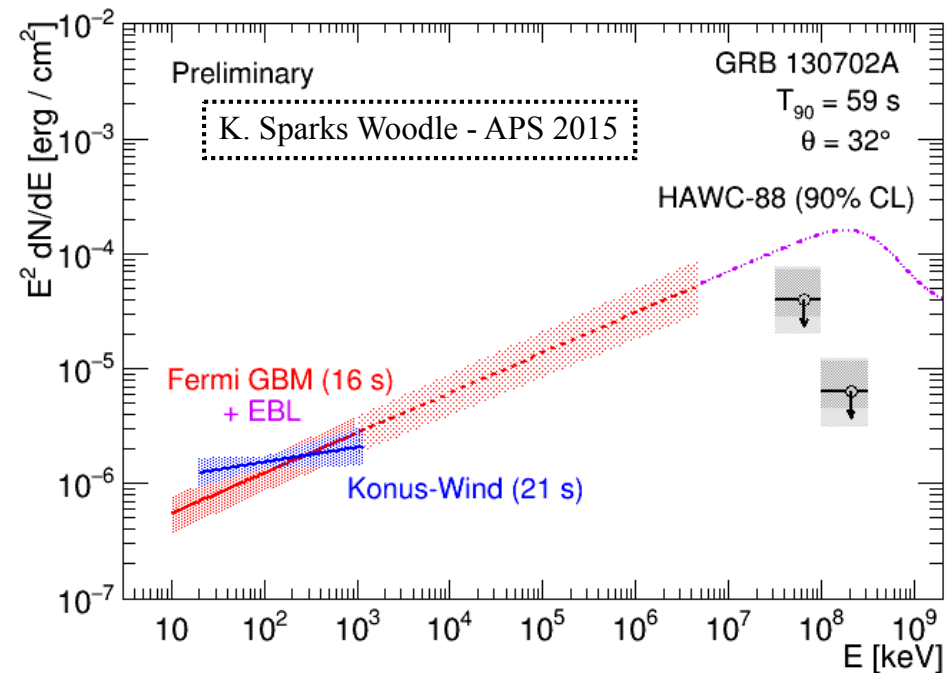
- HAWC
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- Primer año: límites
- Mejoras a HAWC



Límites y cotas

- Búsqueda de GRBs
- Búsquedas de materia oscura
- Cotas a PBH
- Seguimiento a GW
- Seguimiento a neutrinos
- Centro Galáctico

Seguimiento a largo plazo



HAWC follow-ups

TITLE: GCN CIRCULAR
NUMBER: 19423
SUBJECT: GRB 160509A: non-observation of VHE emission with HAWC
DATE: 16/05/11 17:27:37 GMT
FROM: Dirk Lennarz at HAWC <dirk.lennarz@gatech.edu>

D. Lennarz (Michigan State University), I. Taboada (Georgia Tech) report on behalf of the HAWC collaboration (<http://www.hawc-observatory.org/collaboration/>):

We used data from the HAWC detector to perform a search for VHE emission in temporal coincidence with GRB 160509A (F.Longo et al., GCN 19403). At the time of the LAT trigger, the elevation of the burst in HAWC's field of view was only 27.98 degrees (it was rising, but culminated at an elevation of 33 degrees). The sensitivity of HAWC at this elevation is more than 2 orders of magnitude poorer than near the zenith. Furthermore, the energy threshold towards the horizon is much higher. Combined with the moderate redshift of $z=1.17$ (N. R. Tanvir et al., GCN 19419) it makes a detection by HAWC unlikely.

