Guillermo Haro 2011

Surveying the high energy γ-ray sky

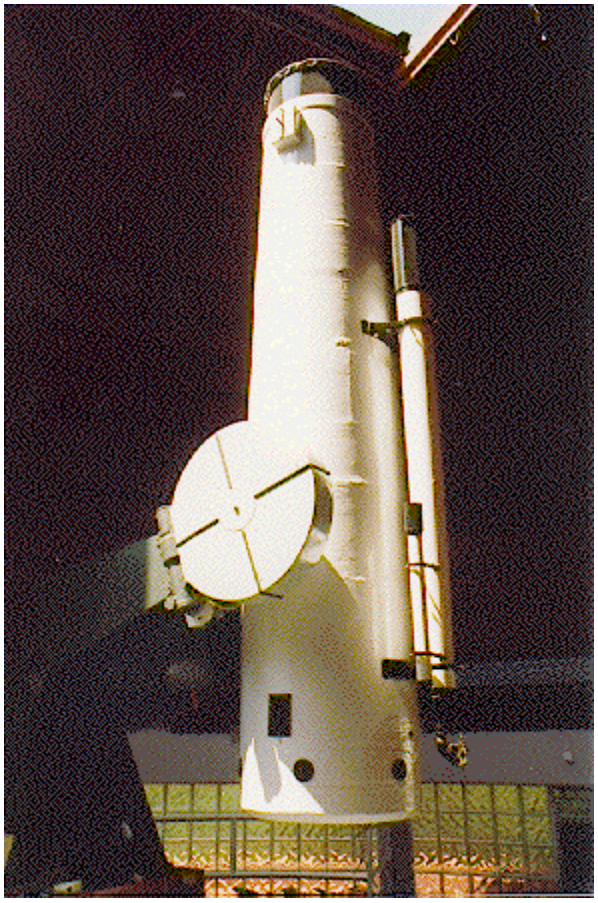
Alberto Carramiñana
Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE)
Tonantzintla, Puebla, México

GH workshop, 5 July 2011

Welcome to Tonantzintla

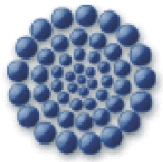
Site of the Observatorio Astrofísico Nacional (1942-1971)

- First science research center in Mexico outside DF
- HH objects; T Tauri; flare stars; planetary nebulae; blue galaxies (TON / PHL)



Welcome to INAOE

Instituto Nacional de Astrofísica, Óptica y Electrónica

- Founded by Guillermo Haro in 1971
- Research in areas of expertise
- Postgraduate studies
- Scientific, technological and R&D projects
- Presence at Tonantzintla, Cananea, Sierra Negra and Ciudad Serdán
- Part of the 

network of public research centers

Welcome to GH workshop

GH program founded in 1996 to promote collaborative research in Astrophysics

- 1996: Starburst activity in galaxies (wk + conf)
- 1998: Interstellar turbulence
- 2000: AGN-starburst connection (advanced lectures)
- 2002: mm-wave cosmology
- 2005: Pan-Chromatic view on clusters of galaxies
- 2008: science with SASIR
- 2010: compact superstellar clusters

GH workshop format

- Morning talks promoting ample discussion
- GH lunch at INAOE (registered participants)
- Afternoon sessions: groups, dedicated sessions, ...
- Social activities: Sierra Negra visit; trip to Oaxaca
- Public talk -- Miguel Mostafá “Atrapando las partículas más rápidas del Universo”

GH2011

"Surveying the high energy γ-ray sky"

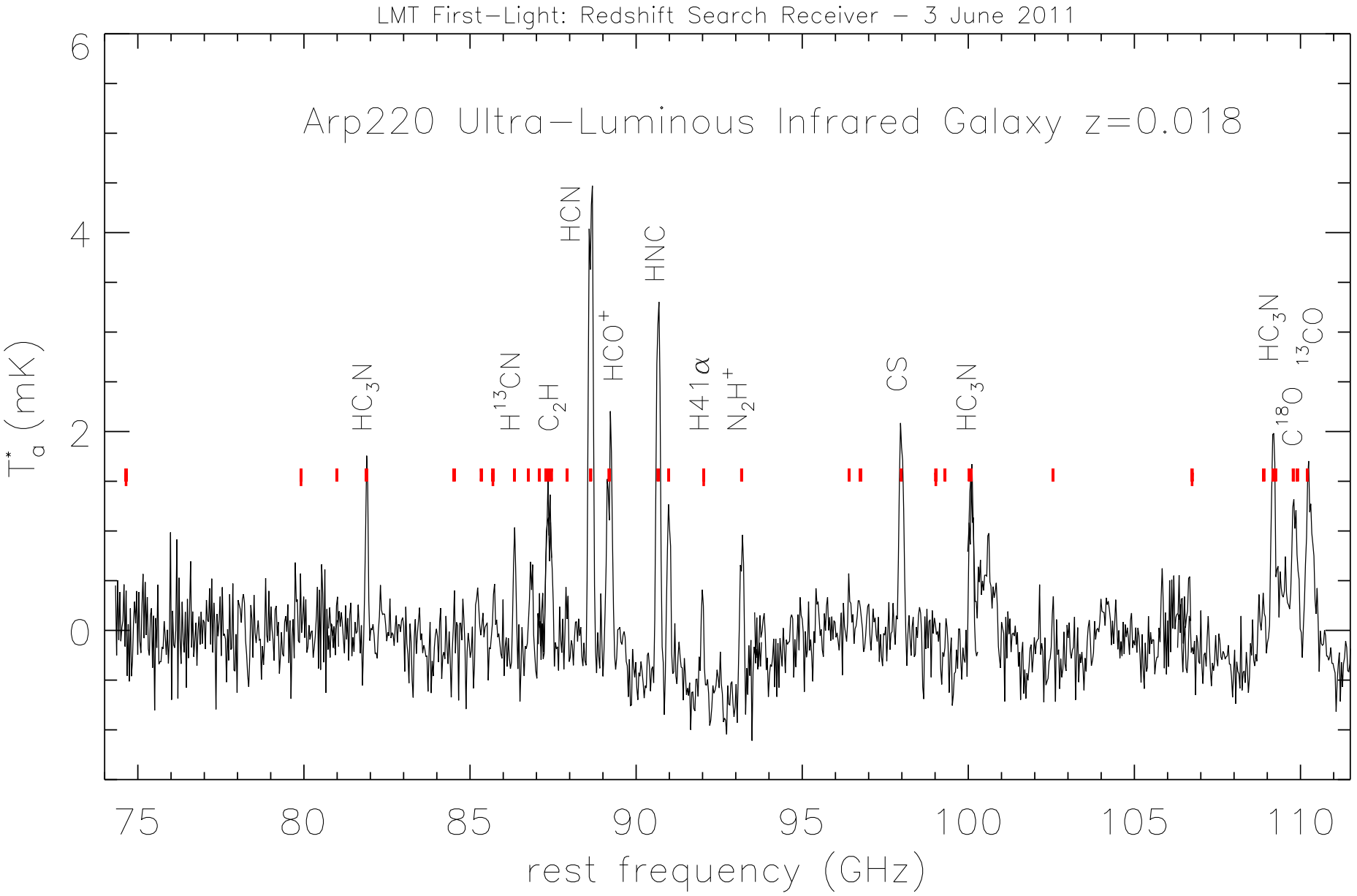
Motivated by:

- recent and current surveys of the HE γ-ray sky

- connection with traditional fields of astrophysical research in Mexico (star formation; AGNs)

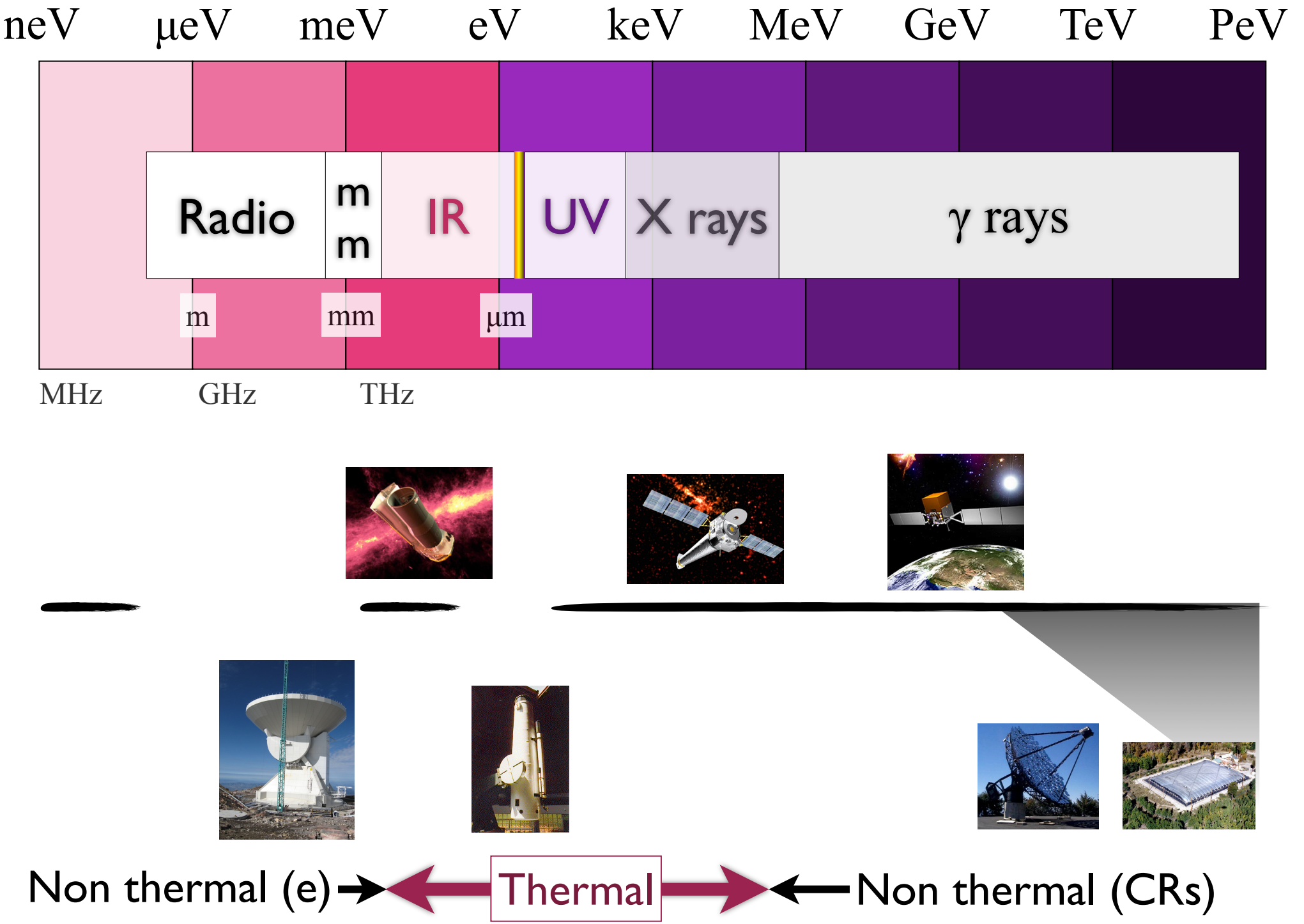
- Mexican participation in synergic projects:

HAWC; SPM + OAGH optical and NIR surveys; Large Millimeter Telescope; other Sierra Negra projects (LAGO, SNT); SASIR/RATIR;


LMT First−Light: Redshift Search Receiver − 3 June 2011
Arp220 Ultra−Luminous Infrared Galaxy z=0.018
T_a^* (mK)
rest frequency (GHz)
HC$_3$N
H^{13}CN
C$_2$H
HCN
HCO$^+$
HNC
H41α
N$_2$H$^+$
CS
HC$_3$N
HC$_3$N
C^{18}O
^{13}CO

Surveying HE γ-rays

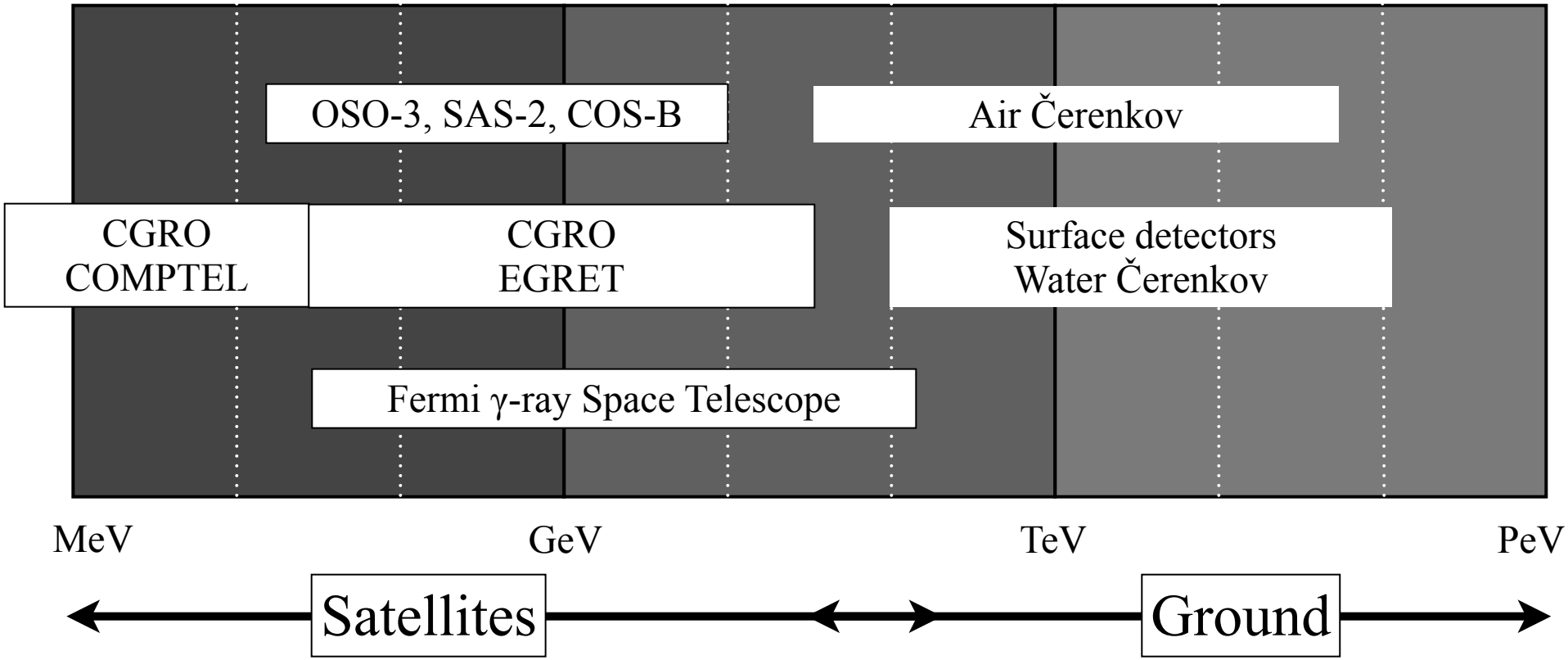
- Gamma-rays not produced under thermal equilibrium
- Diagnostic of particle acceleration
  - magnetic fields
  - strong shocks
  - related with non-thermal radio emission


neV
μeV
meV
eV
keV
MeV
GeV
TeV
PeV
Radio
m
m
IR
UV
X rays
γ rays
m
mm
μm
MHz
GHz
THz
Non thermal (e)
Thermal
Non thermal (CRs)

γ-ray production processes

- Radioactive decay:
  - Al26 @ 1.809 MeV with $t_{1/2} \approx 0.72$ Myrs
- Pair annihilation: $ee \rightarrow \gamma\gamma$
- Bremsstrahlung: $eZ \rightarrow eZ\gamma$
- Inverse Compton scattering: $e\gamma \rightarrow e\gamma$
- Neutral pion decay: $\pi^0 \rightarrow \gamma\gamma$

The gamma band



γ-ray space observatories

Telescope	Operations	Photons	Highlight
OSO III	1967-68	621	Galactic plane
SAS II	1972-73	13k	Vela and Crab pulsars; γ 195+5
COS B	1975-82	200k	First catalogue (25 sources); extragalactic sources (3C 273)
CGRO - COMPTEL	1991-2000		First (and only) all-sky MeV survey
CGRO - EGRET	1991-2000	1.5 M	Blazars as a class of sources; 3EG catalog (271 sources)
Fermi *γ*-ST	2008 +	195 M	Launched 2008. PSR Catalog; 1FGL

CsI layers to the number initiated in the plastic layers was 10 ± 1 for the more frequent atmospheric events, and 10 ± 4 for the few sky events recorded during the brief period. We consider both values to be consistent with the conclusion that most of the atmospheric and the sky events were electromagnetic in nature.

c) *Celestial Distribution of Sky Events*

The celestial distribution of all of the sky events is shown on an equal-solid-angle projection in figure 7 together with the relative exposure as indicated by the distribution of the random events (to avoid crowding, only one in 10 of the random events used in the numerical analysis is displayed). Evidently some of the nonuniformity in the celestial distribution of sky events merely reflects the nonuniformity of the exposure.

