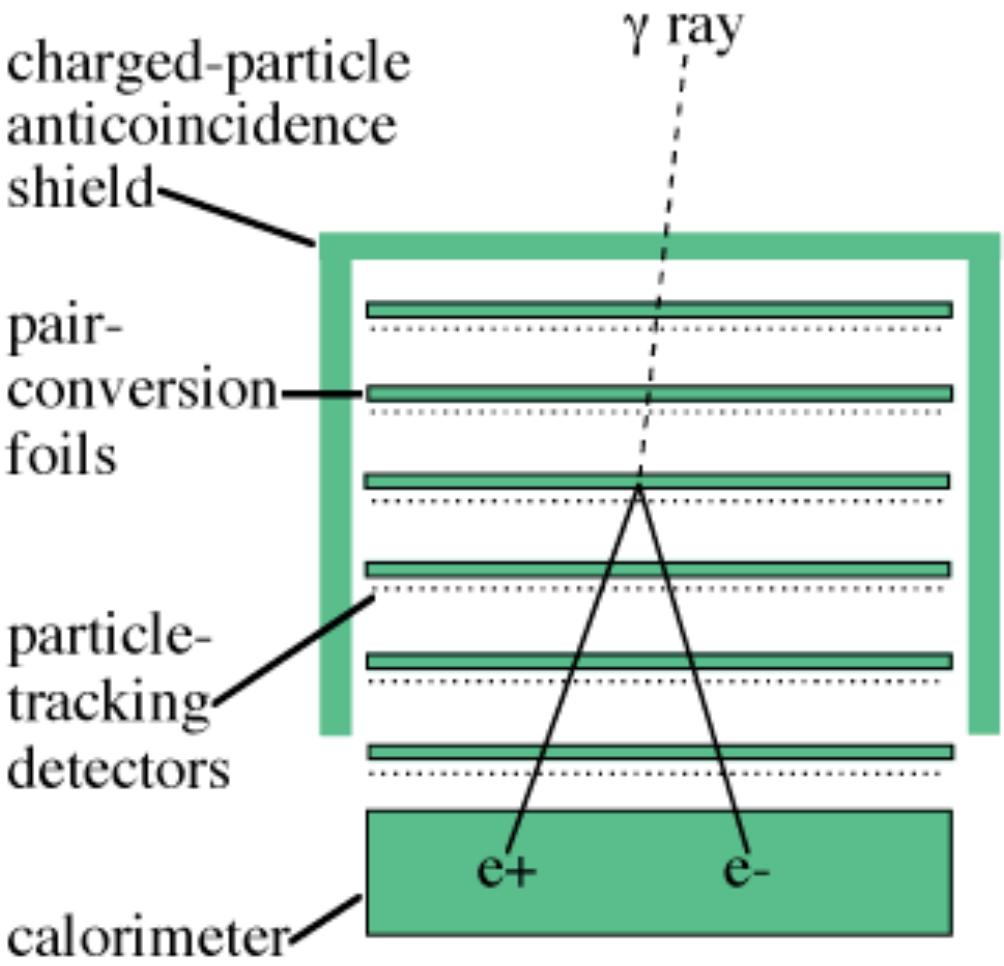
Astrofisica Nucleare e Subnucleare

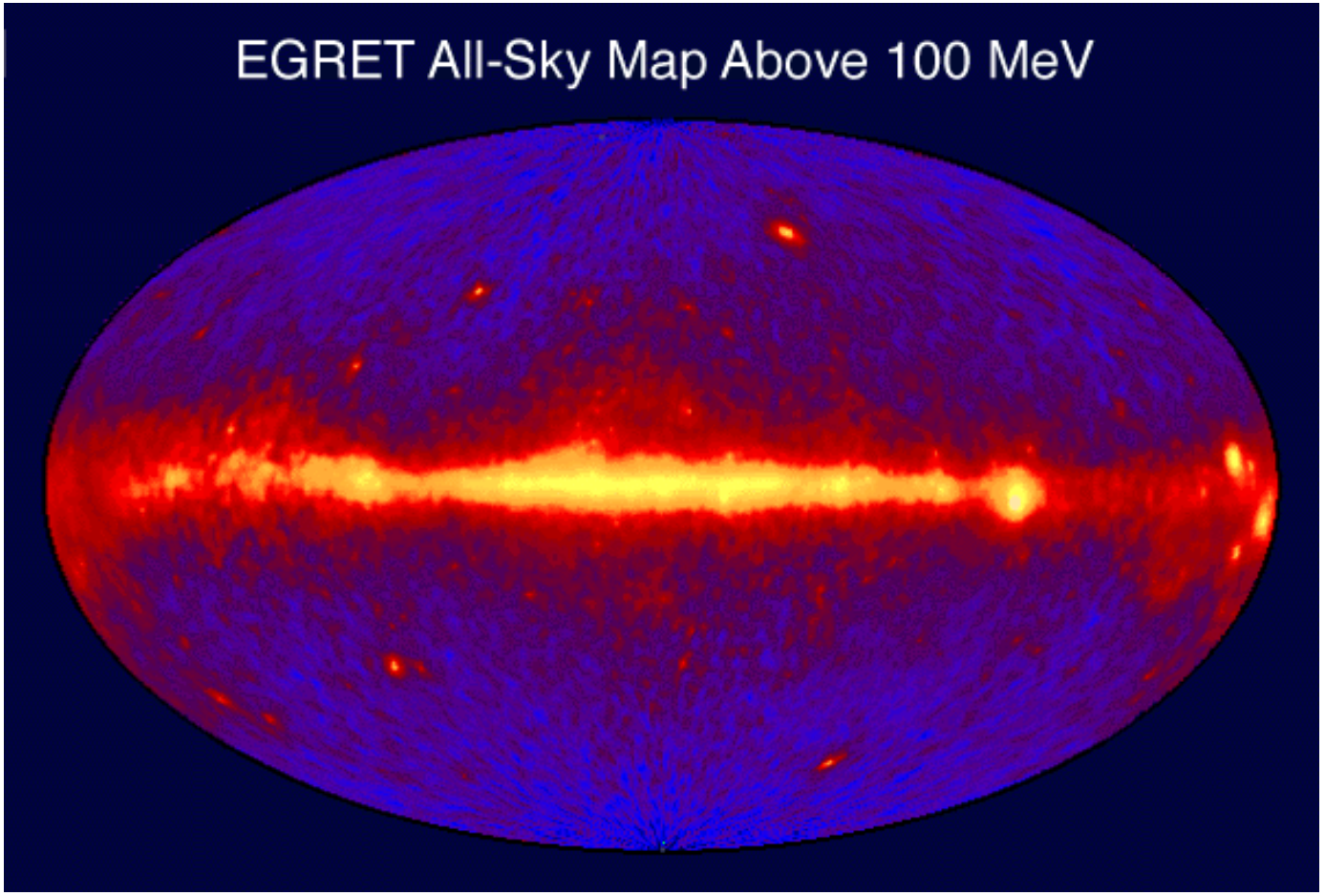
GeV Astrophysics - II

Detector Project



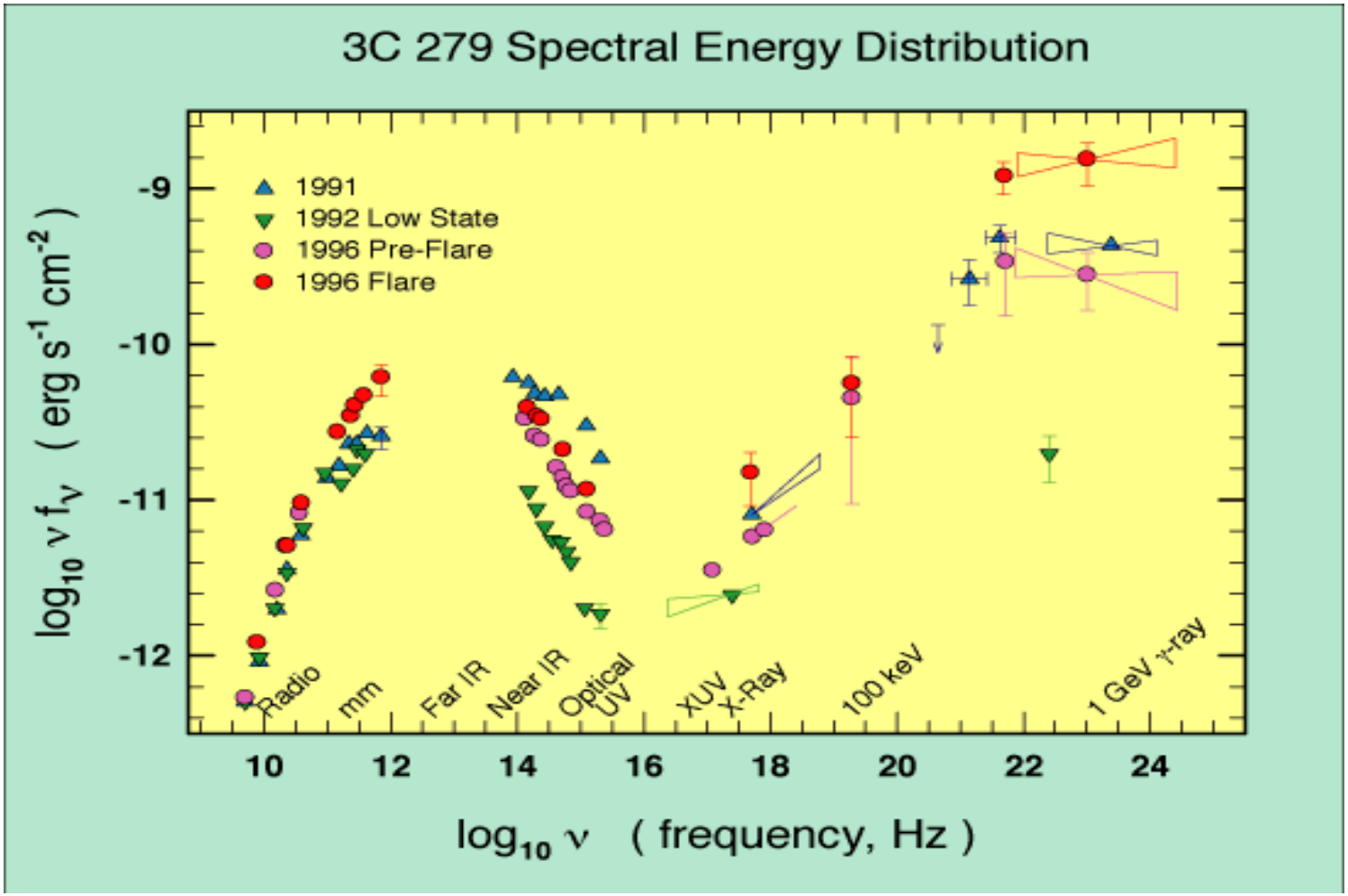
GeV Gamma-ray Astrophysics
The EGRET legacy

The HE sky from EGRET

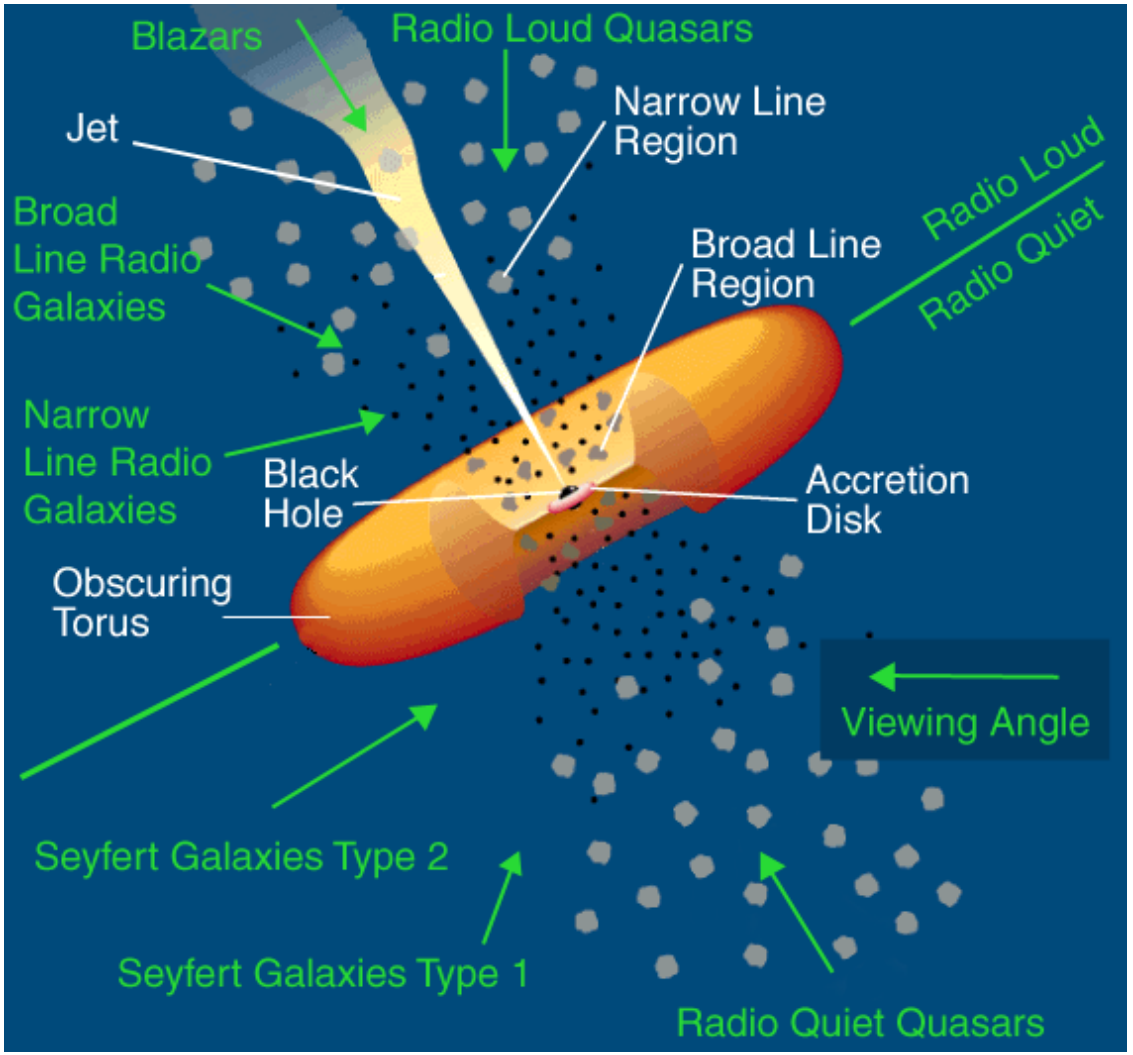


Challenge # 1

- Need simultaneous multiwavelength data to study variability and emission processes



Active Galactic Nuclei



AGN and the Extragalactic Background Light (EBL)

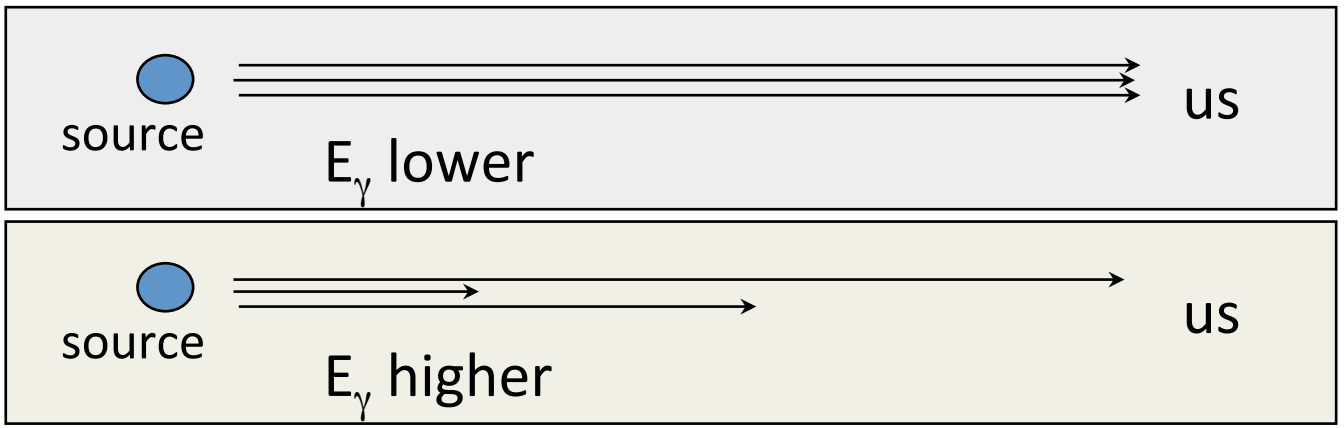
Look for roll-offs in blazar spectra due to attenuation:
(Stecker, De Jager & Salamon; Madau & Phinney; Macminn & Primack)

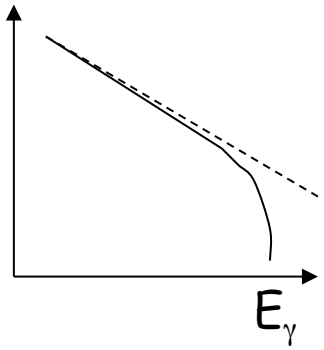
the start: A.I. Nikishov, Sov. Phys. JETP 14 (1962) 393.

If $\gamma\gamma$ c.m. energy > $2m_e$, pair creation will attenuate flux. For a flux of γ -rays with energy, E, this cross-section is maximized when the partner, ε, is

$$\epsilon \sim \frac{1}{3}\left(\frac{1TeV}{E}\right)eV$$

For 10 GeV- 100 GeV γ - rays, this corresponds to a partner photon energy in the optical - UV range. Density is sensitive to time of galaxy formation.





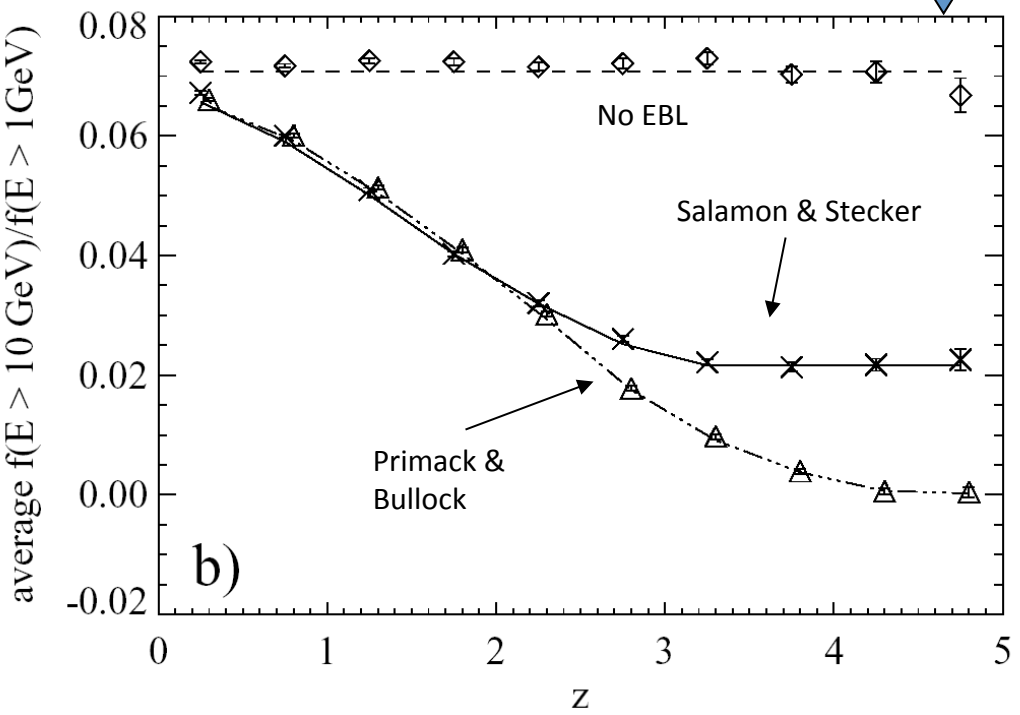
AGN and EBL

- **Important advances offered by Fermi:**

  (1) thousands of blazars - instead of peculiarities of individual sources, look for systematic effects vs redshift.

  (2) key energy range for cosmological distances (TeV-IR attenuation more local due to opacity).

- Effect is model-dependent (this is good):

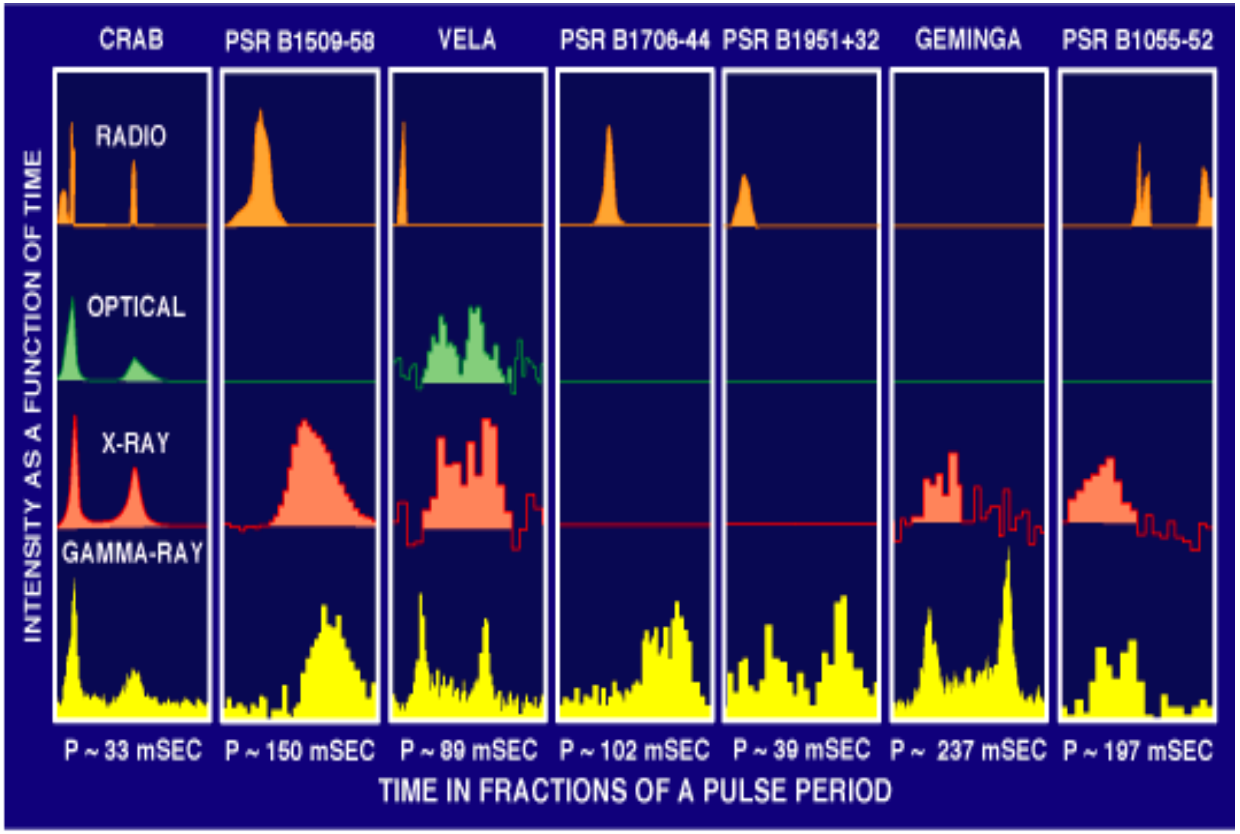


Caveats

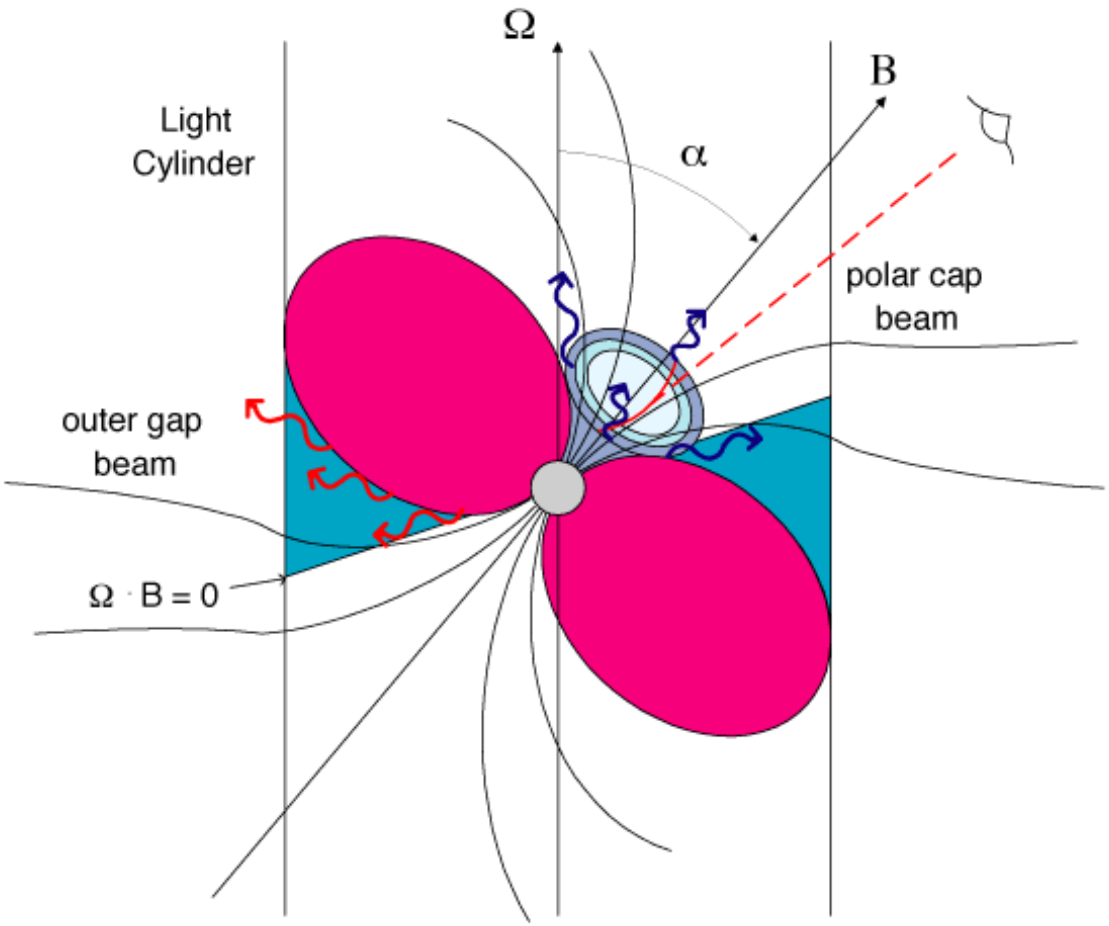
- How many blazars have intrinsic roll-offs in this energy range (10-100 GeV)? (An important question by itself for GLAST!)
- What if there is conspiratorial evolution in the intrinsic roll-of vs redshift? More difficult, however there may also be independent constraints (e.g., direct observation of integrated EBL).
- Must measure the redshifts for a large sample of these blazars!

Challenge # 2

- Need more exposure and optimal timing (and radio monitoring) to discover more gamma-ray PSRs.



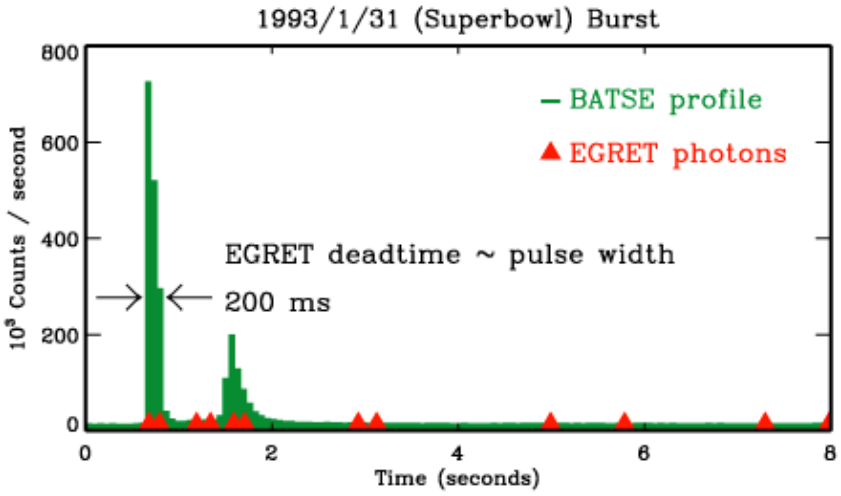
Pulsars



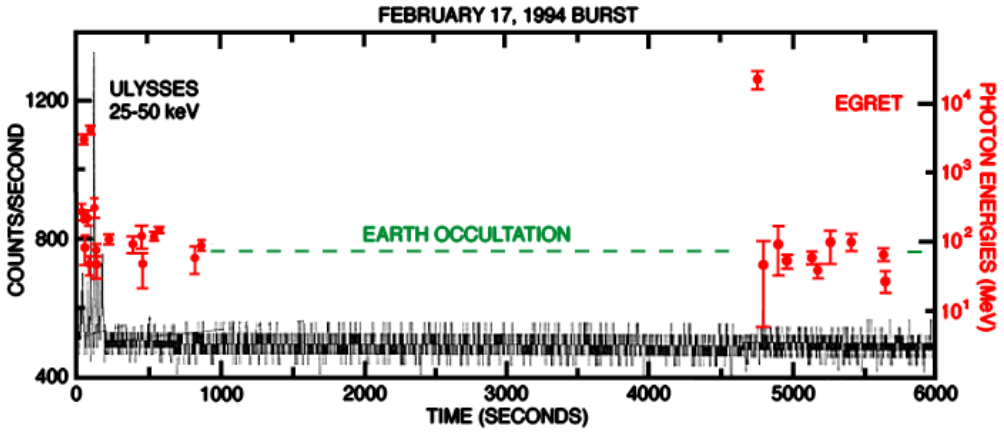
Challenge # 3

- Need fast timing for gamma-ray detection (improving EGRET deadtime, 100 msec → 100 microsec or less).

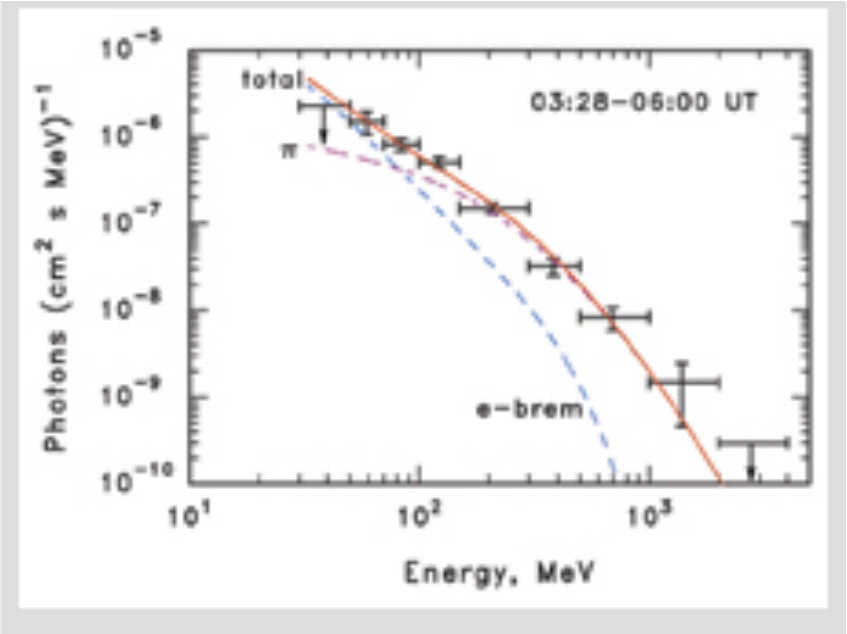
Prompt Emission (GRB 930131)

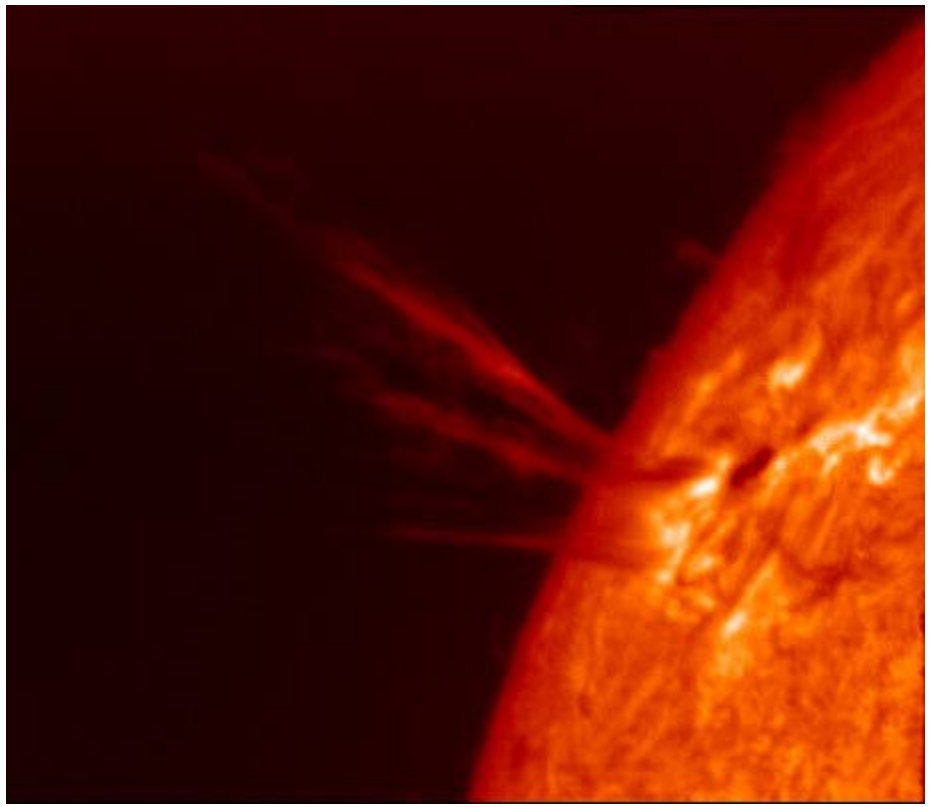


Delayed Emission (GRB 940217)



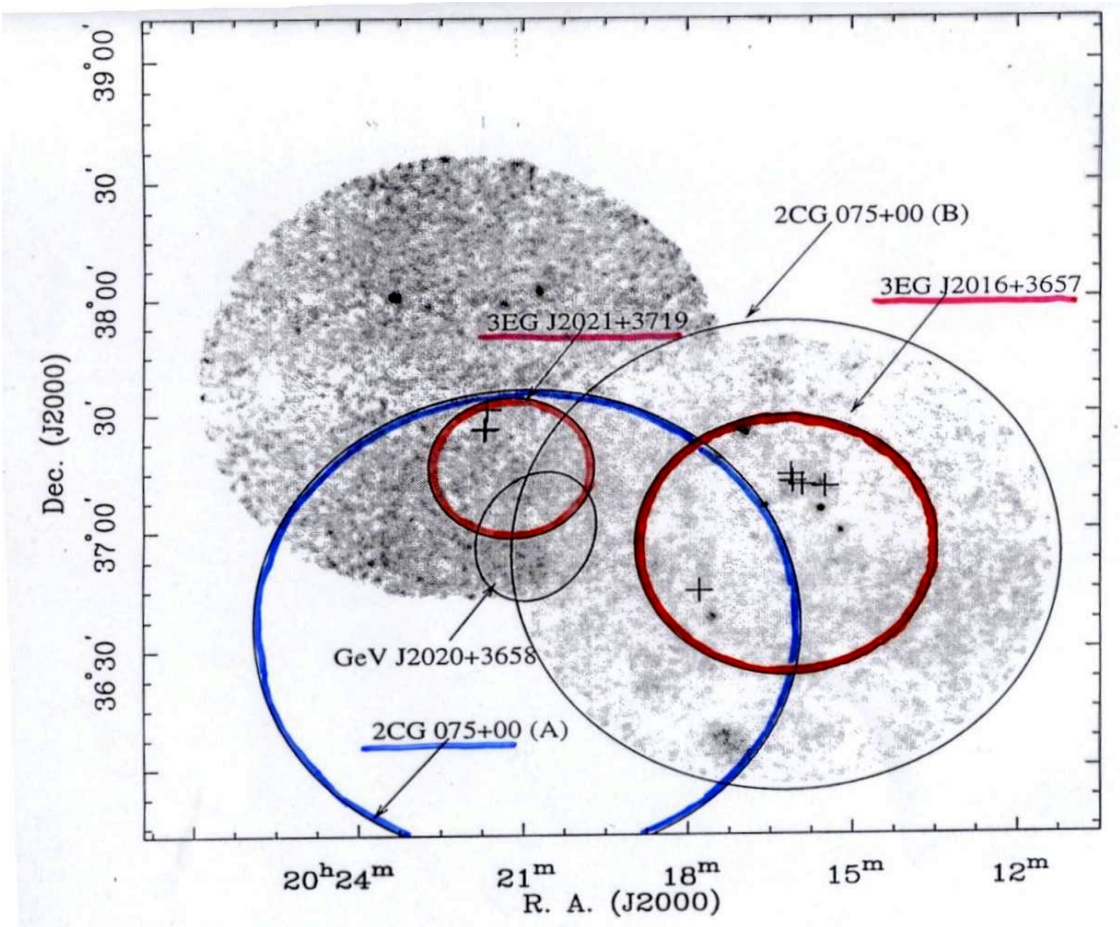
Solar flares



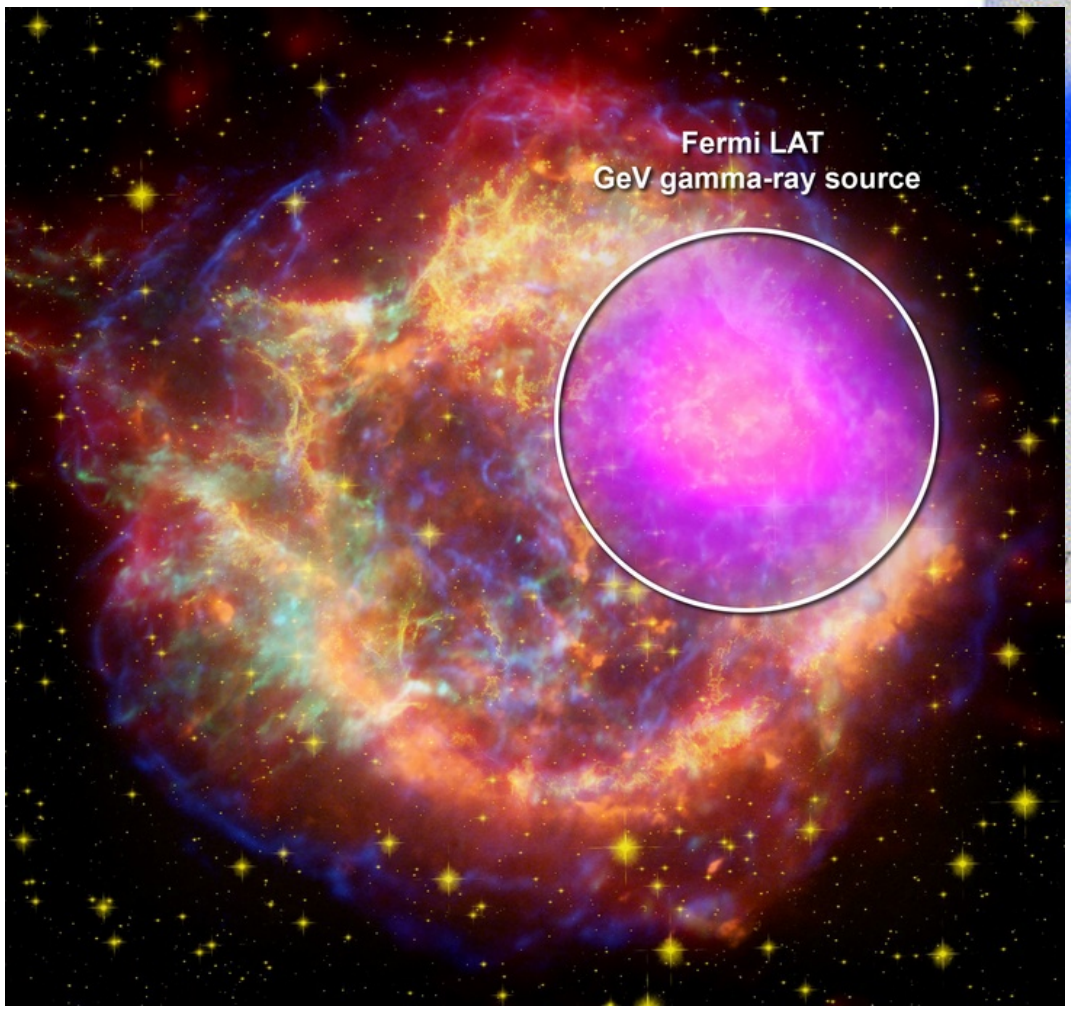


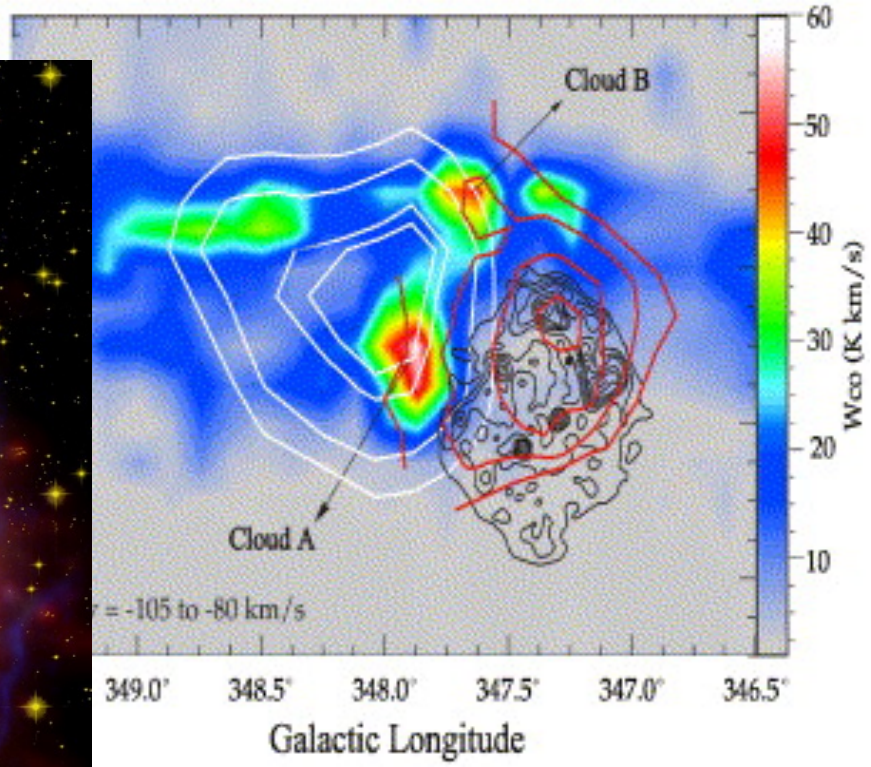
Challenge # 4

- Need arcminute positioning of gamma-ray sources (improving EGRET error box radii by a factor of 2-10).