We used four search windows with respect to the LAT trigger time: one in the range -5 s to 45 s, which covers the main GBM emission episode (O.J. Roberts et al., GCN 19411) and appears to be correlated with the >100 MeV soft emission observed by the LAT (F.Longo et al., GCN 19413), a window from -5 s to 375 s, which extends slightly beyond the T90 observed by GBM and a time window from 45 s to 375 s, where the LAT data is fit with a power-law of index -2.0 ± 0.1 . We also searched -20 s to 20 s around the time of the highest-energy LAT photon (52 GeV) 77 seconds after the GBM trigger. A 2 degree angular bin is defined around the position of the Swift-XRT afterglow position (J. A. Kennea et al., GCN 19408) and the number of background events is estimated using an ON/OFF method. We find the counts in the search bin to deviate by $1.9 / 0.9 / 0.2 / -1.4$ sigma from the background expectation. Our observations are consistent with background only.

The search was conducted using the main data acquisition that

GRB 160509A

of showers. It uses data applying gamma-hadron separation. on with respect to the VHE fluence re.

HAWC is a very-high-energy gamma-ray observatory operating in Central Mexico at a latitude of 19 deg north. HAWC has an instantaneous field of view of 2 sr and surveys 2/3 of the sky every day. A detailed description of the sensitivity of HAWC to GRBs can be found in A.U. Abeysekara et al., *Astroparticle Physics* 35, 641-650 (2012).

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HAWC TeV gamma-ray follow-up observation of the sky region of IceCube's multi-PeV neutrino-induced event

ATel #7868; *Ignacio Taboada (GATECH) on behalf of the HAWC collaboration*
on 3 Aug 2015; 13:25 UT

Credential Certification: Alberto Carramiñana (alberto@inaoep.mx)

