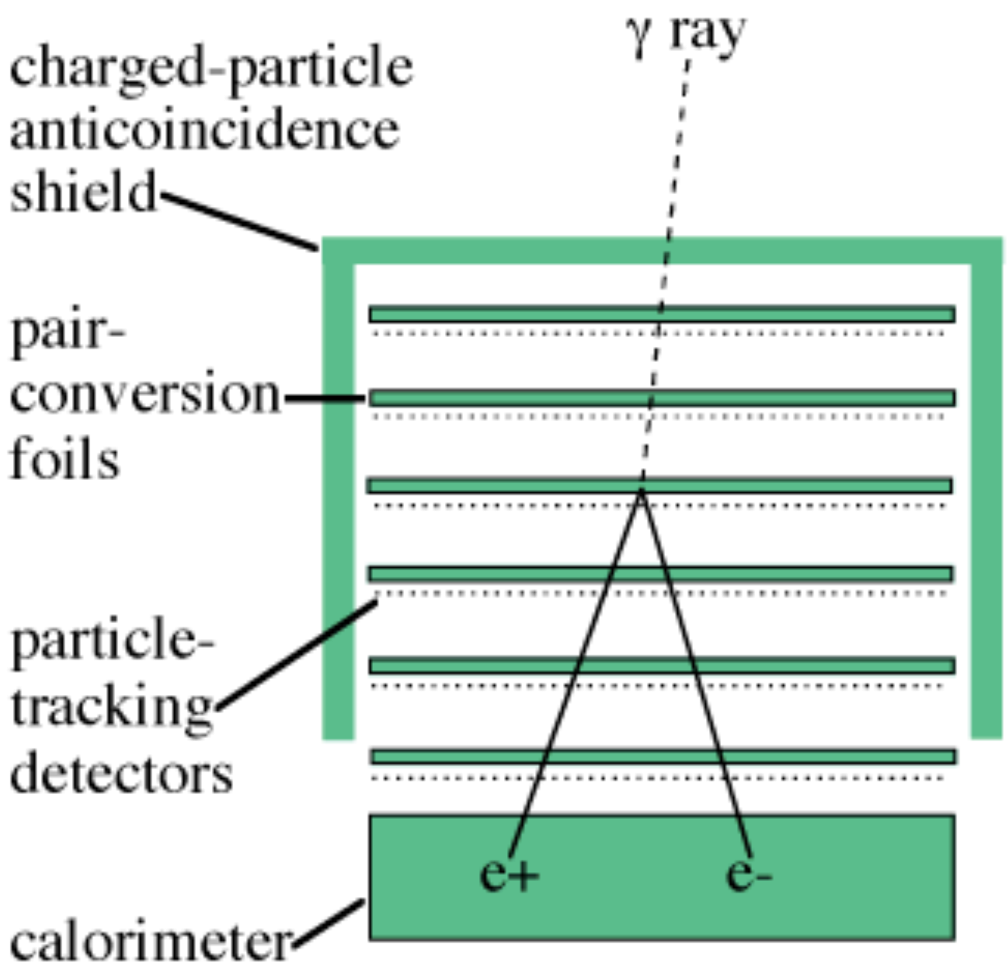
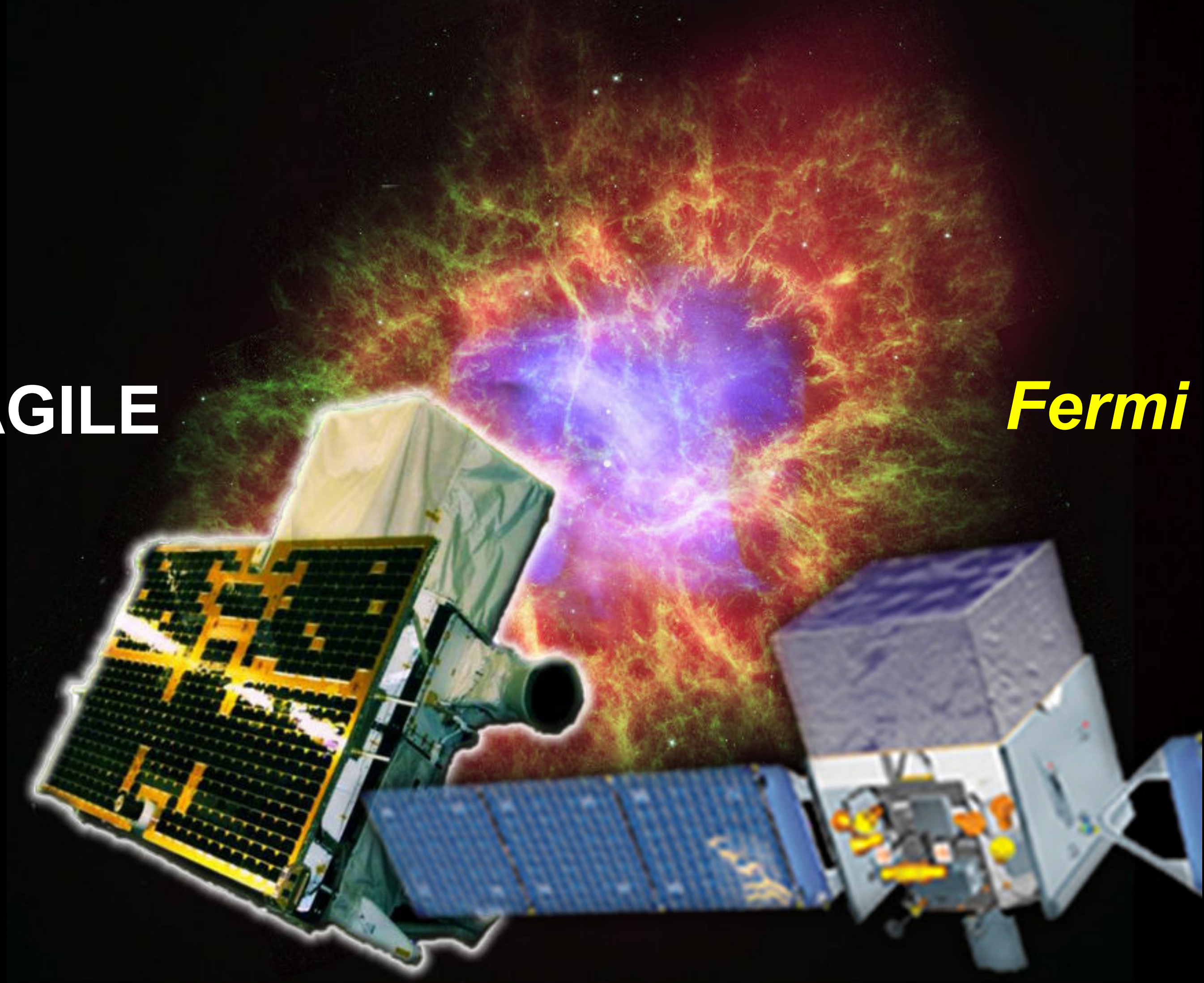
Astrofisica Nucleare e Subnucleare
GeV Astrophysics