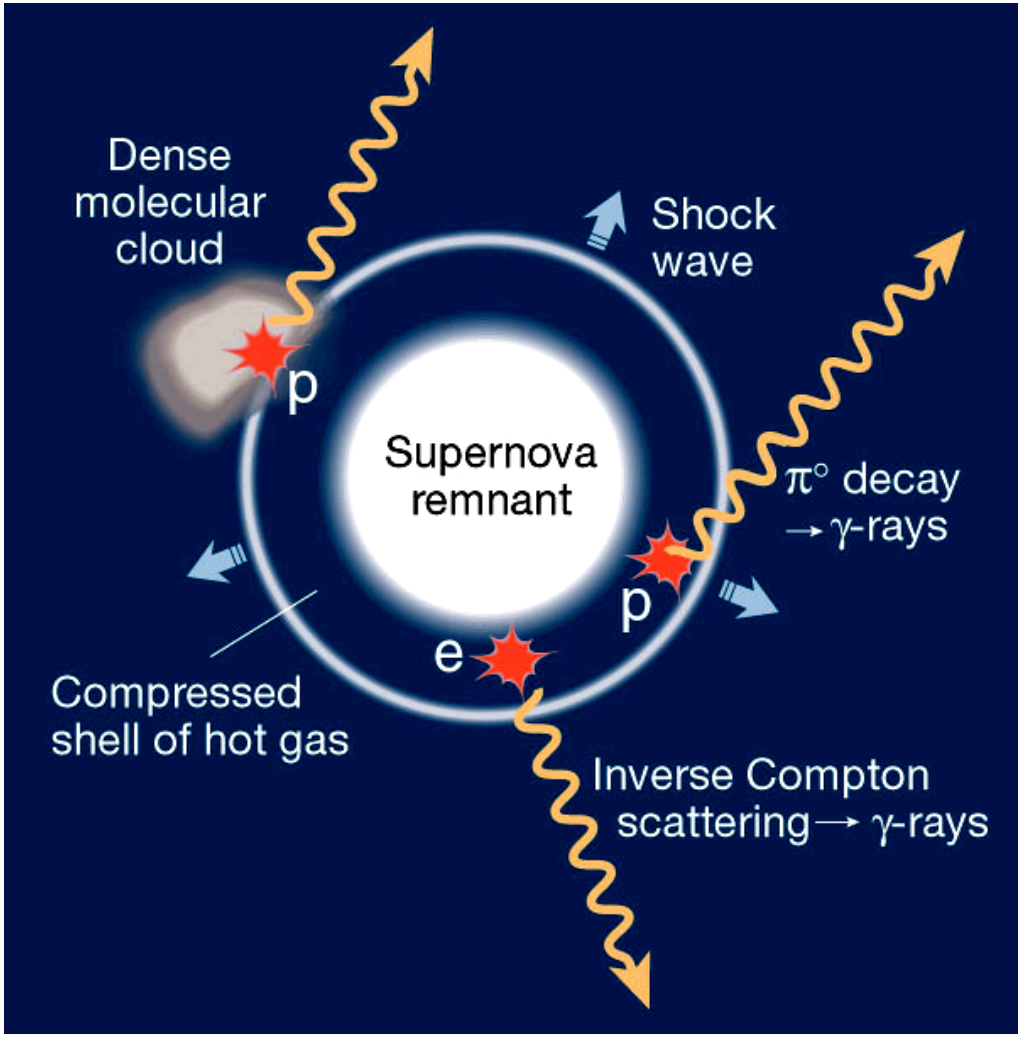


Supernova Remnants



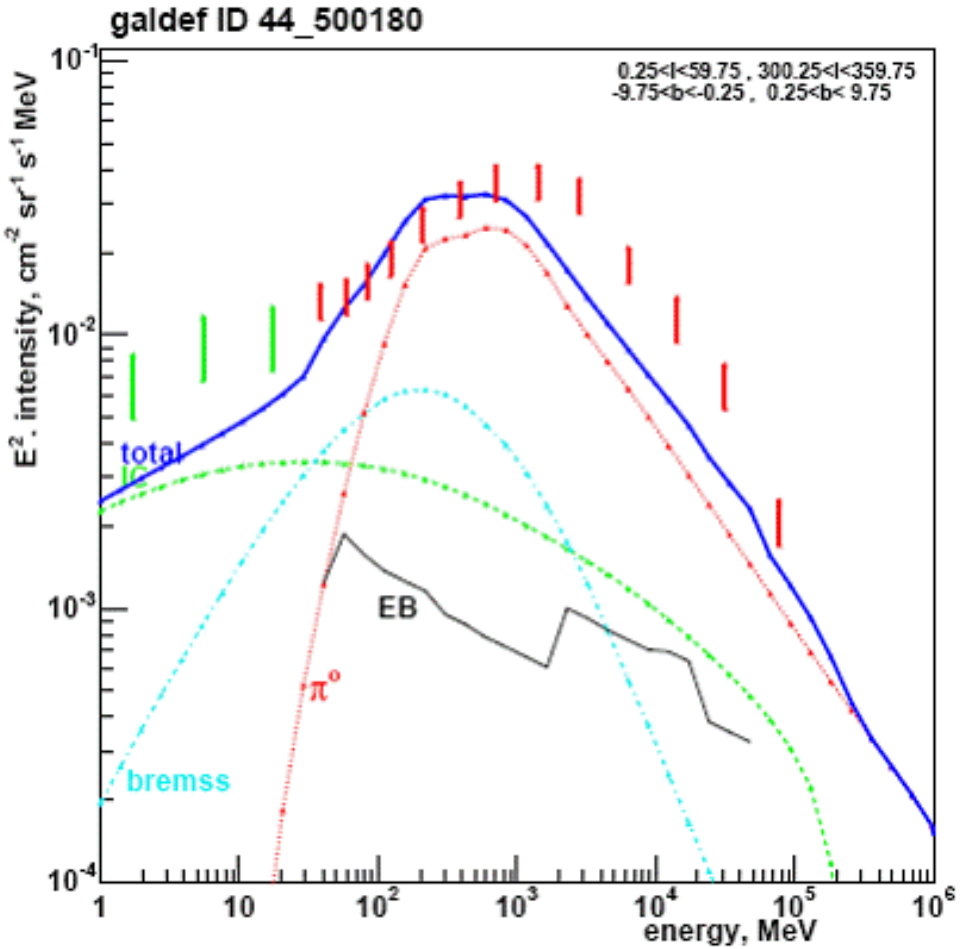


SNR

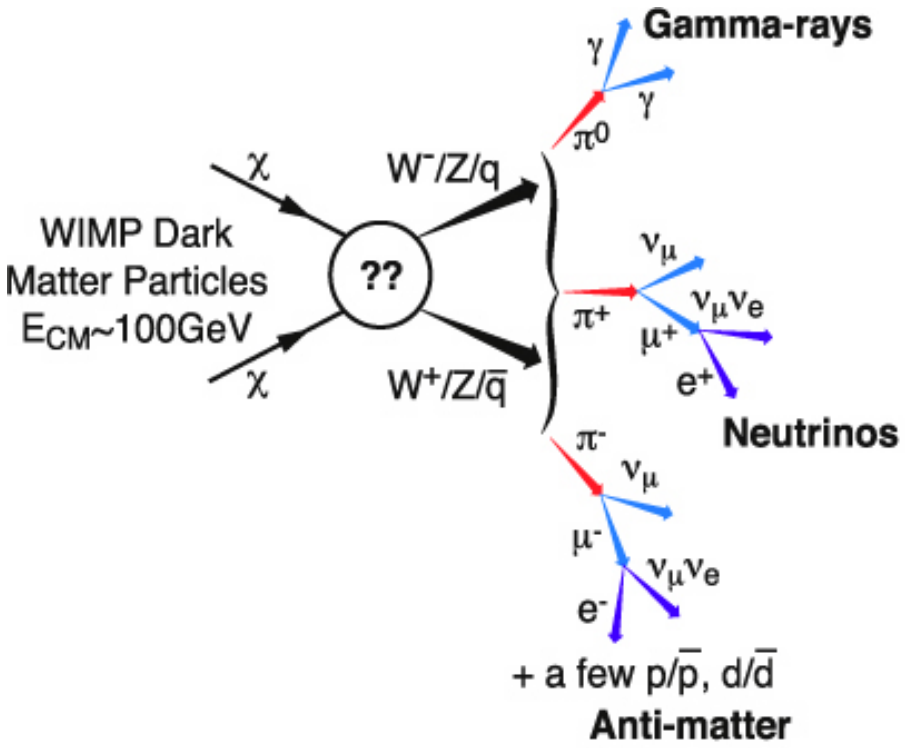

Dense
molecular
cloud
Shock
wave
p
Supernova
remnant
π° decay
→ γ-rays
p
e
Compressed
shell of hot gas
Inverse Compton
scattering → γ-rays

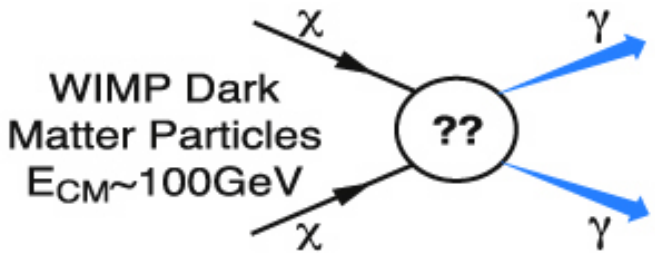
Challenge # 5

- Need improvements in Spectral Resolution fo check for DM signals

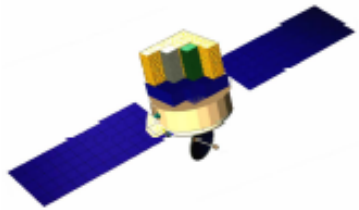


Dark Matter


Gamma-rays
γ
γ
π0
χ
W-/Z/q
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
W+/Z/q̄
νμ
π+
νμνe
μ+
e+
Neutrinos
π-
νμ
μ-
νμνe
e-
+ a few p/p̄, d/d̄
Anti-matter


χ
γ
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
γ

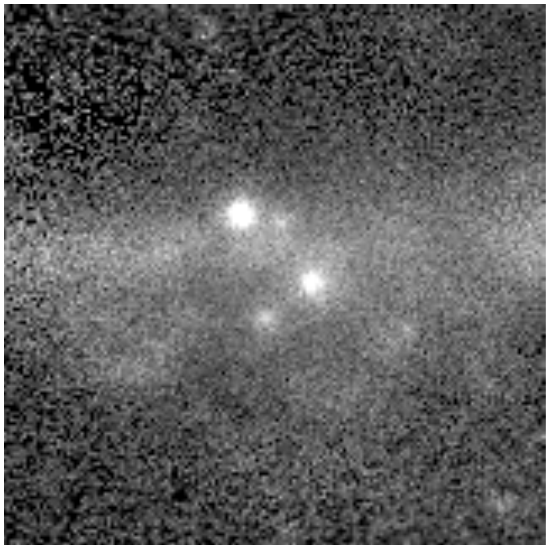
Detector Project

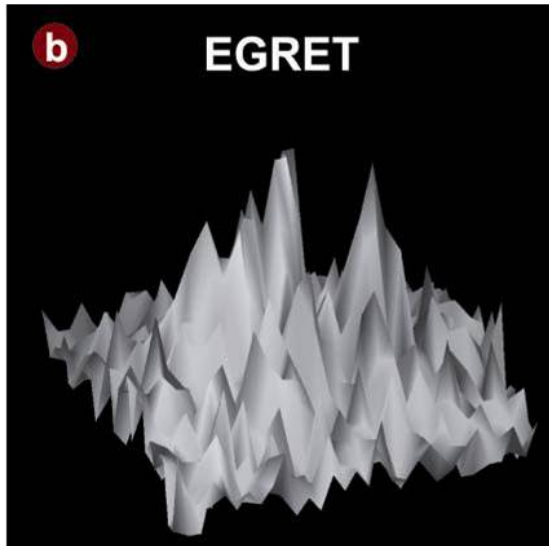


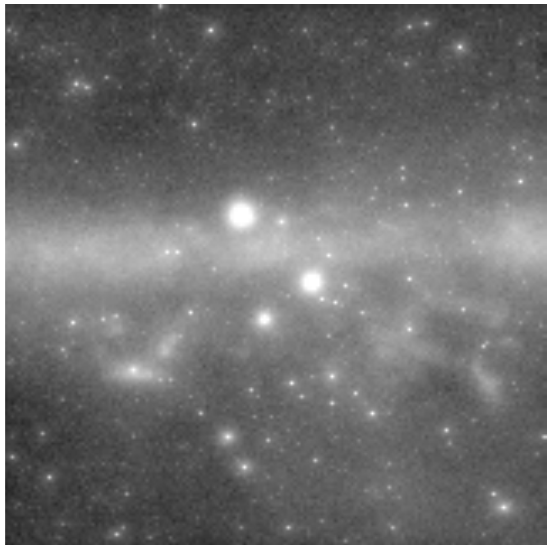
Sources Classes Predicted for GLAST

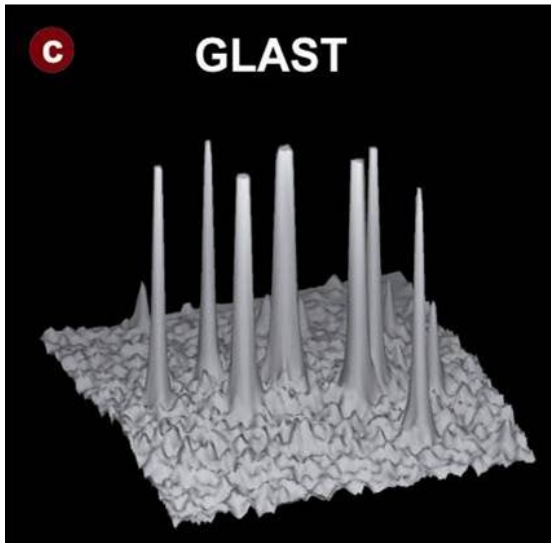
Source Class	Basis for Prediction
Active Galactic Nuclei (AGN)	EGRET quasars
Diffuse Cosmic Background	EGRET, Theory
Gamma Ray Bursts (GRBs)	EGRET, BATSE, Milagrito
Molecular Clouds, Supernova Remnants Normal Galaxies	COS-B, EGRET, Theory
Galactic Neutrons Stars (NS) & Black Holes (BHs)	COS-B, EGRET
Unidentified Gamma-ray Sources	COS-B, EGRET
Dark Matter	Theory

Technology impact -- PSF









Cygnus region (15^0 x 15^0), $E\gamma > 1$ GeV

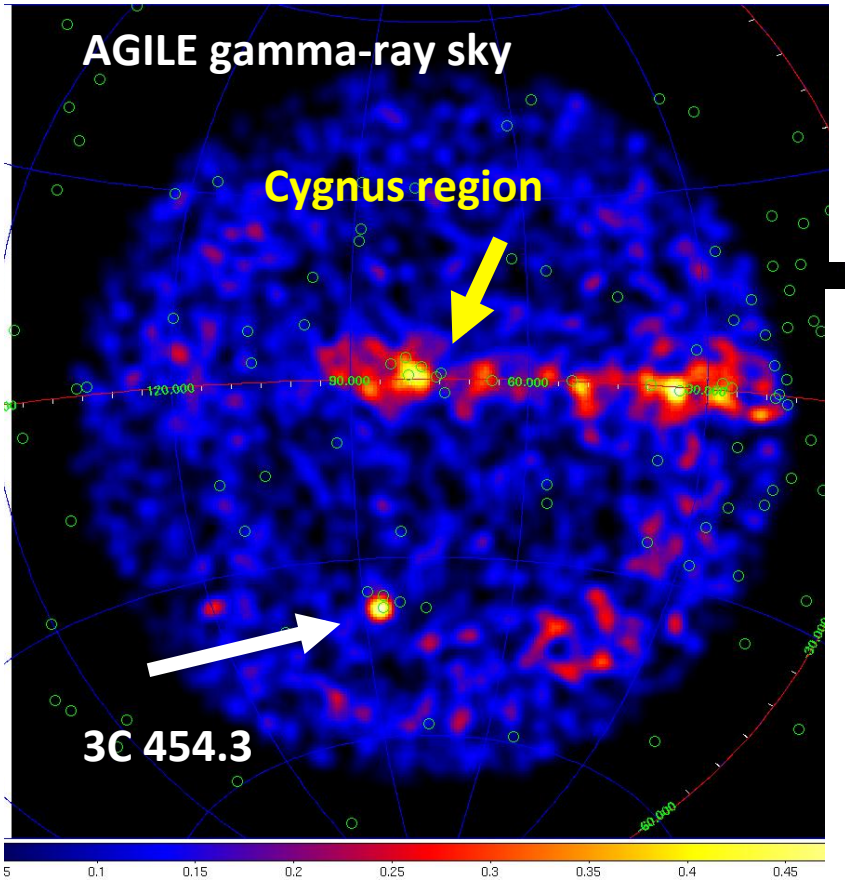
EGRET
(1991-2000)
Phases 1-5

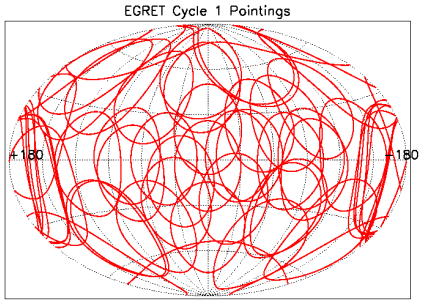
Spark chamber
- **sense electrode spacing ~mm**
- **sensitive layer depth ~cm**
  - ***up to 28 hit over >1m***

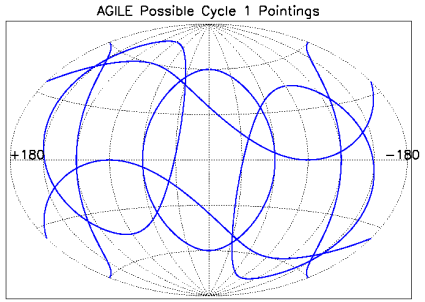
LAT
(2008- >2013)
1-yr simulation

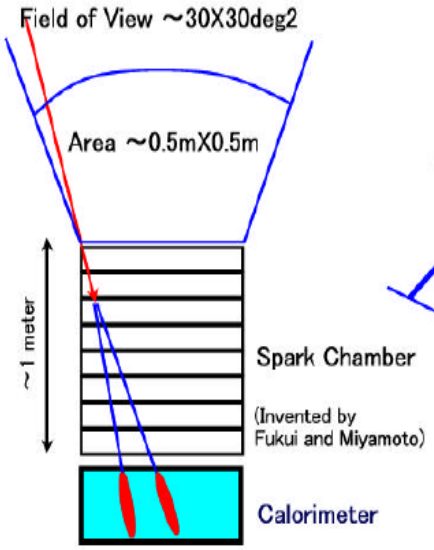
Si-strip detectors
- **sense electrode spacing ~0.2mm**
  - ***better single hit resolution***
- **sensitive layer depth ~0.4mm**
  - ***up to 36 hit over 0.8m***
  - ***converter proximity to minimize MCS***

Technology impact - FoV

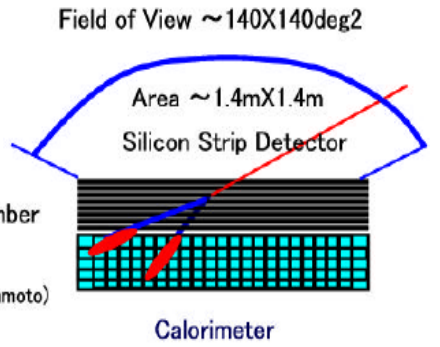






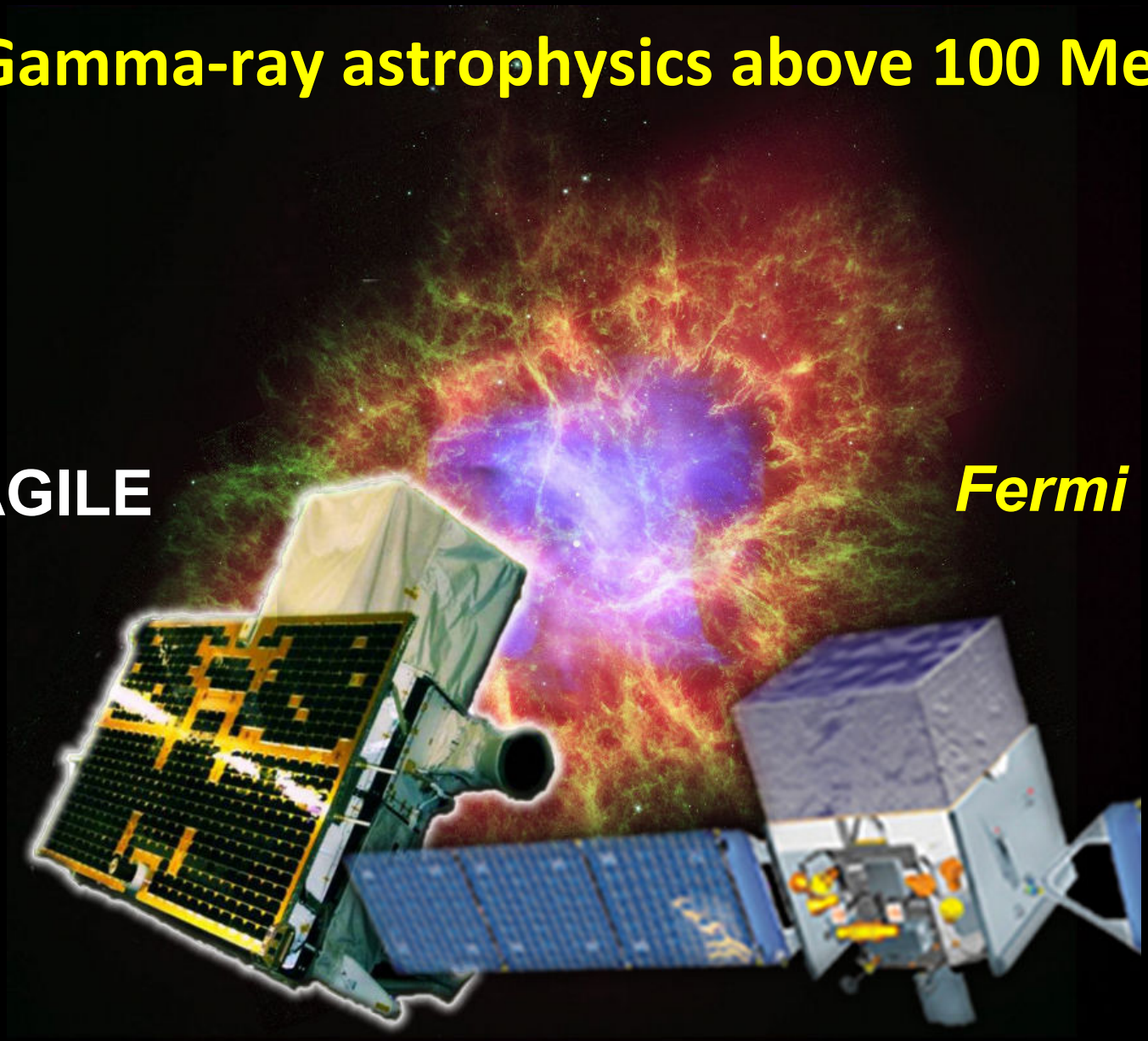


EGRET on Compton GRO



GLAST Large Area Telescope

Gamma-ray astrophysics above 100 MeV



Picture of the day, Feb. 28, 2011, NASA-HEASARC

Exercise on GeV gamma-rays

- Find the web sites of AGILE and Fermi/LAT
- Check the status of “new” gamma-ray detectors (CALET, DAMPE, Gamma-400, HERD)

AGILE

http://agile.rm.iasf.cnr.it/

AGILE

Space Science Data Center

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Welcome to the AGILE Data Center Home Page at SSDC

These pages provide updated information and services in support to the general scientific community for the mission AGILE, which is a small Scientific Mission of the Italian Space Agency (ASI) with participation of INFN, IASF/INAF and CIFS .

AGILE is devoted to gamma-ray astrophysics and it is a first and unique combination of a gamma-ray (AGILE-GRID) and a hard X-ray (SuperAGILE) instrument, for the simultaneous detection and imaging of photons in the 30 MeV - 50 GeV and in the 18 - 60 keV energy ranges. After more than 13 years of operations, AGILE is working nominally, providing valuable data and important scientific results.

AGILE operations:
Launch date 23 April, 2007
Planned Nominal Phase: 2 + 2 extended years
Elapsed: 13 years in orbit completed on 23 April, 2020
Current Extended Phase: ASI extended AGILE operations up to 31 May, 2022

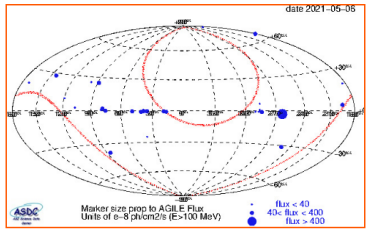
The AGILE Mission Board (AMB) has executive power overseeing all the scientific matters of the AGILE Mission and is composed of:

- AGILE Principal Investigator: Marco Tavani, INAF Rome (Chair)
- ASI Project Scientist: Paolo Giommi, ASI
- ASI Mission Director: Fabio D'Amico, ASI
  (Former ASI Mission Directors: Luca Salotti, up to September 20, 2010 and Giovanni Valentini up to January 22, 2015)
- AGILE Co-Principal Investigator: Guido Barbiellini, INFN Trieste
- 1 ASI representative: Elisabetta Tommasi di Vignano
  (Former ASI representative: Sergio Colafrancesco up to June, 2010)

- INAF Project Scientist: Carlotta Pittori (from November 10, 2020)

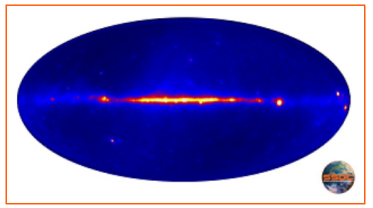
AGILE current spinning sky view

(Click here for previous pointing details)



Click here to access the AGILE Spinning FOV plotter

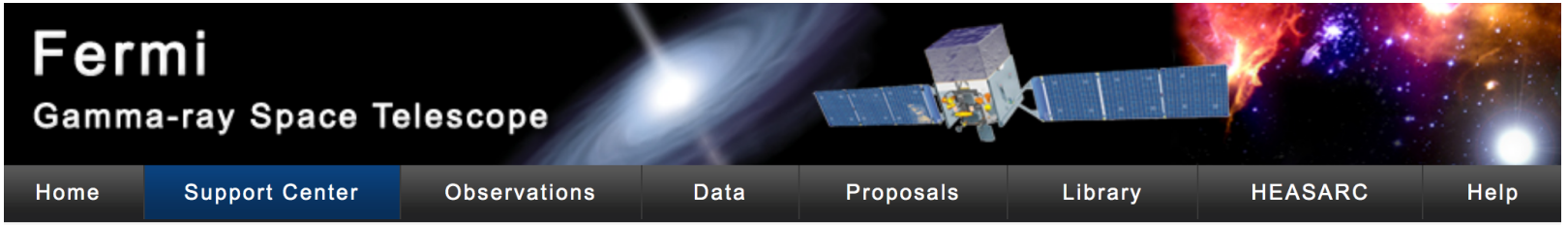
Click here to access the AGILE Real Data FOV Plotter



AGILE total intensity map up to Sep. 30, 2017.

https://agile.ssdc.asi.it/

Fermi/LAT



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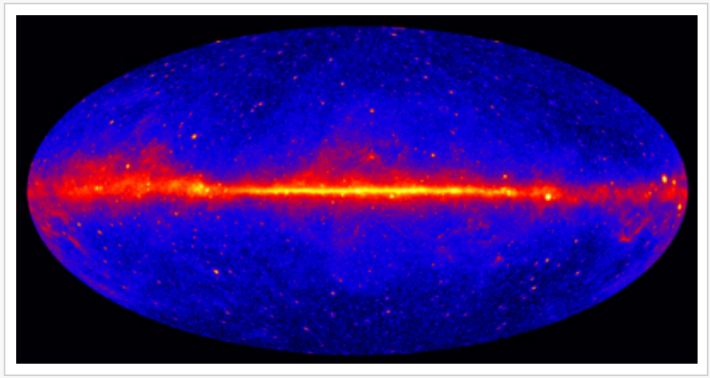
The Fermi Science Support Center (FSSC) runs the guest investigator program, creates and maintains the mission time line, provides analysis tools for the scientific community, and archives and serves the Fermi data. This web site is the portal to Fermi for all guest investigators.



This view shows the entire sky at energies greater than 1 GeV based on five years of data from the LAT instrument on NASA's Fermi Gamma-ray Space Telescope. Brighter colors indicate brighter gamma-ray sources.
Image Credit: NASA/DOE/Fermi LAT Collaboration

Look into the "Resources" section for finding schedules, publications, useful links etc. The "Proposals" section is where you will be able to find the relevant information and tools to prepare and submit proposals for guest investigator projects. At "Data" you will be able to access the Fermi databases and find the software to analyse them. Address all questions and requests to the helpdesk in "Help".

Fermi Observations for MW 675

Mission week 675 starts with a continuation of the asymmetric rocking +50/-60 profile from the previous week. On day of year 126 (2021-05-06) at 01:59 there is a 10 minute freeze observation during which an updated asymmetric profile is loaded. This profile continues until DOY 129 (2021-05-09) at 03:01 when there is a 10 minute freeze observation during which a symmetric +/-50 deg. profile is loaded. This profile continues until the end of the week. Note that positive rock angles are south, and negative angles are north.

» More Timeline Info

Latest News

» Fermi Sky Blog
» Fermi Blog

Apr 20, 2021

Updated Spacecraft Position and History Files Available

The updated files include the addition of the SC_VELOCITY column. This column contains a vector with the spacecraft velocity in meters per

https://fermi.gsfc.nasa.gov/ssc/

Fermi/LAT

Stanford | The Fermi Large Area Telescope

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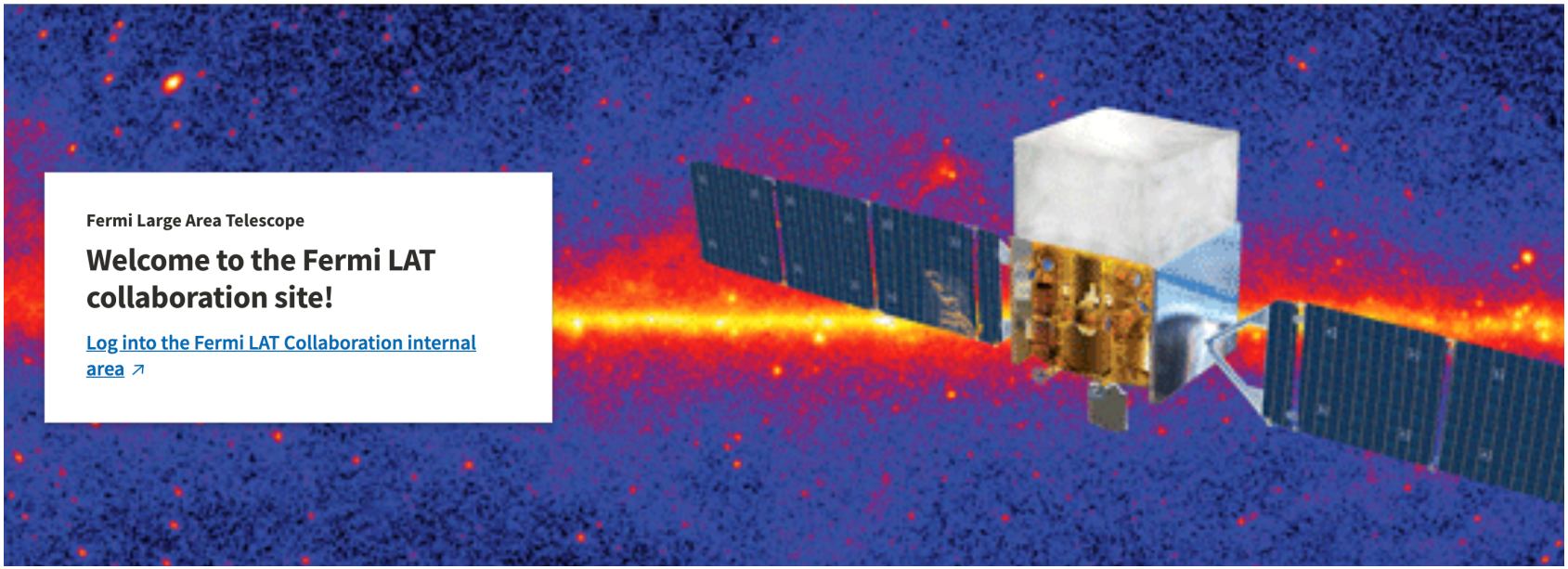
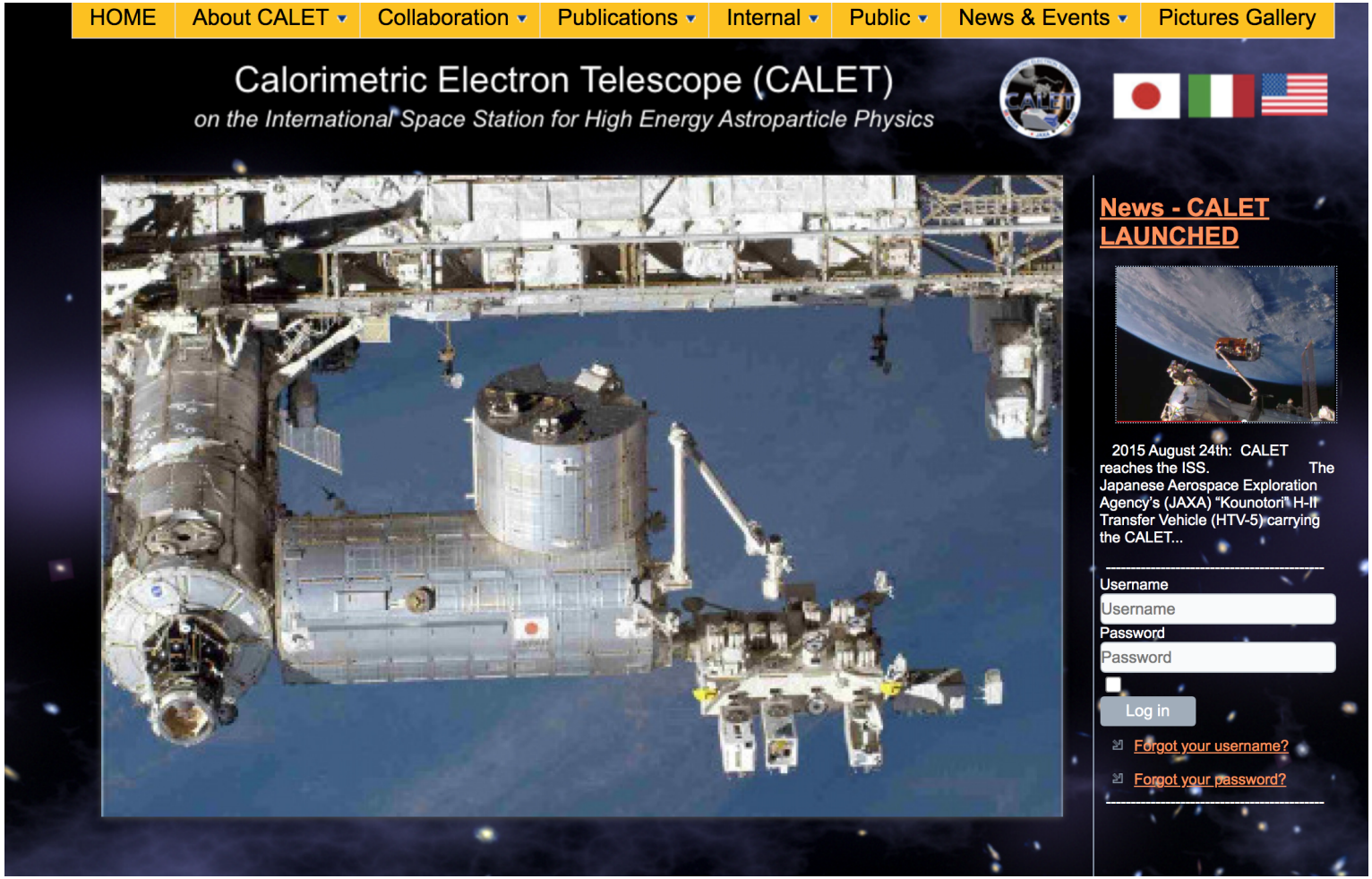


https://glast.sites.stanford.edu/

CALET



http://calet.pi.infn.it/

CALET

http://calet.phys.lsu.edu/

DAMPE

DArk Matter Particle Explorer

- Home
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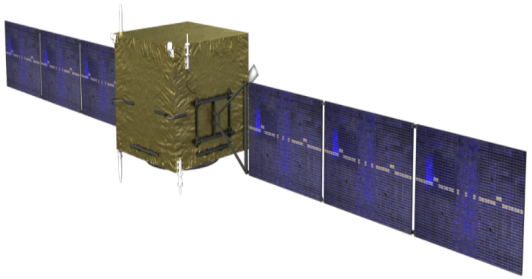
- STK
- BGO
- NUD
- News
- Publication
- The DAMPE Collaboration

DAMPE has been launched the 17th December 2015 at 00:12 UTC!



http://dpnc.unige.ch/dampe/

HERD

HERD
The High Energy cosmic Radiation Detection facility

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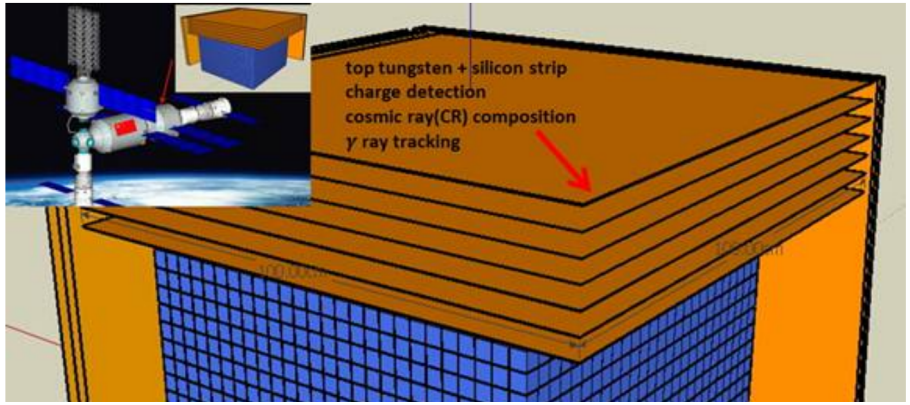
The High Energy cosmic Radiation Detection facility (HERD)

HERD(High Energy Cosmic Radiation Detection) facility is one of the Cosmic Lighthouse Program onboard China's Space Station, planned to be launched and assembled in 2020. The main science objectives of HERD onboard china's space station are detecting dark matter particle, study of cosmic ray composition and high energy gamma-ray observations. The main constraints imposed on HERD are: total weight less than around 2 tons and total power consumption less than around 2 kilowatts.

