

Observatorios & observaciones de rayos gamma

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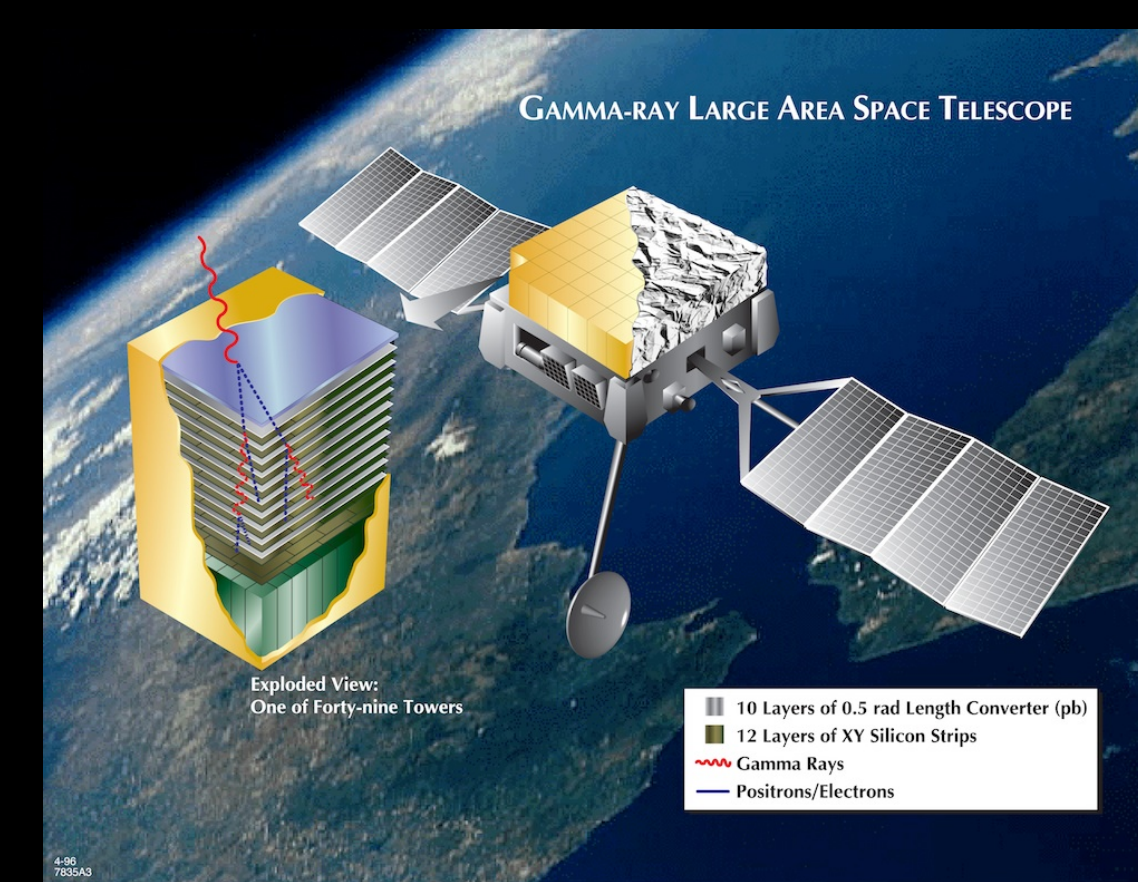
3. Observatorios

3.1. Bandas astrofísicas

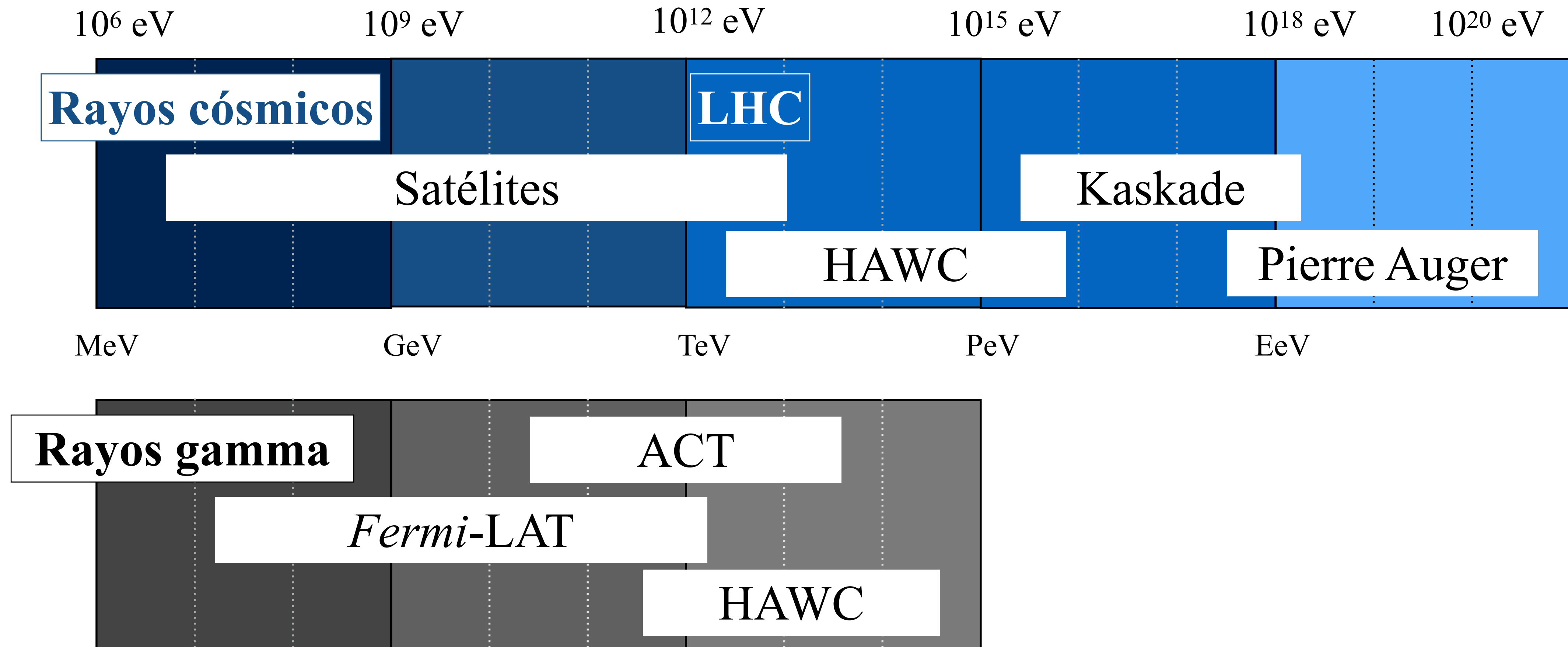
3.2. Telescopios espaciales

3.3. Telescopios Cherenkov atmosféricos

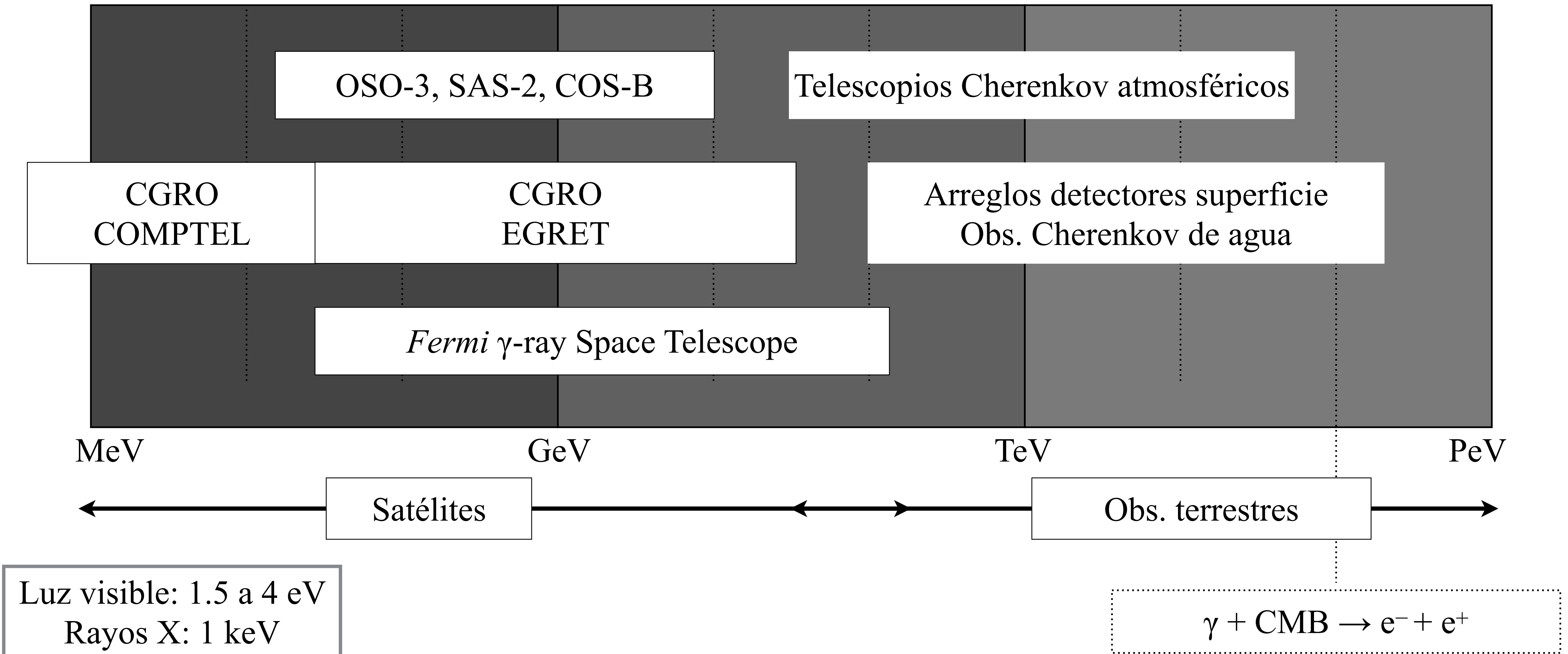
3.4. Arreglos de superficie



3.1. Bandas astrofísicas



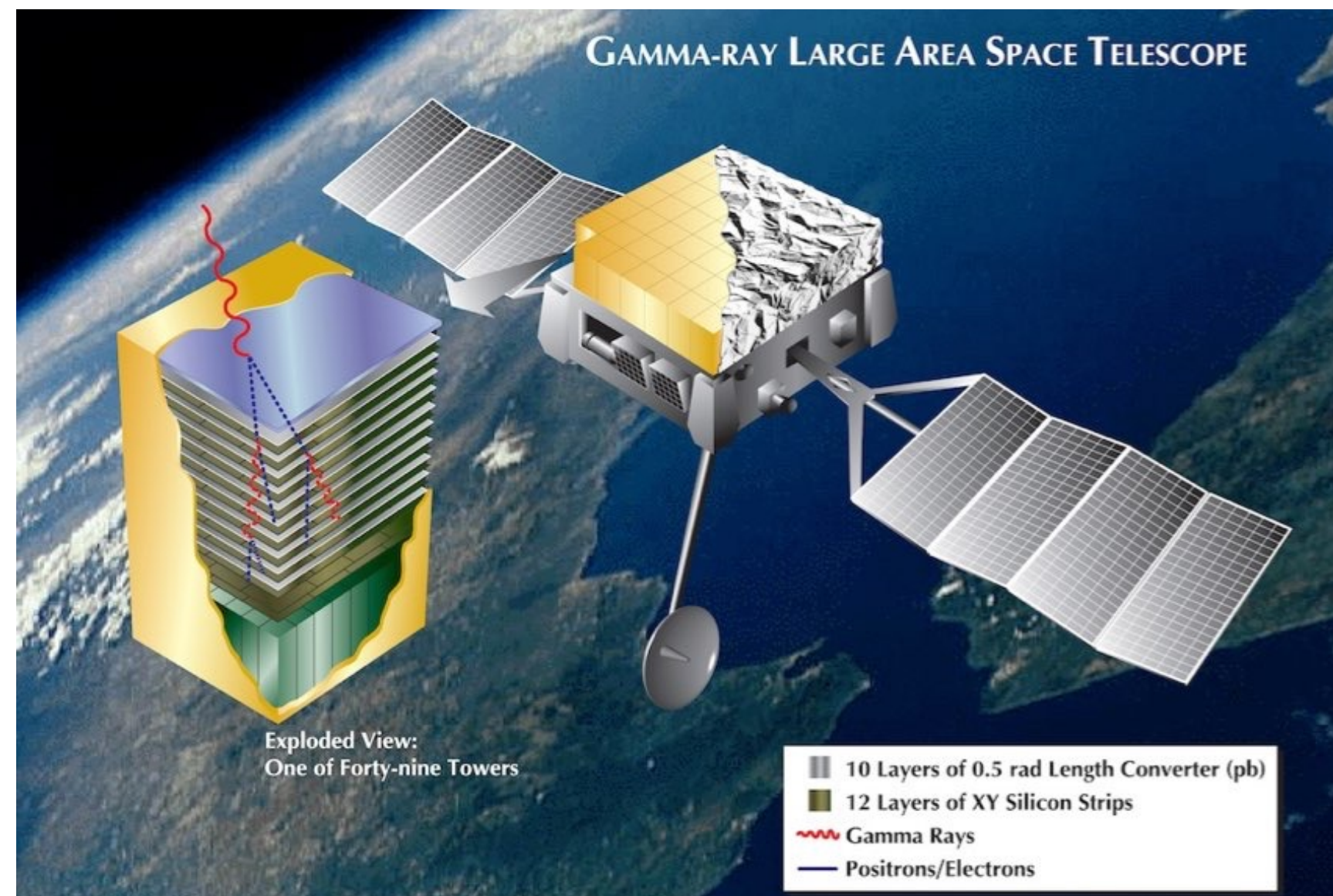
3.1. Bandas astrofísicas



3.1. Observatorios de rayos γ

- Telescopios espaciales basados en:
 - efecto foto-eléctrico: BATSE, OSSE, Swift-BAT (misma tecnología que en telescopios de rayos X duros).
 - efecto Compton: COMPTEL.
 - producción de pares: OSO-3, SAS-2, COS-B, EGRET, Fermi-LAT.
- Observatorios en tierra basados en:
 - detección de luz Cherenkov en la atmósfera: MAGIC, HESS, VERITAS, CTA.
 - detección directa de partículas secundarias: MILAGRO, Tibet AS- γ , HAWC, LHAASO, SWGO.

Sr

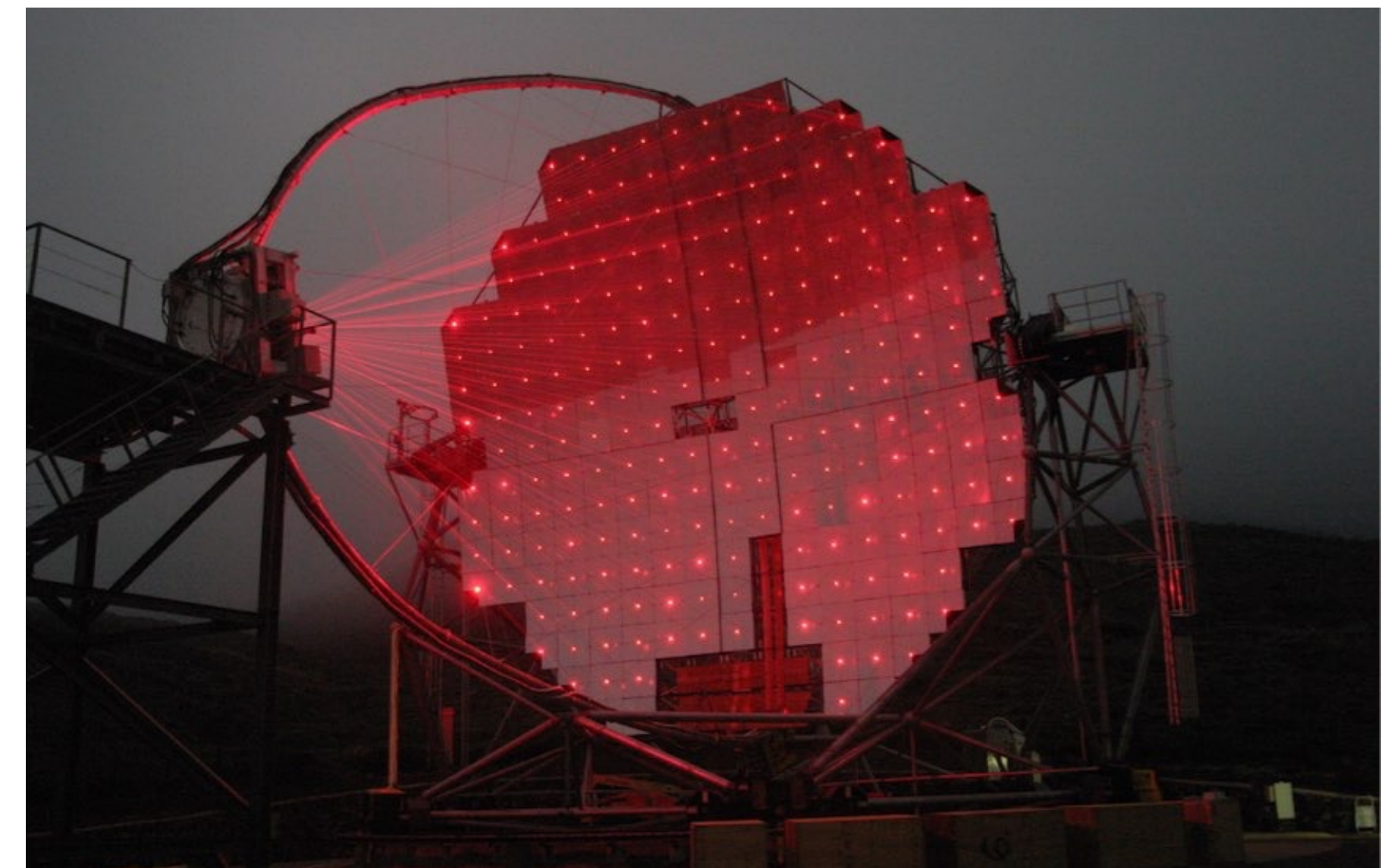


Deg

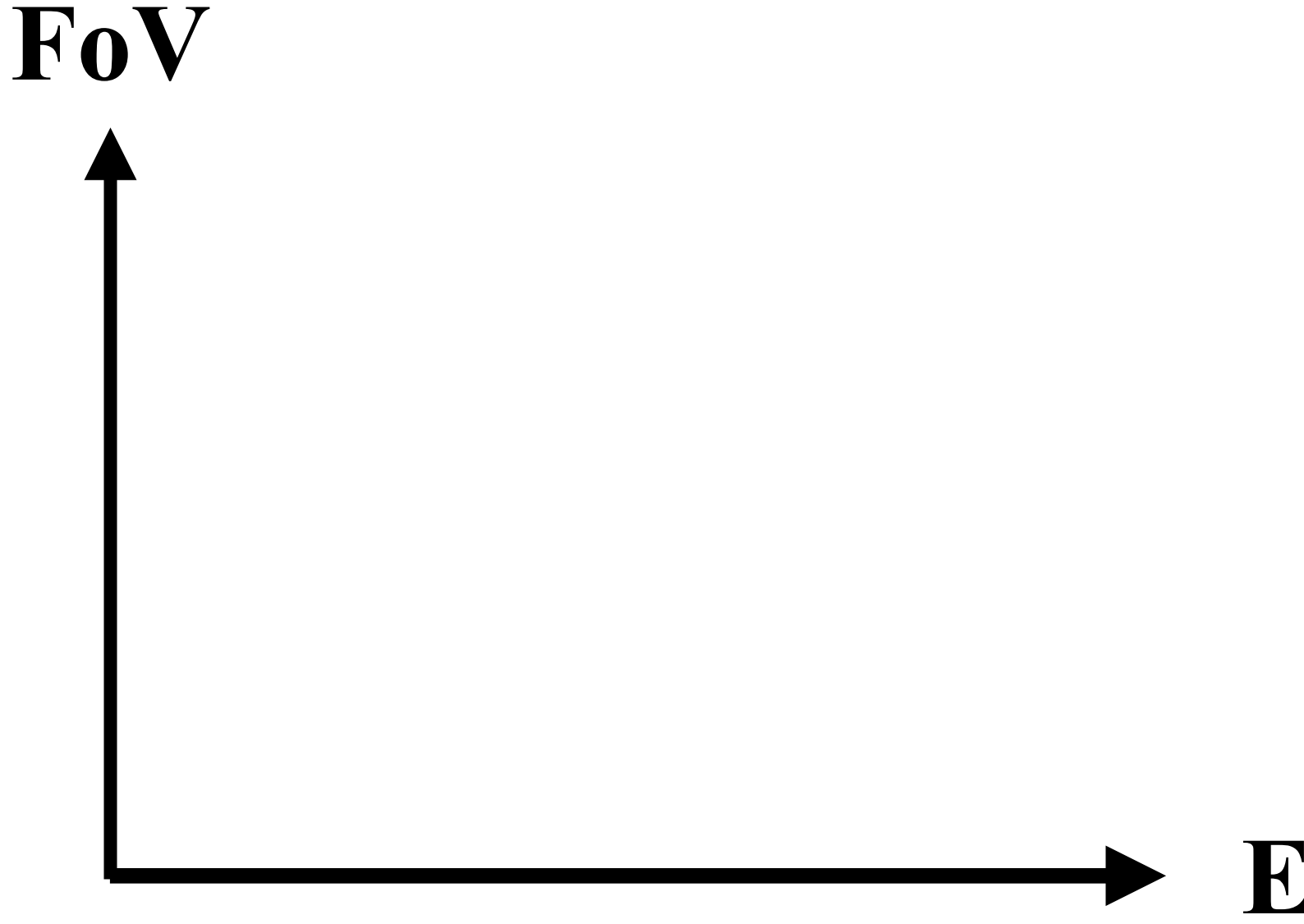
FoV



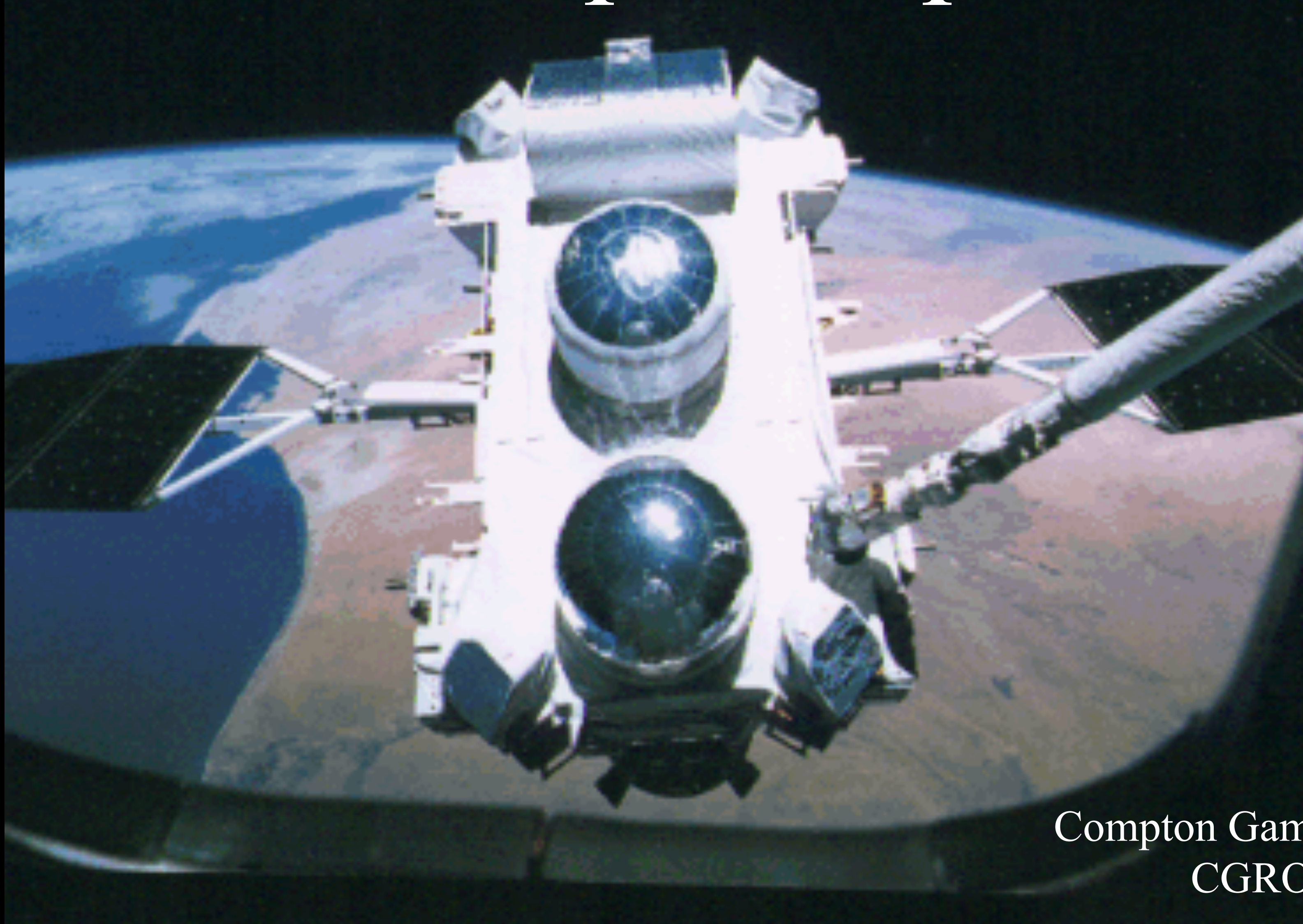
GeV



TeV

Sr	Telescopios de producción de pares 0.1 - 100 GeV En órbita: área de detección limitada Eliminación completa del ruido Campo de visión grande, alto ciclo de operación ⇒ surveys y monitoreo Emisión en ráfaga (AGN, GRB) Fuentes extendidas y emisión difusa	Arreglos detectores de superficie 100 GeV - 100 TeV Area de detección grande Buena eliminación del ruido Campo de visión grande y alto ciclo de operación ⇒ surveys, monitoreo y fuentes extendidas Emisión en ráfaga (AGN, GRB) Las energías más altas
Deg		Telescopios Cherenkov atmosféricos 50 GeV - 100 TeV Area de detección grande Excelente eliminación del ruido Campo de visión limitado, bajo ciclo de operación ⇒ estudio detallado de fuentes conocidas surveys profundos de regiones específicas Espectros con alta resolución
	GeV	TeV

3.2. Telescopios espaciales



Compton Gamma-Ray Observatory
CGRO (1991-2000)

Telescopios de producción de pares

- OSO-3 (1967-1969)
- SAS-2 (1972-1973)
- COS-B (1975-1982)
- EGRET - CGRO (1991-2000)
- Fermi γ -Ray Space Telescope (2008+)

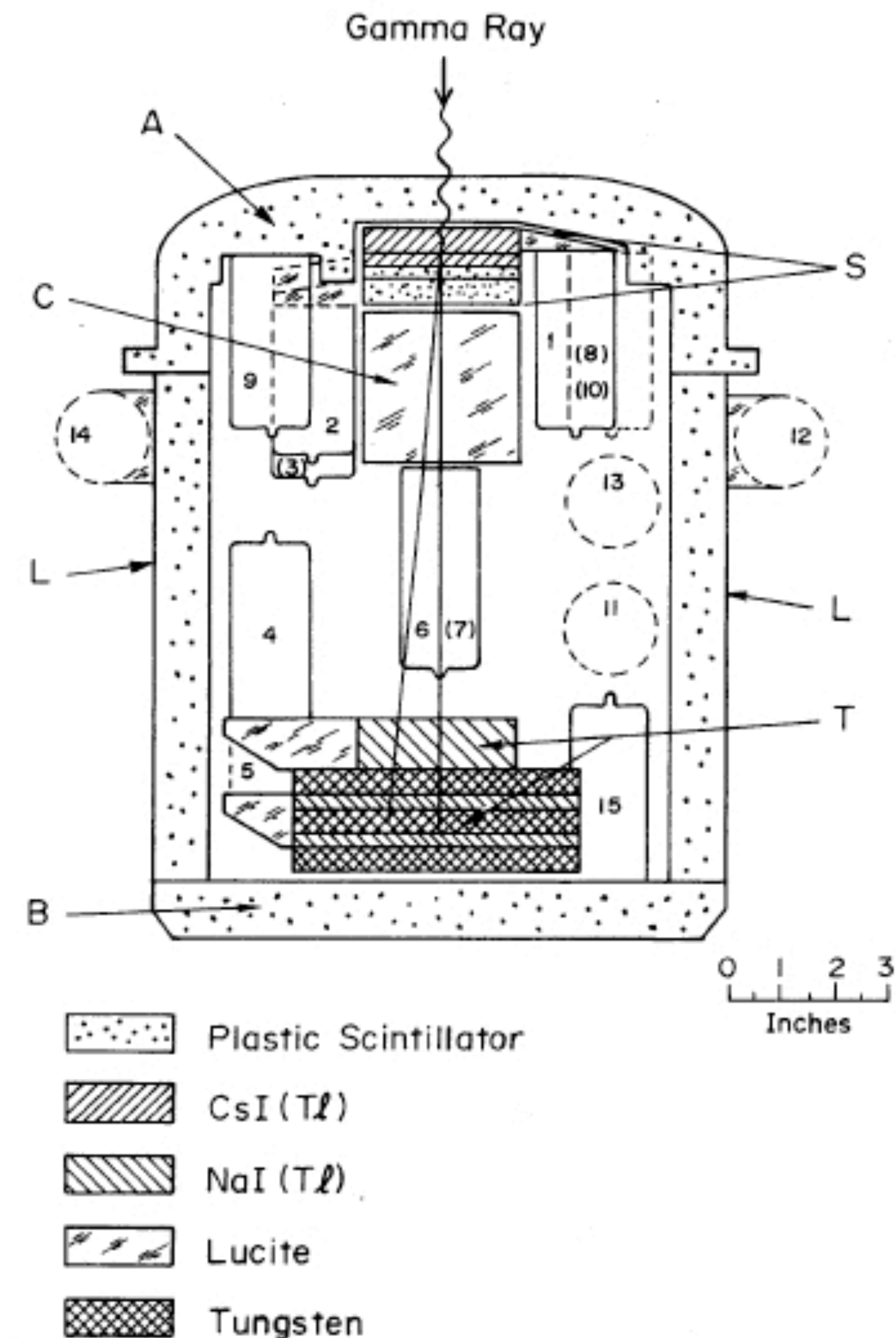


FIG. 1.—Scale drawing of the OSO-3 γ -ray instrument. The photomultipliers are labeled 1 through 15. A typical event in which an incident γ -ray produces a pair of electrons in S is indicated schematically.

Emisión difusa Galáctica

Registrando 621 fotones ($E > 50$ MeV), OSO-3 (1967-68) descubrió la emisión difusa Galáctica, y la extragaláctica

(Kraushaar, W.L. et al. 1972, ApJ 177, 341)

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W. L. KRAUSHAAR *ET AL.*

Vol. 177

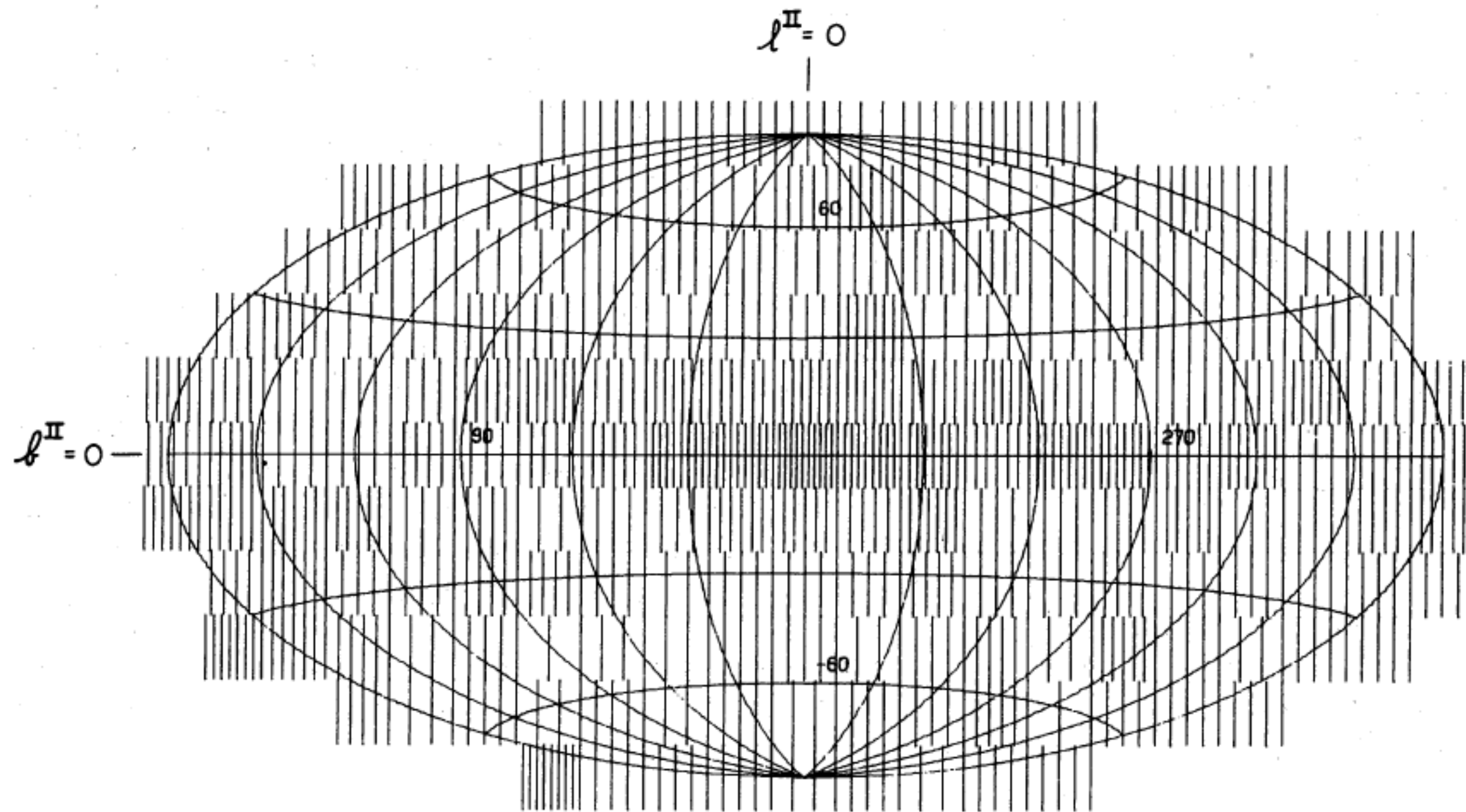


FIG. 8.—Sky map of the γ -ray intensity in galactic coordinates. The element of area on the map to which the formula given in the text applies is approximately 245 square degrees.

No. 2, 1972

HIGH-ENERGY COSMIC GAMMA RAYS

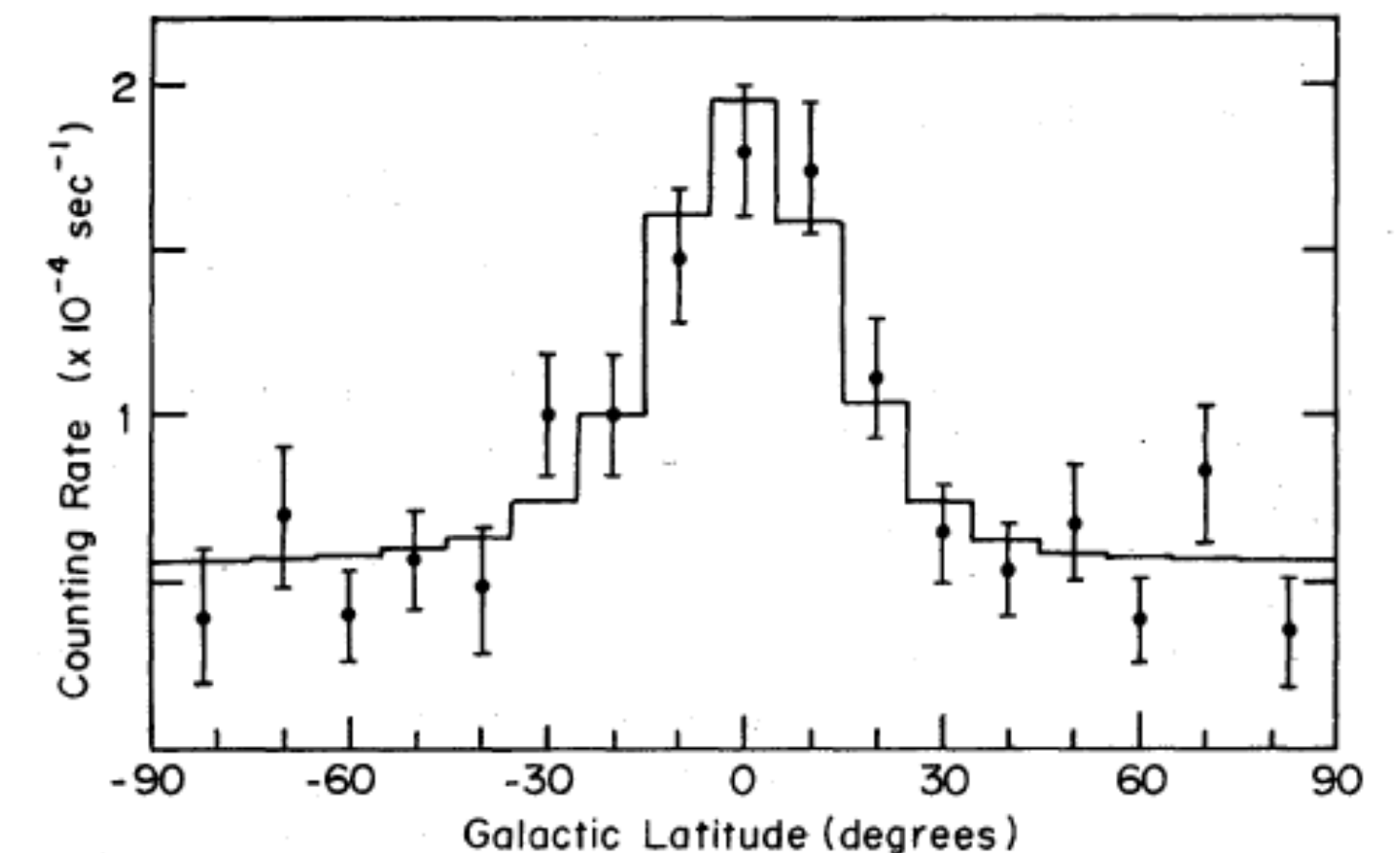
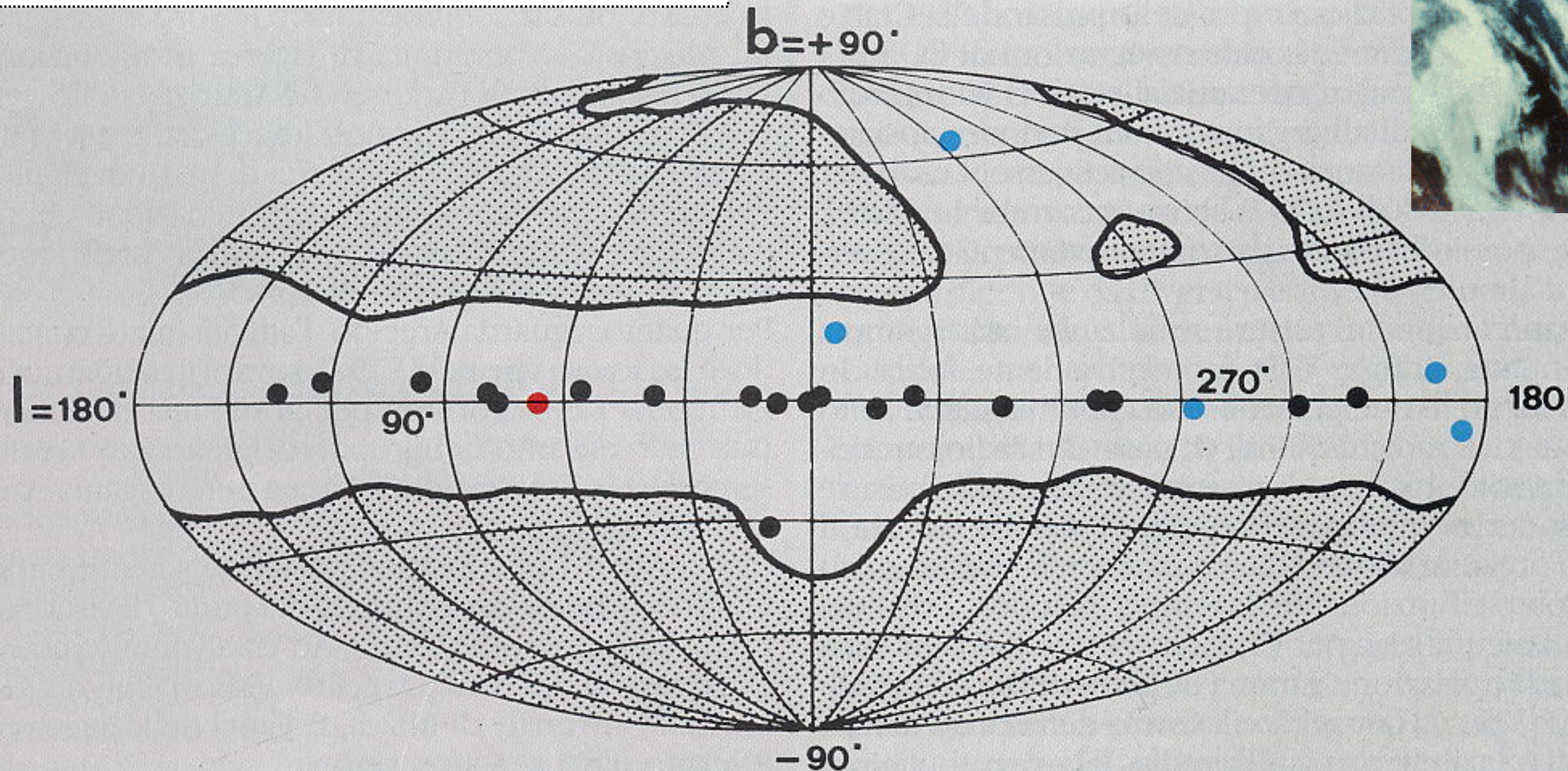
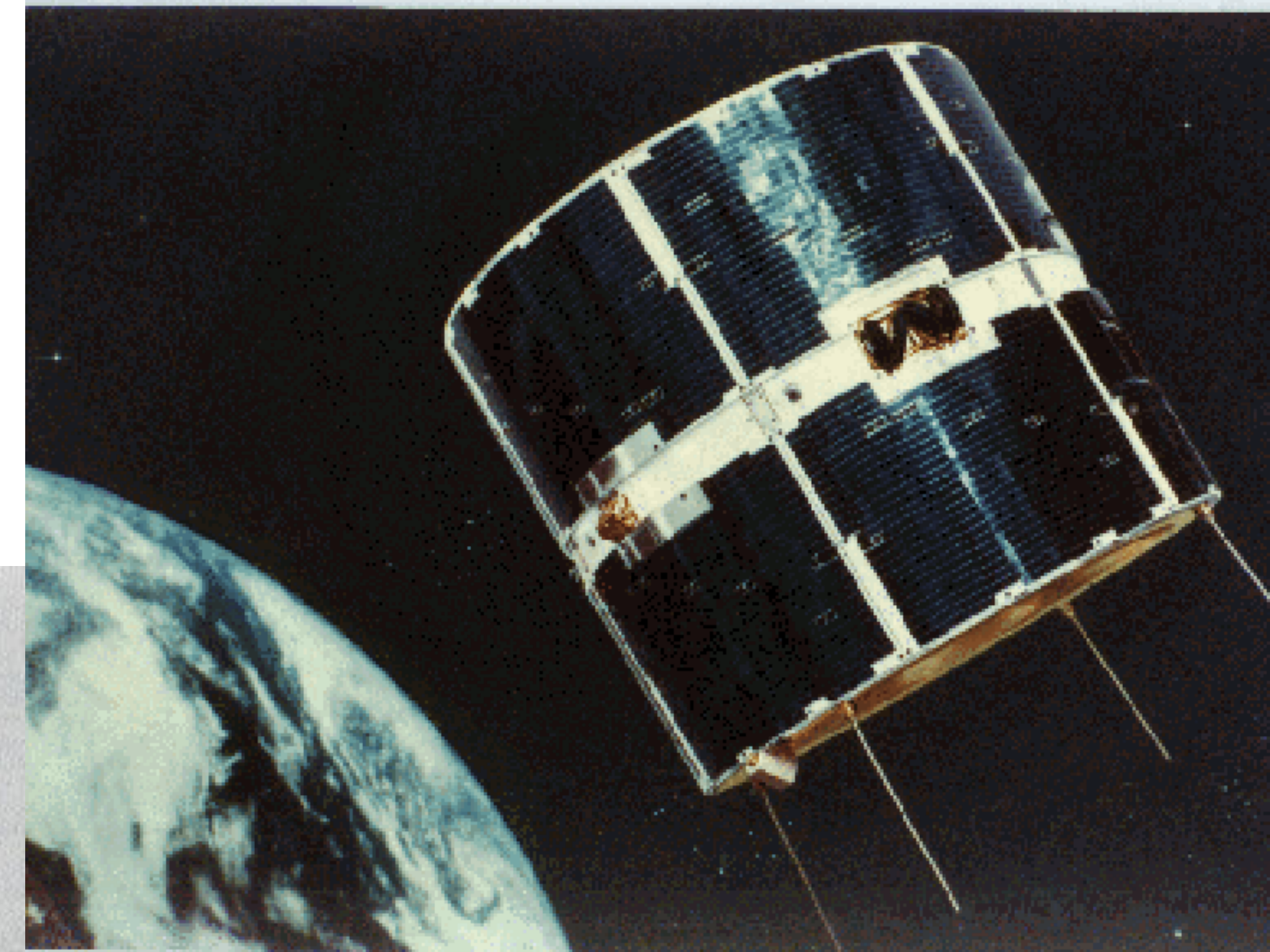
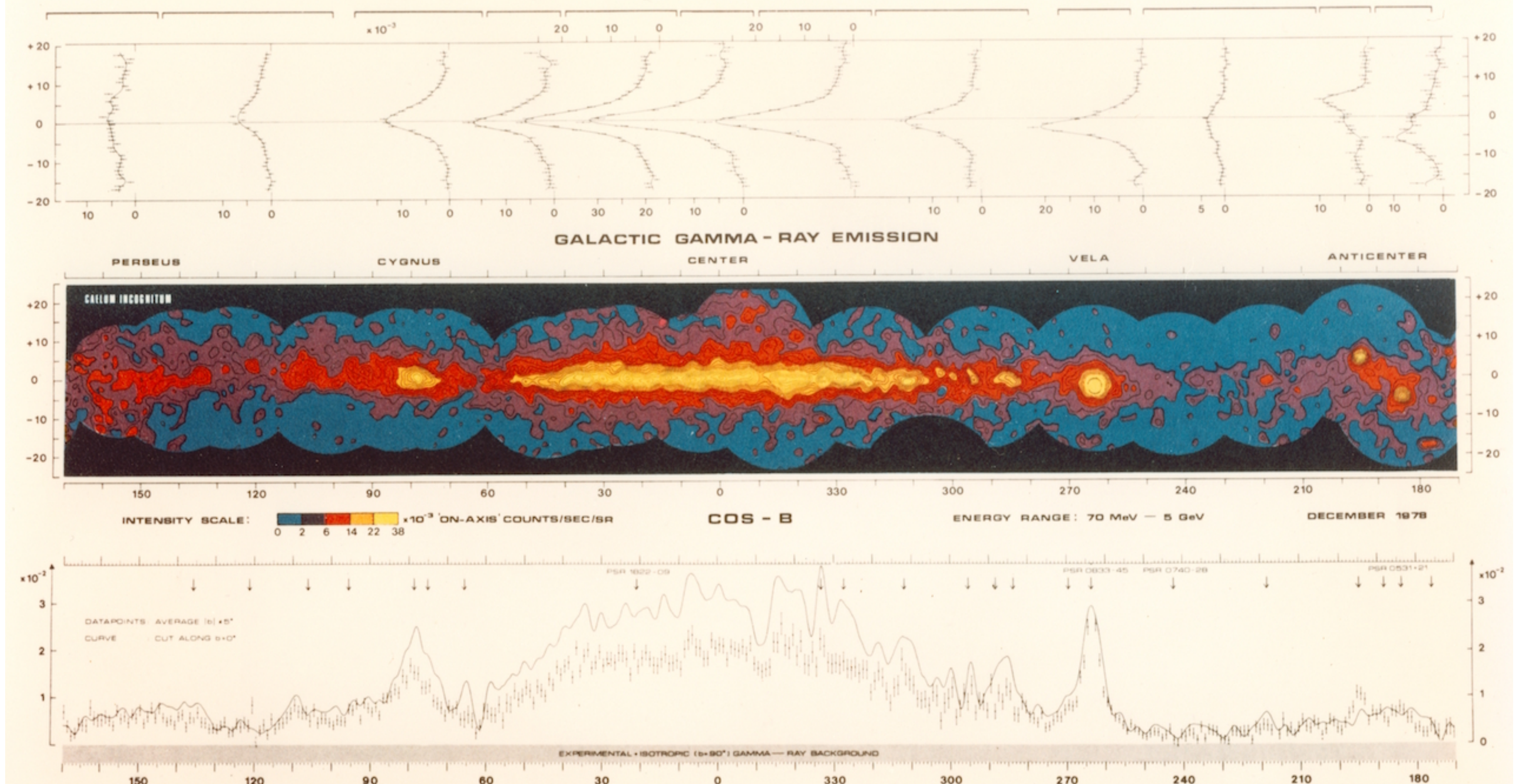


FIG. 10.—Combined galactic latitude distribution of all sky events exclusive of galactic longitude range $-30^\circ < l^{\text{II}} < 30^\circ$.