Detector Project



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, other?)

AGILE

RECENT DETECTIONS
Gamma-ray flare from Cygnus X-3 detected by AGILE
ATel # 13458
Swift X-ray Observations of the Repeating FRB 180916.J0158+65
ATel # 13446
AGILE gamma-ray observations of Cygnus X-3 during the current quenched/hypersoft state
ATel # 13423
AGILE detection of enhanced gamma-ray activity from the FSRQ PKS 0208-512
ATel # 13352
Enhanced gamma-ray activity from Eta Carinae
ATel # 13329
AGILE confirmation of the gamma-ray flaring activity from the narrow-line Seyfert1 Galaxy PKS 2004-447
ATel # 13244
agile
http://agile.rm.iasf.cnr.it/
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INFN
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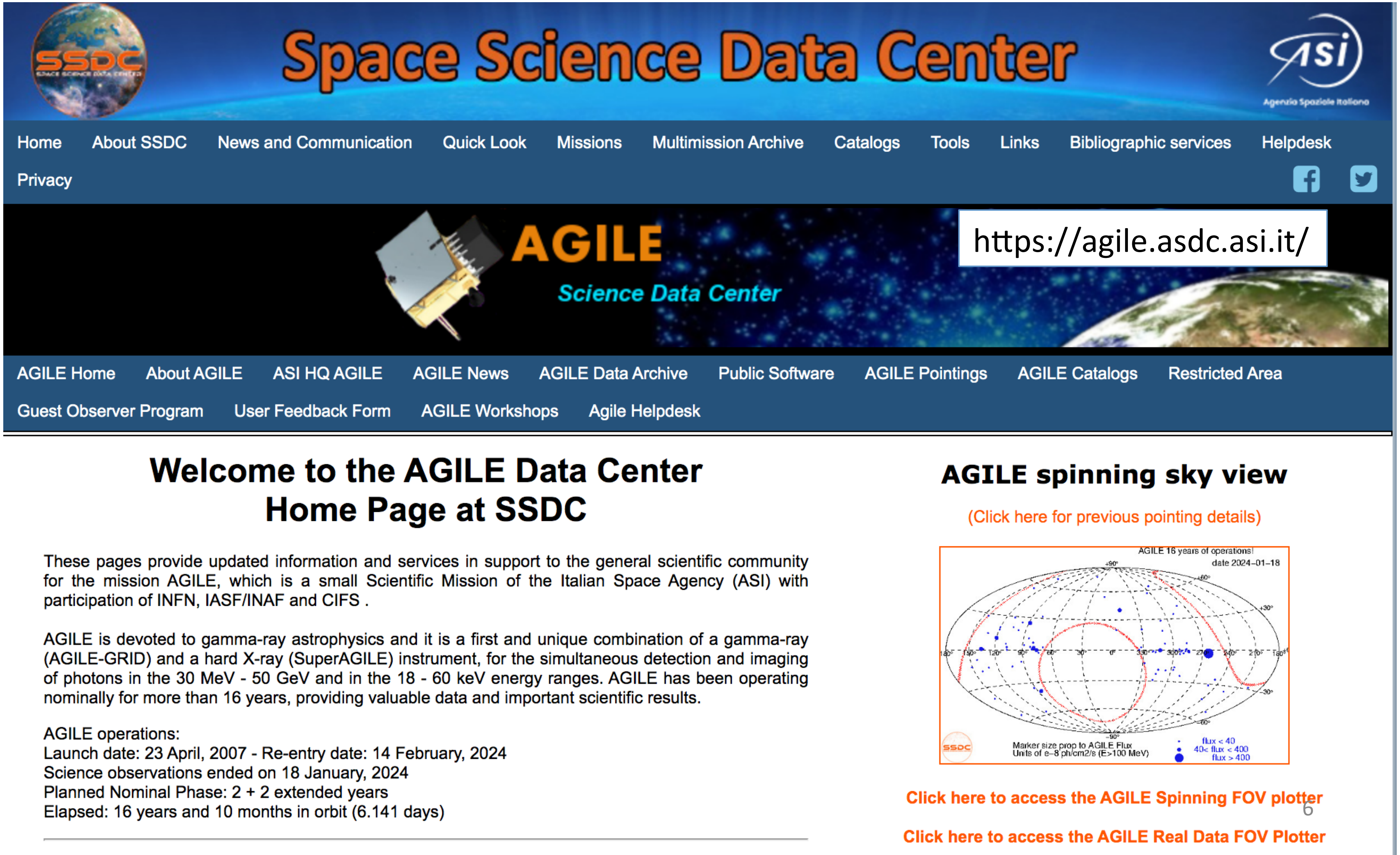
AGILE Team
AGILE in ASI
AGILE Data Center
Contacts
AT reserved
AGILE Launch
AGILE Principal Investigator and ASI Directors
Time elapsed since the AGILE launch on April 23, 2007 at 10:00 GMT
Days Hours Mins Secs
6215:22:04:13

AGILE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AGILE Workshops
Agile Helpdesk
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. AGILE has been operating nominally for more than 16 years, providing valuable data and important scientific results.
AGILE operations:
Launch date: 23 April, 2007 - Re-entry date: 14 February, 2024
Science observations ended on 18 January, 2024
Planned Nominal Phase: 2 + 2 extended years
Elapsed: 16 years and 10 months in orbit (6.141 days)
AGILE spinning sky view
(Click here for previous pointing details)
AGILE 16 years of operations!
date 2024-01-18
Marker size prop to AGILE Flux
Units of e-8 ph/cm2/s (E>100 MeV)
flux < 40
40< flux < 400
flux > 400
Click here to access the AGILE Spinning FOV plotter
Click here to access the AGILE Real Data FOV Plotter