Subjects: Gamma Ray, VHE, Neutrinos, Transient

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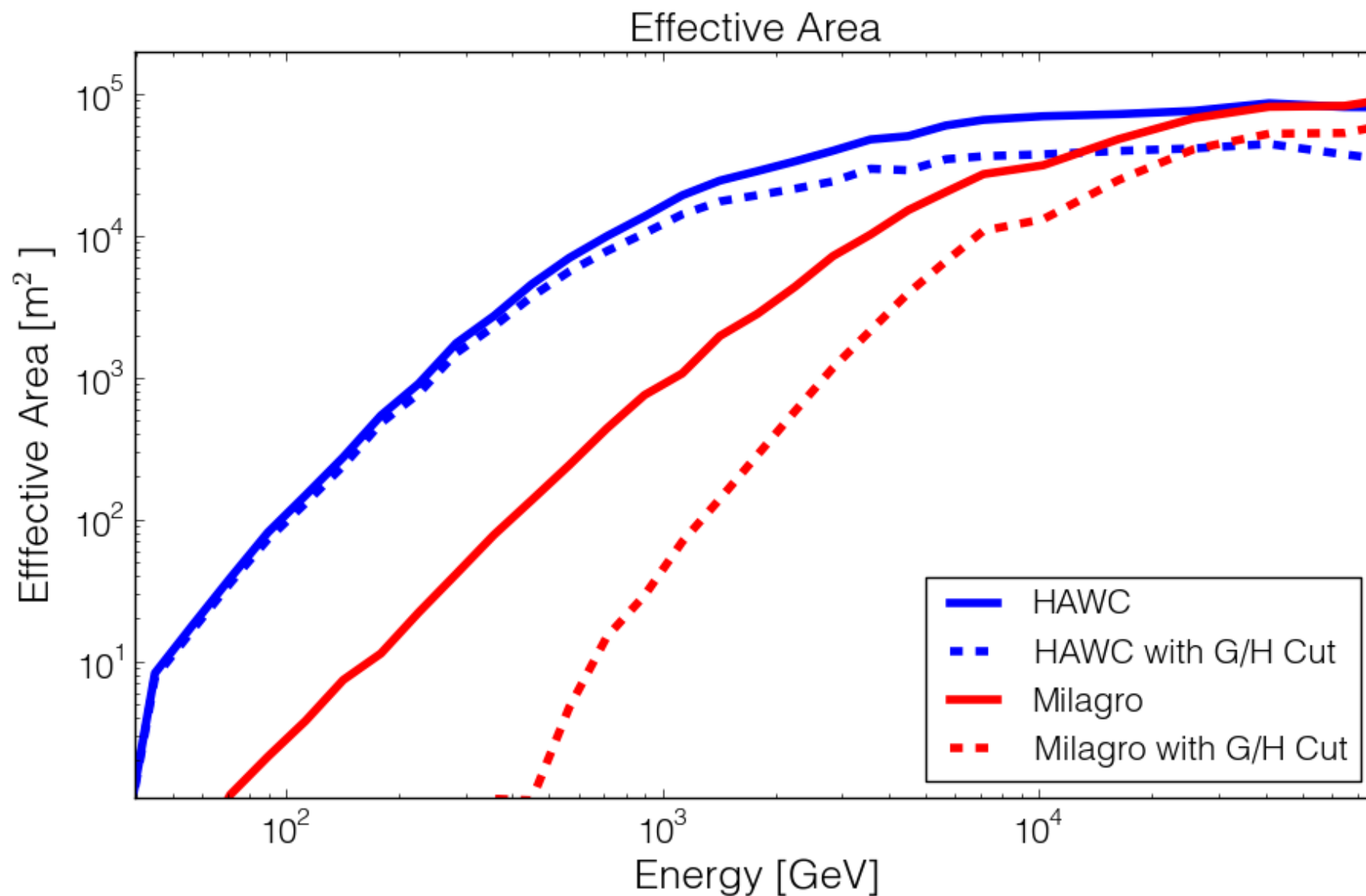
We have studied HAWC TeV gamma-ray archival data in the sky region corresponding to the multi-PeV neutrino-induced event reported by IceCube (ATEL # 7856). Putative cosmic ray sources that produce neutrinos are also expected to produce gamma-rays with approximately the same spectrum. If the source is transient, the neutrino light-curve is expected to be very similar to the gamma-ray light-curve. An observation by HAWC is possible, if, the neutrino spectrum extends from the observed PeV scale to the TeV energy scale to which HAWC is sensitive, and if source is not distant enough that the gamma-rays are attenuated by extragalactic background light. For TeV scale gamma-rays, sources can be observed if they are closer than approximately redshift 0.1. HAWC is a gamma-ray observatory, operating in central Mexico. It has an instantaneous field of view of about 2 sr. It can operate continuously, day or night and in any weather conditions. Over the course of a day, HAWC observes over half the sky in TeV gamma rays. HAWC, began full operations on March 20, 2015, but operated in partial configurations previously. Though the declination of the event is ideal for observations by HAWC, at the time, this region of the sky was at the occulted by Earth. Therefore, we could not perform a search in strict temporal coincidence. We conducted the follow up search using 5 different time periods. None of these searches found a gamma-ray source. In all five studies a region of 2 degrees by 2 degrees centered at the location reported by IceCube was searched. This matches the 1 degree uncertainty reported by IceCube for 99% containment of the PSF. The time periods studied are: 1) August 2, 2013 to May 6, 2015: Time integrated search 2) June 10, 2014: Sidereal day before the neutrino 3) June 11, 2014: Sidereal day after the neutrino 4) June 10-13, 2014: Four sidereal days around the time of the neutrino 5) June 6-15, 2014: Ten sidereal days around the time of the neutrino For the time integrated search, we used data from the partially built HAWC (aka HAWC-111, or 37% of final detector size and 283 days effective live-time) from August 2nd, 2013 to July 7th, 2014 and data with a second partially built HAWC (aka HAWC_250, 83% of final size and 150 days effective live-time) from November 26, 2014 to May 6th, 2015. The date of the neutrino event, June 11th, 2014, corresponds to the end of operation of HAWC-111. The preliminary 5 sigma discovery potential for this first search is (E^2 flux) $1.9e-12$ $TeV/cm^2/s$ at 100TeV assuming a power law flux with index of -2.3. For the other time periods the preliminary one day discovery potential was $3.9e-11$ $TeV/cm^2/s$ at 100TeV with a power-law index of -2.3. The discovery potential scales as the square root of time. The HAWC contact for this observation are Ignacio Taboada (Georgia Institute of Technology, itaboada@gatech.edu) and Michelle Hui (Michigan Technological University, cmhui@mtu.edu)