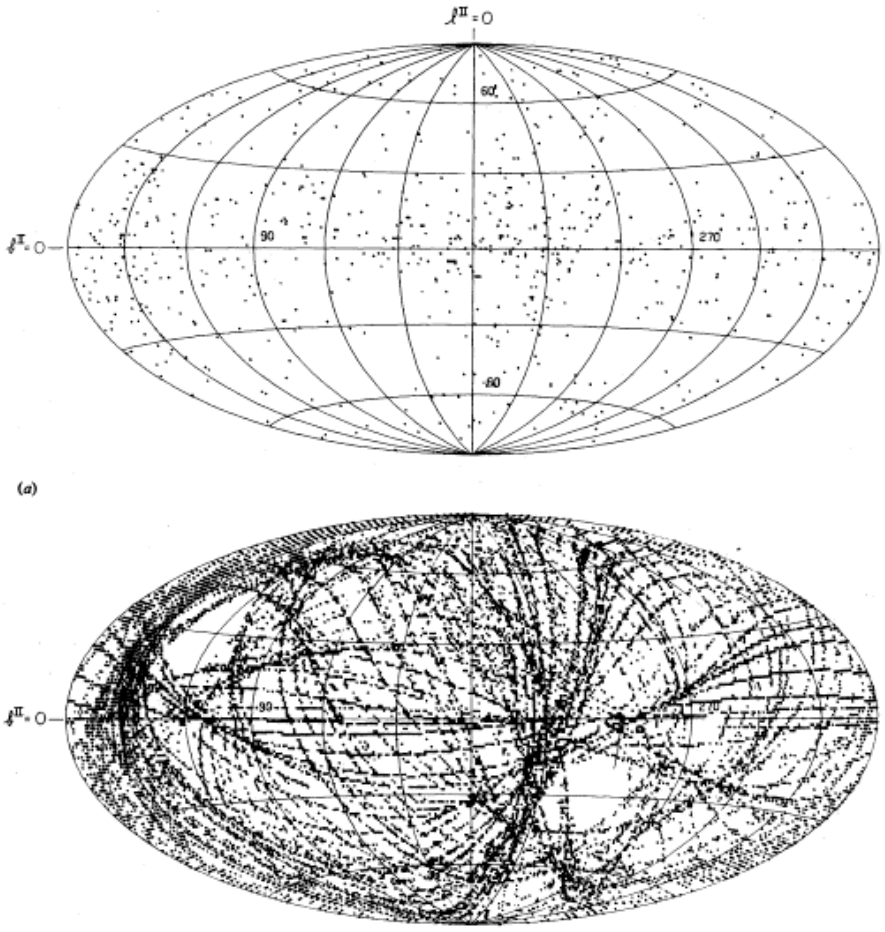


FIG. 7.—Summary maps of the distributions of (*a*) the real and (*b*) one-tenth of the artificial events over the sky in galactic coordinates.

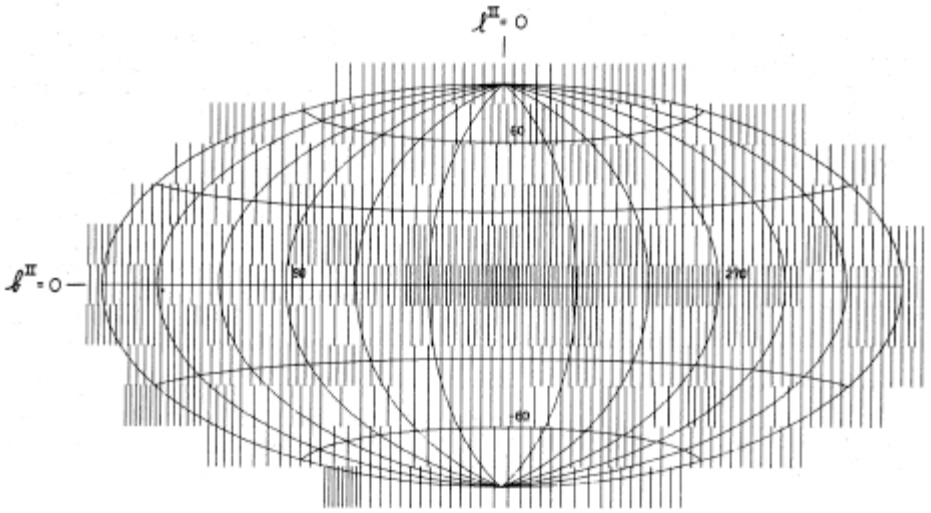
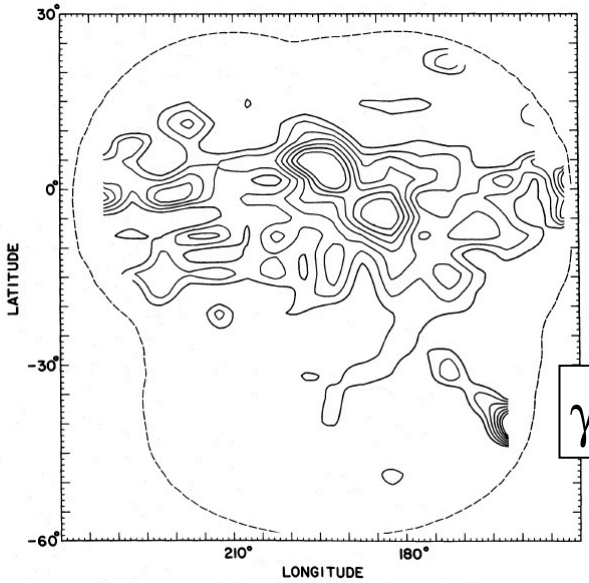


FIG. 8.—Sky map of the γ-ray intensity in galactic coordinates. The element of area on the map to which the formula given in the text applies is approximately 245 square degrees.

Kraushaar et al. (1972)

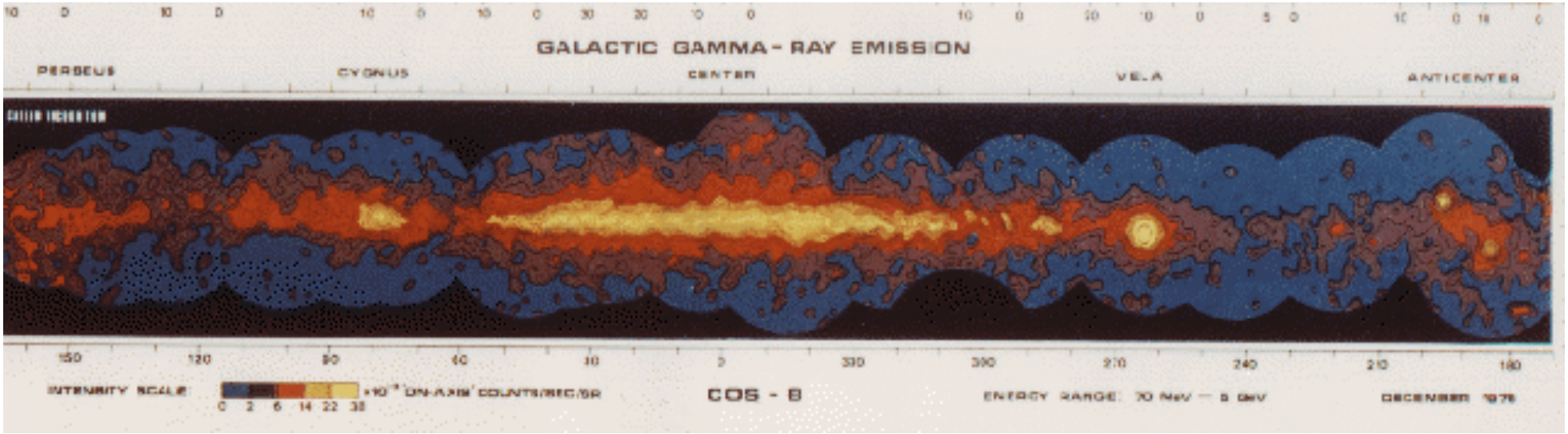
COS-B & SAS-2



γ195+5

FIG. 1.—Contour map of γ-ray intensities observed by SAS-2 at energies above 35 MeV in the galactic anticenter region. The contour lines represent 75%, 66%, 57%, 48%, 39%, 30%, and 21% of the maximum intensity, which is 4.25×10^{-4} photons ($E > 35$ MeV) $cm^{-2} s^{-1} sr^{-1}$. The 66% and 21% contour lines are slightly darker than the others. The apparent positions of the two maxima near 185°, −6° and 195°, +5° differ slightly from these coordinates principally due to the presence of the diffuse emission from the galactic plane, as discussed in the text. *Dashed line*, limit of the SAS-2 exposure in this region.

Thompson et al. 1977



2CG catalog: Swanenburg et al. (1981)

TABLE 1

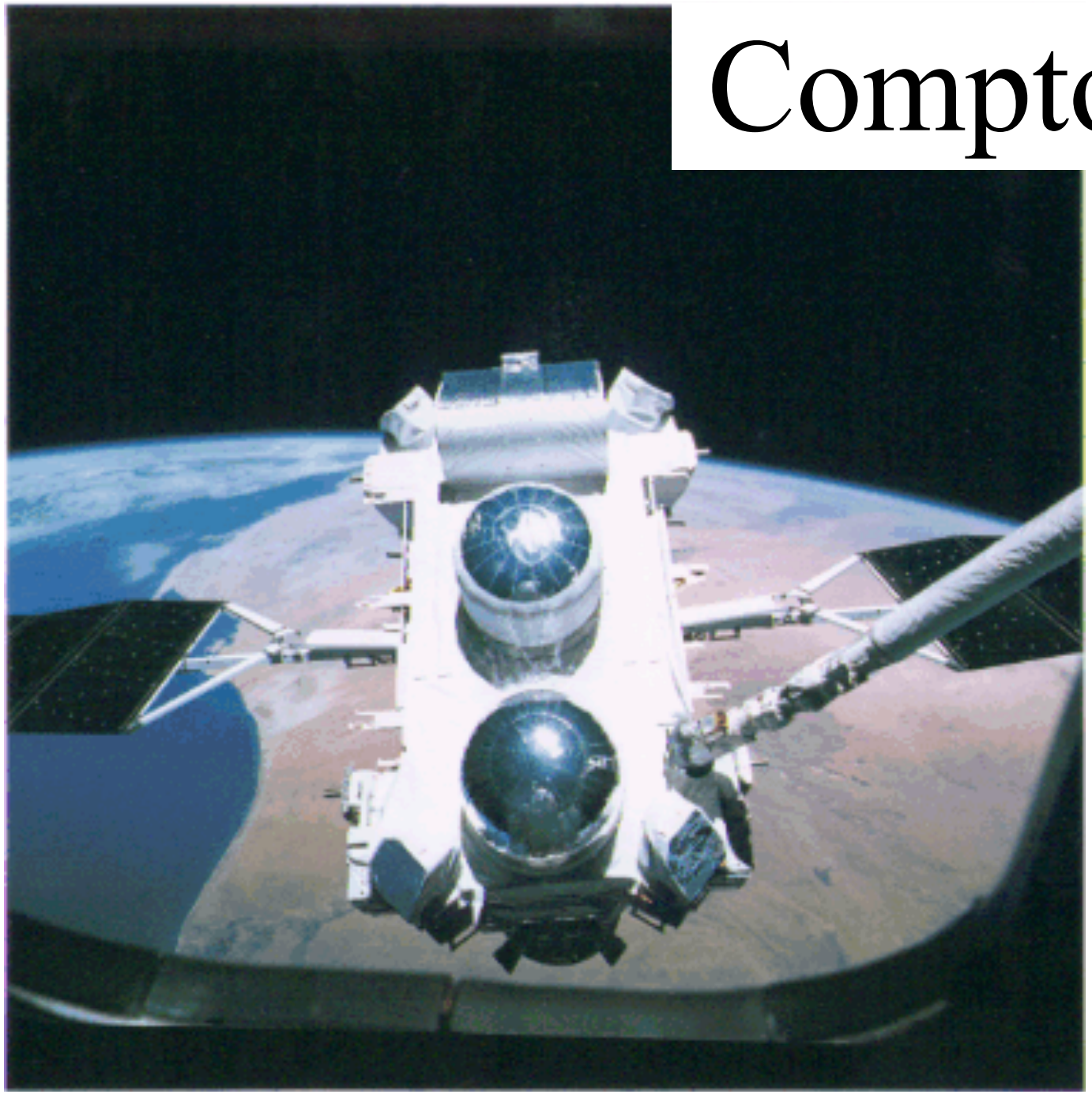
THE 2CG CATALOG OF GAMMA-RAY SOURCES

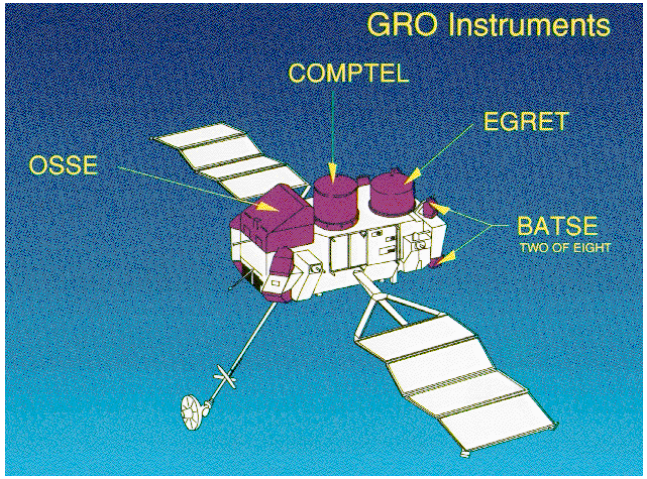
SOURCE NAME	NO. OF OBSERVATIONS	POSITION (degrees) l	POSITION (degrees) b	ERROR RADIUS (degrees)	FLUX[a] $E>100$ MeV (10^{-6} photons cm^{-2} s^{-1})	SPECTRAL[b] PARAMETER	COMMENTS	CG SOURCE (Hermsen *et al.* 1977)	IDENTIFICATION	REFERENCES
2CG 006−00.....	3	6.7	−0.5	1.0	2.4	0.39±0.08		...	...	...
2CG 010−31.....	1	10.5	−31.5	1.5	1.2	...		...	...	...
2CG 013+00.....	4	13.7	+0.6	1.0	1.0	0.68±0.14		...	...	...
2CG 036+01.....	3	36.5	+1.5	1.0	1.9	0.27±0.07		...	...	...
2CG 054+01.....	3	54.2	+1.7	1.0	1.3	0.20±0.09		...	...	...
2CG 065+00.....	4	65.7	0.0	0.8	1.2	0.24±0.09		CG 64+0	...	...
2CG 075+00.....	5	75.0	0.0	1.0	1.3	...	could be an extended feature	CG 75−0	...	...
2CG 078+01.....	5	78.0	+1.5	1.0	2.5	...	could be an extended feature	CG 78+1	...	...
2CG 095+04.....	3	95.5	+4.2	1.5	1.1	...		...	...	...
2CG 121+04.....	3	121.0	+4.0	1.0	1.0	0.43±0.12		CG 121+3		
2CG 135+01.....	3	135.0	+1.5	1.0	1.0	0.31±0.10		CG 135+1	...	...
2CG 184−05.....	4	184.5	−5.8	0.4	3.7	0.18±0.04		CG 185−5	PSR 0531+21	Kniffen *et al.* (1974)
2CG 195+04.....	3	195.1	+4.5	0.4	4.8	0.33+0.04	γ195+5	CG 195−4	...	Thompson *et al.*(1977)
2CG 218−00.....	3	218.5	−0.5	1.3	1.0	0.20±0.08		...	...	...
2CG 235−01.....	2	235.5	−1.0	1.5	1.0	...		...	...	...
2CG 263−02.....	4	263.6	−2.5	0.3	13.2	0.36±0.02		CG 263−2	PSR 0833−45	Thompson *et al.*(1975)
2CG 284−00.....	1	284.3	−0.5	1.0	2.7	...	could be an extended feature	...	...	...
2CG 288−00.....	1	288.3	−0.7	1.3	1.6	...	could be an extended feature	...	...	...
2CG 289+64.....	2	289.3	+64.6	0.8	0.6	0.15±0.07		CG 291+65	3C 273	Swanenburg *et al.*(1978); Bignami *et al.* (1980)
2CG 311−01.....	2	311.5	−1.3	1.0	2.1	...		CG 312−1	...	...
2CG 333+01.....	3	333.5	+1.0	1.0	3.8	...		CG 333+0	...	...
2CG 342−02.....	5	342.9	−2.5	1.0	2.0	0.36±0.09		...	...	...
2CG 353+16.....	4	353.3	+16.0	1.5	1.1	0.24±0.09		...	ρ Oph	Mayer-Hasselwander *et al.* (1980)
2CG 356+00.....	1	356.5	+0.3	1.0	2.6	0.46±0.12	prob. variable	...	...	...
2CG 359−00.....	3	359.5	−0.7	1.0	1.8	...		...	...	...