Fermi LAT

Stanford | The Fermi Large Area Telescope

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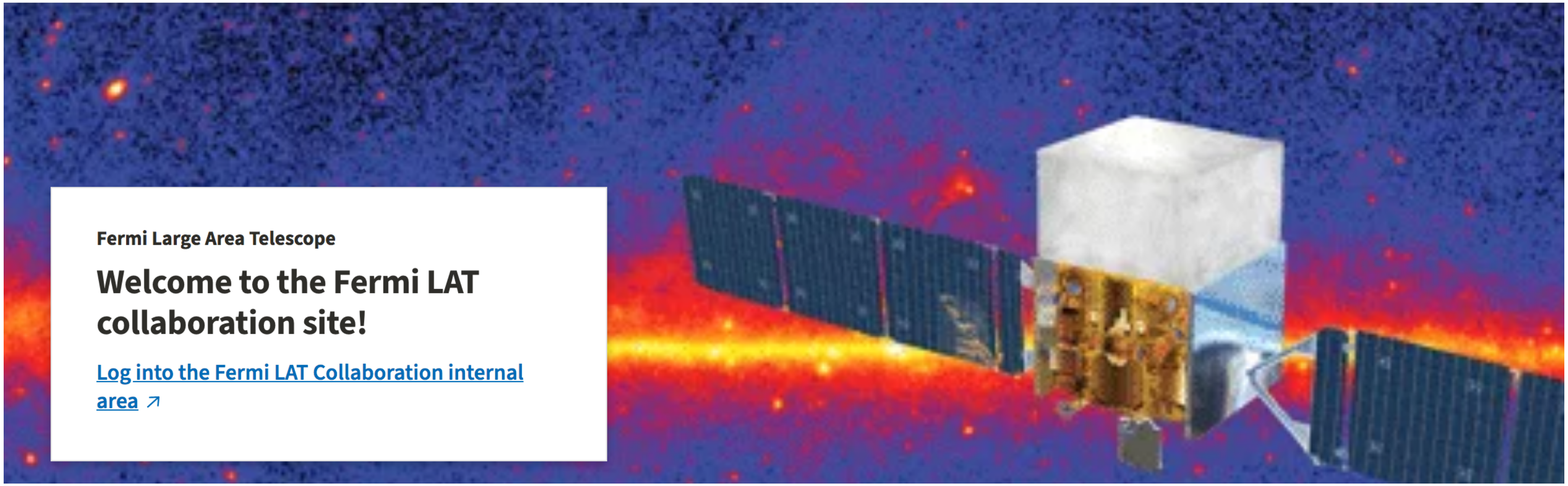

https://glast.sites.stanford.edu/

Fermi LAT


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Gamma-ray Space Telescope
https://fermi.gsfc.nasa.gov/
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Support Center
Mission Page
Students/Teachers
Eleventh International Fermi Symposium
SEPTEMBER 9-13, 2024
COLLEGE PARK, MARYLAND, USA
11TH INTERNATONAL FERMI SYMPOSIUM
Topics include Gamma-ray Studies of:
• Supernova Remnants and Pulsar Wind Nebulae
• Gamma-ray Bursts and Other Transients
• Blazars and Other Galaxies
• Future Missions and Instruments
• Multimessenger Sources
• Other Galactic Sources
• Diffuse Emission
• Solar System
• Dark Matter
• Pulsars
Important Dates
• Abstracts Due – May 1, 2024
• Registration Deadline – August 1, 2024
fermi.gsfc.nasa.gov/science/mtgs/symposia/eleventh/
Latest News
Apr 23, 2024
Explore the Universe with the First E-Book from NASA's Fermi
To commemorate a milestone anniversary for NASA's Fermi spacecraft, the mission team has published an e-book called "Our High-Energy Universe: 15 Years with the Fermi Gamma-ray Space Telescope."
+ Read More
Apr 16, 2024
NASA's Fermi Mission Sees No Gamma Rays from Nearby Supernova
A nearby supernova in 2023 offered astrophysicists an excellent opportunity to test ideas about how these types of explosions boost particles, called cosmic rays, to near light-speed. But surprisingly, NASA's Fermi Gamma-ray Space Telescope detected none of the high-energy gamma-ray light those particles should produce.
+ Read More
Apr 5, 2024
11th International Fermi Symposium
Please join us in College Park, Maryland, USA on