COS-B

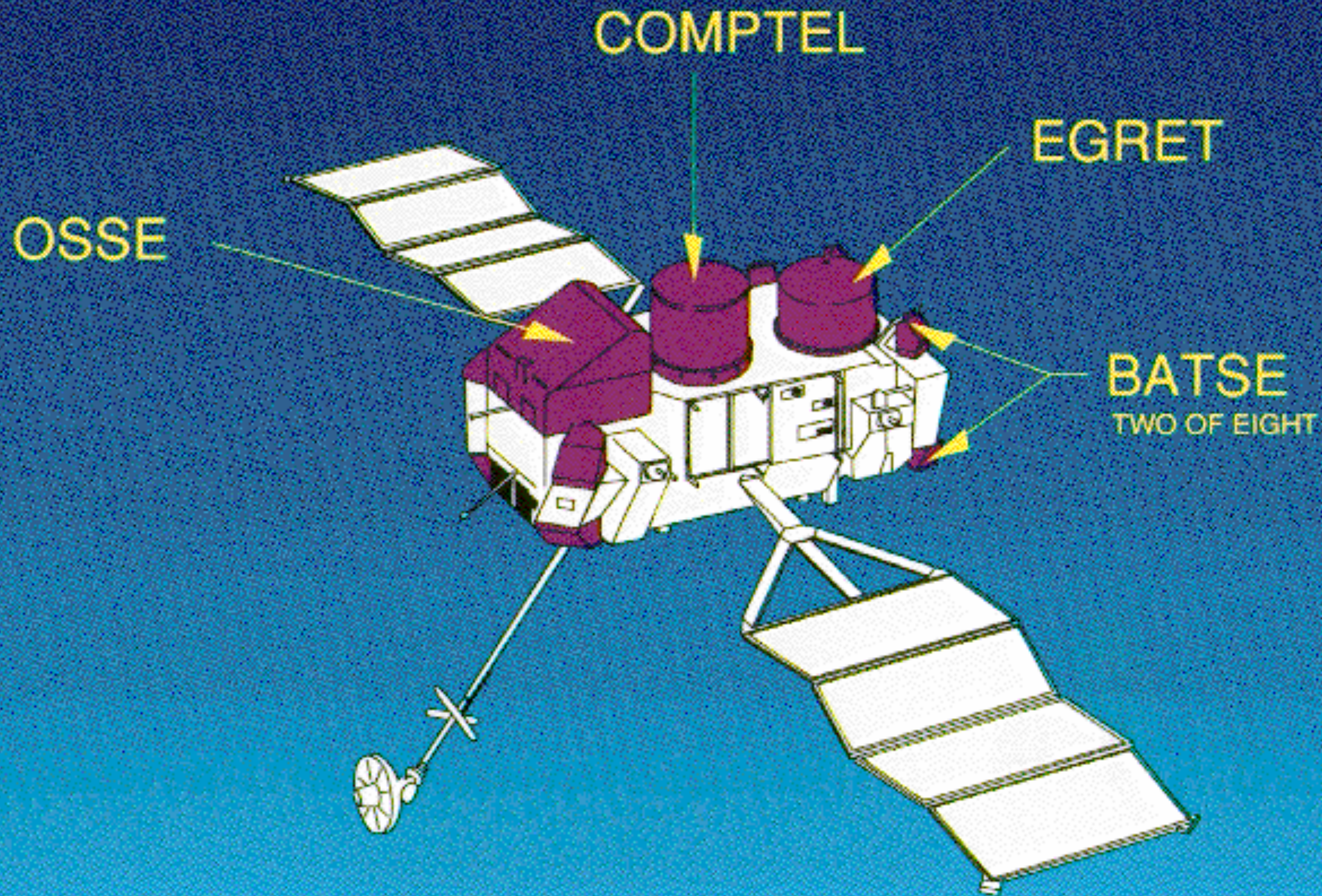
2CG - Swanenburg et al. (1981)



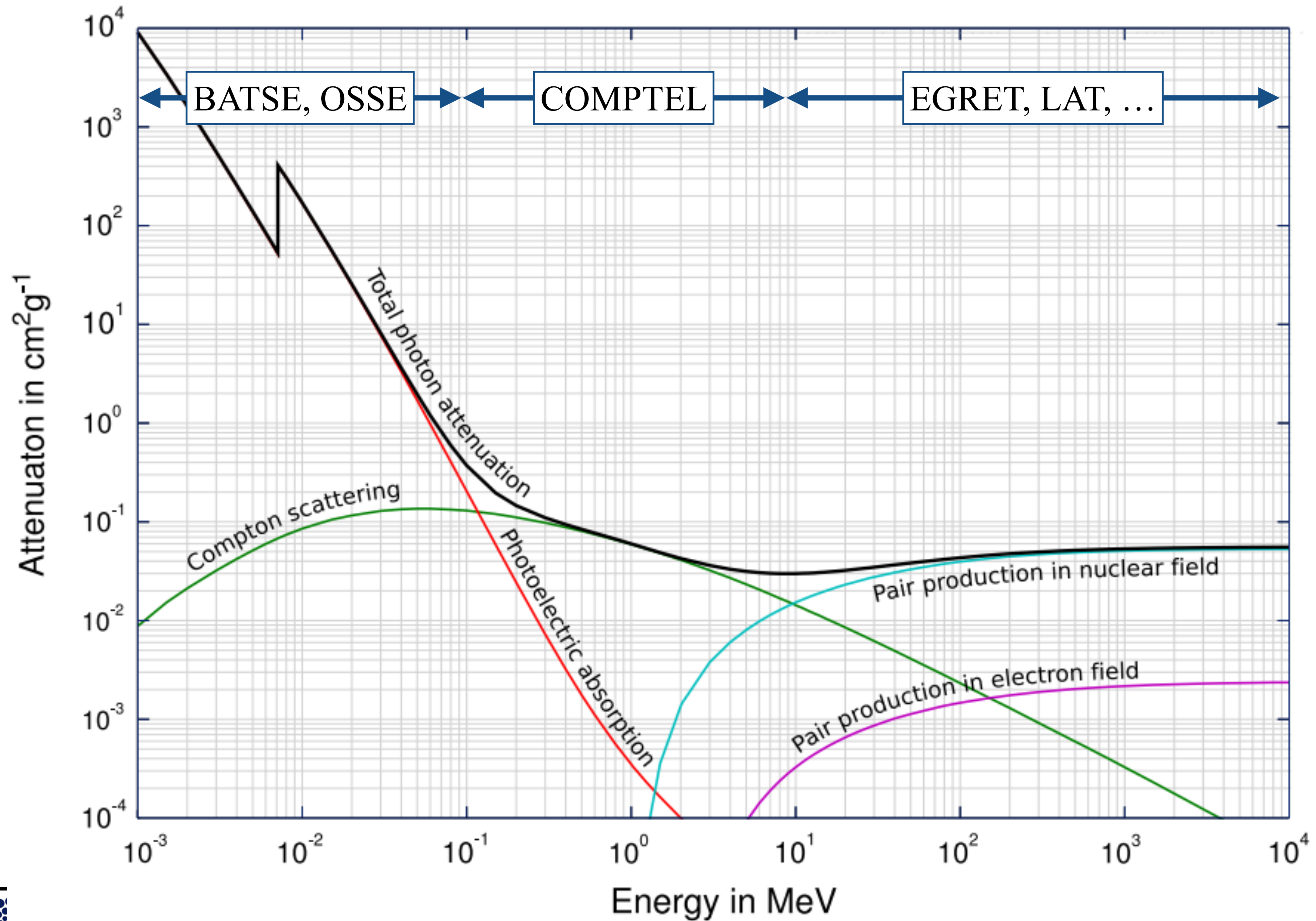


COS-B : Mayer-Hasselwander et al. (1982)

GRO Instruments

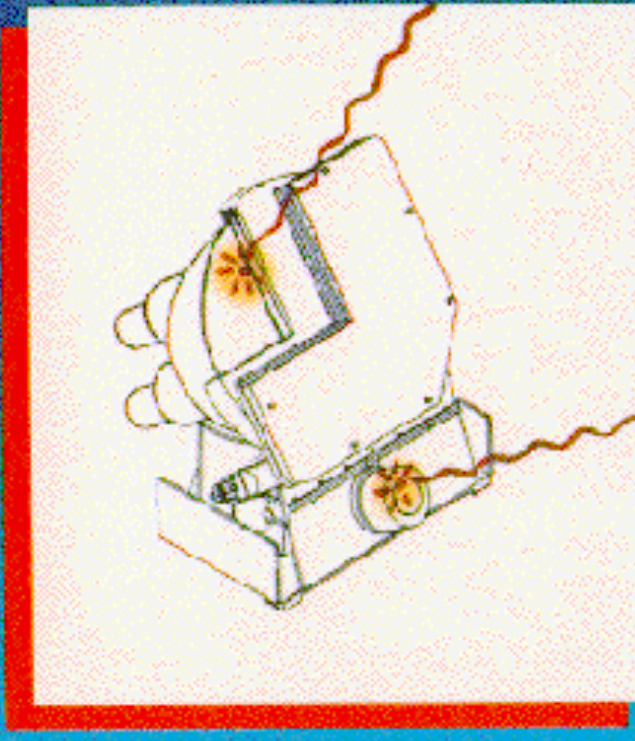
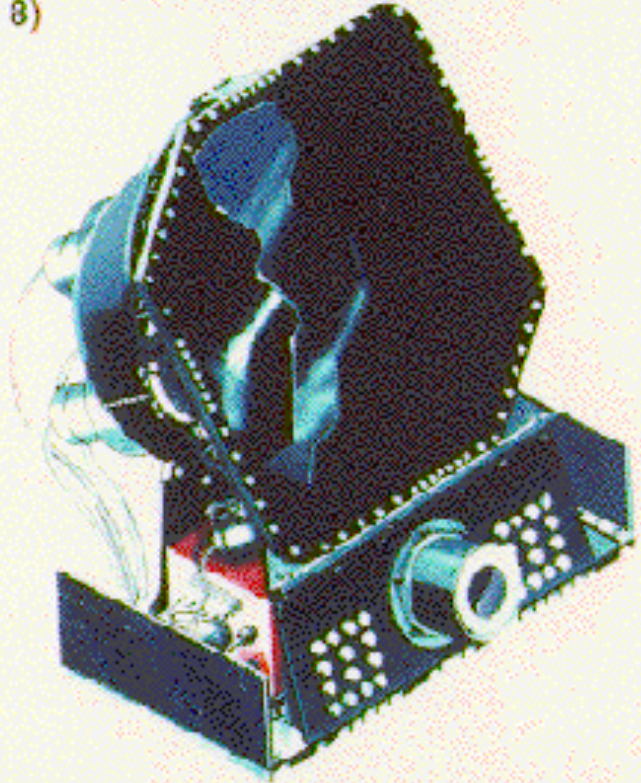


Compton Gamma-Ray Observatory
CGRO (1991-2000)



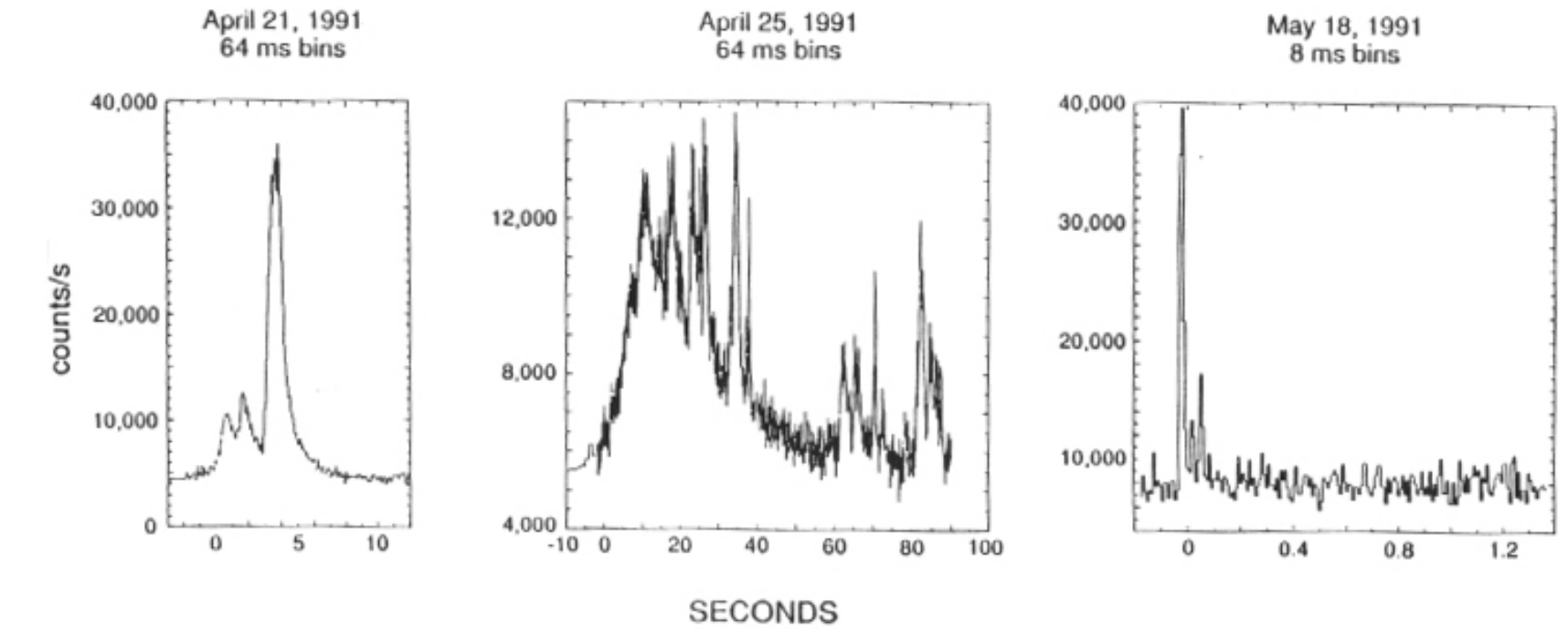
Burst and Transient Source Experiment (BATSE)

BATSE
DETECTOR MODULE
(1 OF 8)

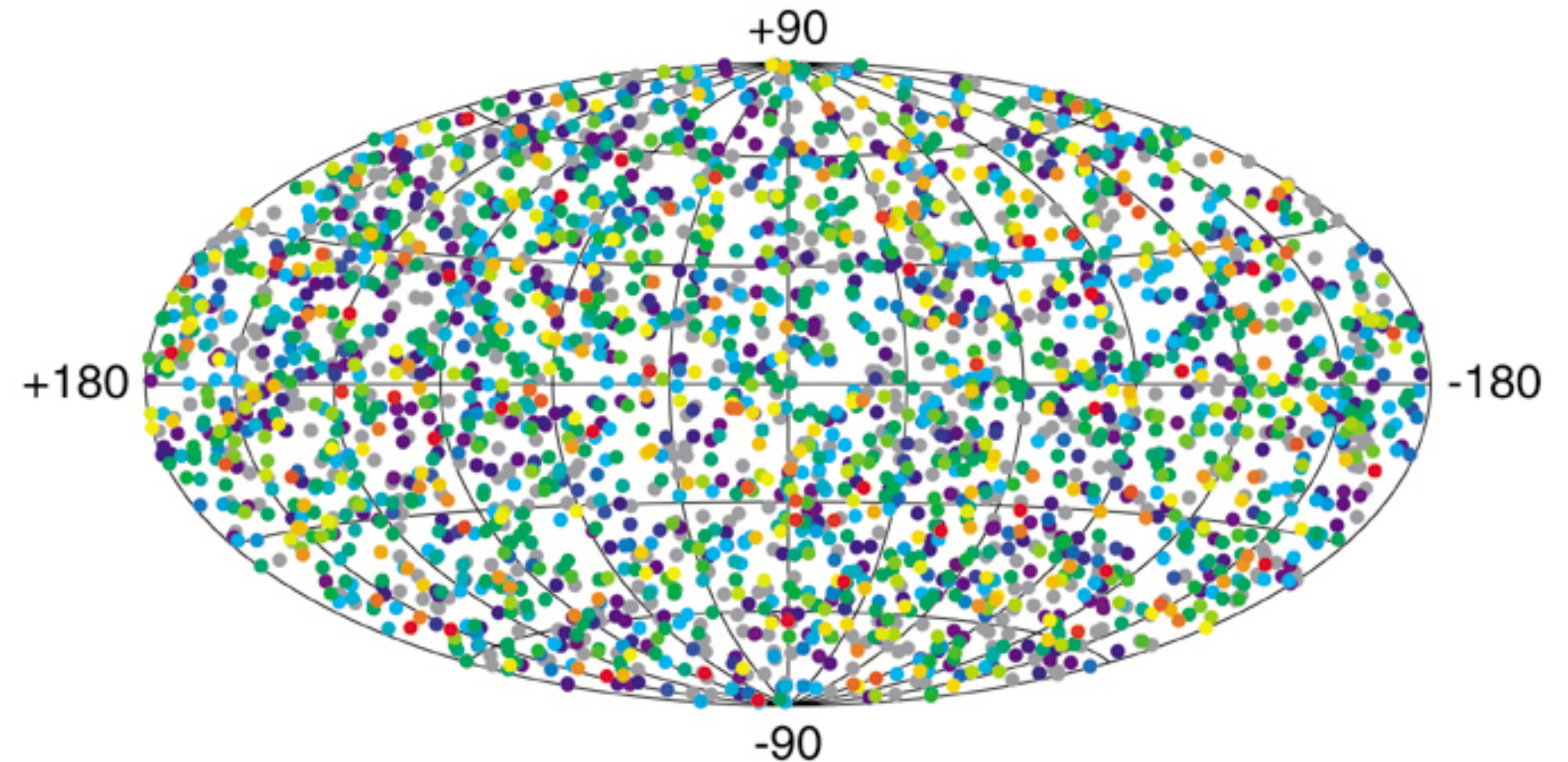
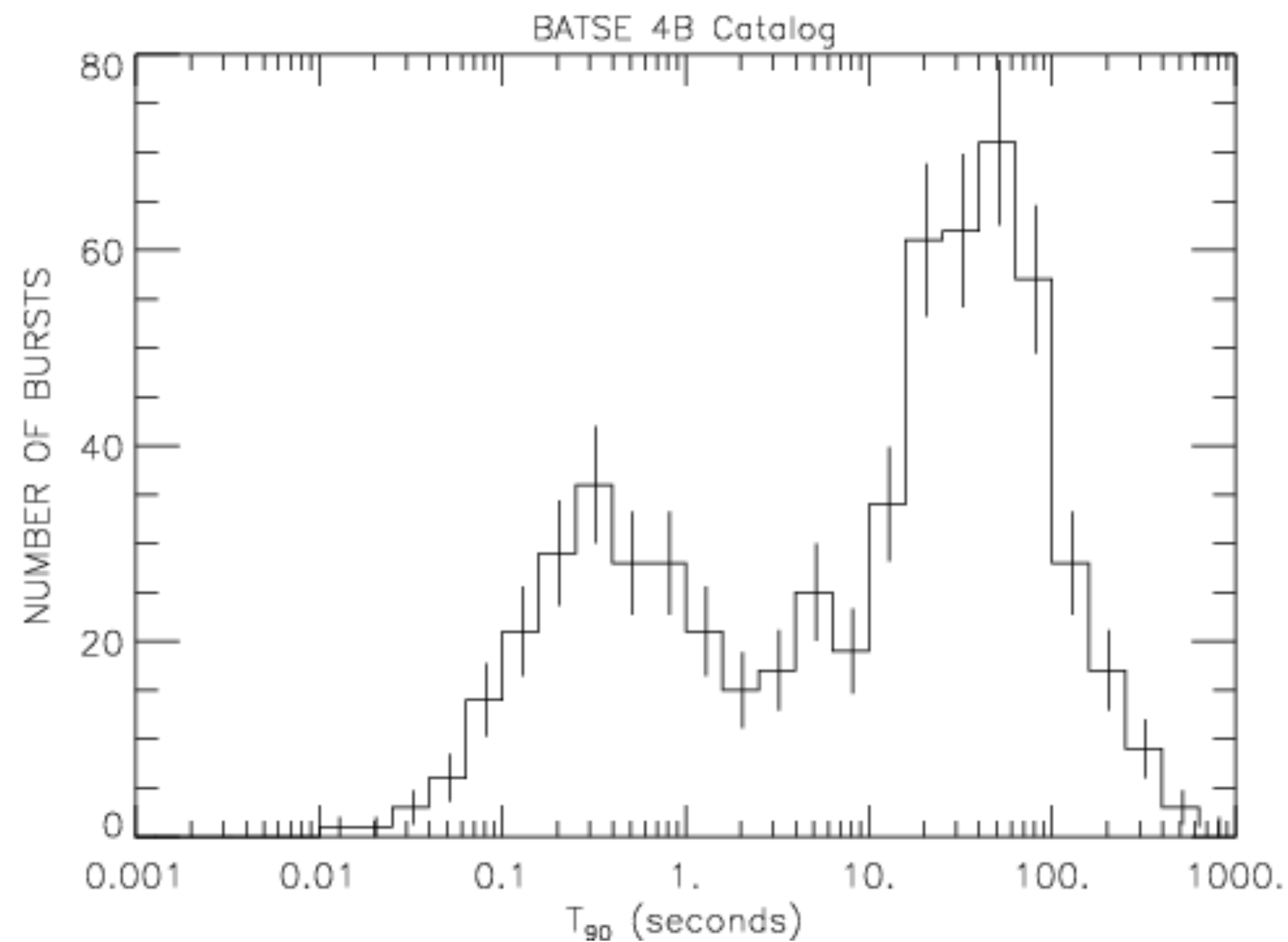


BATSE

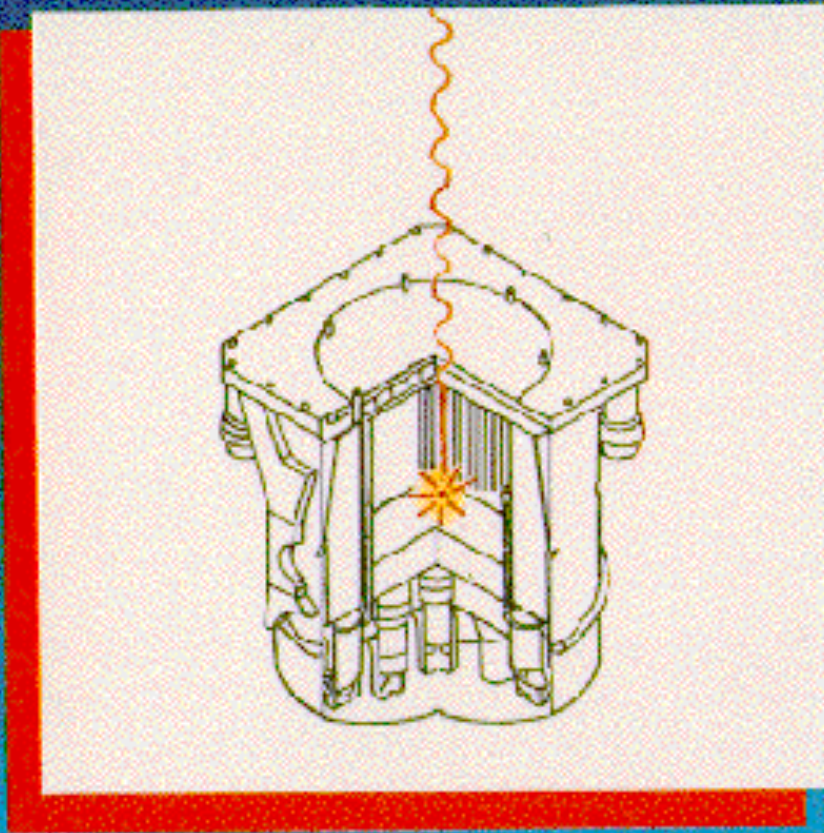
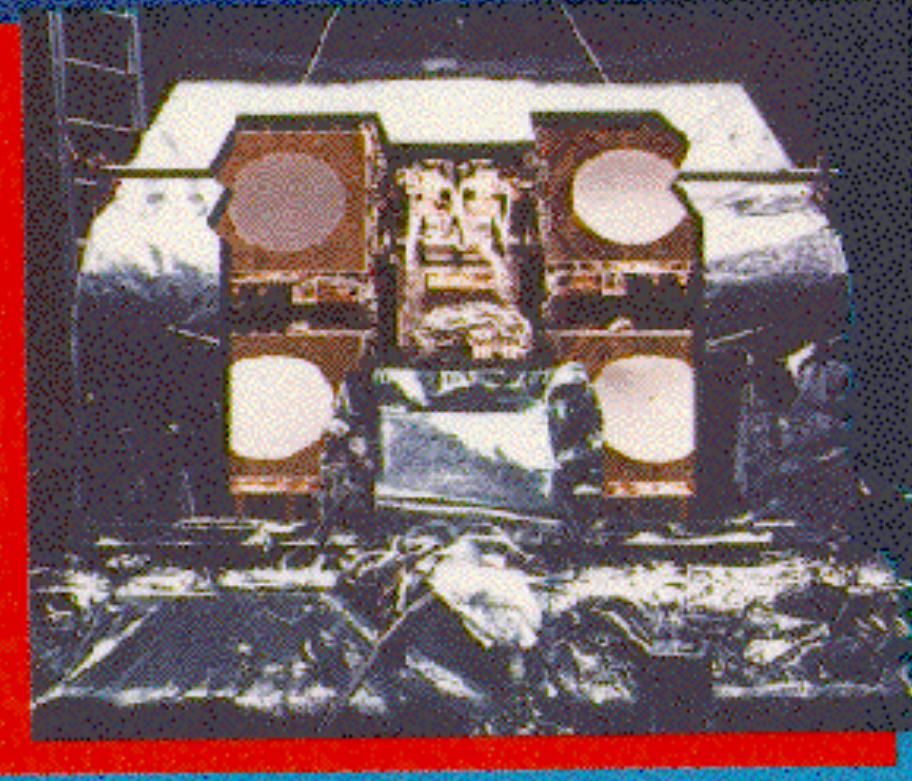
BATSE—GRO 3 Types of Gamma-Ray Bursts 50-300 keV



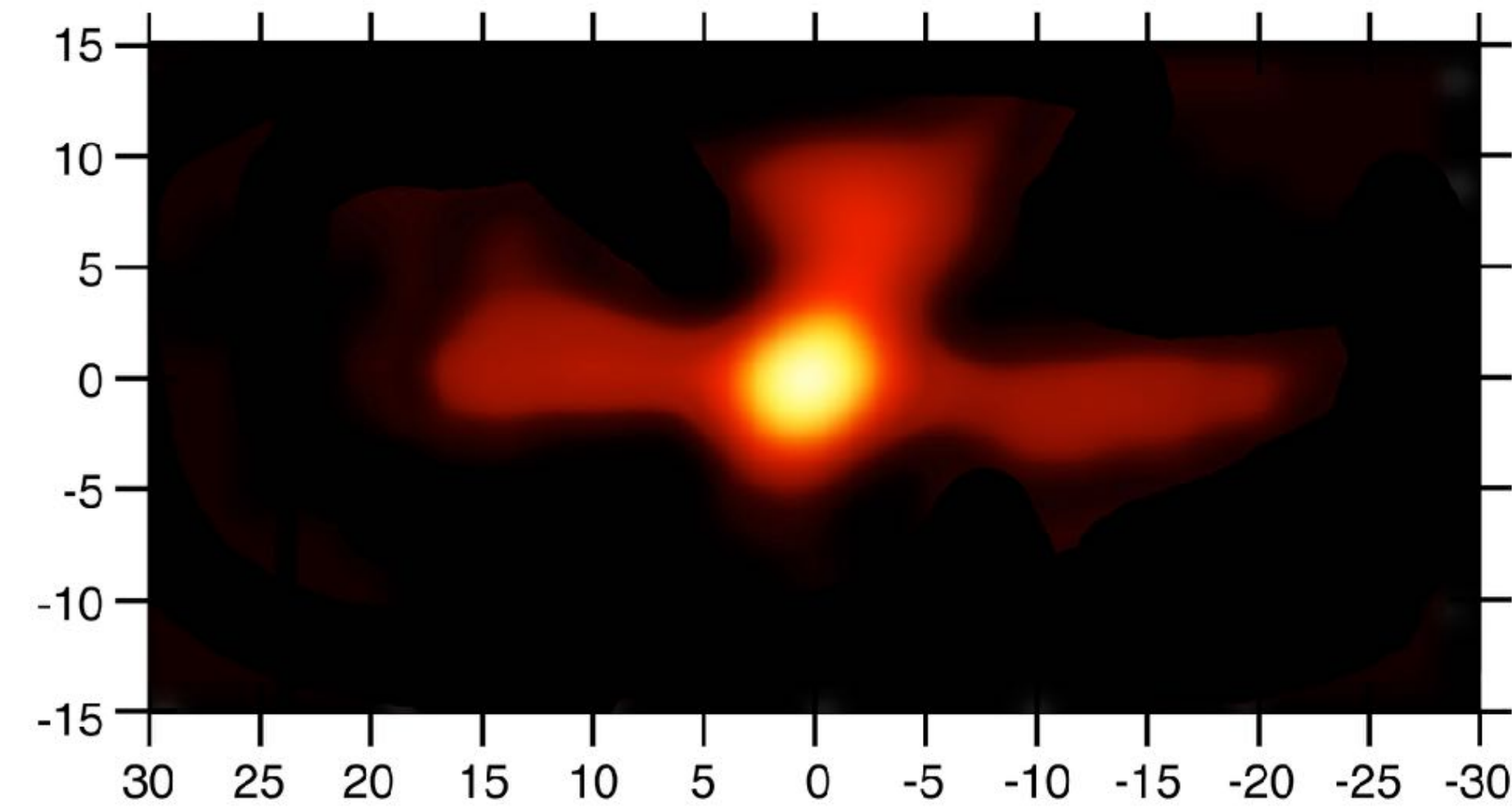
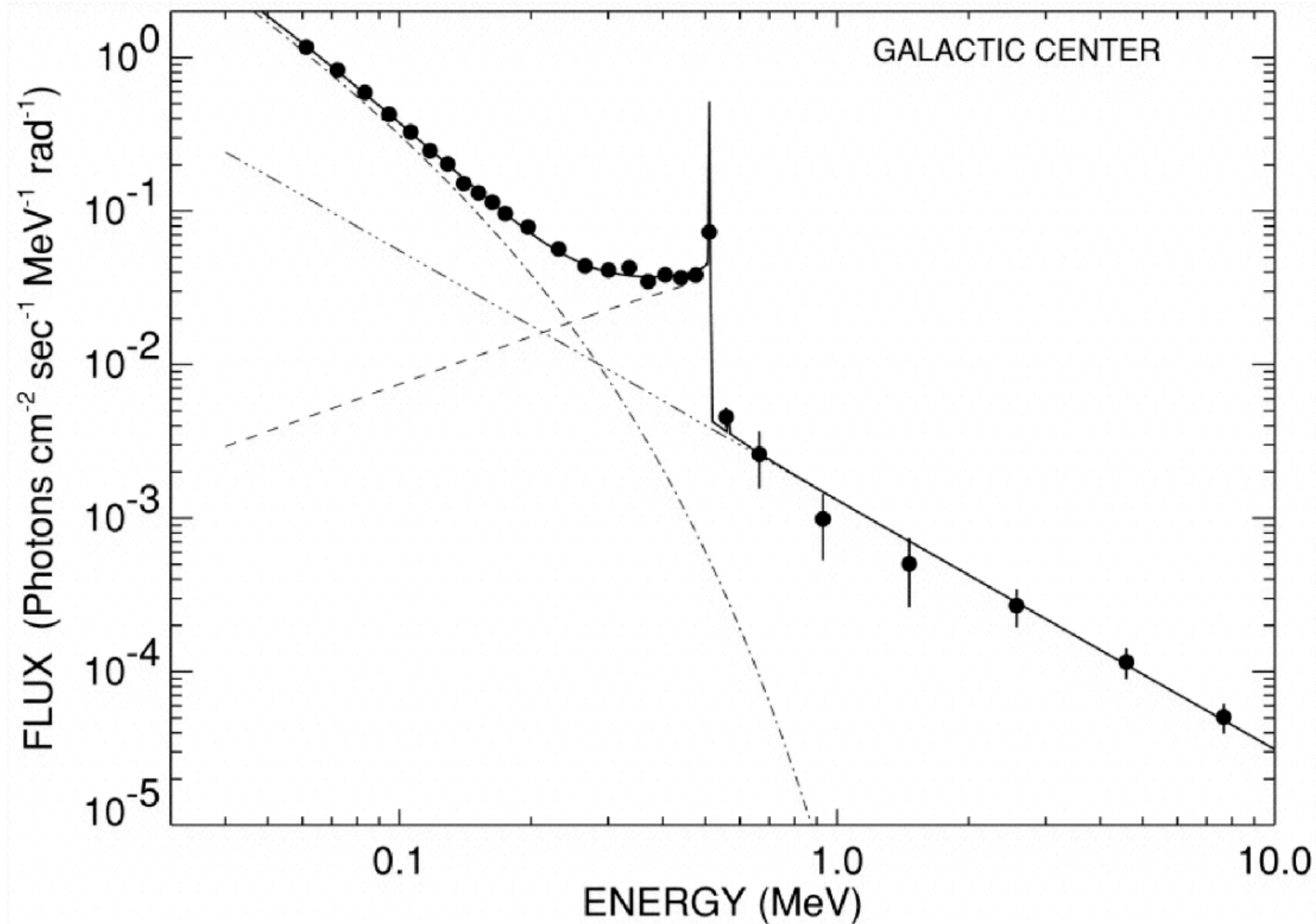
2704 BATSE Gamma-Ray Bursts

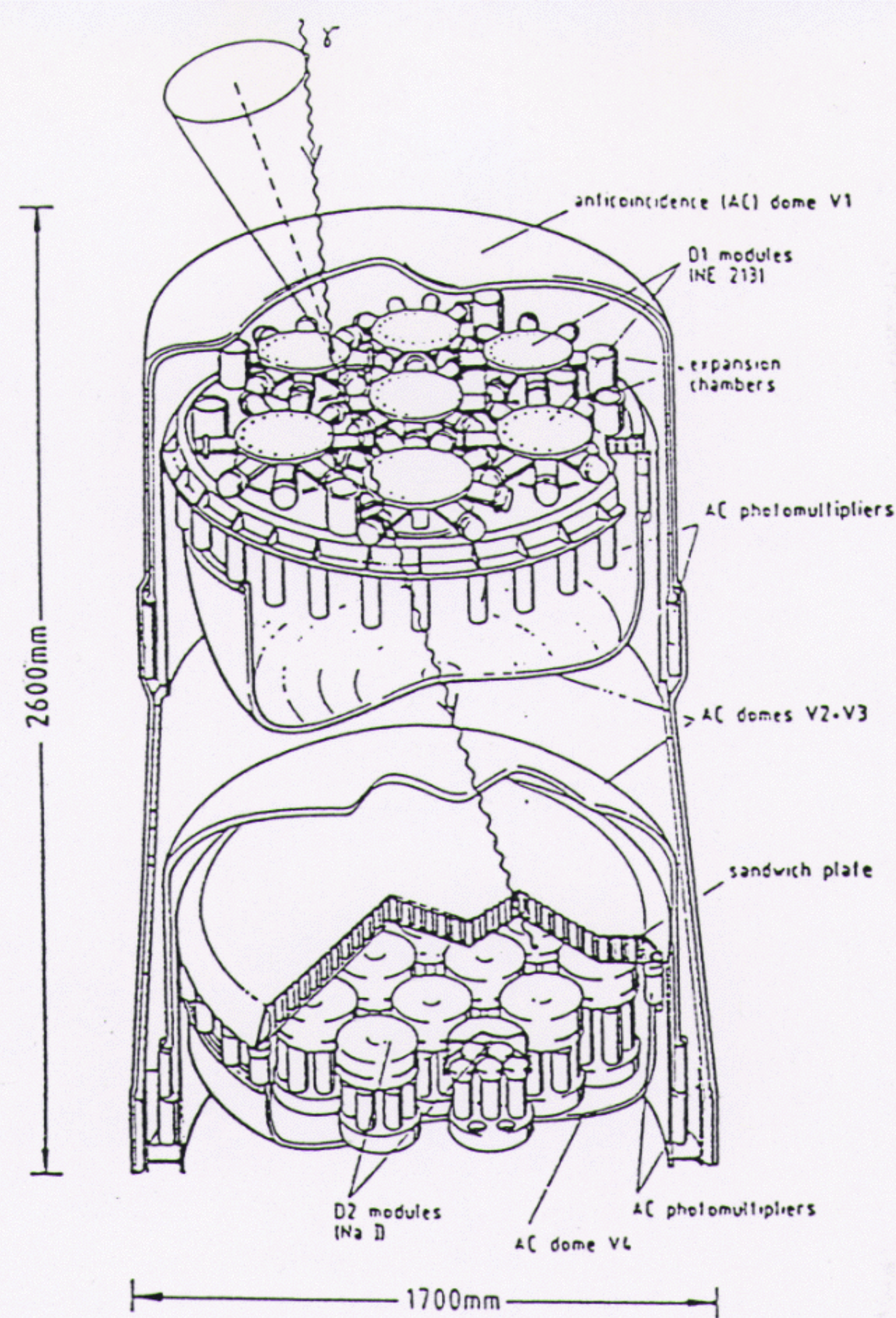


Oriented Scintillation Spectrometer Experiment (OSSE)



The annihilation fountain



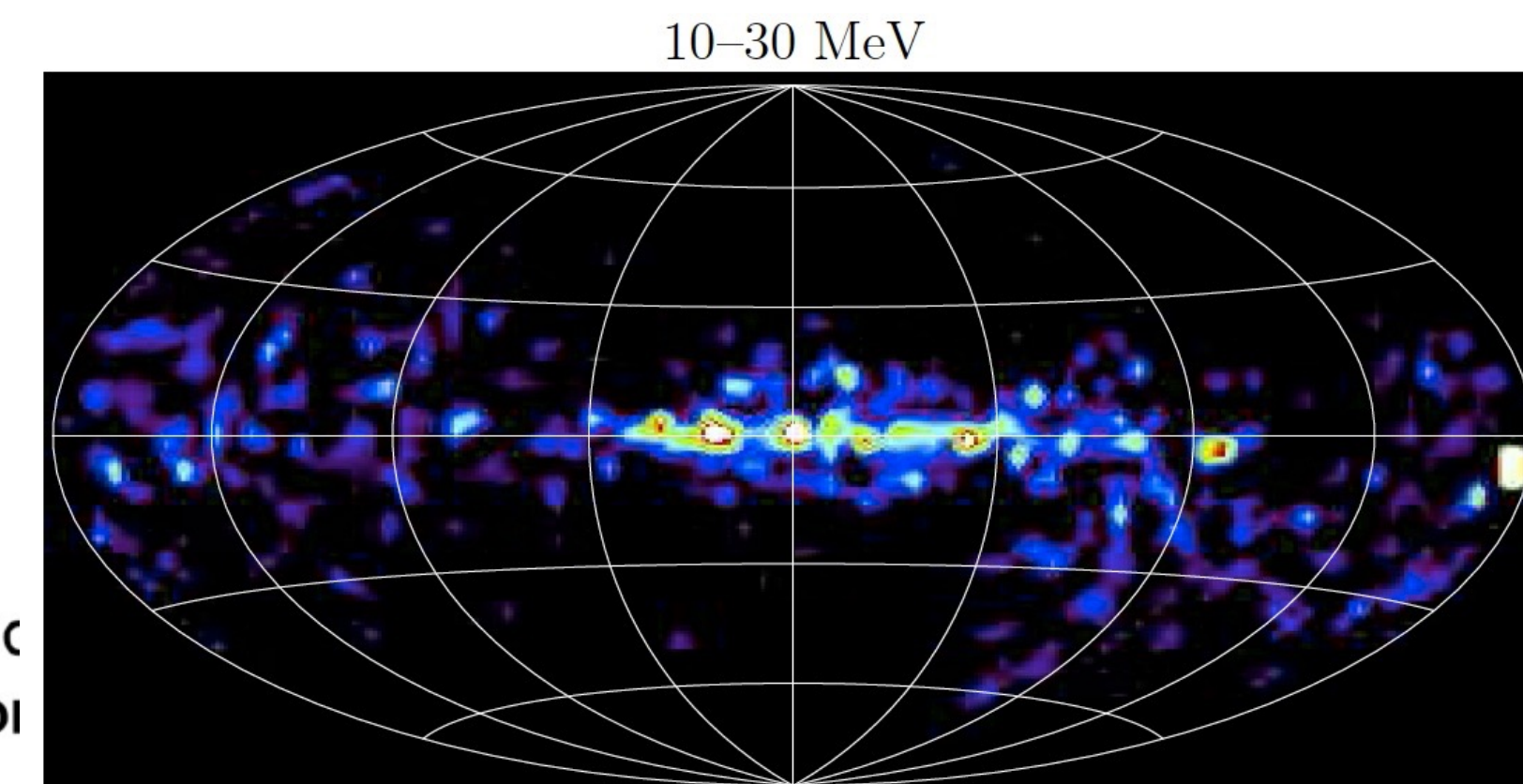
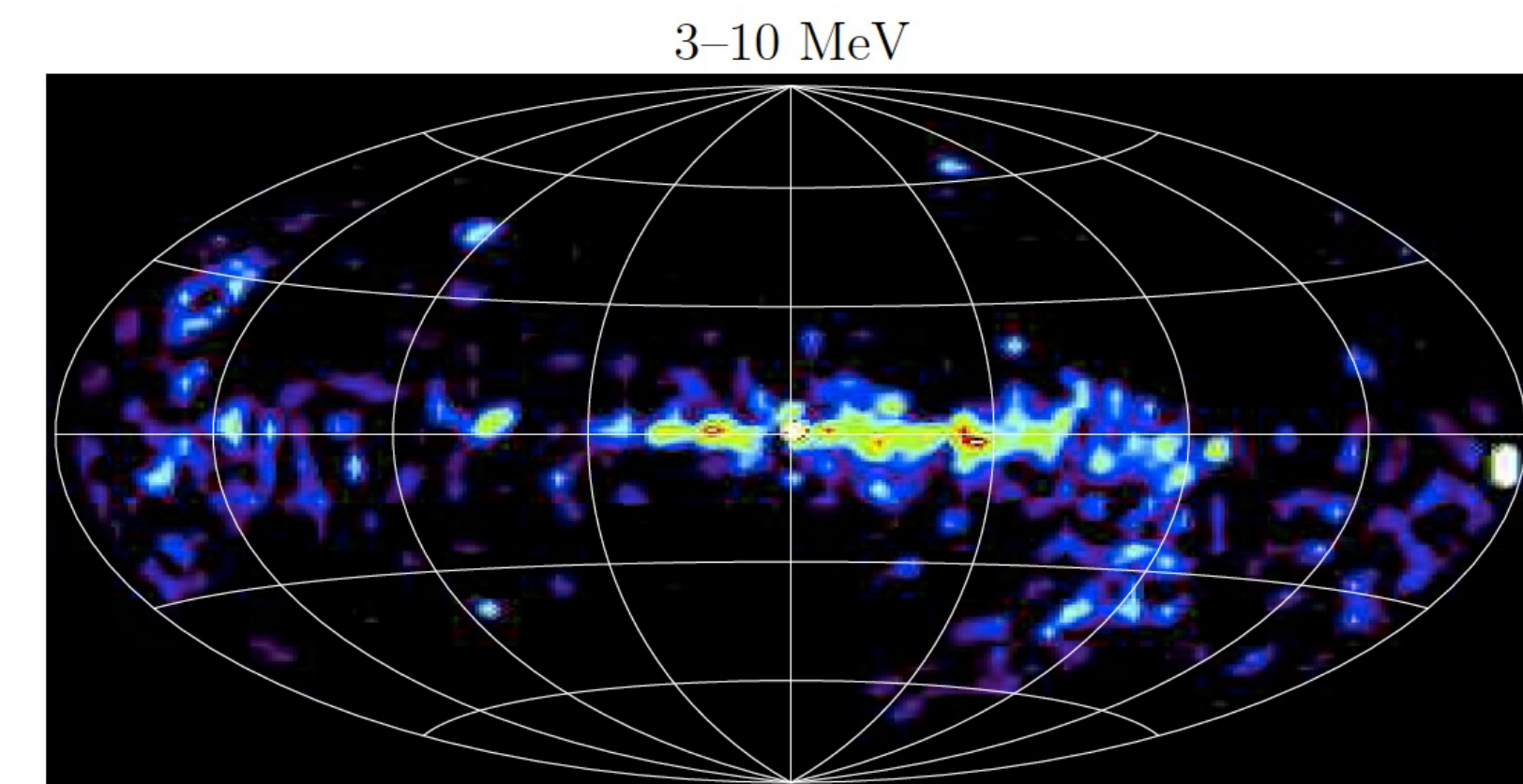
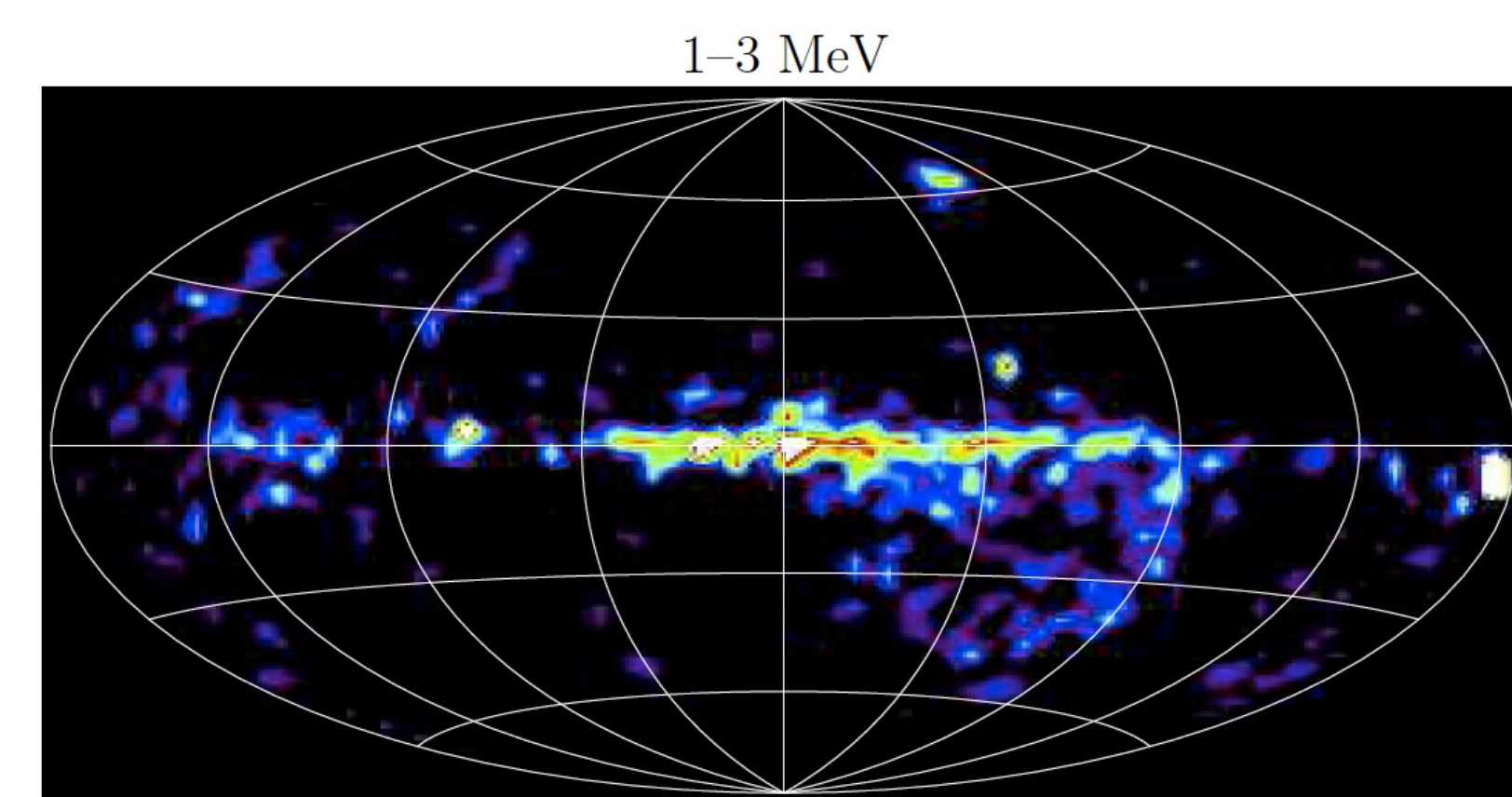
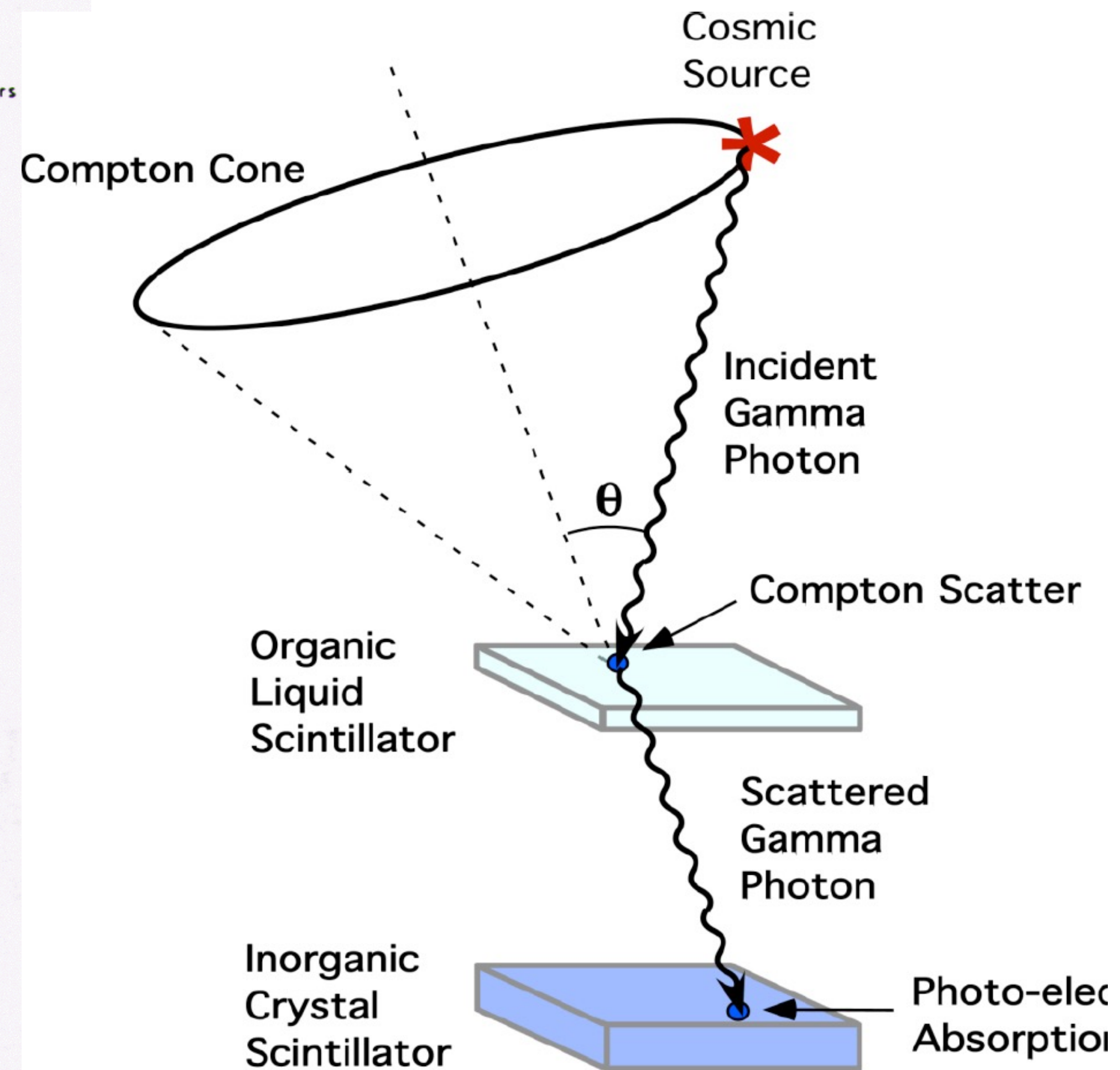


Schematics of COMPTEL

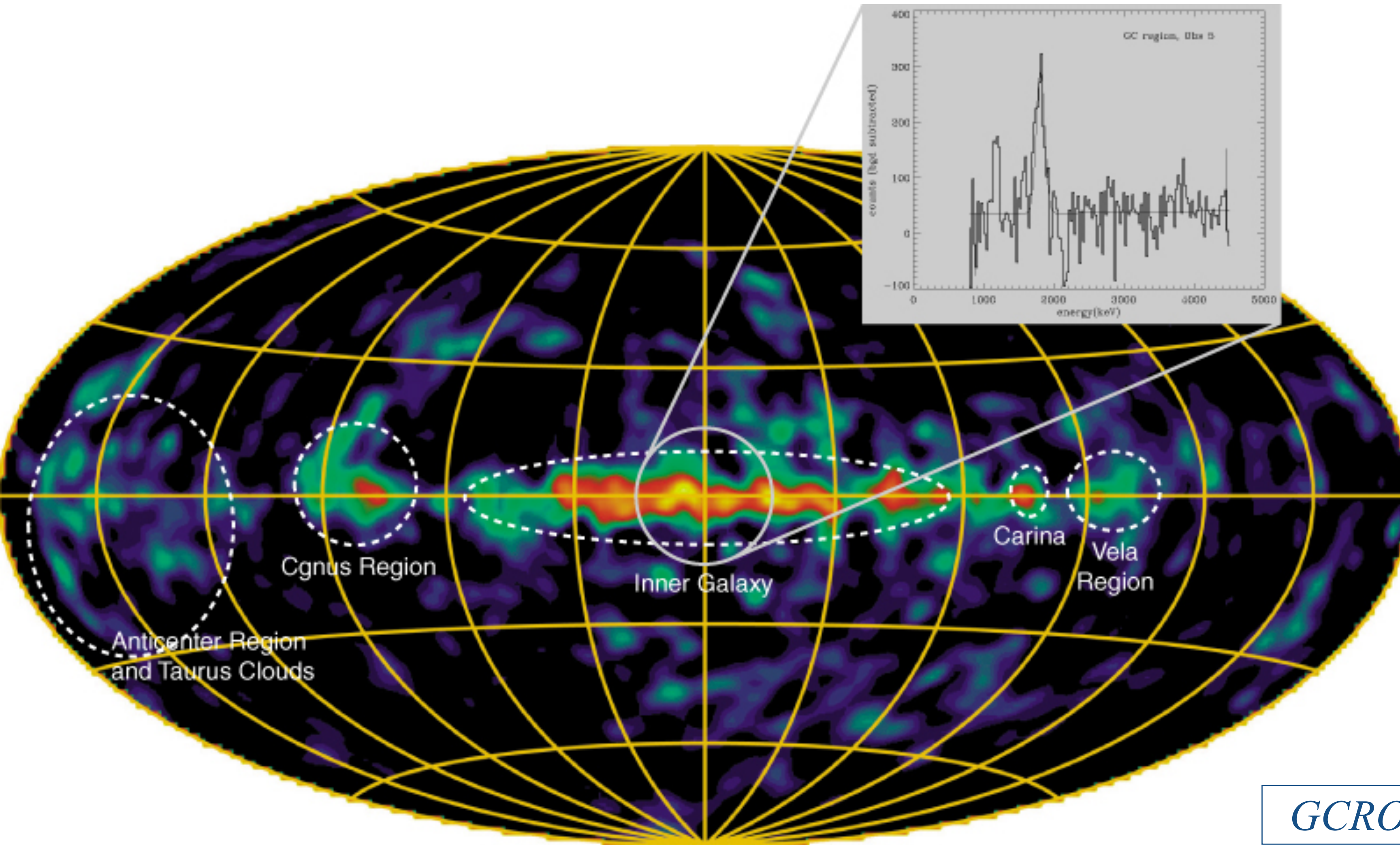
$$E_T = E_1 + E_2$$

$$\cos \bar{\theta} = 1 - \frac{m_0 c^2}{E_2} + \frac{m_0 c^2}{E_1 + E_2}$$

COMPTEL



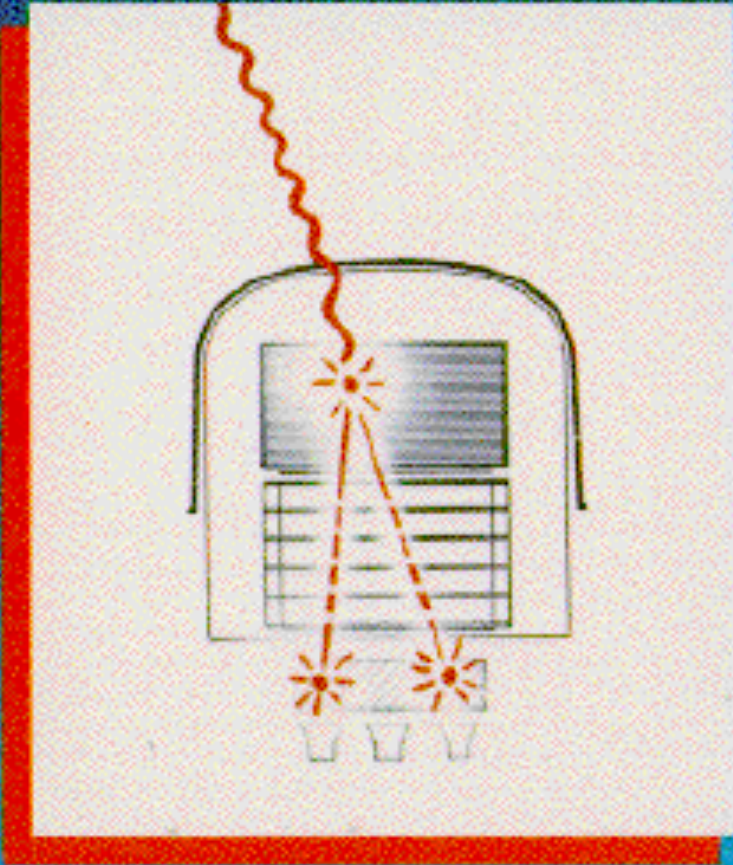
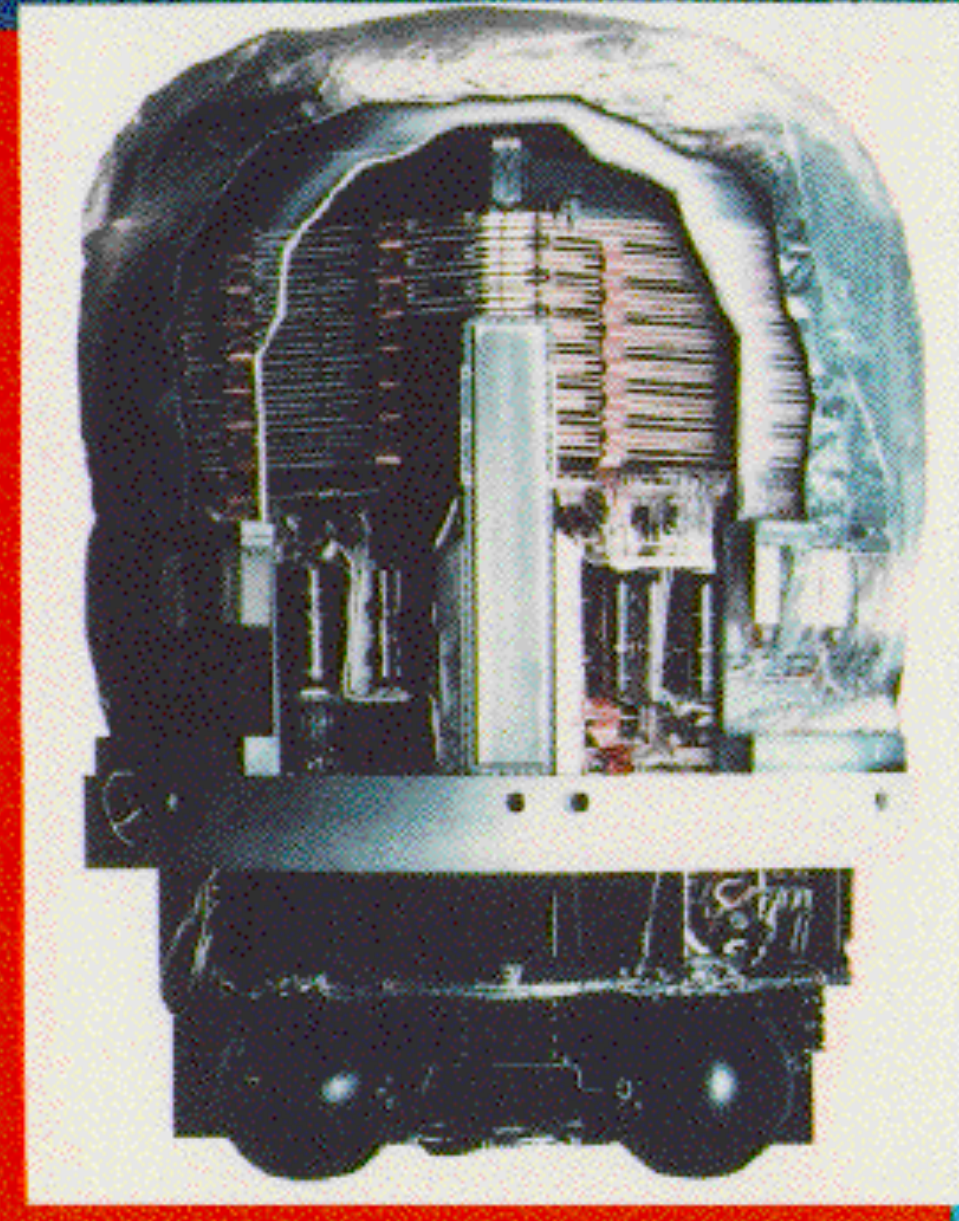
^{26}Al en la Galaxia



- El ^{26}Al decae en 0.7 Myr.
- Se produce en etapas avanzadas de nucleosíntesis en estrellas masivas.
- Su observación permite mapear la presencia de estas estrellas en la Galaxia en escalas de tiempo de 1 Myr.