[a] Assuming E^{-2} spectra.

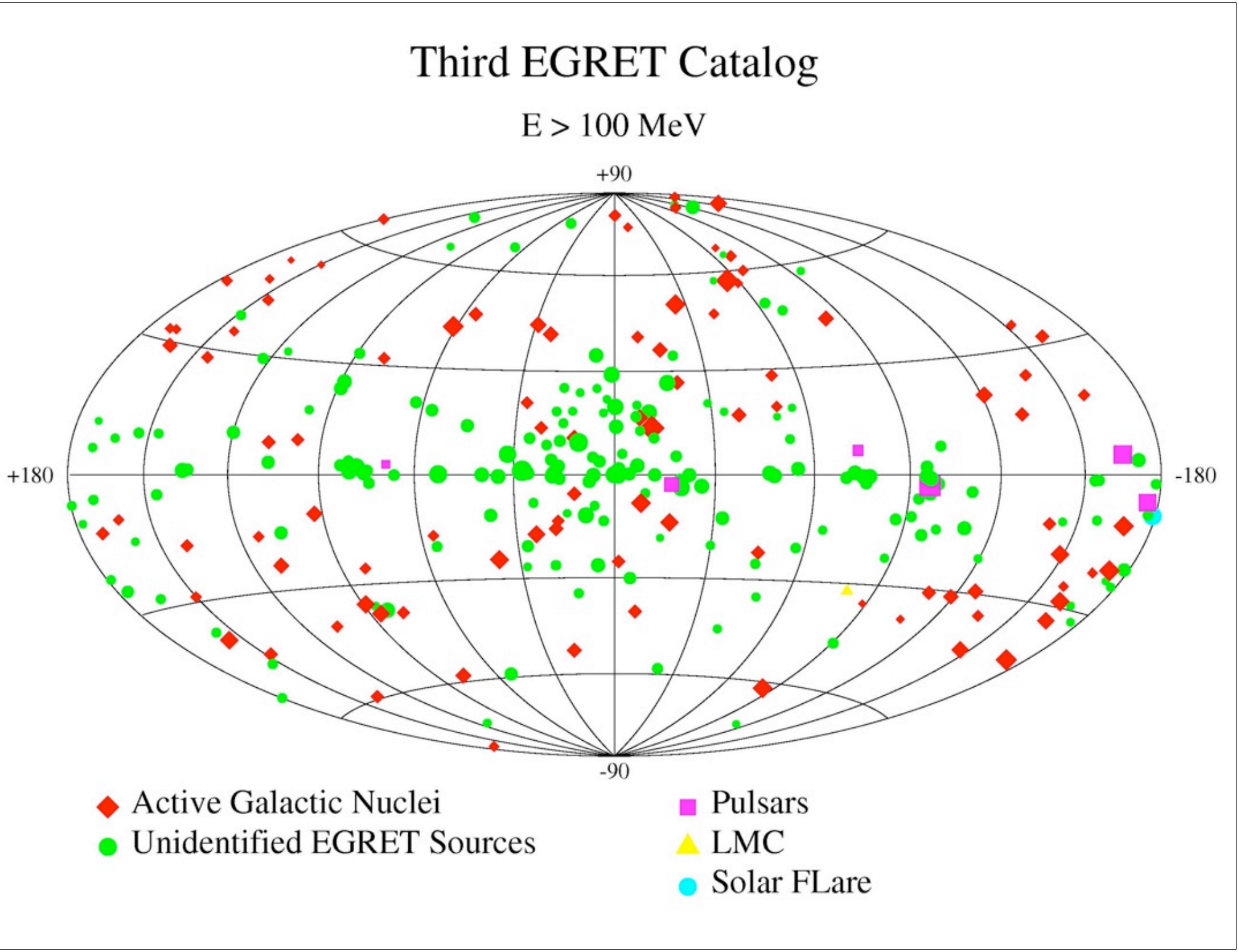
[b] Intensity ($E > 300$ MeV)/Intensity ($E > 100$ MeV), assuming E^{-2} spectra calculating both intensities.

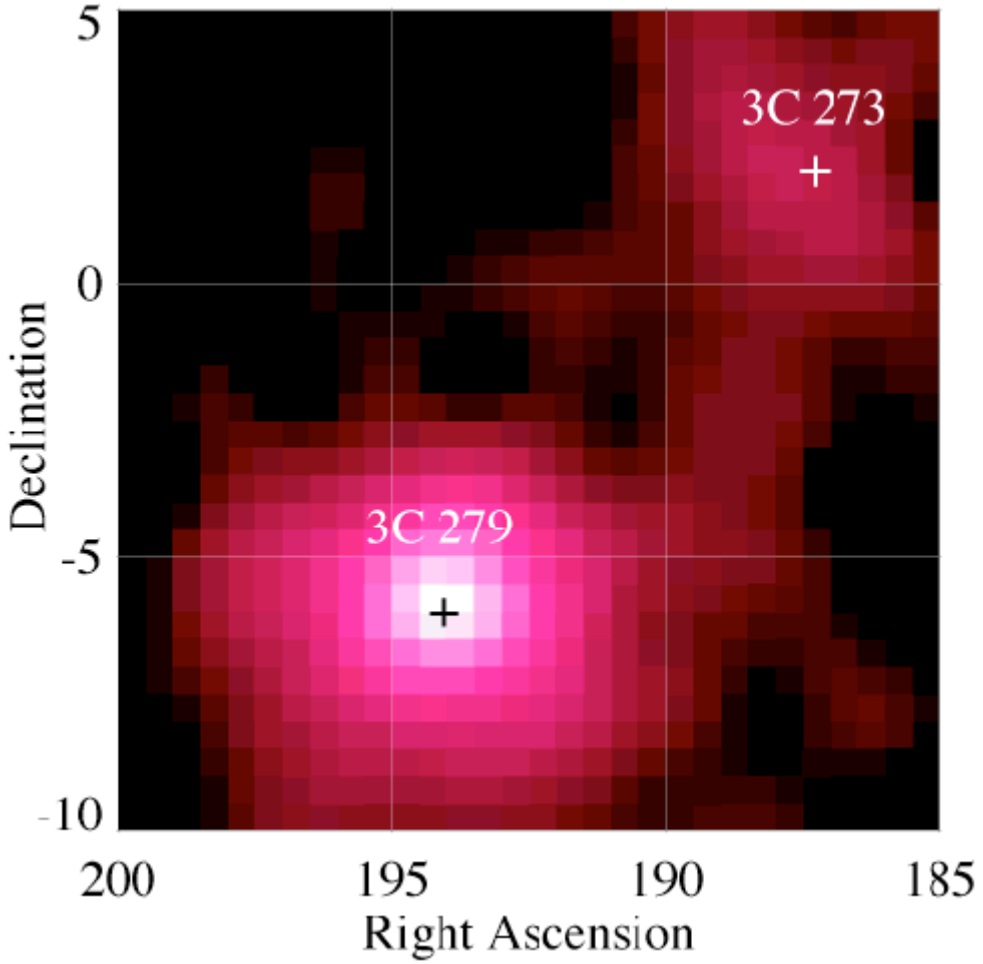
Compton GRO

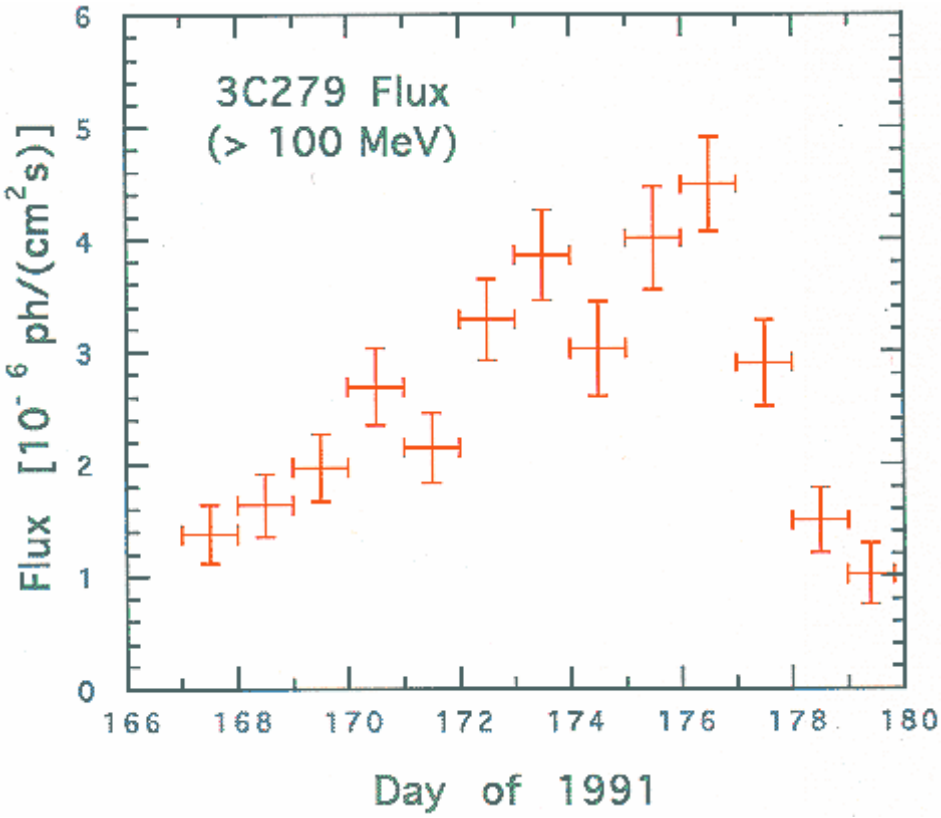




In orbit from 5 April 1991 to 4 June 2000


Third EGRET Catalog
E > 100 MeV
+90
+180
-180
-90
Active Galactic Nuclei
Unidentified EGRET Sources
Pulsars
LMC
Solar FLare


3C 273
3C 279
5
0
-5
-10
200
195
190
185
Declination
Right Ascension


3C279 Flux
(> 100 MeV)
Flux [10⁻⁶ ph/(cm²s)]
0
1
2
3
4
5
6
166
168
170
172
174
176
178
180
Day of 1991

EGRET sources

- Milky Way (& LMC): star formation → cosmic-ray interaction with gas in interstellar medium
  - Sun, M31 and starbursts galaxies undetected.
- Pulsars: isolated rotating neutron stars → particle acceleration through electrodynamical processes in magnetosphere
- Blazars: radio loud flat spectrum QSOs → relativistic shocks in jets of accreting SMBH
- Unidentified sources: presumably PSRs + AGNs

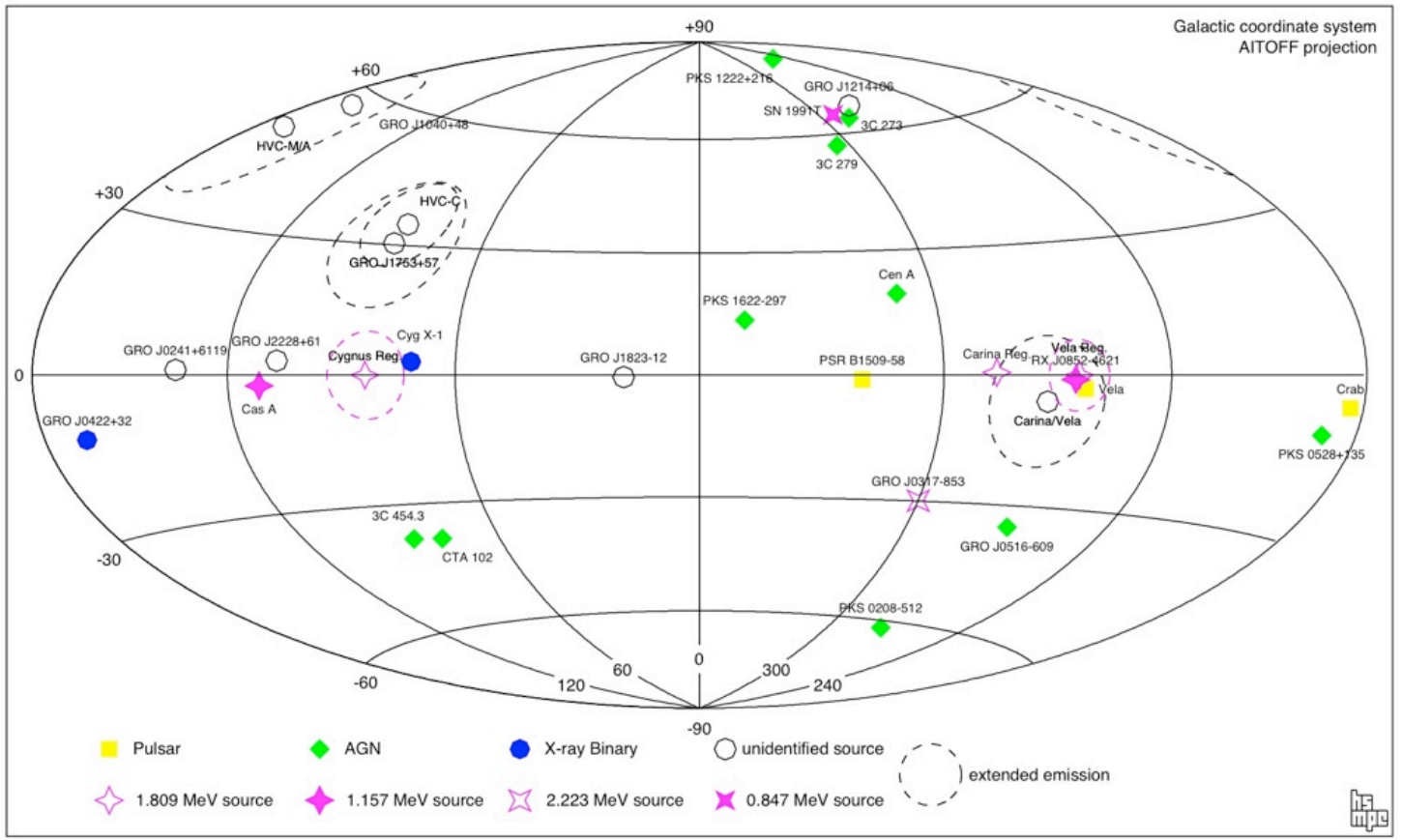
Table 13: Summary of Most Significant COMPTEL Source Detections.