Astrofisica Nucleare e Subnucleare

Electromagnetic Showers

ELECTROMAGNETIC SHOWERS
SCIAMI ELETTROMAGNETICI

$$-\frac{dE}{dX} \simeq \frac{E}{X_0}$$

SIA $e^{\pm}$ CHE γ

$E = E_i e^{-\frac{X}{X_0}}$

ΔX DOPO UNA LUNGHEZZA DI RADIAZIONE $= X_0$
(AFTER ONE RADIATION LENGTH)

$$-dE = \frac{E\,dX}{X_0} \qquad \Delta E \simeq E\frac{\Delta X}{X_0} \simeq E$$

RADIAZIONE
(RADIATION) $e^{\pm} \longrightarrow e^{\pm}\gamma$ BREMSSTRAHLUNG

CONVERSIONE
(CONVERSION) $\gamma \longrightarrow e^{+}e^{-}$ CREAZIONE COPPIE
(PAIR CREATION)

$$1 \longrightarrow 2$$

$$E_i \longrightarrow 2\left(\frac{E_i}{2}\right)$$

DOPO TANTE LUNGHEZZE DI RADIAZIONE
(AFTER MANY RADIATION LENGTHS)

$$X = t\,X_0 \qquad t = \frac{X}{X_0}$$

$$1 \rightarrow 2^{t} \equiv N$$

$$E_i \longrightarrow 2^{t}\left(\frac{E_i}{2^{t}}\right) = N\left(\frac{E_i}{N}\right) = N\,E(t)$$

$$E(t) = \frac{E_i}{N} = \frac{E_i}{2^{t}}$$

QUANDO $E(t)$ ARRIVA A E_c
(WHEN) (REACHES) $\left(E = \frac{E_i}{N} = E_c\right)$

DIVENTANO DOMINANTI :
(BECOME DOMINANT)