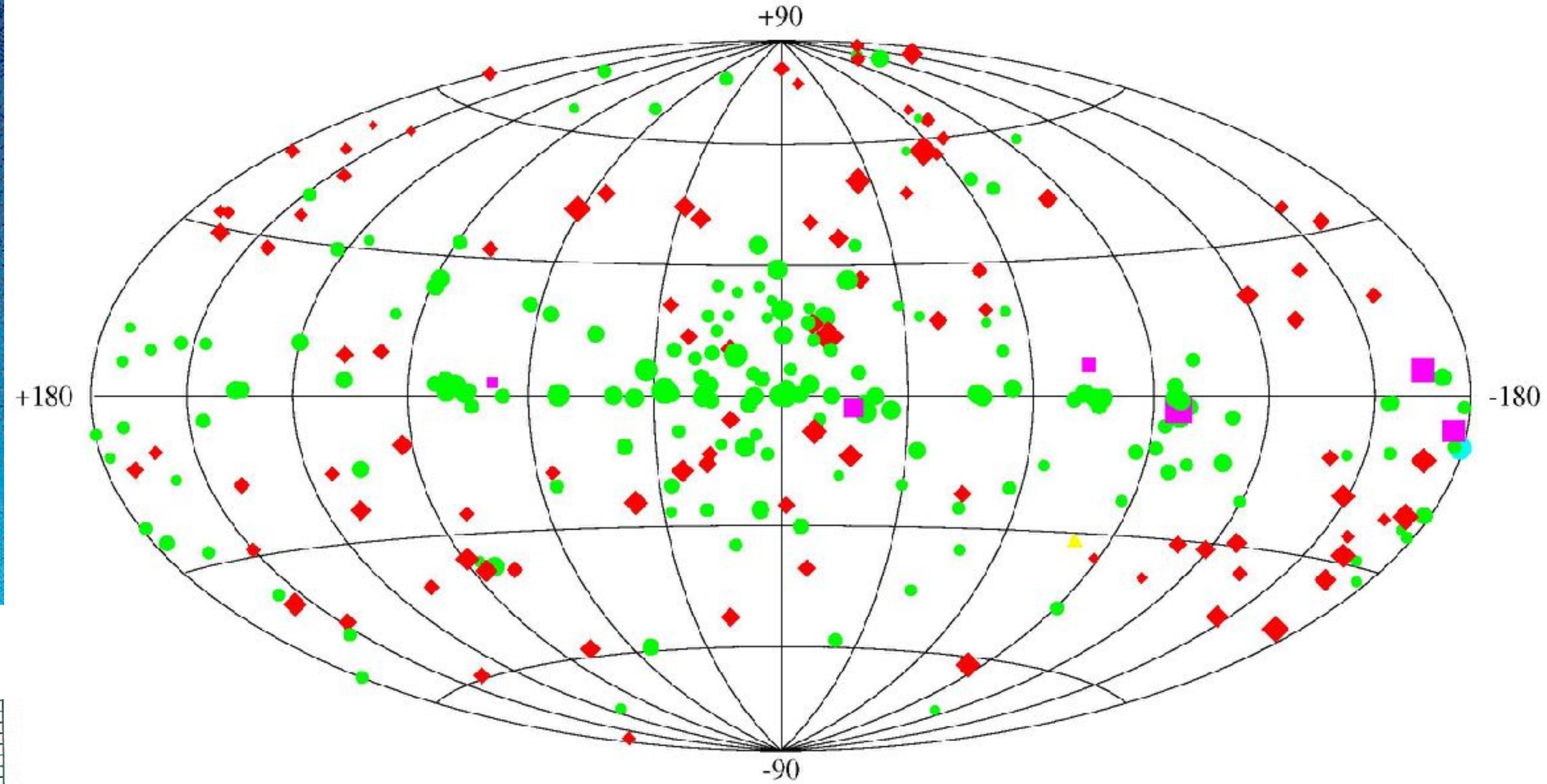
GCRO-COMPTEL map (Diehl et al. 1995)

Energetic Gamma Ray Experiment Telescope (EGRET)



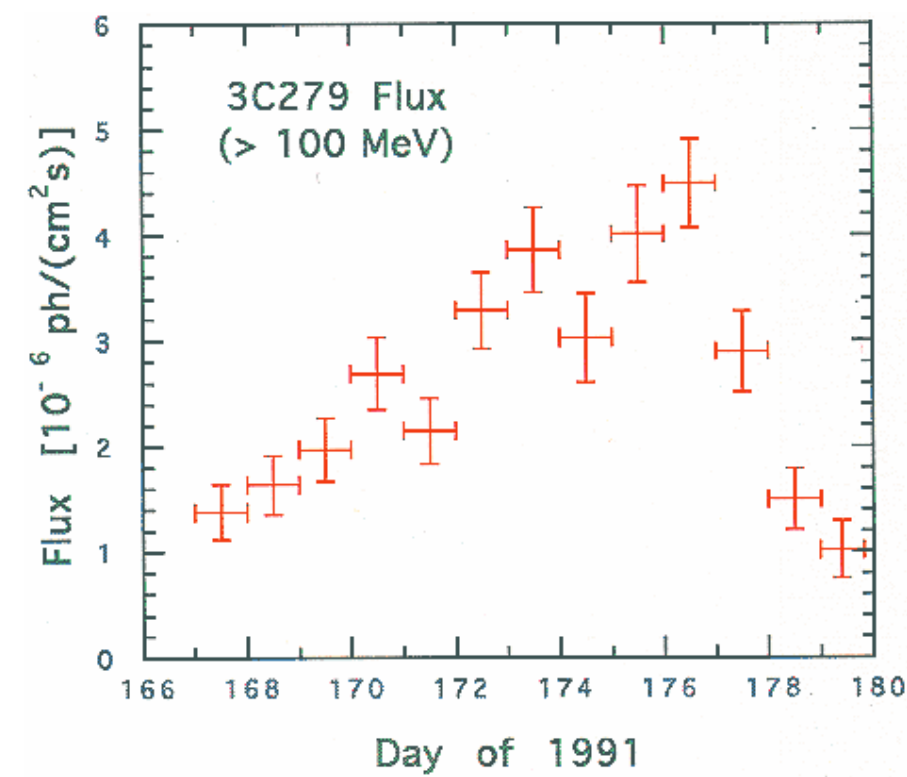
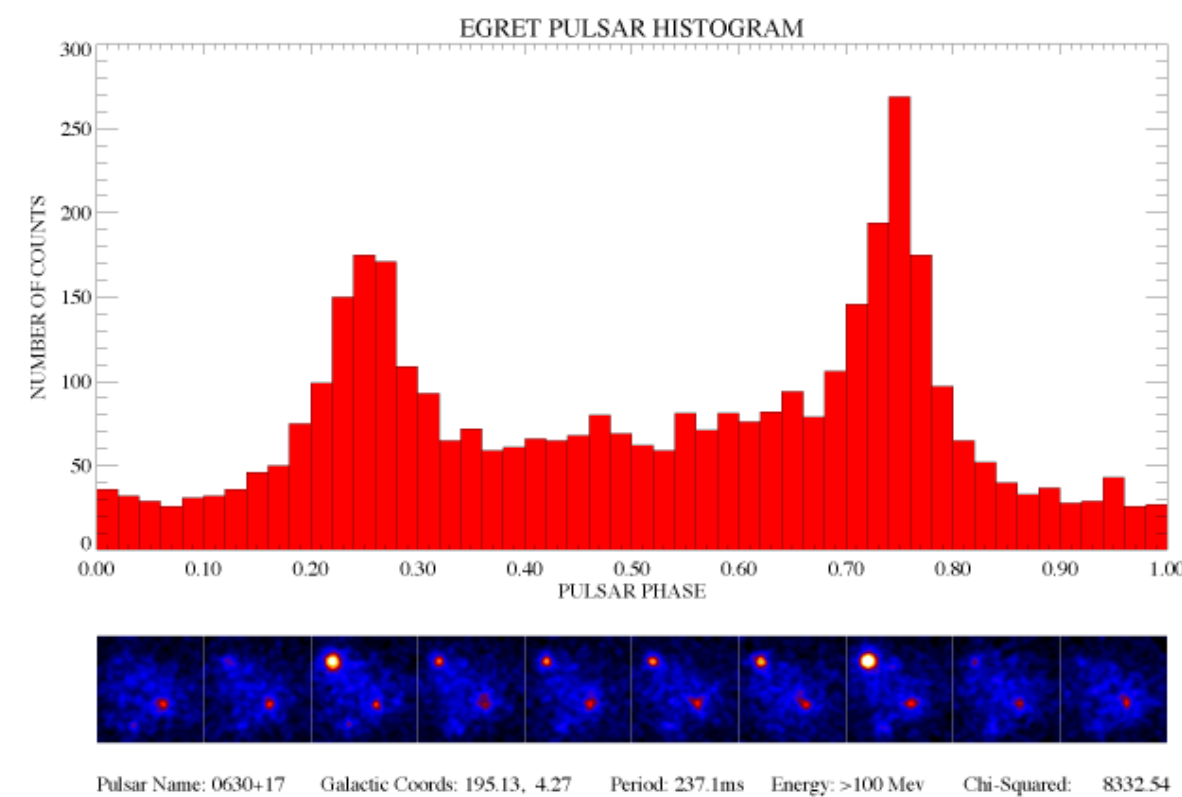
Third EGRET Catalog

$E > 100 \text{ MeV}$

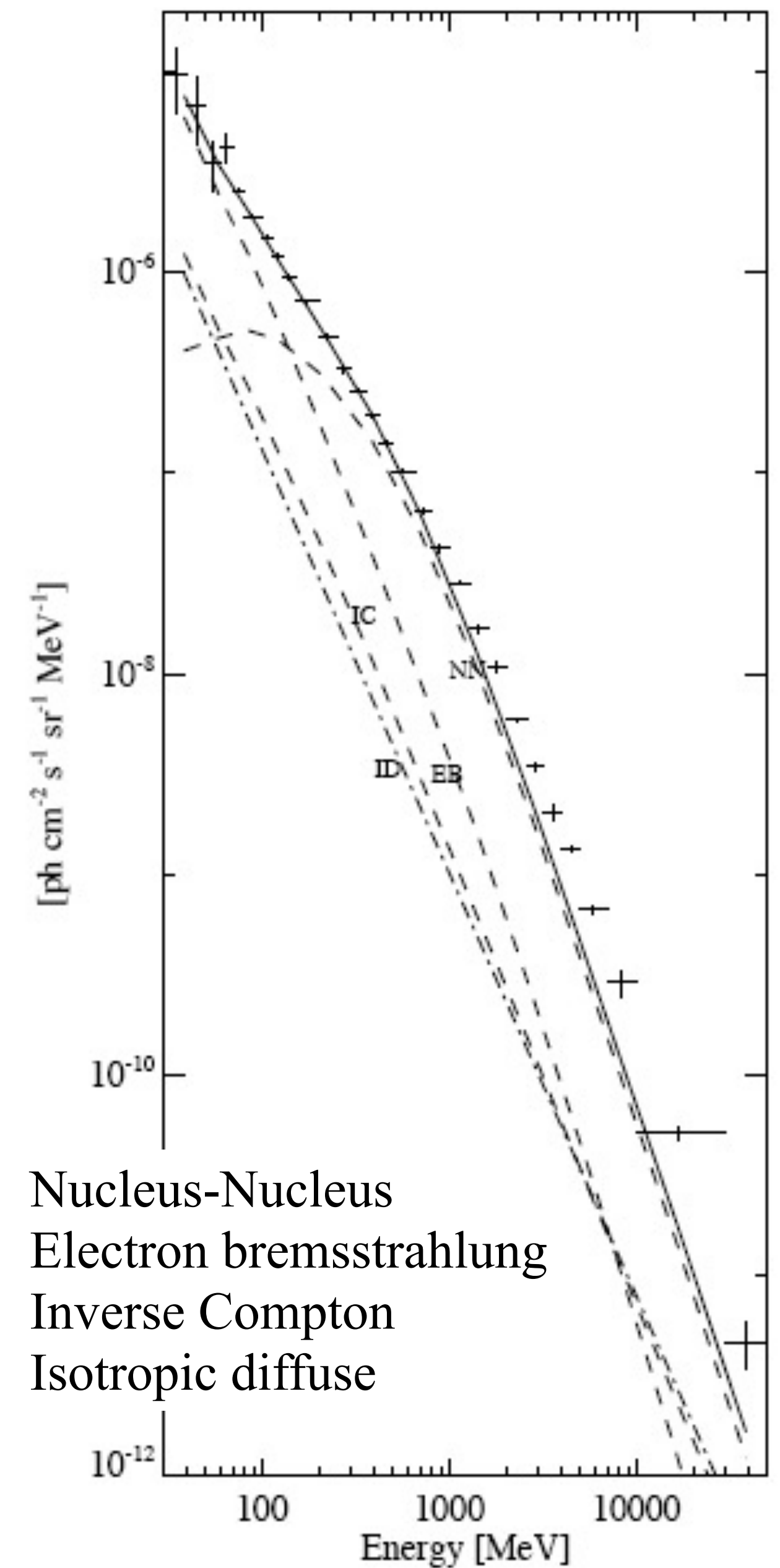
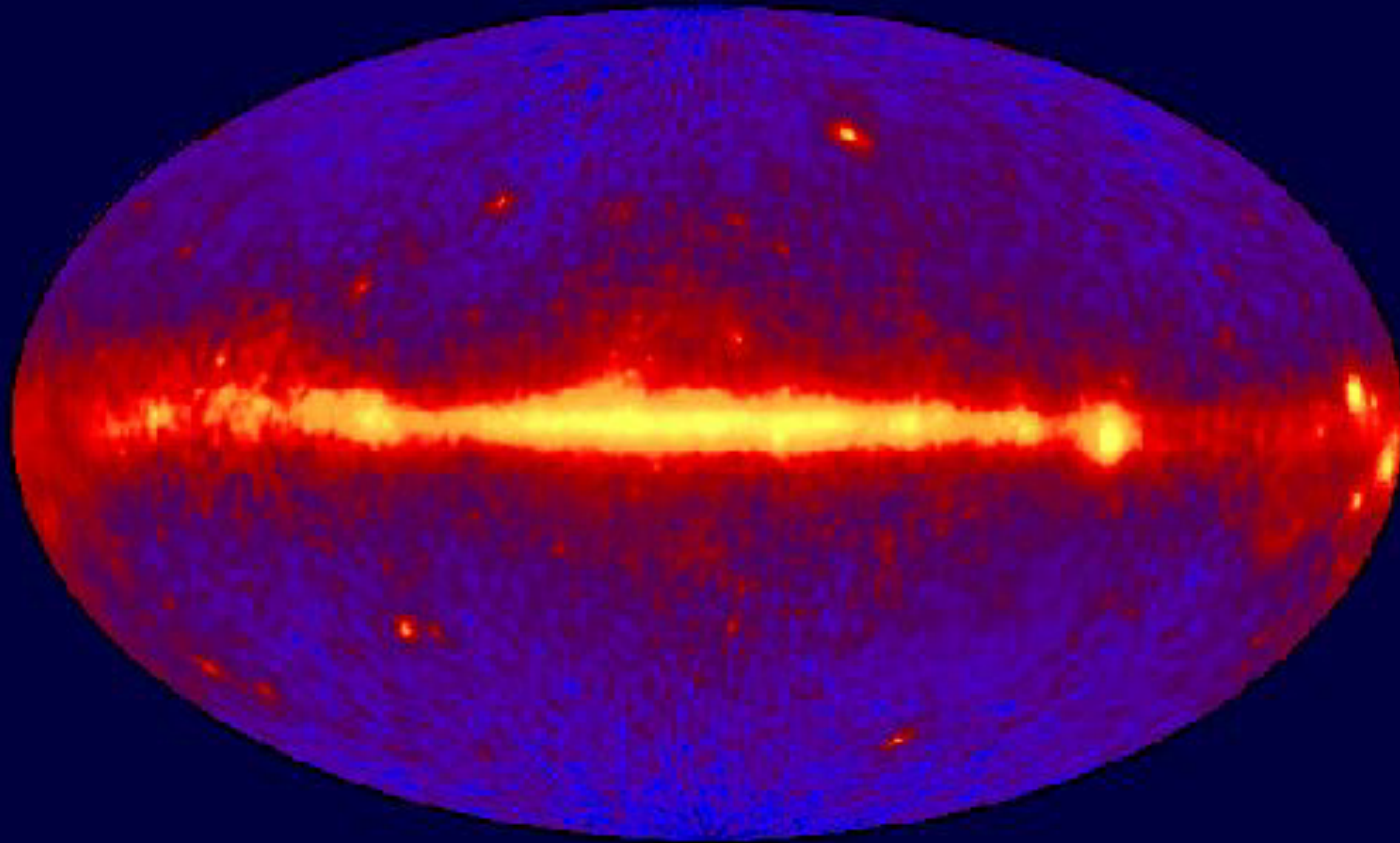


- ◆ Active Galactic Nuclei
- Unidentified EGRET Sources

- Pulsars
- ▲ LMC
- Solar FLare

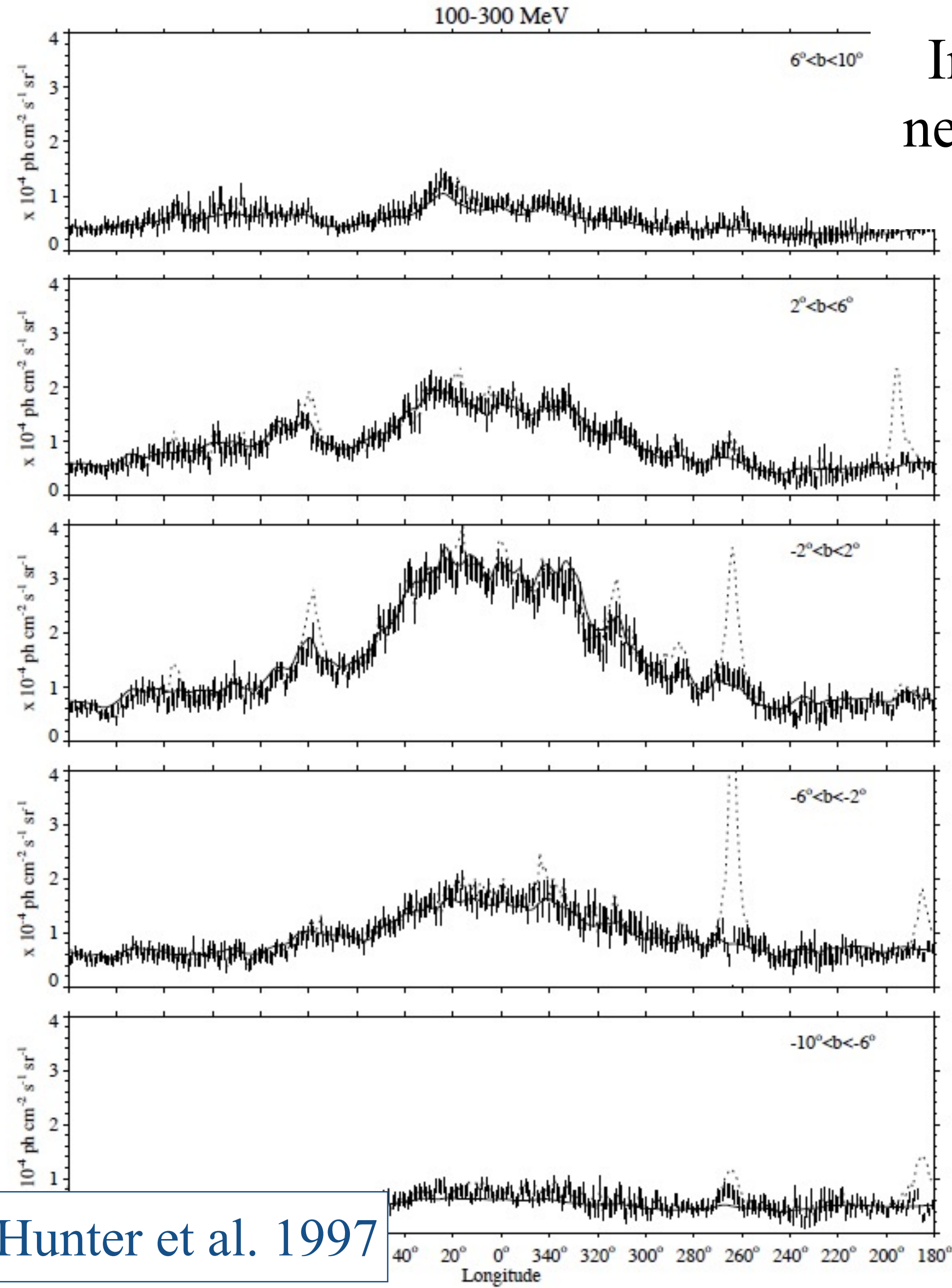


EGRET All-Sky Gamma-Ray Survey Above 100 MeV



Nucleus-Nucleus
Electron bremsstrahlung
Inverse Compton
Isotropic diffuse

Hunter et al. 1997



Hunter et al. 1997

Interacción de rayos cósmicos con gas neutro y molecular modelada con mapas de HI, CO y parámetros $\{X, R_0\}$.

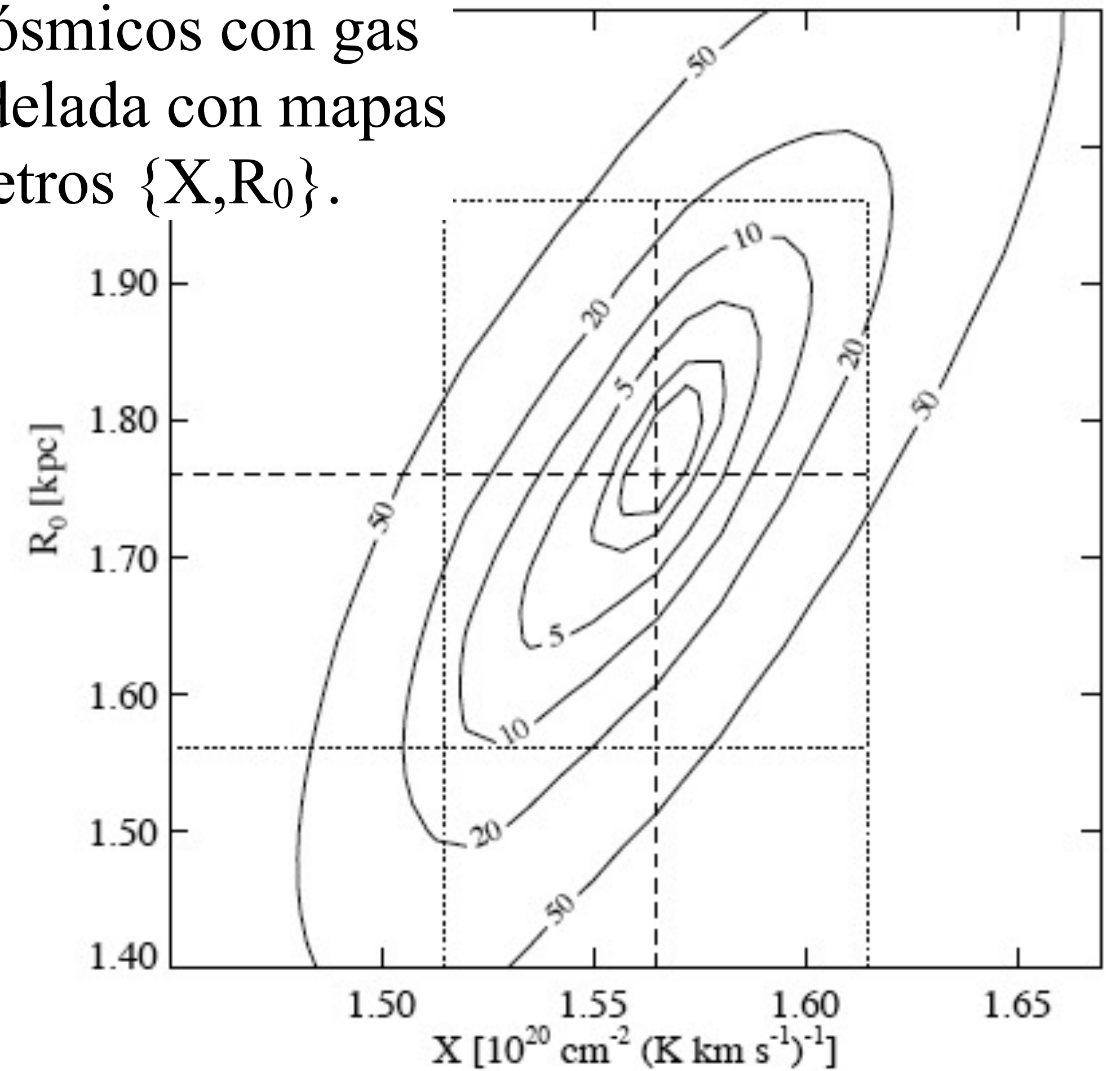


FIG. 10.—Contour plot of the likelihood test statistic, T_s , as a function of the two adjustable model parameters X , the molecular hydrogen calibrating ratio, and r_0 , the coupling scale of the cosmic rays to the surface density of the interstellar gas. The best-fit model parameters, indicated by the minimum T_s value, are shown with dashed lines. The formal 1σ errors correspond to an increase in T_s by 1. The best-fit values and their adopted errors (see § 5.5) are $X = 1.56 \pm 0.05$ and $r_0 = 1.76 \pm 0.2$.



CGRO
(1991-2000)

~~[2000-2008]~~

GLAST → Fermi GST
(11 junio 2008)



Fermi Gamma-ray Space Telescope (2008–)

- ❑ NASA/DoE Project
- ❑ Launched June 11, 2008
- ❑ NRL Fermi Involvement

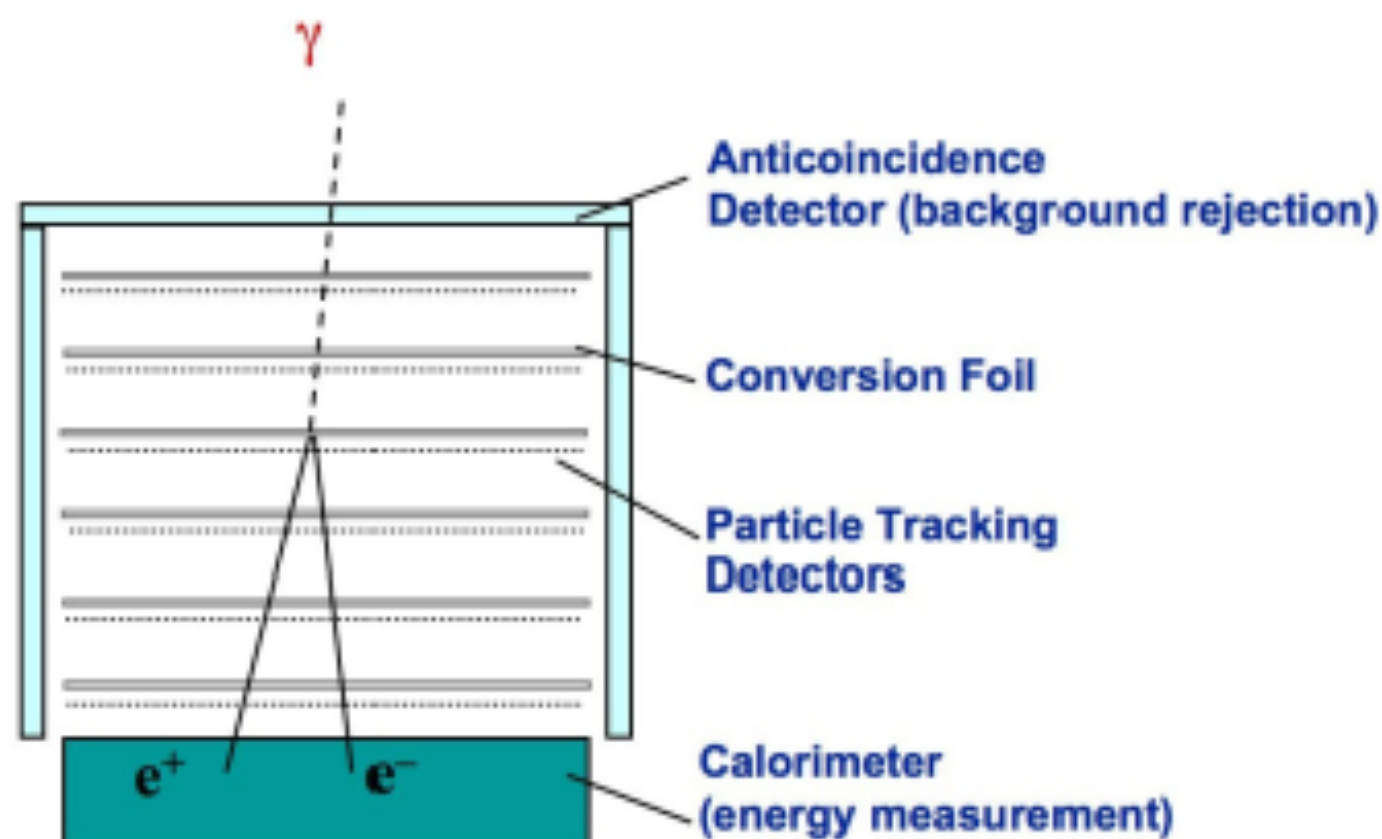
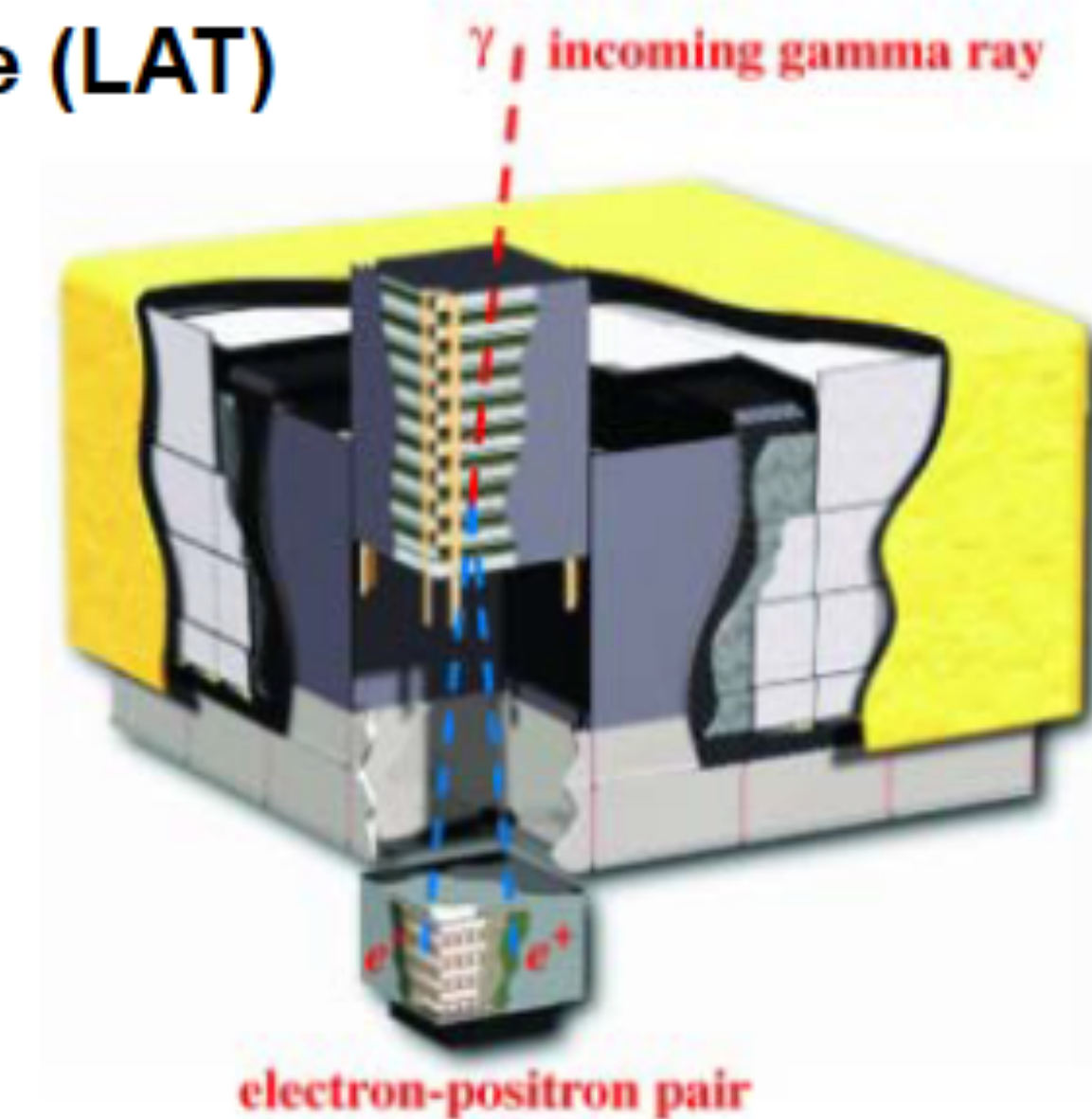
- Calorimeter
- Environmental testing
- Interdisciplinary scientist

USA (GSFC/SLAC/NRL)

Italy/Japan/Sweden/Germany

Large Area Telescope (LAT)

20 MeV $\rightarrow$ 300 GeV
2.4 sr Field of View

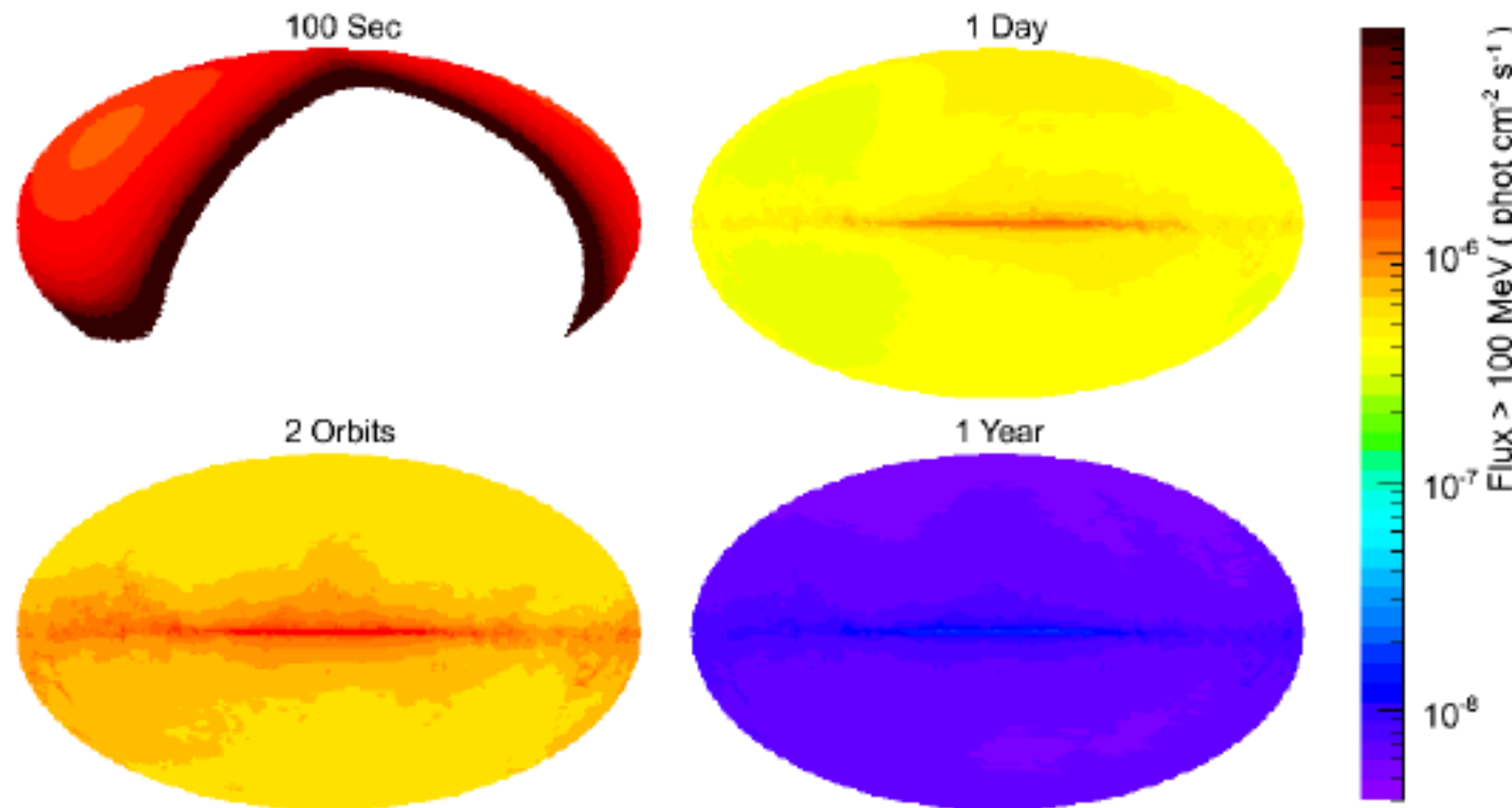


Gamma-ray Burst Monitor (GBM)

8 keV – 40 MeV (12+2 detectors)
Views entire unocculted sky



Operations and observing modes



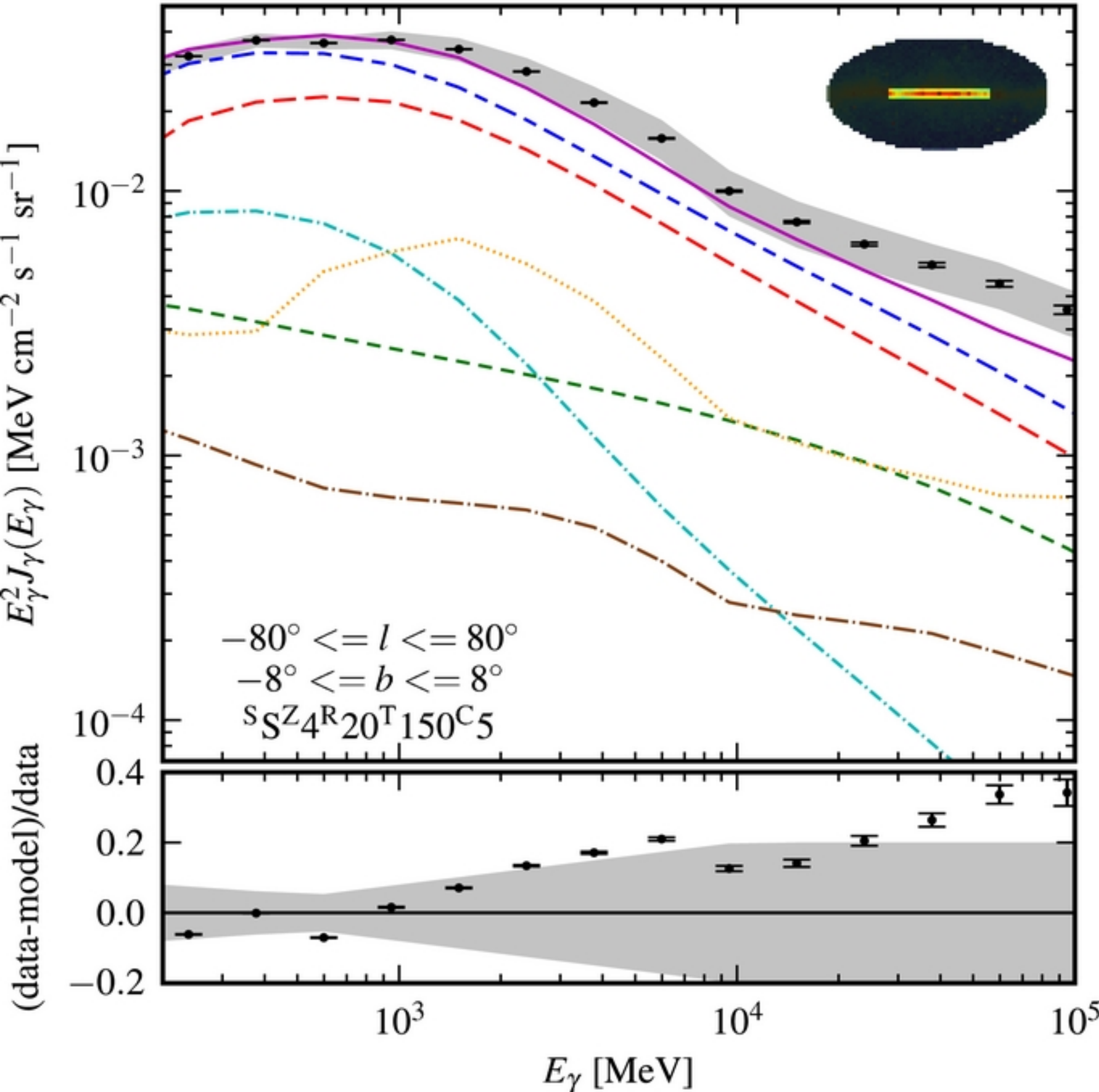
LAT sensitivity on 4 different timescales: 100 s, 1 orbit (96 mins), 1 day and 1 year

- ❑ Almost all observations in survey mode - the LAT observes the entire sky every two orbits (~3 hours), each point on the sky receives ~30 mins exposure during this time.
 - 39 deg rocking angle to Sept 2, 50 deg after September 3, 2009. Very high ontime! ,
- ❑ Autonomous Repointing
 - In response to bright GBM-detected GRBs, LAT-triggered GRBs
- ❑ Dedicated Pointings
 - Crab flares, bright blazars, γ -ray novae

GDE con Fermi

Ackermann et al. 2012, ApJ 750, 3

Modelos de masa de la Galaxia (HI, CO),
de la propagación de RCs desde la
fuentes (GALPROP) e interacciones.