Type of Source	Number of Sources	Comments
Spin-Down Pulsars:	3	Crab, Vela, PSR B1509-58.
Stellar Black Hole Candidates:	2	Cyg X-1, Nova Persei 1992 (GRO J0422+32).
Supernova Remnants: (Continuum Emission)	1	Crab nebula.
Active Galactic Nuclei:	10	CTA 102, 3C 454.3, PKS 0528+134, GRO J 0516-609, PKS 0208-512, 3C 273, PKS 1222+216, 3C 279, Cen A, PKS 1622-297.
Unidentified Sources:		
• $\|b\| < 10°$	4	GRO J1823-12, GRO J2228+61 (2CG 106+1.5), GRO J0241+6119 (2CG 135+01), Carina/Vela region (extended).
• $\|b\| > 10°$	5	GRO J1753+57 (extended), GRO J1040+48, GRO J1214+06, HVC complexes M and A area (extended), HVC complex C (extended).
Gamma-Ray Line Sources:		
• 1.809 MeV (^{26}Al)	3	Cygnus region (extended), Vela region (extended, may include RX J0852-4621), Carina region.
• 1.157 MeV (^{44}Ti)	2	Cas A, RX J0852-4621 (GRO J0852-4642).
• 0847 and 1.238 MeV (^{56}Co)	1	SN 1991T.
• 2.223 MeV (n-capture)	1	GRO J0317-853.
Gamma-Ray Burst Sources: (within COMPTEL field-of- up to Phase IV/Cycle-5)	31	Location error radii vary from 0.34° to 2.79° (mean error radius: view 1.13°).

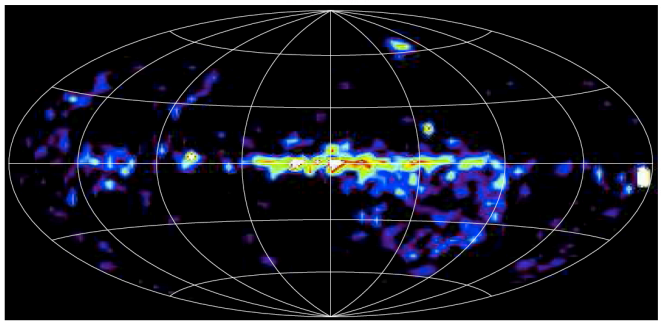
Schönfelder et al. (2000)

COMPTEL Source Catalog

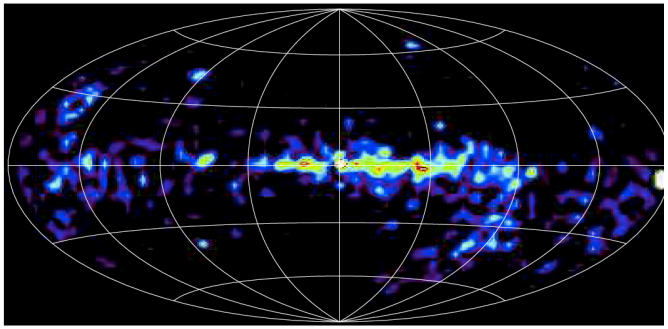
0.75-30 MeV



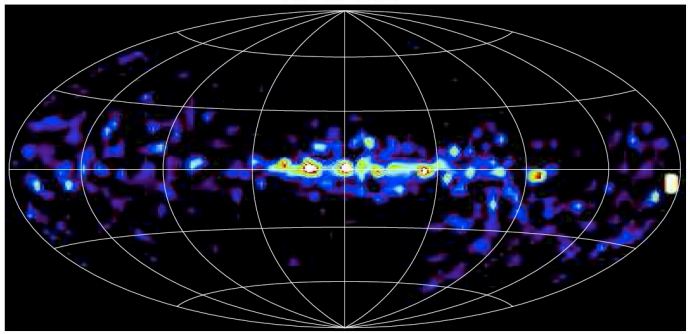
1–3 MeV



3–10 MeV



10–30 MeV

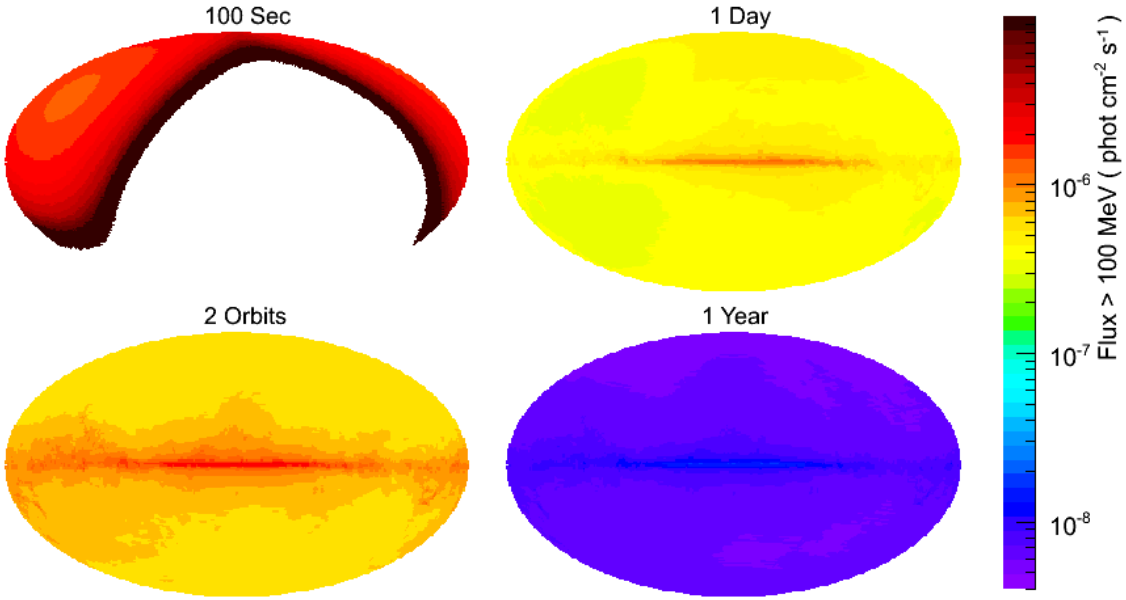


GLAST →

11 junio 2008

	LAT (min. spec.)	EGRET
Energy range	20 MeV - 300 GeV	20 MeV - 30 GeV
Peak effective area	> 8000 cm^2	1500 cm^2
Field of view	> 2 sr	0.5 sr
Single photon angular resolution	<3.5º @ 100 MeV <0.15º @ >10 GeV	5.8º @ 100 MeV 0.5º @ 10 GeV
Energy resolution	< 10%	10%
Deadtime per event	< 100μs	100 ms
Source location	< 0.5 arcmin	15 arcmin
Point source sensitivity	$< 6 \times 10^{-9}$ $cm^{-2}s^{-1}$	$\sim 10^{-7}$ $cm^{-2}s^{-1}$

Fermi operations and observing modes

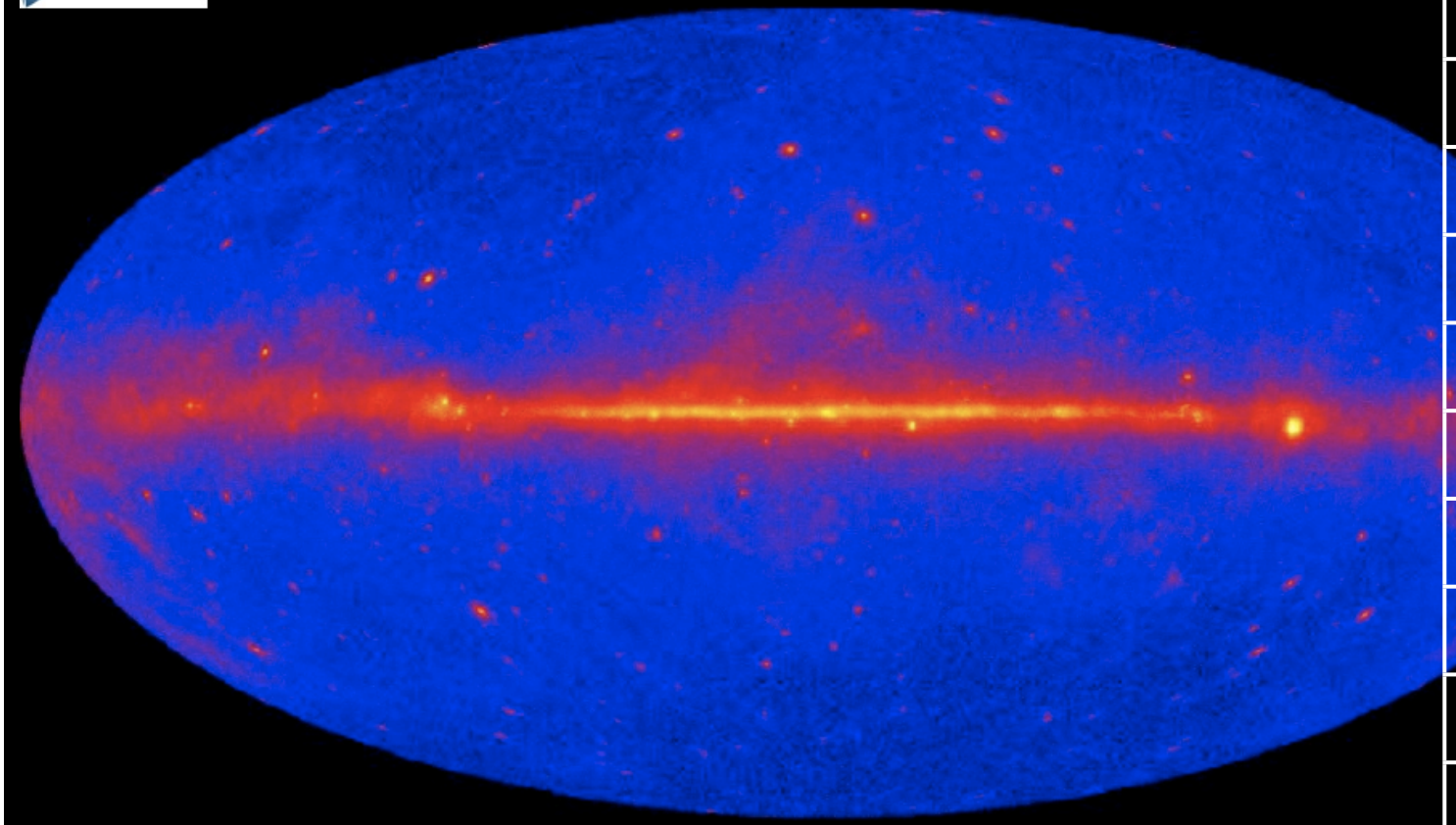


LAT sensitivity on 4 different timescales: 100 s, 1 orbit (96 min), 1 day and 1 year

- 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.
  - 35 deg rocking angle to Sept 2, 50 deg thereafter.
- 30 ARRs
  - 5 hour pointed mode observations in response to bright GBM detected GRB
- LAT Calibrations (13 hours), Engineering (5 days)
  - Very high ontime!

J. Mc Enery talk, 1st Fermi Symp.

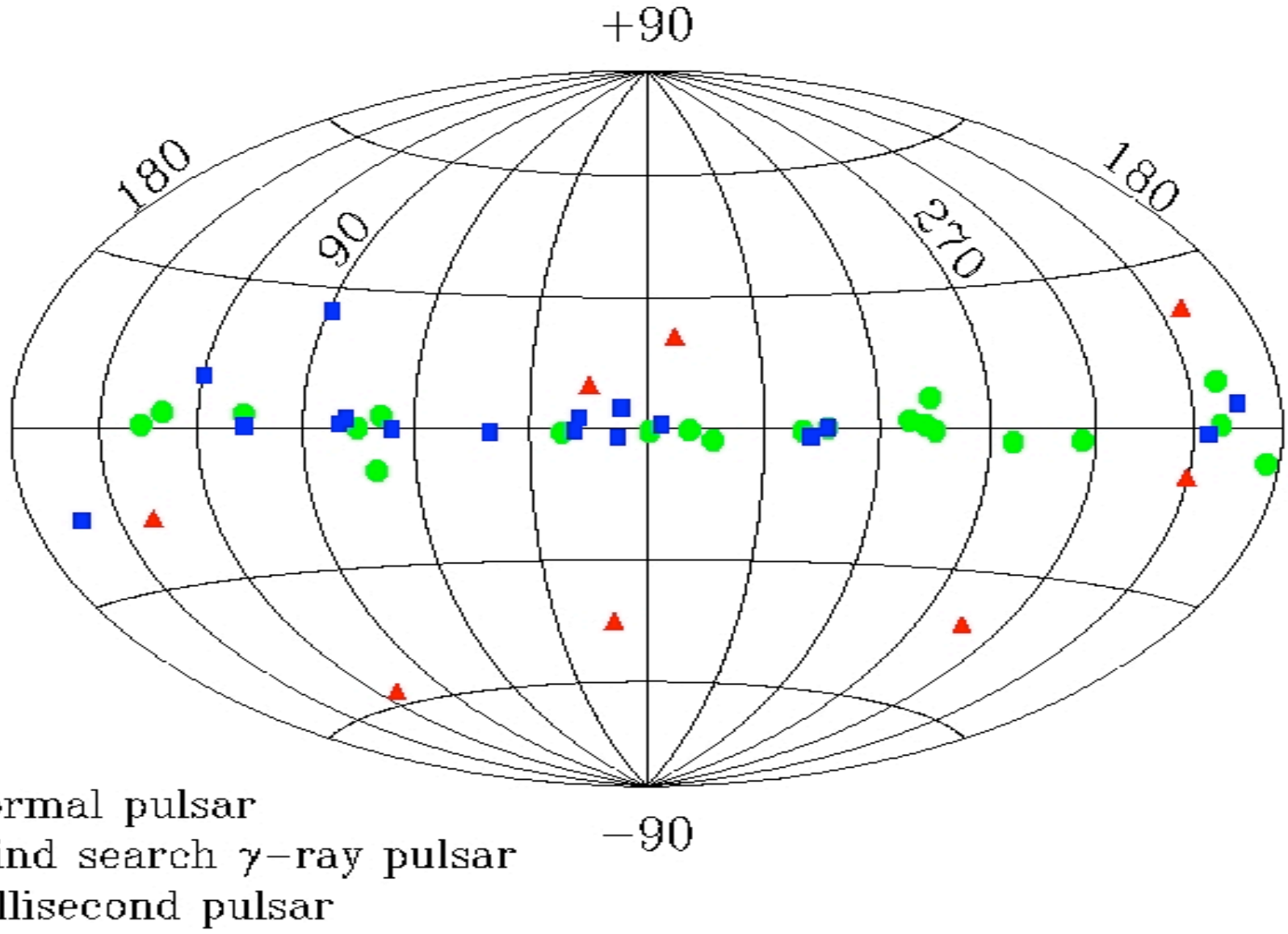
> 1000 LAT sources



- Front > 200 MeV, Back > 400 MeV, log color scale
- Galactic coordinates, Aitoff projection

1FGL	
Extragalactic = 658	
Bl Lac	292
FSRQ	278
Non blazar AGN	25
Uncertain AGN	59
Starburst galaxy	2
Normal galaxy	2
Galactic = 85	
Pulsar	52
SNR	4
snr, pwn, psr	18
Globular cluster	8
XRB	2
μ-cuasar	1
No association = 708	