Primer año de HAWC



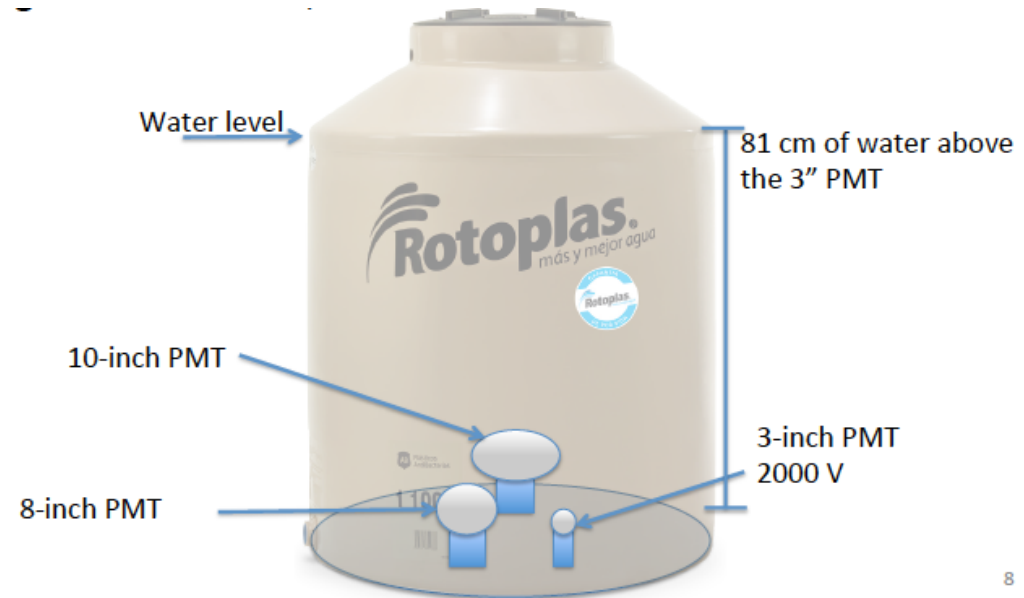
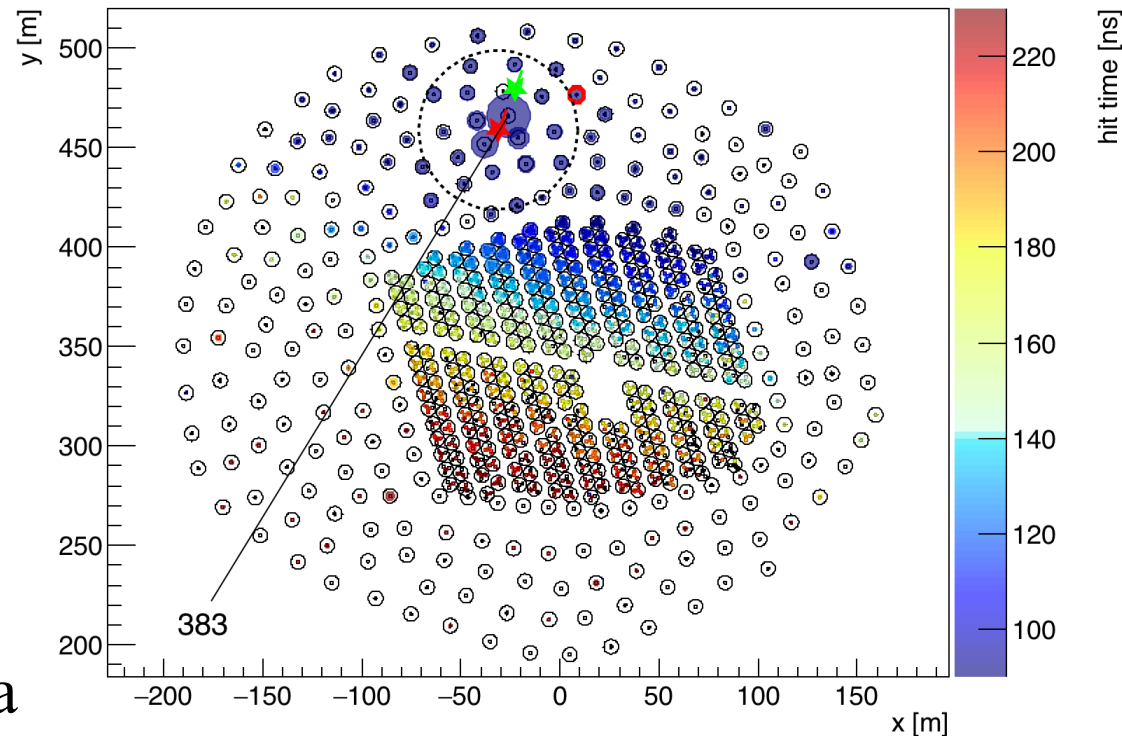
- Mejoras a HAWC