To achieve HERD's science objectives, HERD must have the capability of accurate electron and gamma-ray energy and direction measurement (tens of GeV – 10TeV), adequate cosmic ray energy measurement with charge determination (up to PeV).



News

The 3rd international workshop on HERD was held in Xi'an during Jan. 19-20, 2016.

External Links

IHEP
China Space Station wiki
LHAASO
CR observatory in Tibet
HXMT
POLAR

http://herd.ihep.ac.cn/

HERD

HERD

The High Energy Cosmic Radiation Detection Facility

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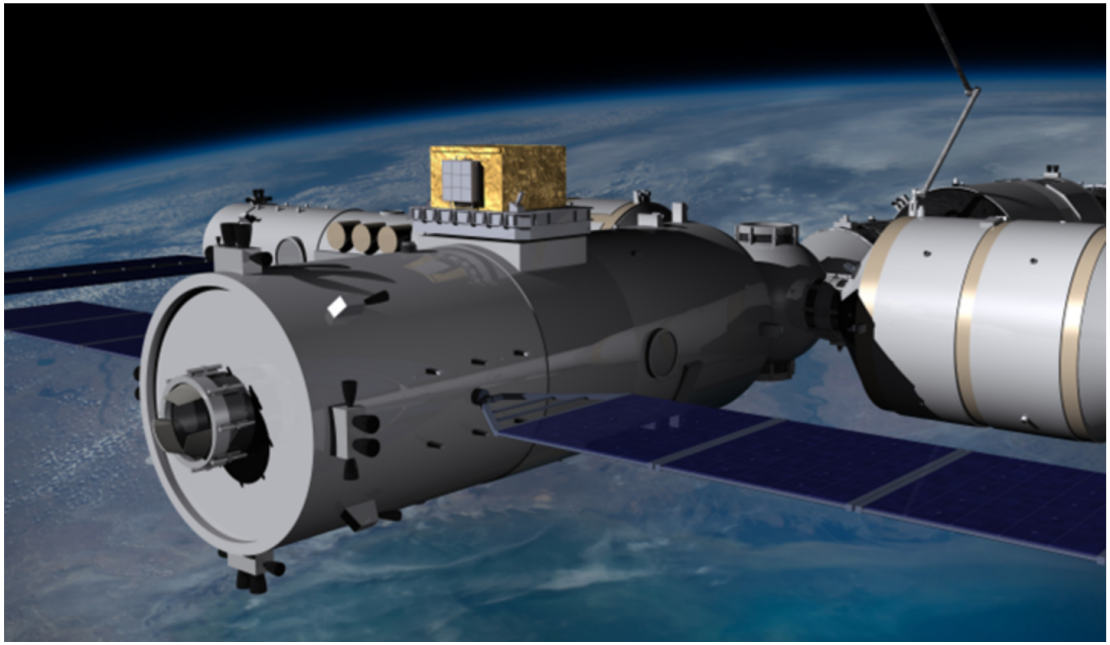

The High Energy cosmic-Radiation Detection (HERD) facility has been proposed as one of several space astronomy payloads onboard the future China's Space Station (CSS), planned for operation starting around 2027

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- “新型空间高能辐射探测的重要科学问…
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- Eighth HERD Workshop Held to Enhance …
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AGILE

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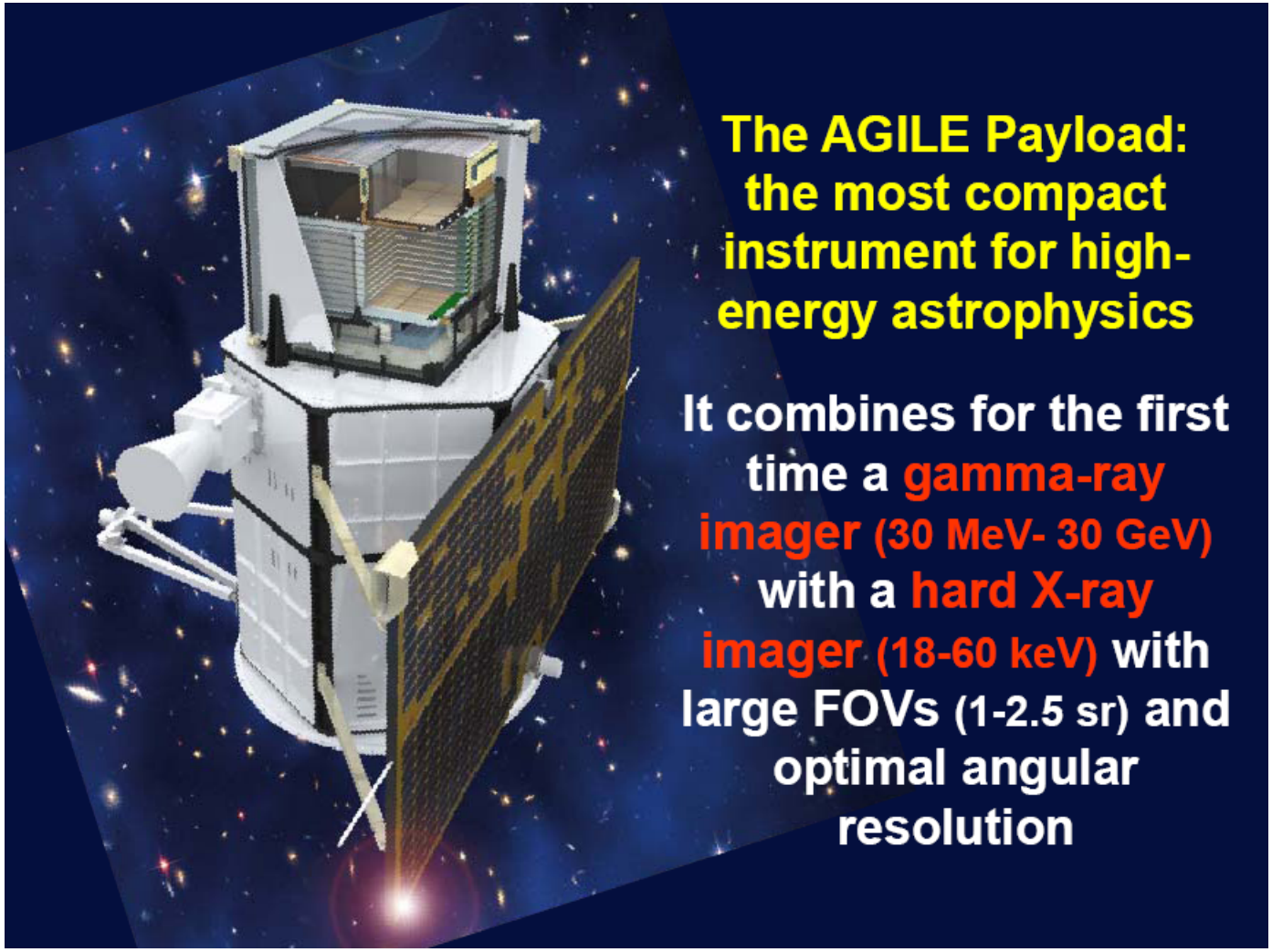
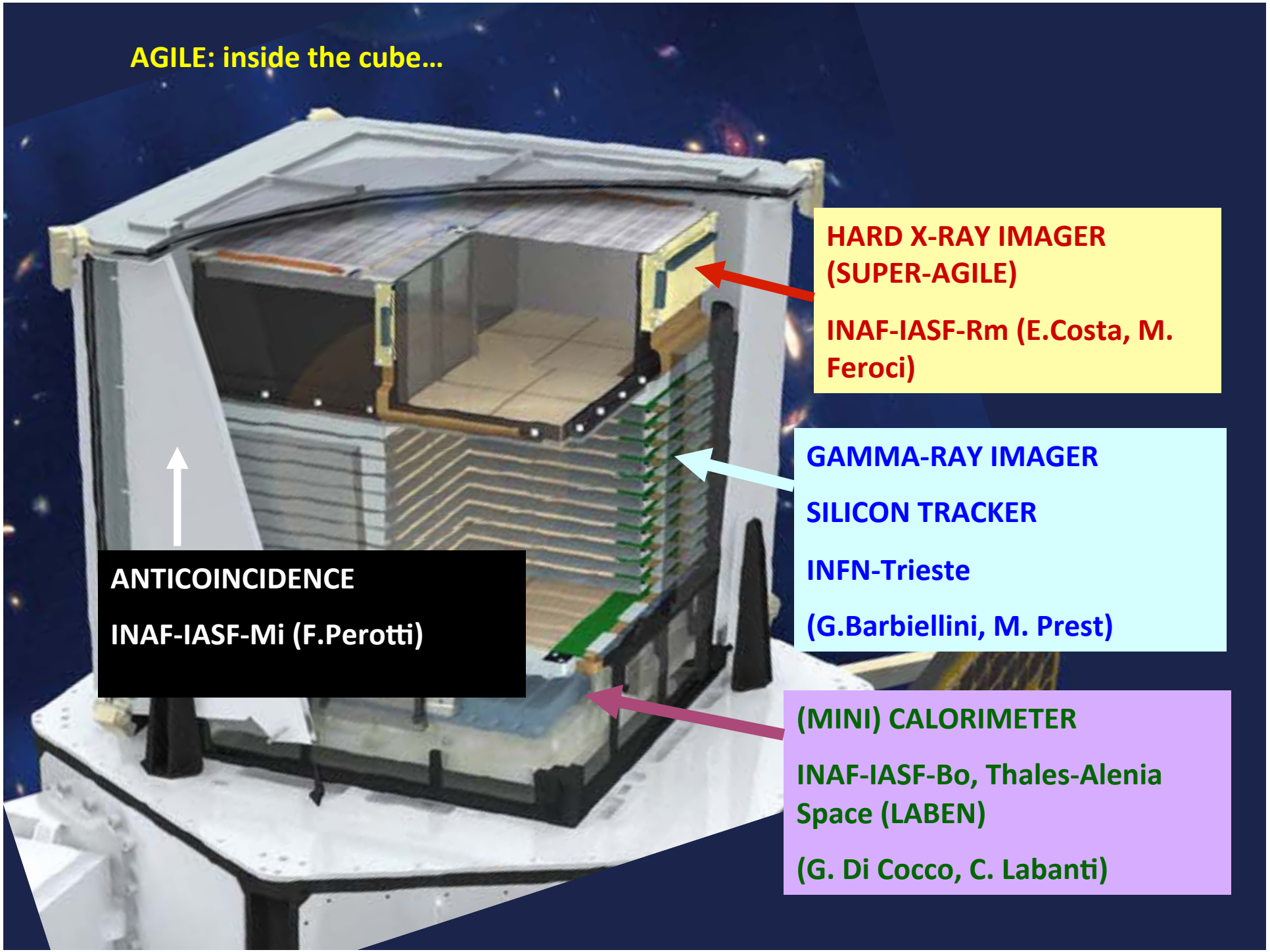
AGILE instrument




AGILE: inside the cube…
HARD X-RAY IMAGER (SUPER-AGILE)
INAF-IASF-Rm (E.Costa, M. Feroci)
GAMMA-RAY IMAGER
SILICON TRACKER
INFN-Trieste
(G.Barbiellini, M. Prest)
ANTICOINCIDENCE
INAF-IASF-Mi (F.Perotti)
(MINI) CALORIMETER
INAF-IASF-Bo, Thales-Alenia Space (LABEN)
(G. Di Cocco, C. Labanti)

The Silicon Tracker

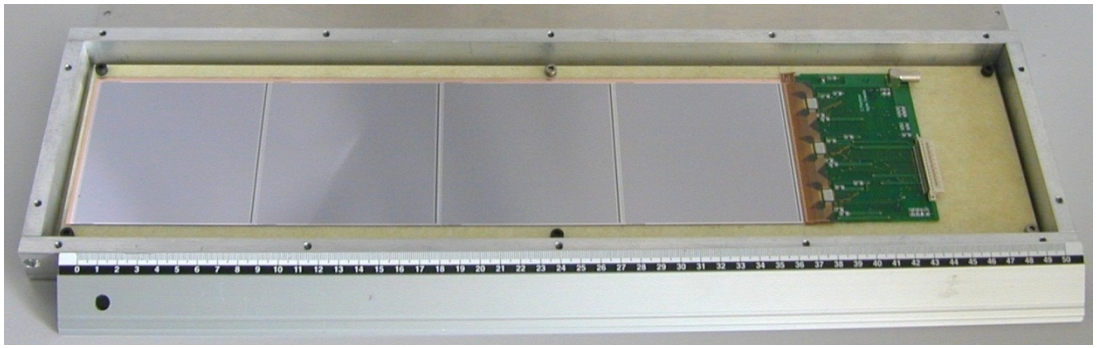
The AGILE silicon detectors

Detector specifications:

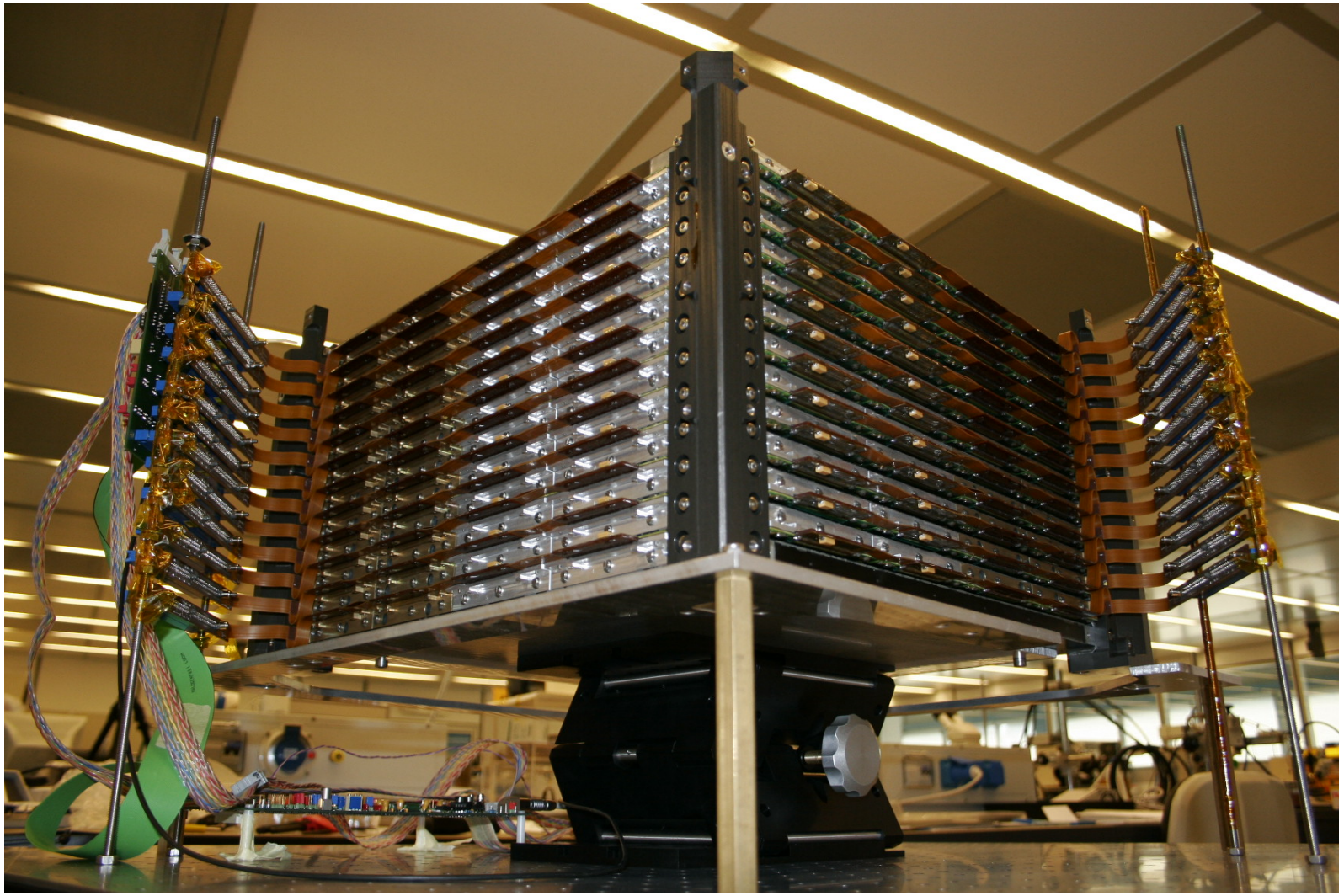
- dimension: 9.5x9.5 cm^2
- thickness: 410 μm (6 inch technology)
- readout pitch: 242 μm;
  physical pitch: 121 μm (one floating strip)
- number of strips/ladder: 384
- Single side and AC-coupled
- leakage current: 2 nA/cm^2 at Vbias=2.5*V_{FD} =200 V
- polarization resistor: 40 MΩ
- coupling capacitor: 55 pF/cm
- Al strip resistance: 4.3 Ω/cm
- max number of bad strips: <1%
- average number of bad strips: <0.5%

The AGILE frontend chip: TA1 → TAA1

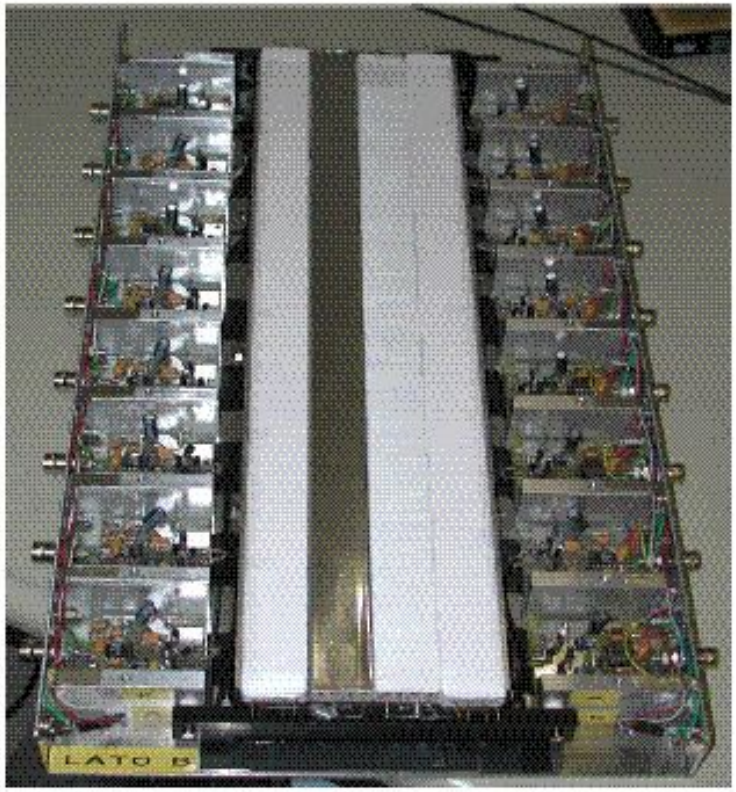
- low noise, low power, SELF-TRIGGERING
- technology: 1.2 μ CMOS, double poly, double metal (final: 0.8 μ BiCMOS on epitaxial layer)
- features:
  - 128 channels
  - gain: 25 mV/fC; range: 18 fC
  - noise (e^- rms): 165+6.1/pF for T_{peak}=2 μs
  - power: <0.4 mW/channel
  - power rails: ±2 V
  - readout frequency: 5 Mhz
  - gain spread: <1.5%
  - threshold offset spread (TA1): 20% (in TAA1 will be implemented a 3 bit DAC per channel)



The AGILE TRK



The CsI Mini-Calorimeter



MINI-CALORIMETER

DETECTOR

30 CsI bars wrapped with tight diffusion material organized in 2 orthogonal trays

- bar dimension: 40x2.3x1.5 cm^3
- total radiation length: $1.5X_0$ (in axis)

FRONTEND ELECTRONICS

- 1 photodiode on each side of the bar
- optically coupled

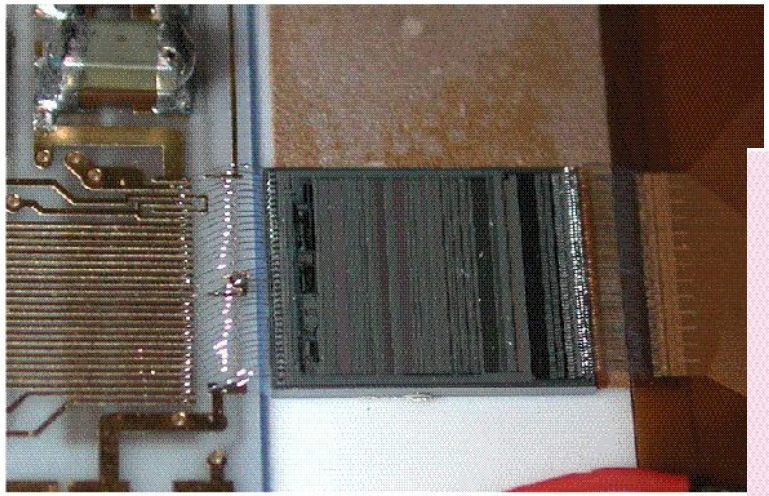
GOAL

- measure energy deposit of the photon conversion pair (GRID mode)
- detect GRBs and transients in the range 0.25-250MeV (BURST mode)

SCIENTIFIC FEATURES

- energy resolution: 22-24%(FWHM) @ 1MeV
  0.7% @ 100MeV
- spatial resolution: 15mm @ 1MeV
  2mm @ 100MeV
- timing resolution: 2μs (BURST mode)

SuperAGILE X-ray detector



SUPER-AGILE

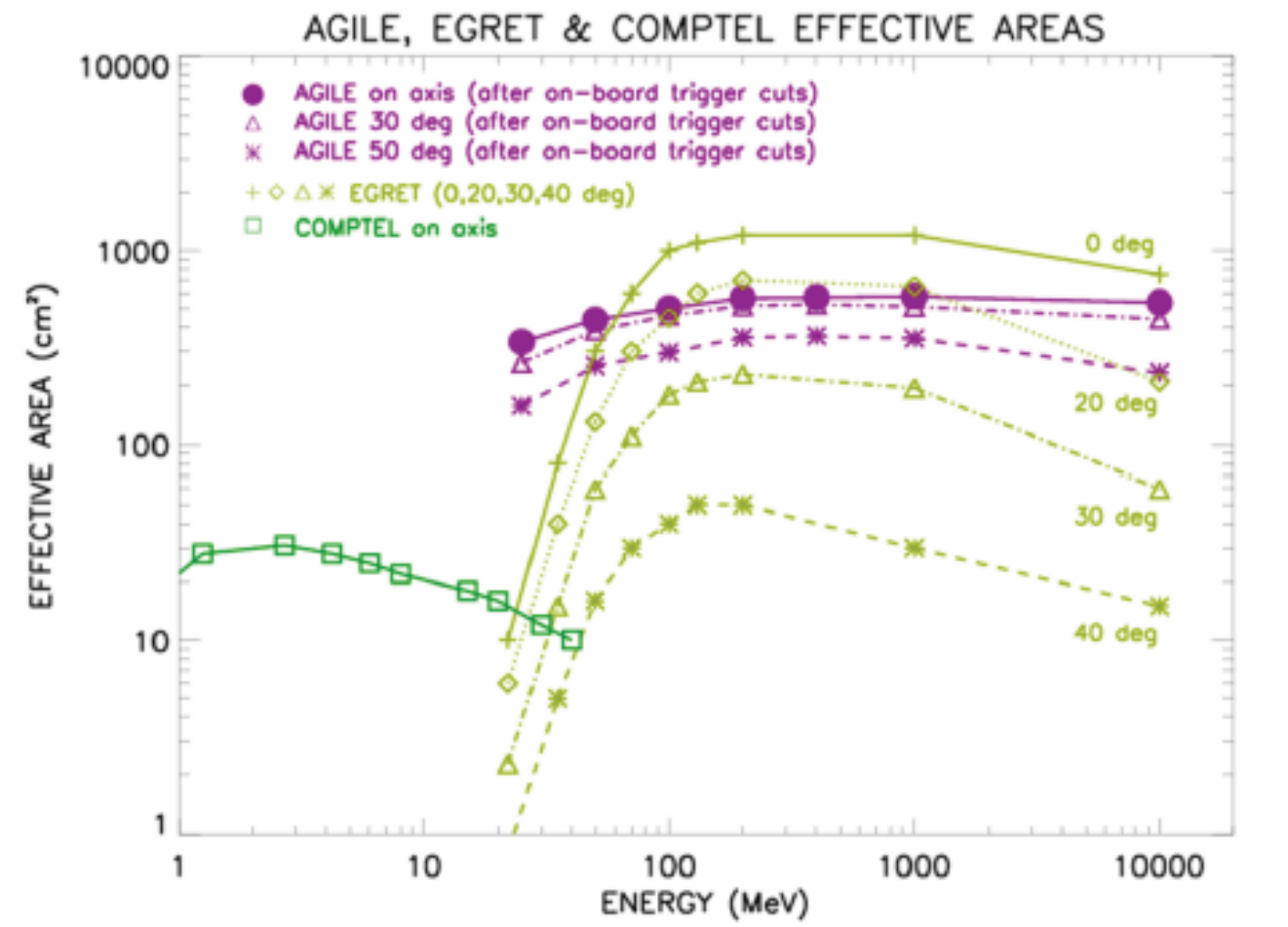
DETECTOR
- plane with 16 silicon tiles organized in 4 1D detectors
- each detector: 1536 readout strips (0.121mm pitch)
- a coded mask system

FRONTEND ELECTRONICS
- 12 self-triggering readout ASICs (128 channels each) per each detector, positioned on a kapton-FR4 hybrid

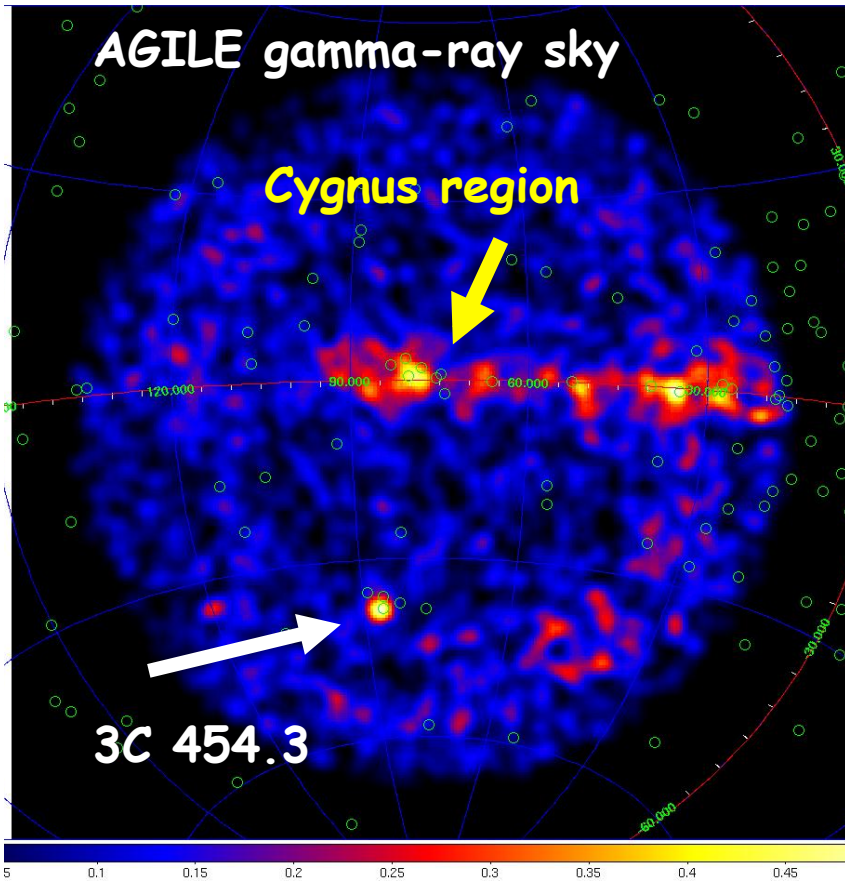
GOAL
measure X-rays in the energy range 10-40keV to detect GRBs, transients, galactic and extra-galactic sources

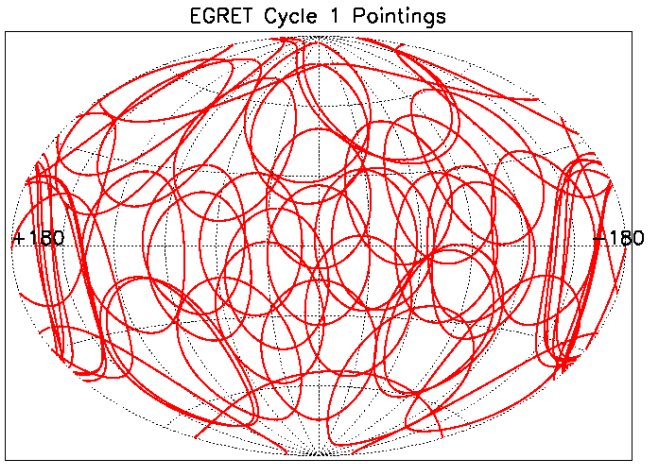
SCIENTIFIC FEATURES
- imaging: 1'-3' at ~20mCrab
- timing resolution: 5μs
- energy resolution: 4keV (FWHM)
- flux sensitivity: ~5mCrab (15keV)