Suma: magenta

Modelo DGE: azul

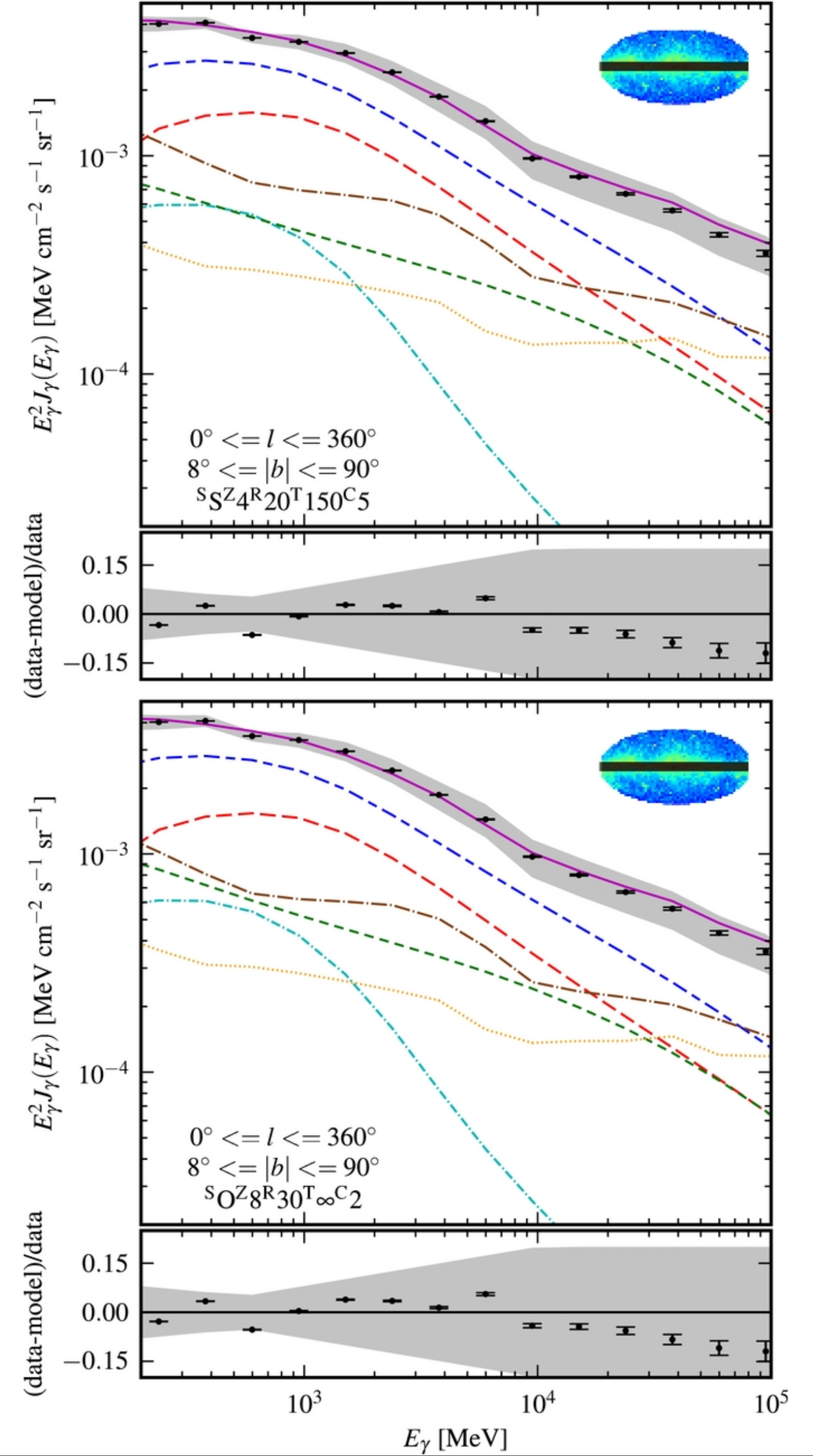
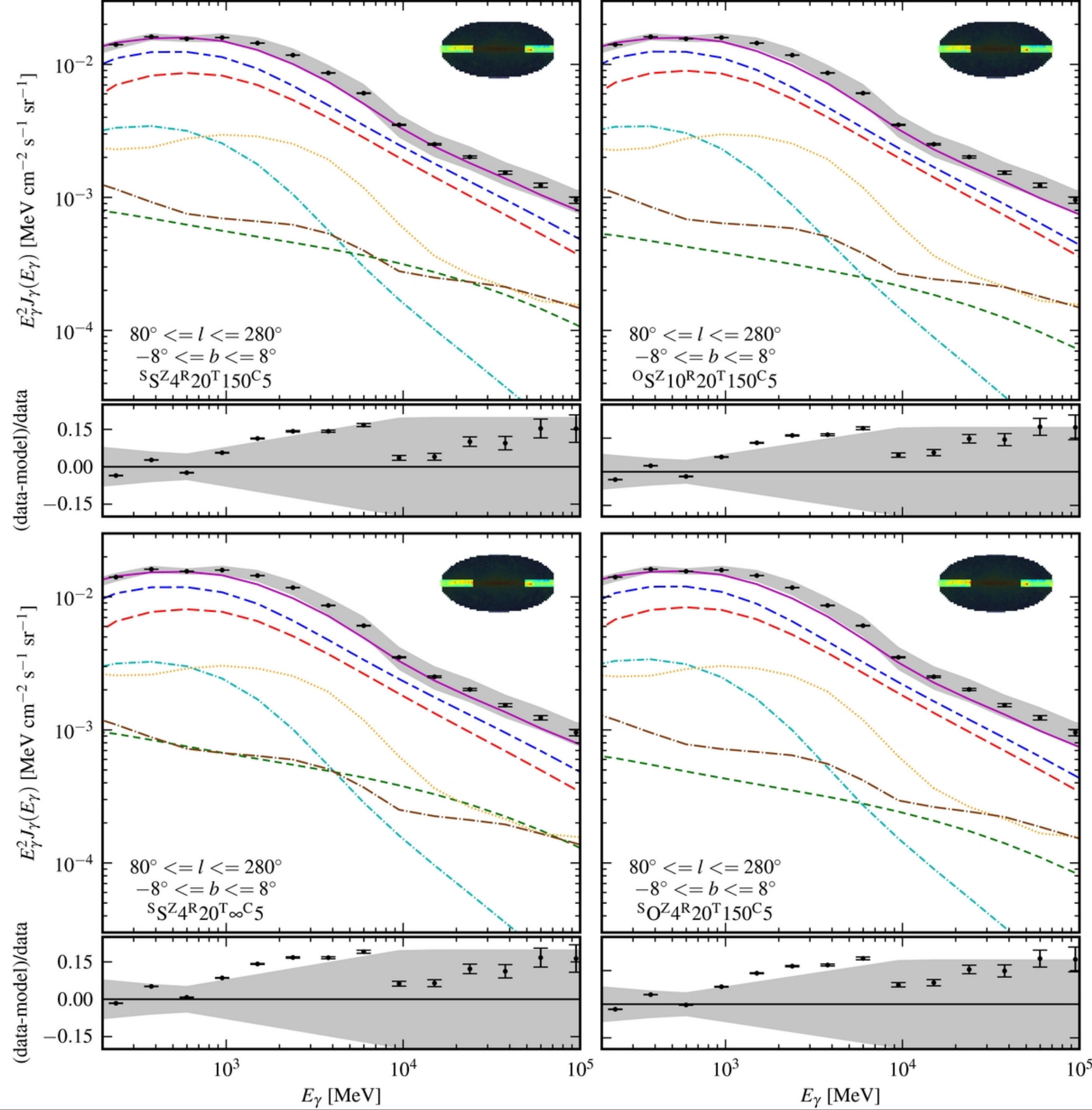
Pion neutro: rojo

Inverse Compton: verde

Bremsstrahlung: cyan

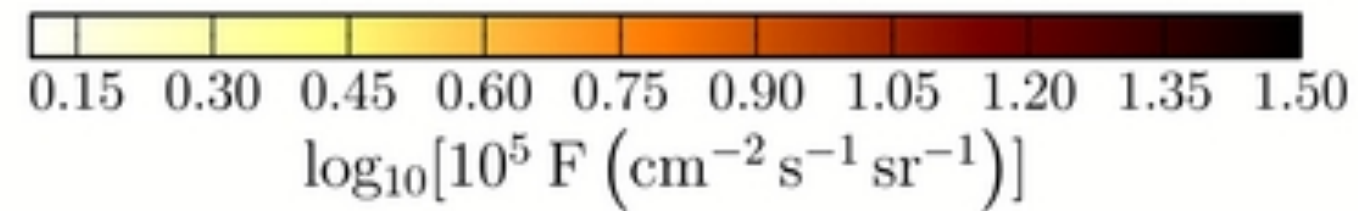
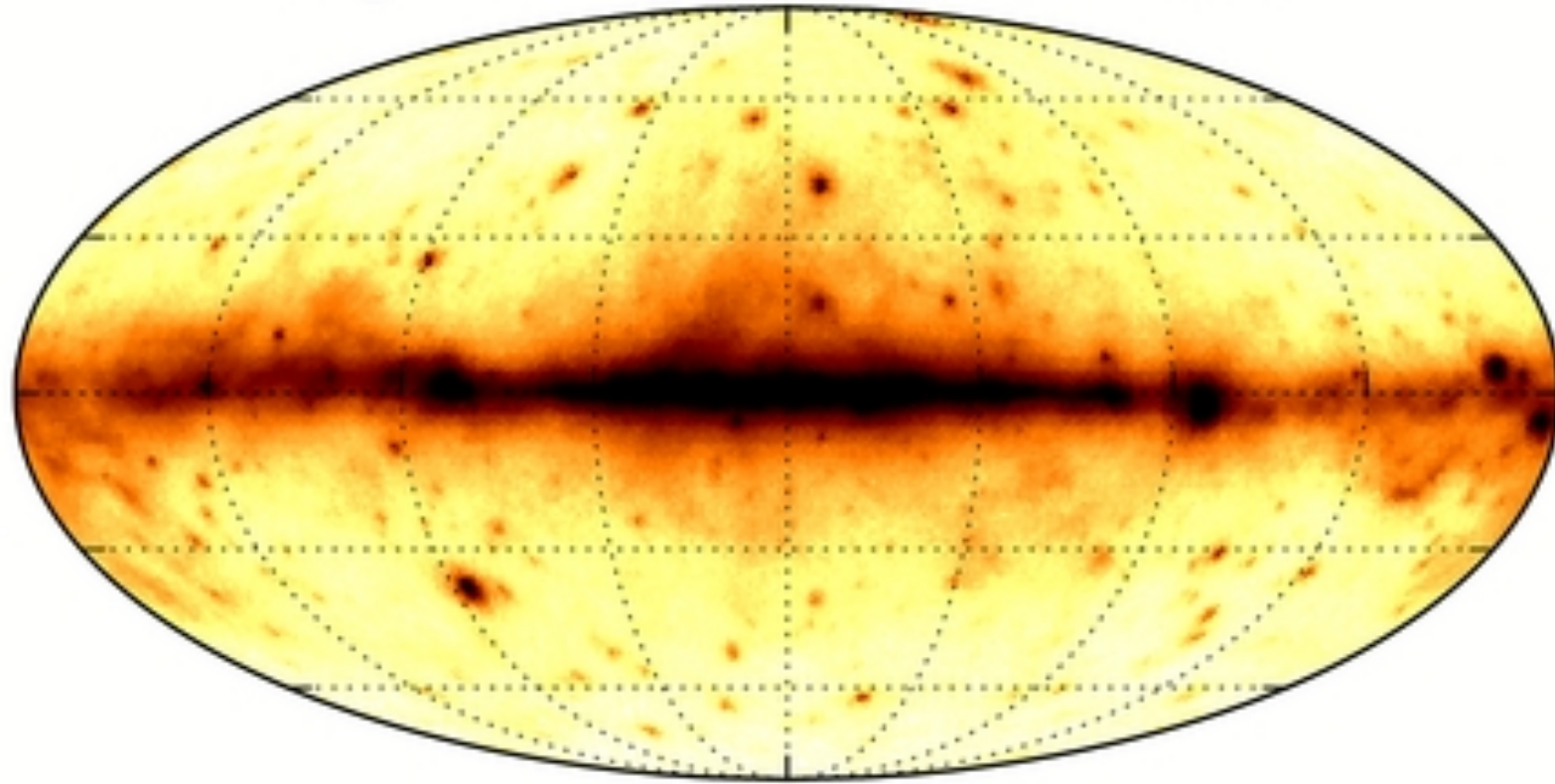
Isotrópico: café

Fuentes: naranja

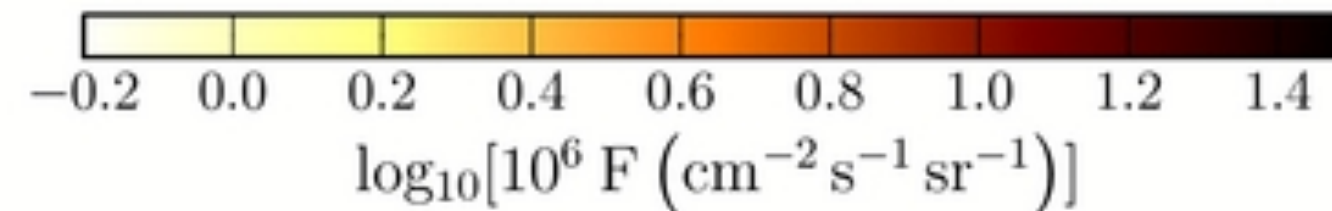
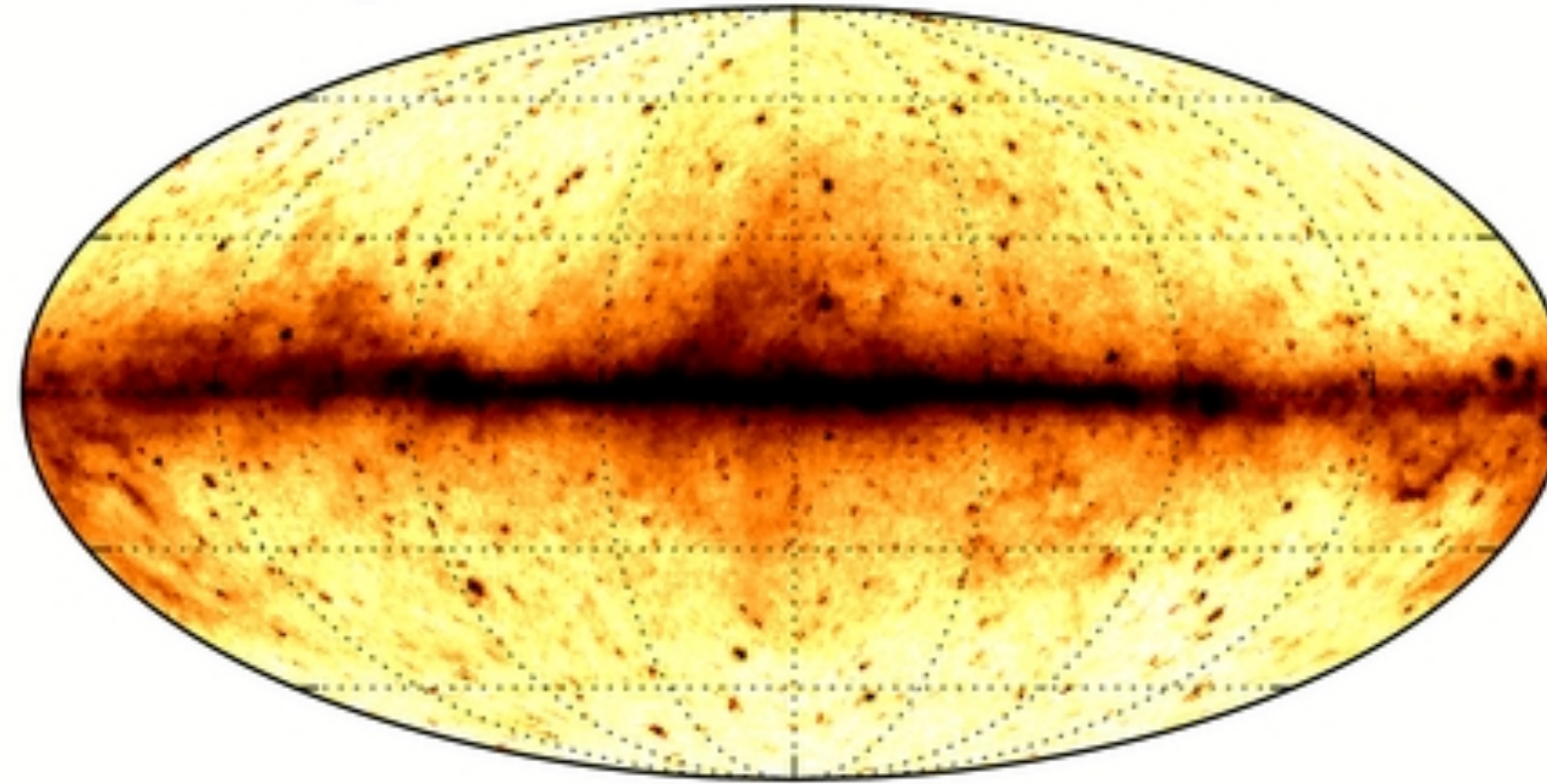


Fermi Bubbles

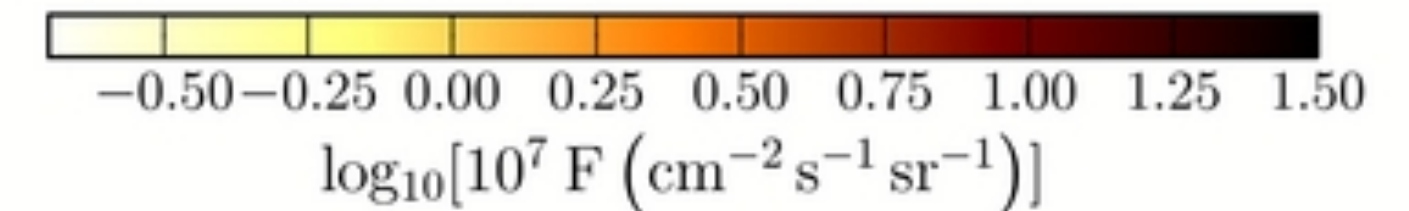
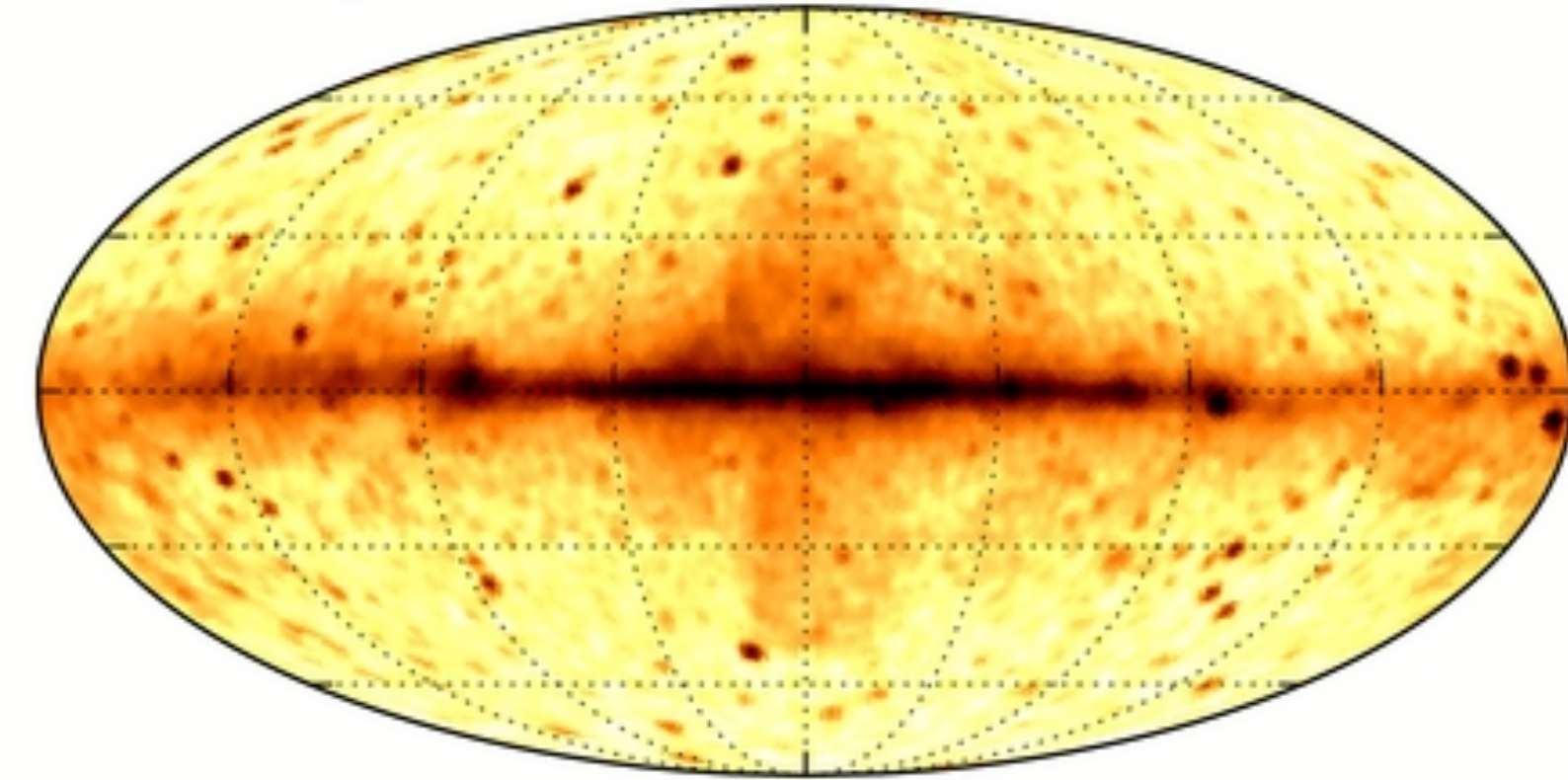
Integrated intensity, $E = 0.1 - 1.0$ GeV



Integrated intensity, $E = 1.0 - 10.0$ GeV



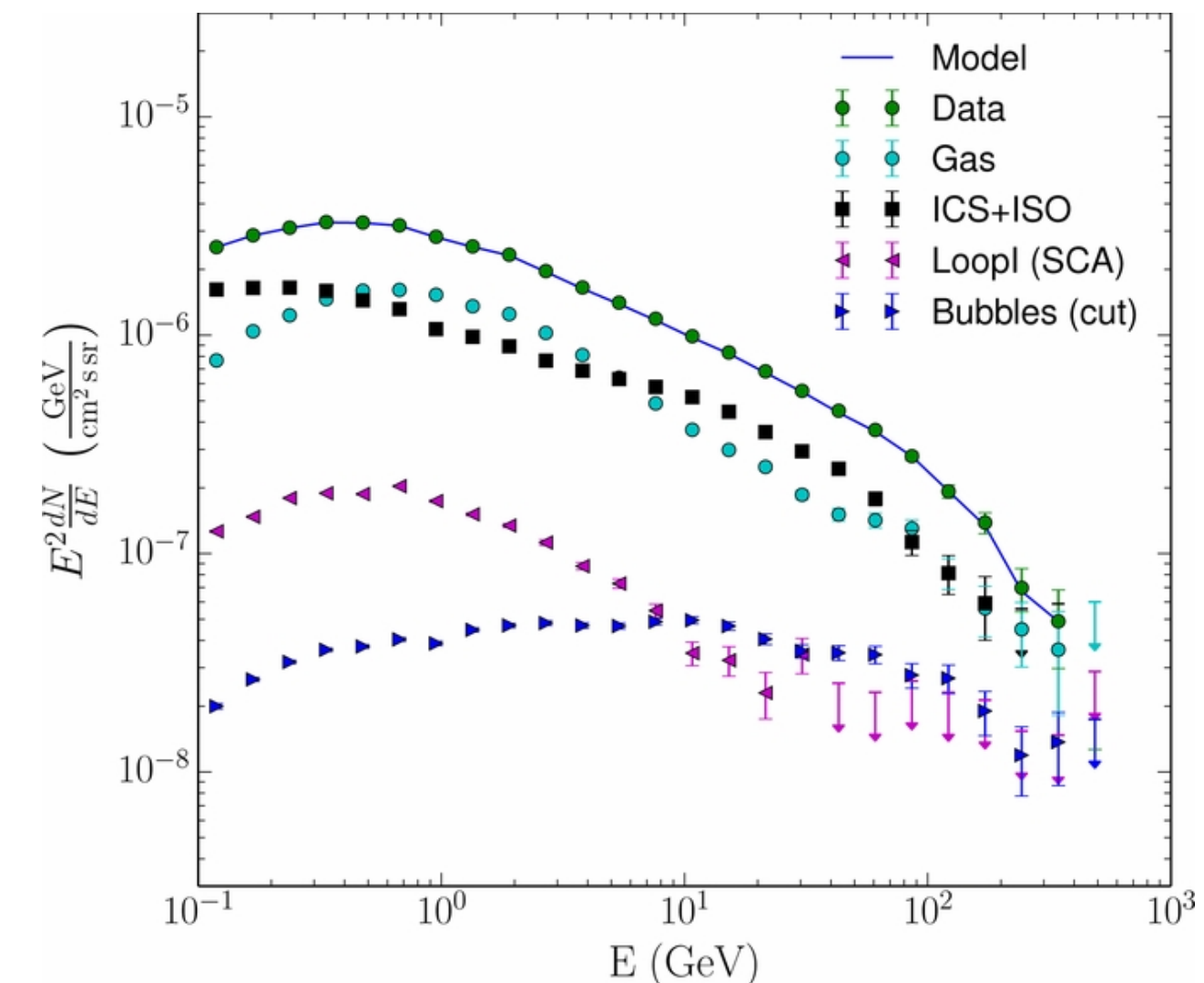
Integrated intensity, $E = 10.0 - 500.0$ GeV

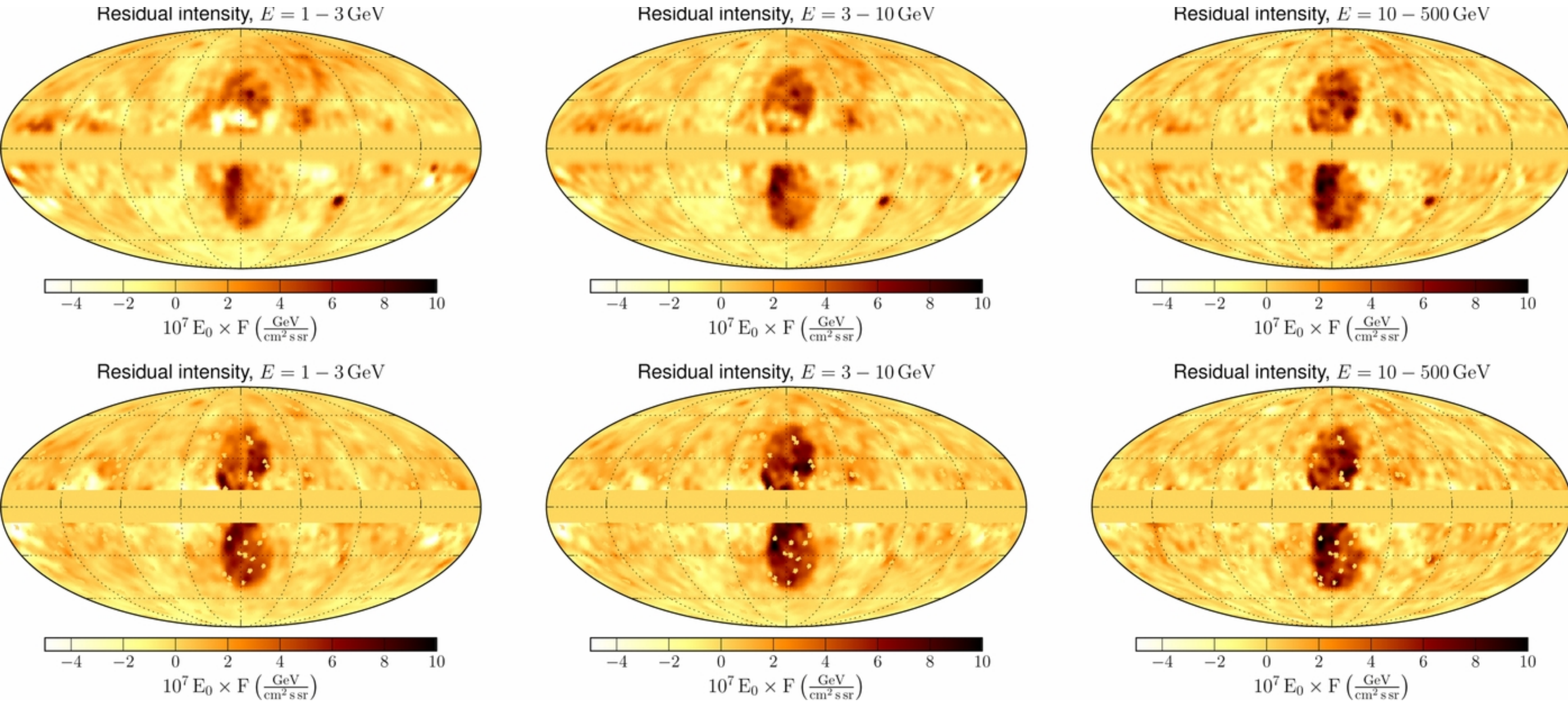


Interpretaciones:

- jet o flujo del hoyo negro Galáctico;
- vientos de SNe
- eventos de acreción por el BH Galáctico

Ackermann et al. 2014, ApJ 793, 64





$$L_{\text{burb}} = (4.4 + 2.4 - 0.9) \times 10^{37} \text{ erg/s}$$

Catálogos de Fermi-LAT

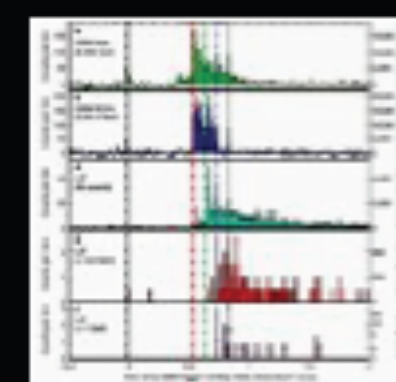
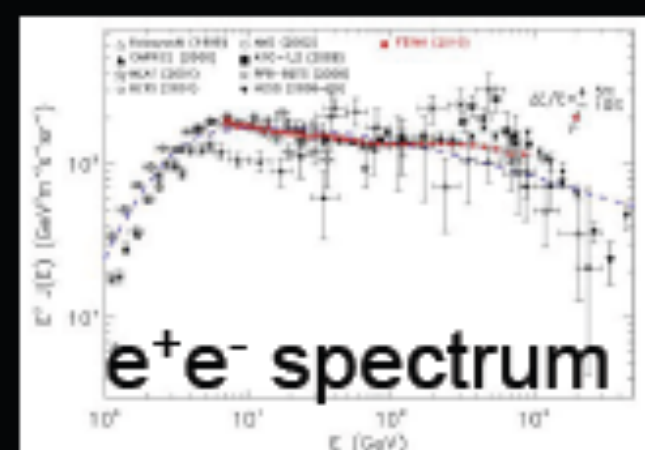
Catálogo	Rango	Flujo	Fuentes
3FGL (Acero et al. 2015)	100 MeV - 300 GeV	$F(1-100 \text{ GeV}) \gtrsim 3 \times 10^{-10} \text{ cm}^{-2} \text{ s}^{-1}$	3033
3FHL (Ajello et al. 2017)	10 GeV - 2 TeV	$F(10 \text{ GeV} - 2 \text{ TeV}) \gtrsim 3 \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$	1558
4FGL $\rightarrow$ DR4 (2024) (Abdollahi et al. 2020)	50 MeV - 1 TeV	$F(0.1-100 \text{ GeV}) \gtrsim 2 \times 10^{-10} \text{ cm}^{-2} \text{ s}^{-1}$	5098 ($\rightarrow$ 7194)

Fermi-LAT

1FGL $\rightarrow$ 4FGL-DR4; 1,2,3FHL; 1,23PC; 1 $\rightarrow$ 4LAC-DR3; FGES; FAVA; SNR; GRB;ST
Ademas de Fermi-GBM

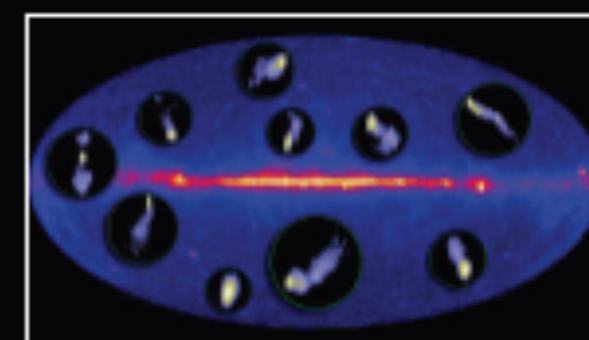
fermi.gsfc.nasa.gov

Fermi Highlights and Discoveries

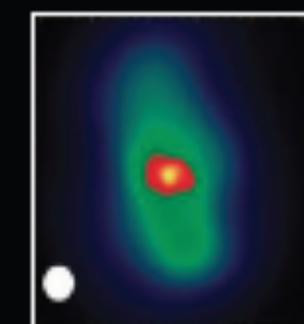


GRBs

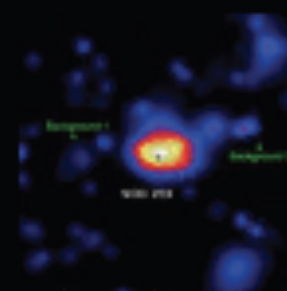
Blazars



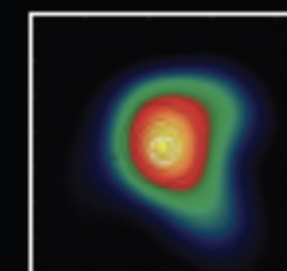
Radio Galaxies



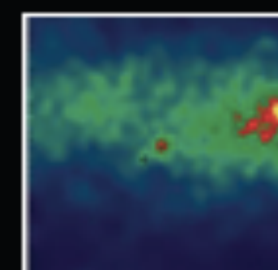
Starburst Galaxies



Globular Clusters



Nova



SNRs & PWN

γ -ray Binaries

Pulsars: isolated, binaries, & MSPs

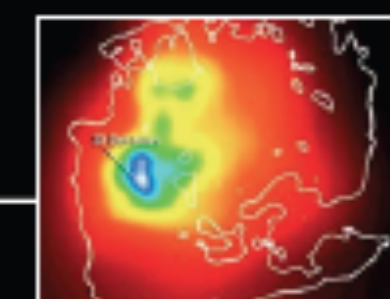
Sun: flares & CR interactions

Terrestrial γ -ray Flashes

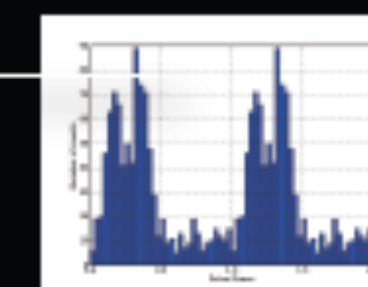
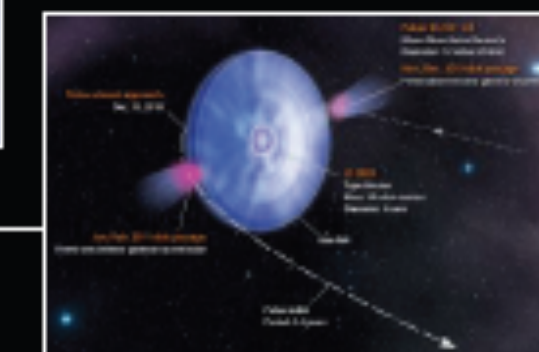
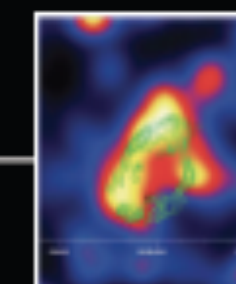
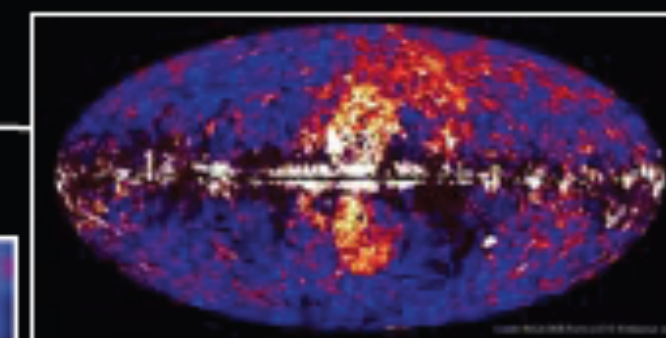


Extragalactic

LMC & SMC



Fermi Bubbles



Unidentified Sources
(577/1873)

Table 7. LAT 4FGL Source Classes

Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	231	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	10
Pulsar wind nebula	PWN	12	pwn	6
Supernova remnant	SNR	24	snr	15
Supernova remnant / Pulsar wind nebula	SPP	2	spp	90
Globular cluster	GLC	0	glc	30
Star-forming region	SFR	3	sfr	0
High-mass binary	HMB	5	hmb	3
Low-mass binary	LMB	1	lmb	1
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
BL Lac type of blazar	BLL	22	bll	1080
FSRQ type of blazar	FSRQ	42	fsrq	639
Radio galaxy	RDG	6	rdg	35
Non-blazar active galaxy	AGN	1	agn	16
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact Steep Spectrum radio source	CSS	0	css	5
Blazar candidate of uncertain type	BCU	3	bcu	1152
Narrow line Seyfert 1	NLSY1	3	nlsy1	5
Seyfert galaxy	SEY	0	sey	1
Starburst galaxy	SBG	0	sbg	7
Normal galaxy (or part)	GAL	2	gal	2
Unknown	UNK	0	unk	118
Total	...	359	...	3215
Unassociated	...	...	...	1525

Fuentes Galácticas

- pulsares
- restos de supernova
- cúmulos globulares
- regiones de formación estelar
- binarias, novas

Fuentes extragalácticas

- galaxias activas: blazares (BL + FSRQ), BCUs, radiogalaxias,
 - Seyferts
 - galaxias normales y starburst
- + GRBs

Desconocidas, no asociadas

NOTE—The designation ‘spp’ indicates potential association with SNR or PWN. Designations shown in capital letters are firm identifications; lower case letters indicate associations.

3.3. Telescopios Cherenkov atmosféricos



Radiación Cherenkov

- ▶ La radiación Cherenkov (Čerenkov) se da cuando una partícula cargada viaja más rápido que la luz en un medio, $v > c/n$.
- ▶ Está restringida a un cono de apertura $\cos \theta = 1/\beta n$.
- ▶ La emisión por unidad de longitud es,

$$\frac{dE}{d\ell} = \frac{2\pi e^2 \nu}{c^2} \left[1 - \frac{1}{\beta^2 n^2(\nu)} \right].$$

	n	Umbral (γ)	$\theta(^{\circ})$	$dE/d\ell$ (eV/cm)
aire	1.00029	40.8	1.4	0.34
agua	1.335	1.5	41.2	327

Gamma-ray astronomy

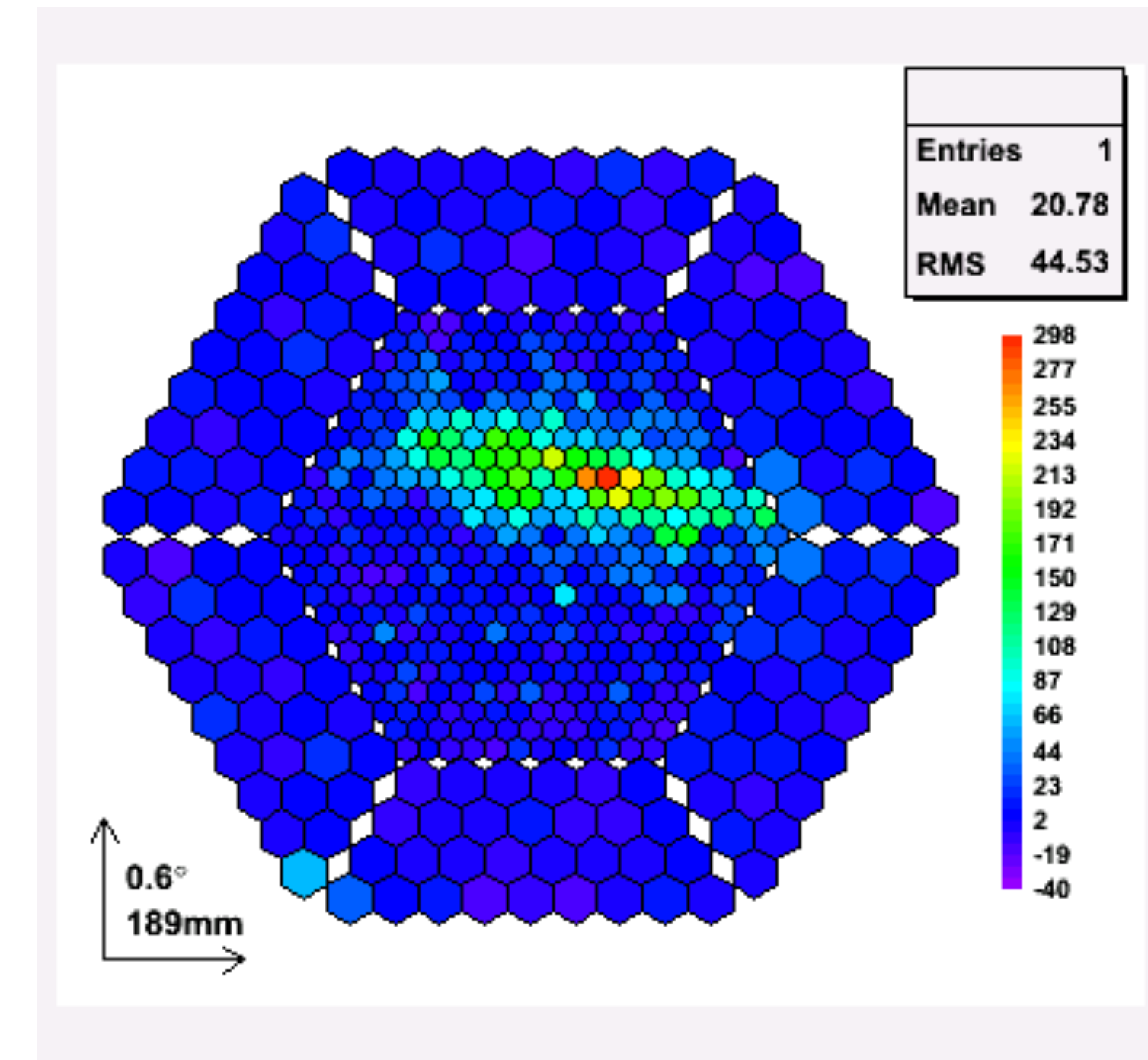
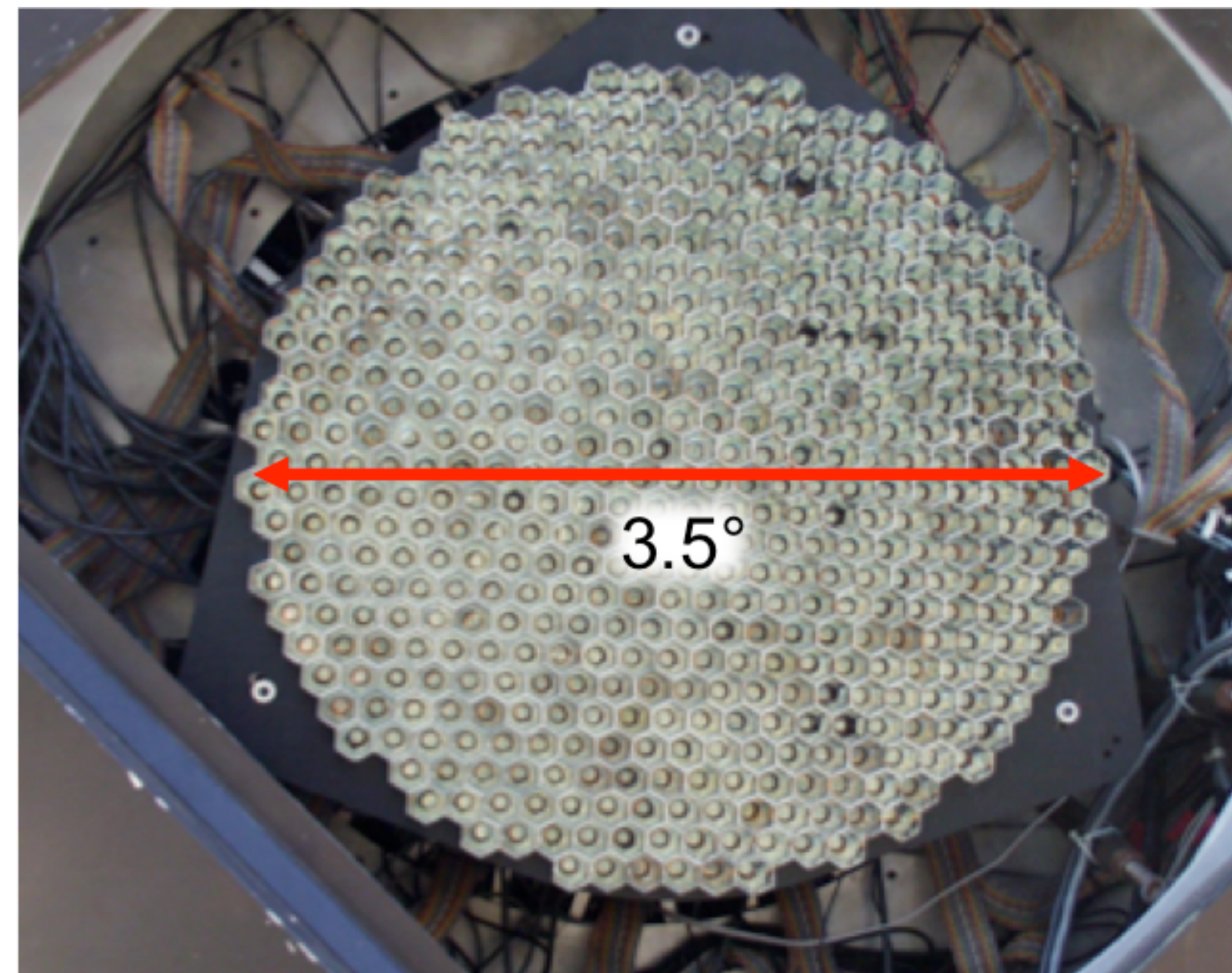
1947 Blackett estimates the contribution of cosmic-ray-induced **Cherenkov** light to be 0.01% of the total intensity of the night sky (general flux of cosmic rays)

1953 Bill Galbraith and John Jelley detect Cherenkov radiation from extended air showers with a dustbin, a 60 cm diameter mirror and a PMT at its focus in coincidence with a nearby Geiger-Müller array. They later confirm it is Cherenkov light in measurements at the Pic du Midi.



3.3. Telescopios Cherenkov atmosféricos

- Operan detectando la luz Cherenkov producida por cascadas de partículas secundarias en la atmósfera.
- Se estudia la imagen de la cascada ($\Delta t \sim \text{ns}$) para rechazar hadrones.



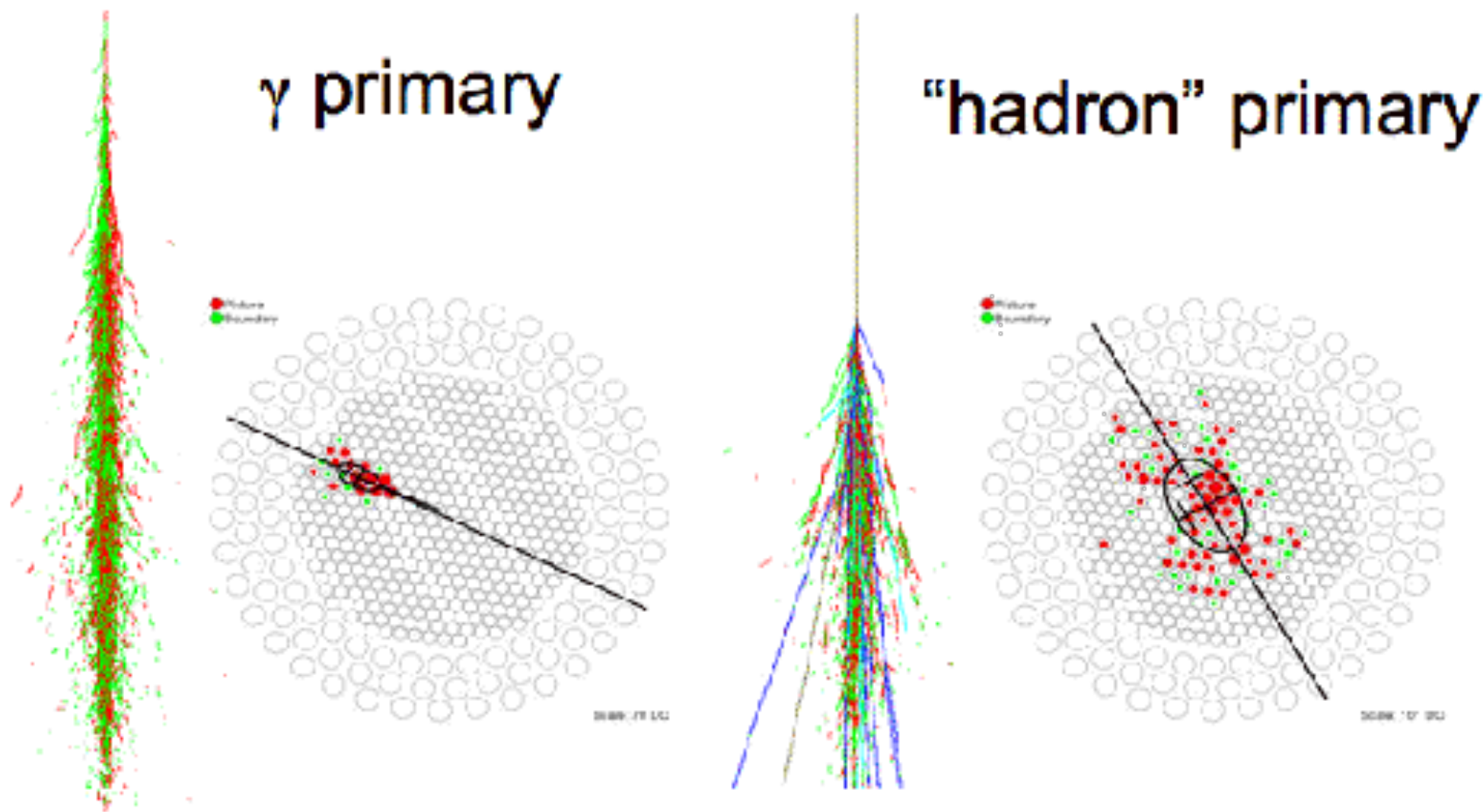


FIGURE 2. The VERITAS observatory, the newest of the third generation IACT observatories, saw first light in April, 2007. Note that VERITAS is in the exact same location as the telescopes shown in Figure 1. Each of the four telescopes has an aperture of 12m (collection area of 106m²) and a camera with 499 pixels.

TABLE 1. Major Existing ACT Facilities

Observatory	Elevation (km)	Telescopes #	Mirror Area (m ²)	FoV (degrees)	First Light	Threshold (GeV)	Sensitivity (% Crab)
H.E.S.S.	1.8	4	428	5	2003	100	0.7
VERITAS	1.3	4	424	3.5	2007	100	1
MAGIC	2.2	1	236	3.5	2005	50	1.6
HAGAR	4.3	7	31	3	2008	60	9
Whipple	2.3	1	75	2.2	1985	400	10
CANGAROO III	0.1	3(4)	172 (230)	4	2006	400	10
PACT	1.1	24	107	3	2001	750	11
TACTIC	1.3	1	10	2.8	2001	1500	70
SHALON	3.3	1	11.2	8	1996	1000?	?

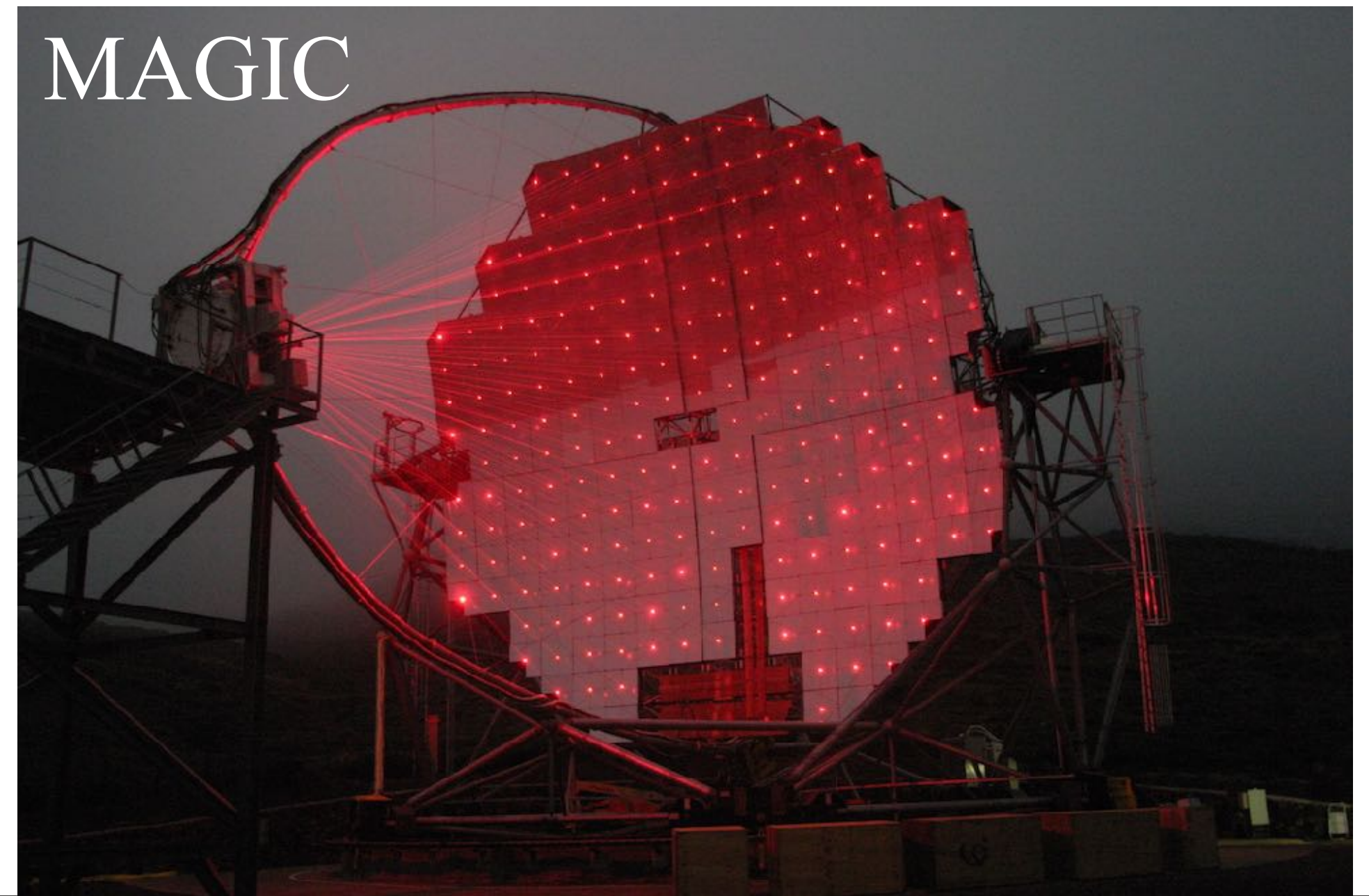


Weekes - astro-ph/0811.1197

HESS



MAGIC



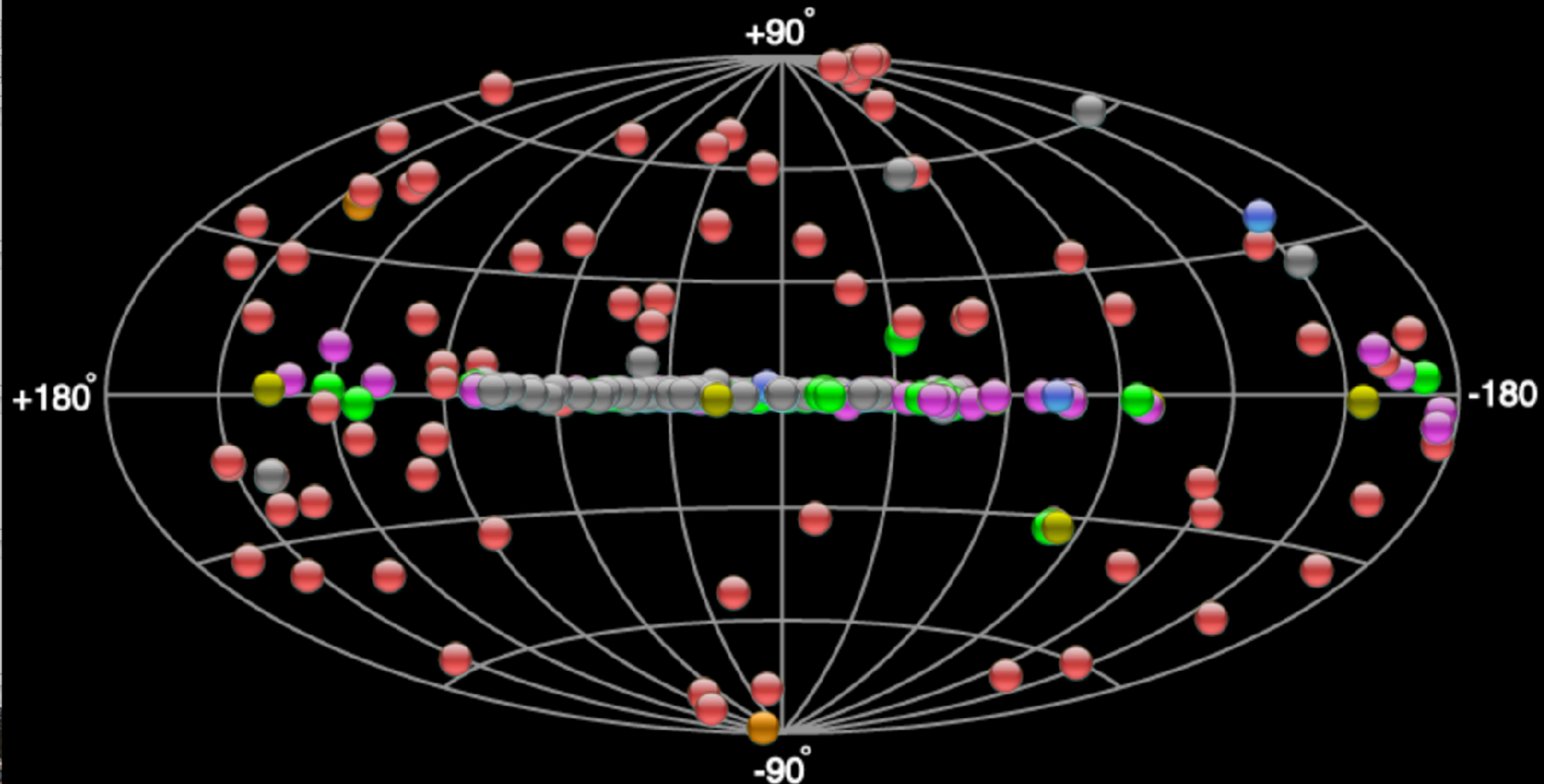
VERITAS



FACT



Welcome to TeVCat!



Try TeVCat 2.0 Beta!

Table Control

Map Control

Tools

Legende..

- Extended TeV Halo, 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, Superbubble
- DARK, UNID, Other
- Binary, XRB, PSR, Gamma BIN

Export Black

Export White



Inicio / Twitter

Mail - Alberto carraminan

Recibidos - acarrami@gm

Inicio | LXV Congreso Nac

EL PAÍS Edición América:

Atmósfera - OneDrive

Welcome to TeVCat, an Or

No seguro

tevc.uchicago.edu

Barra de marcadore...

Watch 72 | A Gather...

SAT - trámites y ser...

Facebook

earth :: a global ma...

HIGH ALTITUDE WA...

NASA Mars

Amazon.com: First...