Fermi PSRcat



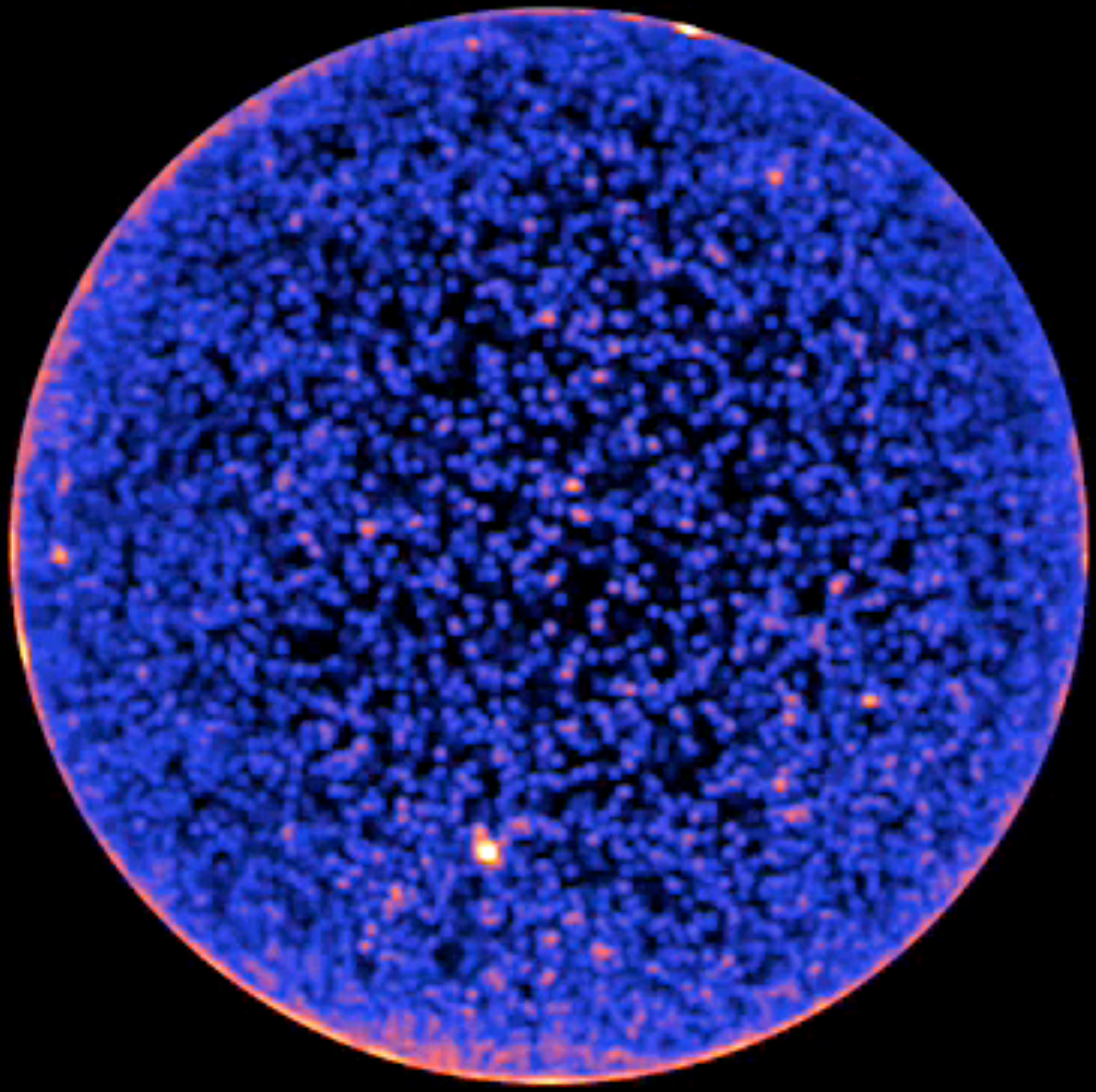
PSR birthrate 1/50 yr with γ-ray selected representing half or more

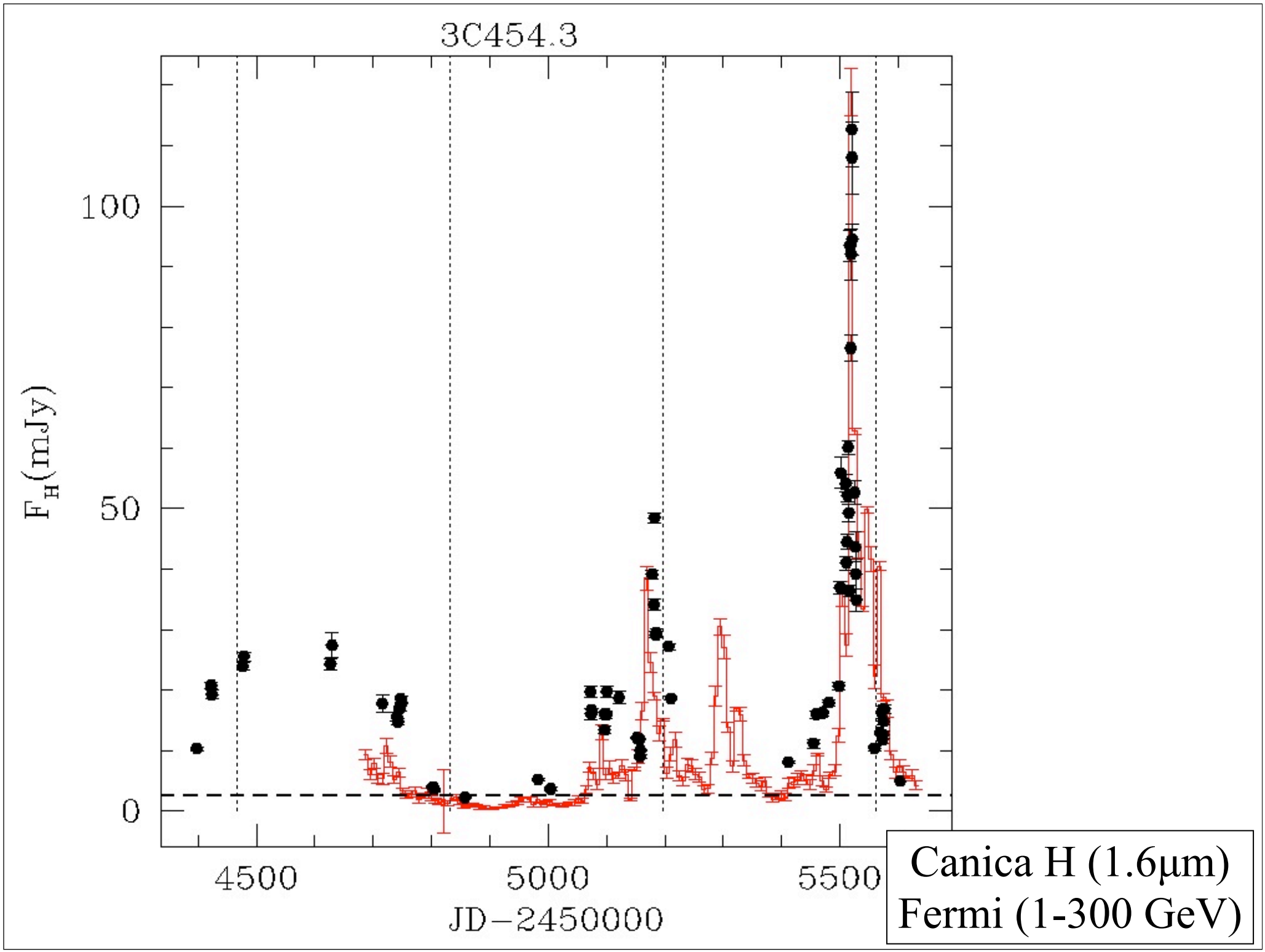
Fermi extragalactic sources

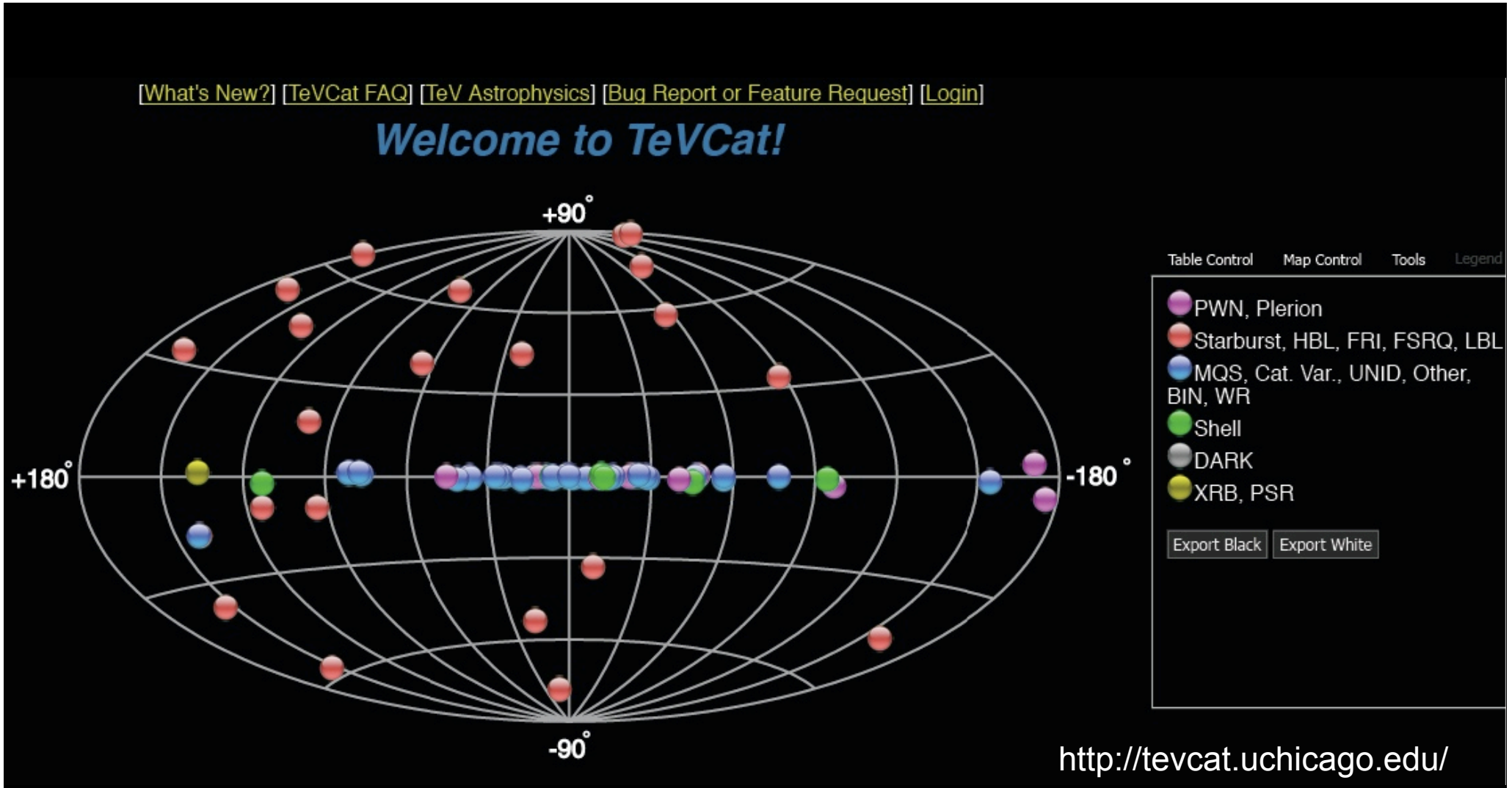
Normal galaxies	Starburst galaxies	Radio galaxies	Seyferts	FSRQ	Bl Lac
MW LMC SMC no M31!?	M82, NGC 253 NGC 4945 (Sb or Sy 2?)	M87, Cen A, NGC1275, NGC1218, NGC 6251	PMN J0948+0022, PKS 1502+036, PKS 2004-447, NGC 6951	Classical EGRETs, 3C 454.3	EGRETs and TeV sources
SF cosmic rays interacting with ISM matter	Larger SF than normal galaxies, no variability found. Weak AGN in M82?	Variable, particle acceleration in mild jet, misaligned AGN	Narrow line Sy1 Sy 2 LINER Maybe radio quiet Seyferts	Highly variable, acceleration in relativistic jet	Steeper γ spectrum, highly variable, acceleration in relativistic jet

Accelerator power: SFR / Jet / AGN →

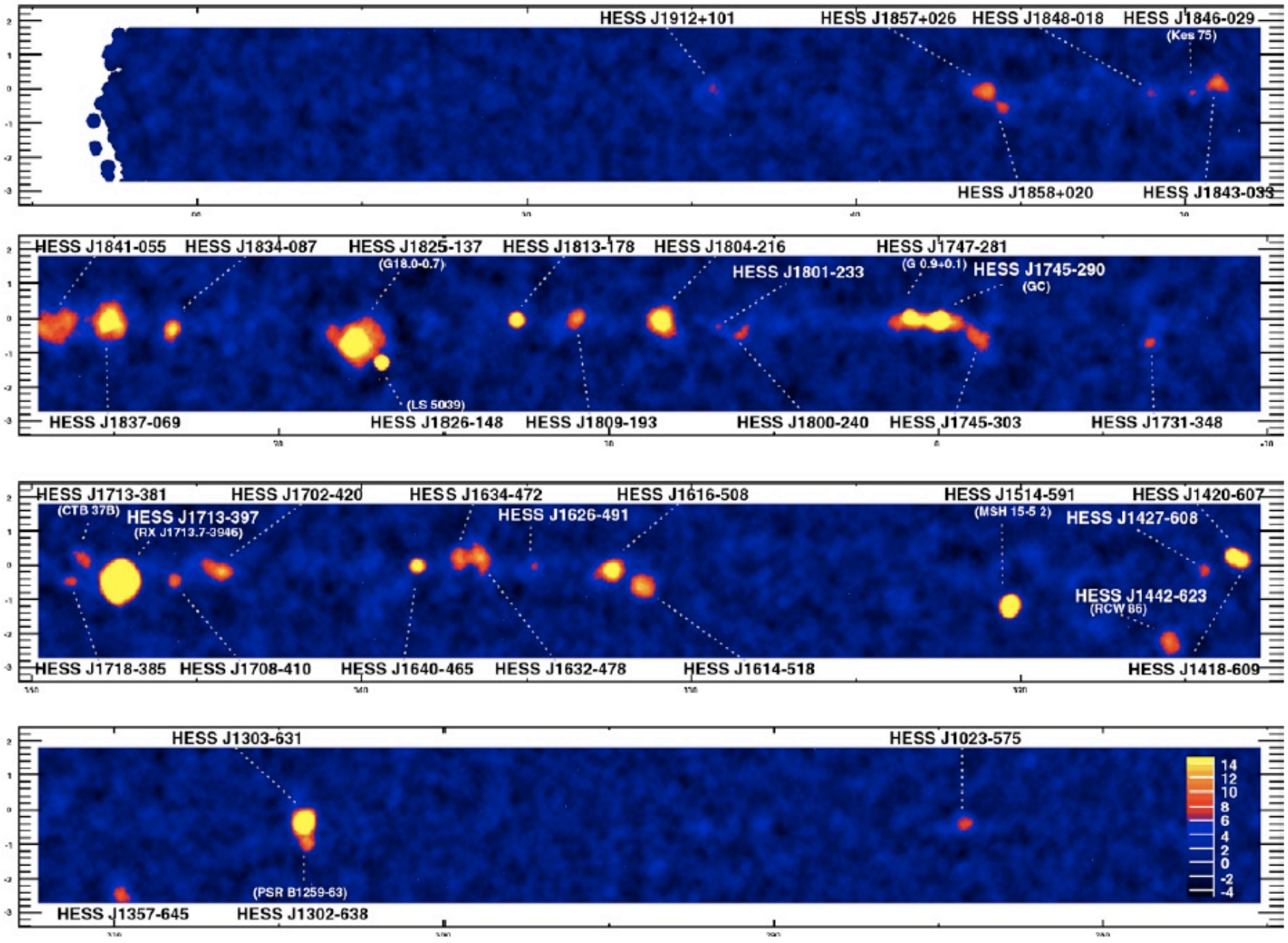
Northern Galactic hemisphere
11 month Fermi movie