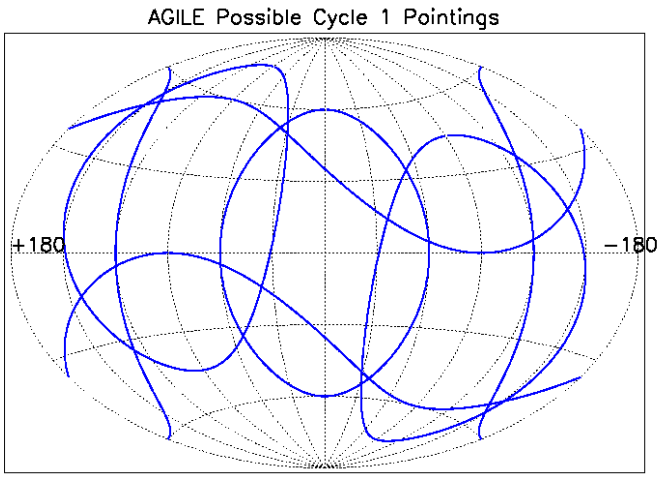
Performance



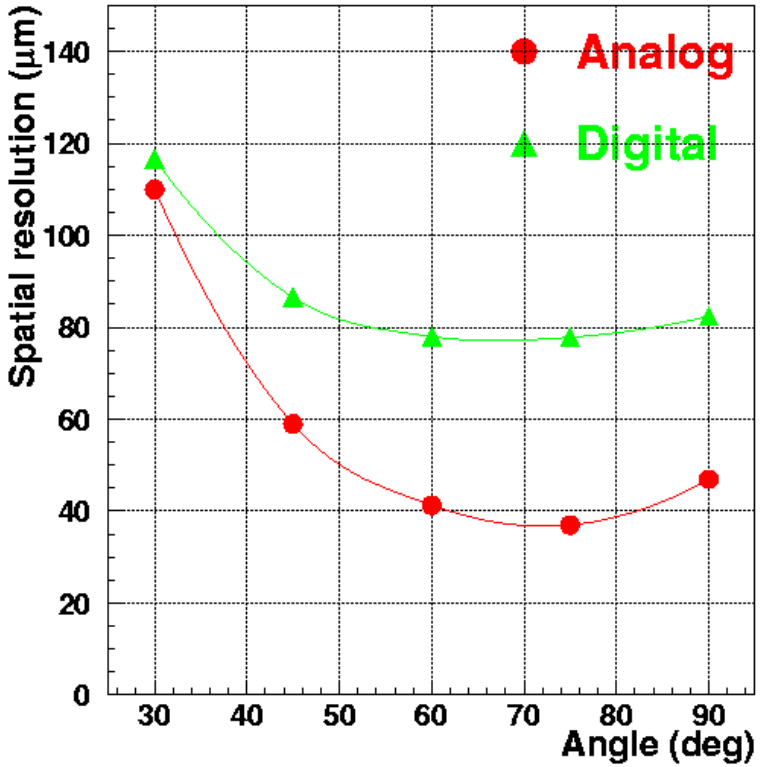
Si Self Trigger and FoV

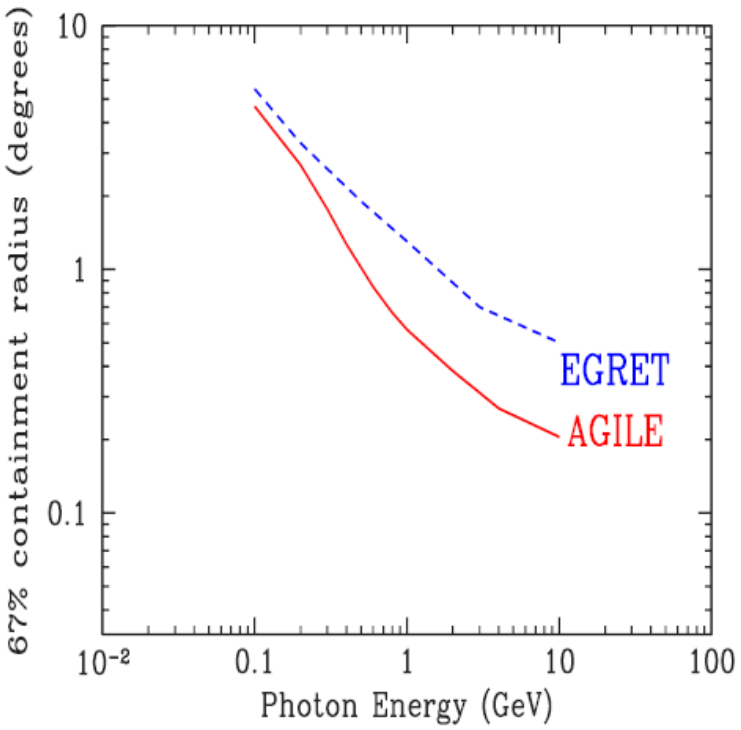






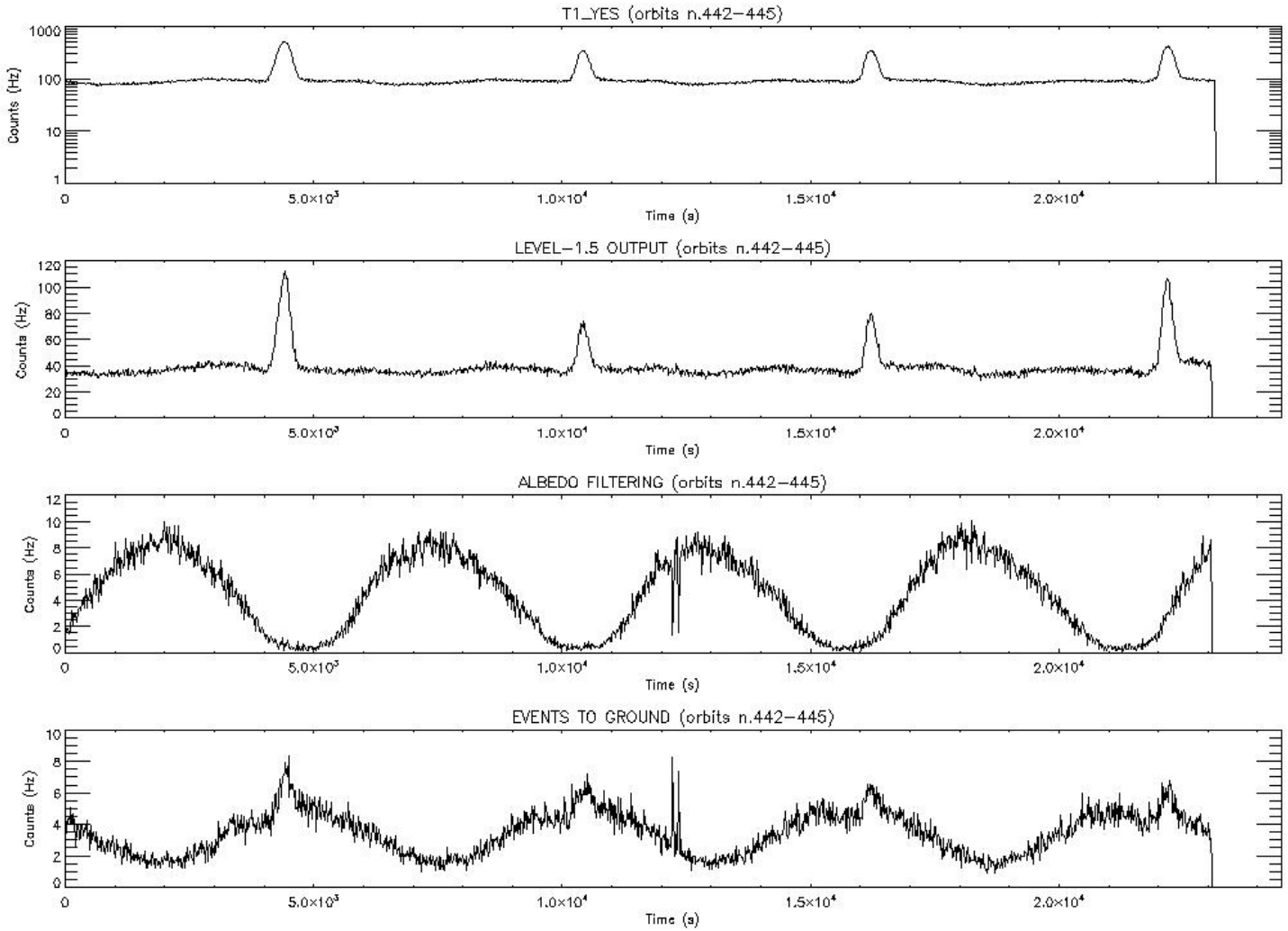
Analog readout and PSF





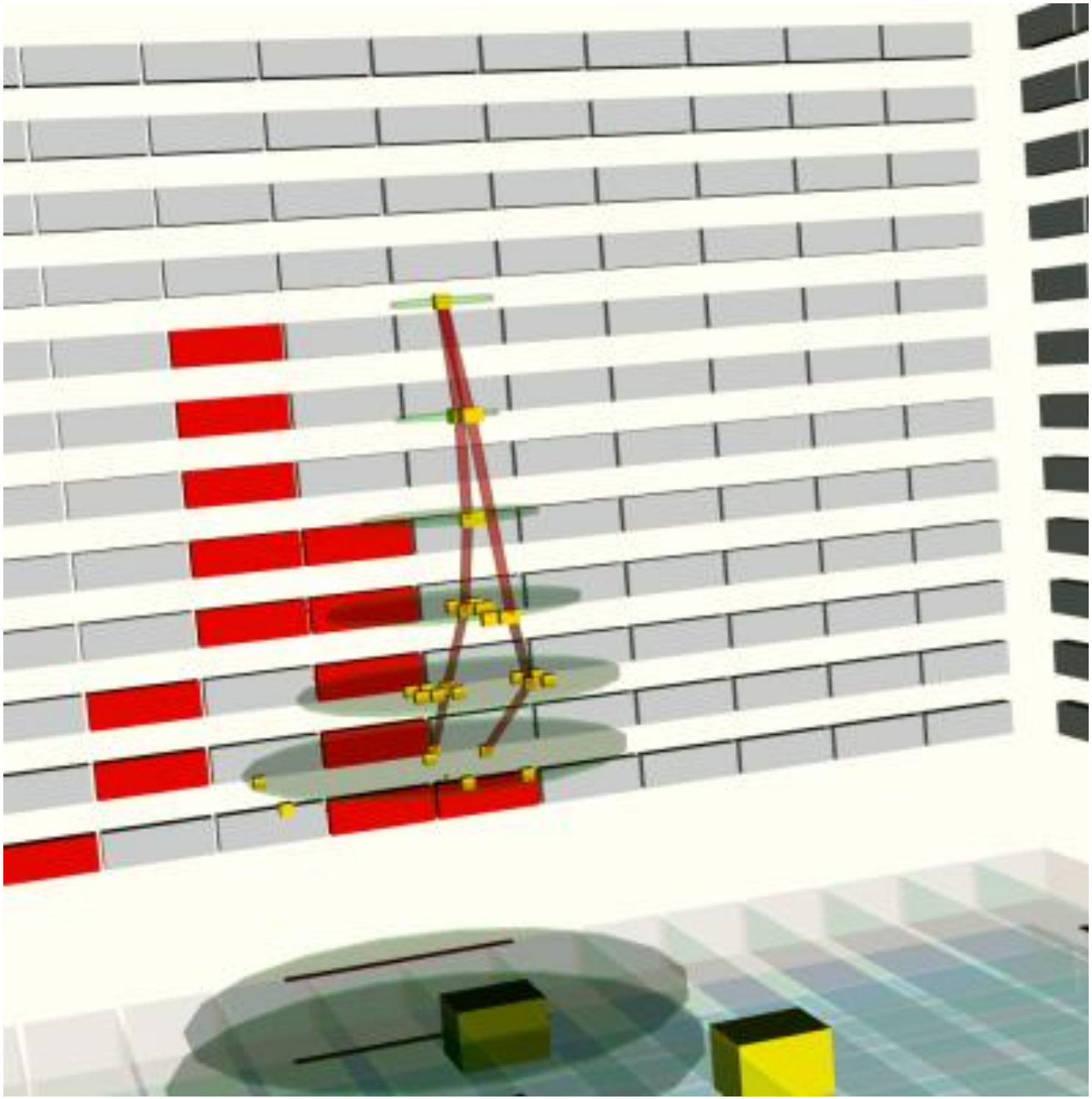
The AGILE launch

AGILE in orbit

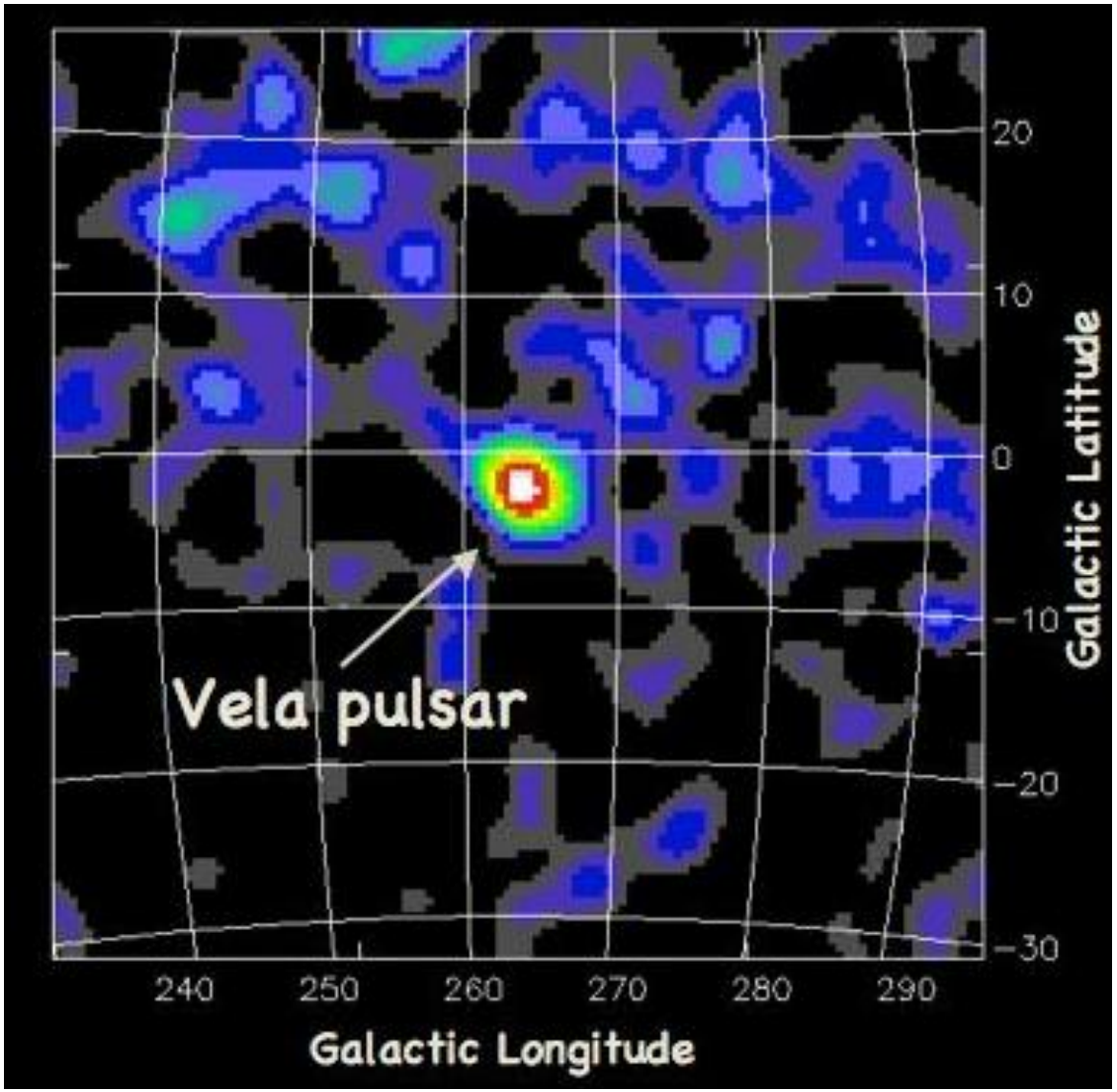


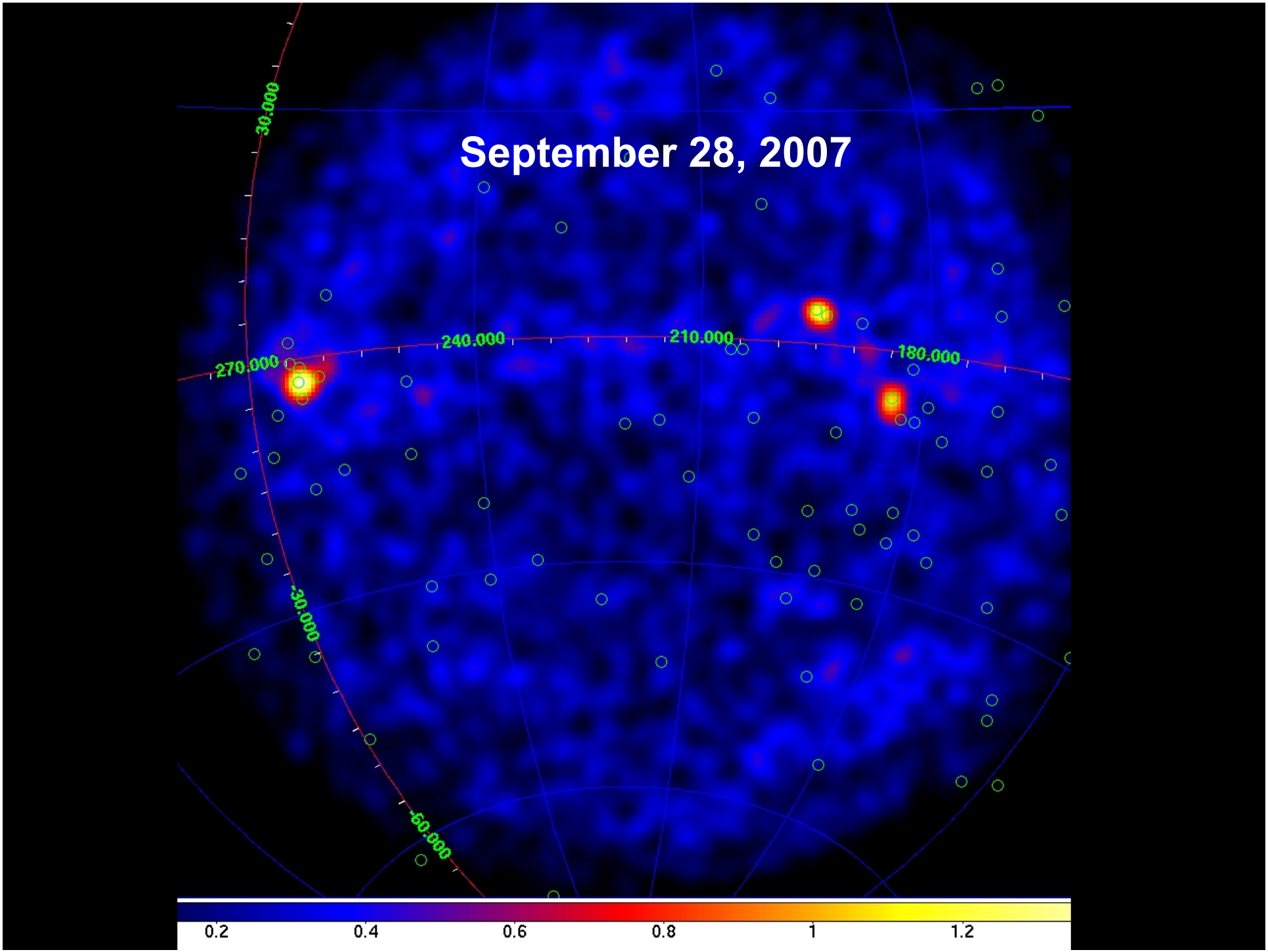
On Orbit Trigger Rates

First gamma-ray detected in orbit with the nominal GRID trigger configuration (May 10, 2007)



First Light

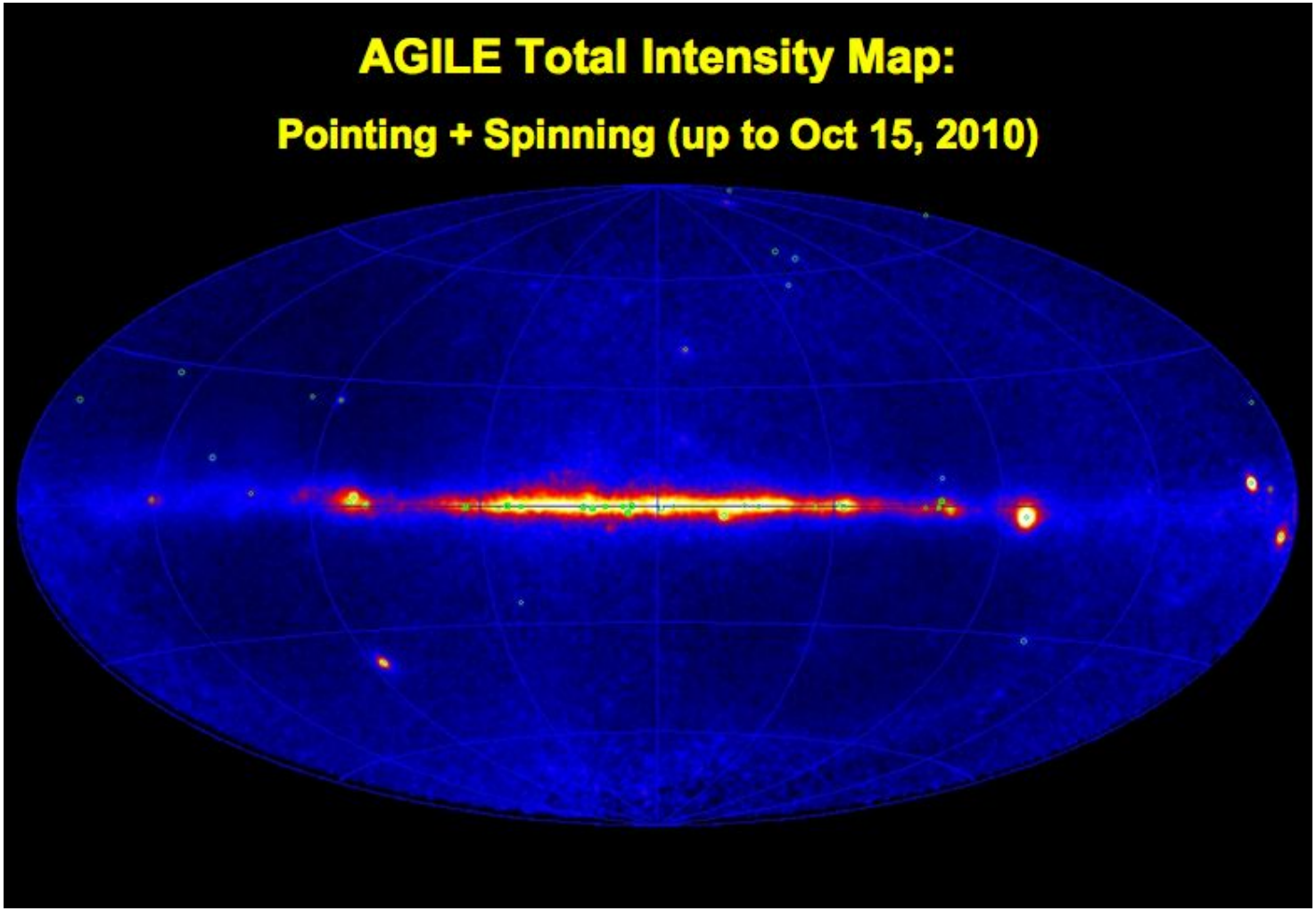

Vela pulsar
20
10
0
−10
−20
−30
Galactic Latitude
240
250
260
270
280
290
Galactic Longitude


September 28, 2007
30.000
240.000
210.000
180.000
270.000
-30.000
-60.000
0.2
0.4
0.6
0.8
1
1.2

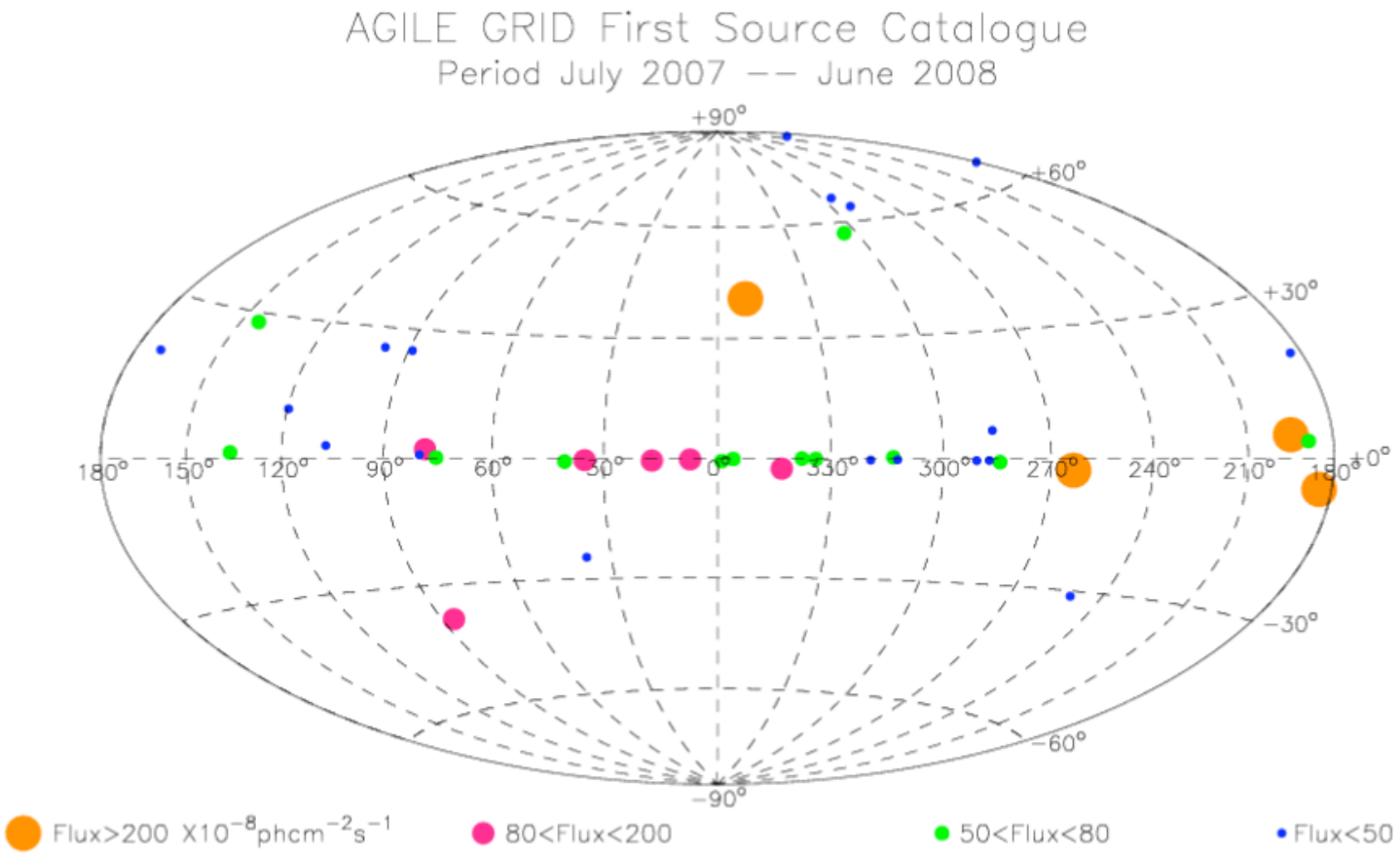
AGILE two lifes

	pointing-AGILE	spinning-AGILE
time period	Jul.07 – Oct.09	Nov. 2010 -
attitude	fixed	variable (spinning, 1º/sec)
sky coverage	1/5	~ 70%
source livetime fraction	~ 0.5	~ 0.2
1-day exposure (30 degree off-axis, 100 MeV)	~ $2\ 10^7$ (cm^2 sec)	(0.5-1) 10^7 (cm^2 sec)

The AGILE sky

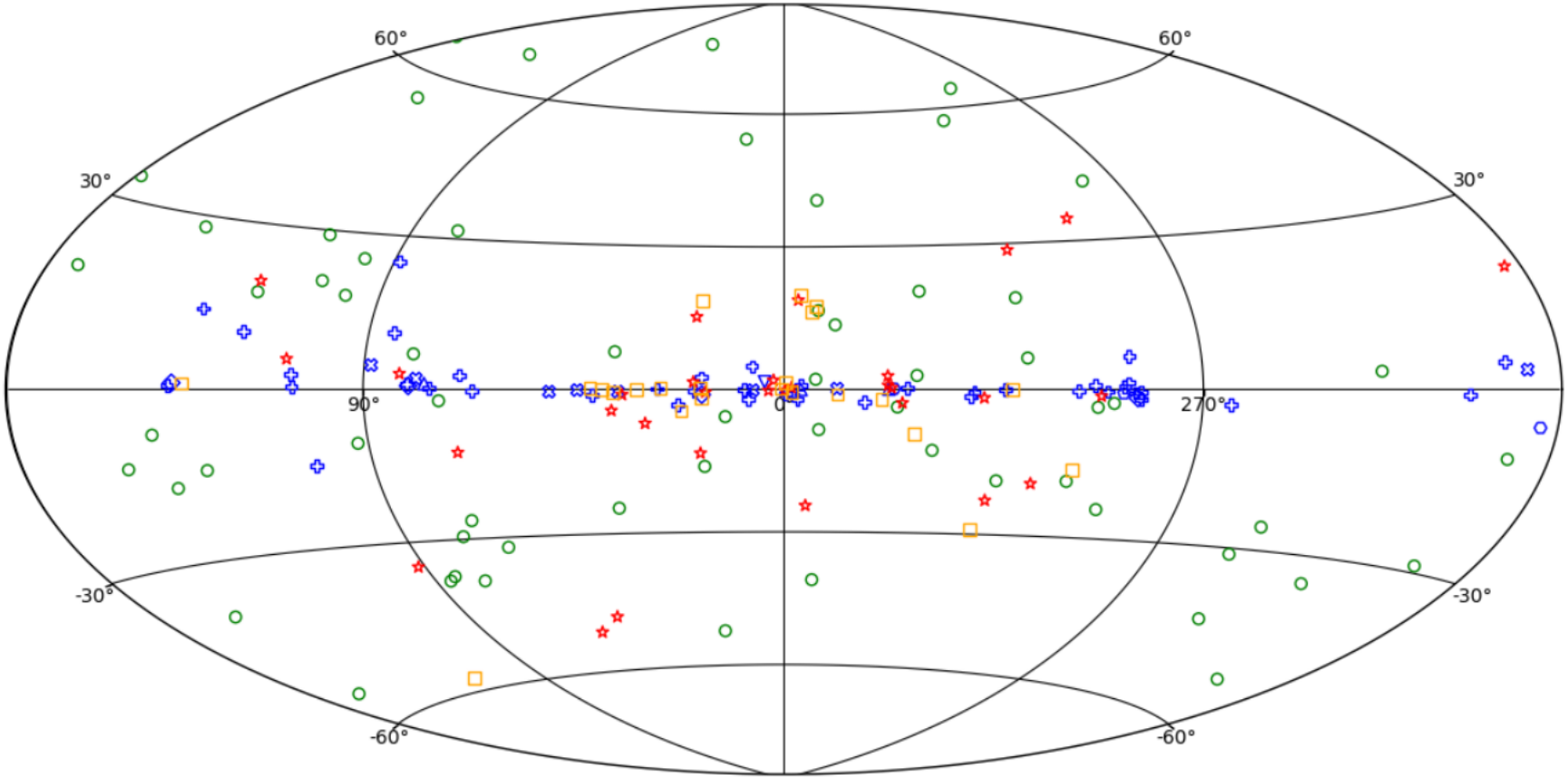


AGILE sources



Pittori et al. 2009

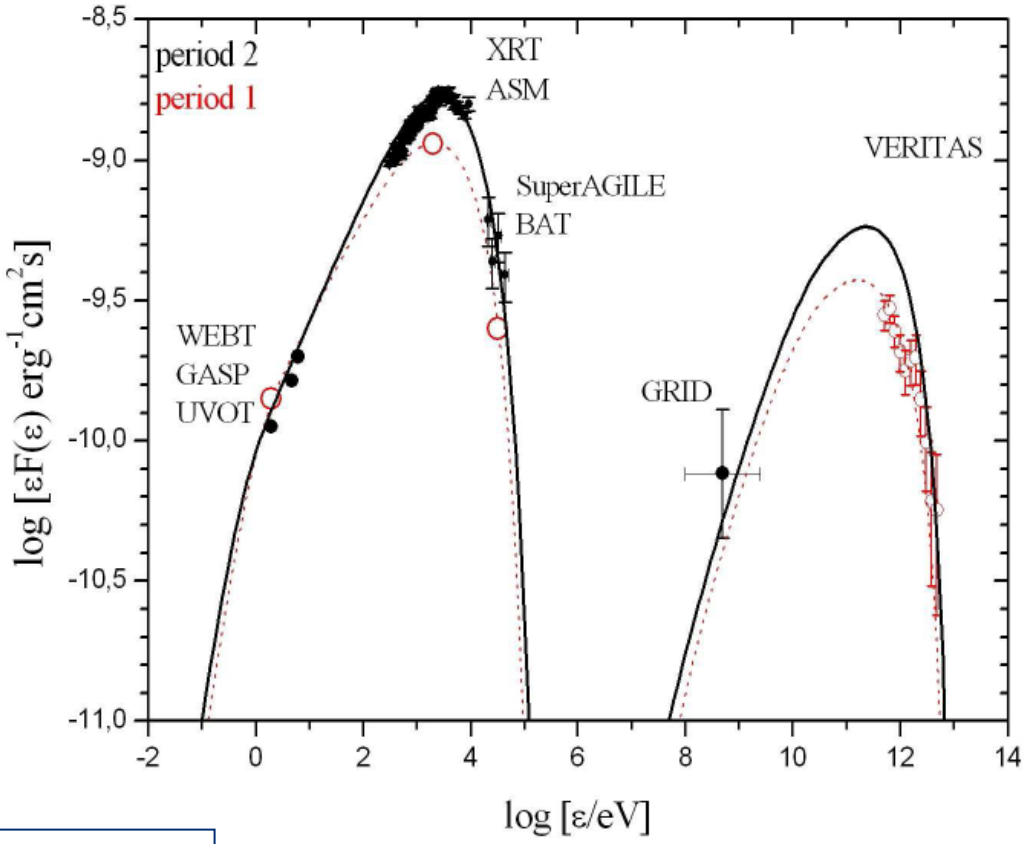
AGILE sources



Bulgarelli et al. 2019

Challenge # 1 – AGN

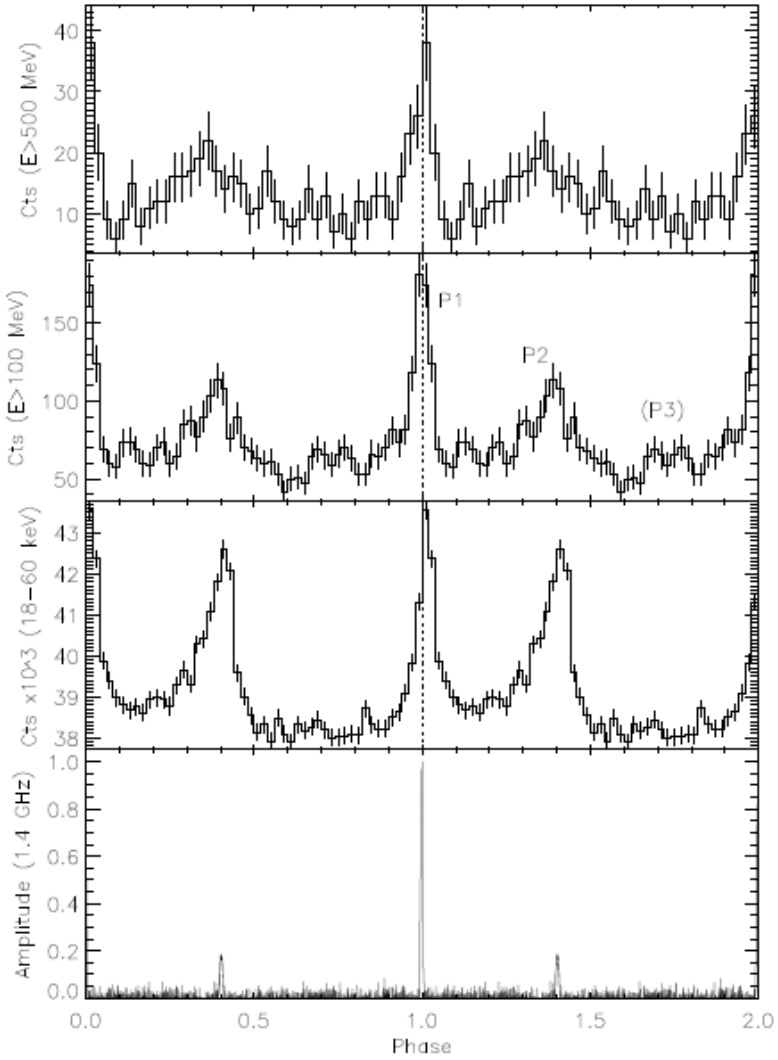
Joint campaign with MAGIC and VERITAS on Mkn 421



Donnarumma et al. 2009

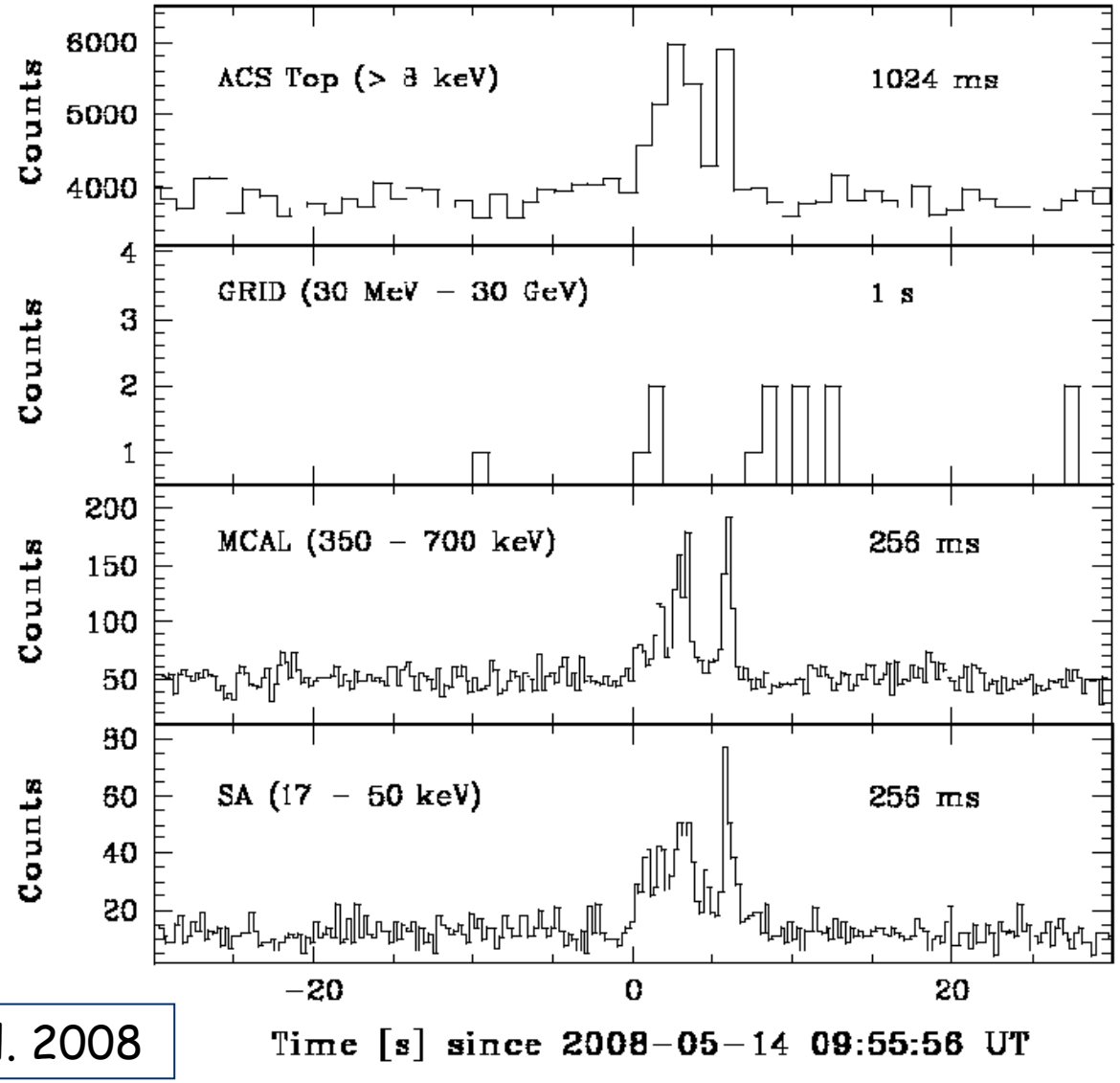
Challenge # 2 – Pulsar

High Precision Timing (eg. Crab PSR)