PER $e^{\pm}$: IONIZZAZIONE

PER γ : COMPTON E FOTOELETTRICO

N SMETTE LA CRESCITA ESPONENZIALE

N RAGGIUNGE IL MASSIMO

$$N_{MAX} = \frac{E_i}{E_c}$$

$$N_{MAX} = 2^{t_{MAX}} = \frac{E_i}{E_c}$$

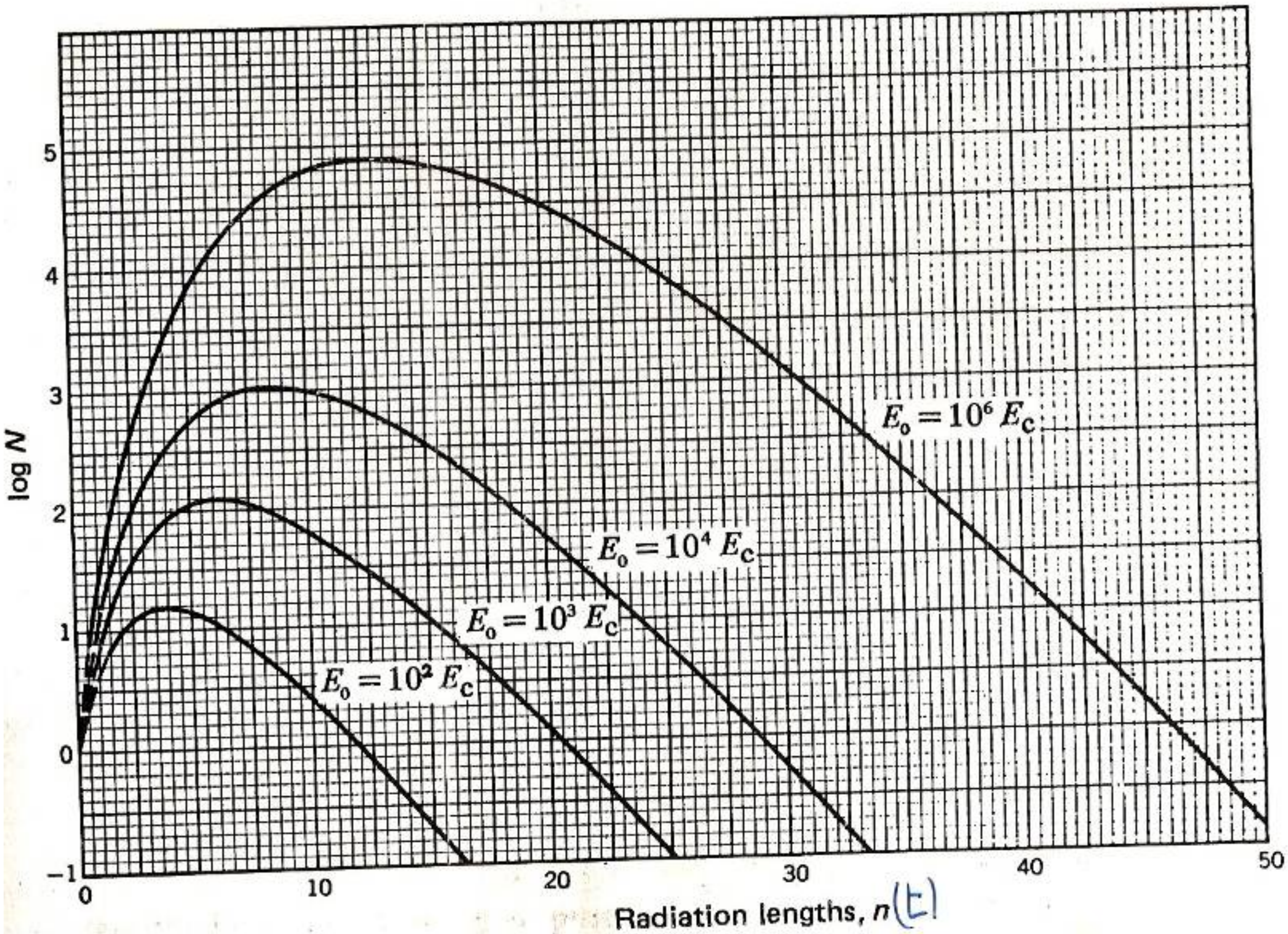
$$t_{MAX} = \ln \frac{E_i}{E_c} \cdot \frac{1}{\ln 2}$$