OperaDef

[\[What's New?\]](#)

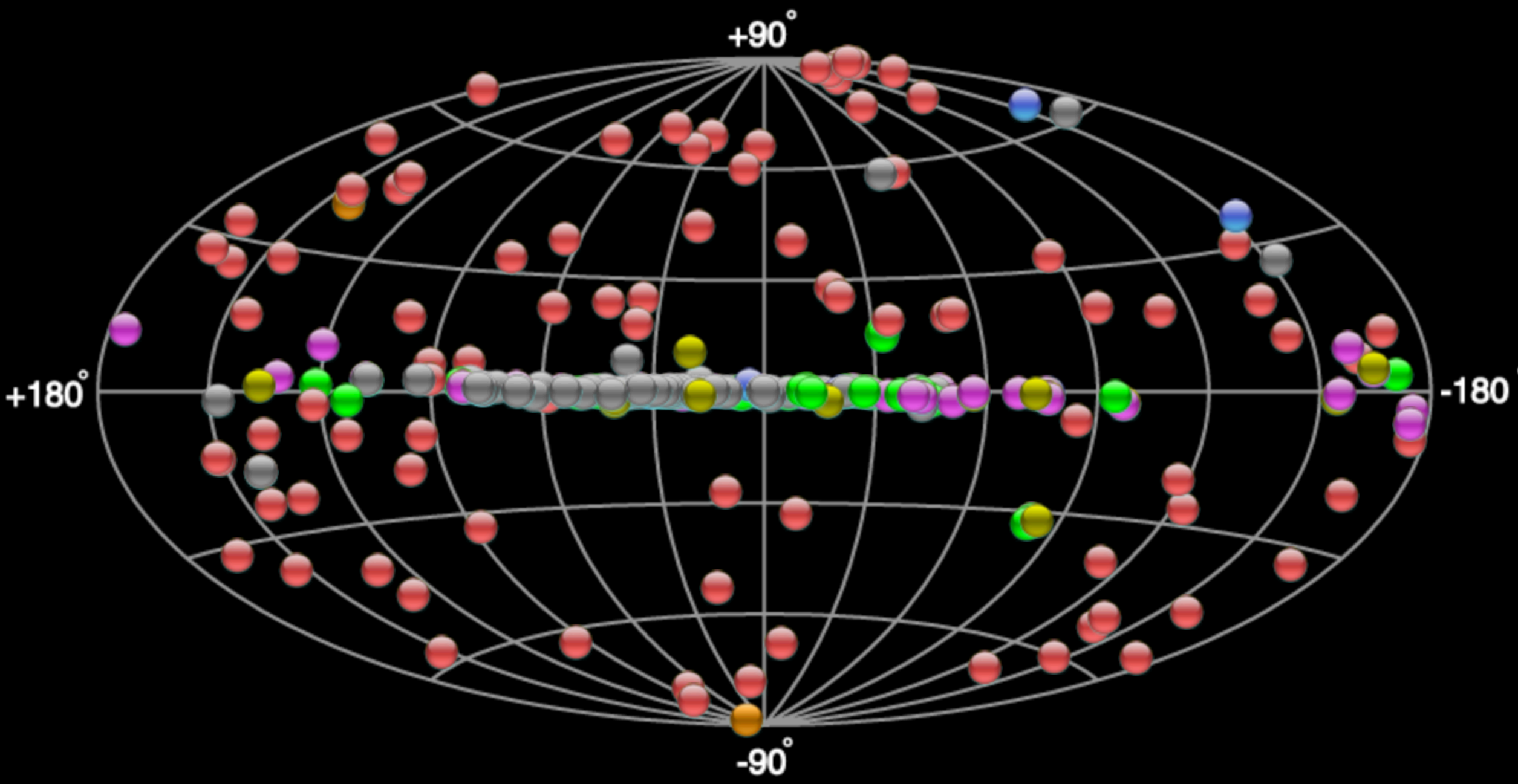
[\[TeVCat FAQ\]](#)

[\[TeV Astrophysics\]](#)

[\[Bug Report or Feature Request\]](#)

[\[Login\]](#)

Welcome to TeVCat!



Try TevCat 2.0 Beta!

Table ControlMap ControlToolsLege...

Table Columns

☐ TeVCat Name

☒ Name

☒ RA

☒ Dec

☒ Type

☐ Discoverer

☒ Date

☒ Distance

☒ Catalog

Select

Catalogs

Default Catalog

Newly Announced

Other Sources

Source Candidates

☒ Filter by Catalog



Select AllUnselect AllPlot SelectedPlot AllPlot UnSelectedFilter SelectedClear Filters

Reg Exp: OK

Name	RA	Dec	Type	Date	Dist	Catalog
GRB 180720B	00 02 07.6	-02 56 06	GRB	2019.05	z = 0.654	Default Catalog
CTA 1	00 06 26	+72 59 01.0	PWN	2011.10	1.4 kpc	Default Catalog
SHBL J001355.9-185406	00 13 52.0	-18 53 29	HBL	2010.11	z = 0.095	Default Catalog
Tycho	00 25 21.6	+64 07 48	Shell	2010.05	3.5 kpc	Default Catalog
KUV 00311-1938	00 33 36	-19 21 00	HBL	2012.07		Default Catalog
1ES 0033+595	00 35 16.8	+59 47 24.0	HBL	2011.10	z = 0.467	Default Catalog
NGC 253	00 47 32.54	-25 17 25.4	Starburst	2009.07	2500 kpc	Default Catalog
GRB 201216C	01 05 28.88	+16 30 58.0	GRB	2020.12	z = 1.1	Newly Announced



AAE @ INAOE - 2024

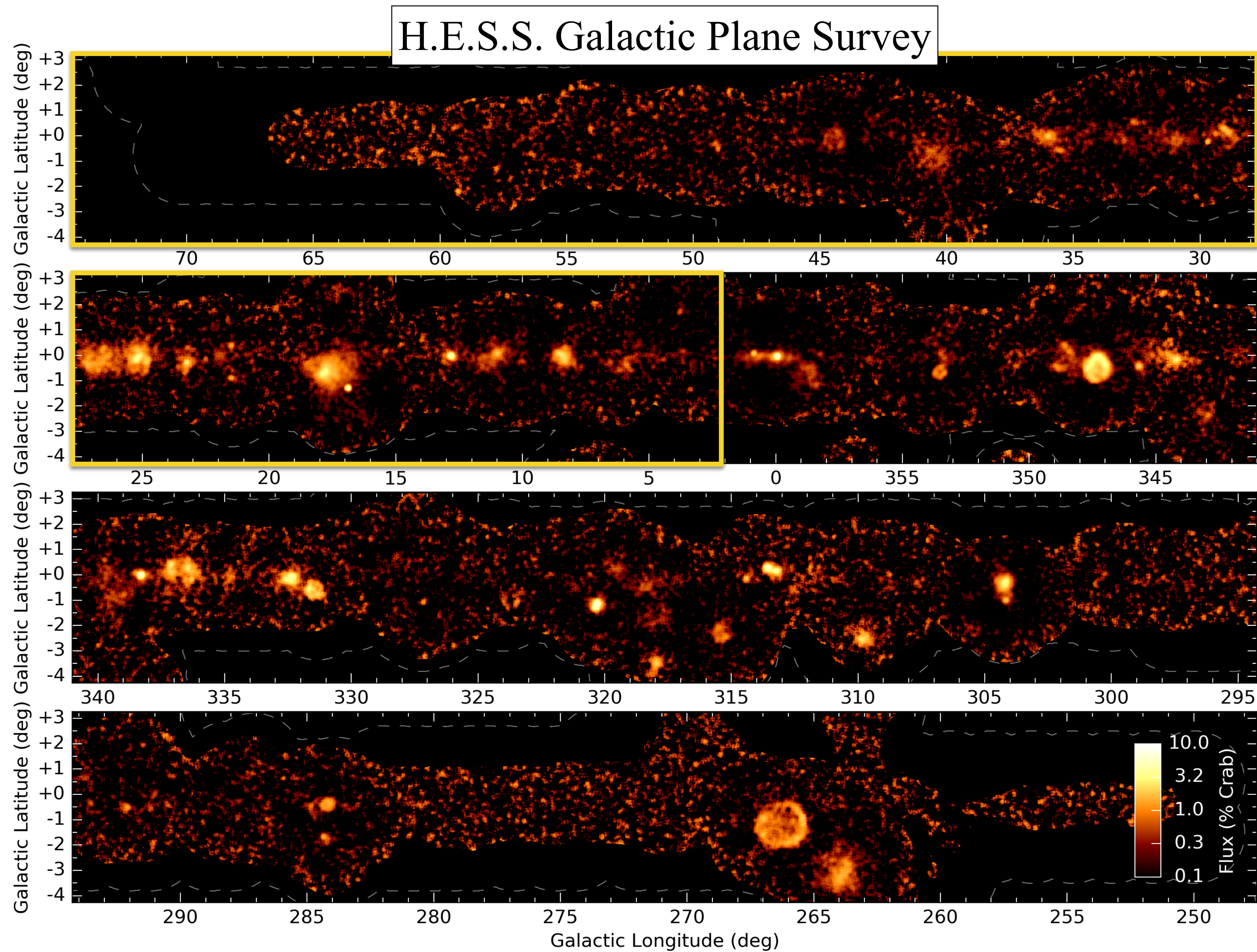


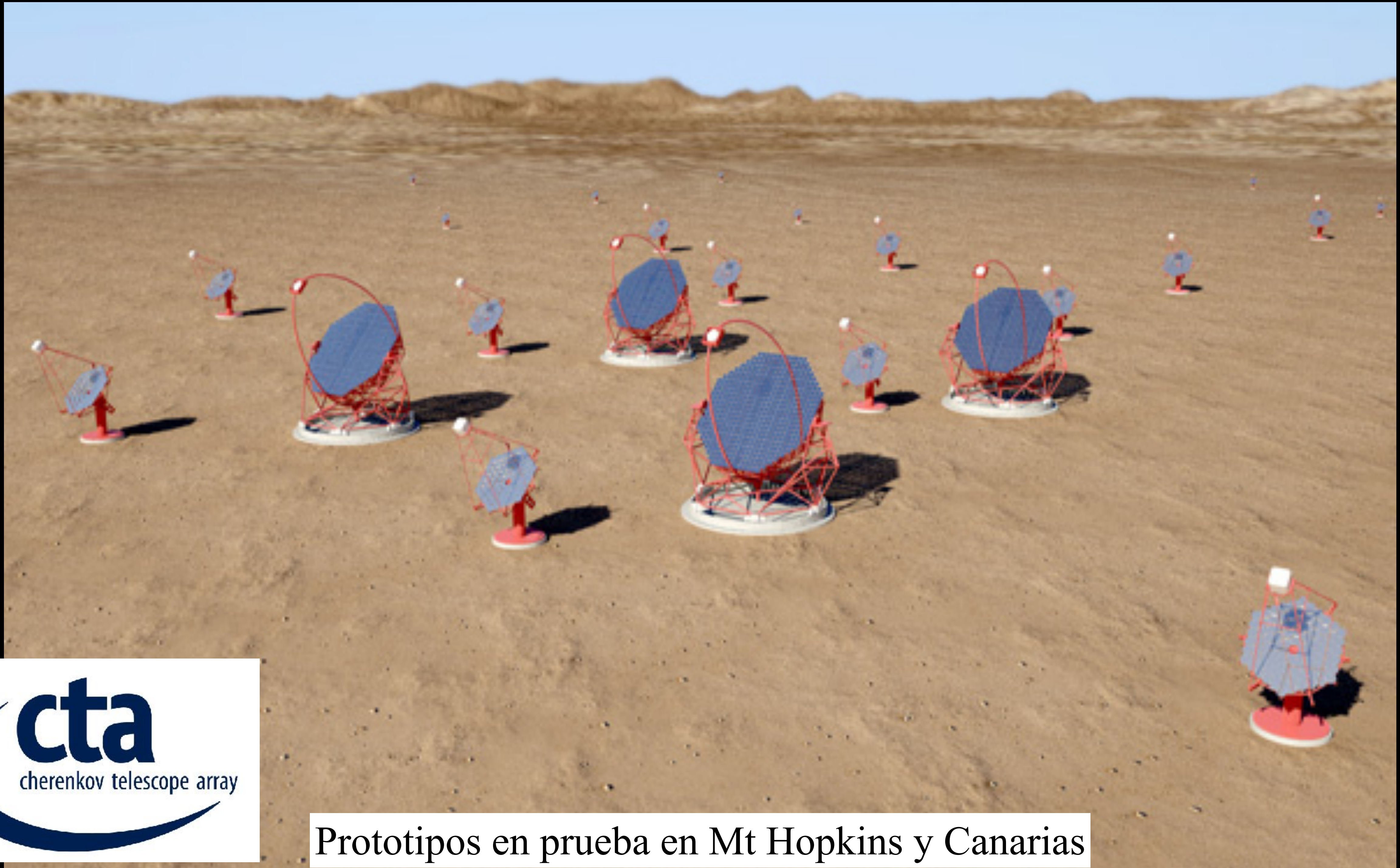
39

H.E.S.S. Galactic Plane Survey

- H.E.S.S. GPS (A&A 612, ..., 2018):
 - 2700h of H.E.S.S. Phase I data taken between 2004 and 2013.
 - Galactic Longitudes: 260° to 65° ; Latitudes: $|b| < 3^\circ$
 - Average sensitivity $\sim 1.5\%$ Crab in the 0.2 - 100 TeV range.
- 78 TeV γ -ray sources:
 - 31 firmly identified: 8 SNR + 12 PWN + 8 composite + 3 binaries
 - of the 47 remaining, 36 potential associations with cataloged objects, mostly PWN and γ -ray pulsars.

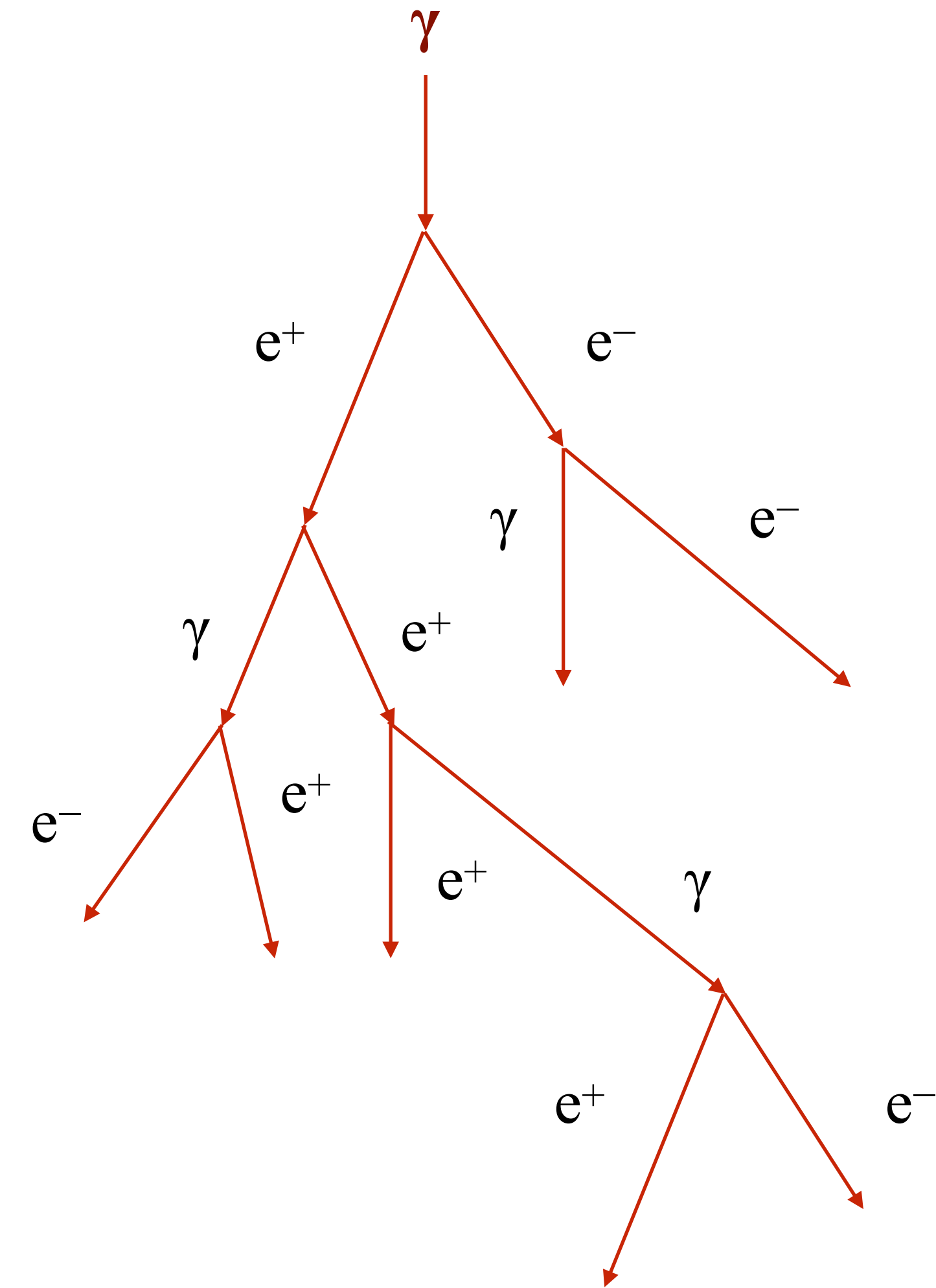
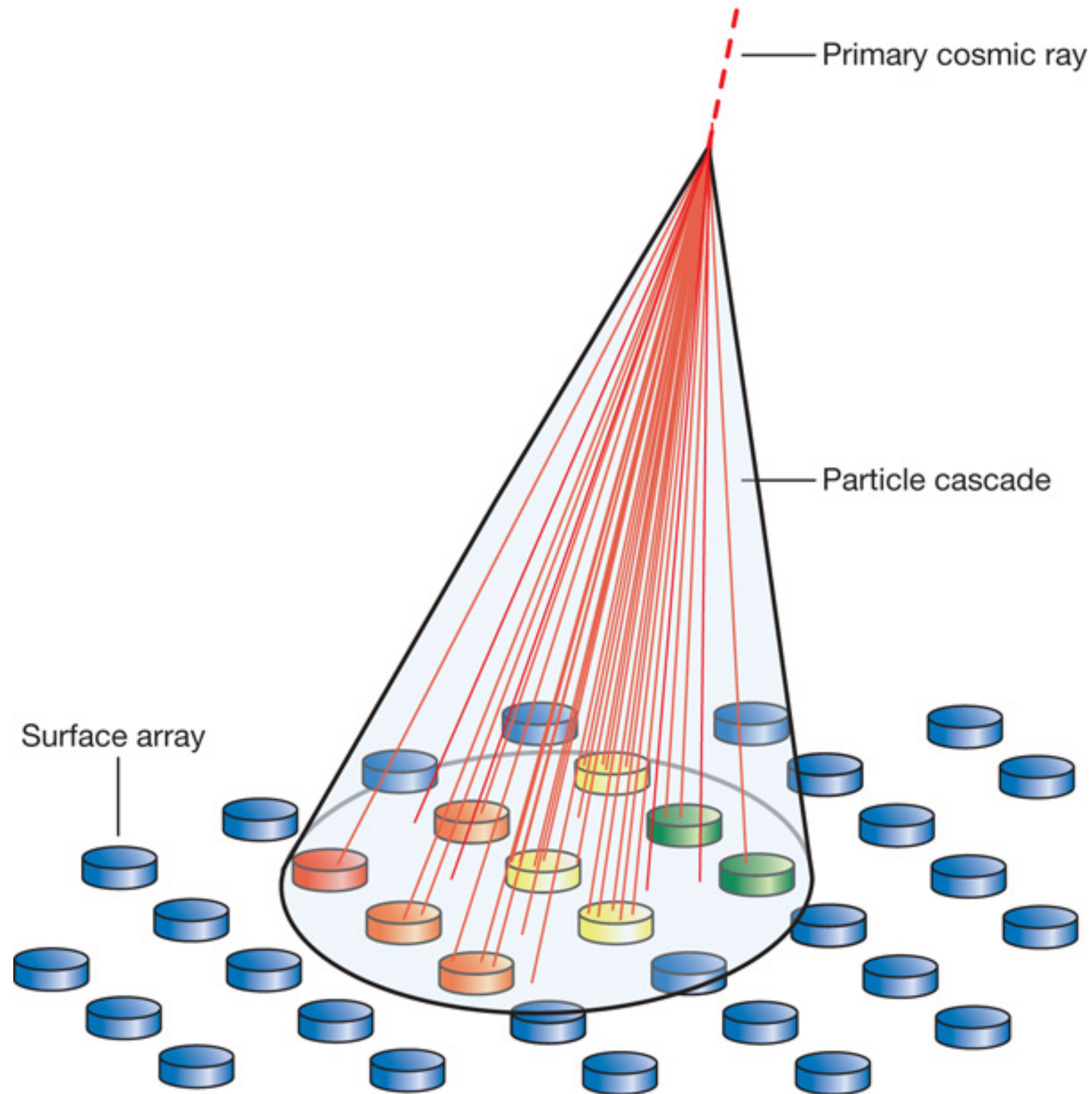
H.E.S.S. Collaboration, A&A 612, A1 (2018)





Prototipos en prueba en Mt Hopkins y Canarias

3.4. Detectores de superficie



HAWC

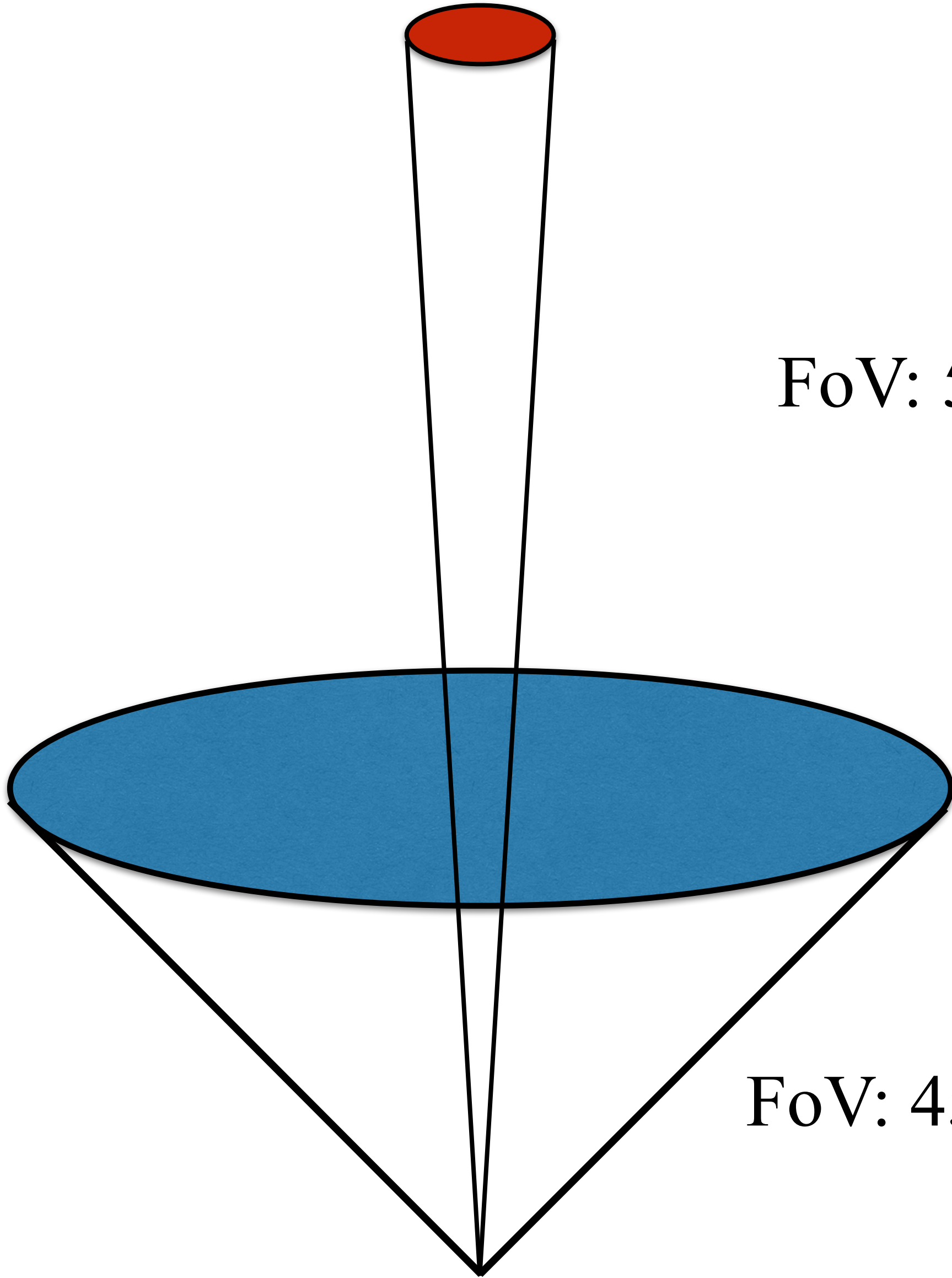
Kascade

Tibet - Yang Ba Jing

Desarrollados originalmente para el estudios de rayos cósmicos

Pueden estudiar fuentes de rayos gamma mediante técnicas de discriminación fotón / hadrón.

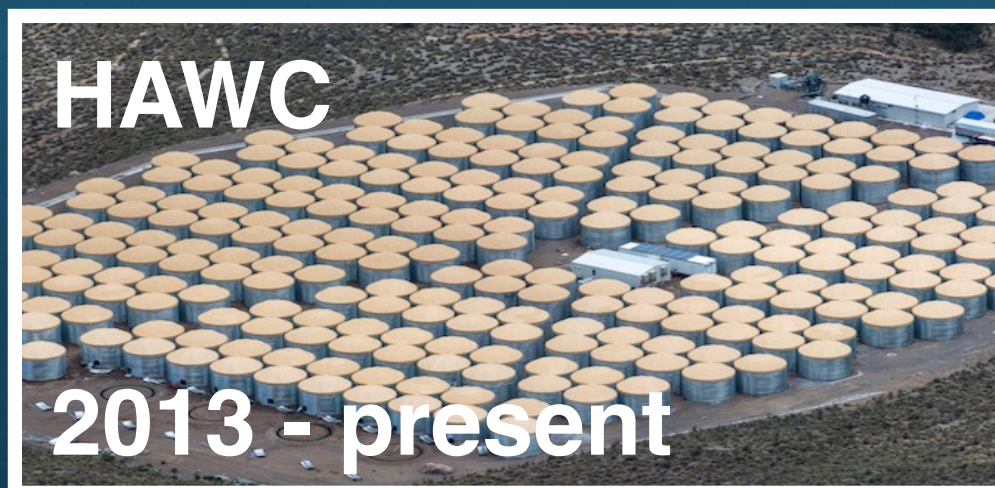
Telescope Array (Utah)

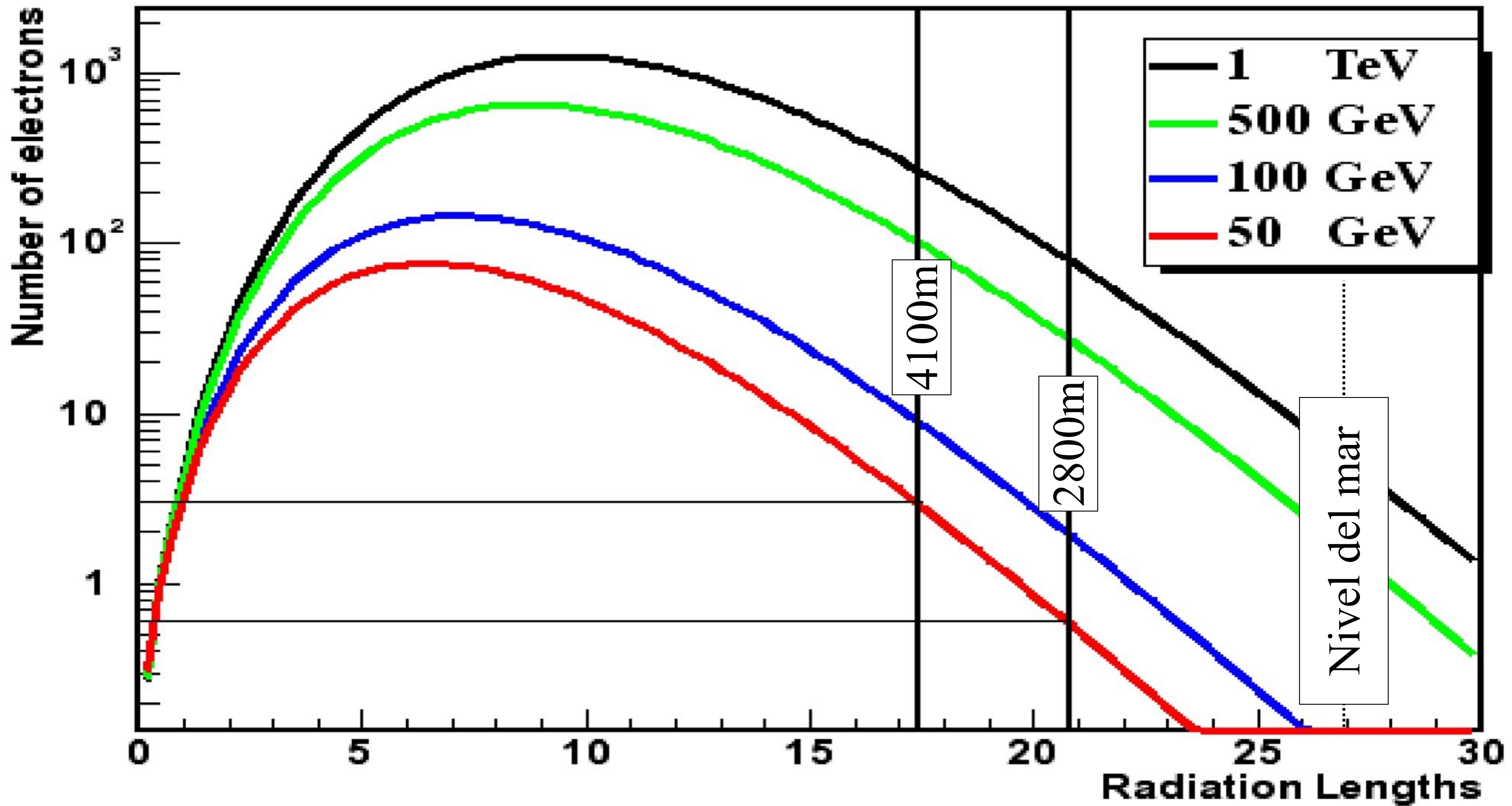


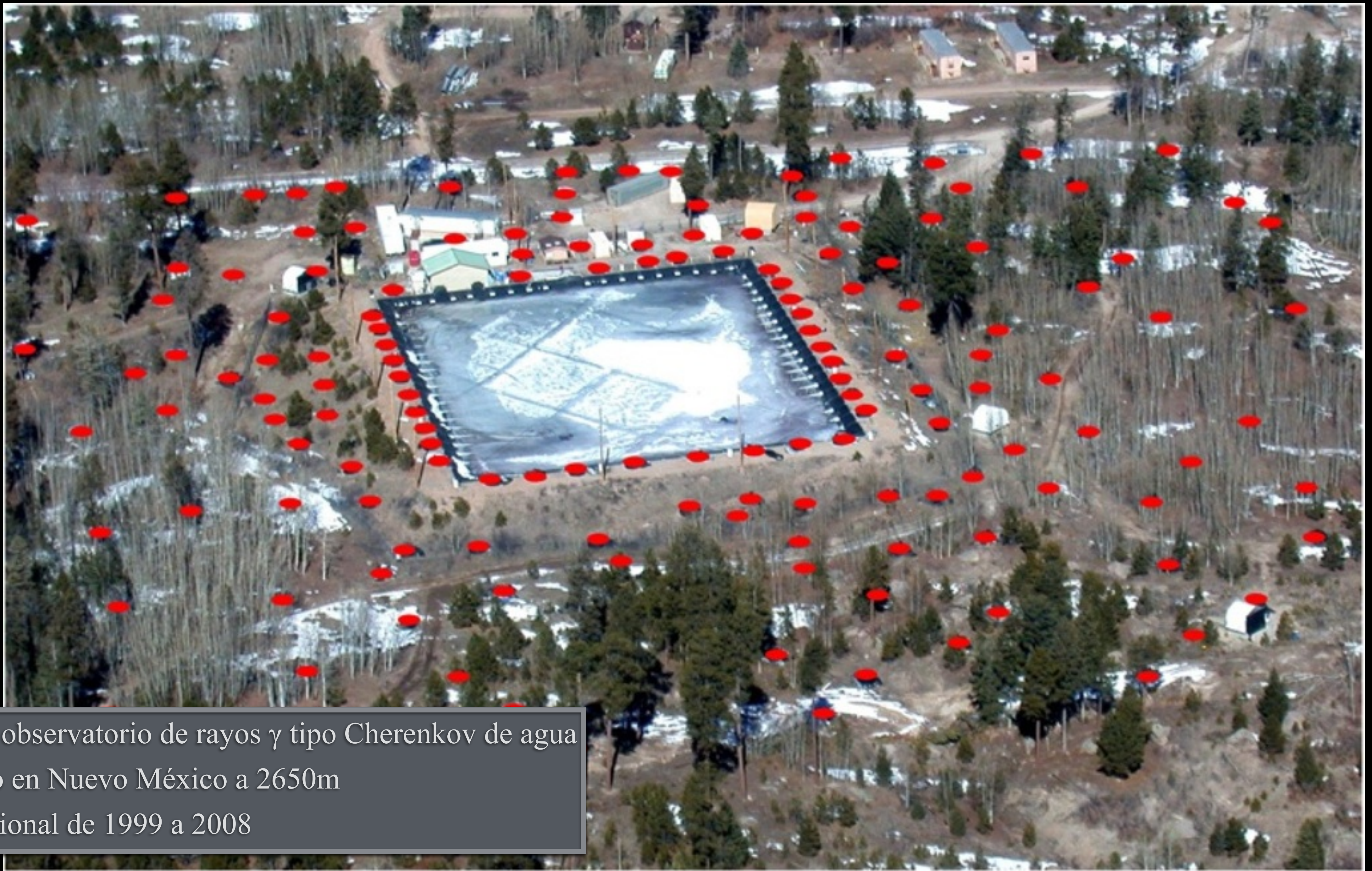
ACTs
FoV: 5° , duty cycle 25%, 1 Crab/(15 min)^{1/2}

EAS
FoV: 45° , duty cycle 95%, 1 Crab/(6h transit)^{1/2}

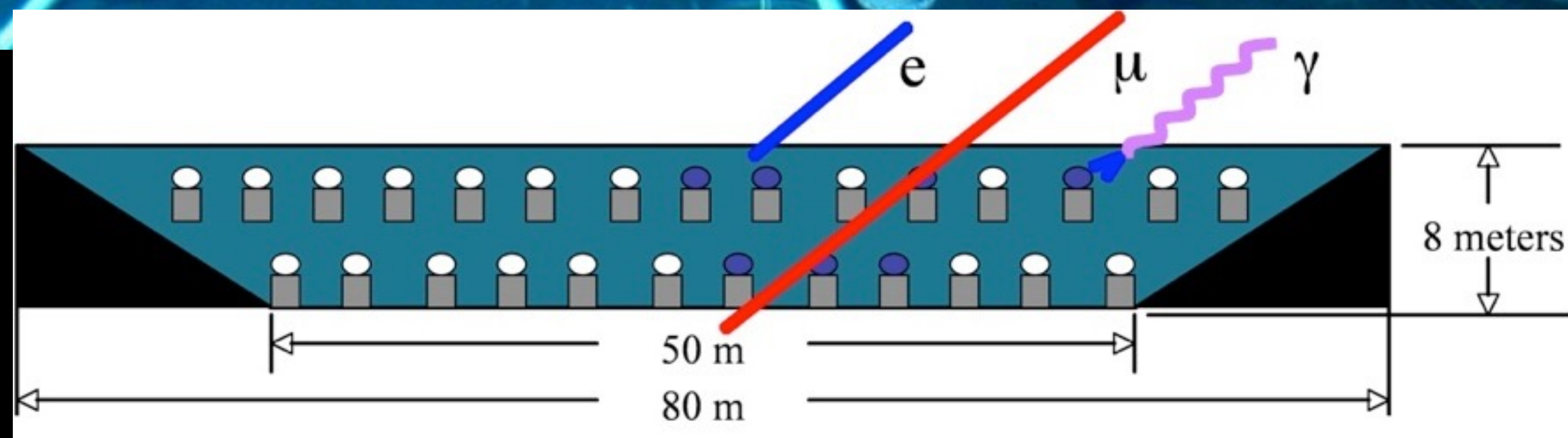
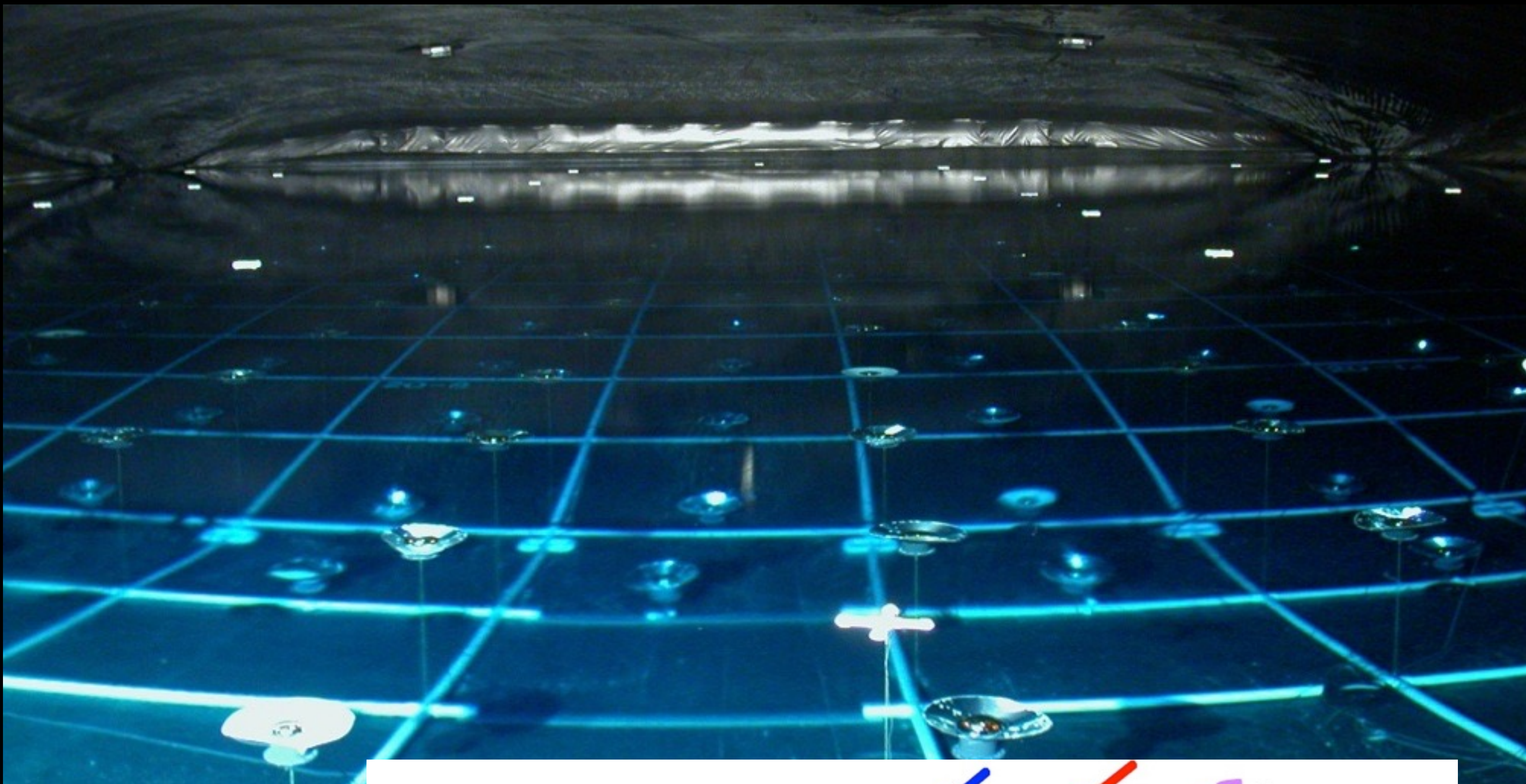
Observatorios de rayos y a gran altura

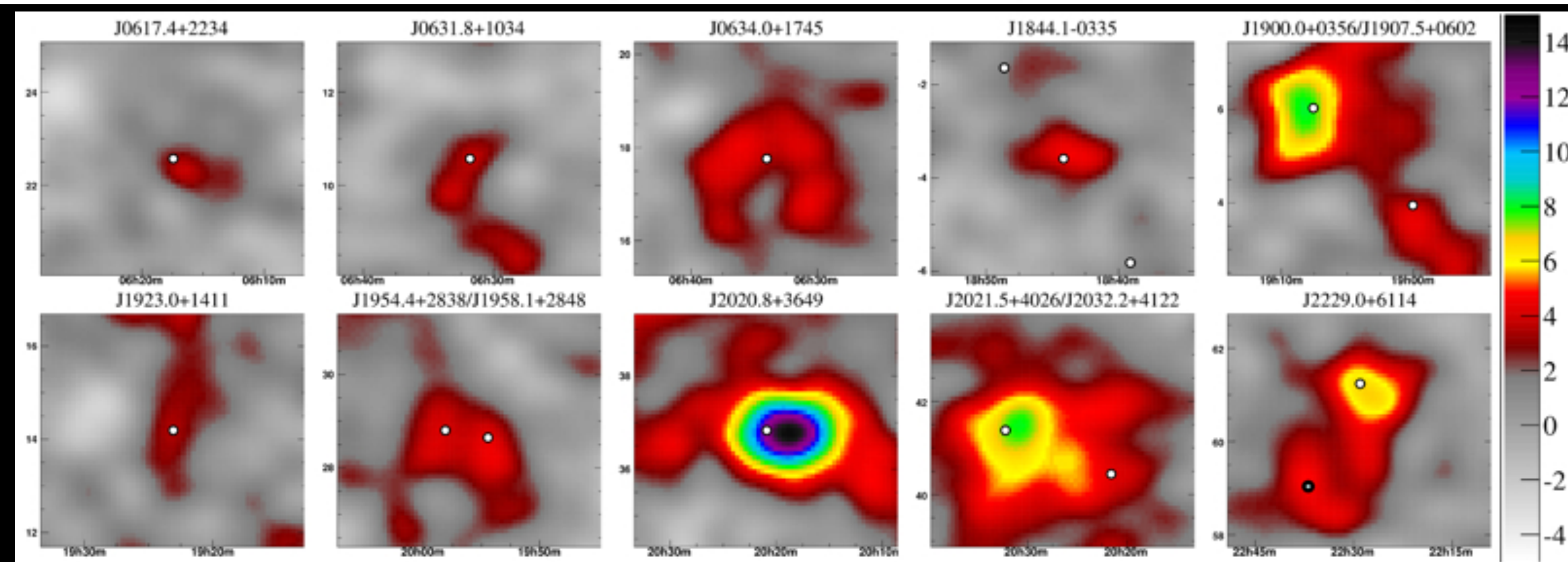
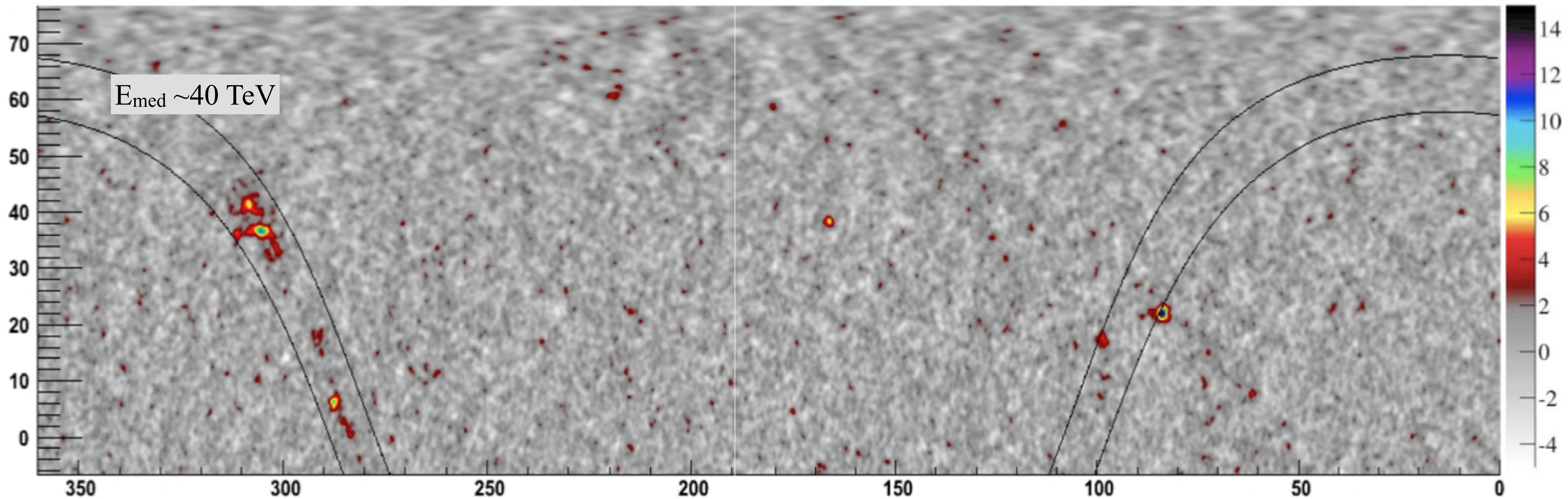






- Primer observatorio de rayos γ tipo Cherenkov de agua
- Situado en Nuevo México a 2650m
- Operacional de 1999 a 2008









Pico de Orizaba
“Citlaltepetl”
5610m

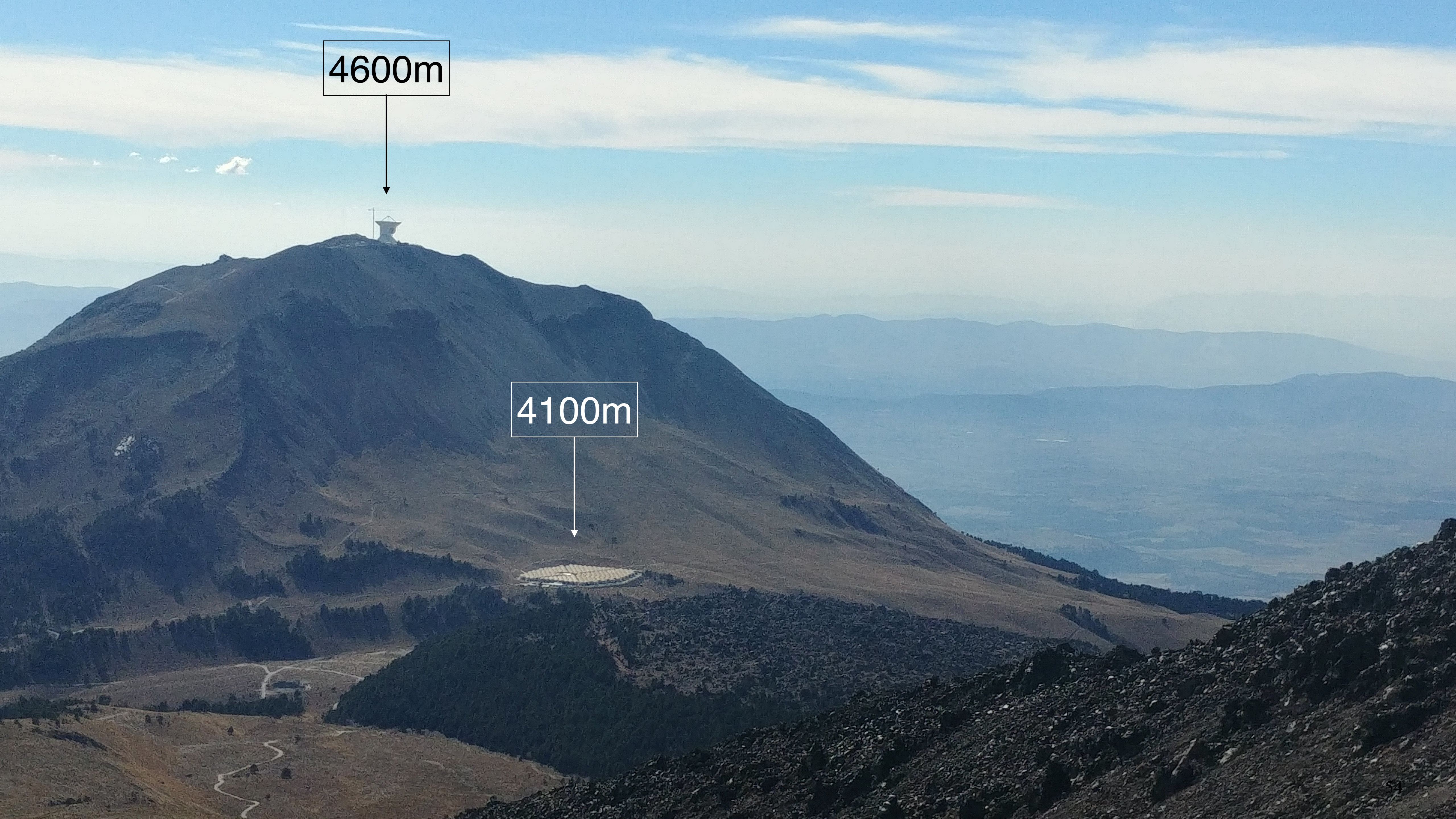
Sierra Negra
“Tliltepetl”
4582m

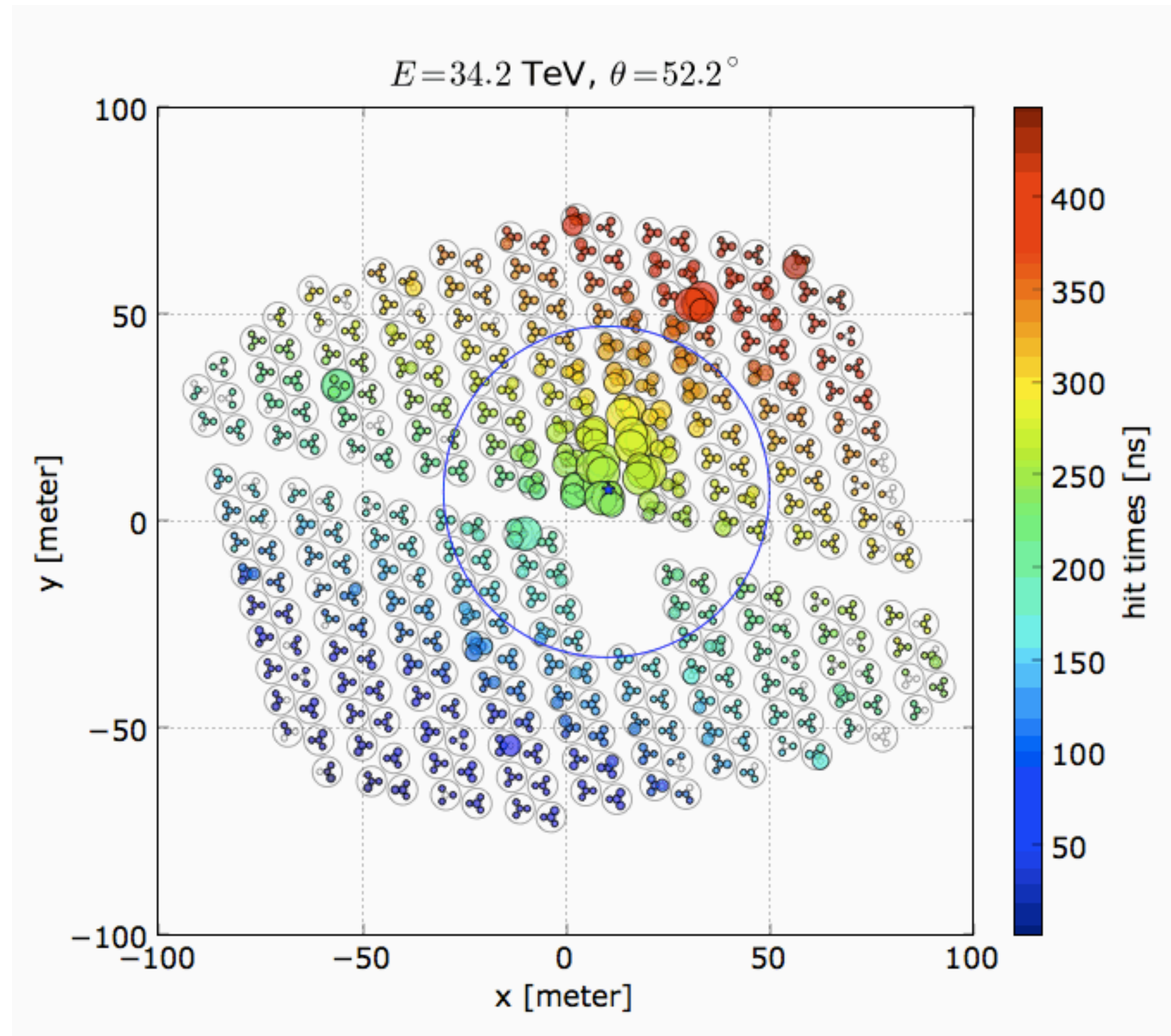
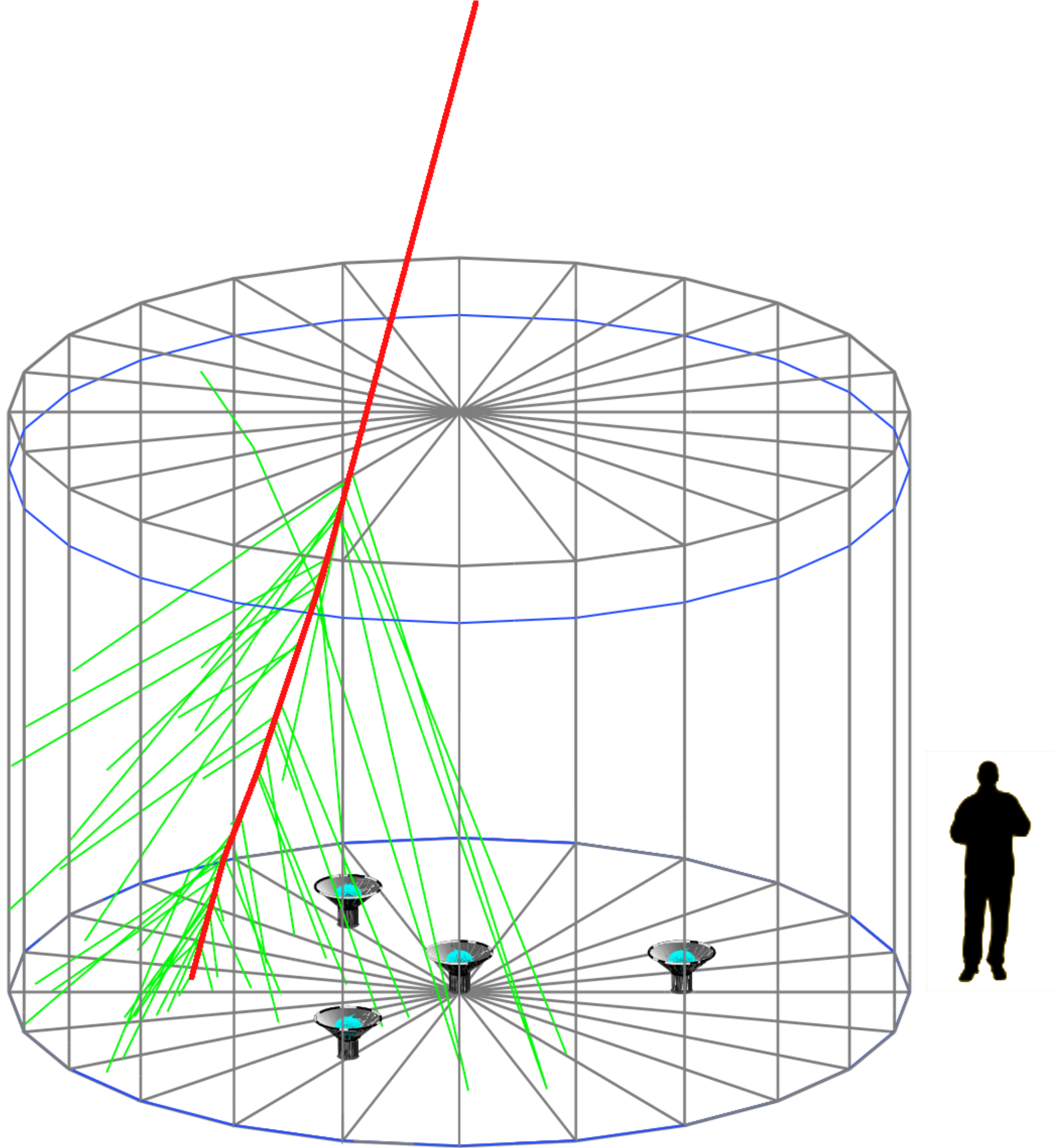
Latitud 19°N, Longitud = 97°W.