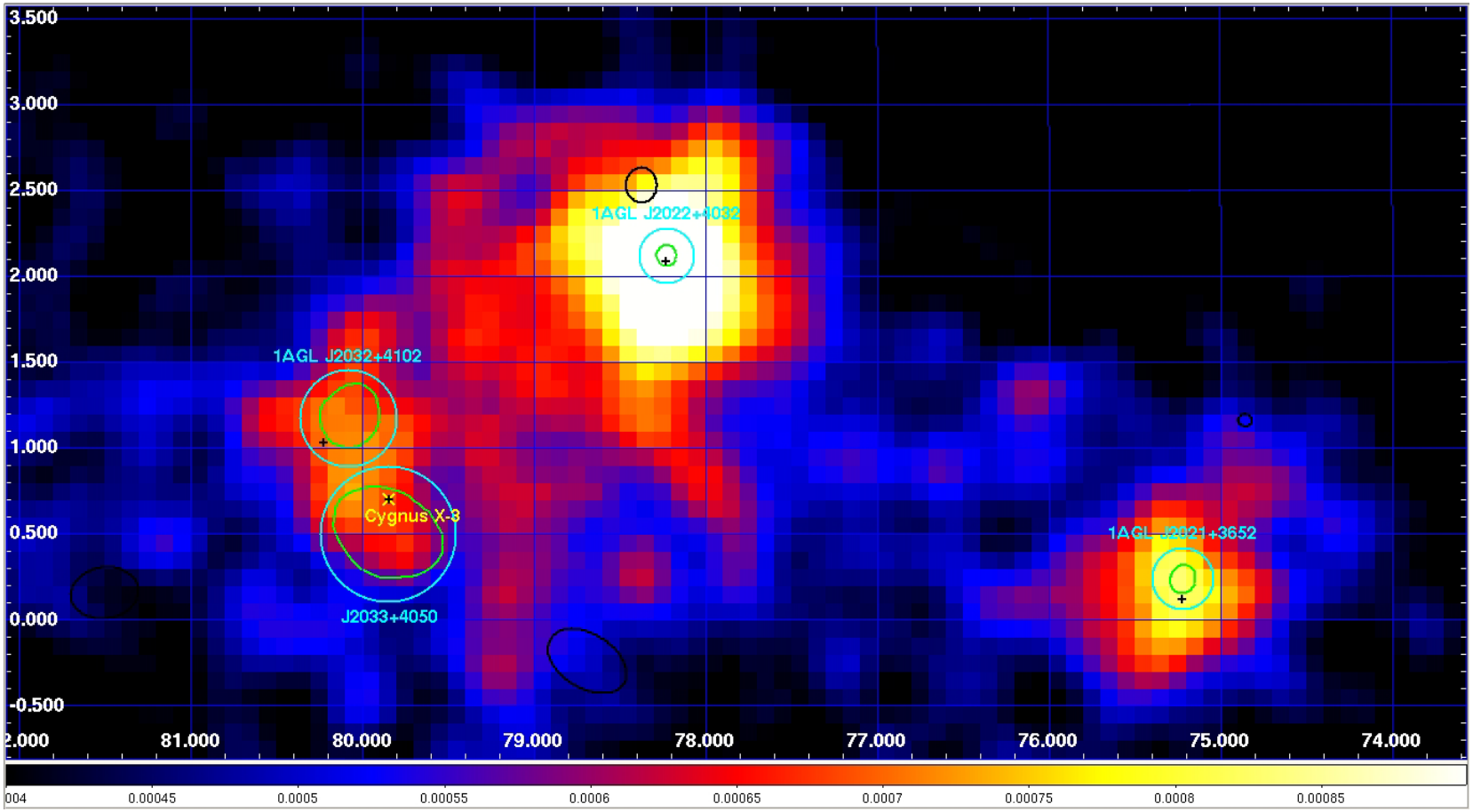
Pellizzoni et al. 2009

Challenge # 3 – GRB



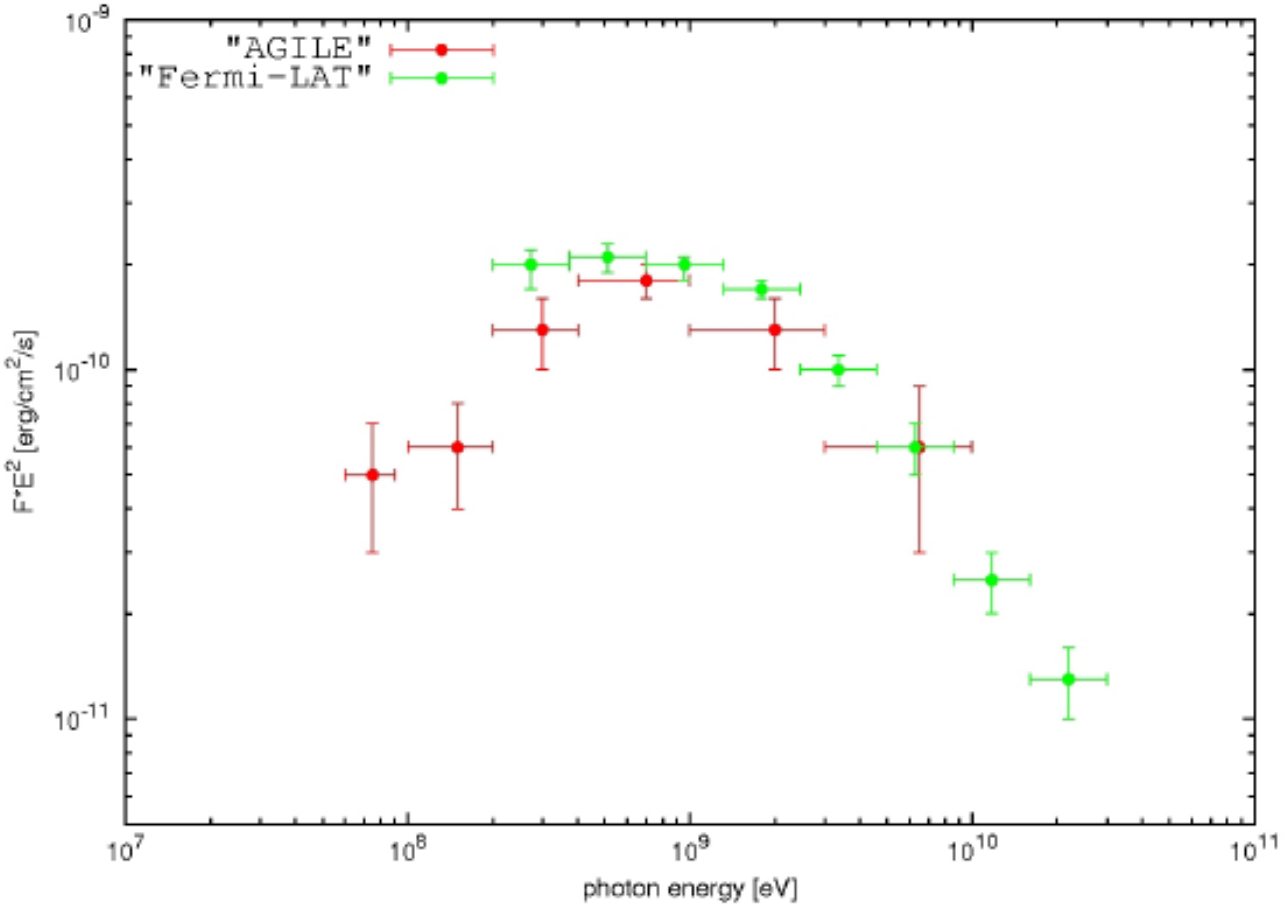
Giuliani et al. 2008

Challenge # 4 – Unidentified



Chen et al. 2011

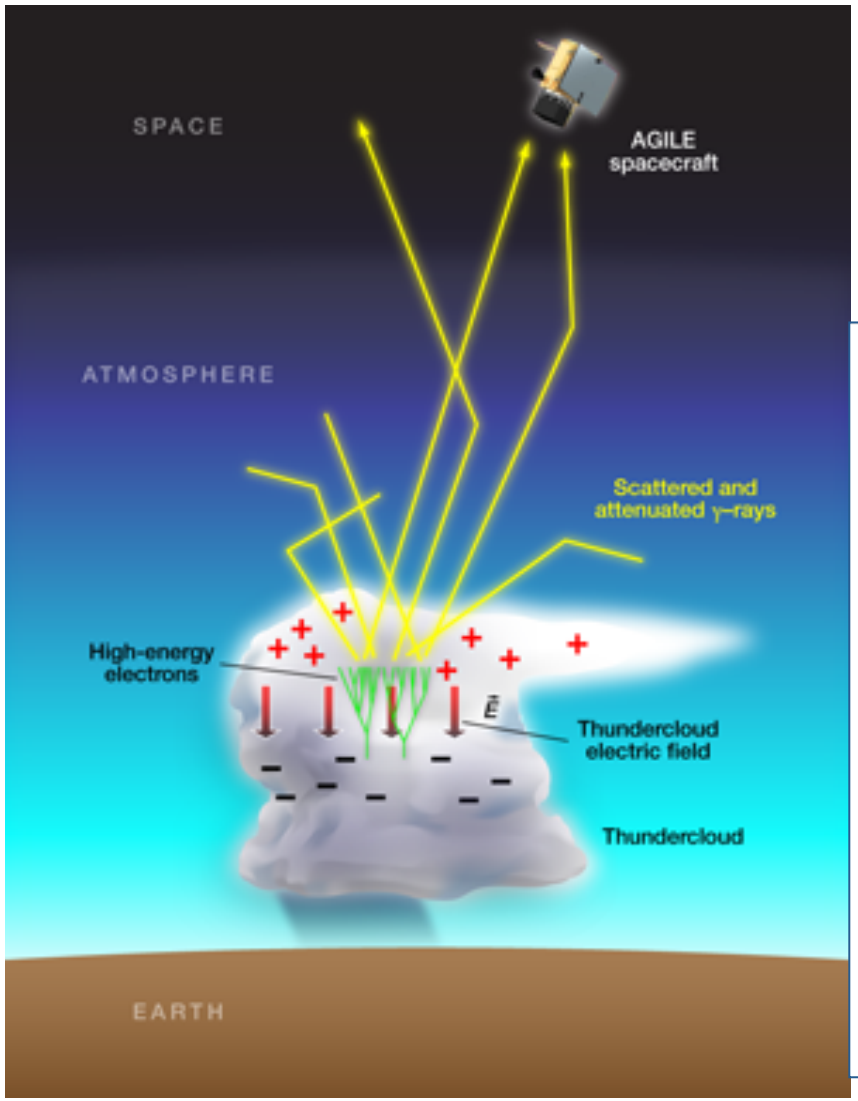
Challenge # 5 – Spectral resolution

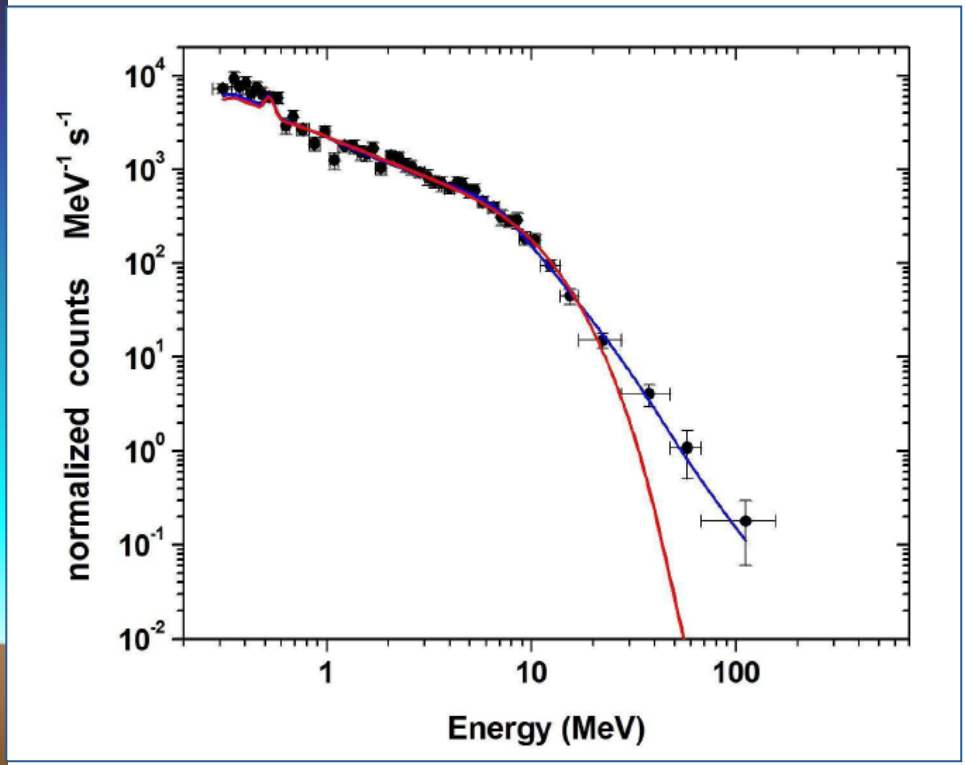


Giuliani et al. 2011

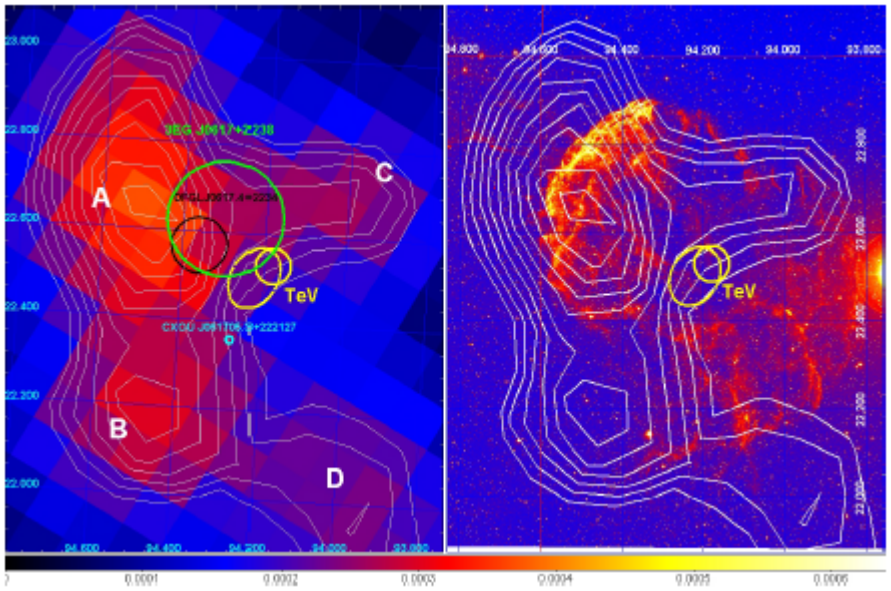
Terrestrial Gamma Ray Flashes

Marisaldi et al. 2010

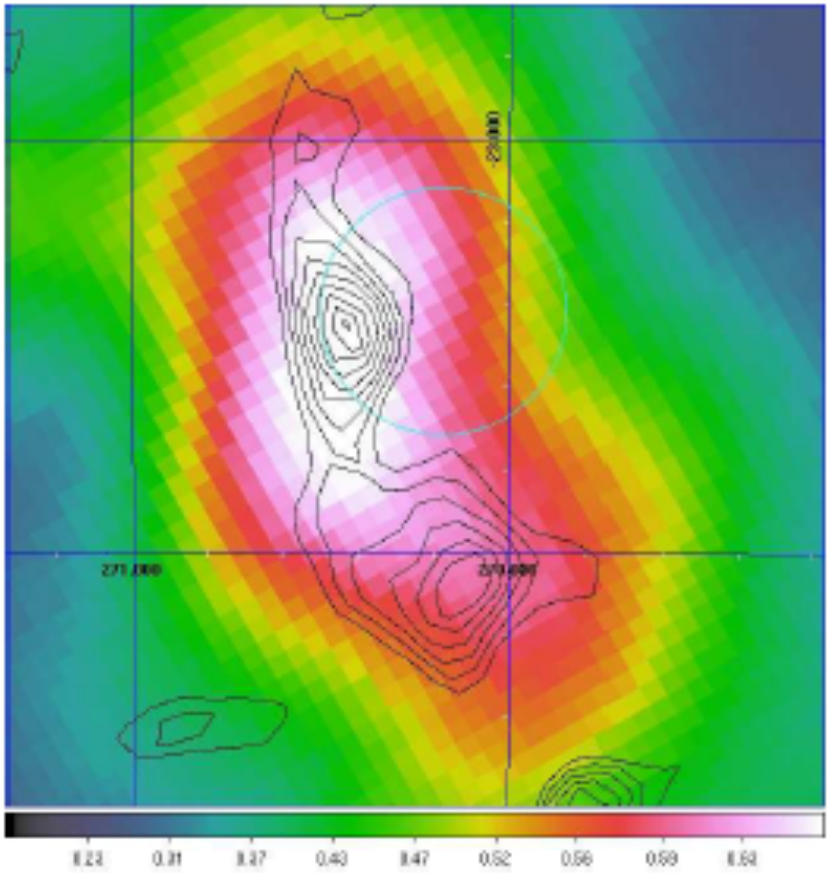




Supernova Remnants

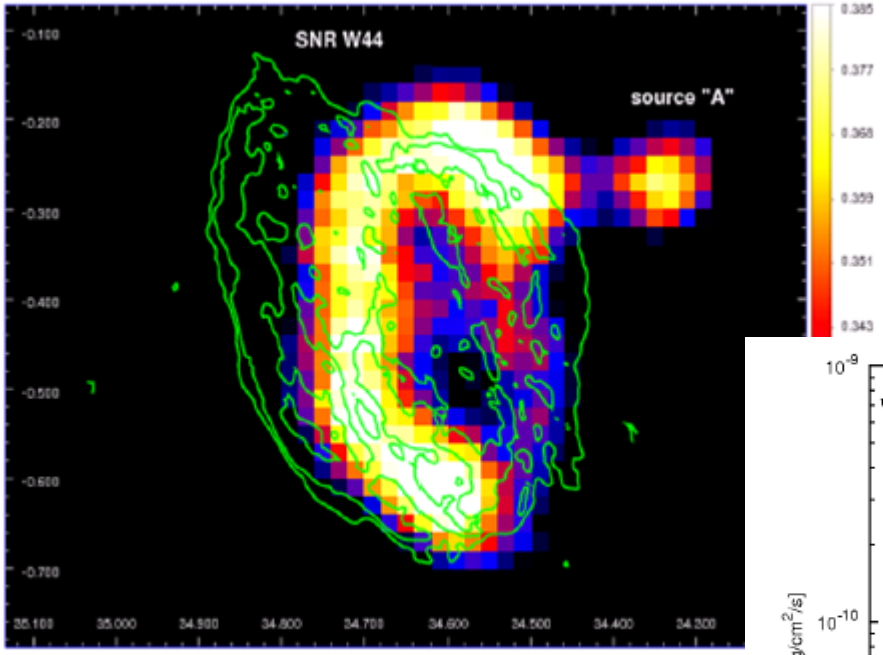


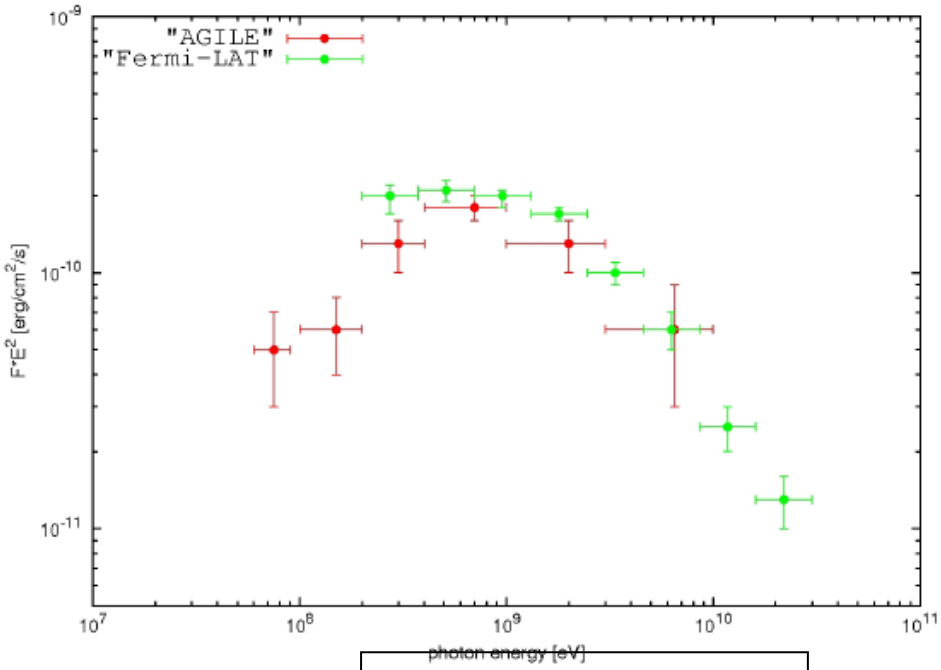
Tavani et al. 2010



Giuliani et al. 2010

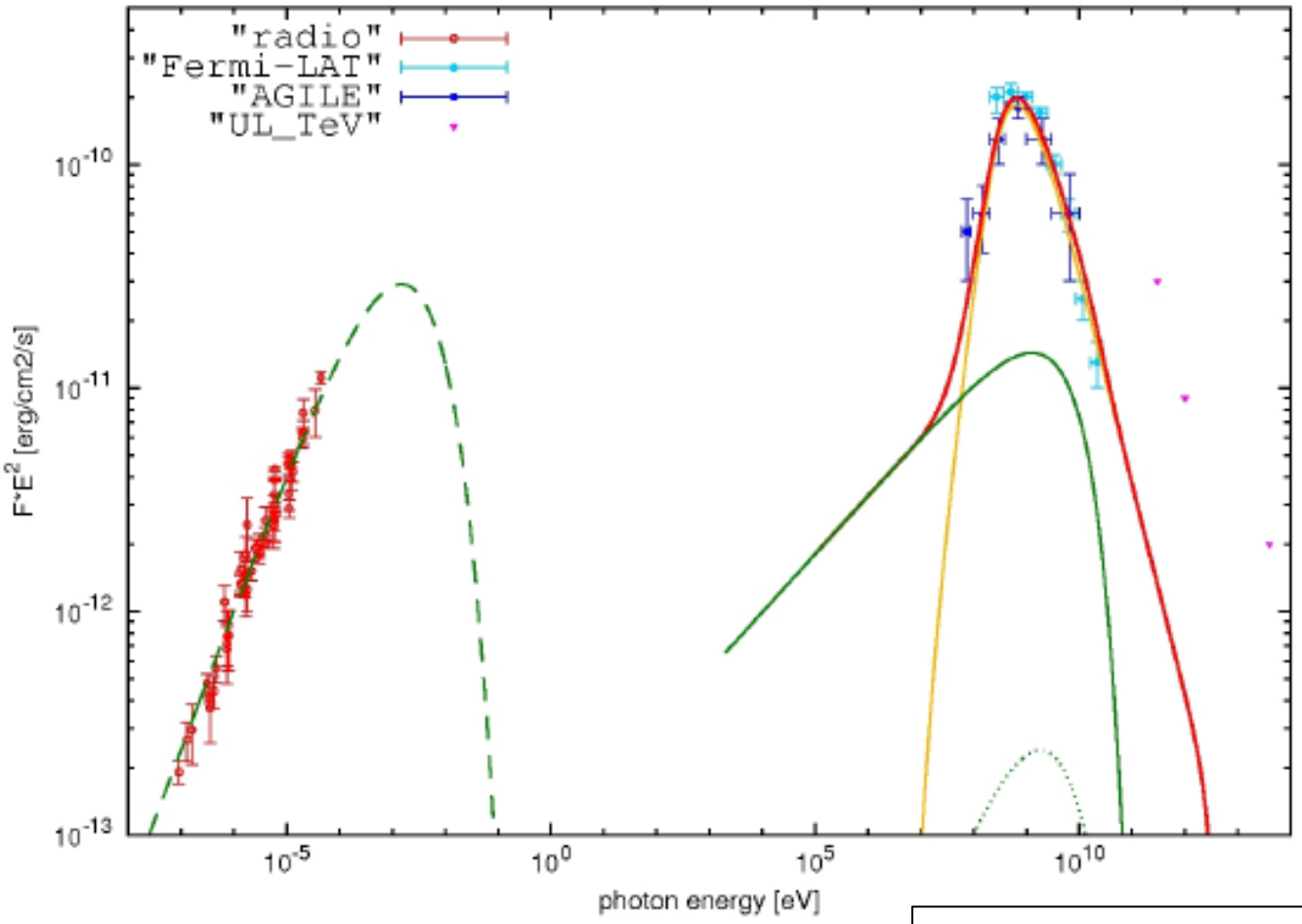
SNR W44





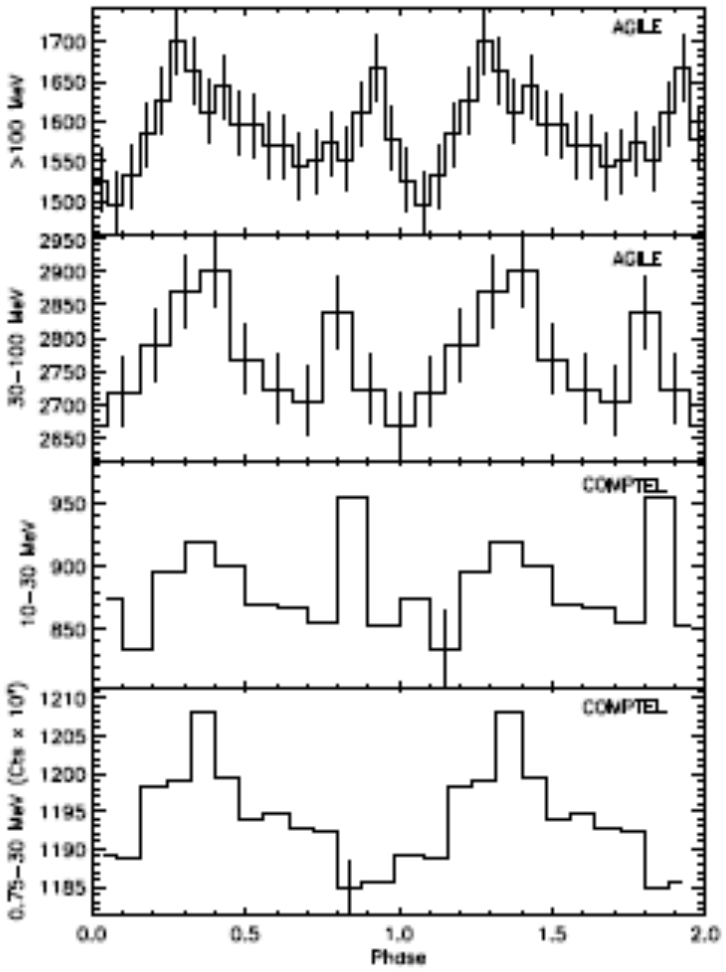
Giuliani et al. 2011

SNR W44

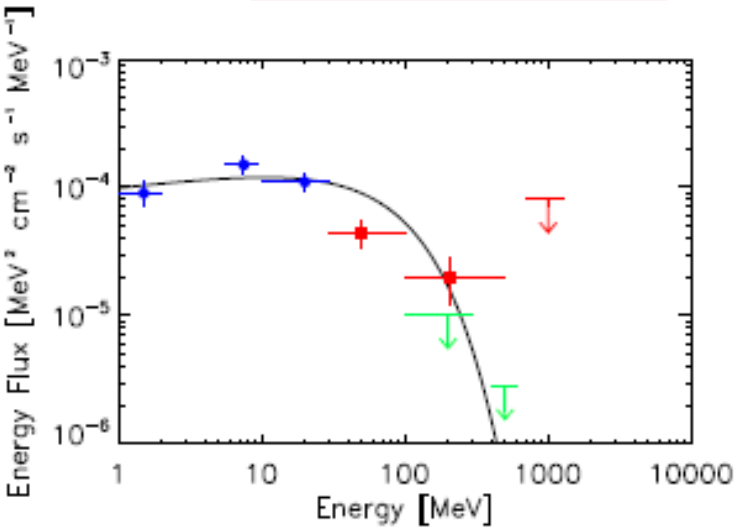


Giuliani et al. 2011

Low Energy Pulsars



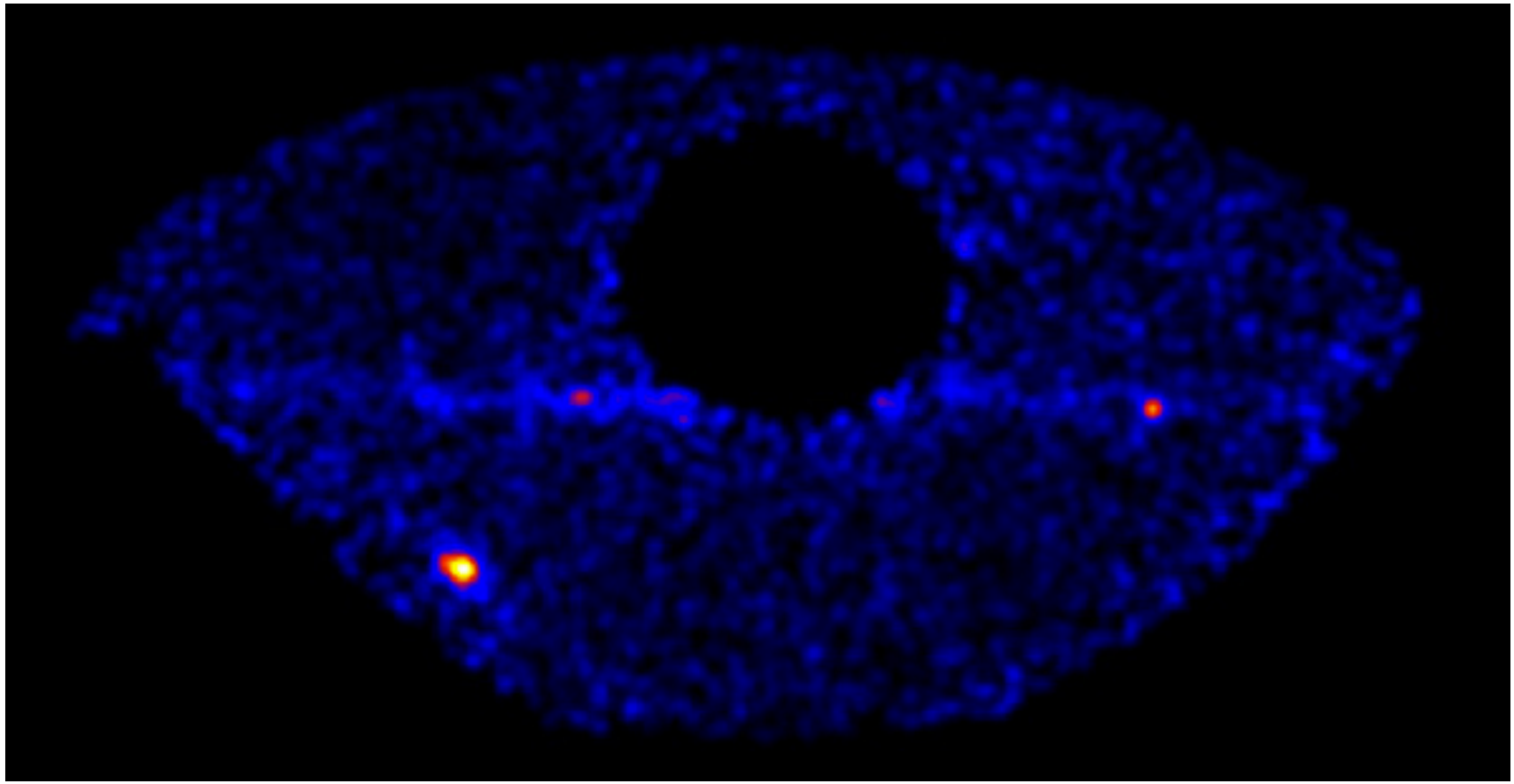
PSR B1509-58



Pilia et al. 2011

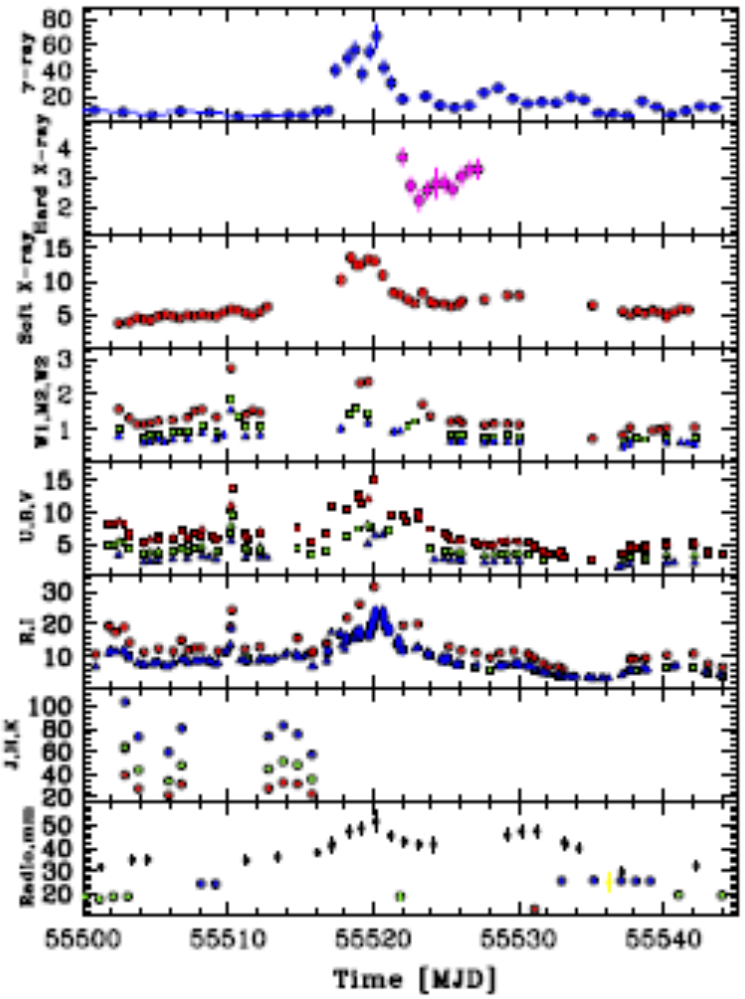
The Flaring 3C454.3

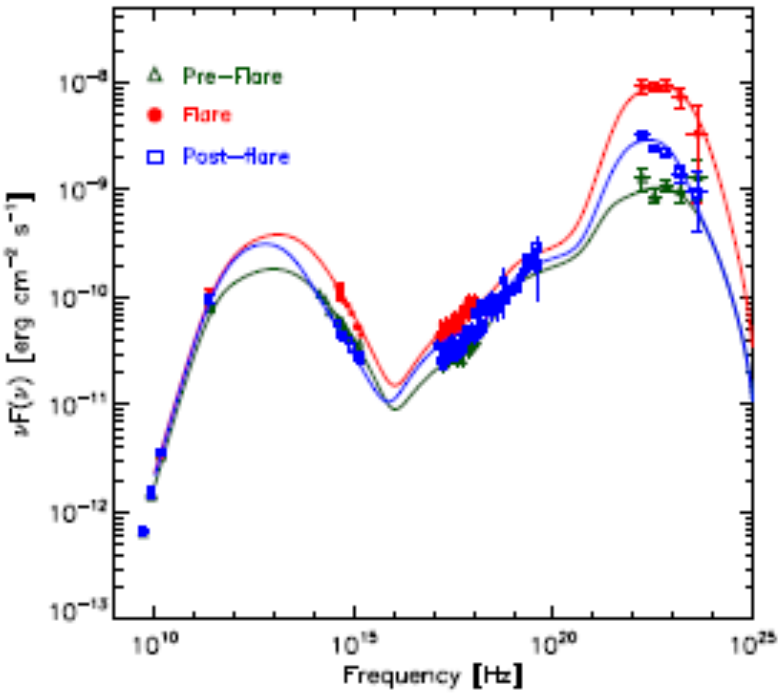
Vercellone et al. 2010



Blazar 3C454.3

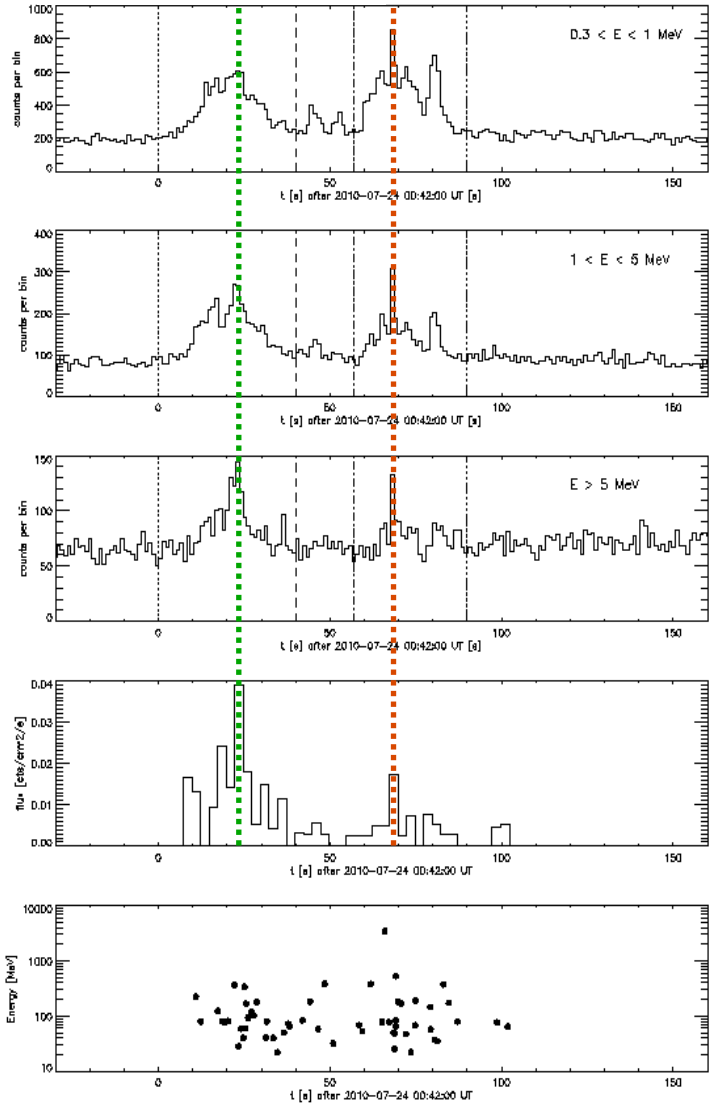
Vercellone et al. 2011





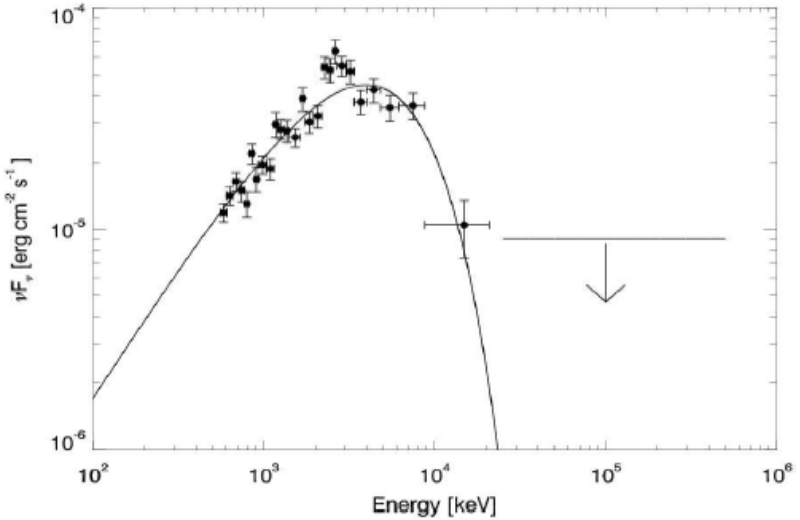
Gamma Ray Bursts

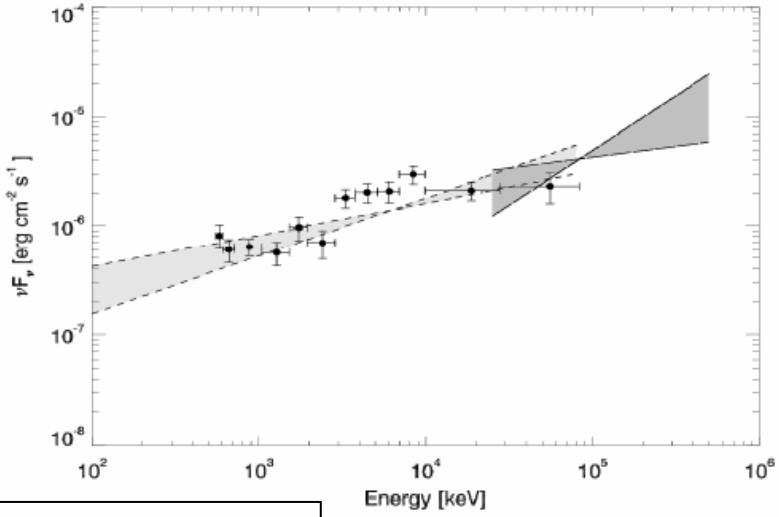
GRB 100724B



GRB 090510

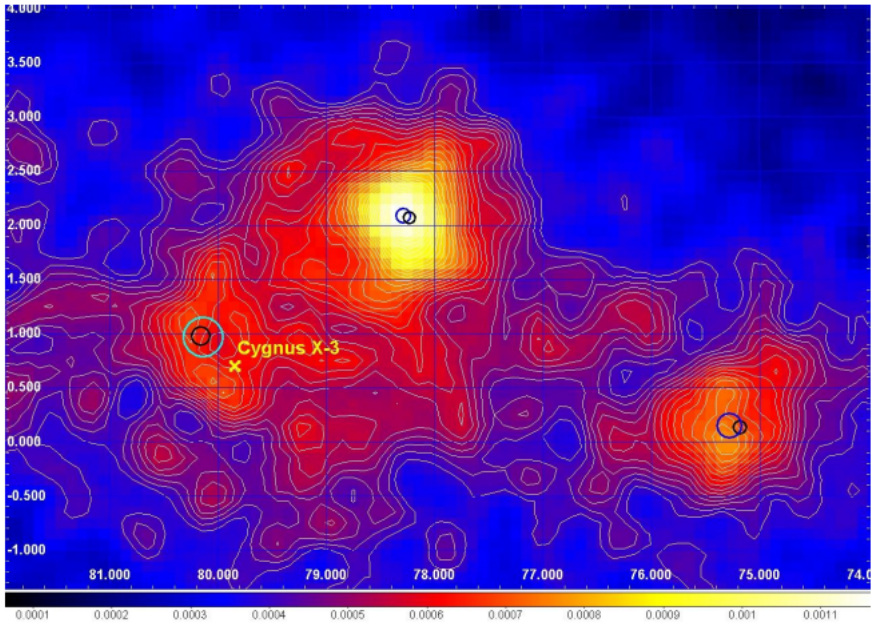
Giuliani et al. 2010

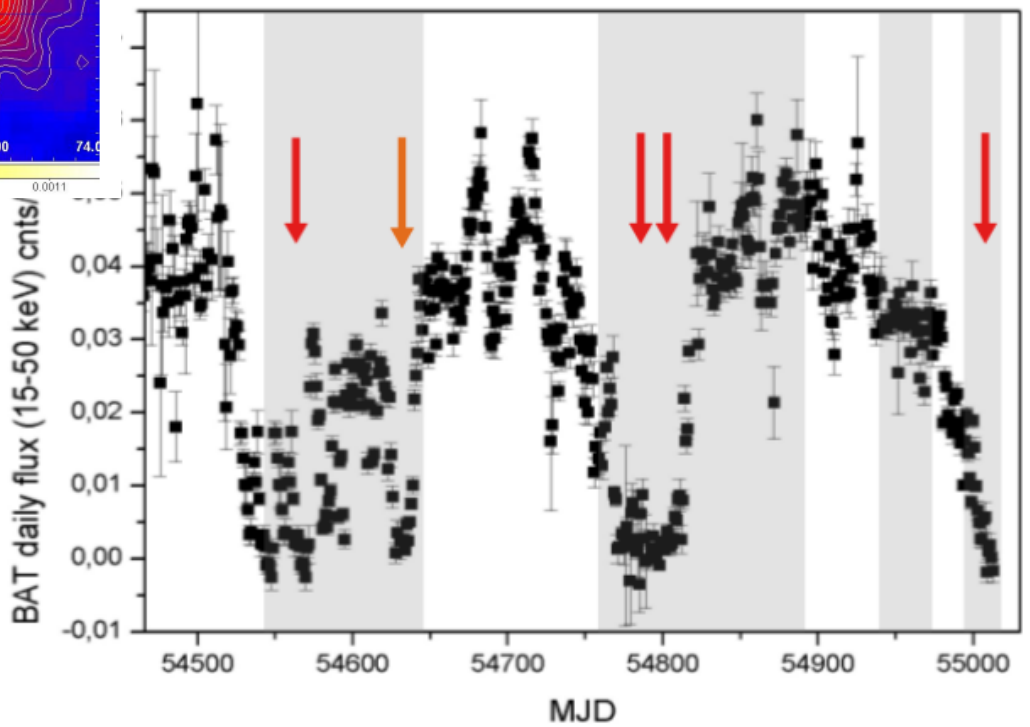




Del Monte et al. 2011

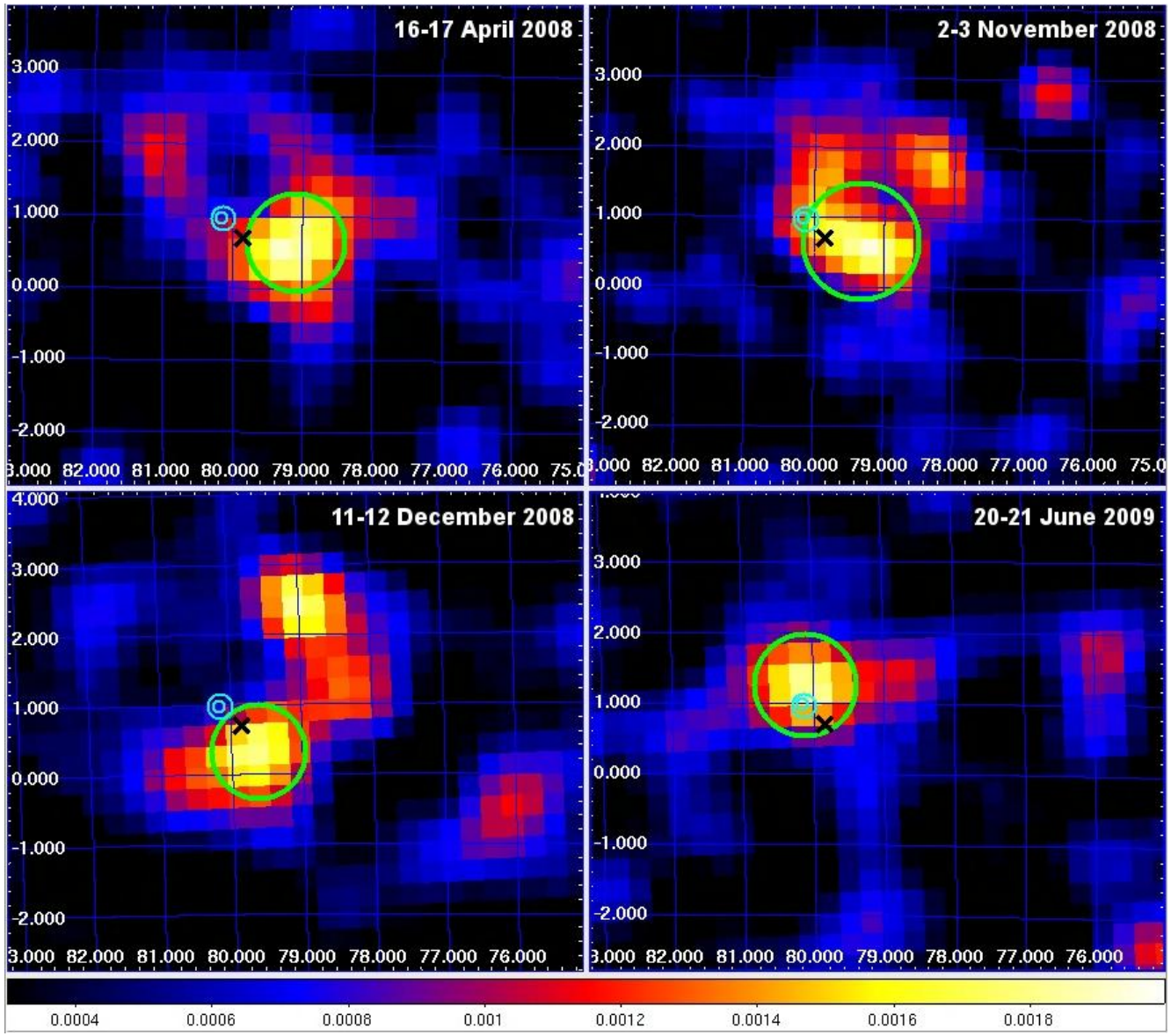
Galactic Transients: Cygnus X3



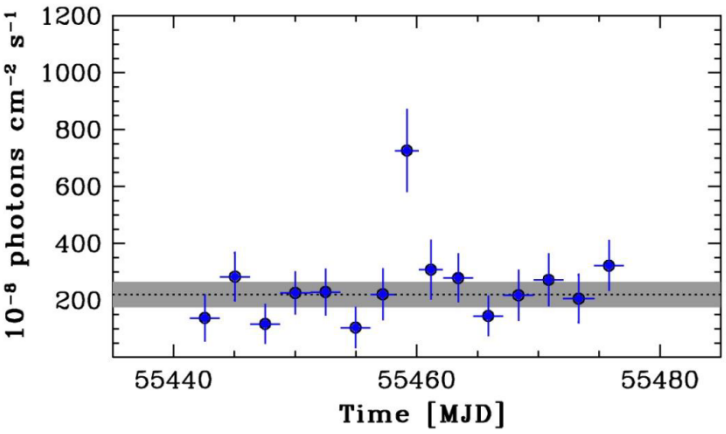


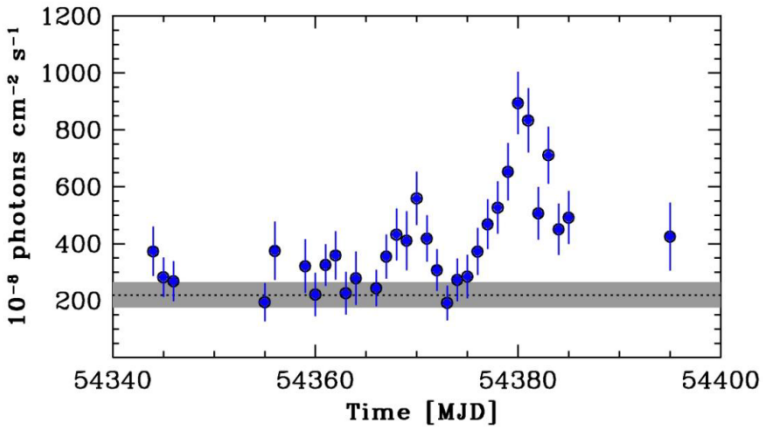
Tavani et al. 2009

AGILE discovery of transient gamma-ray emission from Cygnus X-3

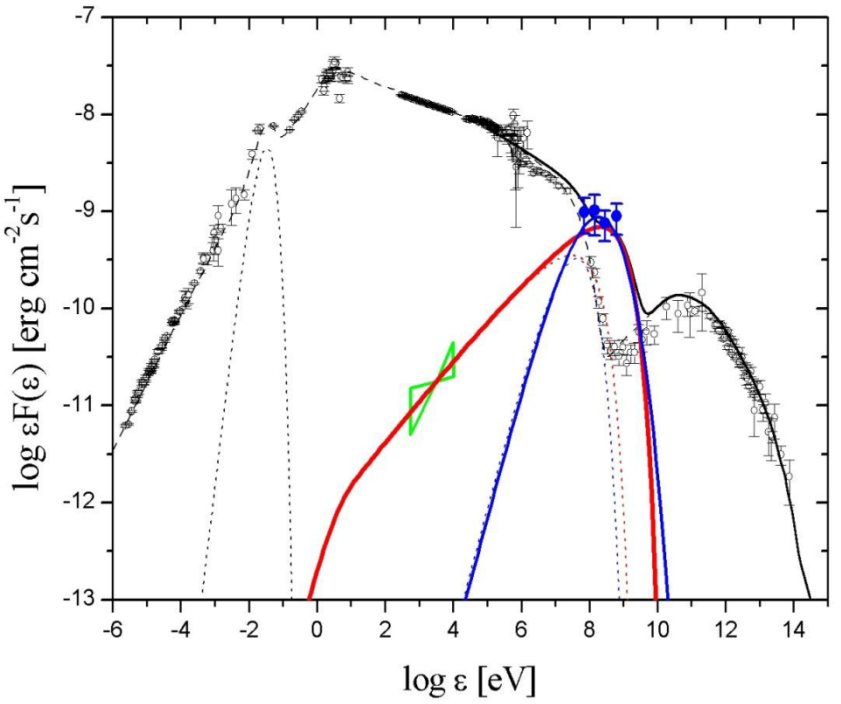


Galactic Transients: The Flaring Crab





Tavani et al. 2011



The Flaring Crab

AGILE detection of enhanced gamma-ray emission from the Crab Nebula region

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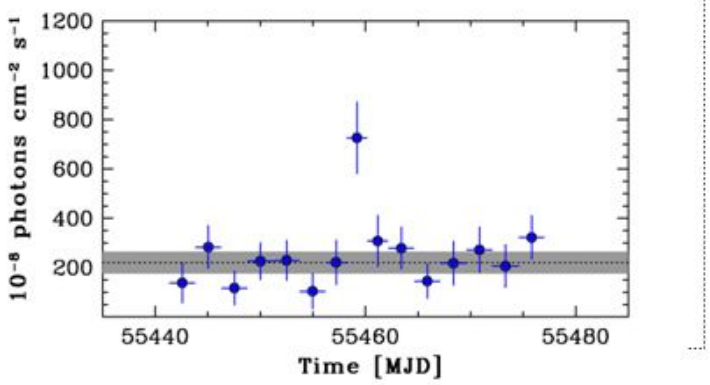
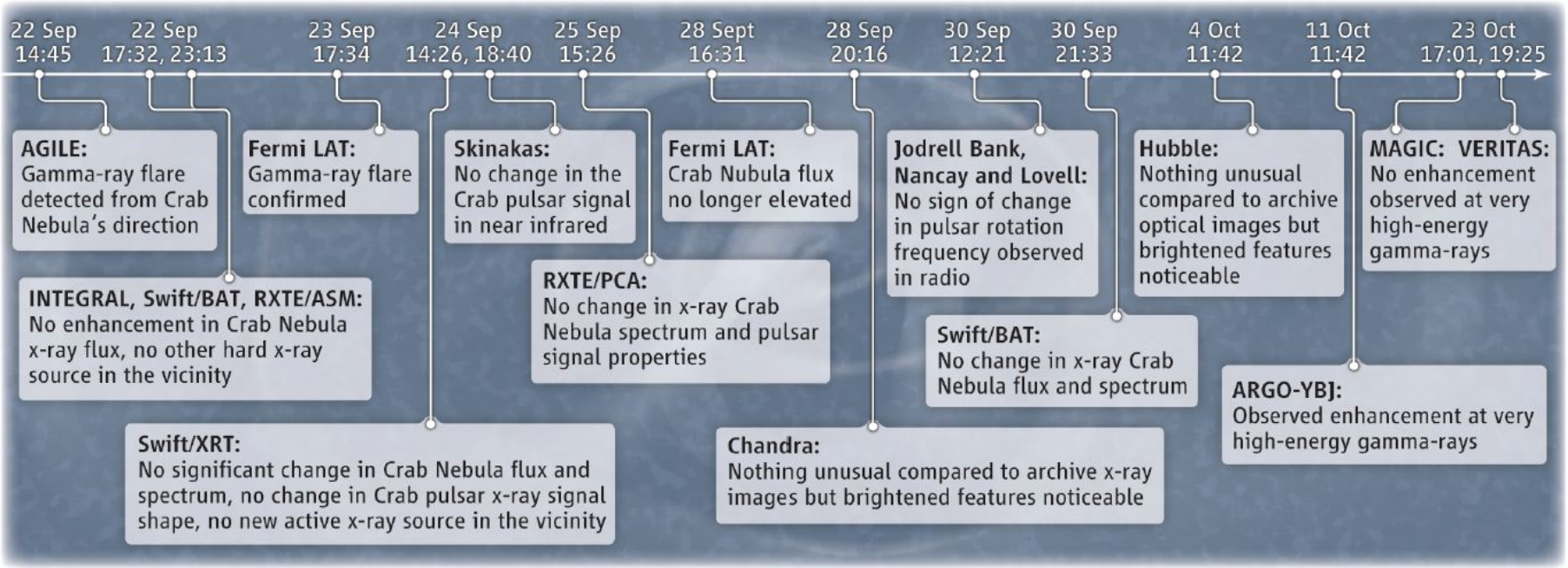
on 22 Sep 2010; 14:45 UT

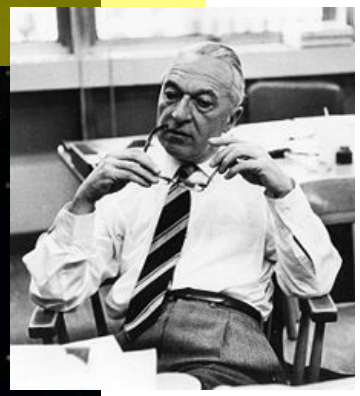
Distributed as an Instant Email Notice (Transients)

Password Certification: Marco Tavani (tavani@iasf-roma.inaf.it)



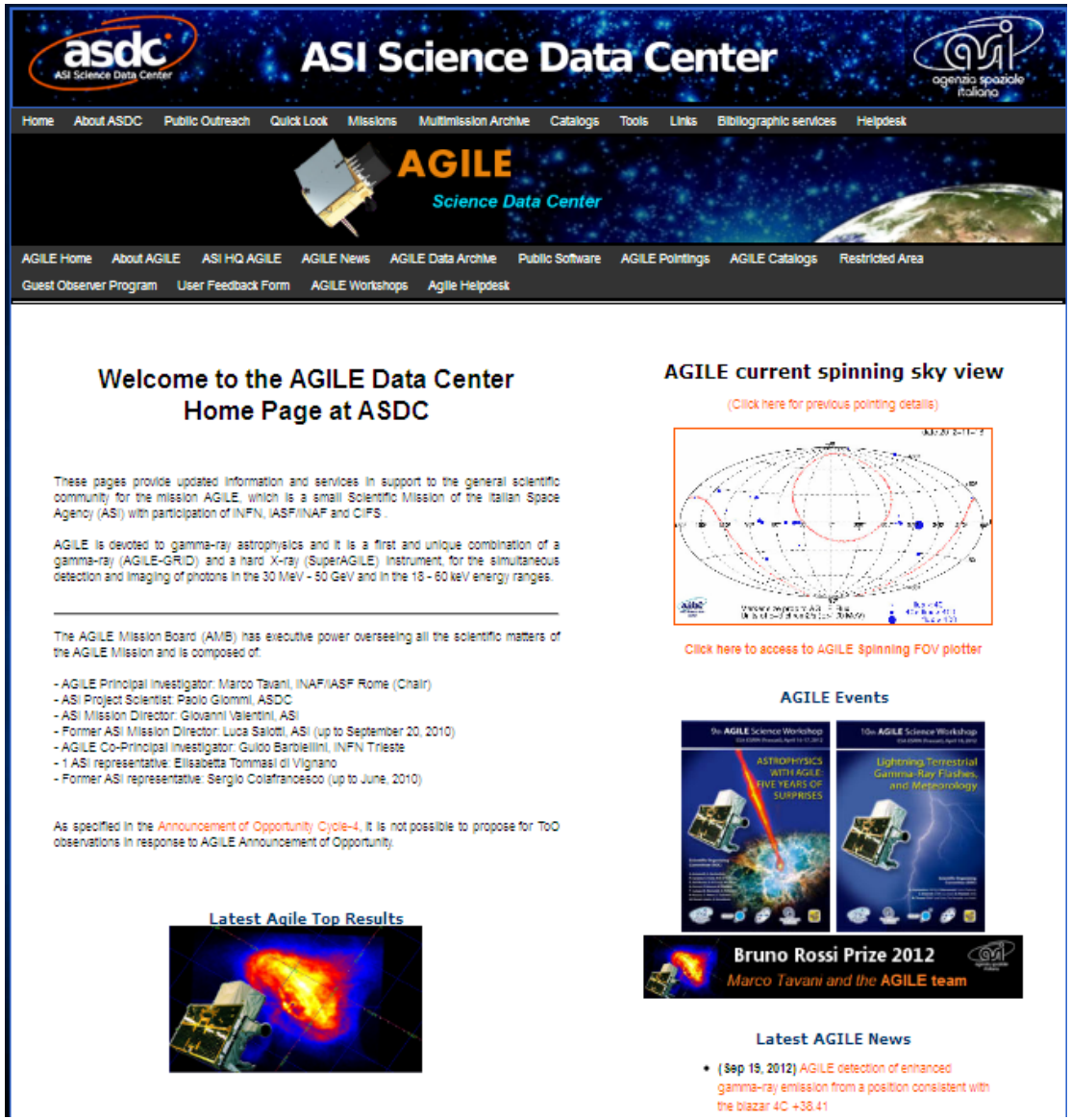


The Bruno Rossi Prize in High Energy Astrophysics awarded by AAS to astrophysicist Marco Tavani and the AGILE Team for the discovery of gamma-ray flares from the Crab Nebula (January 10, 2012).



Bruno B. Rossi