N POI DECRESCE PER

PROGRESSIVA PERDITA DELLE

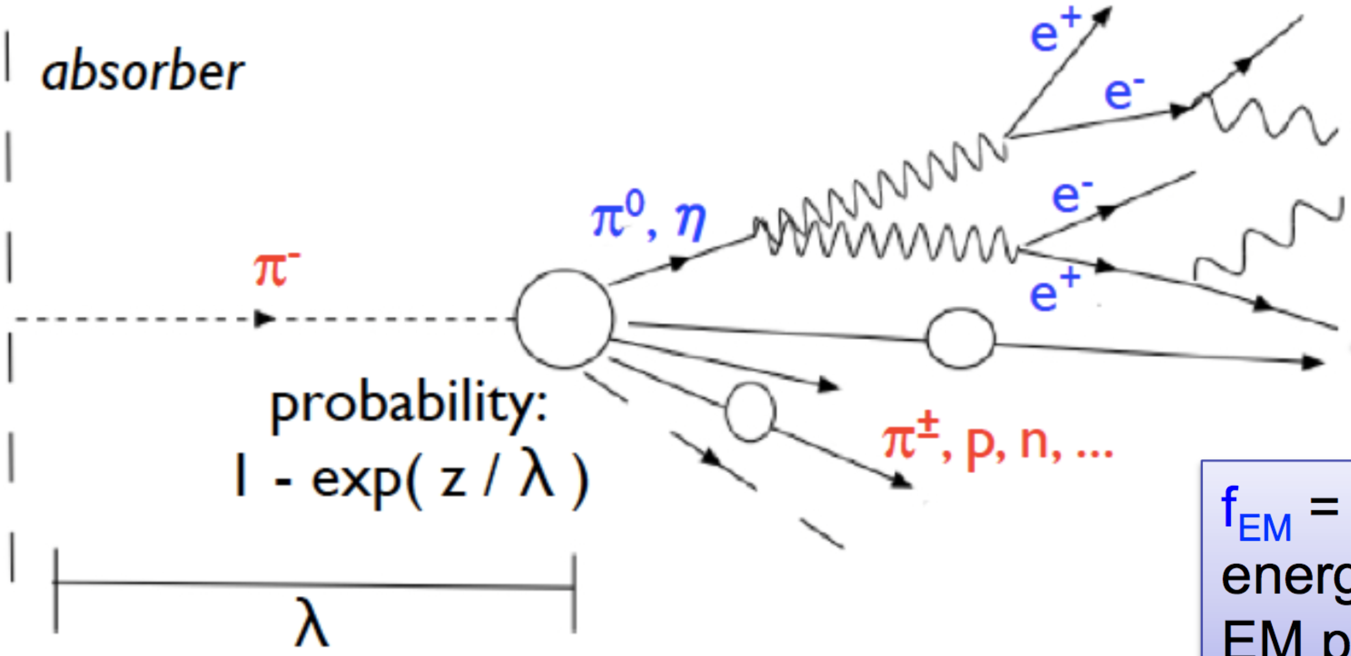
ENERGIE RESIDUE

Fig. 4.6. The total number of particles N in a shower initiated by an electron of energy E_0, as a function of depth n, measured in radiation lengths; E_c is the critical energy of the material. (From Leighton, 1959, p. 693, after Rossi & Greisen, 1941.)



Astrofisica Nucleare e Subnucleare
Hadronic showers

Hadronic showers



π_0 production is a one way street: all energy deposited via EM processes

f_{EM} = fraction of hadron energy deposited via EM processes

Electromagnetic → ionization, excitation (e±)
→ photo effect, scattering (γ)

Hadronic → ionization (π±, p)
→ invisible energy (binding, recoil)

Hadronic shower

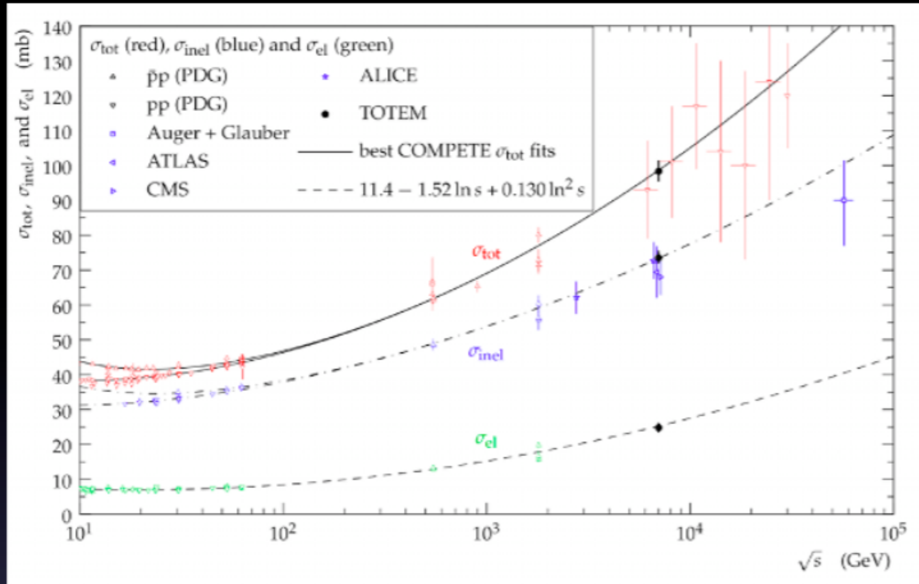
- Hadronic interaction Cross section

$$\sigma_{Tot} = \sigma_{el} + \sigma_{inel}$$

$$\sigma_{el} \approx 10mb \qquad \sigma_{inel} \approx A^{2/3}$$

$$\sigma_{Tot} = \sigma_{tot}(pp)A^{2/3}$$

where: $\sigma_{tot}(pp)$ increases with $\sqrt{s}$



- Hadronic interaction length

$$\lambda_{int} = \frac{1}{\sigma_{tot} \cdot n} = \frac{A\rho}{\sigma_{pp} A^{2/3} N_A} \approx \left(35g/cm^2\right) A^{1/3}$$

$$N(x) = N(0)\mathrm{e}^{-x/\lambda_{int}}$$

- λ_{int} characterizes both longitudinal and transverse shower profile

Rule of thumb argument: the geometric cross section goes as the square of the size of the nucleus, a_N^2, and since the nuclear radius scales as $a_N \sim A^{1/3}$, the nuclear mean free path in gm/cm² units scales as $A^{1/3}$.