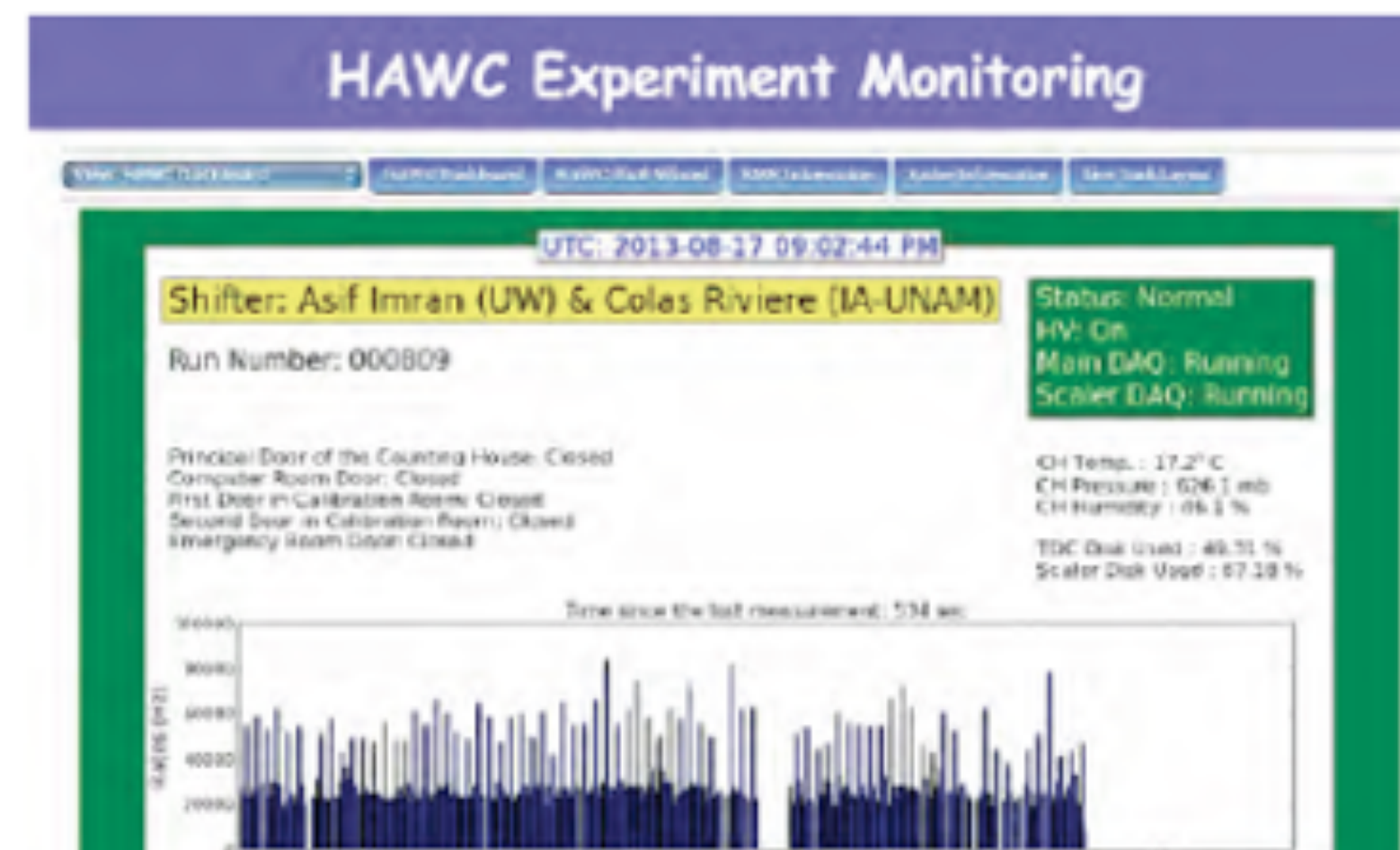
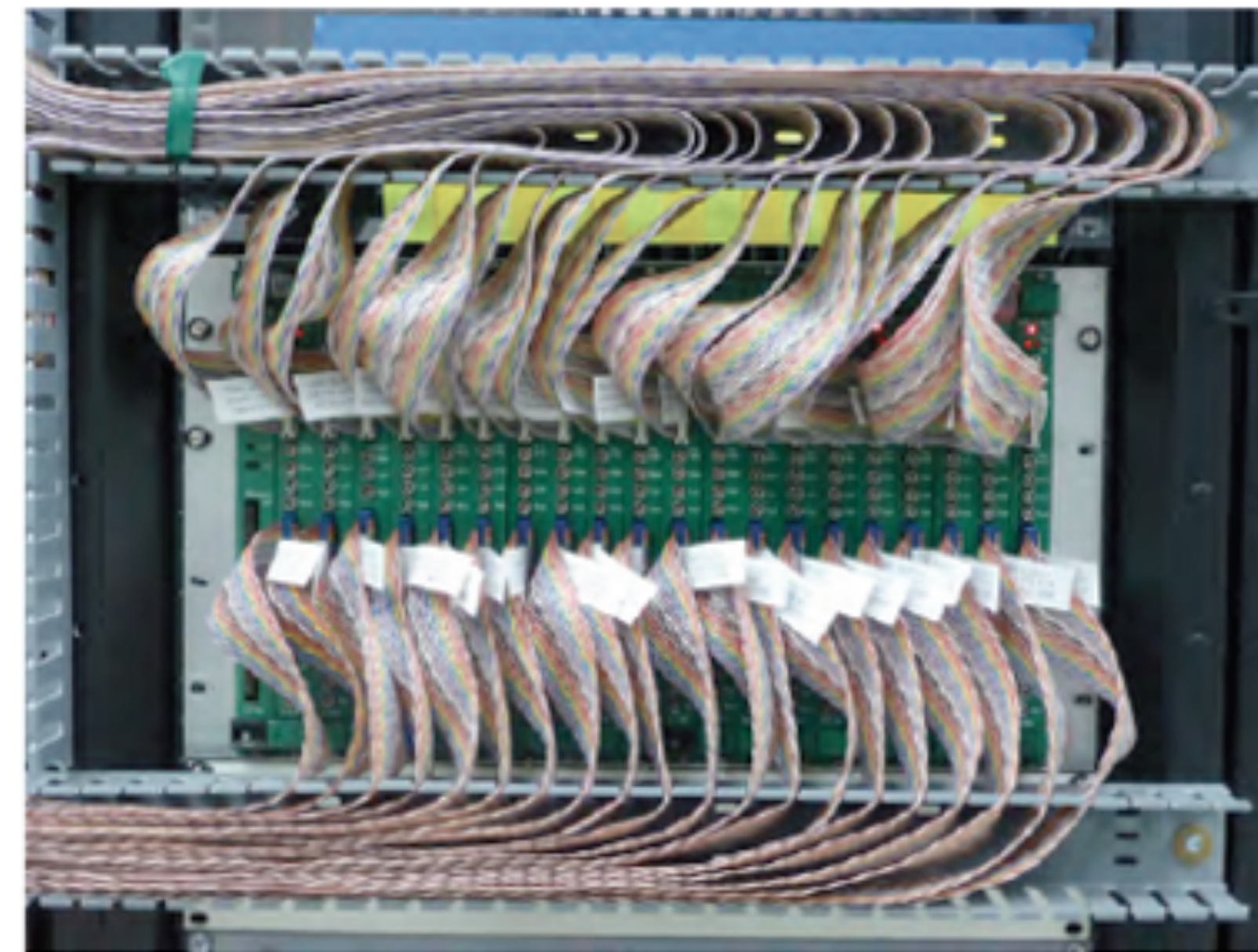
4600m



4100m





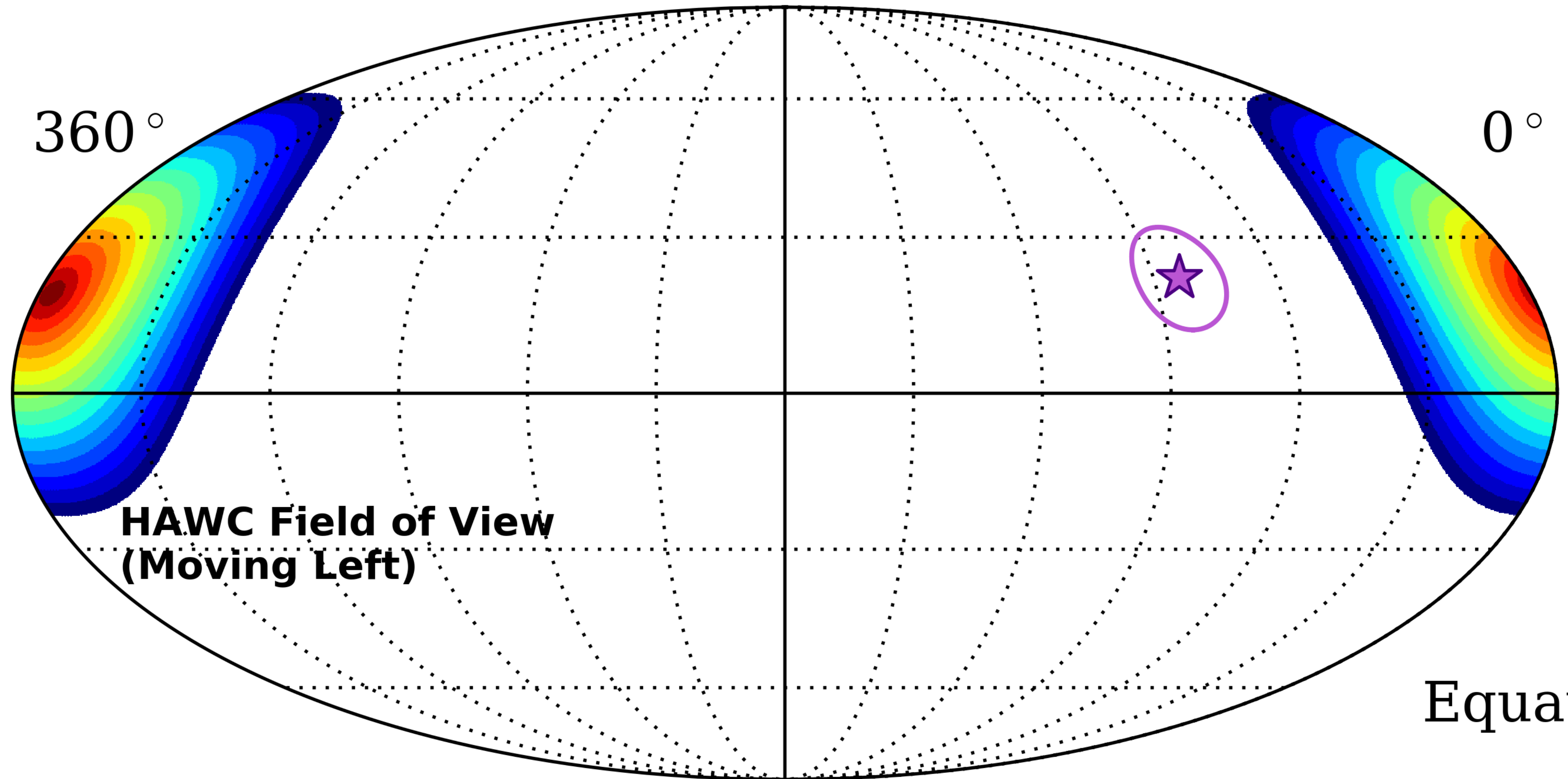


HAWC registra 20,000 rayos cósmicos por segundo, generando 2 Terabytes de datos cada día - todos los días.

2015-12-26 00:00:00 [UTC]

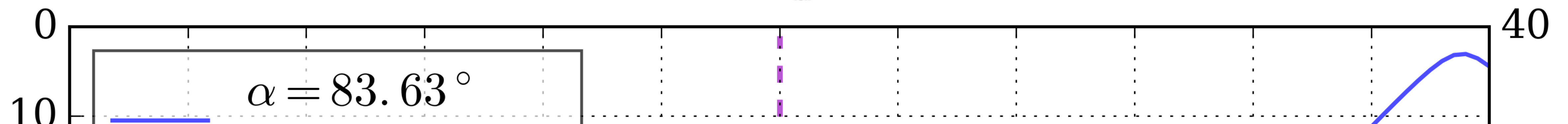
360°

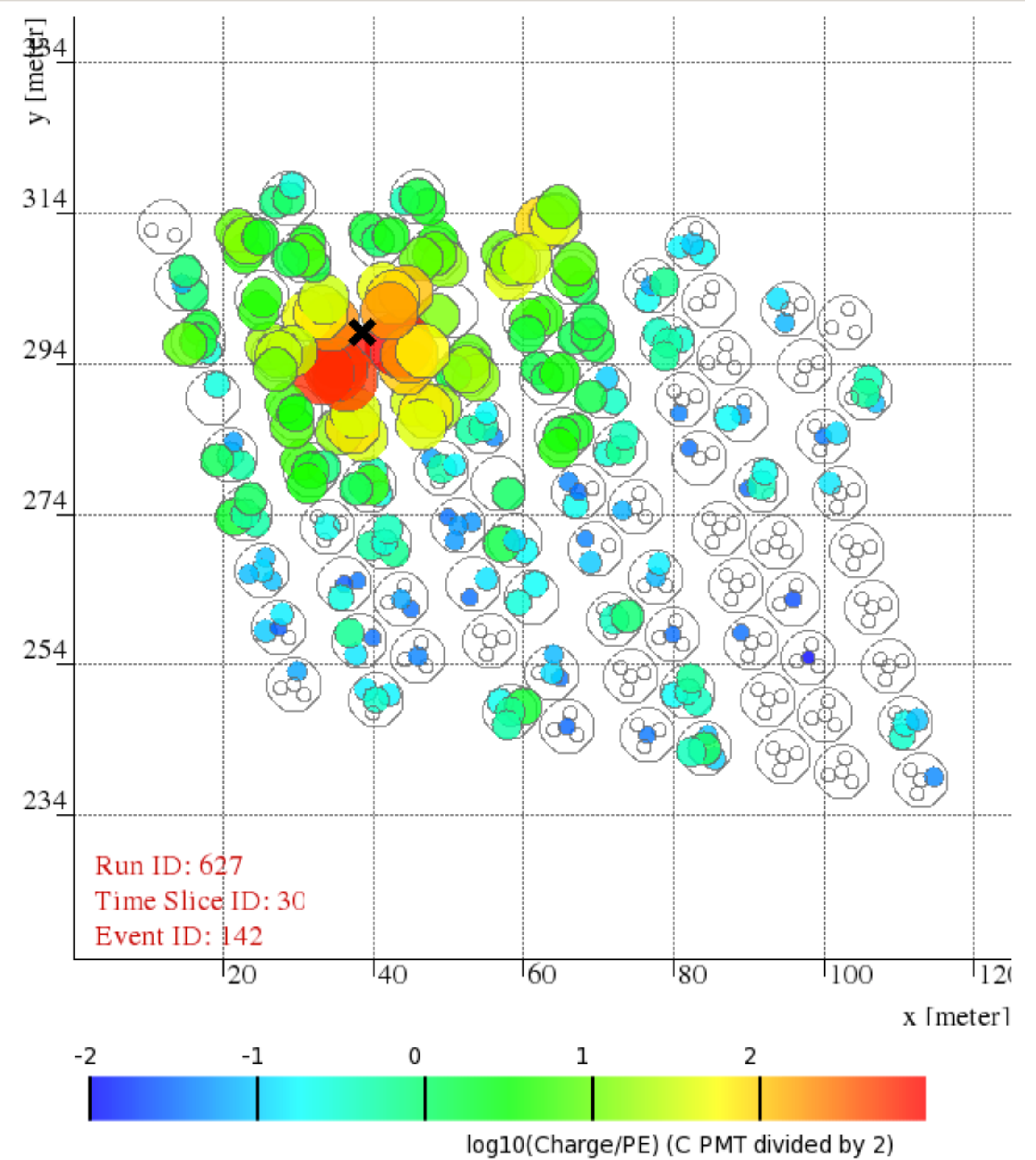
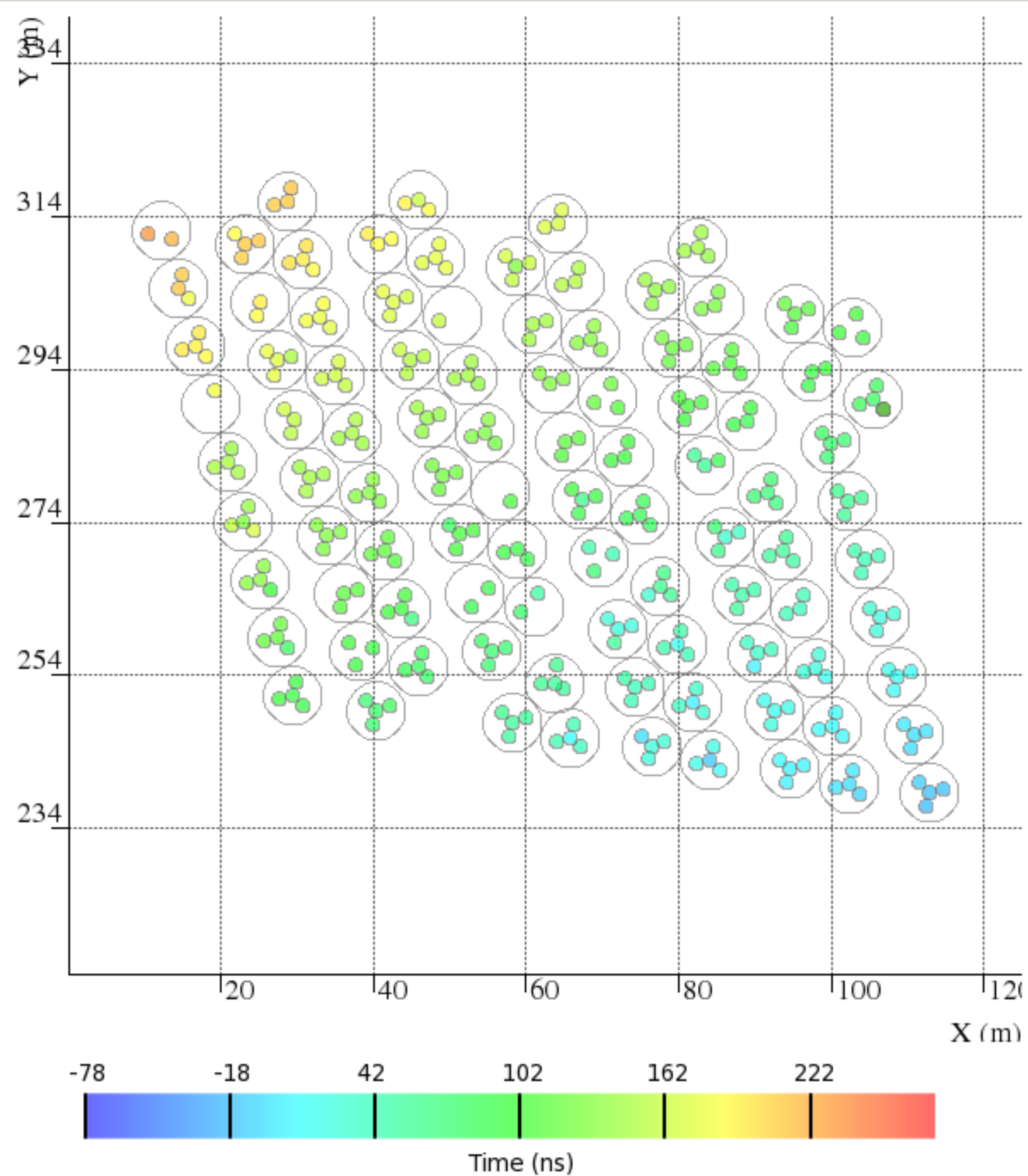
0°

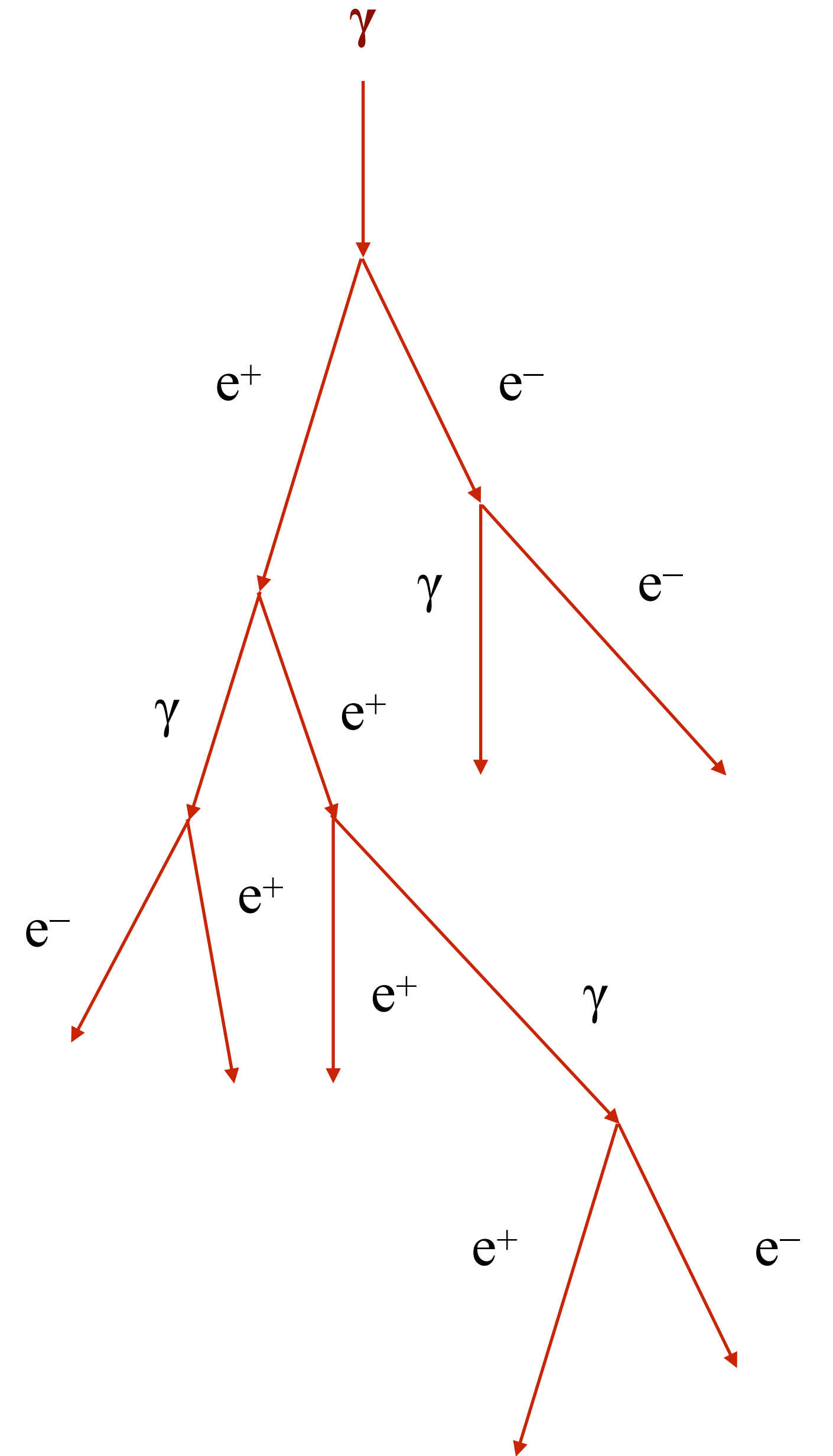
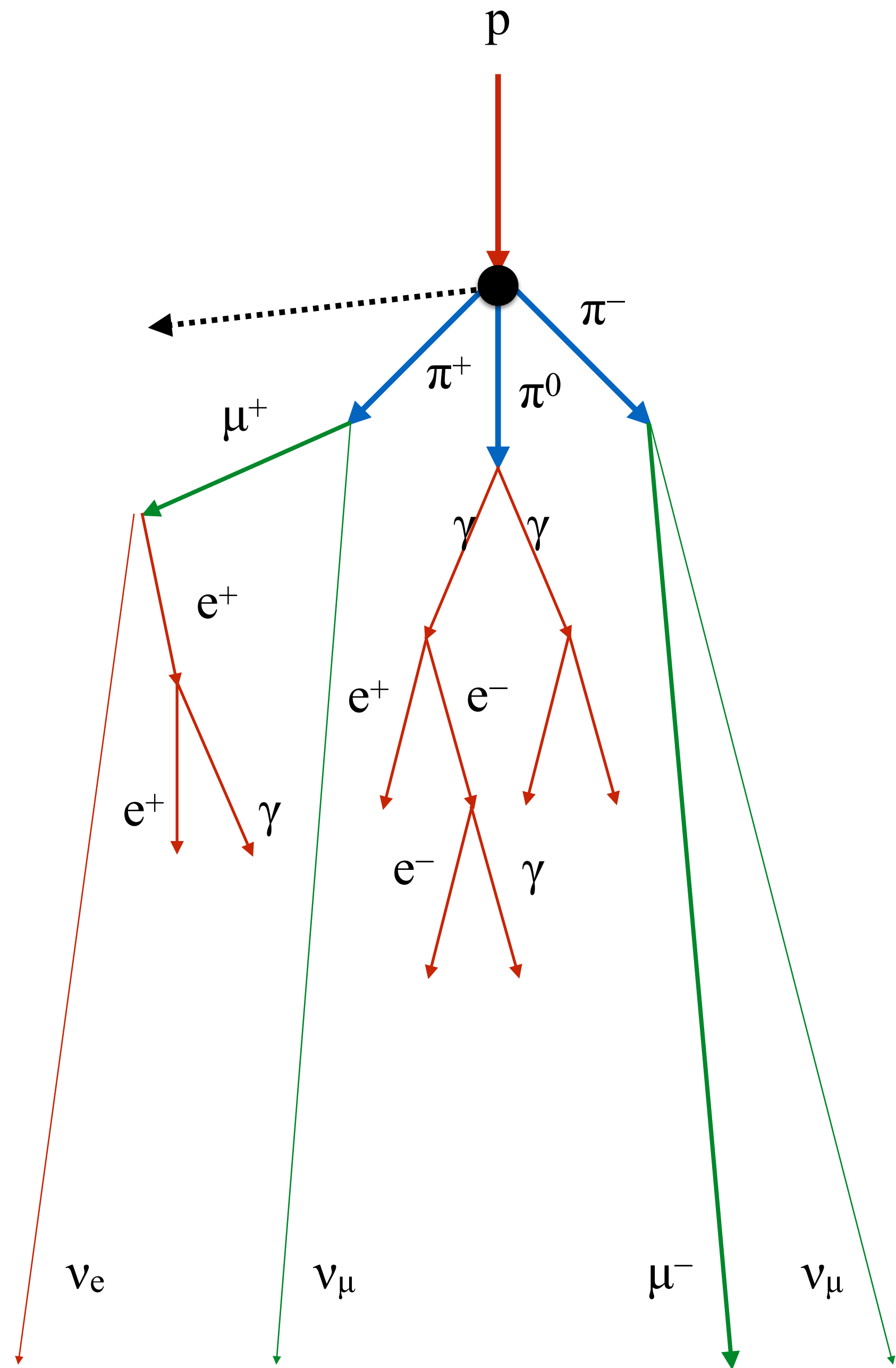


**HAWC Field of View
(Moving Left)**

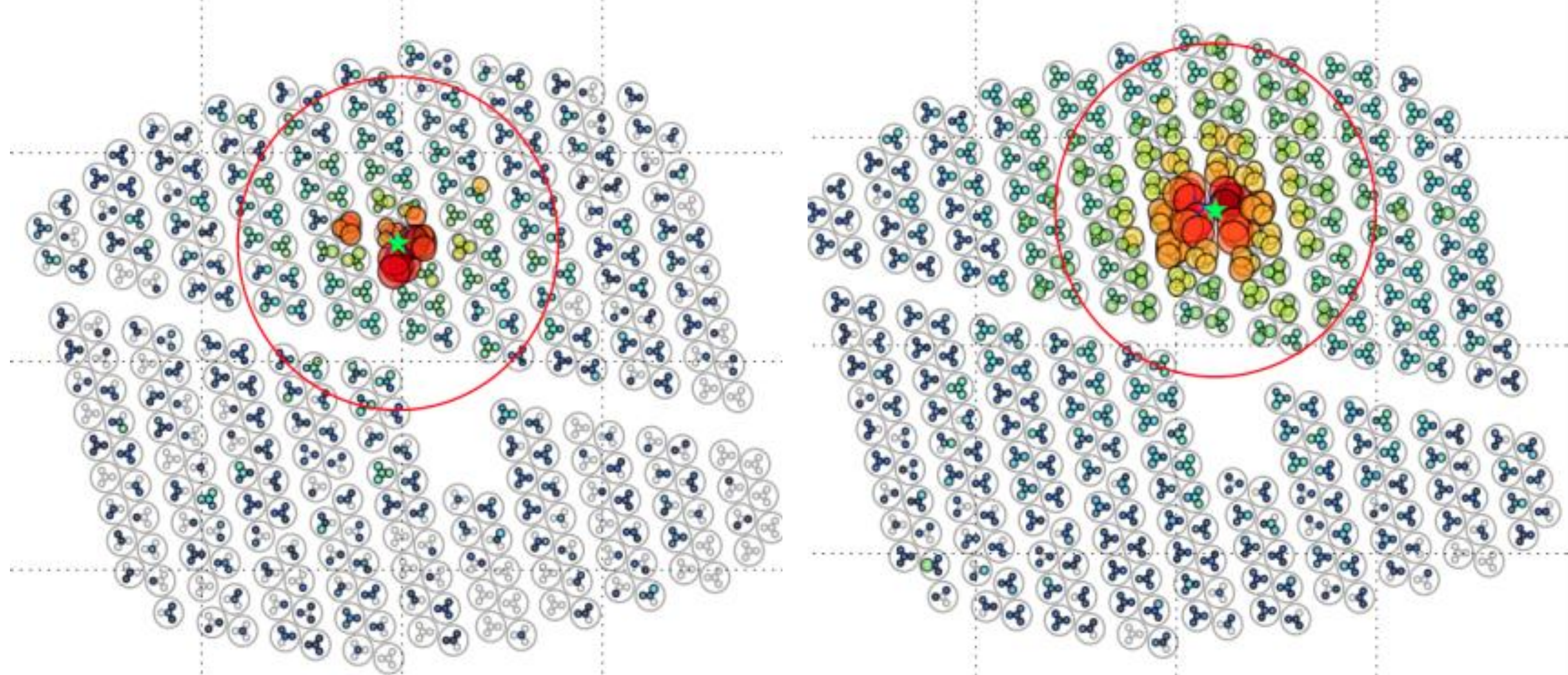
Equatorial



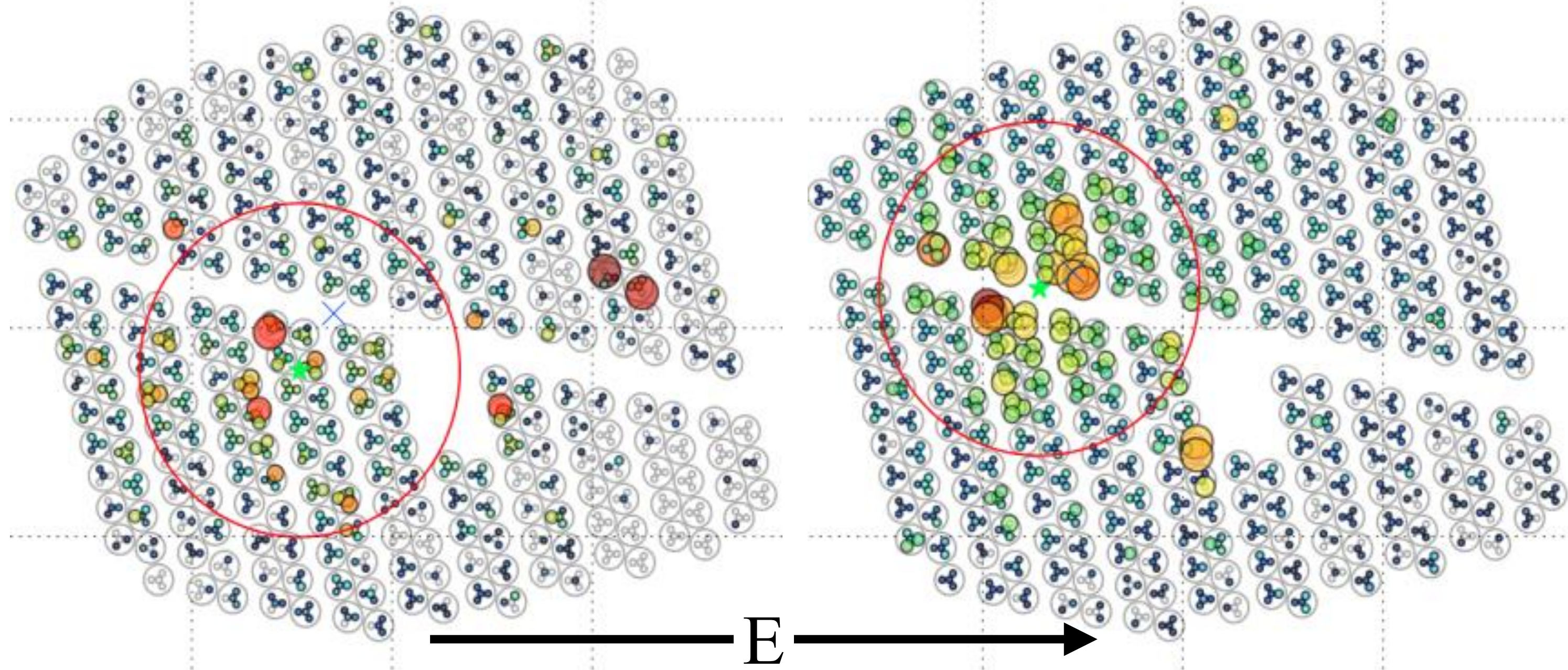




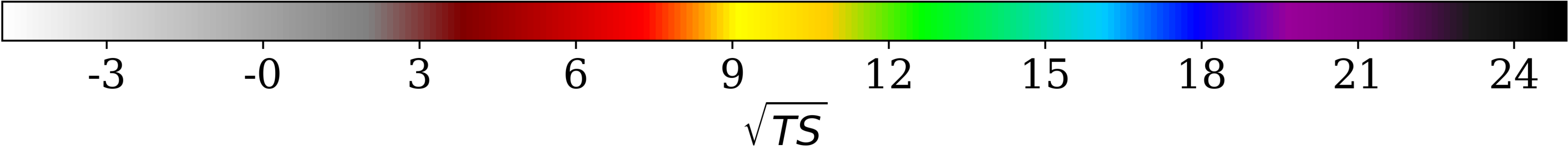
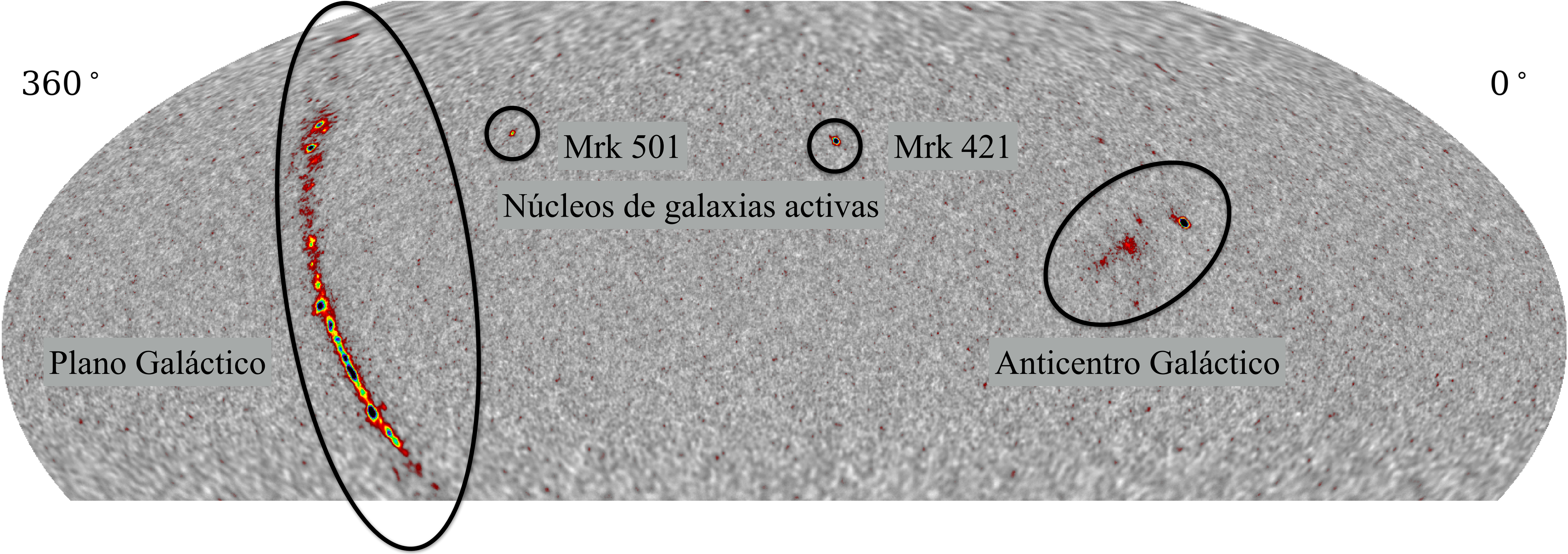
Fotón



Hadrón



All-sky view; 0.0 °; 1523 days



The Crab Pulsar Wind Nebula

Abeysekara et al., 2019, ApJ 881:134

THE ASTROPHYSICAL JOURNAL, 881:134 (13pp), 2019 August 20

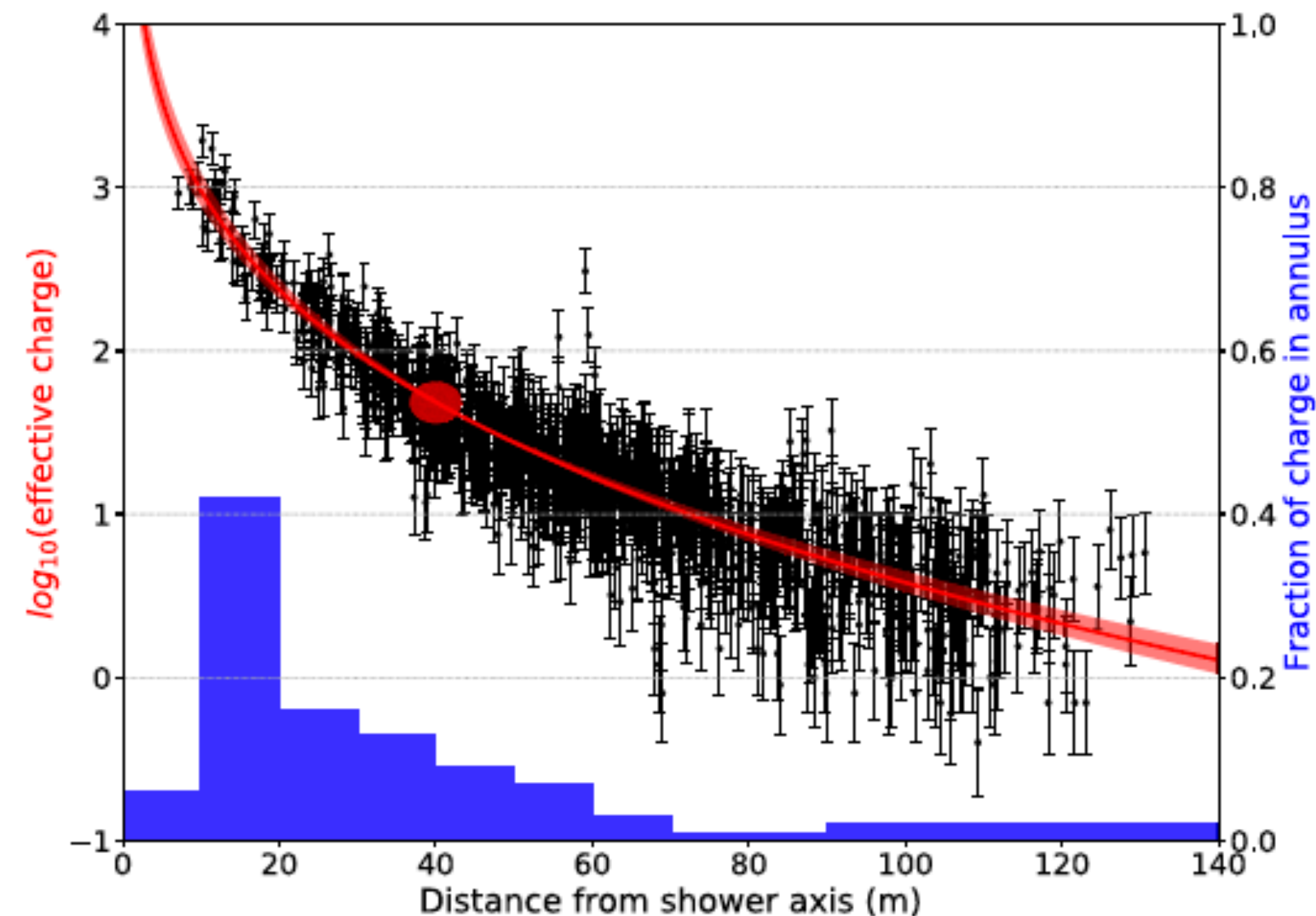


Figure 2. Depiction of the information used by the two energy estimators. The black points show, for a single event, the log of the effective charge measured

THE ASTROPHYSICAL JOURNAL, 881:134 (13pp), 2019 August 20

Abeysekara et al.

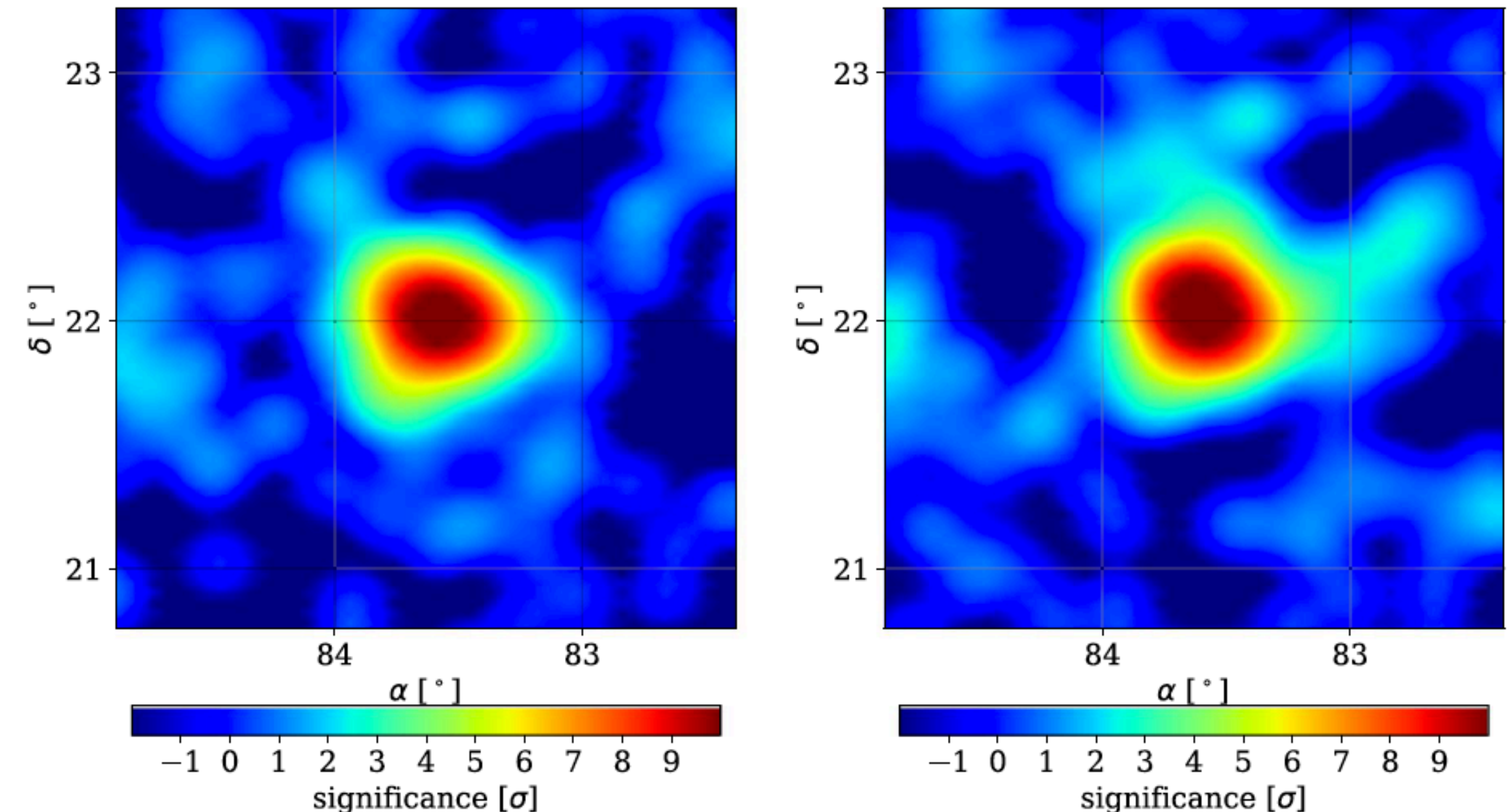
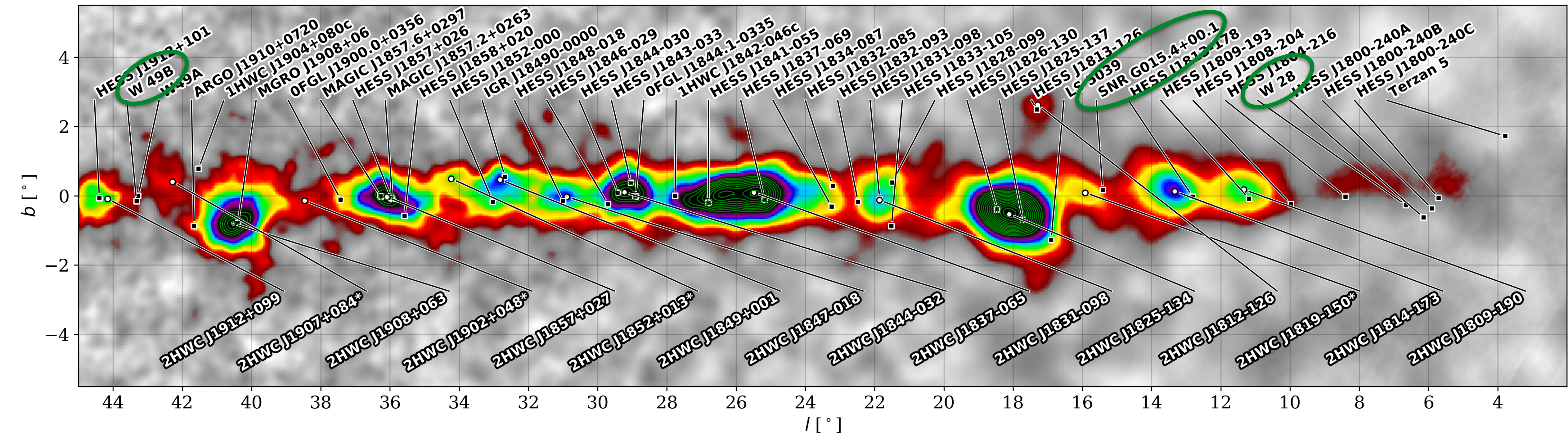
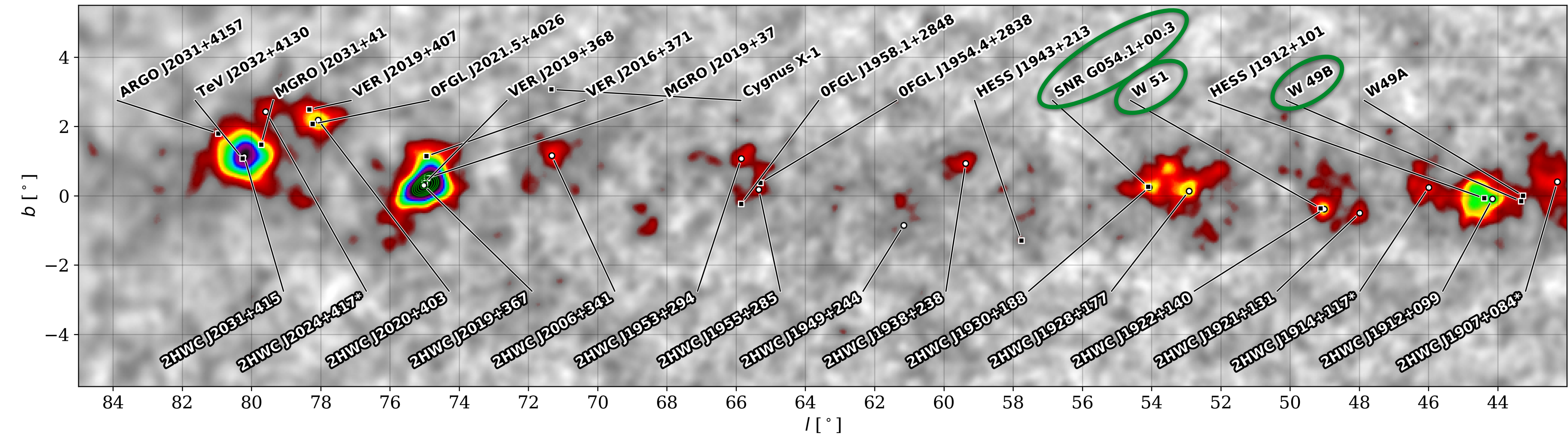


Figure 12. Significance map above 56 TeV in reconstructed energy for the GP (left) and NN (right). The maximum significance is 11.2σ for the GP and 11.6σ for the NN. Both significance maps have been smoothed for presentation purposes.

Estimadores de energía (GP y NN) implementados para estudiar la emisión del Cangrejo desde 1 TeV hasta por encima de 100 TeV.