Where to find data?



http://agile.asdc.asi.it/

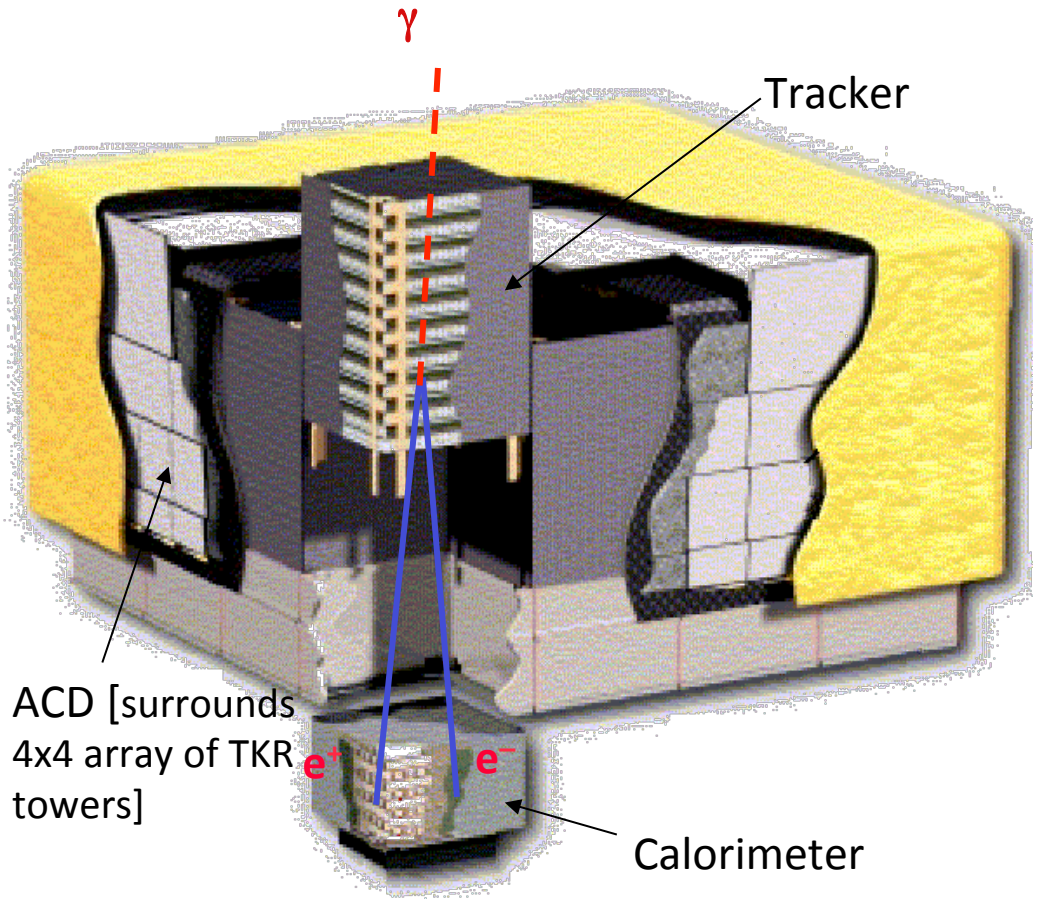
Conclusions

- AGILE crucial contributions to testing particle acceleration theories, plasma instabilities in the Universe and on the Earth !
  - Big surprise: discovery of gamma-ray flares from the Crab Nebula: 2012 Bruno Rossi Prize
  - Origin of cosmic rays, SNR W44, first direct evidence of neutral pion emission
  - Relativistic jets in microquasars and blazars
  - Gamma-ray emission up to 100 MeV from Terrestrial Gamma-Ray Flashes

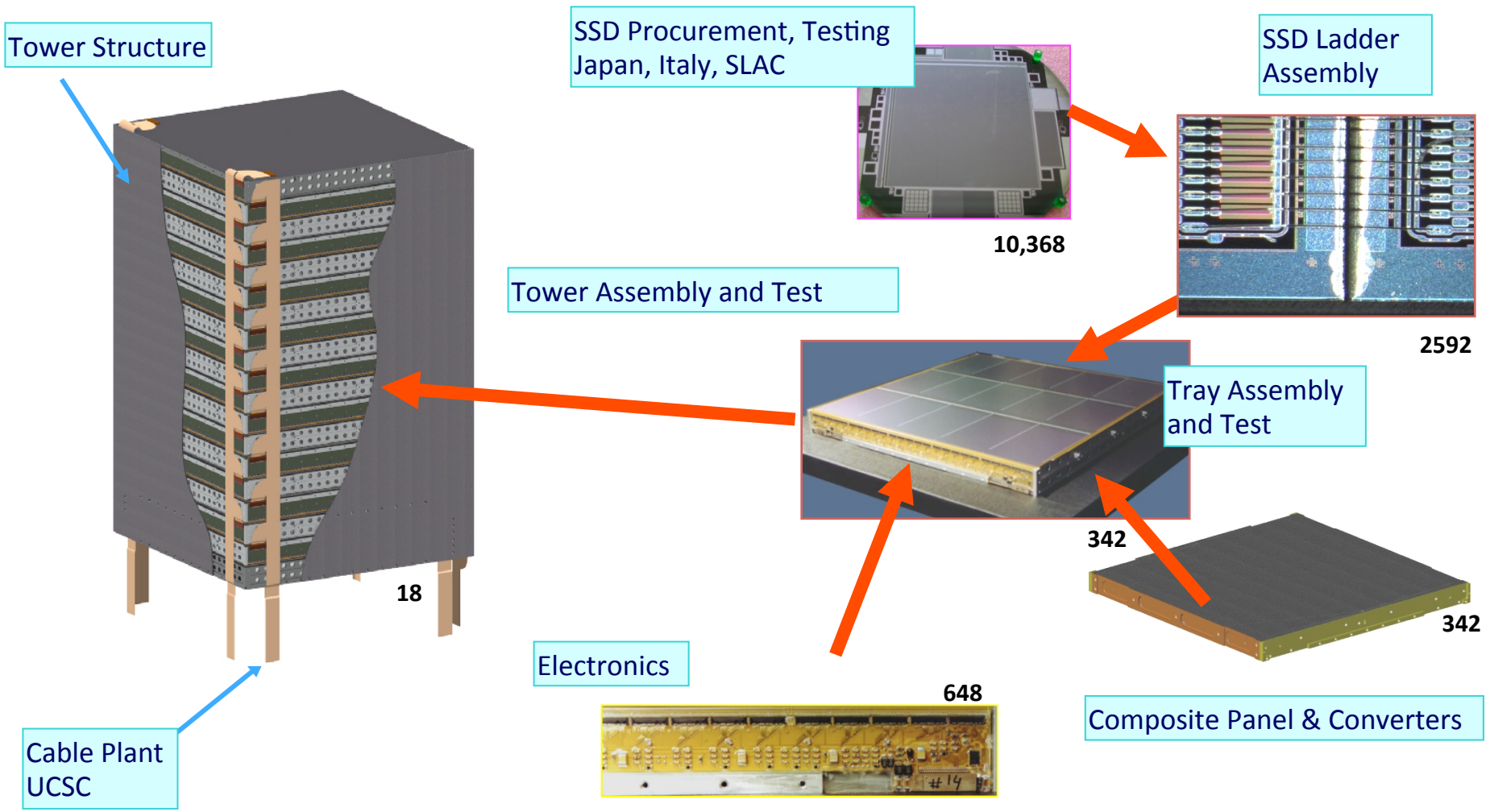
Fermi LAT

Overview of LAT

- Precision Si-strip Tracker (TKR) 18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch) Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter(CAL) Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.
- Segmented Anticoincidence Detector (ACD) 89 plastic scintillator tiles. Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.



Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

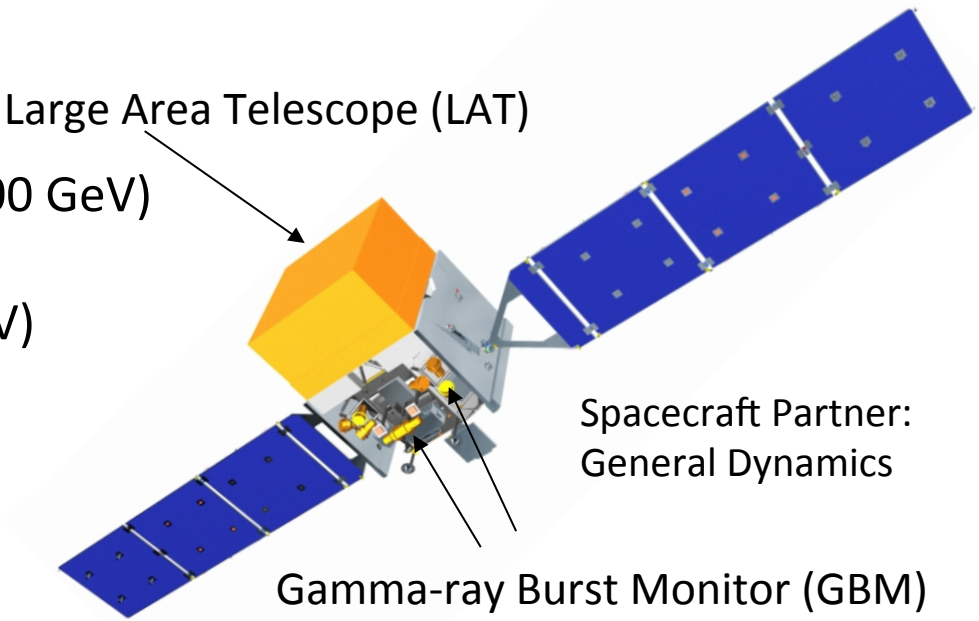

Tower Structure
18
Cable Plant
UCSC
SSD Procurement, Testing
Japan, Italy, SLAC
10,368
SSD Ladder
Assembly
2592
Tower Assembly and Test
Tray Assembly
and Test
342
342
Electronics
648
Composite Panel & Converters

Launch!

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

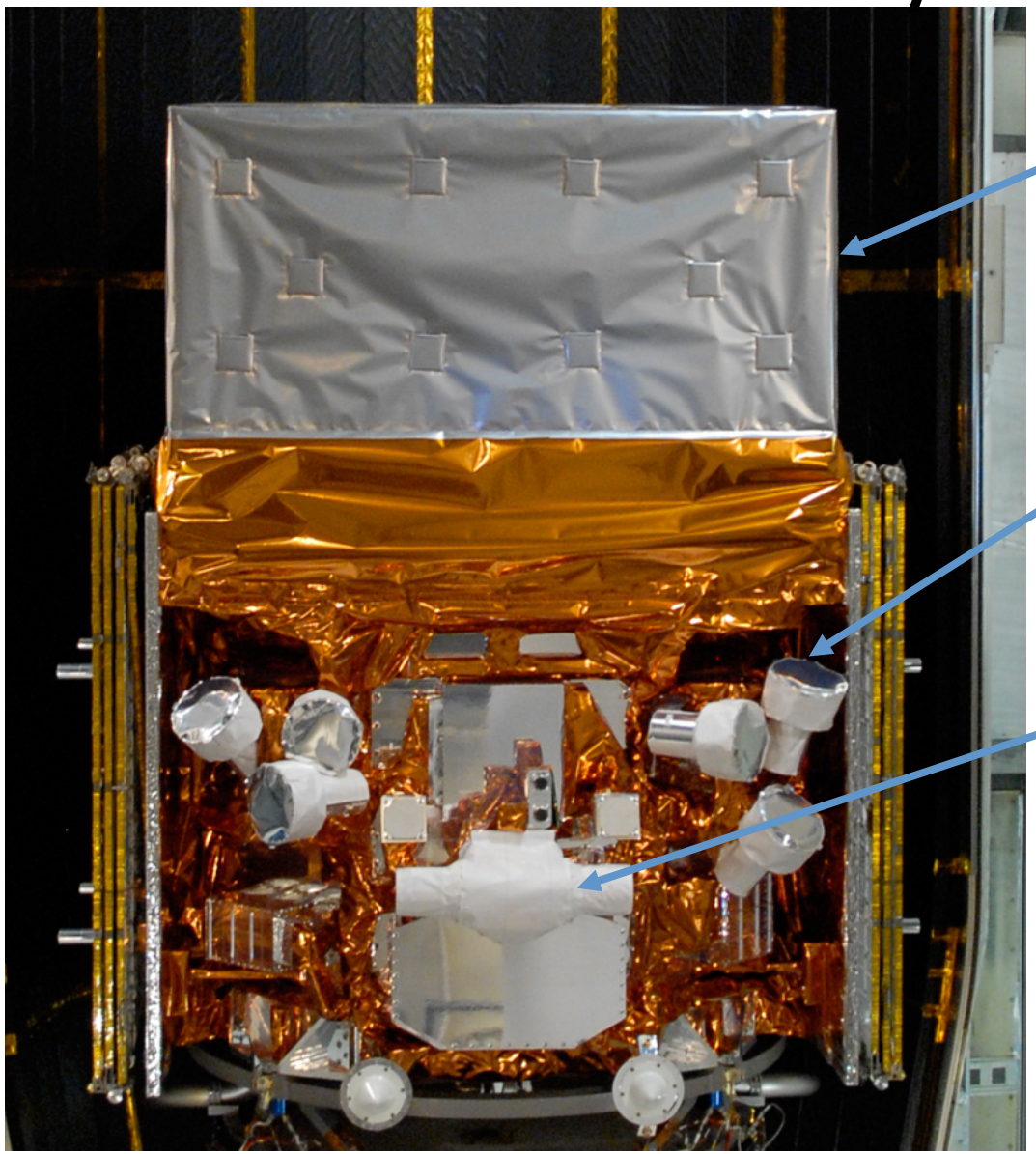
Key Features

- Two instruments:
  - LAT:
    - high energy (20 MeV – >300 GeV)
  - GBM:
    - low energy (8 keV – 40 MeV)

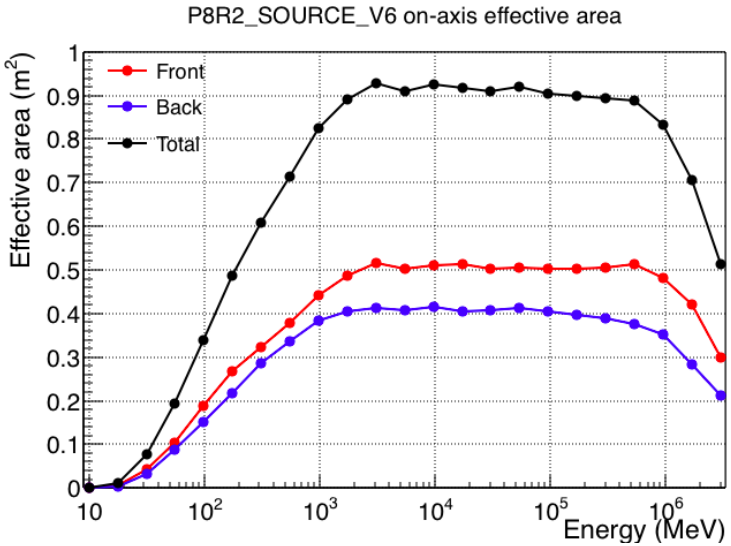


- Huge field of view
  - LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV - 100 GeV
- Large leap in all key capabilities. Great discovery potential.

The Observatory



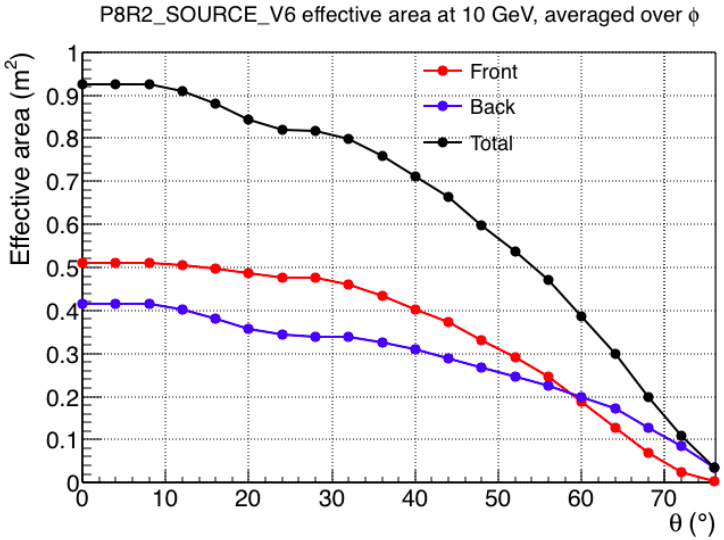
Effective Area (A_{eff})



< 100 MeV limited by 3-in a row requirement

< 1 GeV limited discriminating information

> 100 GeV self-veto from backsplash

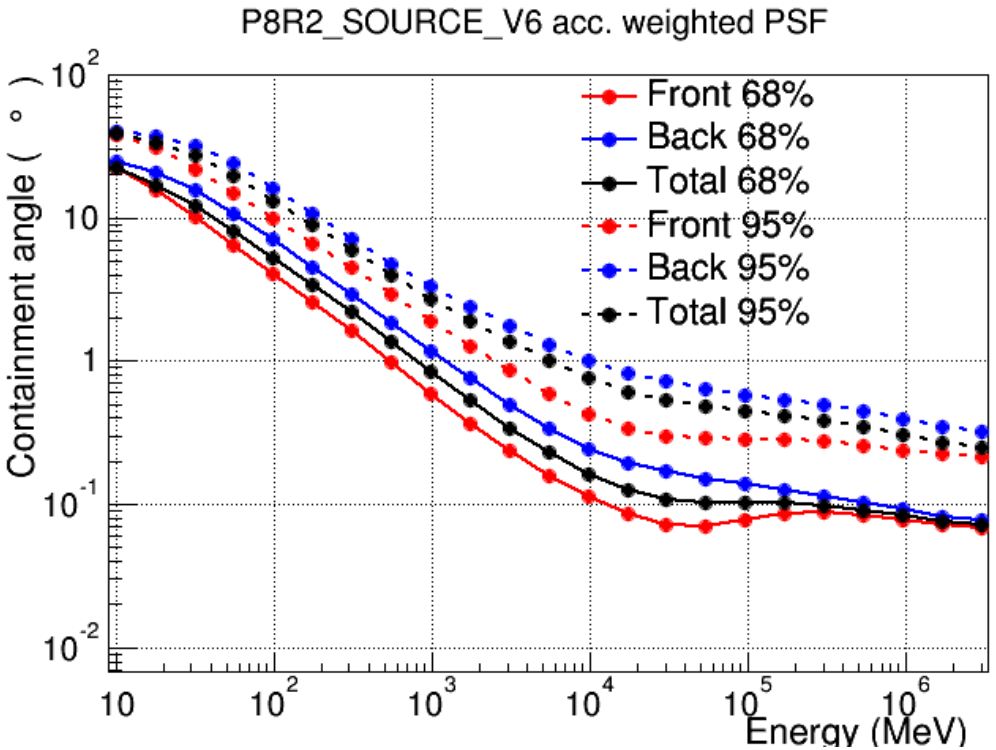


Off-axis: more material, less cross section

Shift from front/back events as we go off-axis

http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

Point Spread Function (P)

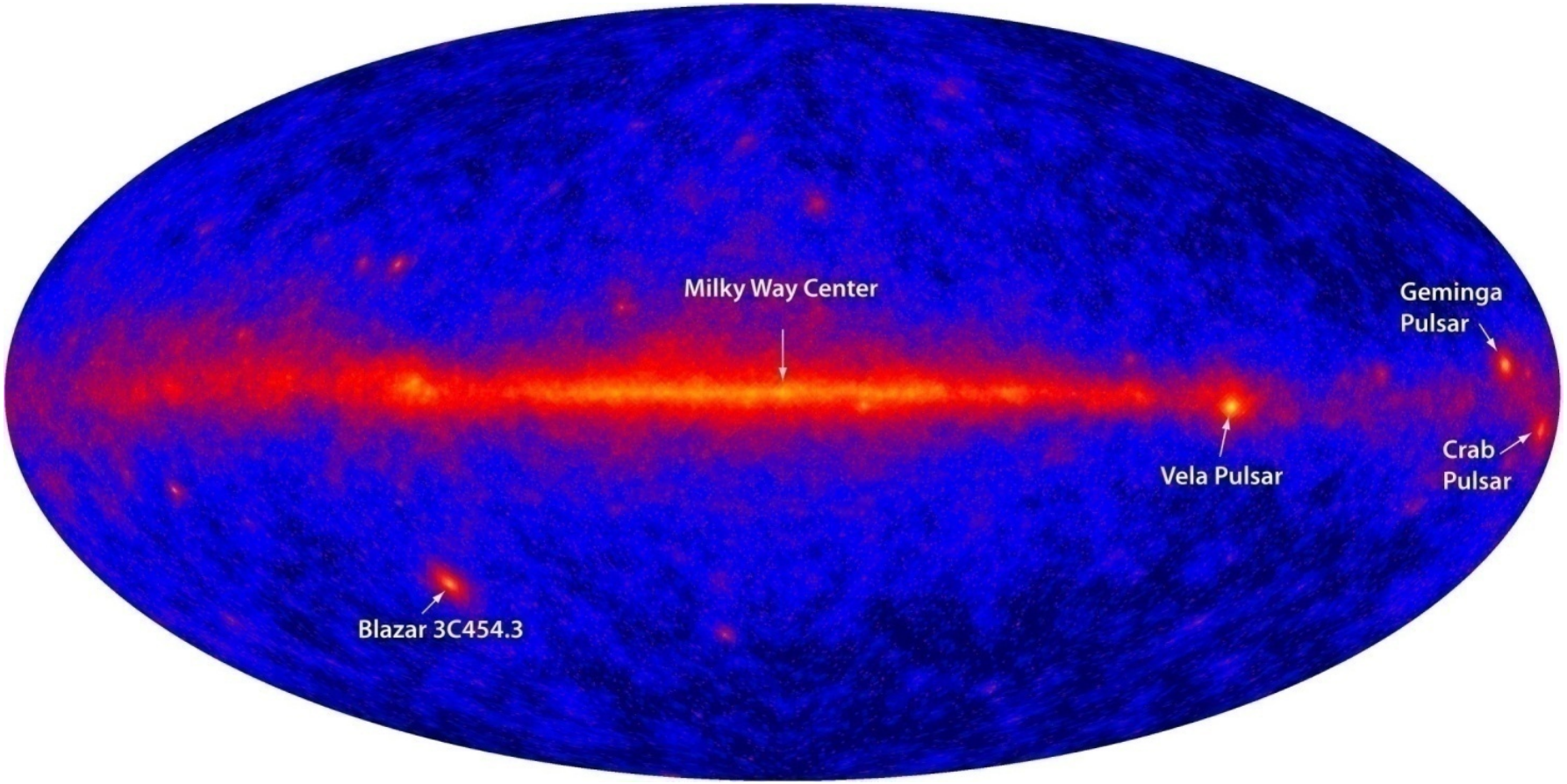


Low energy: dominated by MS

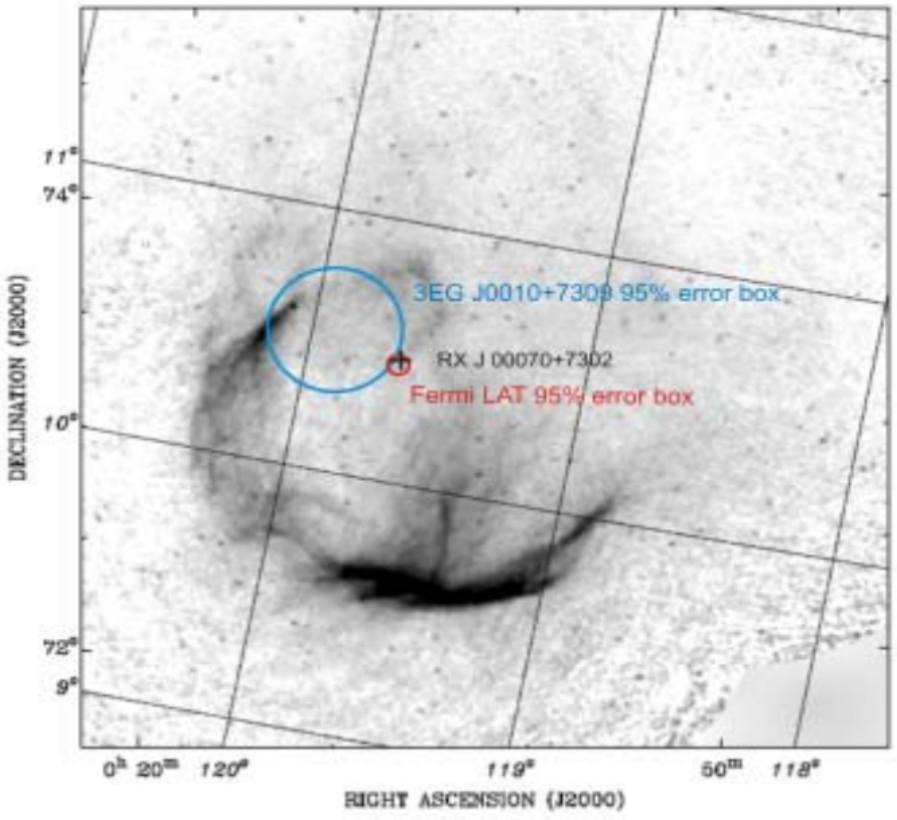
High energy: dominated by strip pitch

http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

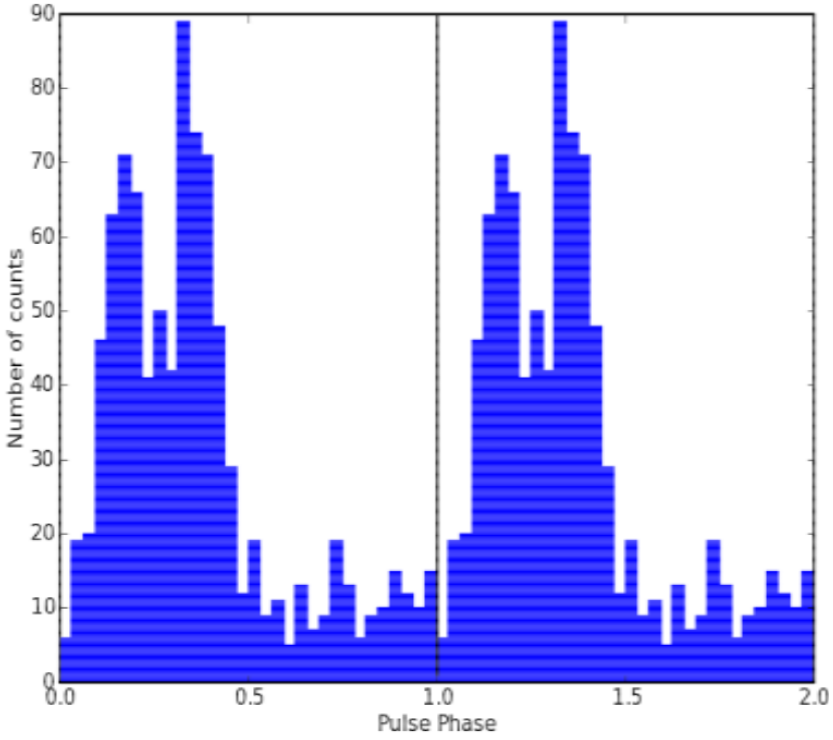
LAT first light



LAT discovers a radio-quiet pulsar!