3C454.3
100
50
0
F_H(mJy)
4500
5000
5500
JD−2450000
Canica H (1.6μm)
Fermi (1-300 GeV)



TeV celestial knowledge dominated by atmospheric Cherenkov telescope observations



-85º < long. < +60º |b|<2.5º

TeV emission from SNR

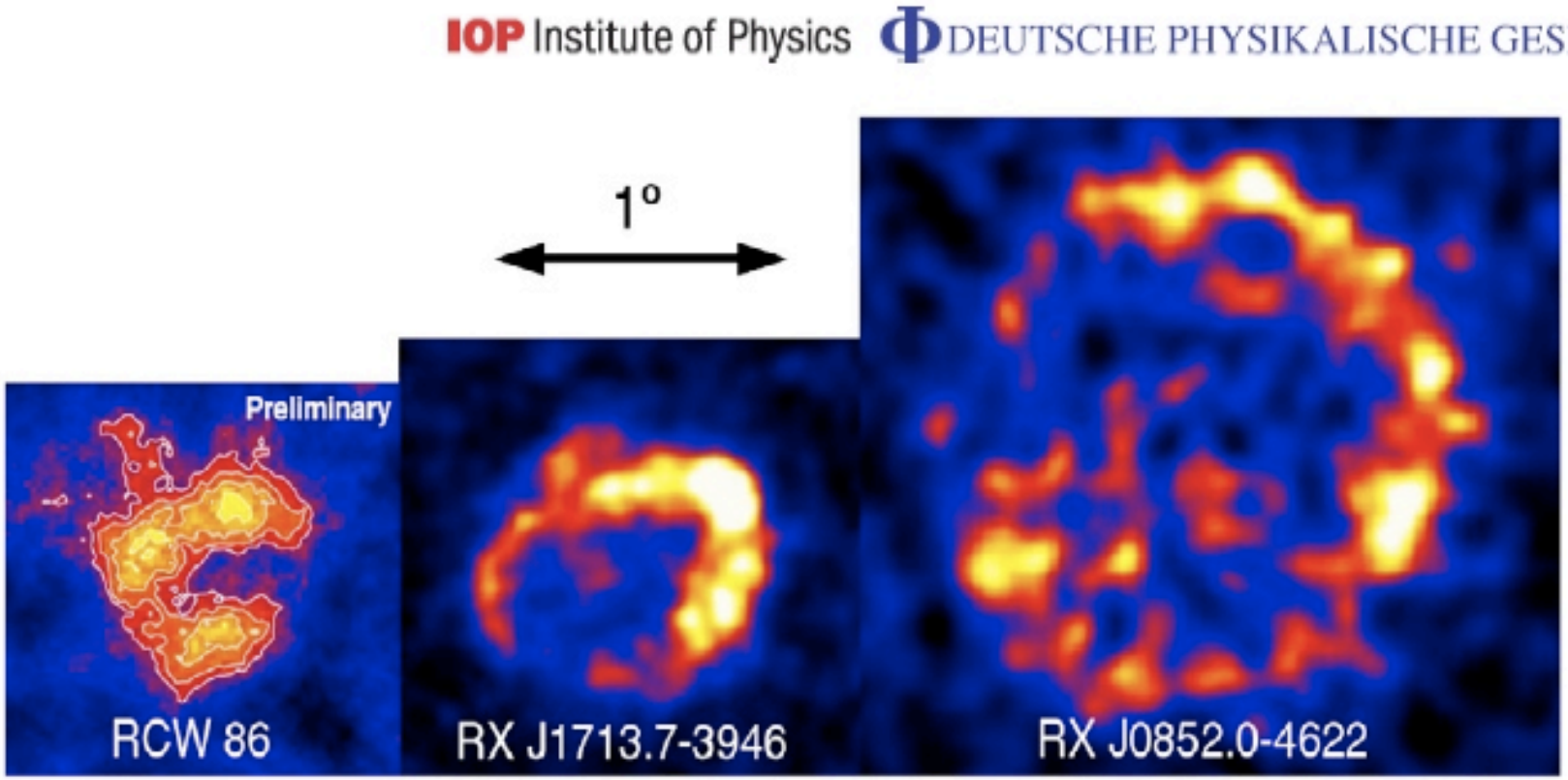
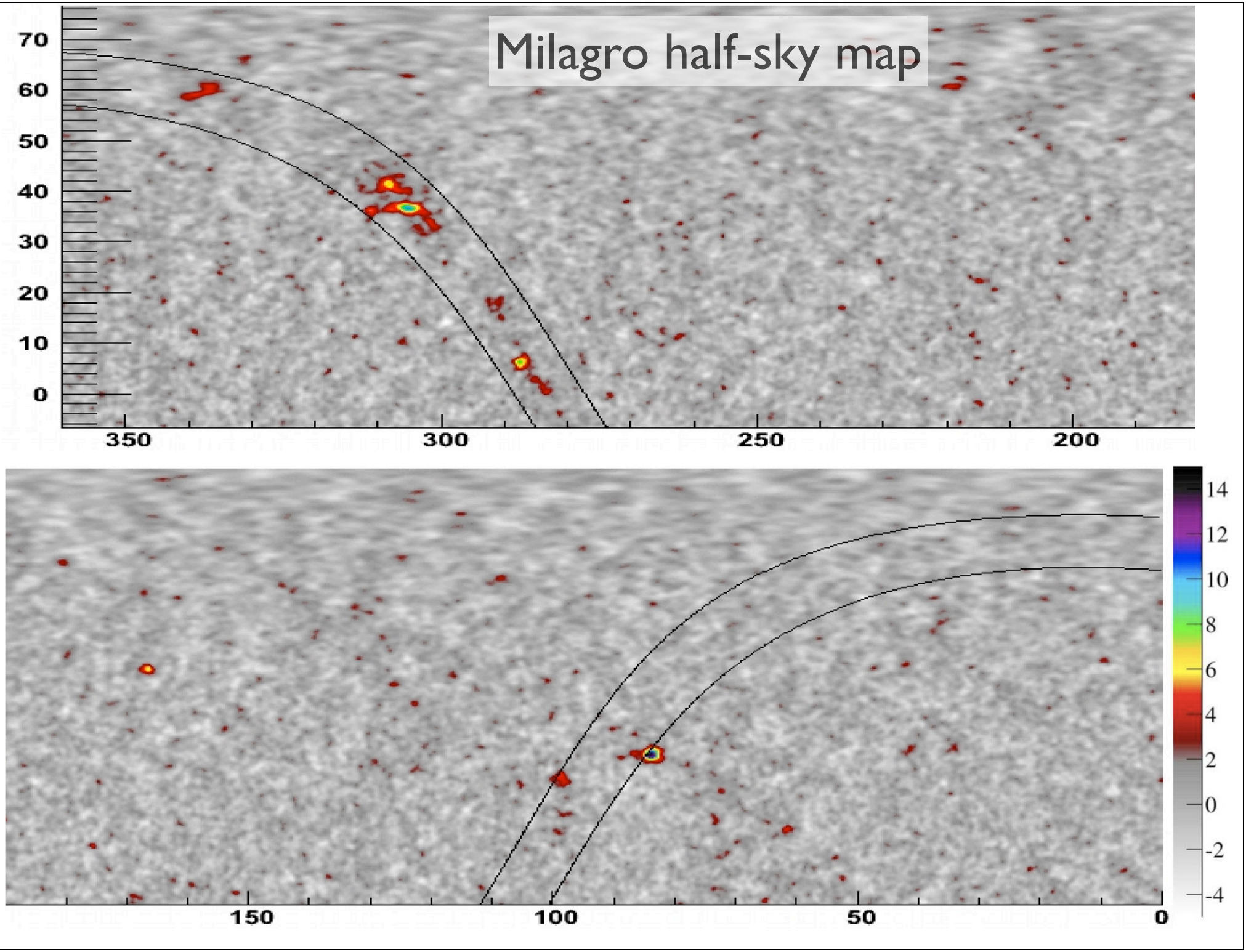
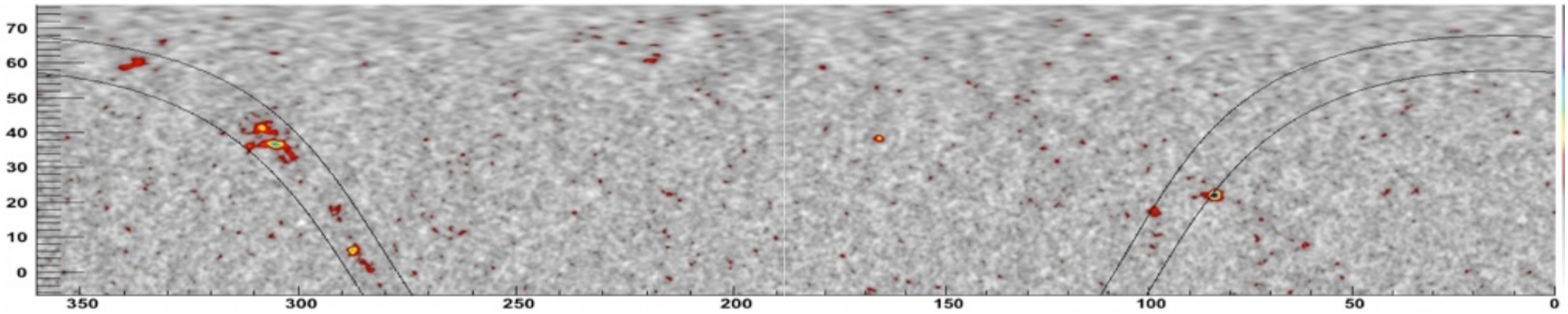
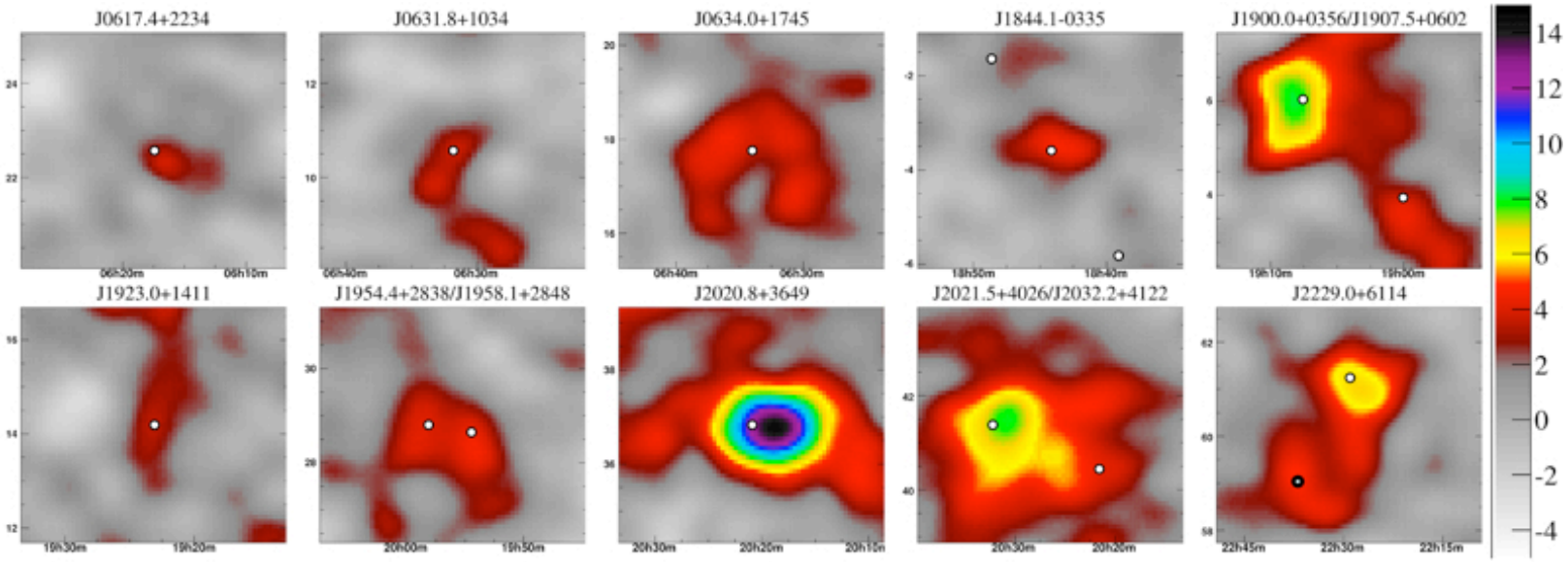


Figure 4. The shell-type TeV γ-ray supernova remnants: RCW 86 [54], RX J1713.7−3946 [63] and RX J0852.0−4622 (*Vela Junior*) [53]. All images are smoothed and were obtained using HESS.

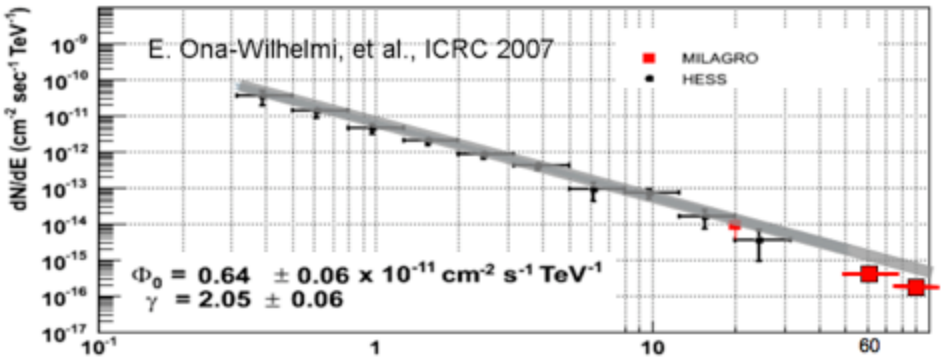

Milagro half-sky map
70
60
50
40
30
20
10
0
350
300
250
200
150
100
50
0
14
12
10
8
6
4
2
0
-2
-4