Desempeño del diseño de HAWC



HAWC outriggers

- Arreglo periférico a HAWC para incrementar la sensibilidad a energías por encima de 10 TeV
⇒ aumento en factor de 4 en área efectiva.
- Más de 300 WCDs de 2500 litros.
- Determination del núcleo de cascadas fuera del arreglo.
- Recursos de LANL, México y MPI-HD.



El anillo metropolitano de fibra óptica

- INAOE y BUAP se unieron para implementar una conexión robusta a Internet, con el apoyo de CUDI.
- Representa una de los primeros anillos metropolitanos de fibra óptica en México.

Miércoles 14 de Octubre del 2015 | Webmail | Contacto | Registrarse

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<http://www.cudi.edu.mx/noticia/puebla-primeros-anillos-de-fibra-optica>

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BOLETÍN INFORMATIVO

Inicio

Puebla, instalará los primeros anillos de fibra óptica en México

Martes, 13 Octubre, 2015

Con una inversión inicial de 1.5 millones de dólares, el proyecto ejecutado entre la BUAP y el INAOE se prevé que concluirá en cuatro meses. Su principal objetivo es abatir costos en servicios de conectividad, además de proporcionar el mismo a...



El Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE) y la Benemérita Universidad Autónoma de Puebla (BUAP), firmarán un convenio para tener 200 kilómetros de fibra óptica que conectará a distintas instituciones con el Laboratorio Nacional de Supercómputo.

Tras informar que la BUAP será sede de la trigésima Reunión Semestral de la Corporación Universitaria para el Desarrollo de Internet (CUDI), otoño 2015, Humberto Salazar Ibarquén, titular de la Dirección General de Cómputo y Tecnologías de la Información y la Comunicación de la universidad, informó que "140 kilómetros de fibra óptica comunicarán al INAOE y el Laboratorio Nacional de Supercómputo del Sureste de México (LNS), con el **Observatorio de Rayos Gamma (HAWC)** y el **Gran Telescopio Milimétrico (GTM)**, 60 kilómetros más serán la red metropolitana que unirá todos los campus de la benemérita, y así interconectar en su totalidad a las instituciones de educación superior de Puebla".

Con el objetivo de abatir costos en servicios de conectividad y proporcionar el servicio a otras instituciones interesadas en los servicios del LNS, el proyecto ejecutado entre la BUAP y el INAOE estará terminado en cuatro meses. Contará con una inversión inicial de 1.5 millones de dólares, anunció Salazar Ibarquén.

La fibra óptica