P ~ 317 ms
Pdot ~ 3.6E-13
Characteristic age ~ 10,000 yrs



Location of EGRET source 3EG J0010+7309, the Fermi-LAT source, and the central X-ray source RX J0007.0+7303
Published in Science Express October 16, 2008

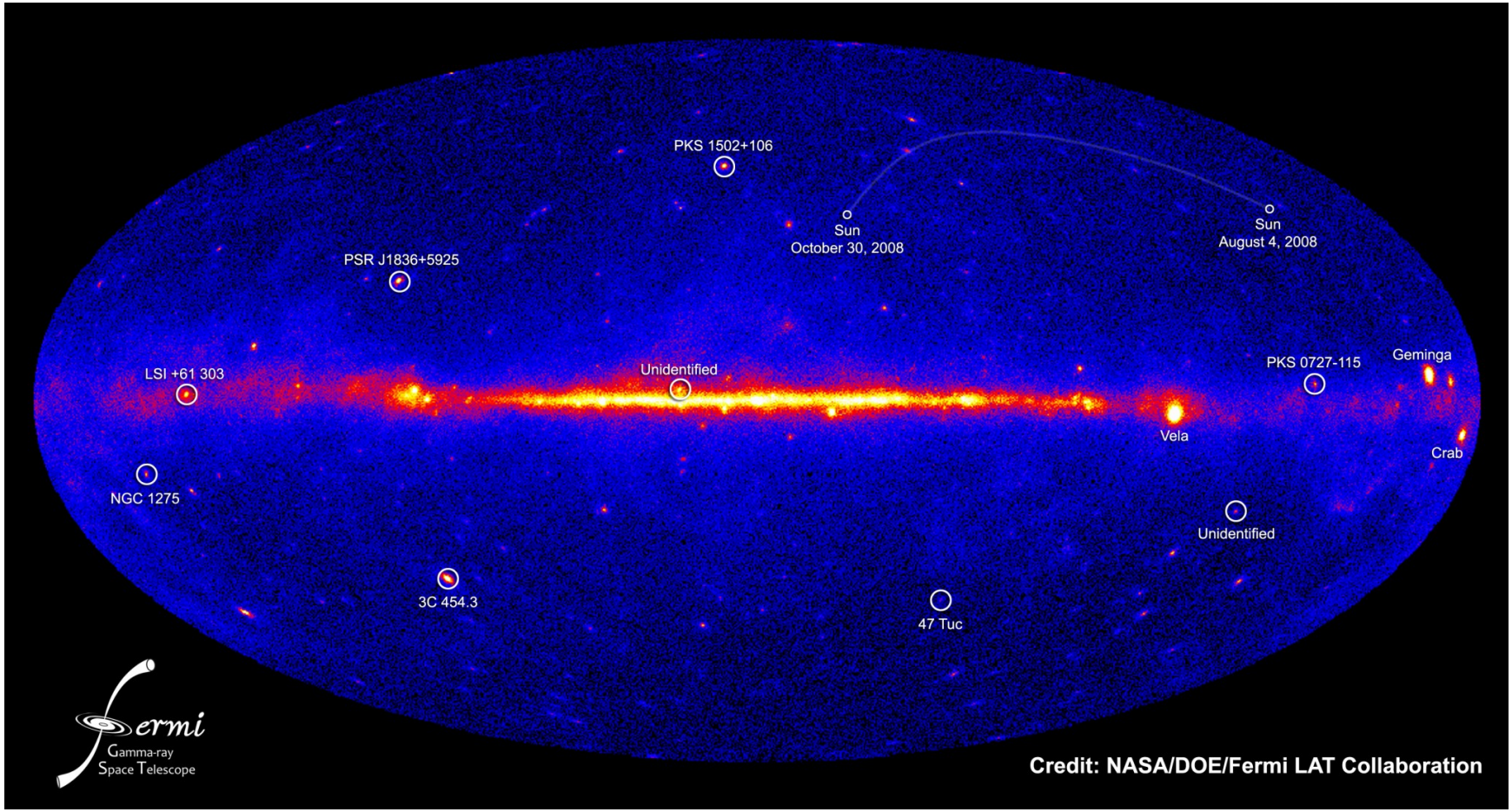
Fermi Gamma-ray Space Telescope

GLAST renamed *Fermi* by NASA on August 26, 2008

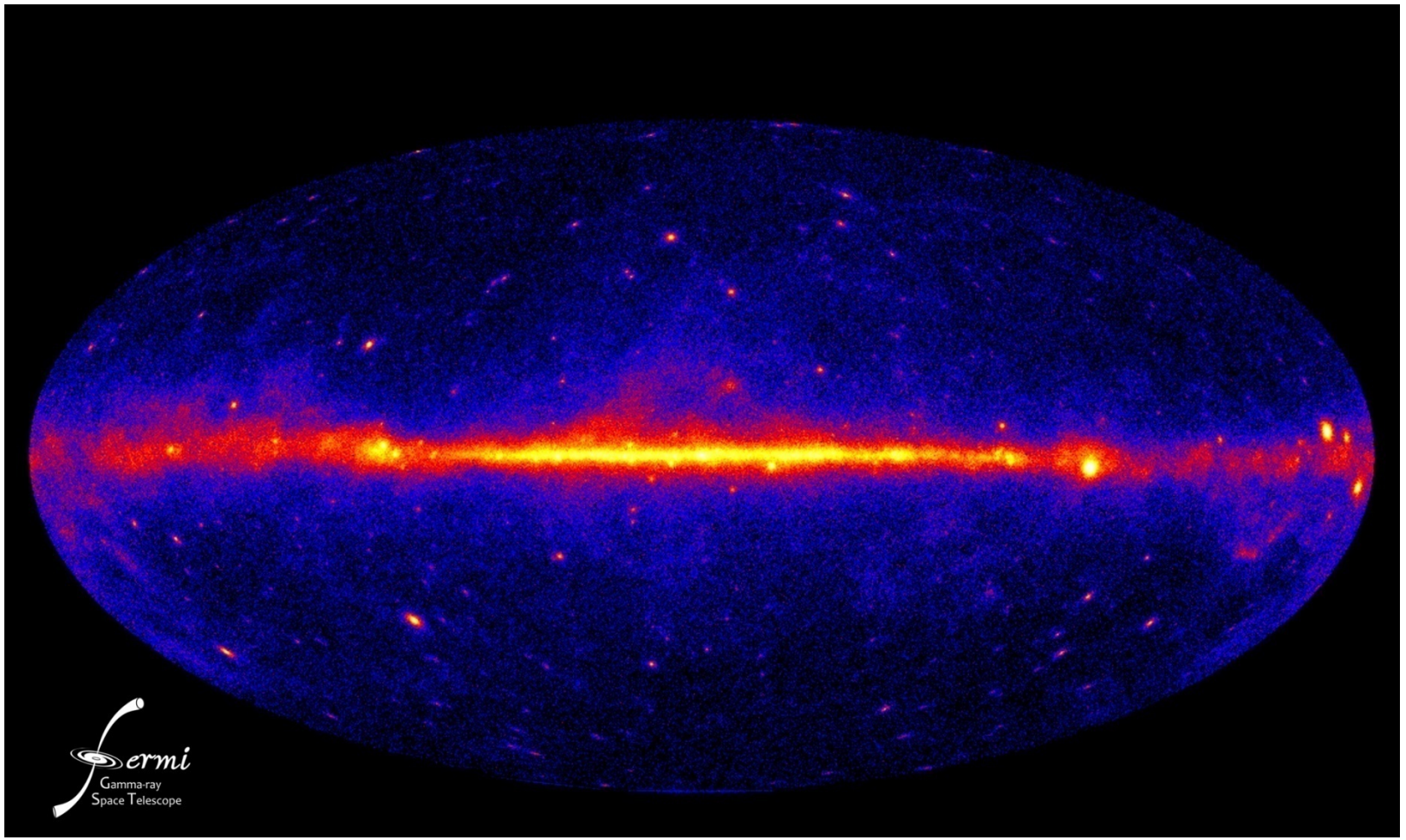
http://fermi.gsfc.nasa.gov/

" Enrico Fermi (1901-1954) was an Italian physicist who immigrated to the United States. He was the first to suggest a viable mechanism for astrophysical particle acceleration. This work is the foundation for our understanding of many types of sources to be studied by NASA's Fermi Gamma-ray Space Telescope, formerly known as GLAST. "

Fermi LAT 3 months sky



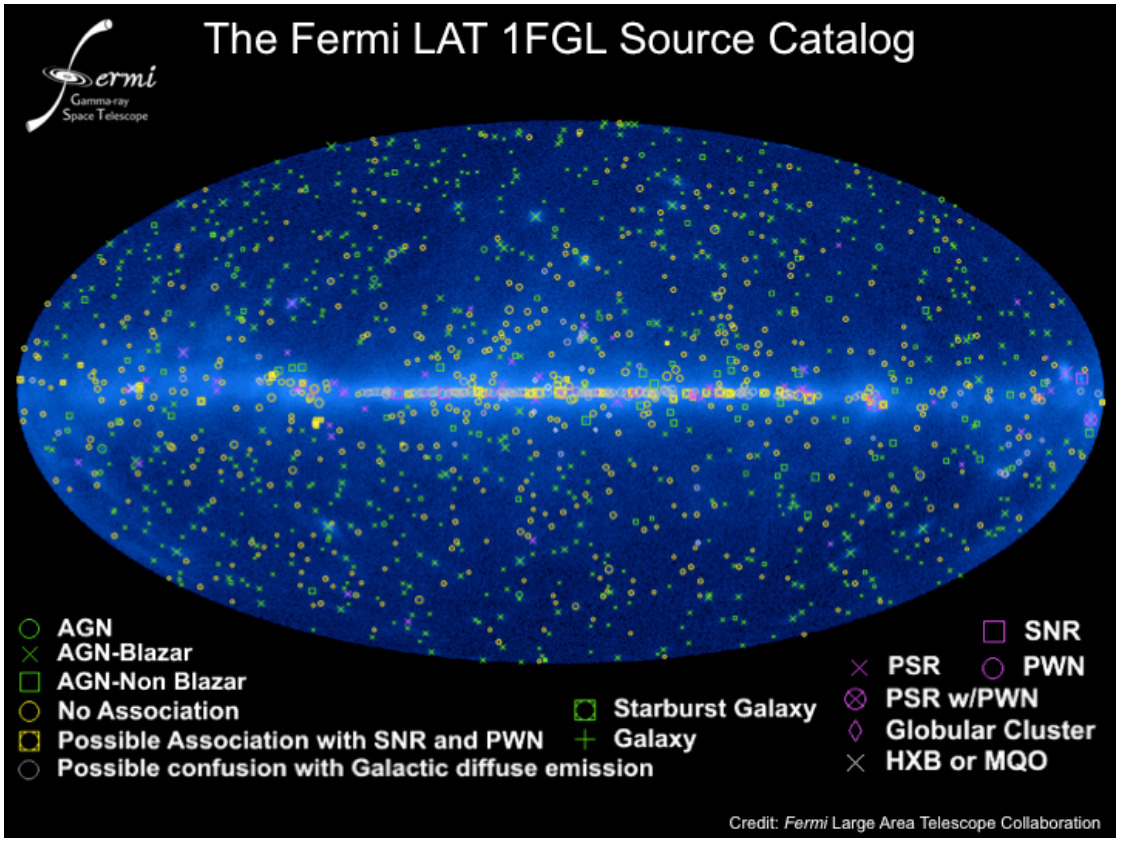
Fermi 1 yr sky



Fermi Year One Catalog

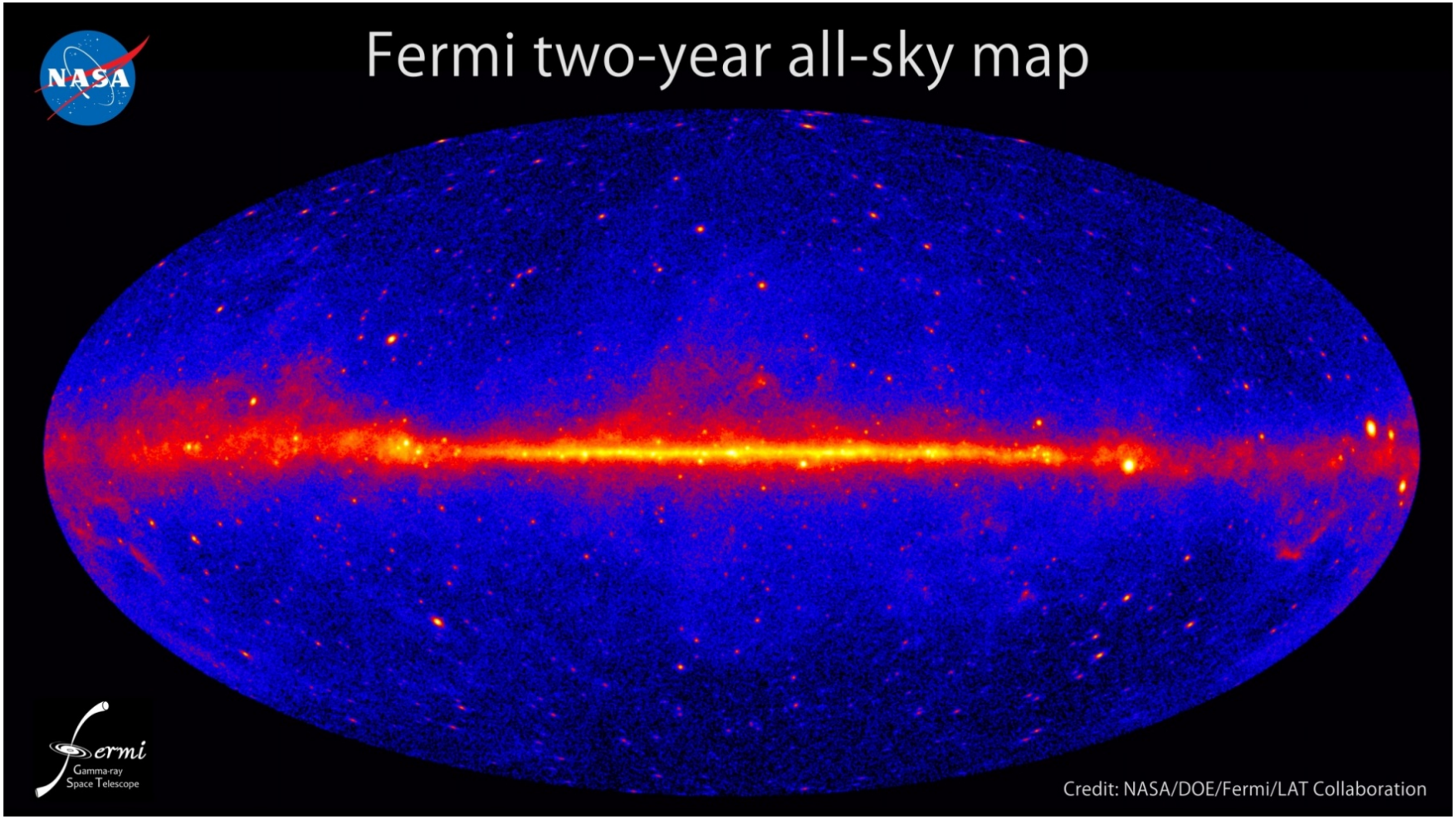
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr_catalog/

More than 1000 sources in year one catalog !

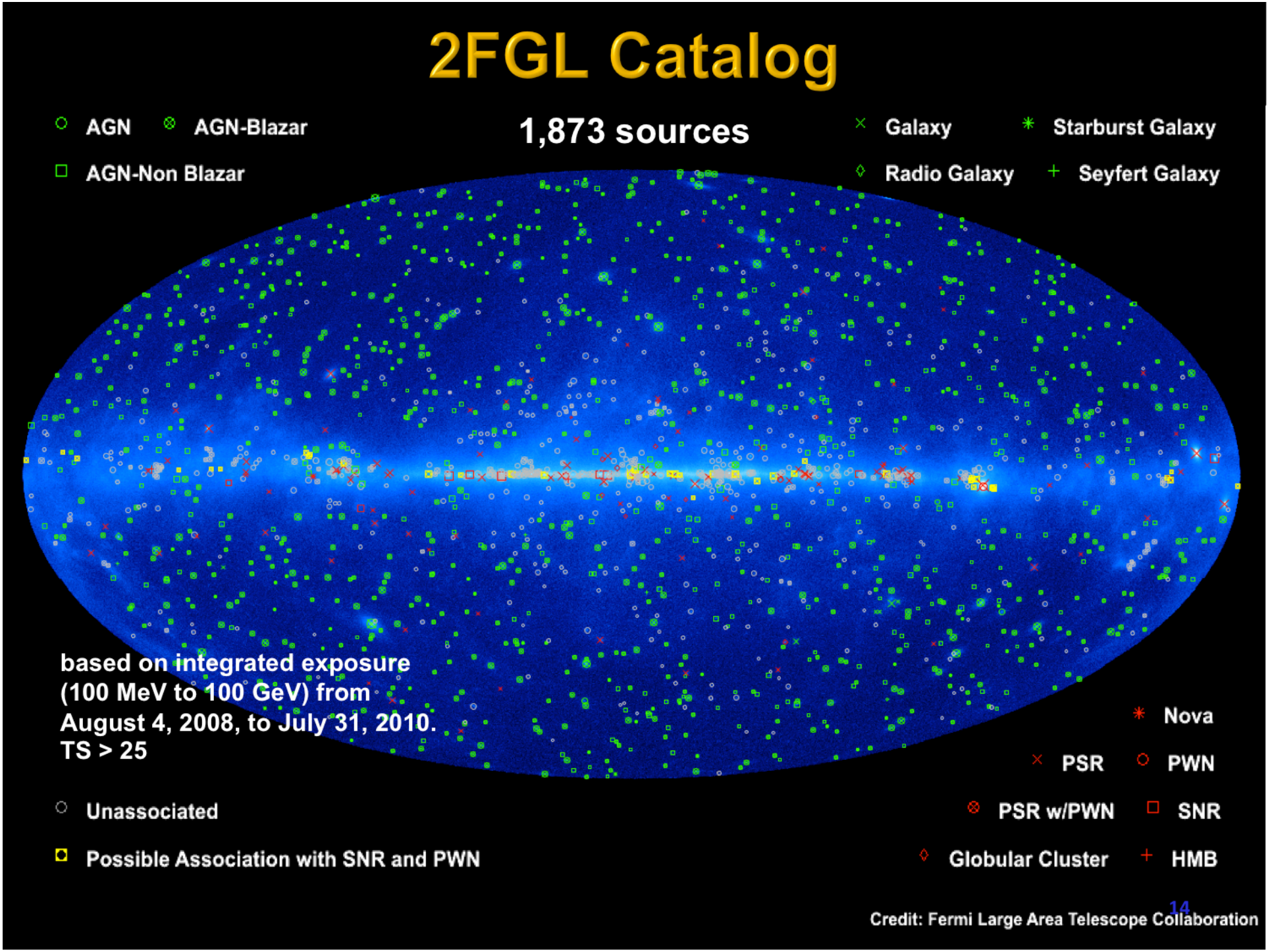


- About 250 sources show evidence of variability
- Half the sources are associated positionally, mostly blazars and PSRs
- Other classes of sources exist in small numbers (XRB, PWN, SNR, starbursts, globular clusters, radio galaxies, narrow-line Seyferts)
- Uncertainties due to the diffuse model, particularly in the Galactic ridge

2 year sky

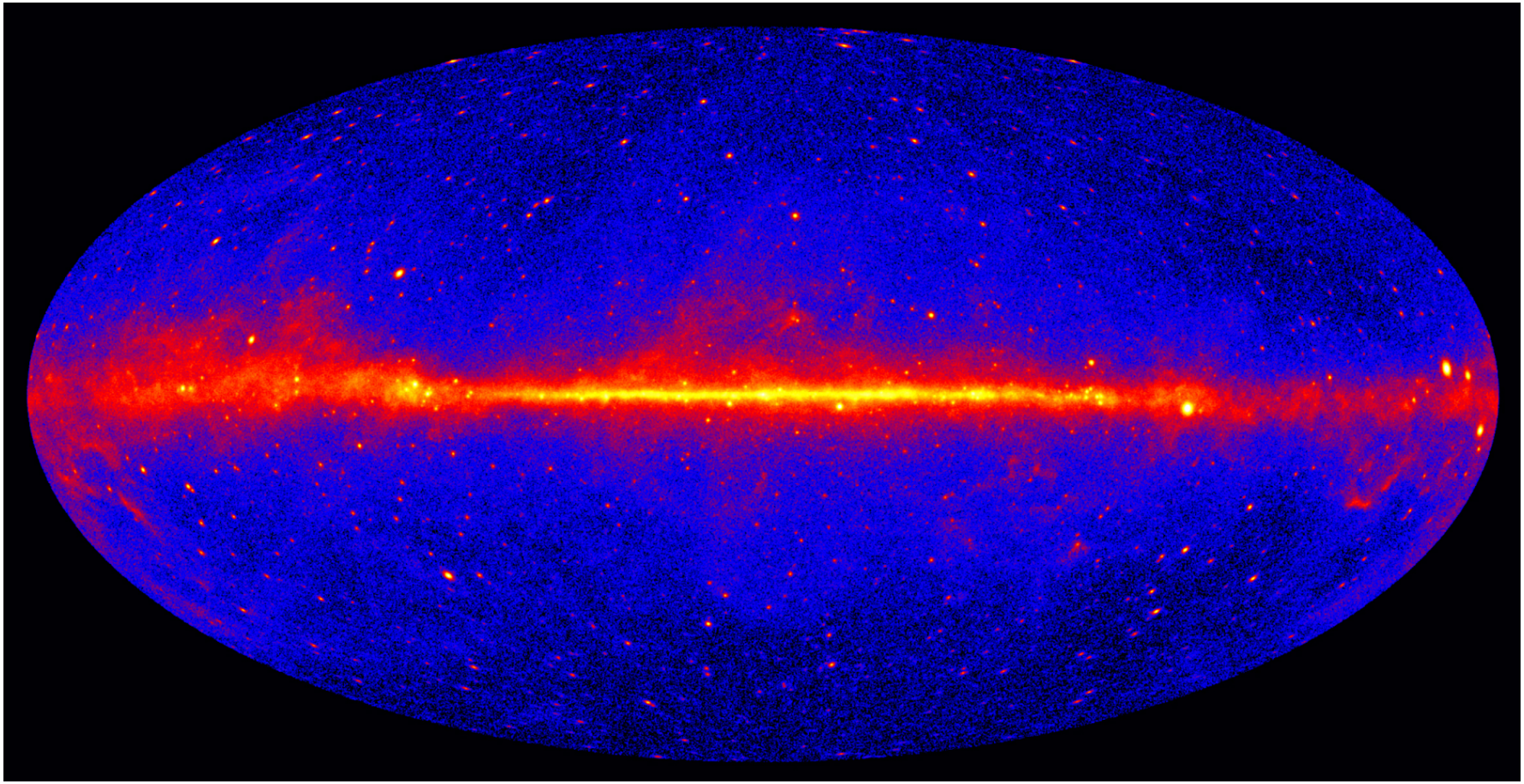

Fermi two-year all-sky map
NASA
Fermi
Gamma-ray
Space Telescope
Credit: NASA/DOE/Fermi/LAT Collaboration

2FGL Catalog

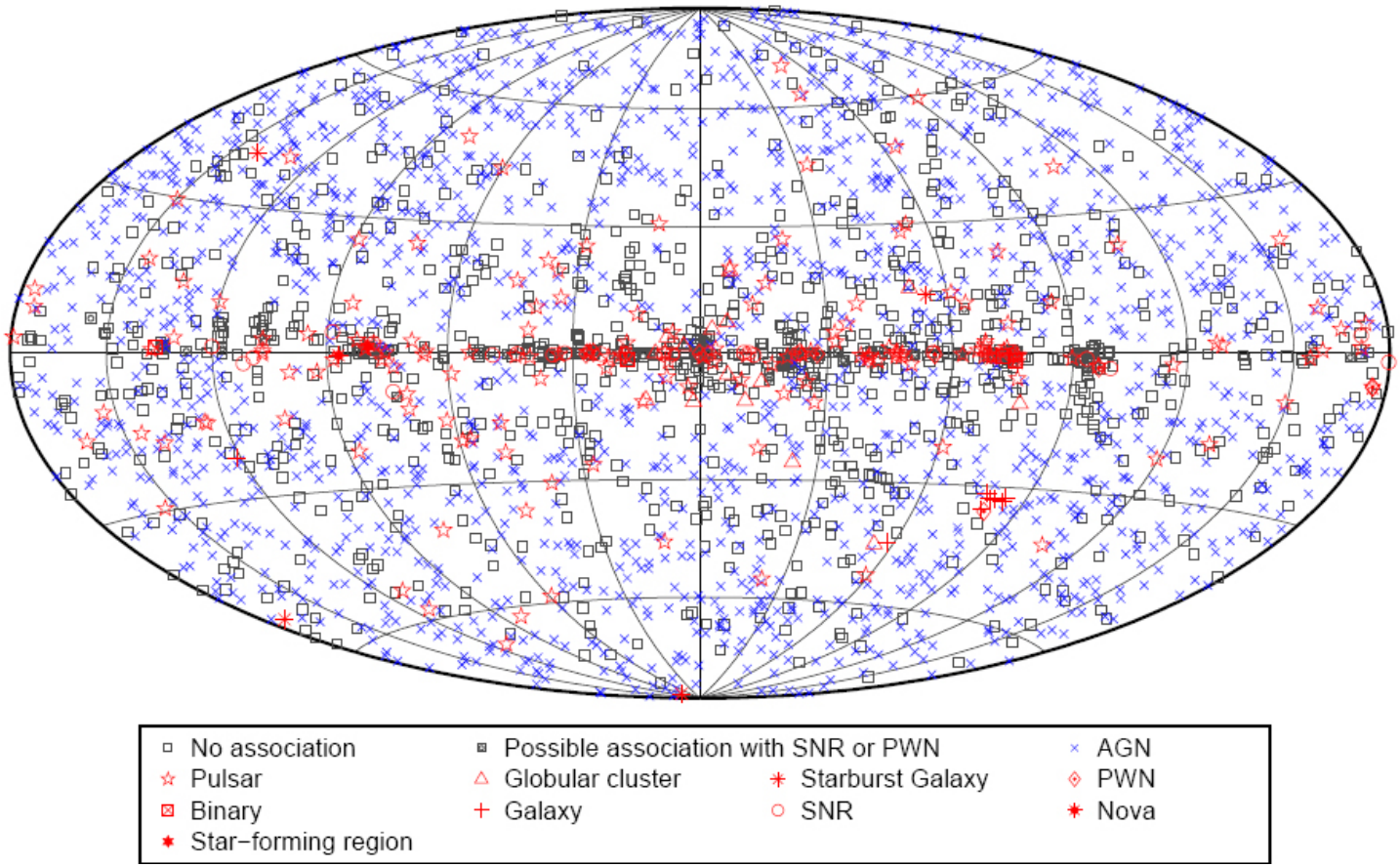


Credit: Fermi Large Area Telescope Collaboration

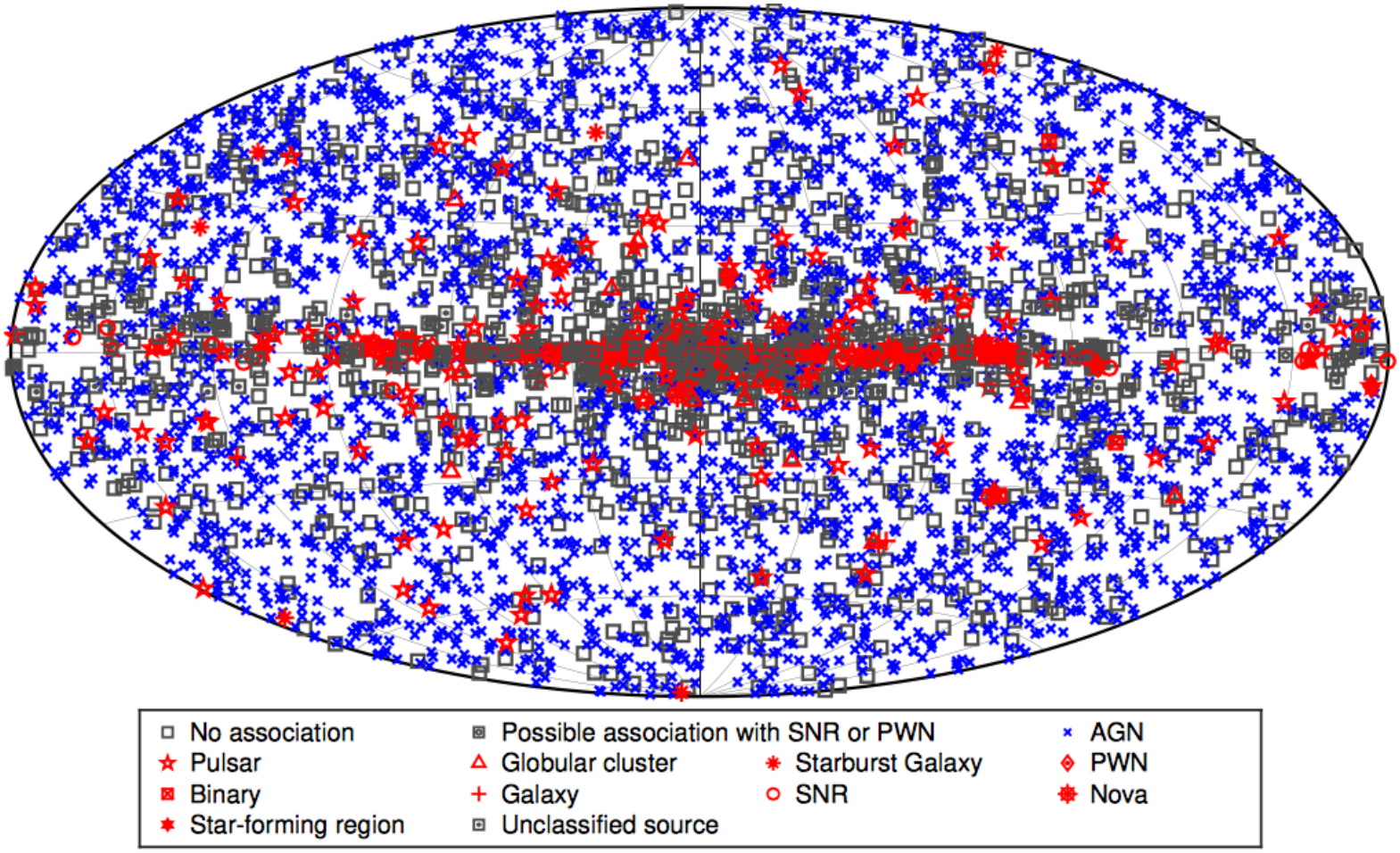
4 years sky



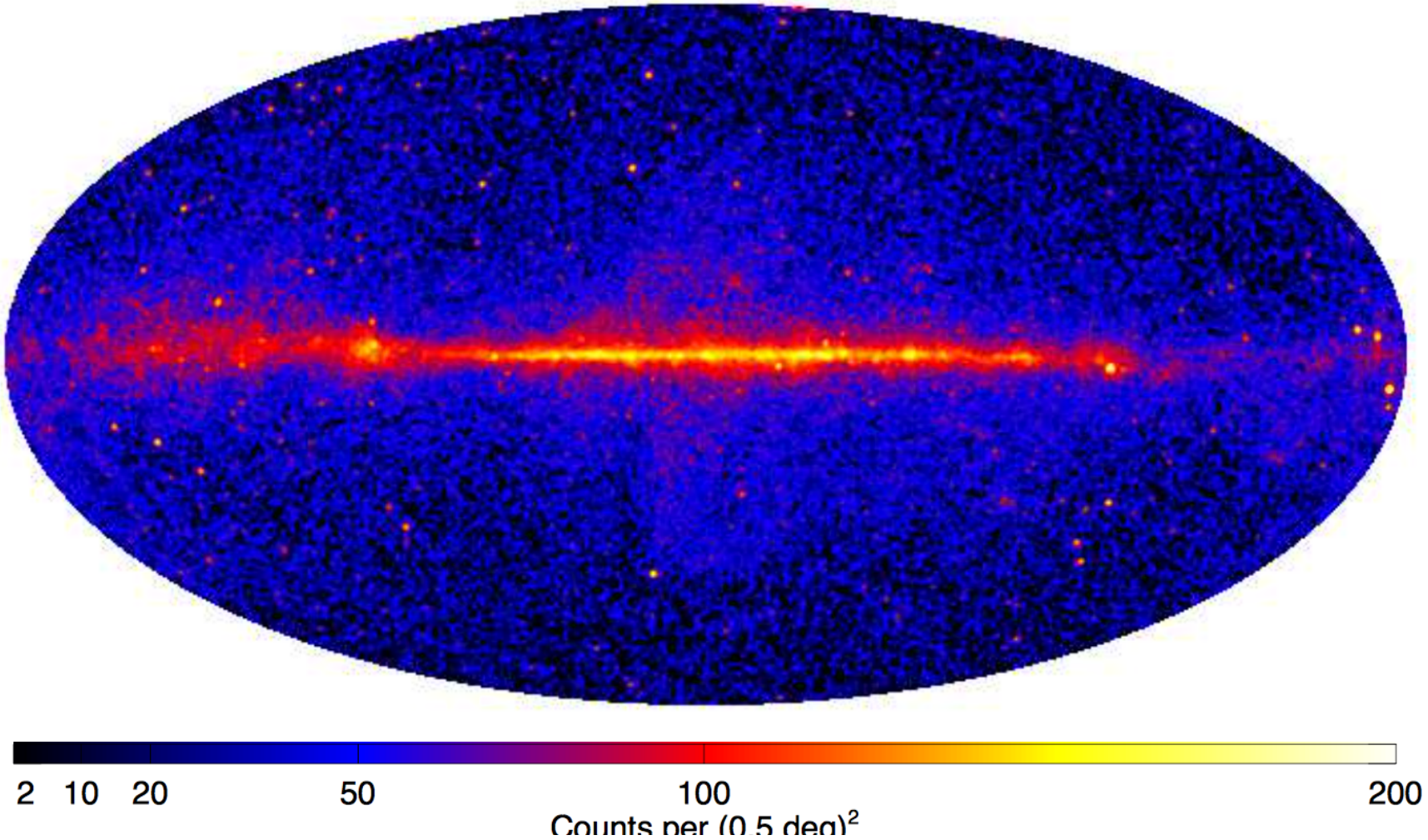
3FGL catalog – 3033 sources



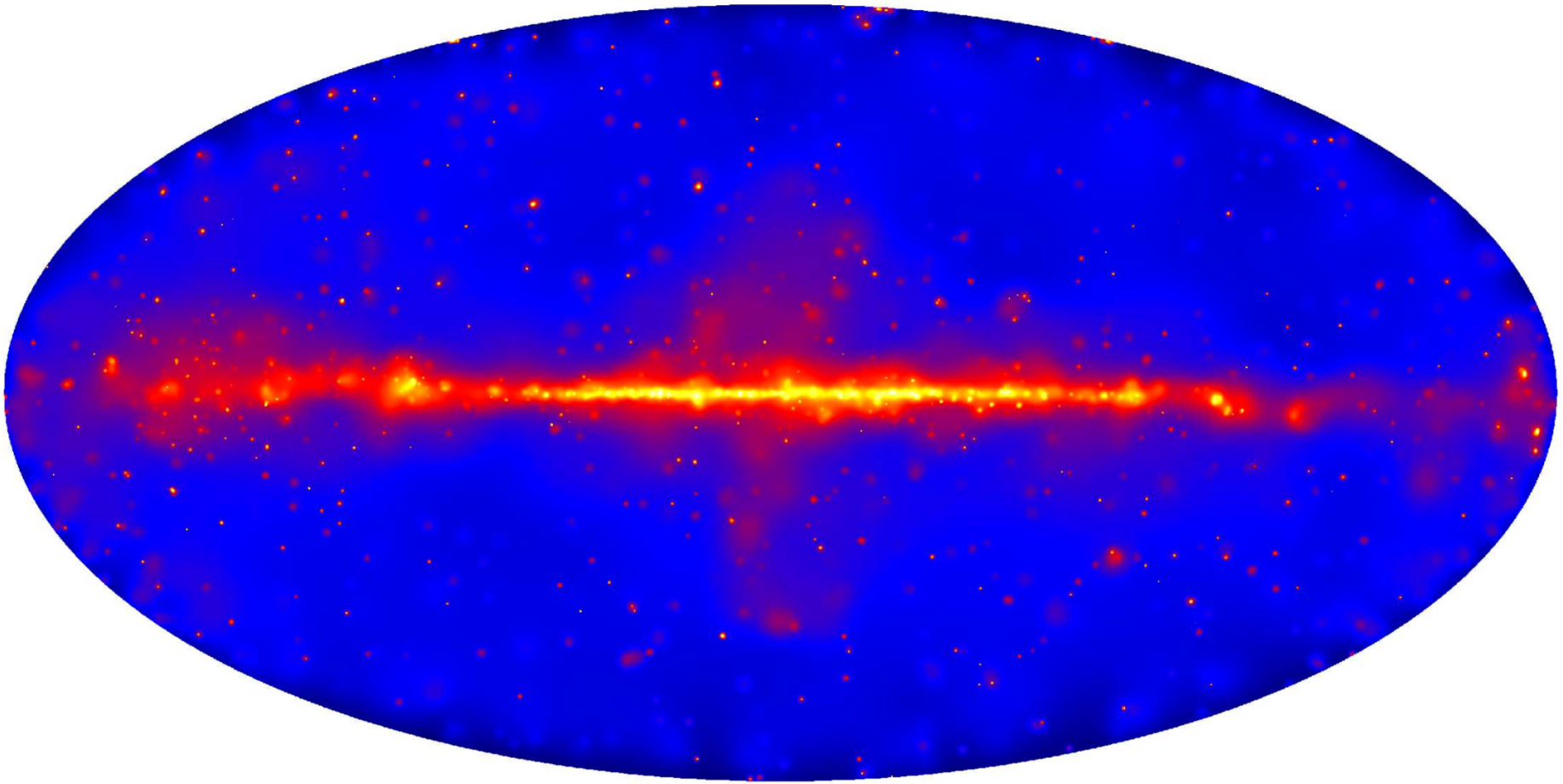
4FGL catalog



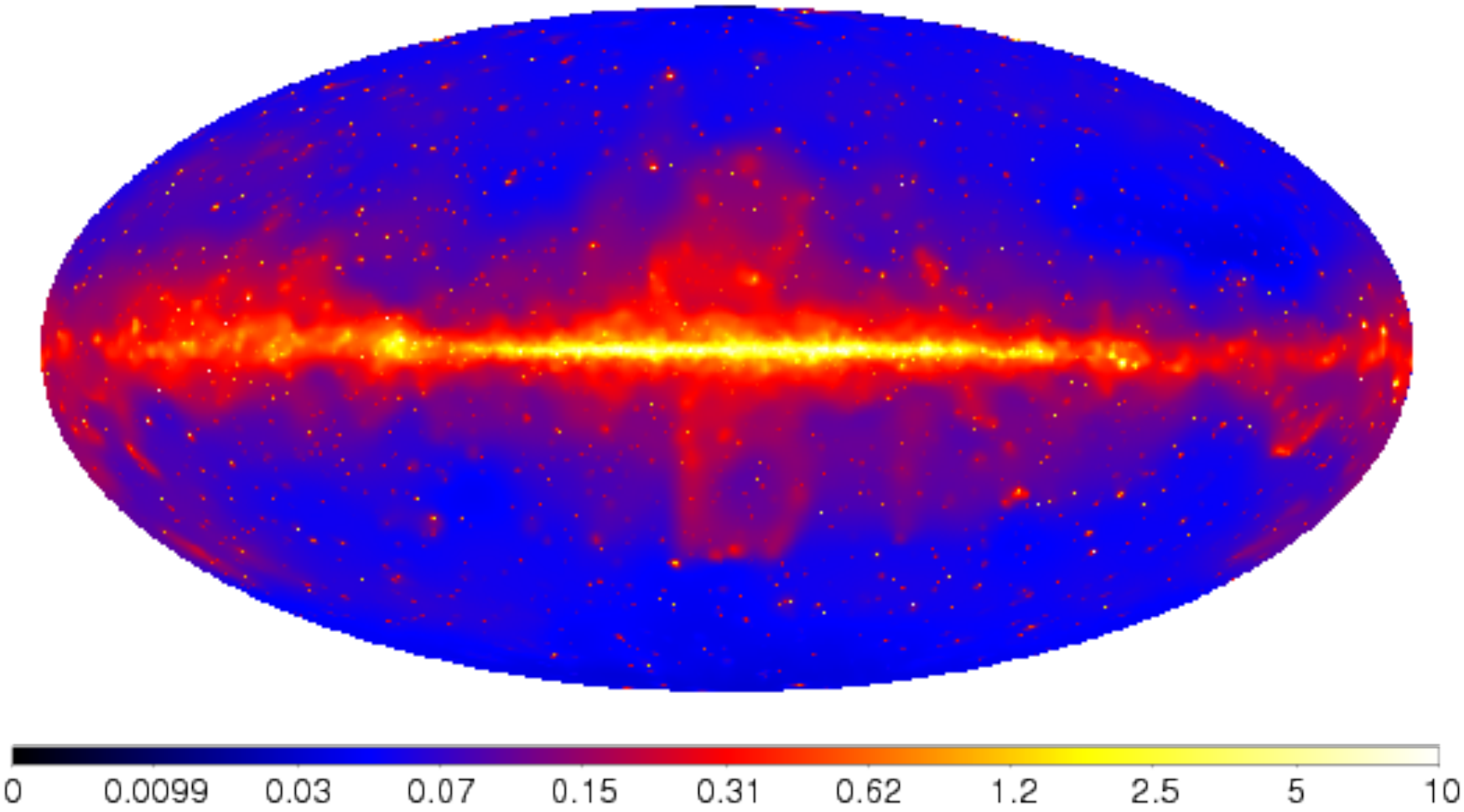
1 FHL (3 years, Pass7, E>10 GeV)