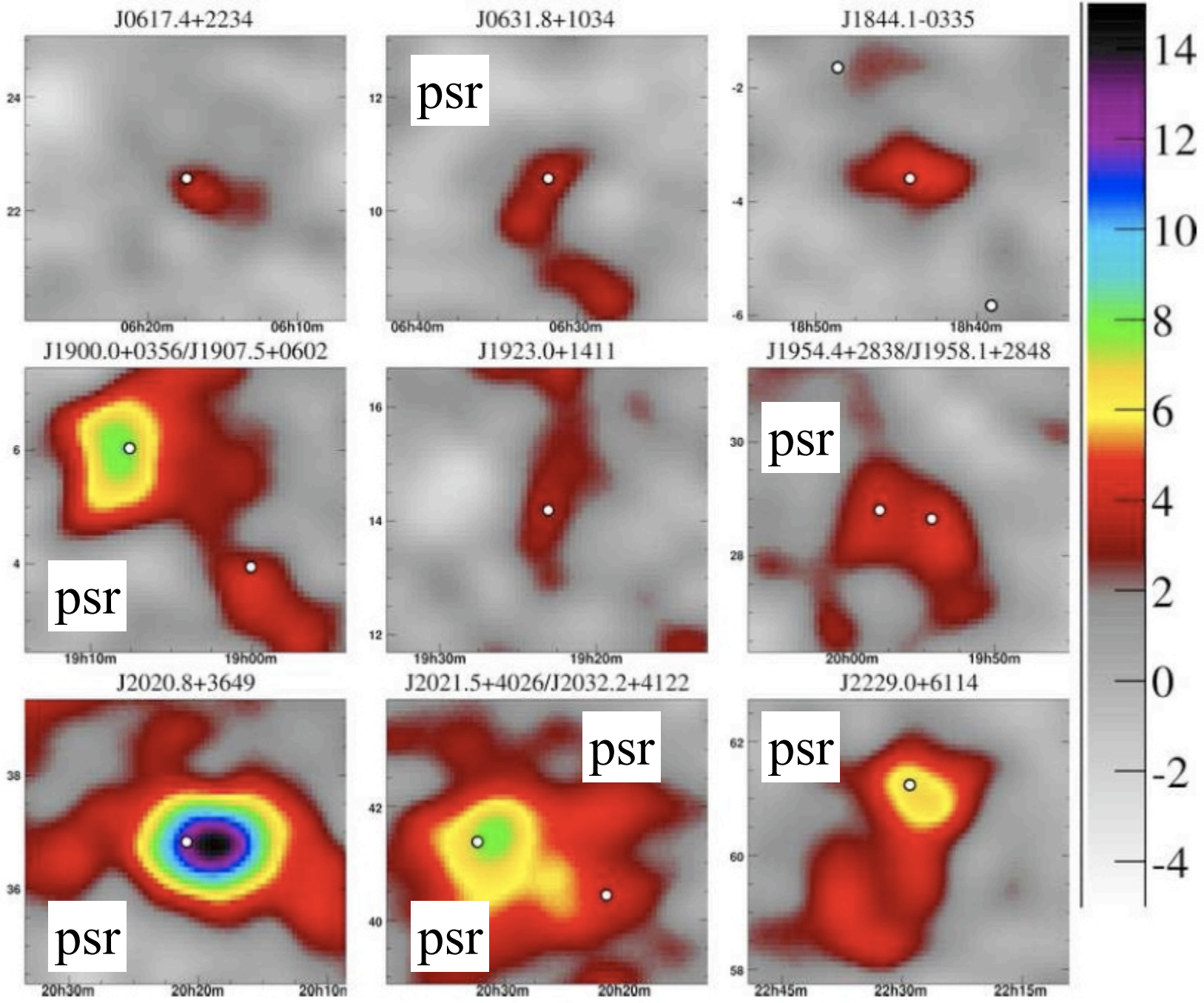
AR



De 34 fuentes 0FGL Galácticas en el campo de visión de Milagro 6 son detectadas con S/N > 5σ (14 con > 3σ)
- GeV pulsares & TeV nebulae



Fermi bright sources / psr in Milagro map



Beyond Milagro

The High Altitude Water Cherenkov Observatory

Citius, Altius, Fortius

- Requirements
  - Dimensions: 150m ×150m × 4.8m
  - Segmented: 5m cells
  - Above 4000m
  - 10 years of operations

HAWC = 15 * Milagro

- Science case:
  - Deep sky survey
  - Deep Galactic plane survey
  - Mapping of extended diffuse sources
  - Blazars - flares
  - Gamma-Ray Burst
  - Extragalactic Background Light pair absorption
  - Solar flares
  - Dark Matter Searches
  - Cosmic Rays


HAWC

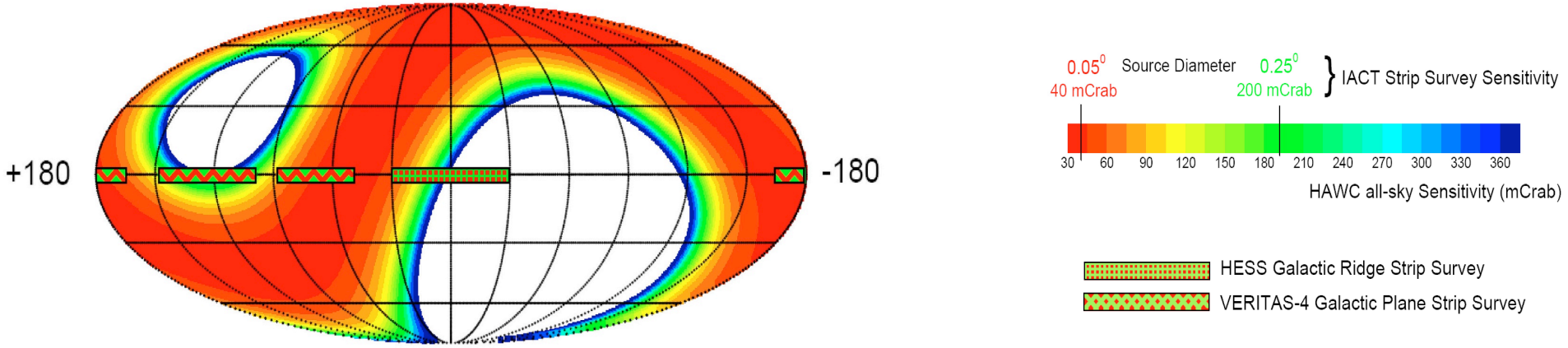
The HAWC collaboration

HAWC-MX
INAOE
Inst.Fisica UNAM
Inst. Astronomía UNAM
Inst. Geofísica UNAM
Inst. Ciencias Nucleares UNAM
BUAP - Puebla
Univ.Guanajuato
UNACh - Chiapas
UMSNH - Mich.
UdG - Guadalajara
CINVESTAV
IPN
UAEH - Hidalgo

HAWC is a collaboration of over 20 MX+US institutions.

Project contemplates 3 years of installation and 10 years operation.

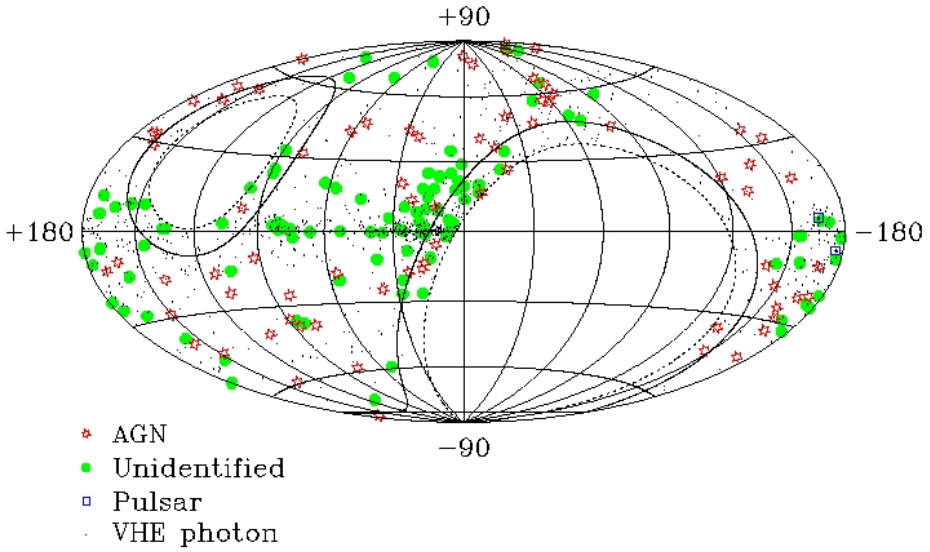
HAWC-US
Univ. Maryland
Los Alamos NL
Univ.Wisconsin
Colorado State U.
Penn State U.
Univ. Utah
UC Irvine
UC Santa Cruz
U New Mexico
Michigan SU
U New Hampshire
Georgia Tech
Michigan Tech. U.
George Mason U.
NASA/GSFC



	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	0.40^0 – 0.75°	0.25° – 0.50°
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

Table 1- A comparison of Milagro and HAWC. Note that comparisons are generally made for a Crab-like spectrum of differential photon spectral index -2.6. However, with a lower threshold some comparisons are between events at different energies. In some cases, the HAWC values will improve when we optimize our reconstruction for angular resolution and background rejection.

HAWC - GRBs



- Relevamiento diario de 2/3 de cielo E>TeV
- Expectativa de detección de GRBs en TeV

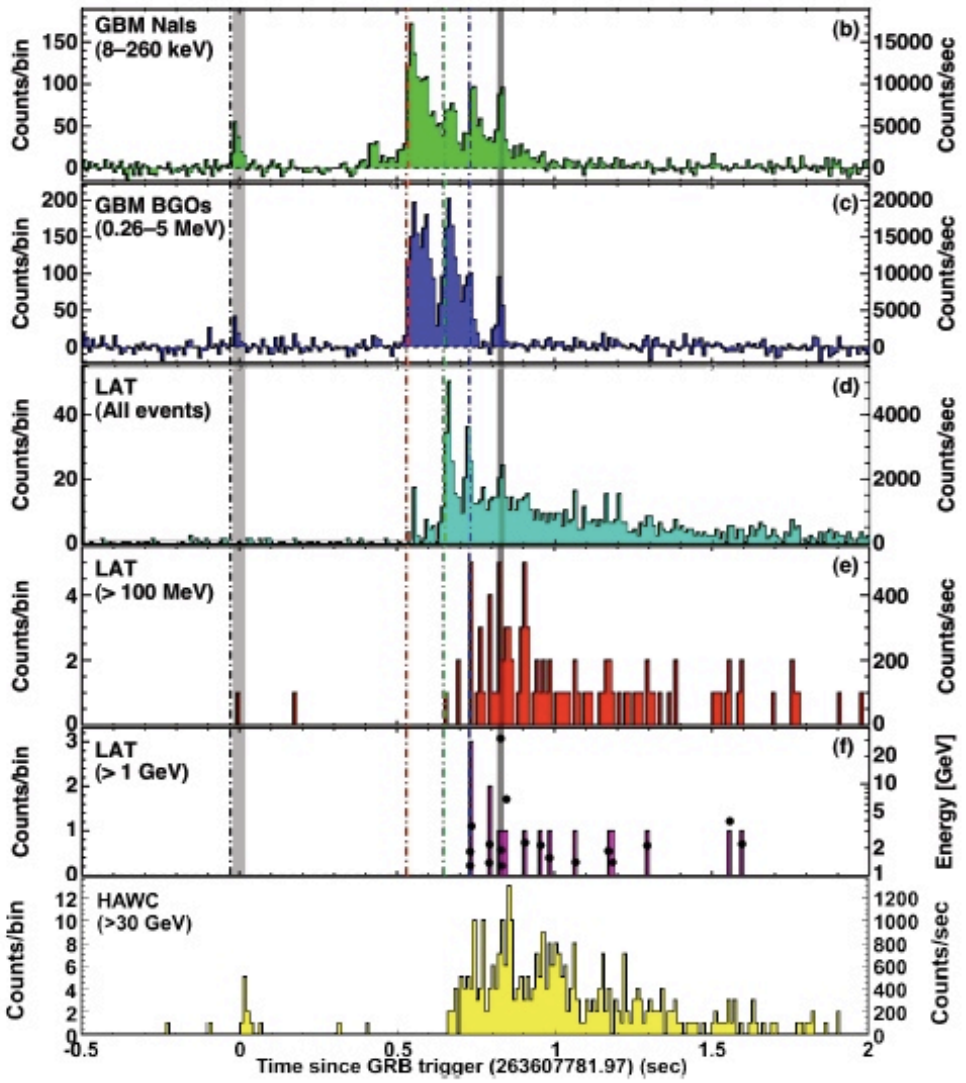
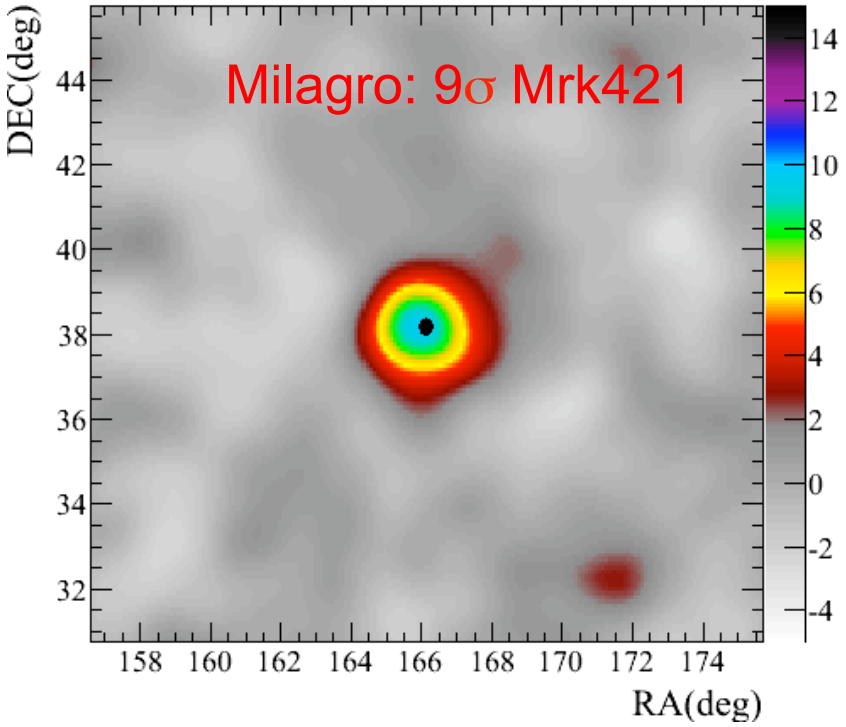
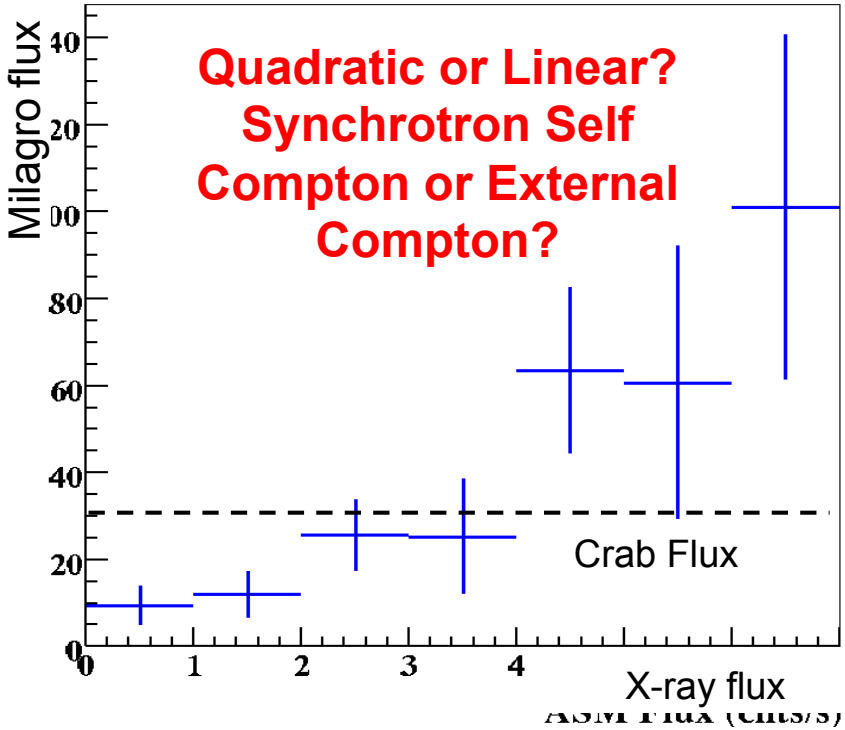