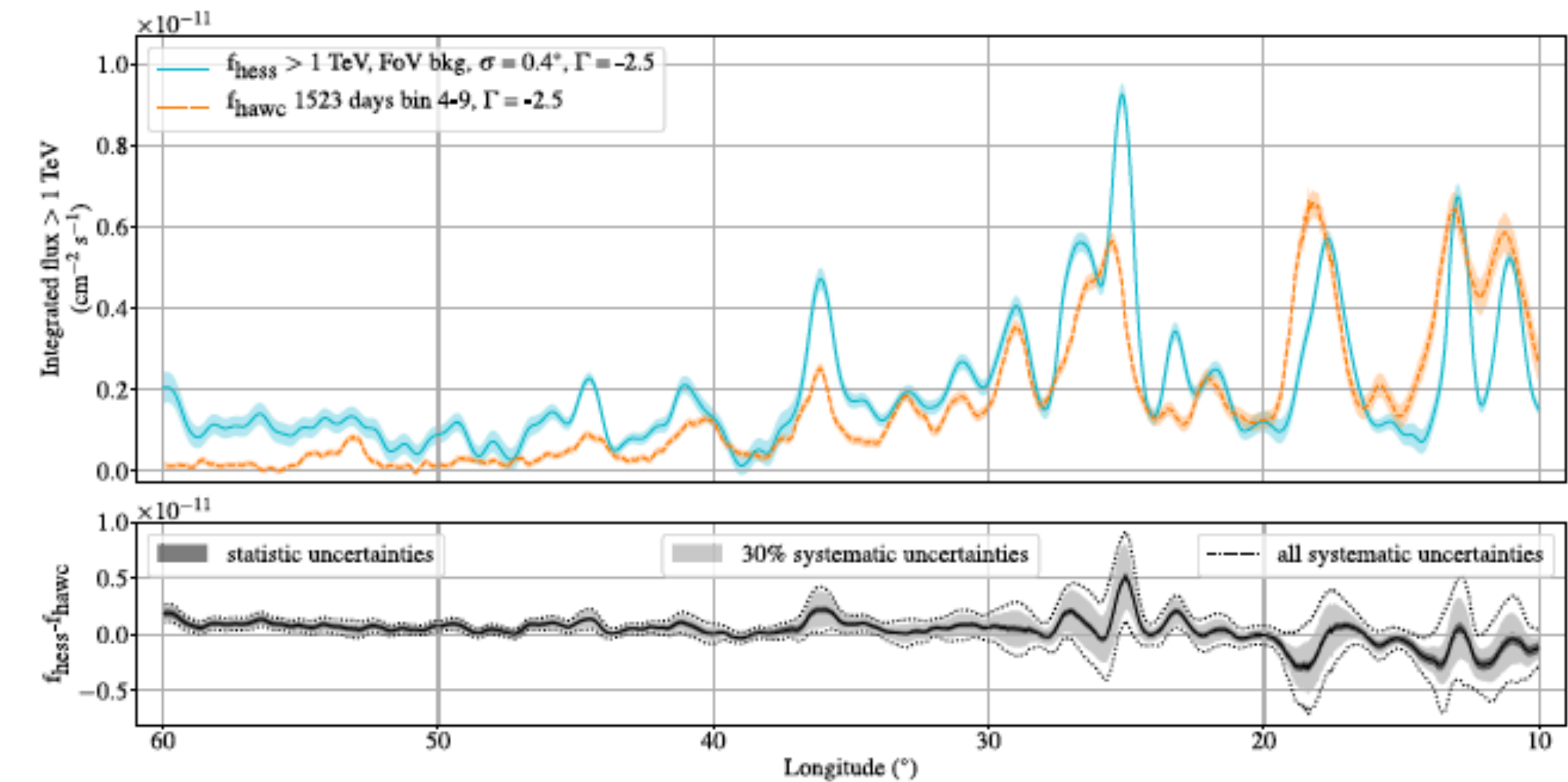
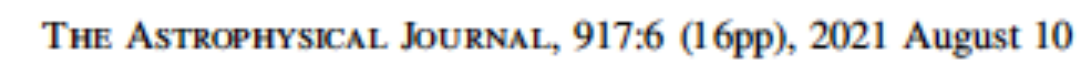
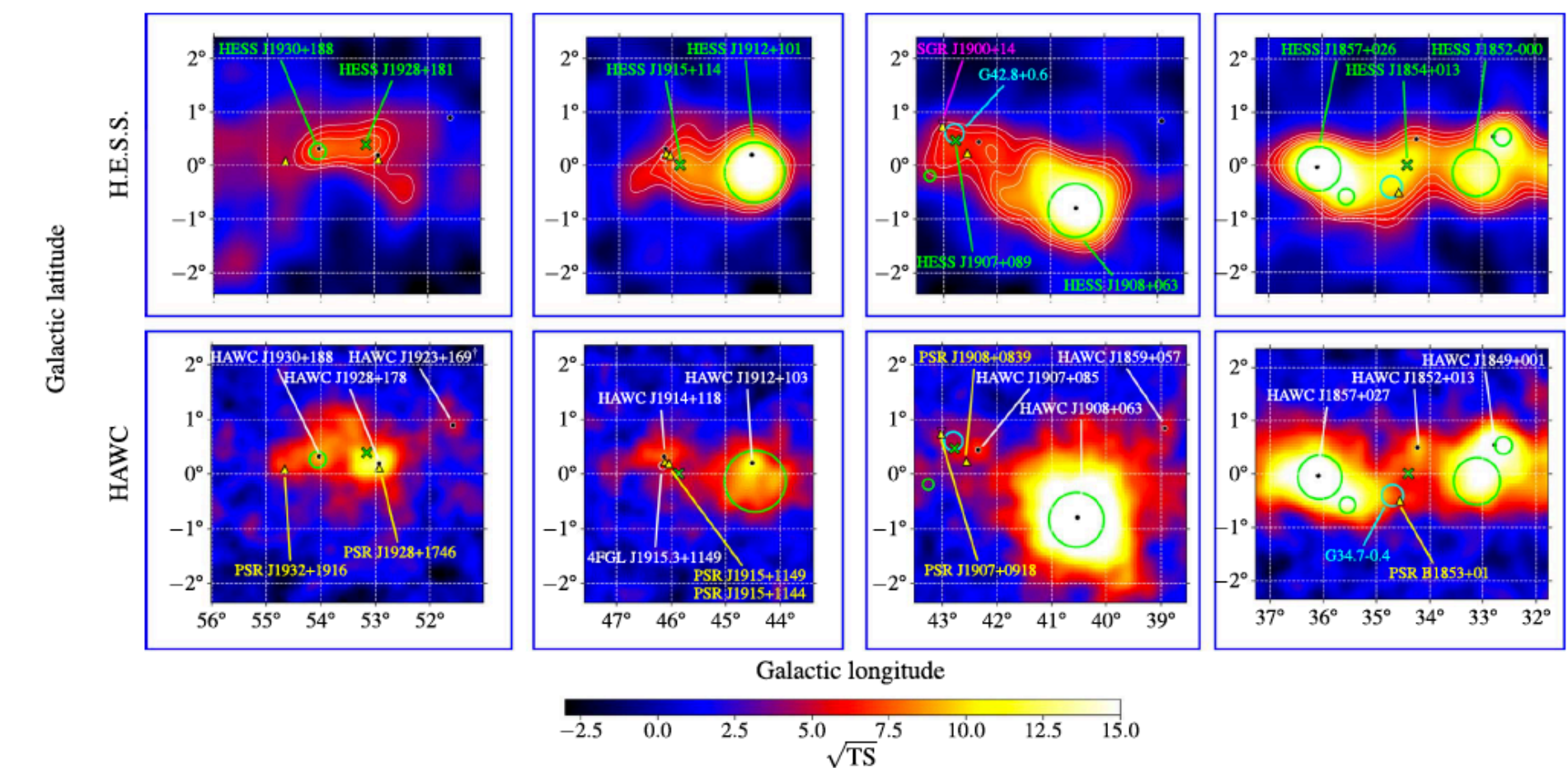
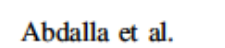
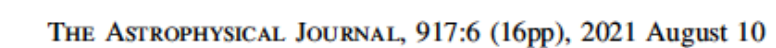
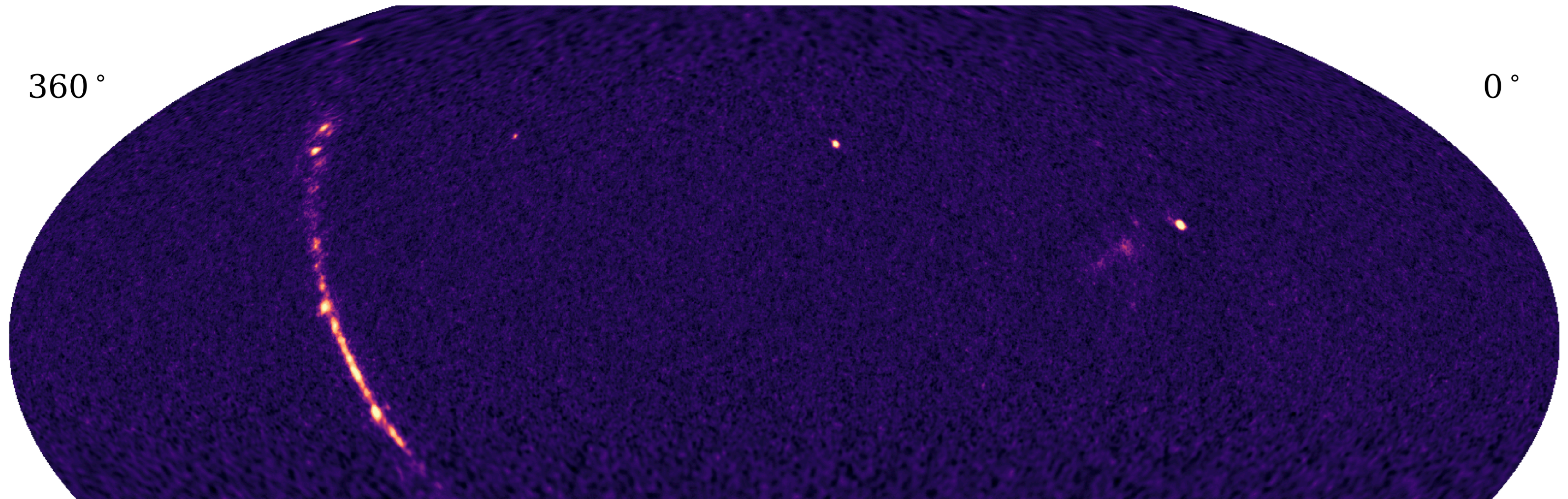


Figure 4. Longitude profiles of the integrated flux above 1 TeV at $b = 0^\circ$ for the new H.E.S.S. map, using the 0.4° Gaussian an method in cyan, and the HAWC map in dashed orange. The bottom panel shows the difference between the H.E.S.S. and HAWC histogram (mean and standard deviation given on top of the histogram). The systematic uncertainties are derived for each parameter use Appendix B) and added quadratically, are represented by the dotted envelop. More details on the derivation of the systematic uncer

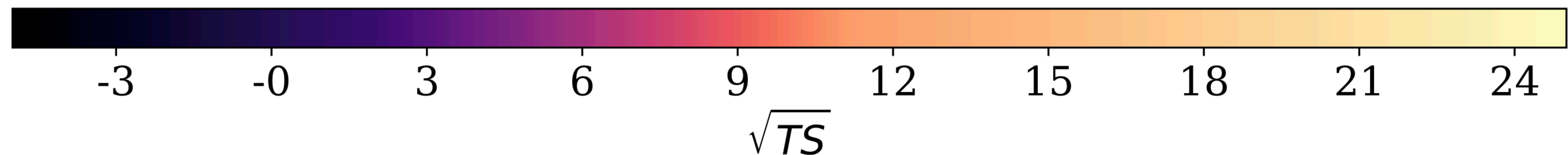


3HWC - el tercer catálogo de HAWC



65 fuentes en 1523 días de exposición; 20 nuevas en TeV

Albert et al., 2020, ApJ 905:76



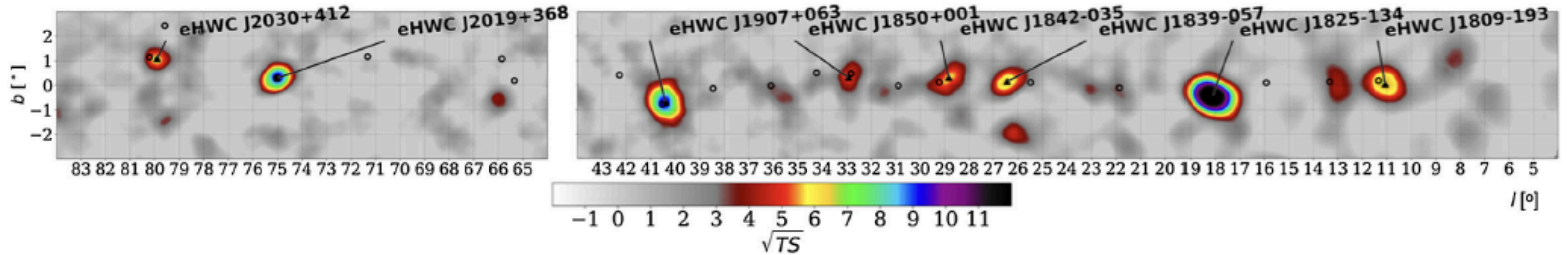


FIG. 1. $\sqrt{TS}$ map of the galactic plane for $\hat{E} > 56$ TeV emission. A disk of radius 0.5° is assumed as the morphology. Black triangles denote the high-energy sources. For comparison, black open circles show sources from the 2HWC catalog.

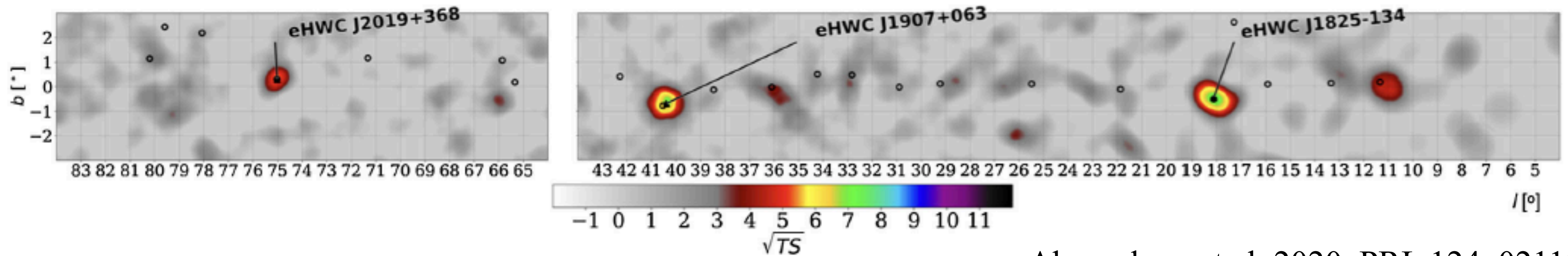
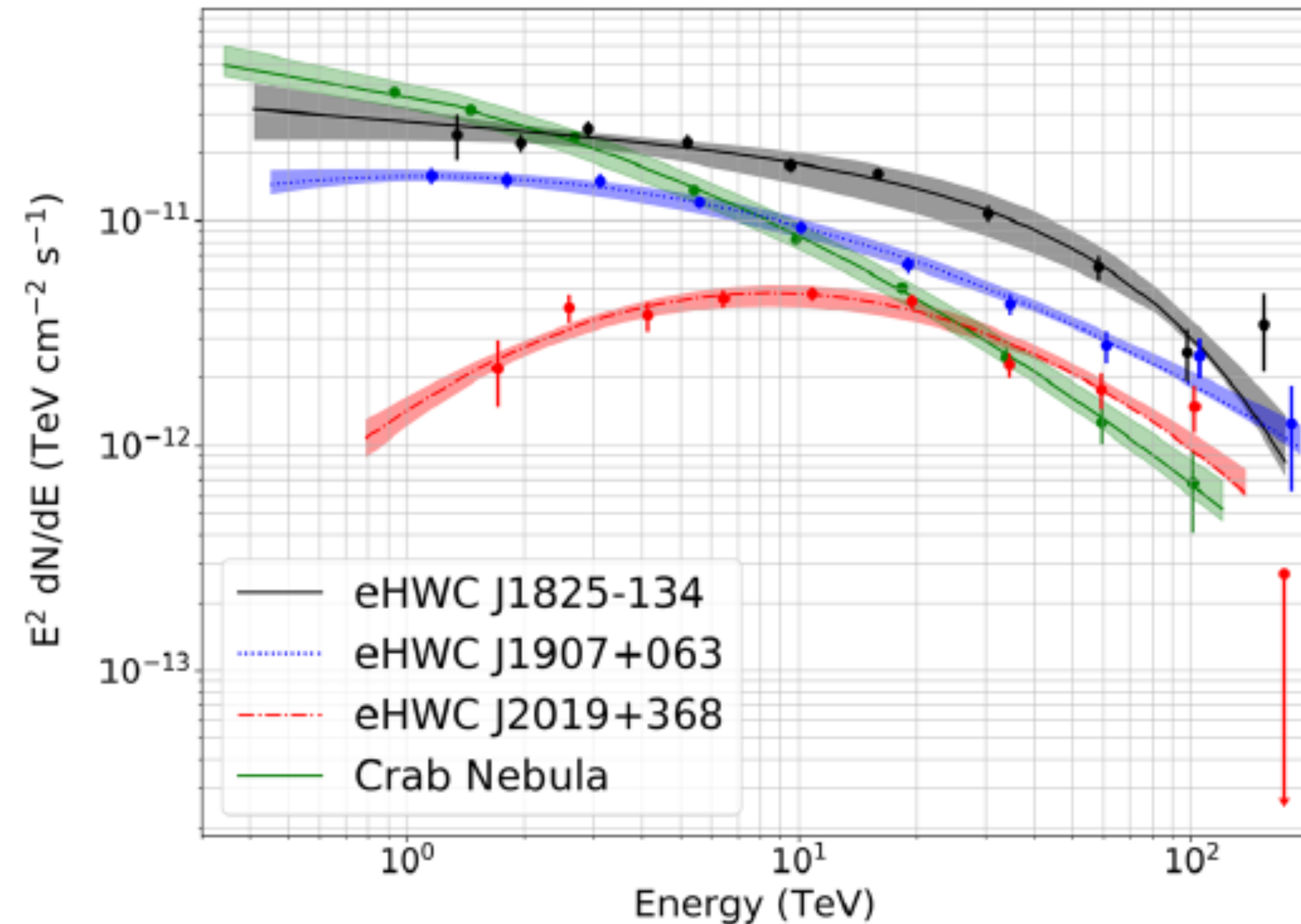


FIG. 2. The same as Fig. 1, but for $\hat{E} > 100$ TeV. The symbol convention is identical to Fig. 1.

Abeysekara et al. 2020, PRL 124, 021102

Fuentes a mayor energía



[1] Abeysekara et al. 2020, PRL 124, 021102

[2] Albert et al. 2021, ApJ 907, L30.

- Nueve fuentes $E > 56$ TeV; las más energéticas alcanzan >100 TeV.
- En todas hay un pulsar a menos de 0.5° con $\dot{E}_{rot} = 4\pi^2 I \dot{P} / P^3 > 10^{36} \text{ erg s}^{-1}$.
- Los pulsares más energéticos tienen mayor capacidad de aceleración,

$$\Delta\Phi \lesssim 1.06 \times 10^{15} \text{ Volts } \dot{E}_{36}^{1/2}.$$

- Aceleradores **leptónicos** por naturaleza.



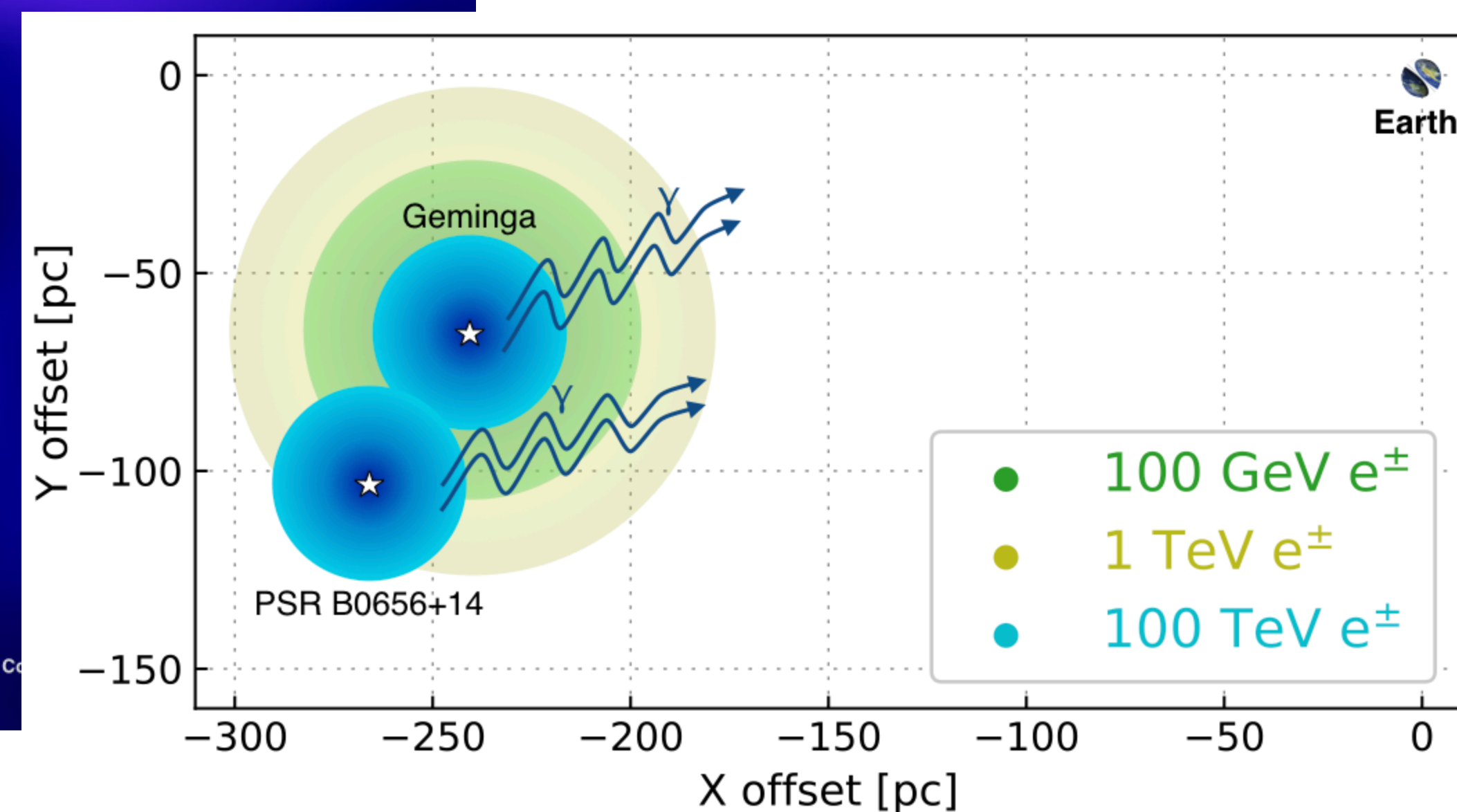
La Luna (misma escala)

Geminga

PSR B0656+14

Geminga y Monogem

TeV Halos



Abeysekara et al. (2017; Science 358, 911-194)

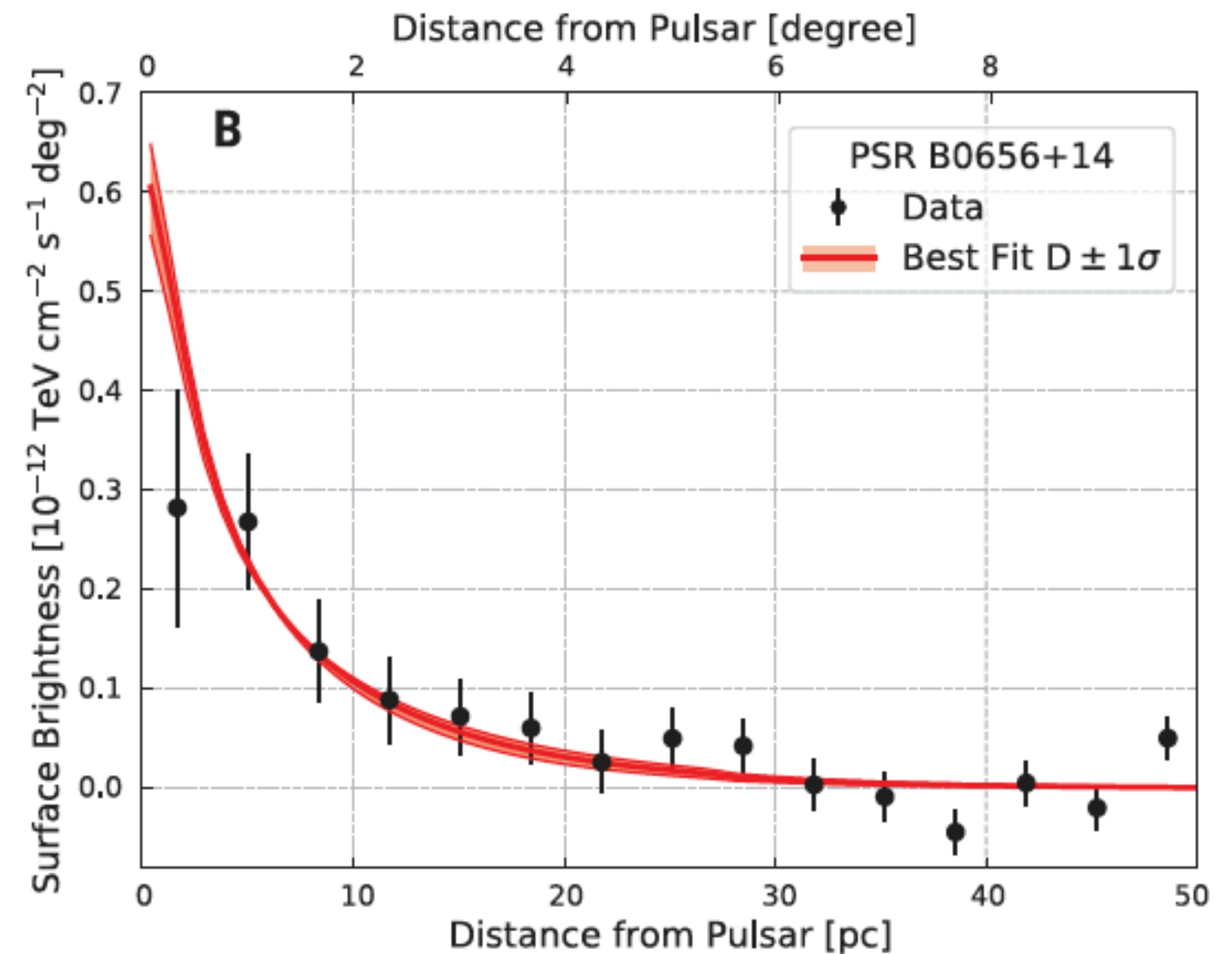
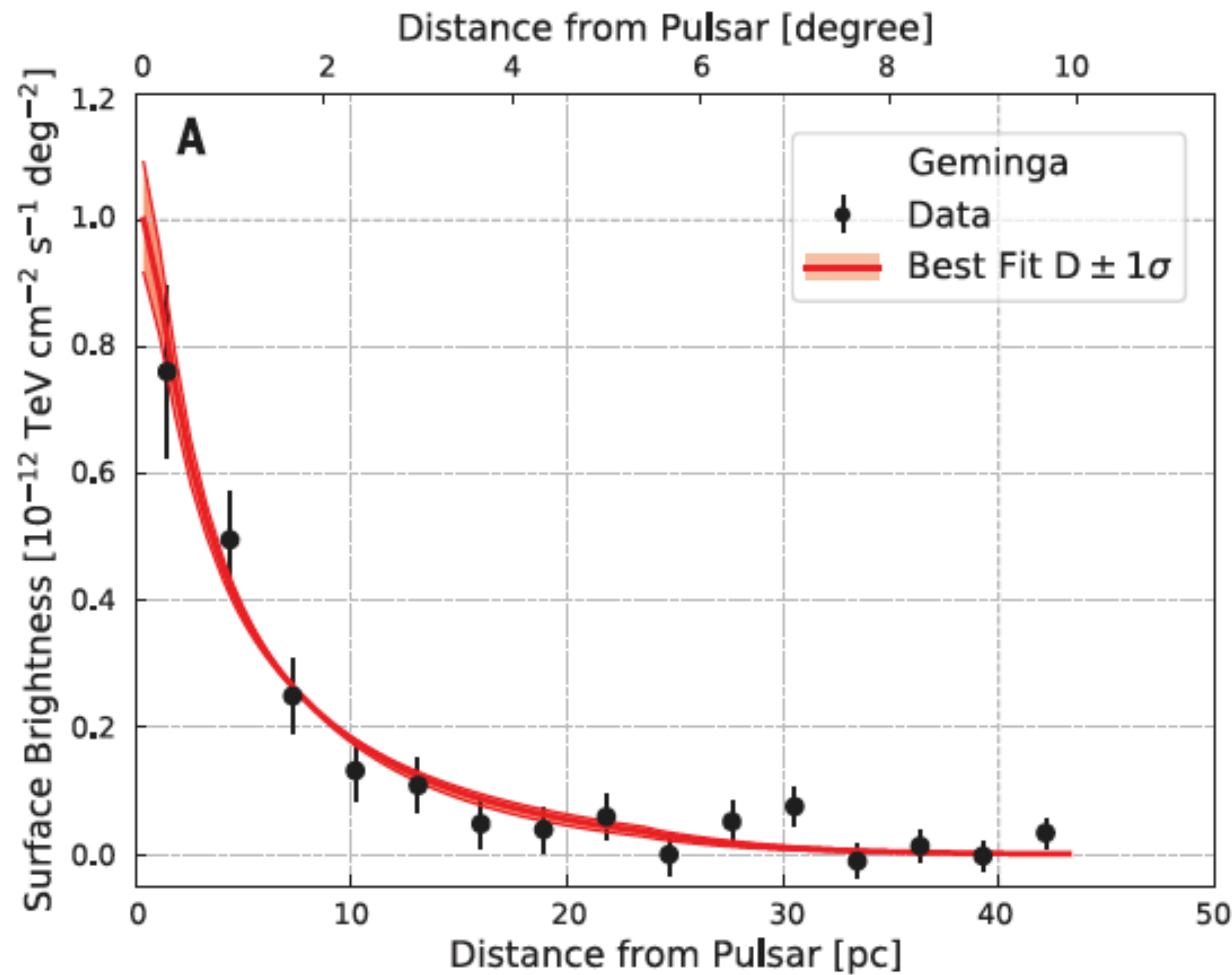


Fig. 2. Surface brightness of the tera-electron volt gamma-ray emission. Surface brightness is shown as a function of distance from the Geminga (**A**) and PSR B0656+14 (**B**) pulsars. The solid line represents the best-fitting model with a common diffusion coefficient, and the

shaded band is the $\pm 1\sigma$ statistical uncertainty. Error bars are statistical errors. The distance from each pulsar in parsecs is calculated based on nominal distances of 250 and 288 pc for Geminga and PSR B0656+14, respectively (14).

Abeysekara et al. (2017; Science 358, 911-194)

PWN $\rightarrow$ TeV Halos

The Highest Energy HAWC Sources are Likely Leptonic and Powered by Pulsars

Takahiro Sudoh,^{a,1} Tim Linden,^b Dan Hooper^{c,d}

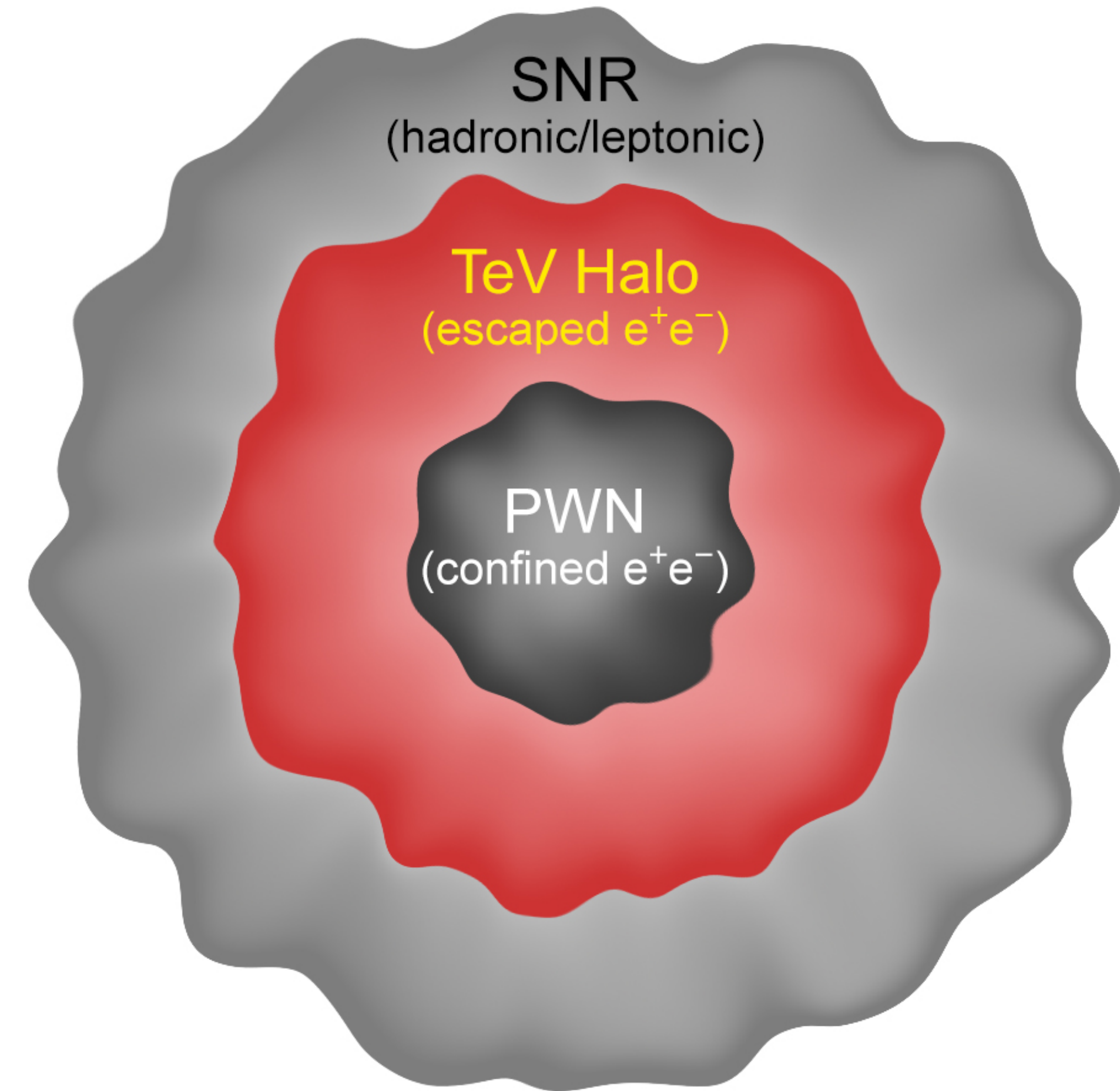
^aDepartment of Astronomy, University of Tokyo, Hongo, Tokyo 113-0033, Japan

^bStockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden

^cTheoretical Astrophysics Group, Fermi National Accelerator Laboratory, Batavia, Illinois, 60510, USA

^dDepartment of Astronomy and Astrophysics and the Kavli Institute for Cosmological Physics (KICP), University of Chicago, Chicago, Illinois, 60637, USA

E-mail: sudoh@astron.s.u-tokyo.ac.jp, linden@fysik.su.se, dhooper@fnal.gov



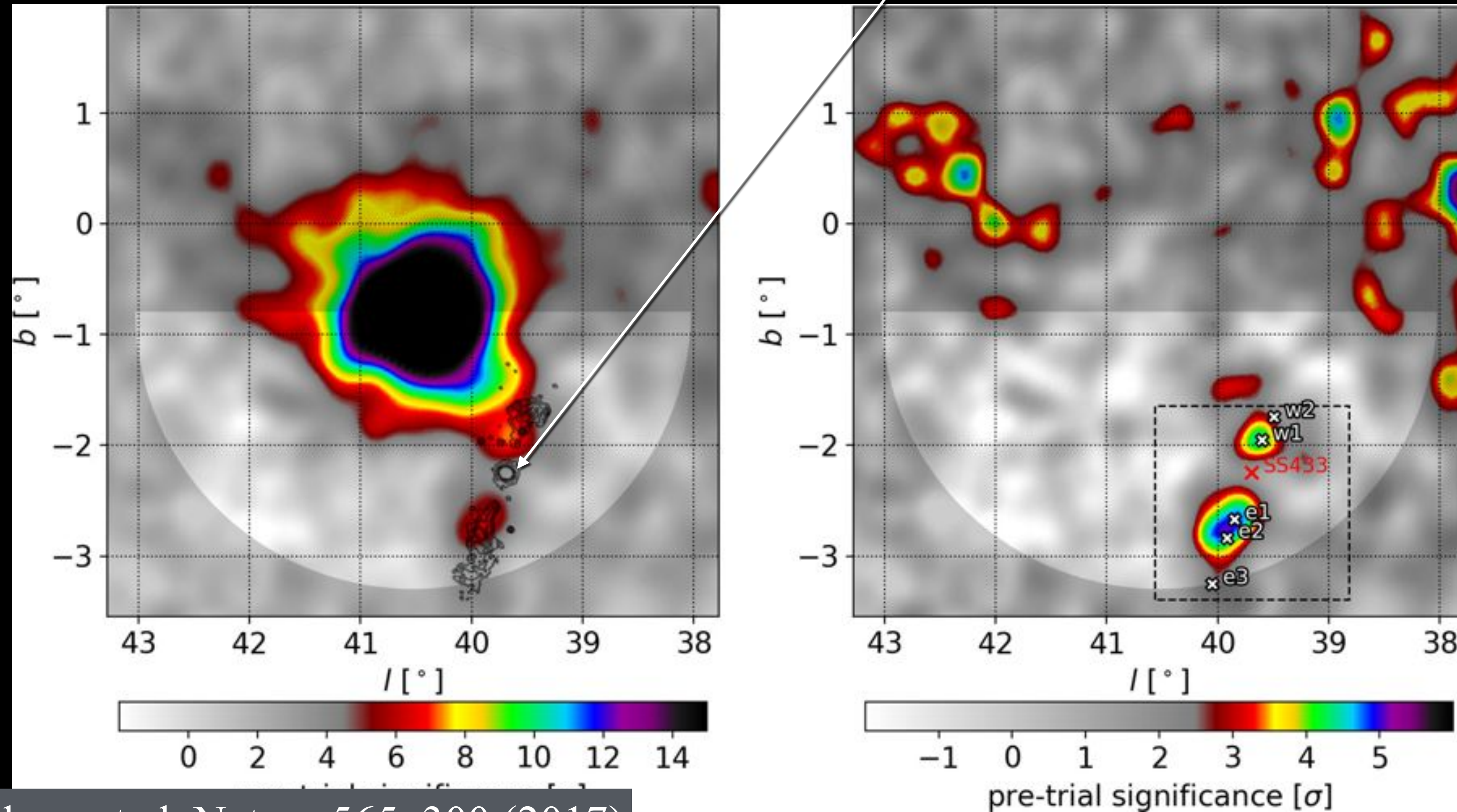
Sudoh, Linden, Beacom (2019, 2021)

SS 433: multi-TeV microquasar

- SS 433: sistema estelar binario con un hoyo negro, $M > 10 M_{\odot}$.
- Espectroscopía óptica evidencia materia moviéndose a $0.26c$.
- HAWC detecta emisión de rayos γ (> 25 TeV), coincidente con los lóbulos de rayos X.
- Modelo leptónico favorecido sobre hadrónico.



NASA - <https://apod.nasa.gov/apod/ap960306.html>

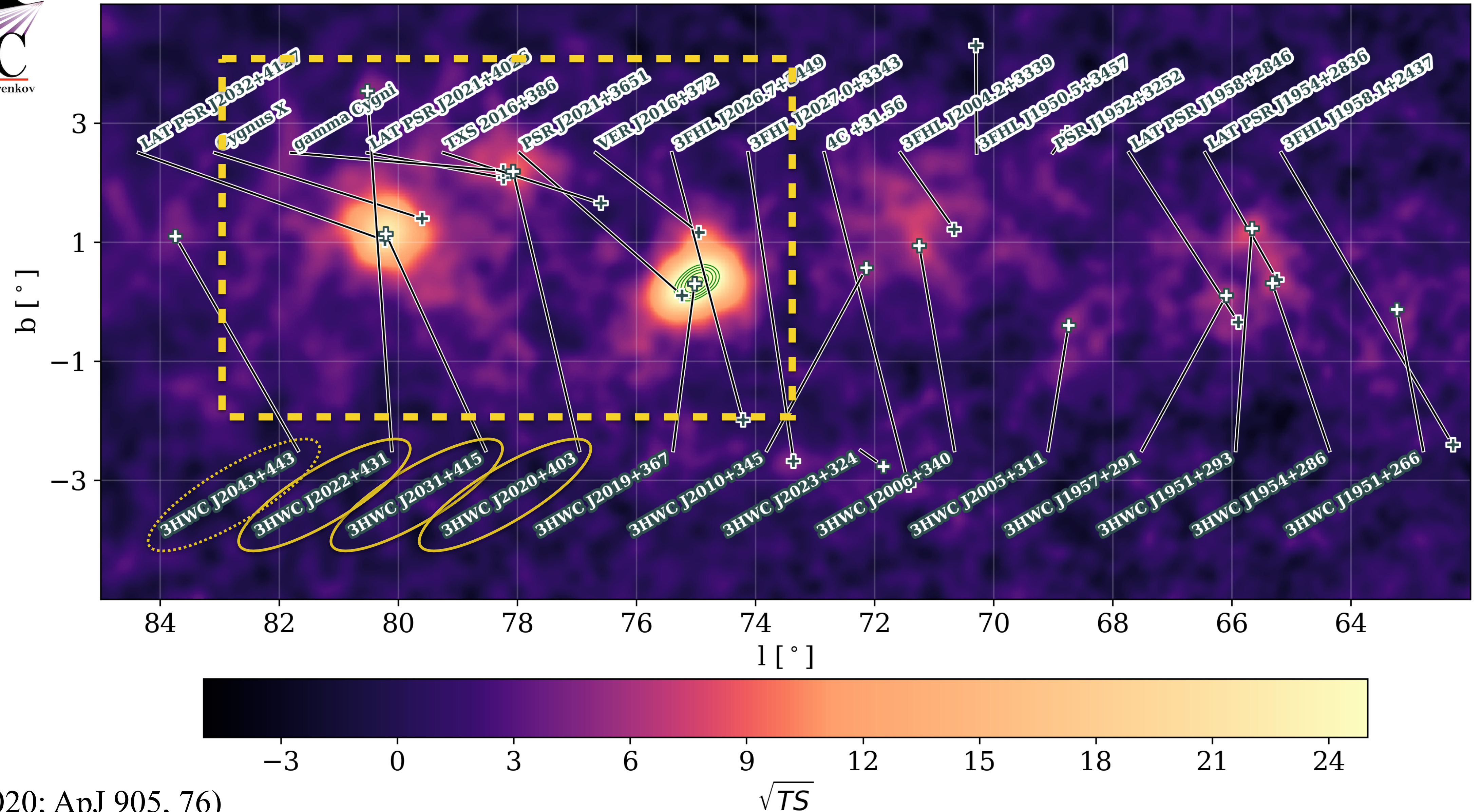


Abeysekara et al. Nature 565, 300 (2017)

CYGNUS...

Cygnus X - APOD, 4 agosto 2018

Galactic plane I; 0.0 °; 1523 days



Albert et al. (2020; ApJ 905, 76)



HAY SECRETOS EN EL UNIVERSO QUE NO DEBERÍAN SER DESCUBIERTOS



ELEMENTO
PRODUCCIONES

CYGNUS



Cygnus X

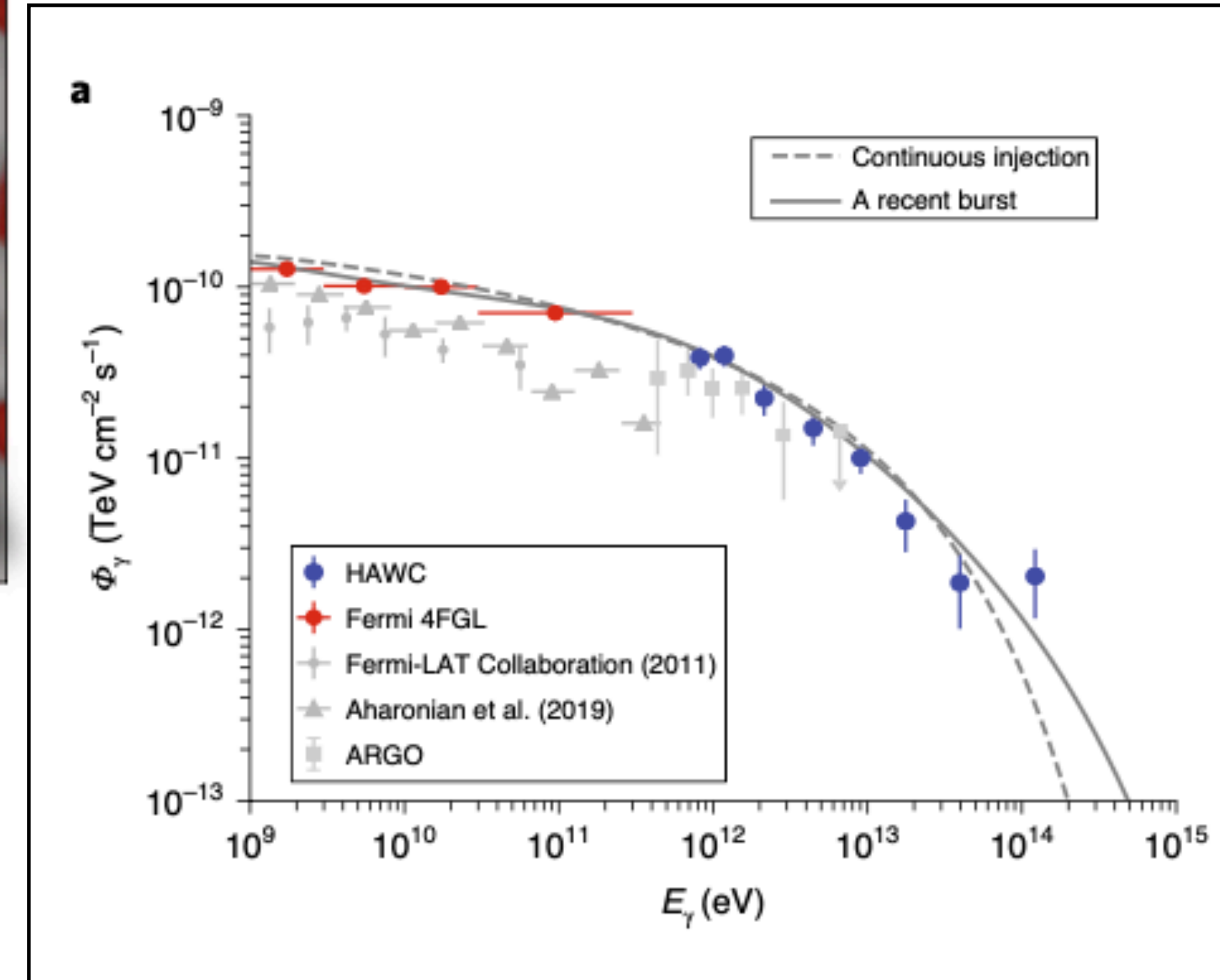
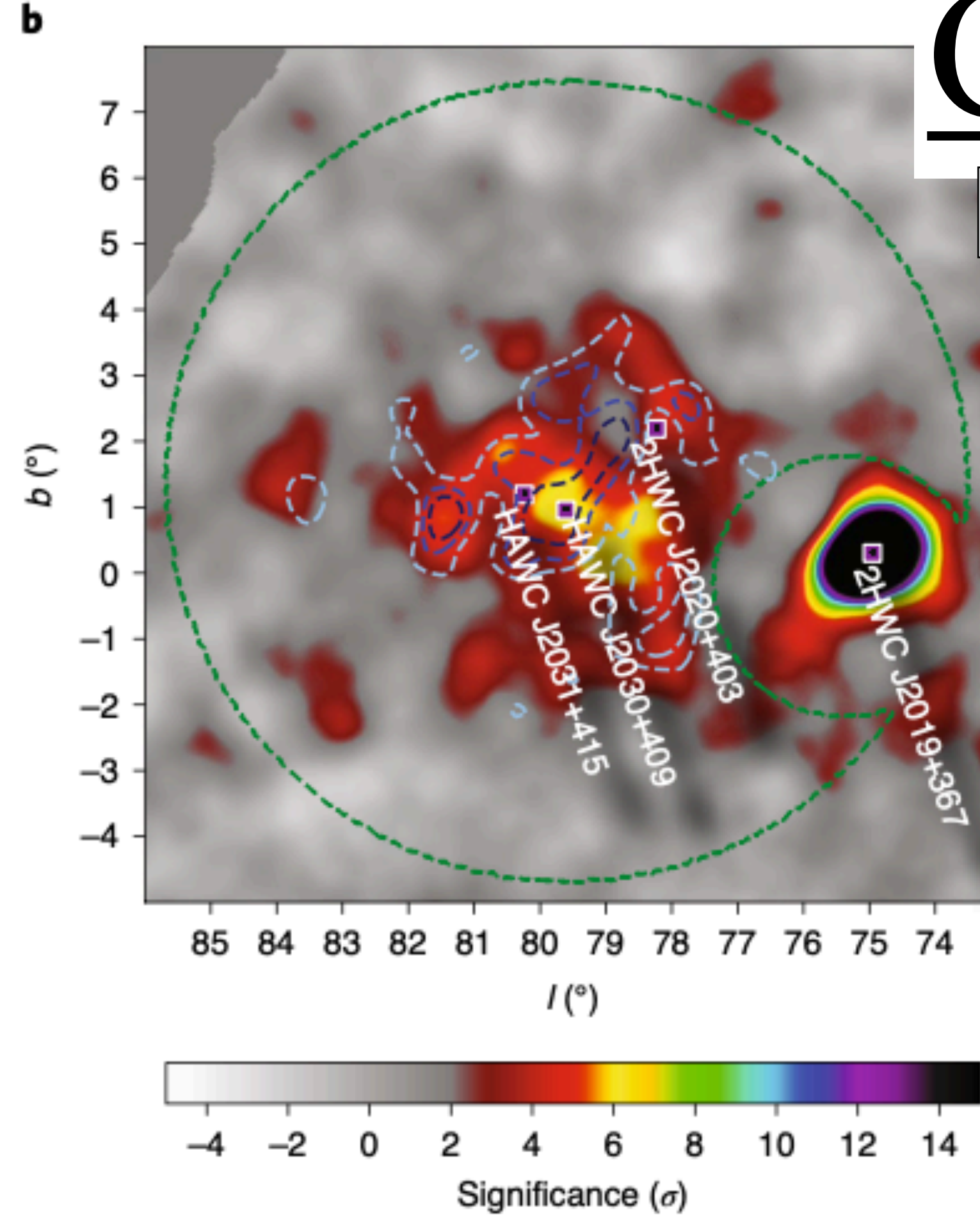
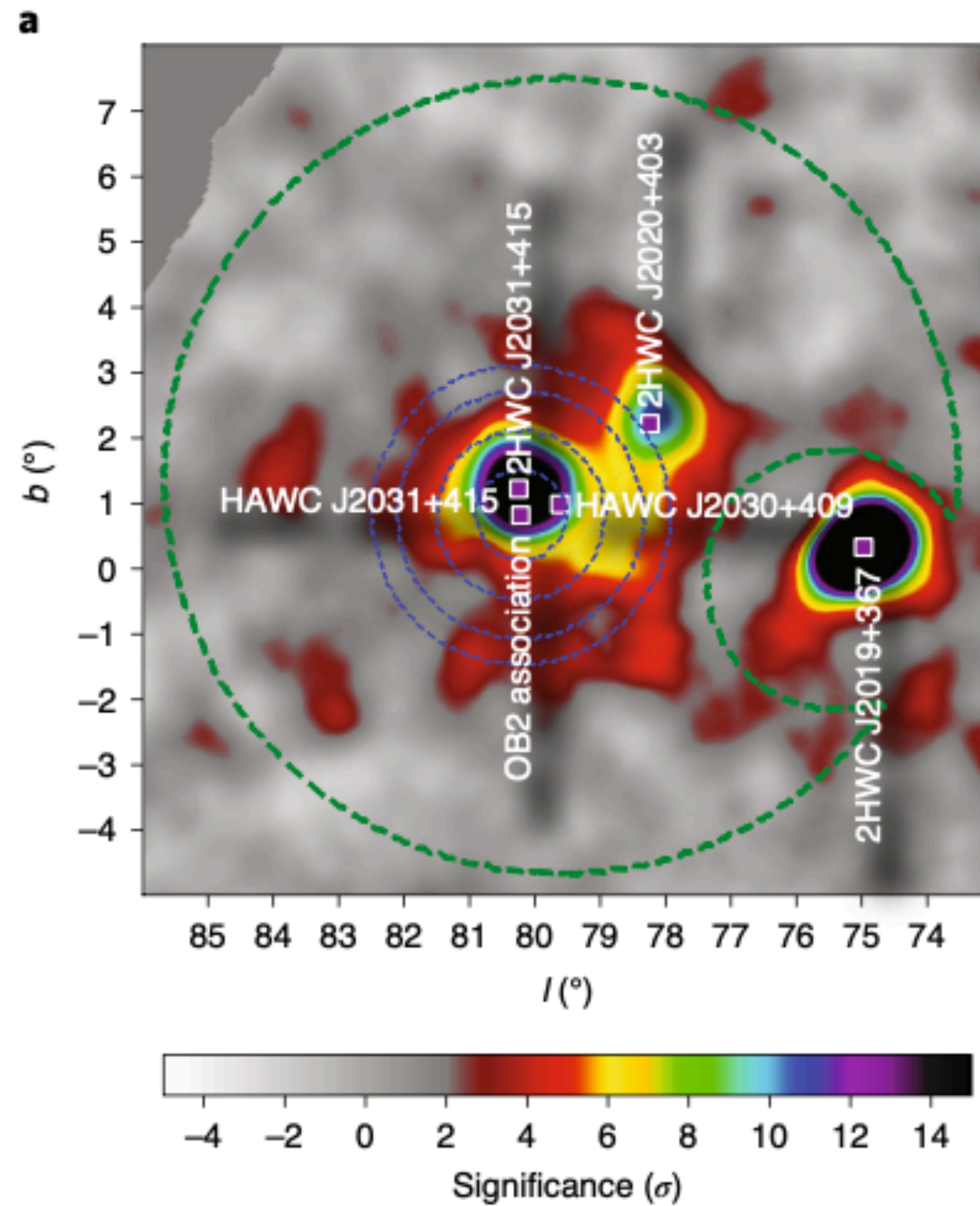
- Región de formación estelar de alta masa a 1.4 kpc de distancia.
- Contiene $10^6 M_{\odot}$ de estrellas con edades de 1 a 7 Myrs dentro en ~ 100 pc. Incluye Cygnus OB₂.
- Imagen de Spitzer centro: $\ell=79.4^{\circ}$, $b=+0.5^{\circ}$. Campo: $4.2^{\circ} \times 3.8^{\circ}$.
3.6 μm , 4.5 μm , 8 μm , 24 μm .