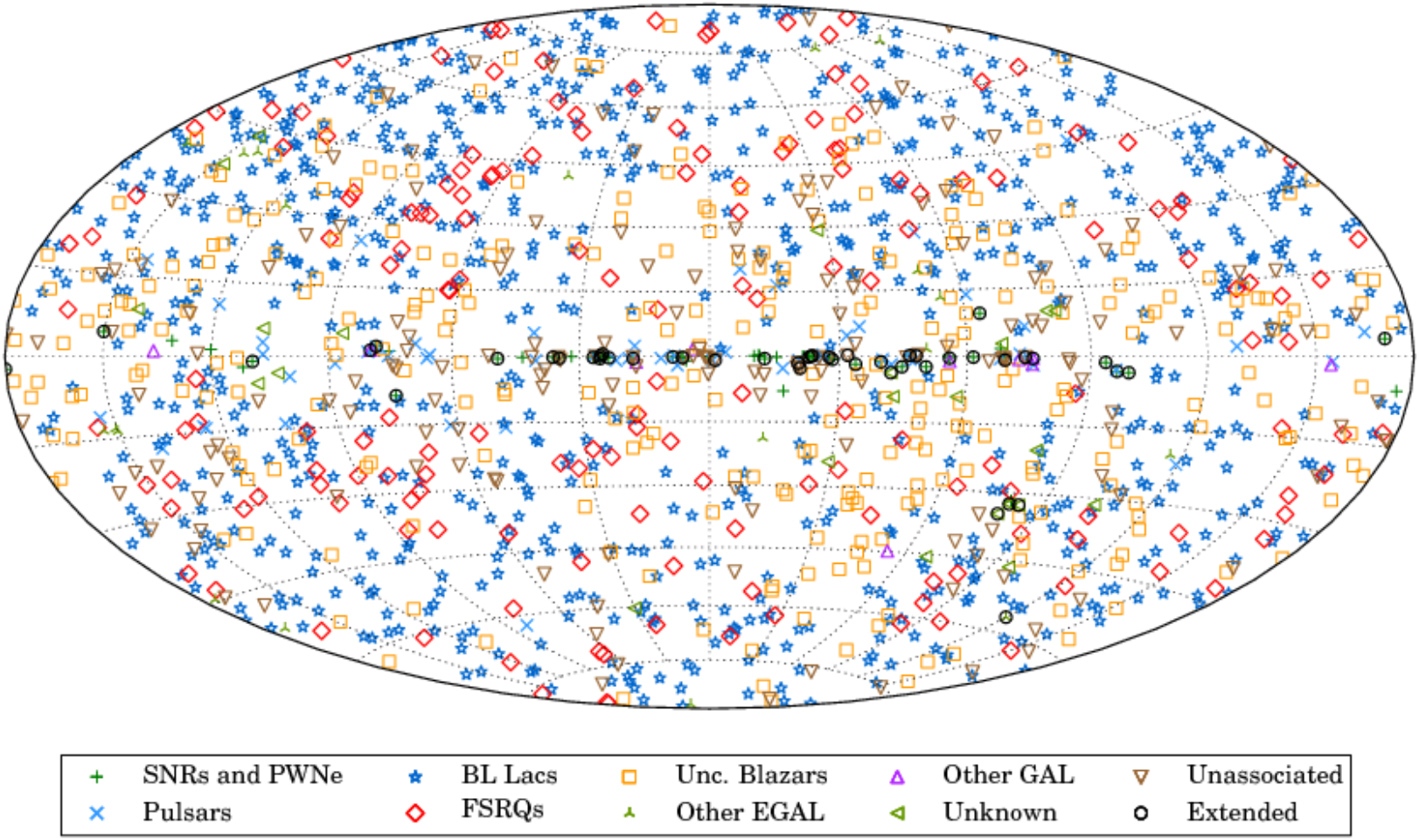
2FHL (P8 data >50 GeV) – 80 months



3FHL (E>10 GeV – P8)

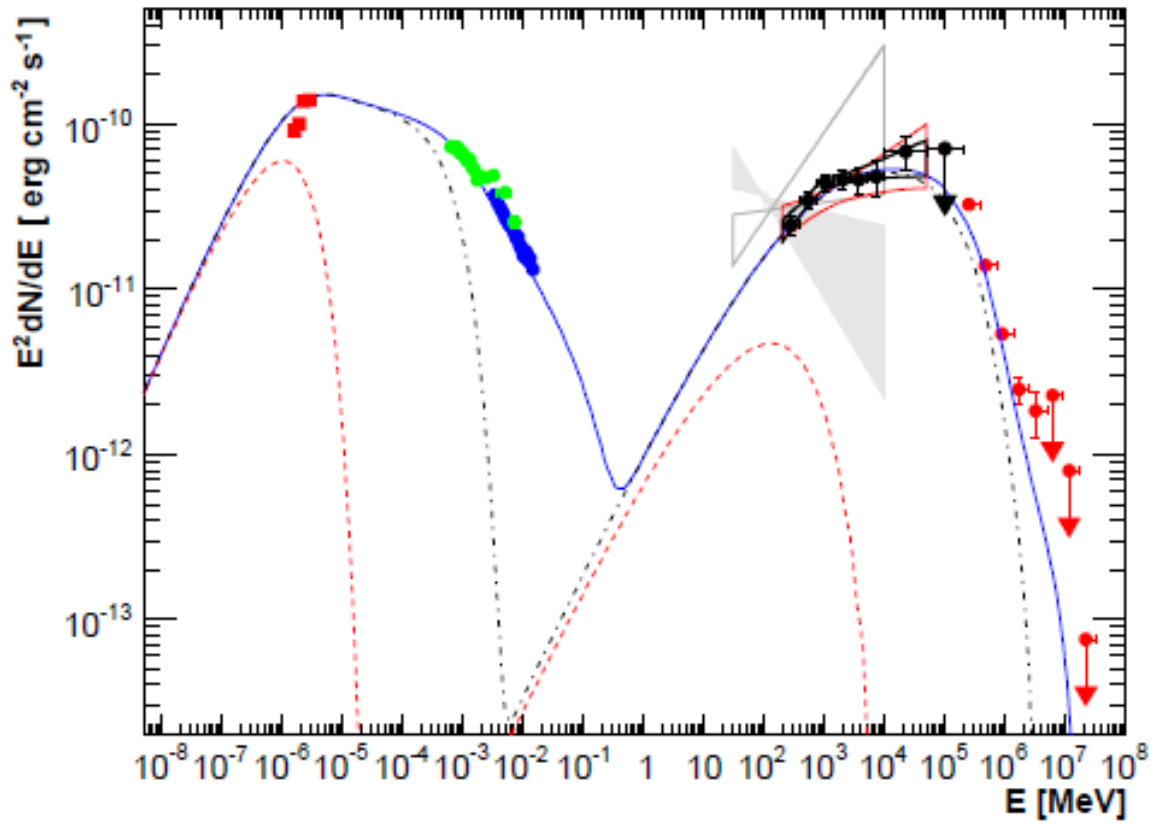


3 FHL


SNRs and PWNe
Pulsars
BL Lacs
FSRQs
Unc. Blazars
Other EGAL
Other GAL
Unknown
Unassociated
Extended

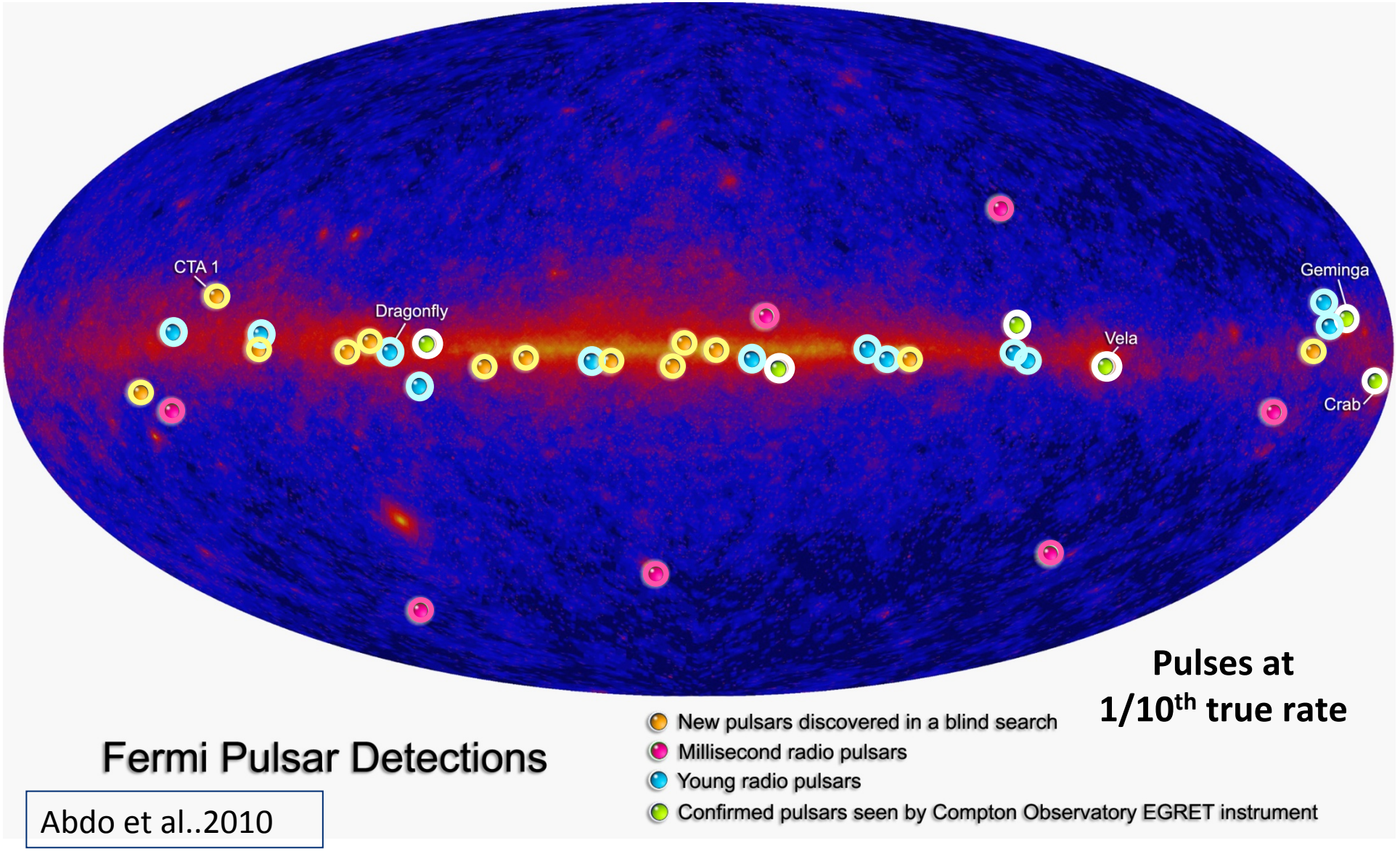
Challenge # 1 – AGN

Joint campaign on PKS 2155 with HESS



Aharonian et al. 2009

Challenge # 2 – Pulsars Blind Search



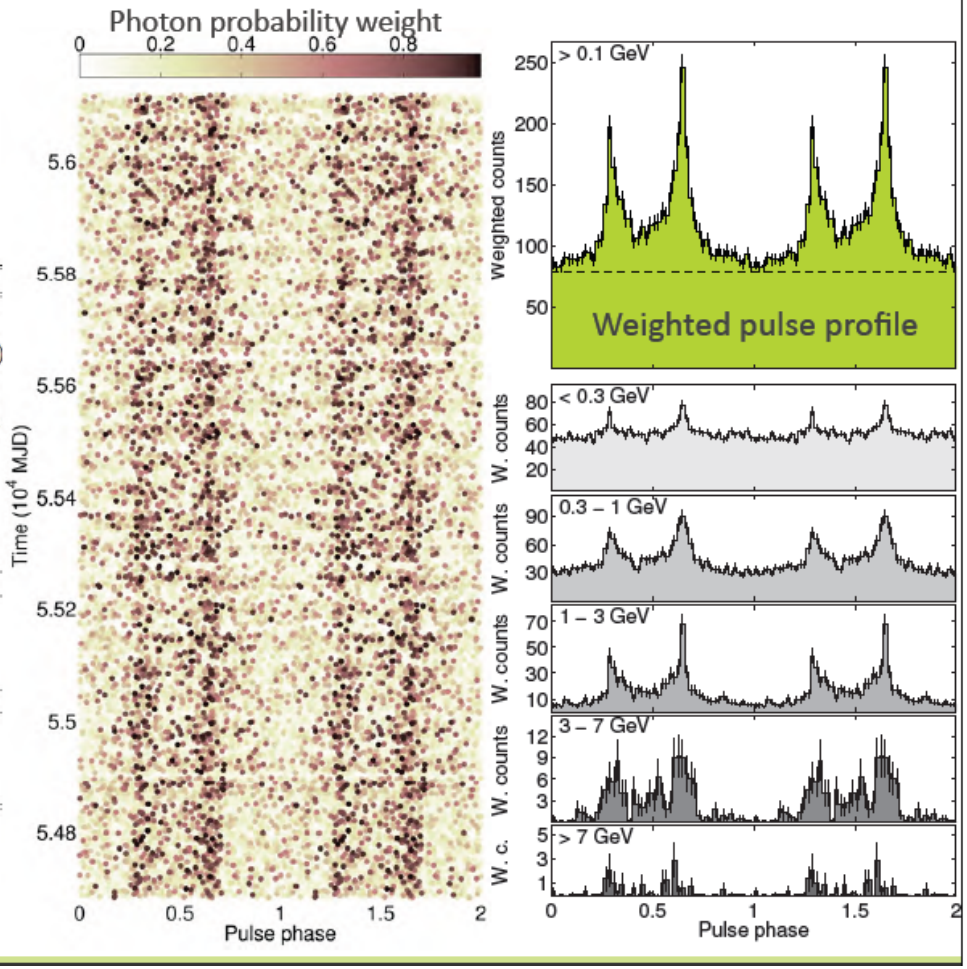
Abdo et al..2010

The first blind ms Pulsar

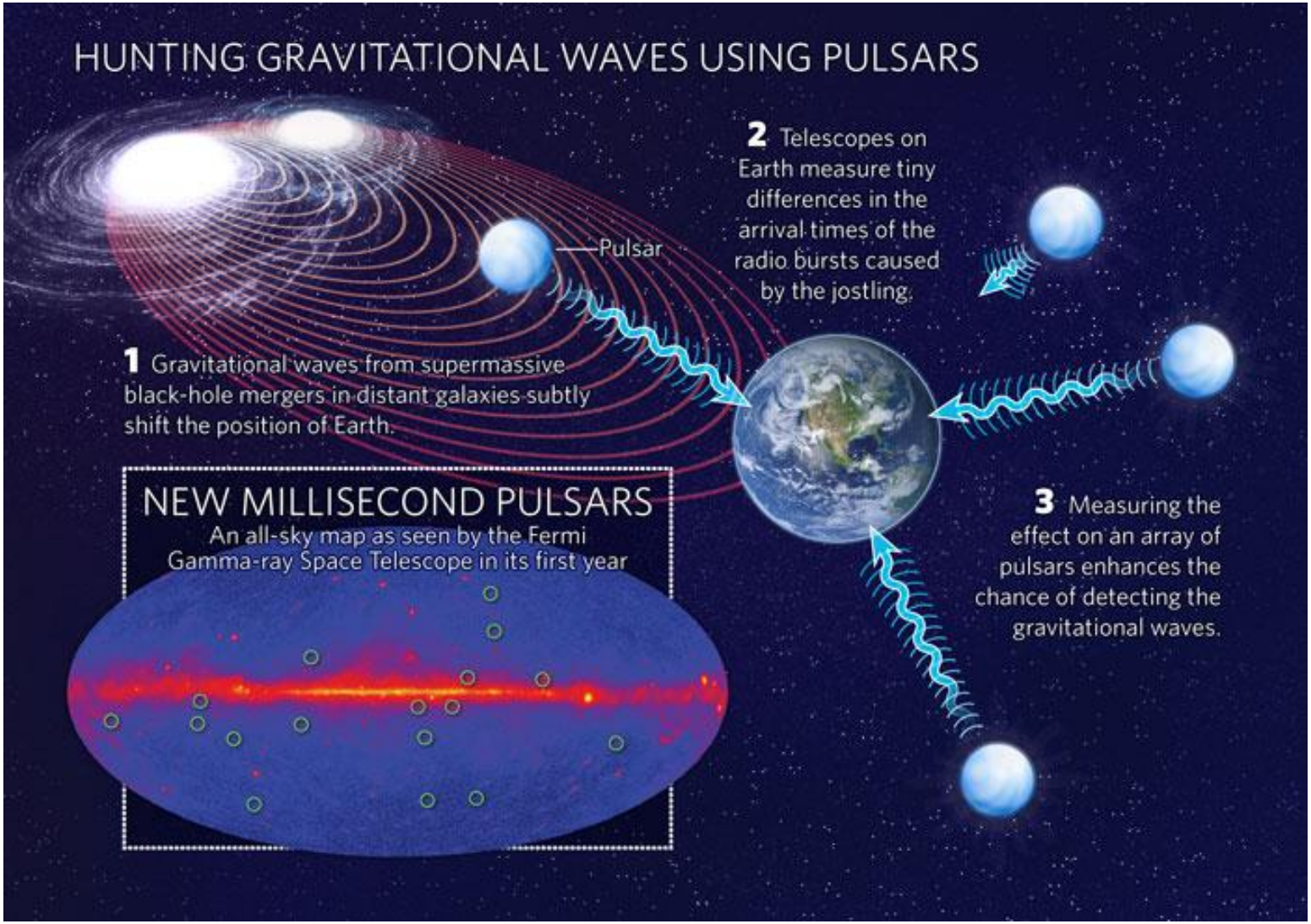
The PSR J1311-3430 system (1/2)

- Following the discovery:
  → pulsar timing to precisely measure the system parameters ( )

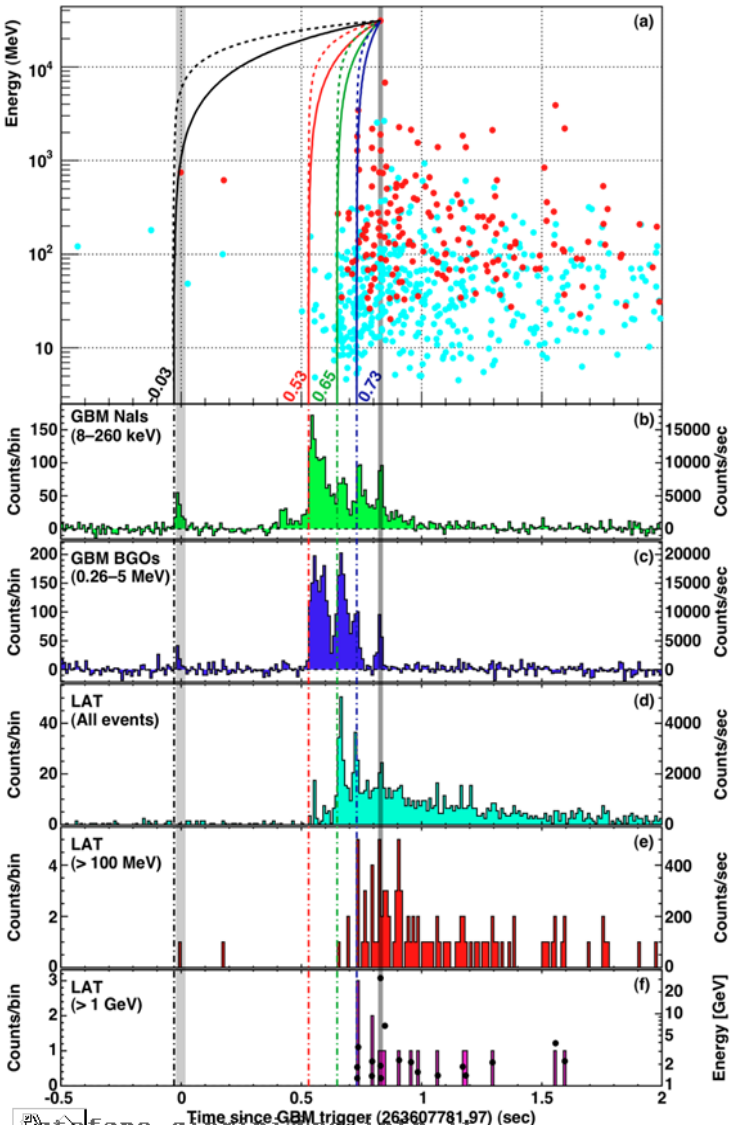
Parameter	Value
Right ascension (J2000.0) (hh:mm:ss)	13:11:45.7242(2)
Declination (J2000.0) (dd:mm:ss)	−34:30:30.350(4)
Spin frequency, f (Hz)	390.56839326407(4)
Frequency derivative, $\dot{f}$ (Hz s^{-1})	$-3.198(2) \times 10^{-15}$
Reference time scale	TDB
Reference time (MJD)	55266.90789575858
Orbital period $P_{\rm orb}$ (d)	0.0651157335(7)
Projected pulsar semi-major axis x (lt-s)	0.010581(4)
Time of ascending node $T_{\rm asc}$ (MJD)	56009.129454(7)
Eccentricity e	< 0.001
Data span (MJD)	54682 - 56119
Weighted RMS residual (μs)	17
Derived Quantities	
Companion mass m_c ($M_\odot$)	> 0.0082
Spin-down luminosity $\dot{E}$ (erg s^{-1})	4.9×10^{34}
Characteristic age τ_c (yr)	1.9×10^{9}
Surface magnetic field B_S (G)	2.3×10^{8}
Gamma-Ray Spectral Parameters	
Photon index, Γ	1.8 ± 0.1
Cutoff energy, E_c (GeV)	3.2 ± 0.4
Photon flux above 0.1 GeV, F (10^{-8} photons cm^{-2} s^{-1})	9.2 ± 0.5
Energy flux above 0.1 GeV, G (10^{-11} erg cm^{-2} s^{-1})	6.2 ± 0.2



New MSP and GW detection



Challenge # 3 – GRB



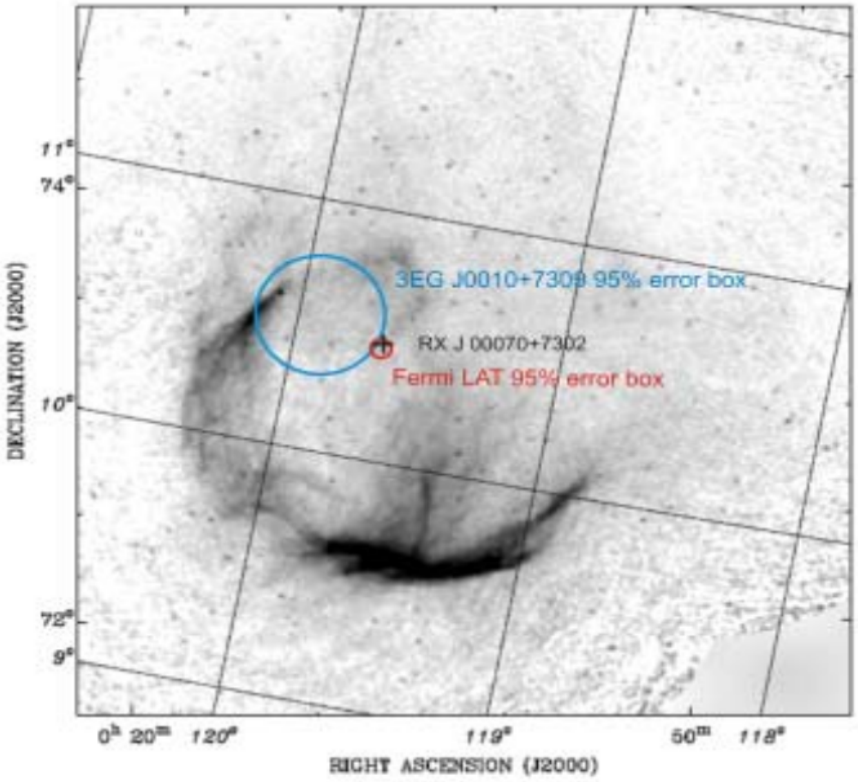
- This GRB is a perfect case for studying Lorentz Invariance Violation
  - z = 0.9 (5.381 Gyr)
  - Emission of 31 GeV photon after 859 ms since the trigger
- Only conservative assumption!
  - the HE photon is not emitted *before* the LE photons, at different events.

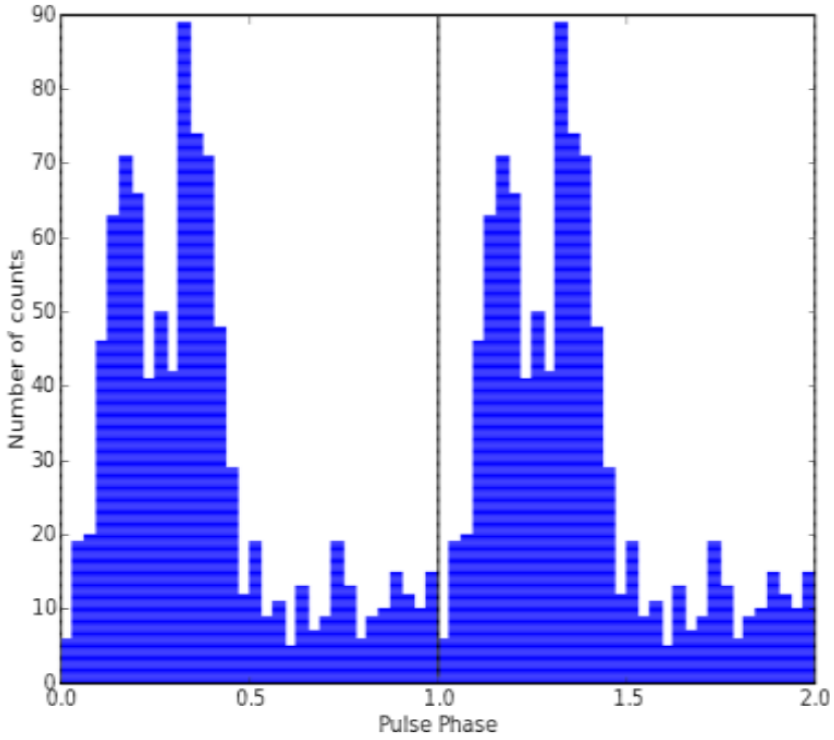
Table 2 | Limits on Lorentz Invariance Violation

#	$t_{start} - T_0$ (ms)	Limit on $\|\Delta t\|$ (ms)	Reasoning for choice of t_{start} or limit on Δt or $\|\Delta t/\Delta E\|$	E_l † (MeV)	Valid for s_n*	Lower limit on $M_{QG,1}/M_{Planck}$
(a)❖	−30	< 859	start of any < 1 MeV emission	0.1	1	> 1.19
(b)❖	530	< 299	start of main < 1 MeV emission	0.1	1	> 3.42
(c)❖	*648*	< 181	start of main > 0.1 GeV emission	100	1	> 5.63
(d)❖	730	< 99	start of > 1 GeV emission	1000	1	> 10.0
(e)♦	—	< 10	association with < 1 MeV spike	0.1	±1	> 102
(f)♦	—	< 19	If 0.75 GeV‡ γ-ray from 1st spike	0.1	−1	> 1.33
(g)♠	$\|\Delta t/\Delta E\| < 30$ ms/GeV		lag analysis of > 1 GeV spikes	—	±1	> 1.22

Challenge # 4 – Unidentified

CTA 1 Discovery

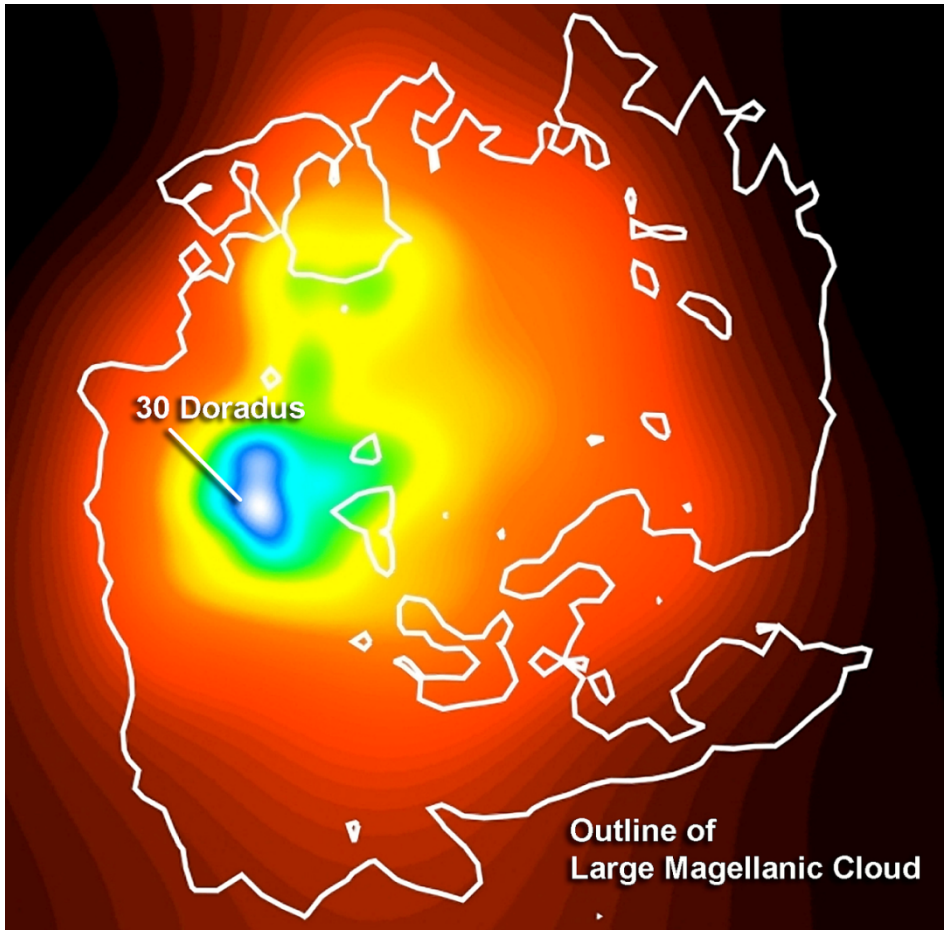




Abdo et al. 2008

Challenge # 4
Location of Gamma-ray emission

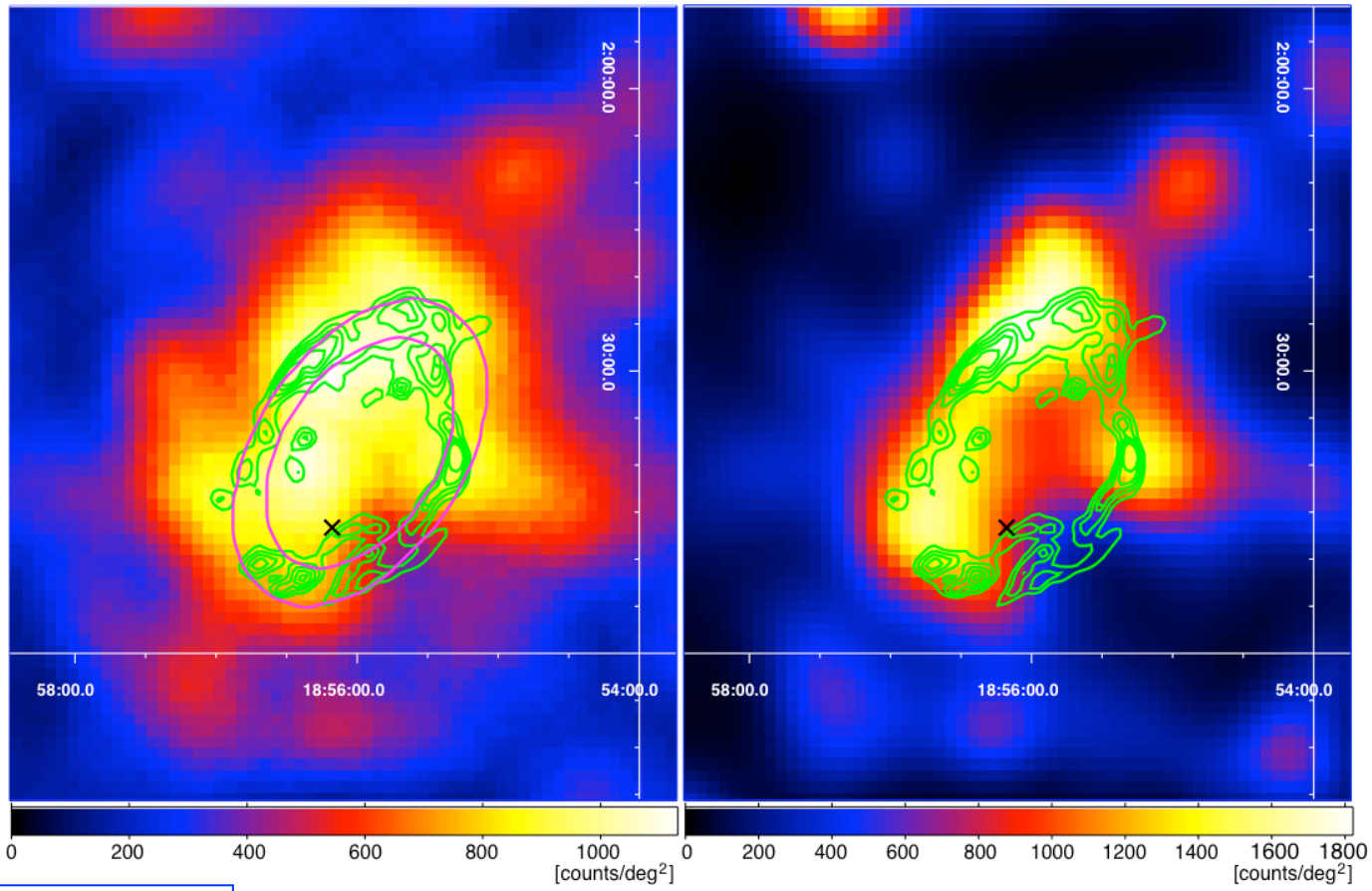
Observations of the Large Magellanic Cloud with *Fermi*



Abdo, A. A. et al. 2010

Challenge # 4
Location of Gamma-ray emission

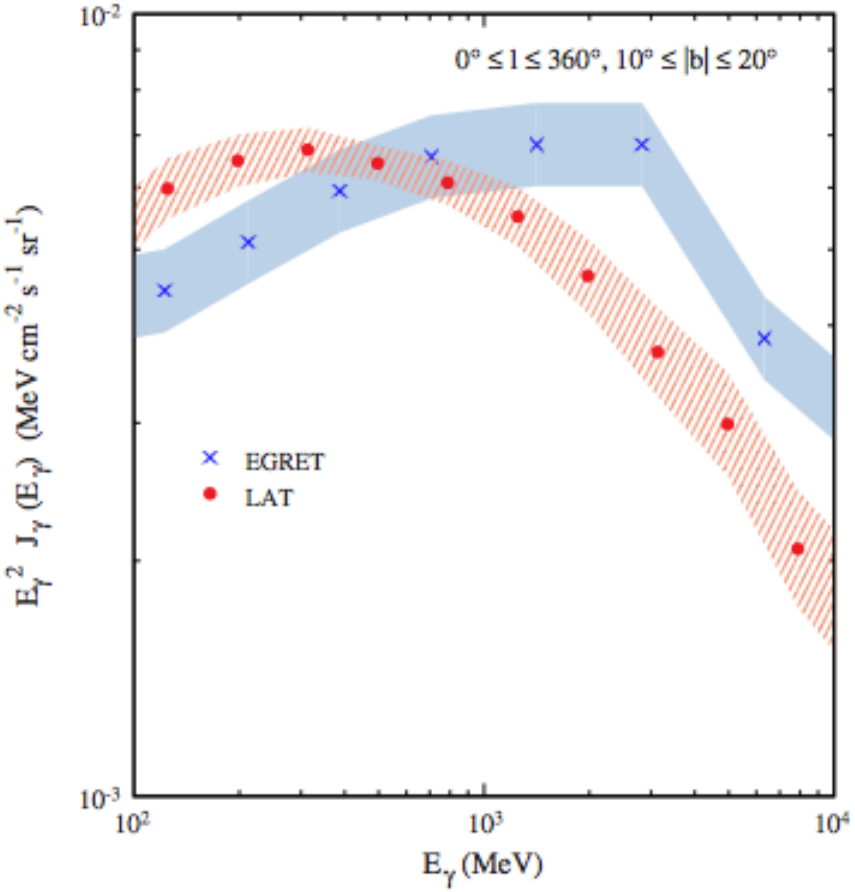
Gamma-Ray Emission from the Shell of Supernova Remnant W44 Revealed by the Fermi LAT

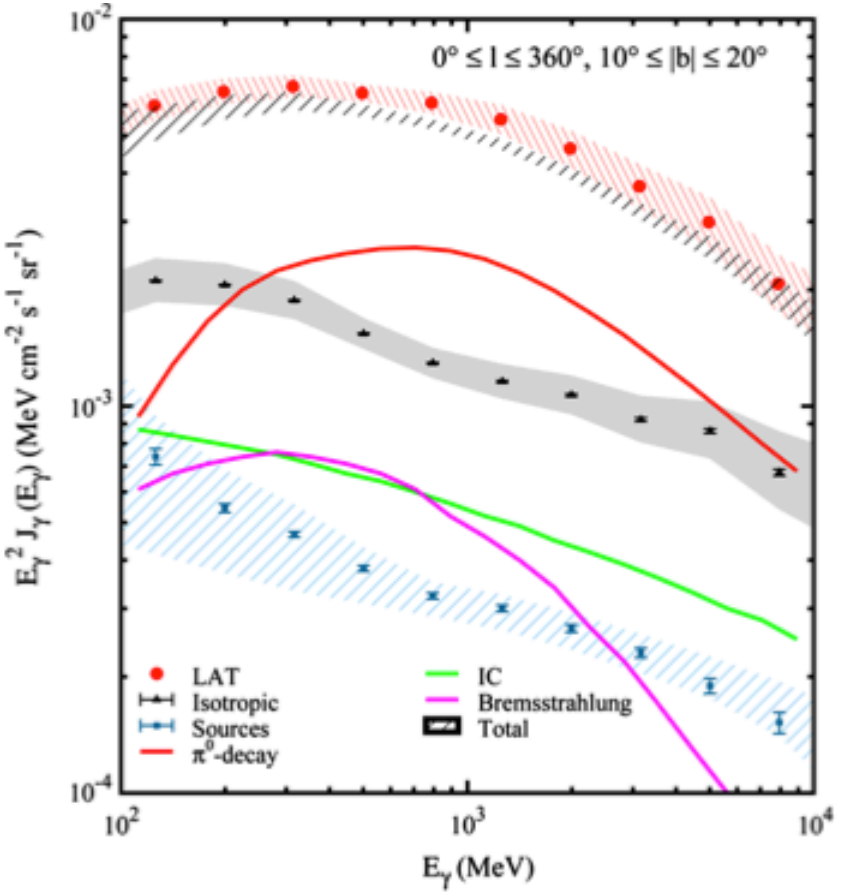


Abdo, A. A. et al. 2010

Challenge # 5 – Spectral Resolution

Fermi Large Area Telescope Measurements of the Diffuse Gamma-Ray Emission at Intermediate Galactic Latitudes





Abdo, A. A. et al. 2009

Supernova Remnants