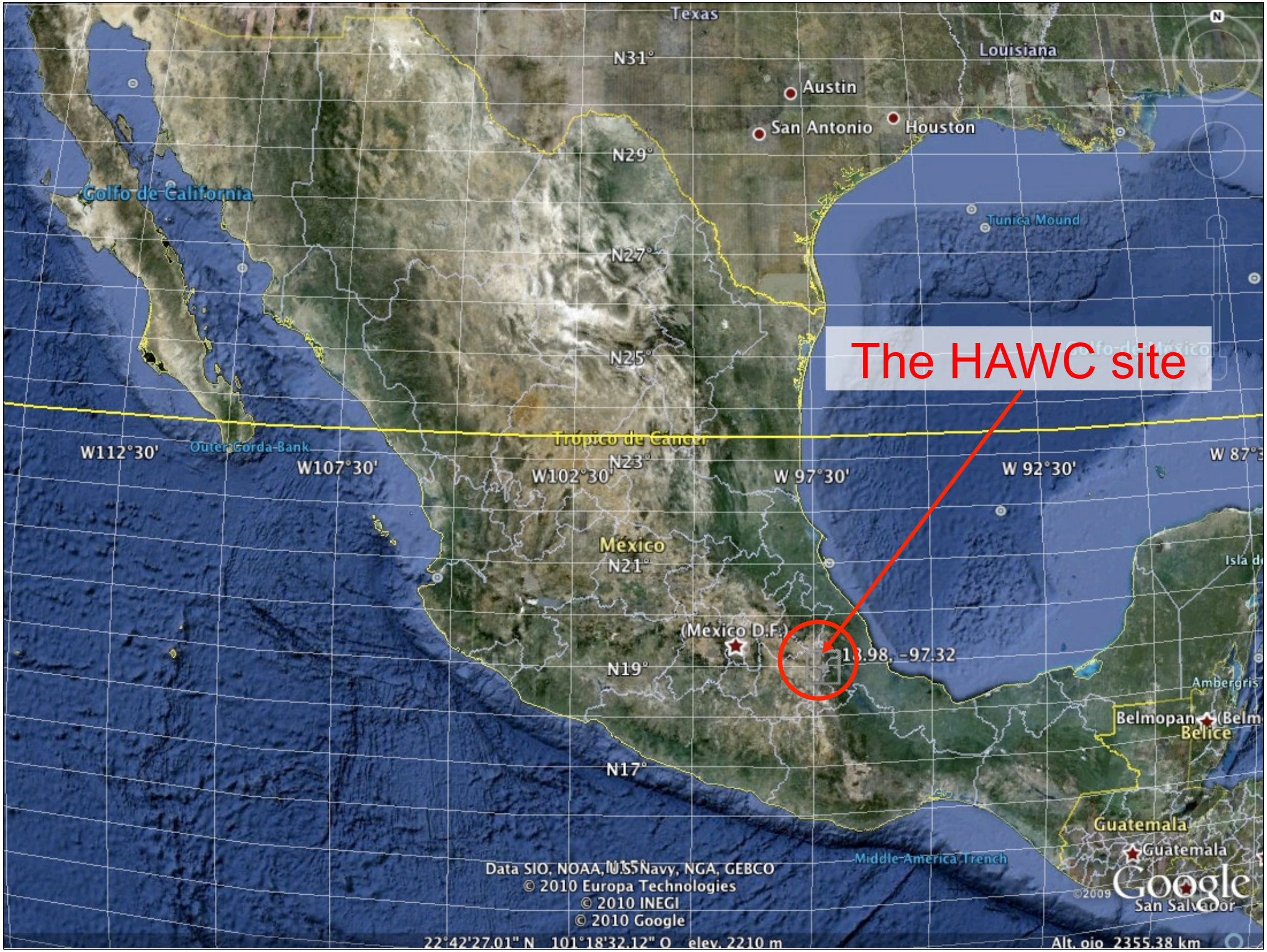
Figure 6 Fermi observation of GRB090510 at z=0.9 (top 5 panels) and HAWC's simulated lightcurve (including background). Approximately 200 events are simulated within the 0.5-1.0s interval which corresponds to a cutoff energy of about 125 GeV if the GRB were observed with cosθ > 0.9.

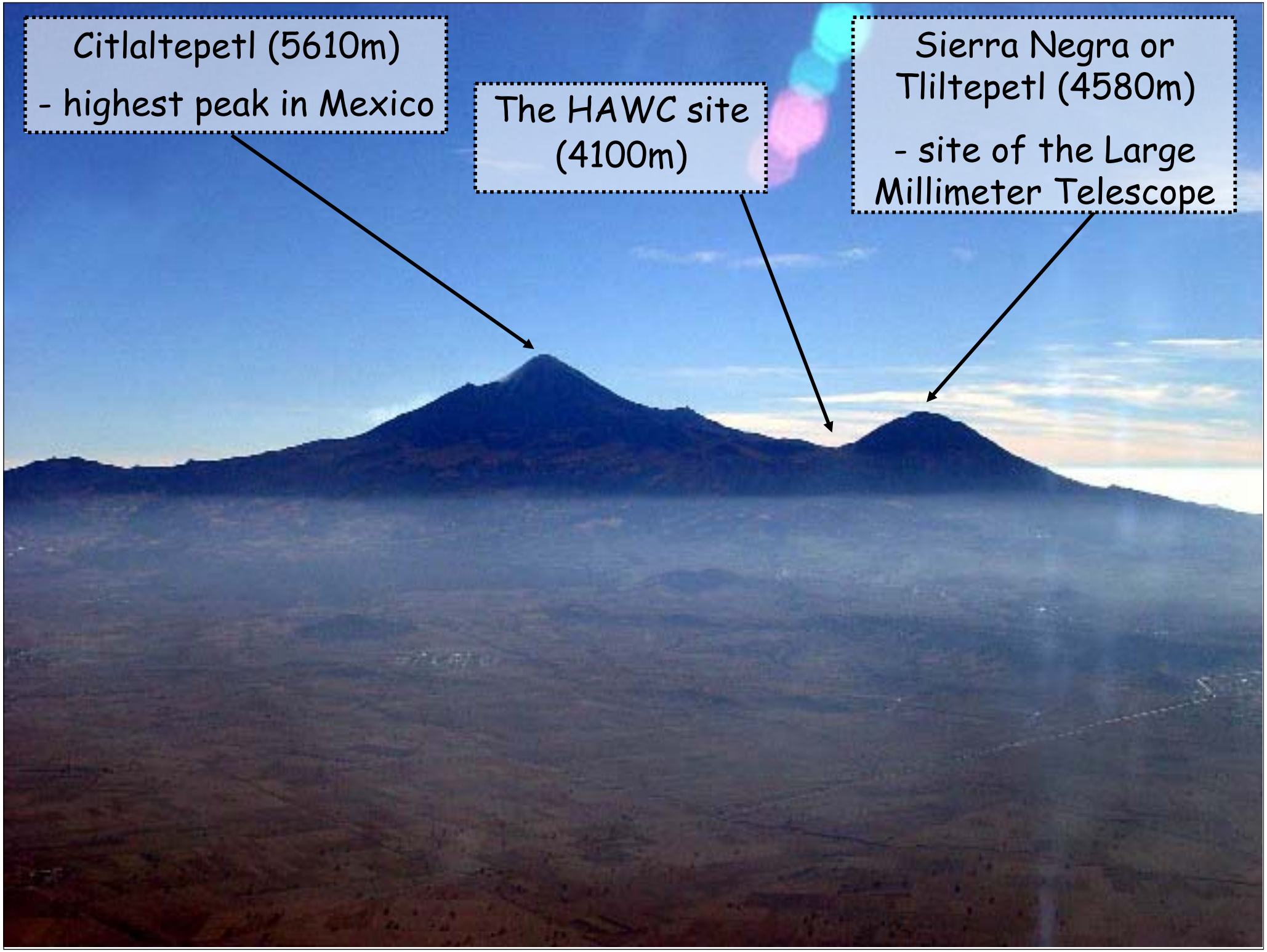
Ráfagas en AGNs

- HAWC hará observaciones diarias sin restricciones de clima, luna o Sol.
- Señal a ruido de 5σ para flujos de (10,1,0.1) Crab en (3 min, 5 hrs, 1/3 año)
- HAWC tendrá un sistema de alerta para seguimiento multi-frecuencia
- Correlaciones (como rayos X) permiten determinar en mecanismo de emisión
- Potencial de estudiar ráfagas TeV huérfanas y buscar emisión coincidente de neutrinos y RCUE



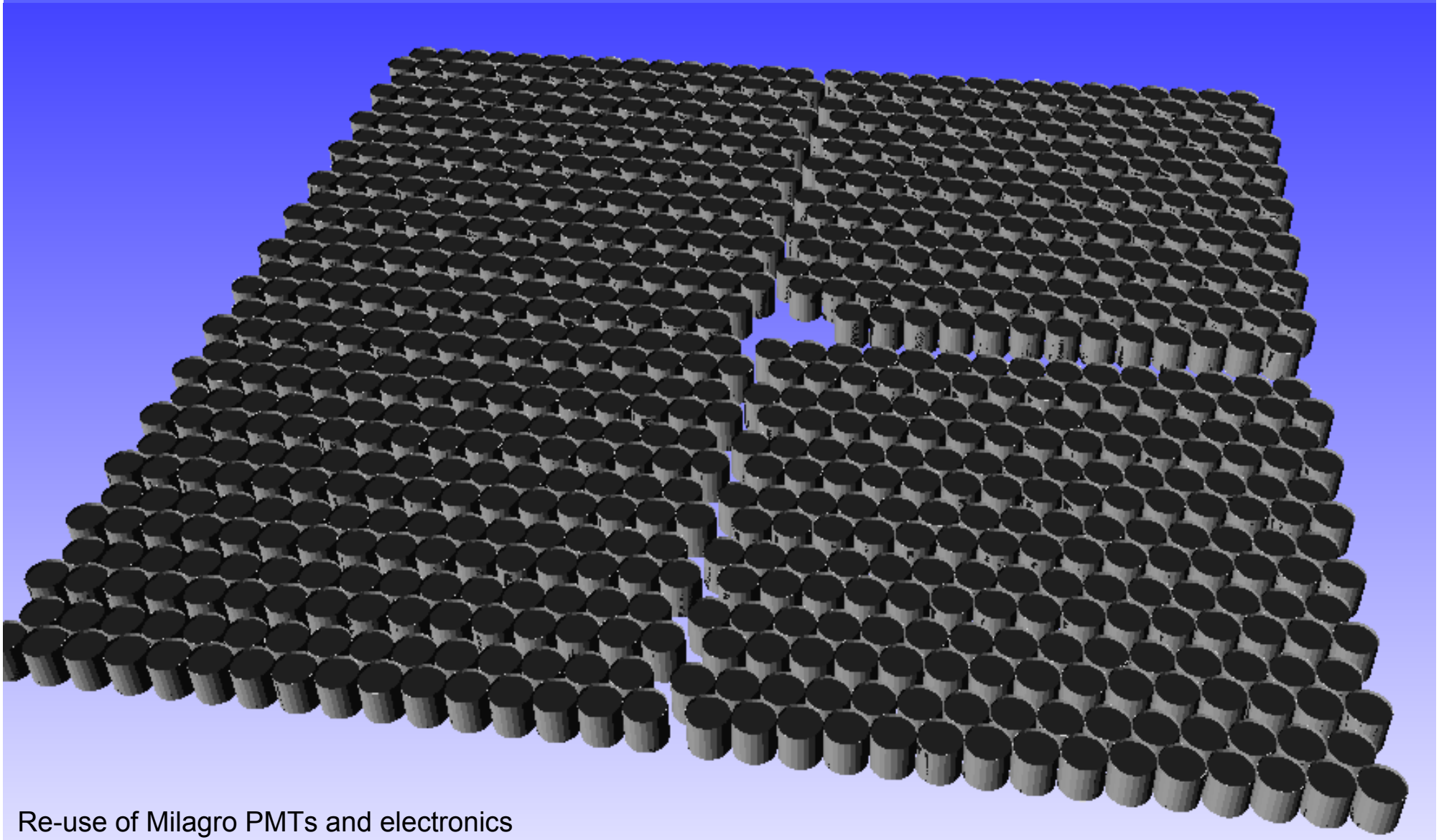



The HAWC site
Texas
Louisiana
Austin
San Antonio
Houston
N31°
N29°
N27°
N25°
N23°
N21°
N19°
N17°
Golfo de California
Tunica Mound
Trópico de Cáncer
W112°30'
W107°30'
W102°30'
W 97°30'
W 92°30'
Outer Gorda Bank
México
(México D.F.)
Ambergris
Belmopan
Belice
Guatemala
Middle America Trench
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2010 Europa Technologies
© 2010 INEGI
© 2010 Google
Google
©2009
San Salvador


Citlaltepetl (5610m)
- highest peak in Mexico
The HAWC site (4100m)
Sierra Negra or Tliltepetl (4580m)
- site of the Large Millimeter Telescope

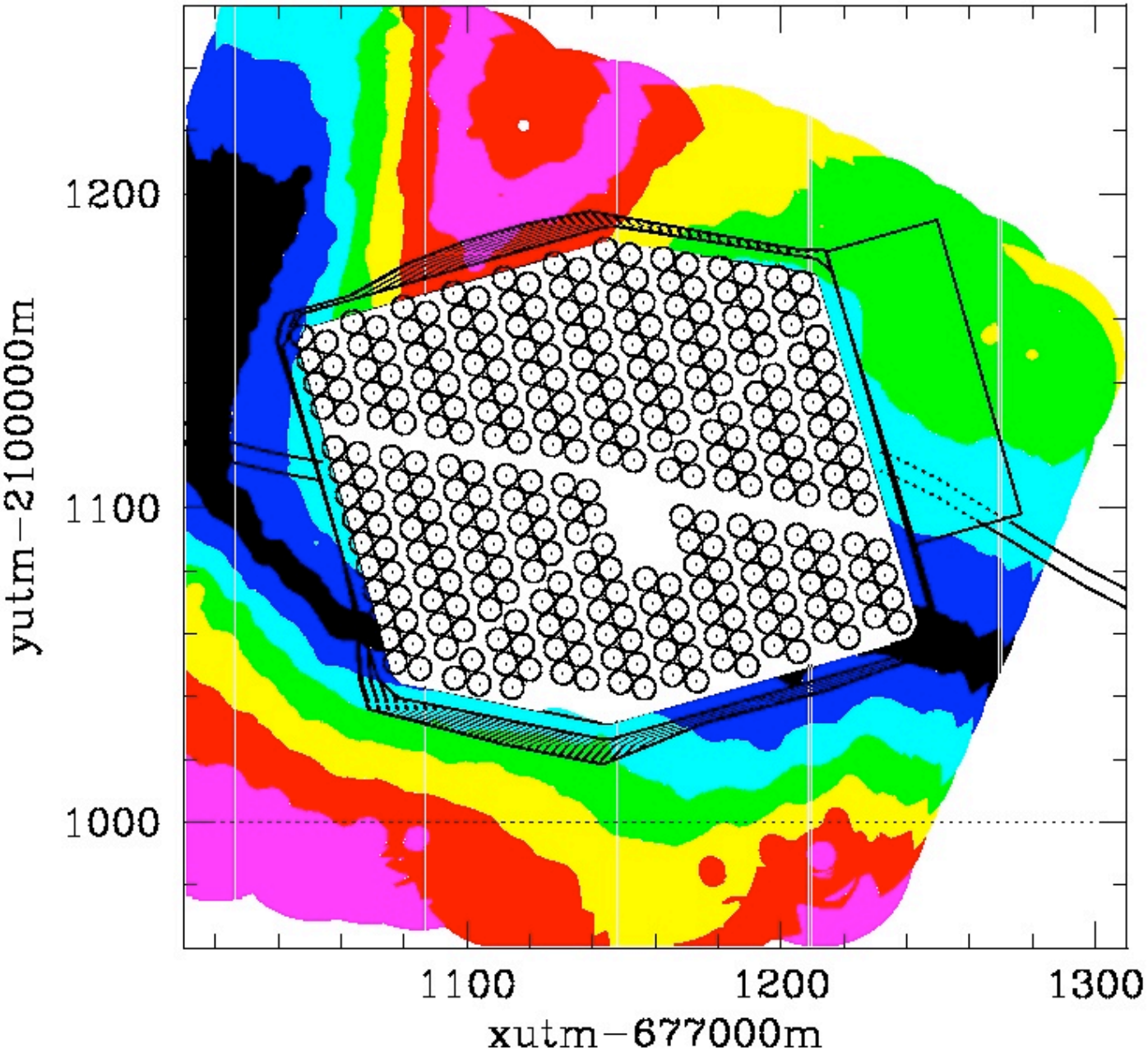
HAWC v1.0

Array of 900 x 5m diameter × 4.3m deep tanks



Re-use of Milagro PMTs and electronics


VAMOS - HAWC
engineering array
June 2011


1200
1100
1000
yutm−2100000m
1100
1200
1300
xutm−677000m


25 de mayo 2011