APOD: 2012 January 18

<https://www.spitzer.caltech.edu/image/ssc2012-02a-stars-brewing-in-cygnus-x>

Cygnus Cocoon

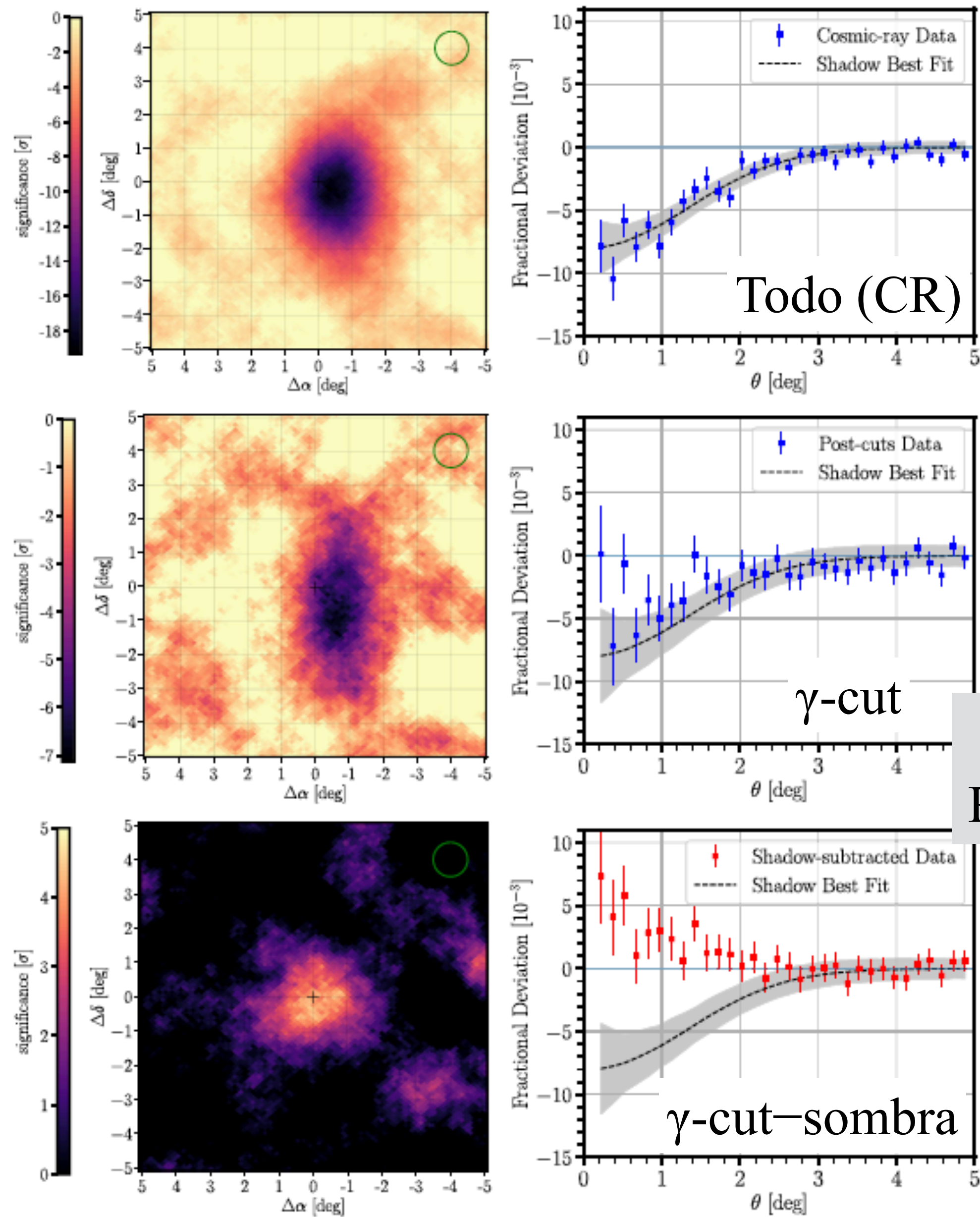
Abeysekara et al., Nature Astron, March 2021.



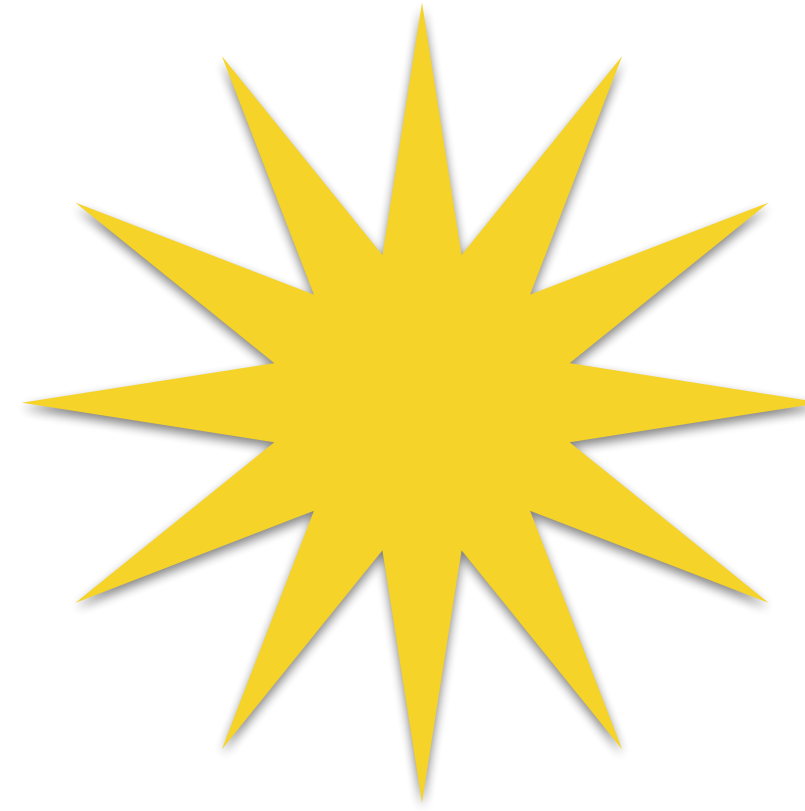
Izquierda: varias fuentes de HAWC en la región de Cygnus...

Derecha: sustracción de HAWC J2031+415 (PWN) y 2HWC J2020+403 (γ Cygni).

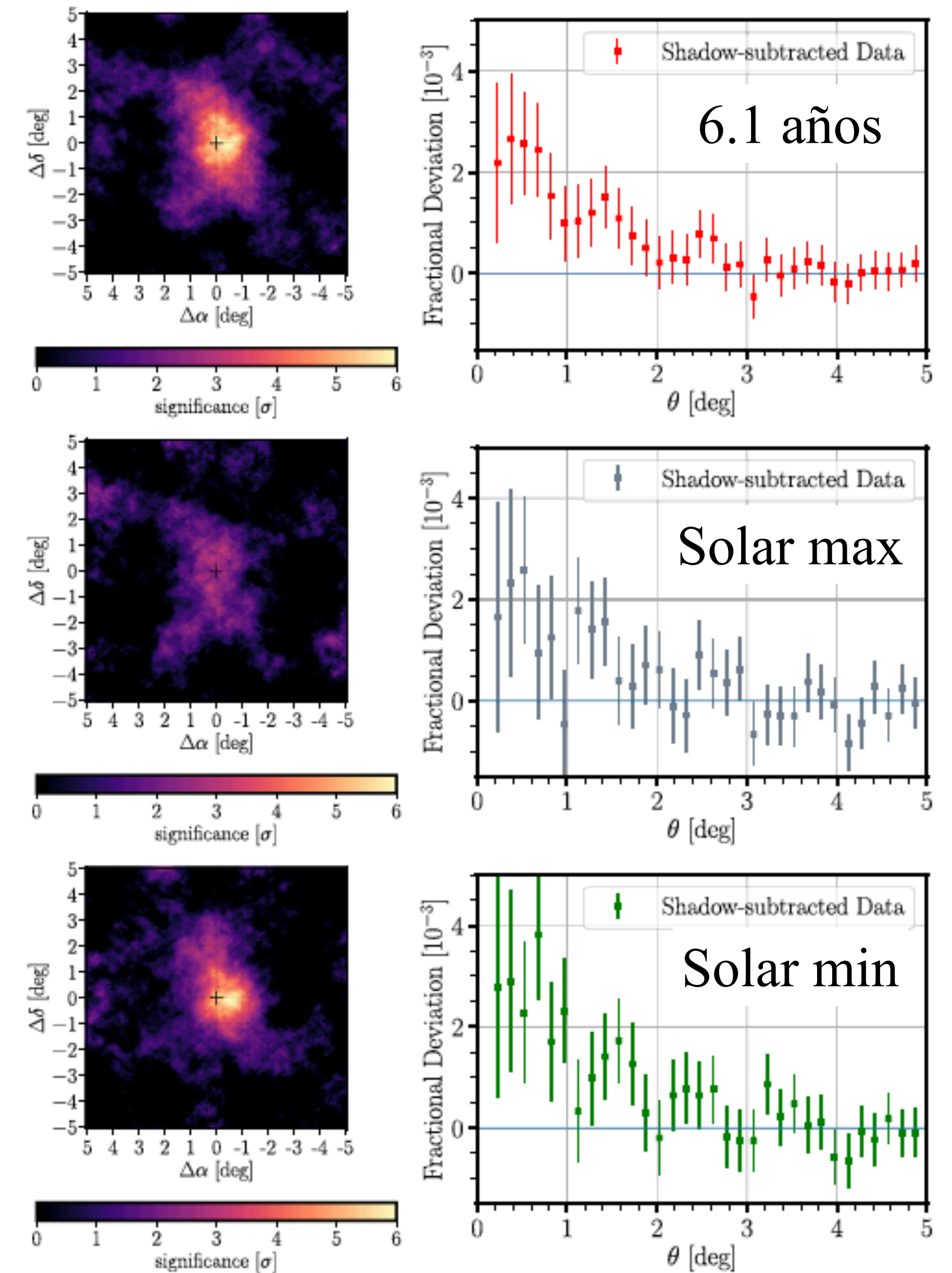
Los datos favorecen modelos hadrónicos.

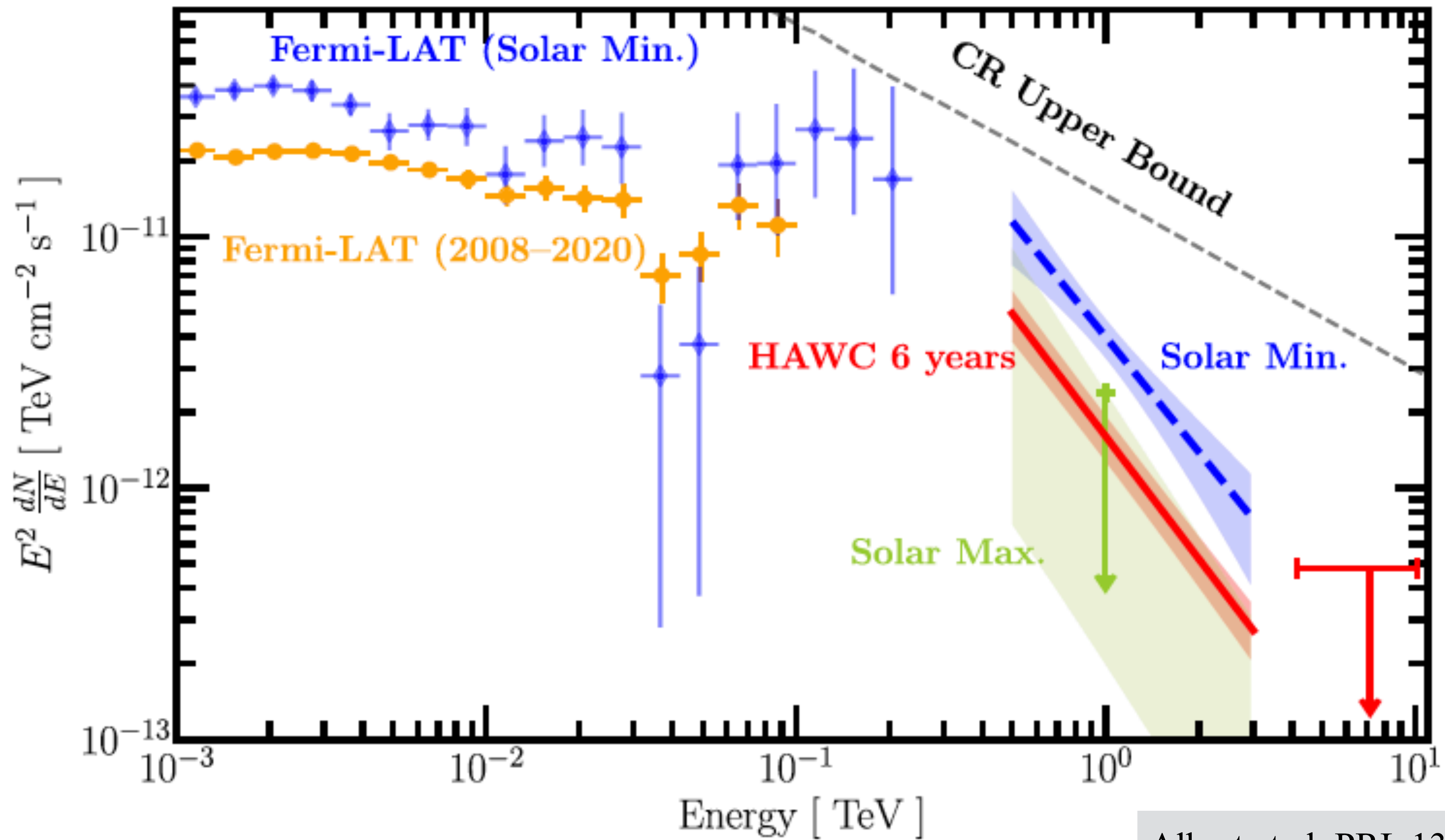


El Sol



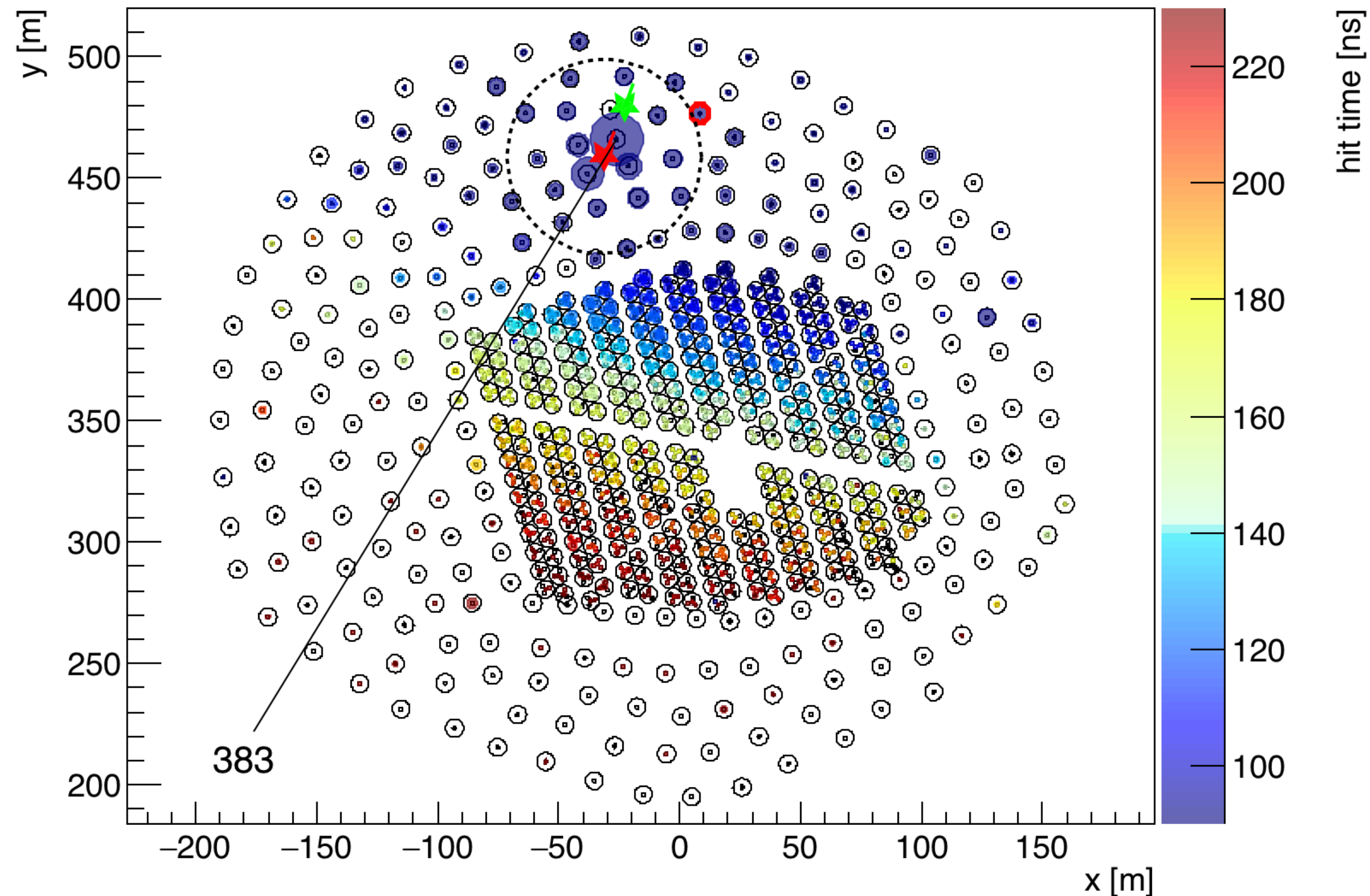
Albert et al,
PRL 131, 051201 (2023)





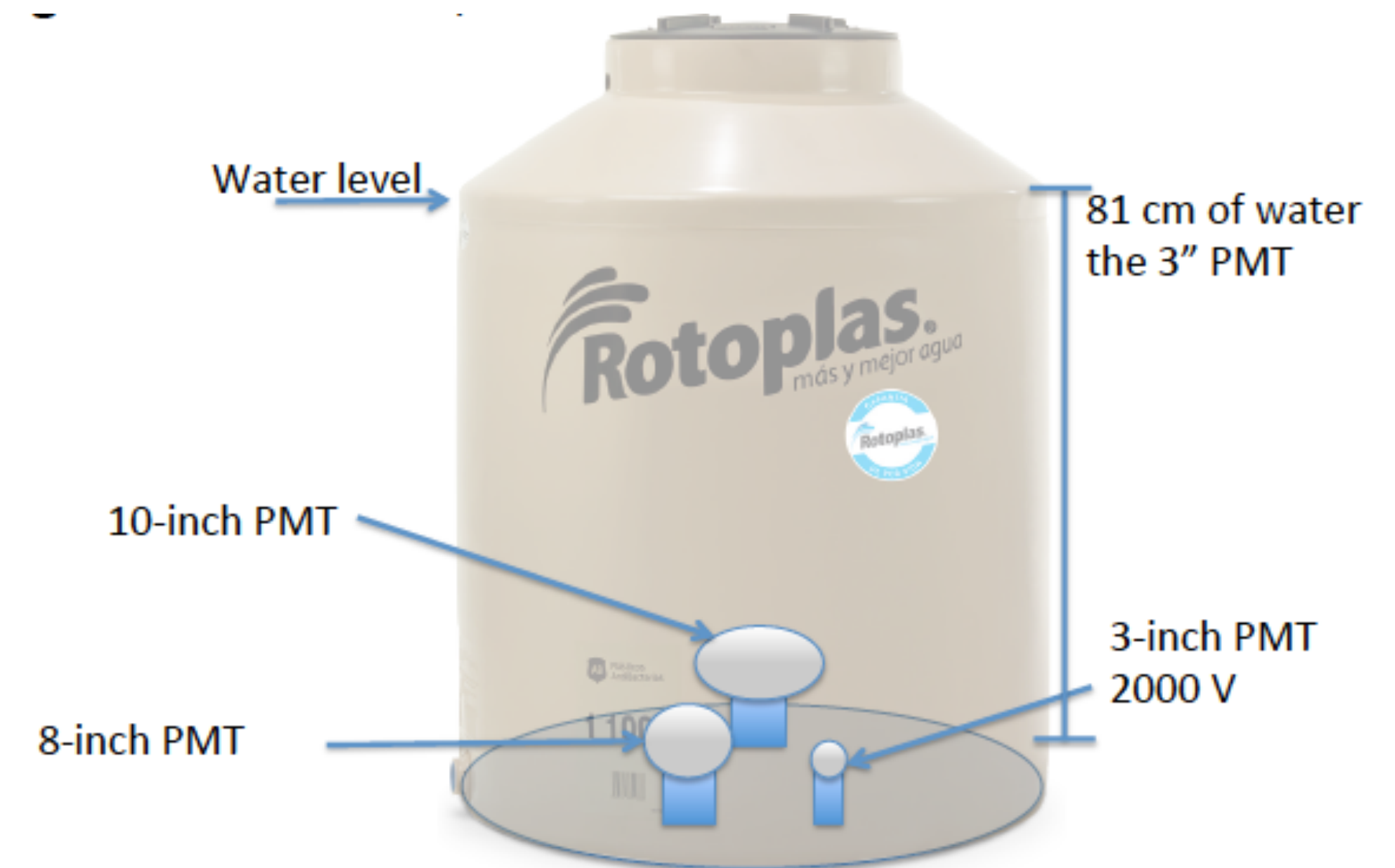
Albert et al, PRL 131, 051201 (2023)

Expansión de HAWC



Expansión de HAWC con un arreglo periférico de bajo costo.

350 detectores de pequeño volumen abarcando 100,000 m² para mejorar la respuesta a altas energías.



Abril 2018



Con outriggers desde 2018

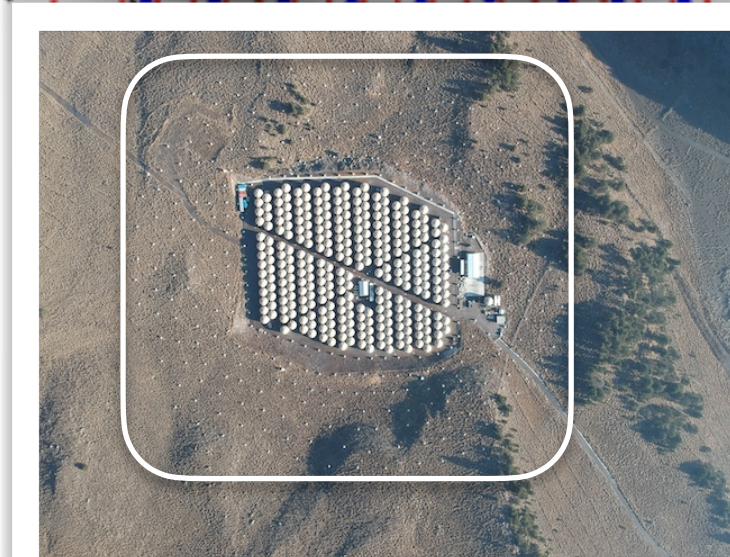
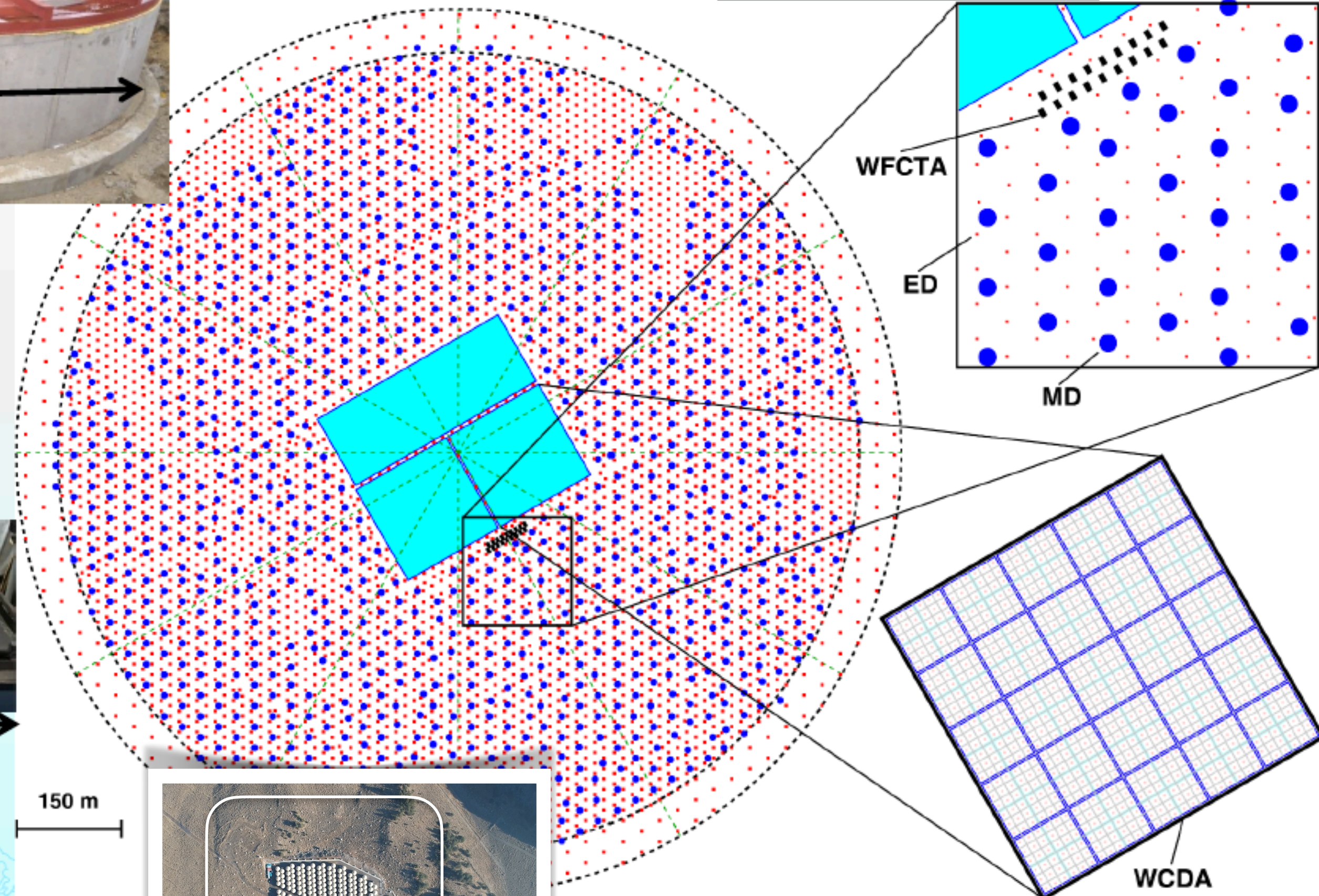
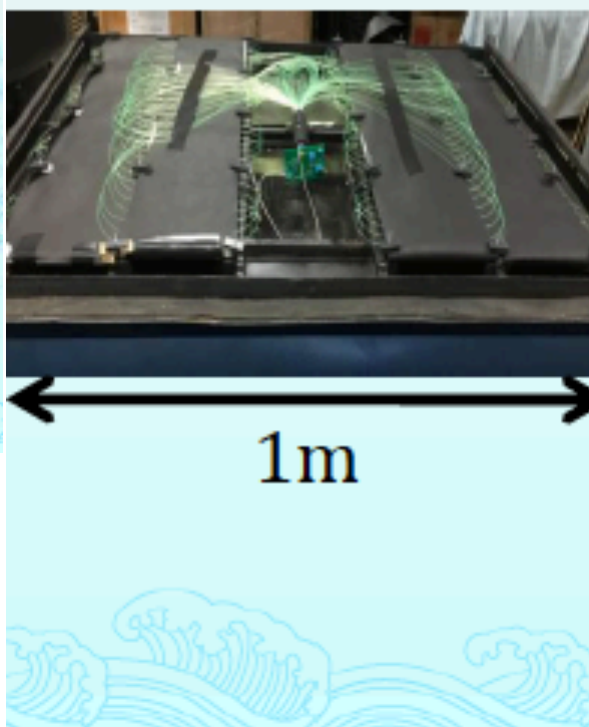
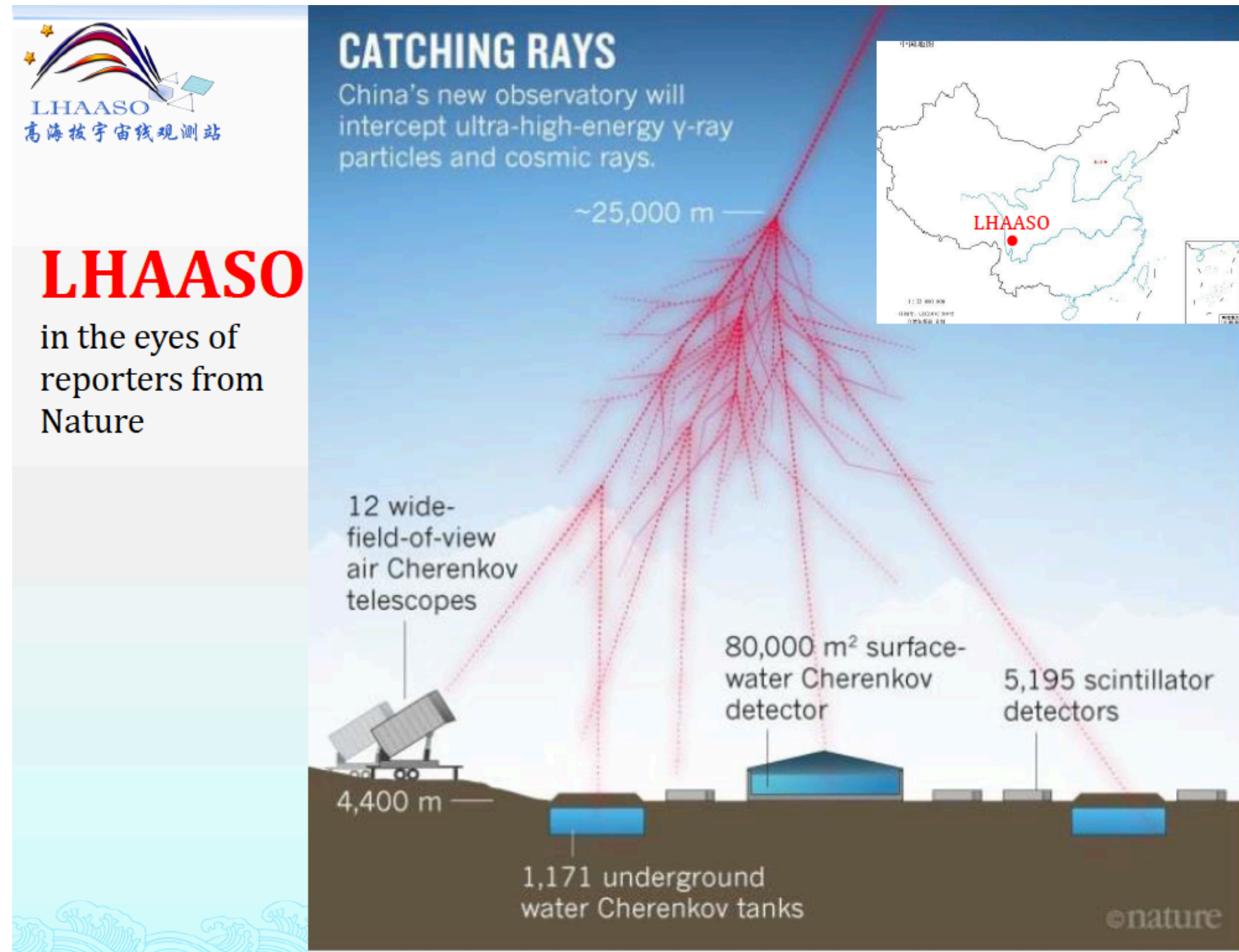
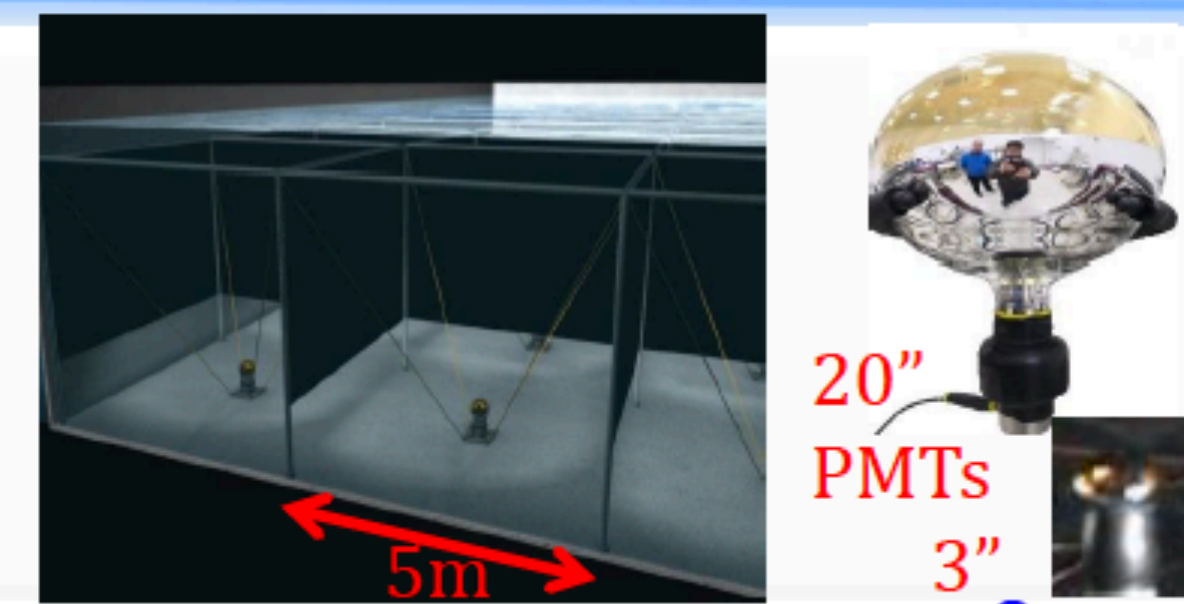


100,000 m²

LHAASO



Detector Layout in LHAASO



Tibet @ 4300 m
En operación desde 2019



LHAASO

in the eyes of
reporters from
Nature

CATCHING RAYS

China's new observatory will
intercept ultra-high-energy γ -ray
particles and cosmic rays.

~25,000 m —



12 wide-
field-of-view
air Cherenkov
telescopes

4,400 m —

80,000 m² surface-
water Cherenkov
detector

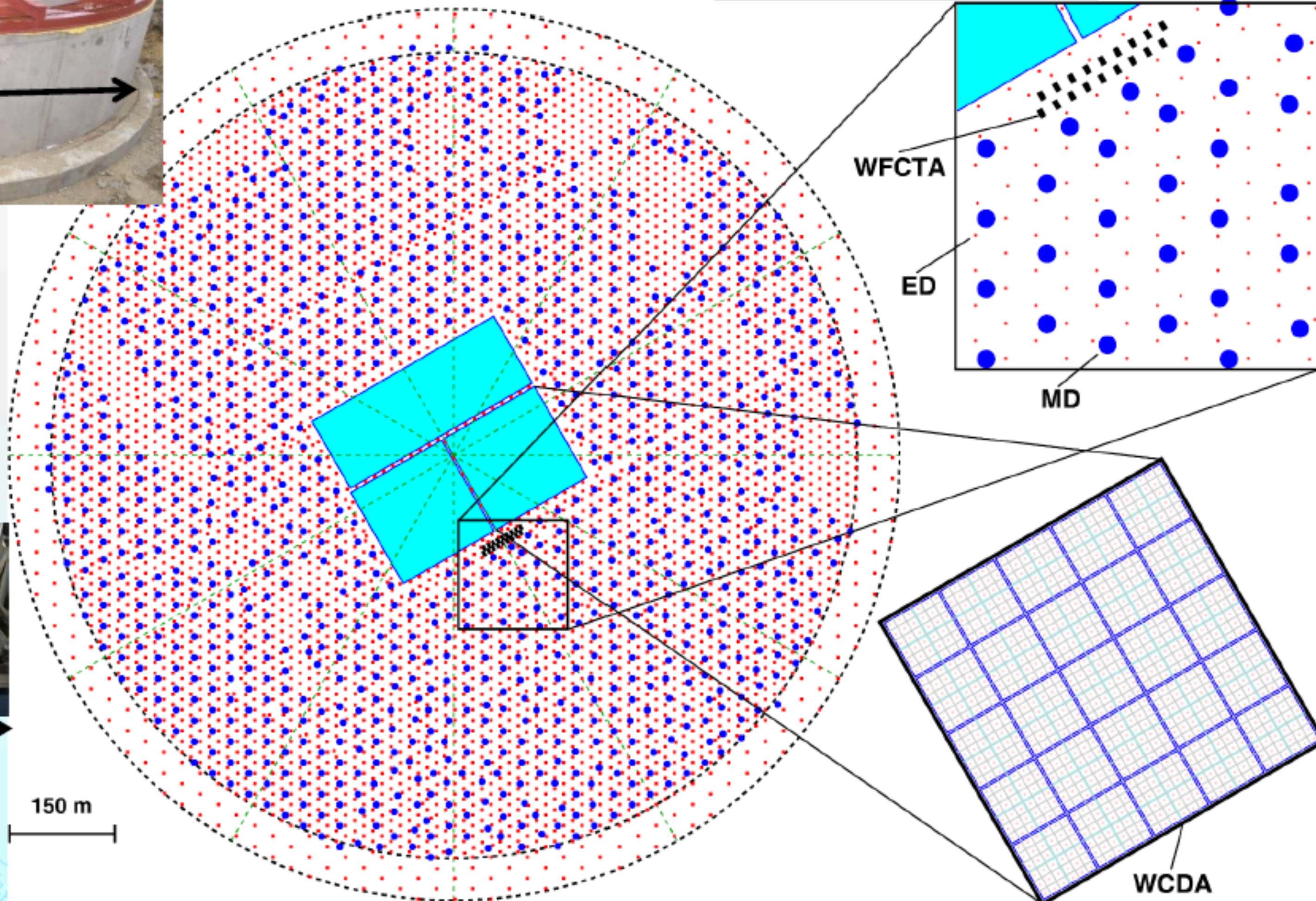
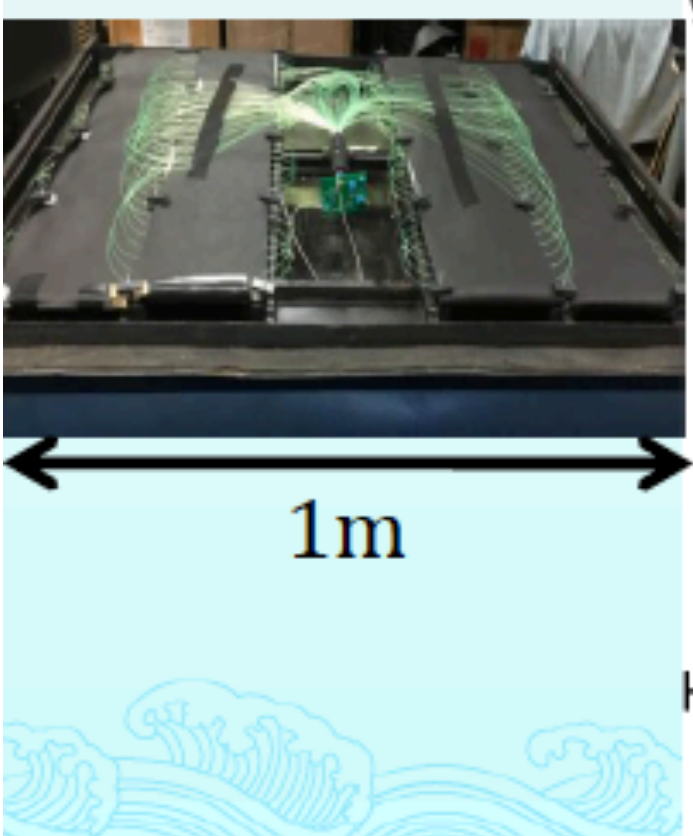
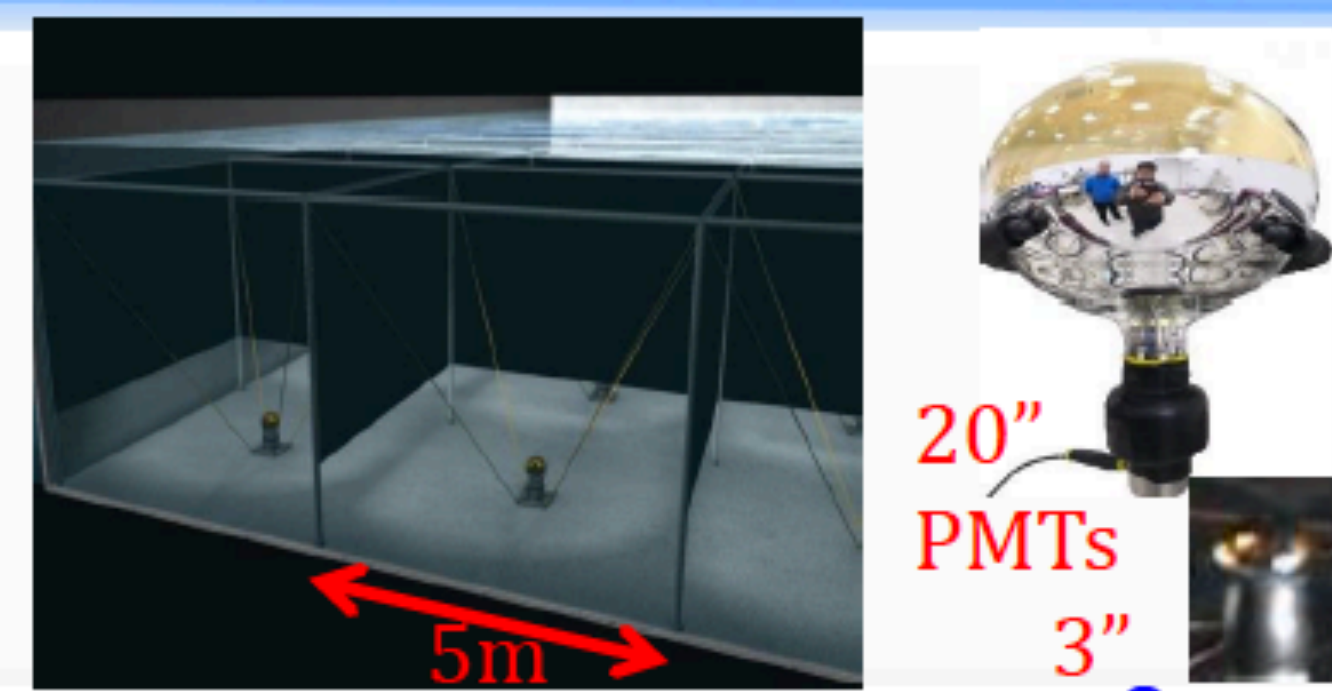
5,195 scintillator
detectors

1,171 underground
water Cherenkov tanks

onature

Tibet @ 4300 m
En operación desde 2019

Detector Layout in LHAASO



HAWC



Table 1 | UHE γ -ray sources

Source name	RA (°)	dec. (°)	Significance above 100 TeV ($\times\sigma$)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	-13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	-5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	-3.65	8.5	$0.26 - 0.10^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	-0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71 - 0.07^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)

Celestial coordinates (RA, dec.); statistical significance of detection above 100 TeV (calculated using a point-like template for the Crab Nebula and LHAASO J2108+5157 and 0.3° extension templates for the other sources); the corresponding differential photon fluxes at 100 TeV; and detected highest photon energies. Errors are estimated as the boundary values of the area that contains $\pm 34.14\%$ of events with respect to the most probable value of the event distribution. In most cases, the distribution is a Gaussian and the error is 1σ .

LHAASO Collaboration, Nature, May 2021

SWGO

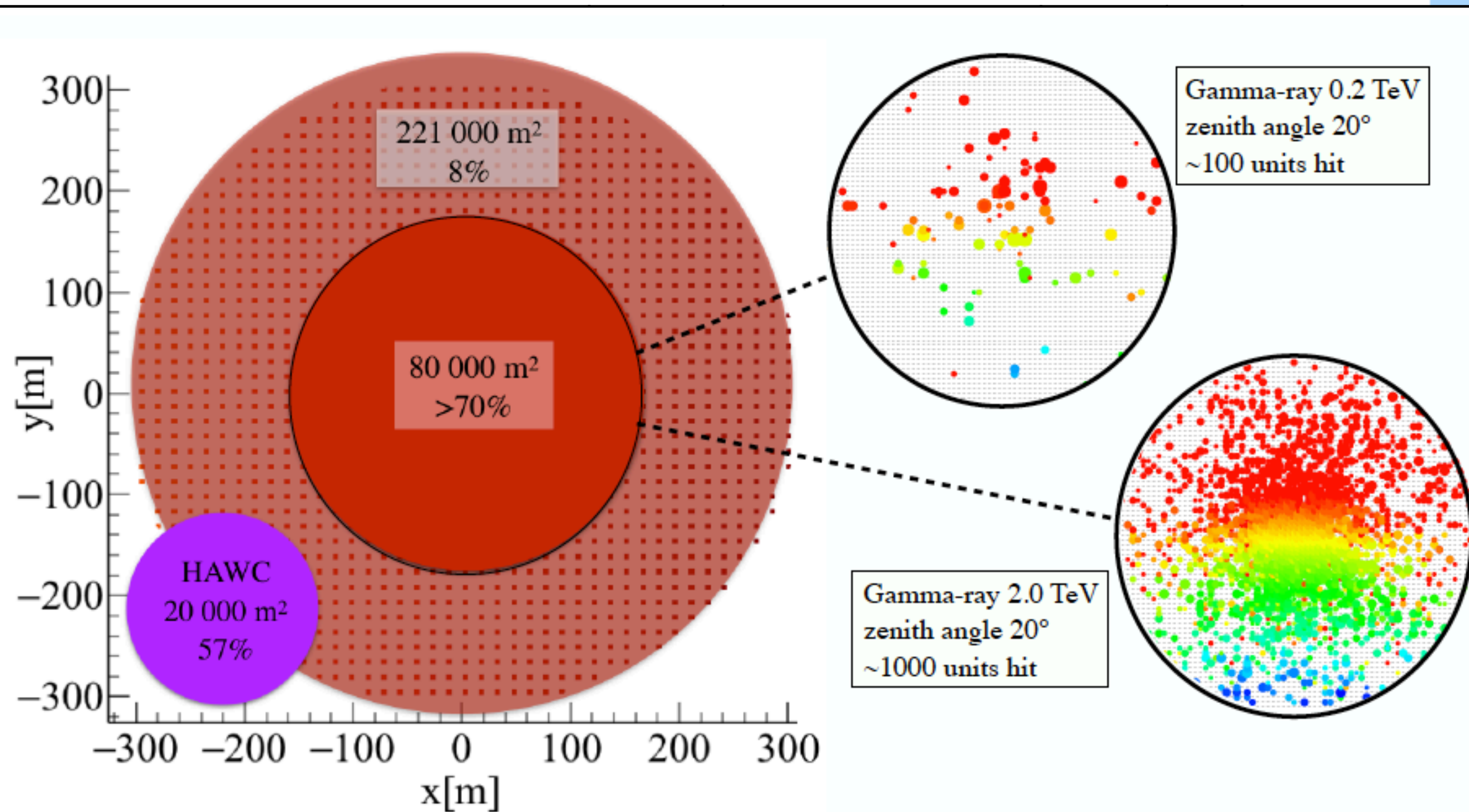
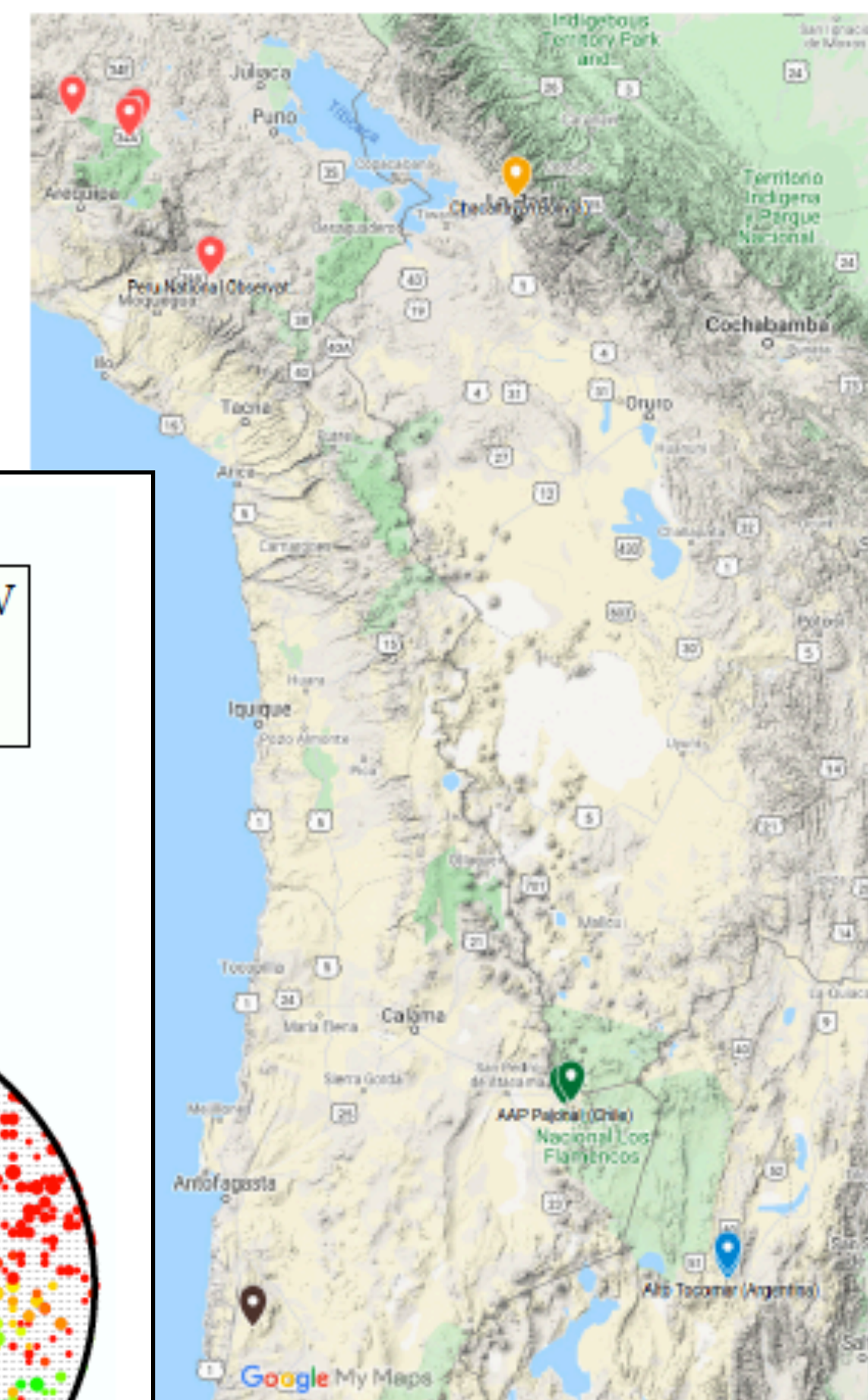


Figure 4: *Left:* Array configuration with instrumented areas and ground coverage indicated



SWGO sites

- Alto Tocomar (Argentina)
- Cerro Vecar (Argentina)
- Chacaltaya (Bolivia)
- AAP Pajonal (Chile)
- AAP Pampa La Bola (Chile)
- Lake Sibinacocha (Peru)
- Imata (Peru)
- Sumbay (Peru)
- Peru National Observatory (Peru)
- Yanque (Peru)

Important places

- Cerro Armazones (CTA-S site)

SWGO LASF4ARI white paper
& Vicha (ICHEP 2020)

El futuro de HAWC

- HAWC ha dejado de ser el mayor instrumento de su tipo.
 - Caso científico post-2025 (LHAASO, SWGO) en proceso.
 - Pocos sitios en el mundo por encima de 4000m para detectores de este tipo.
- Permiso del sitio por SEMARNAT hasta 2025.
 - INAOE por solicitar la extensión a 2035.
- Financiamiento asegurado hasta 2025.
 - ¿Extensiones? ¿Desmantelamiento ~2030?