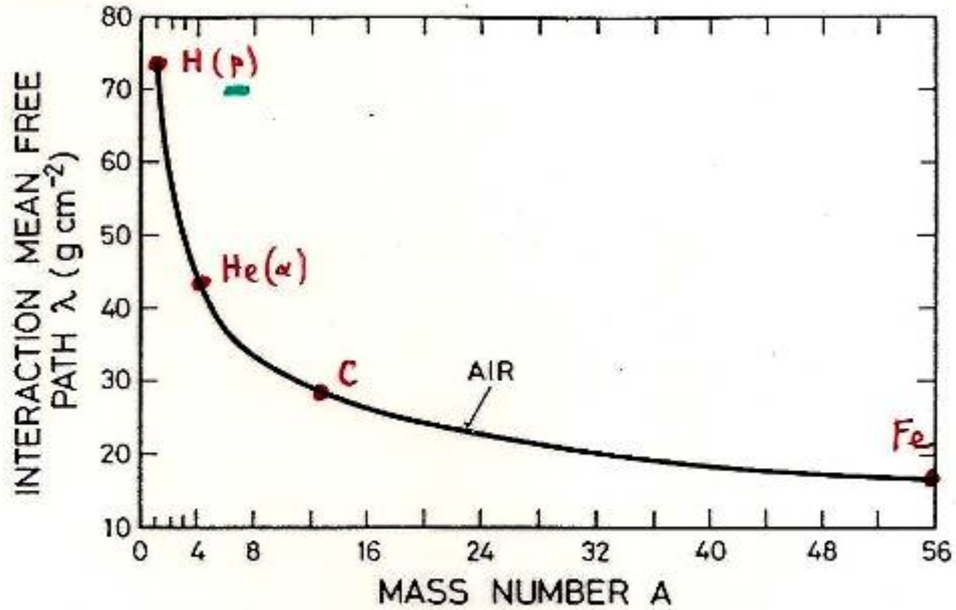


Fig. 1.1.1: Interaction mean free path for high energy nuclear interactions in air versus projectile mass.

$X_{INT.\,NUCL.} \longrightarrow \lambda_I$

Table 5. *Radiation length X_0, critical energy E_c and hadronic absorption length λ_{had}^{int} for some materials*

Material	X_0 (g/cm²)	Kg/m²	E_c (MeV)	λ_{had} (g/cm²)
H_2	63	630	340	52.4
Al	24	240	47	106.4
Ar	20	200	35	119.7
Fe	13.8	138	24	131.9
Pb	6.3	63	6.9	193.7
Lead glass SF 5	9.6	96	~ 11.8	
Plexiglas	40.5	405	80	83.6
H_2O	36	360	93	84.9
NaI(Tl)	9.5	95	12.5	152.0
$Bi_4Ge_3O_{12}$	8.0	80	10.5	164

Hadronic shower

Hadronic interaction:

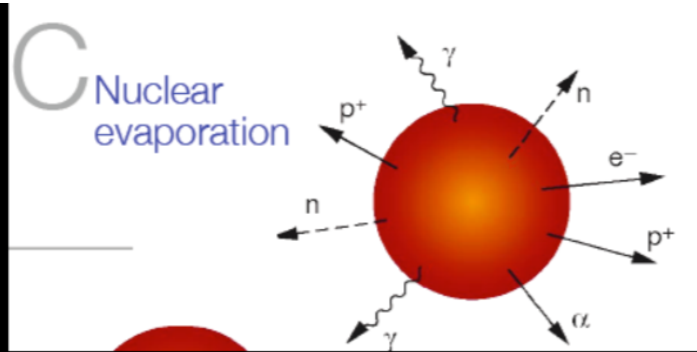
Elastic:

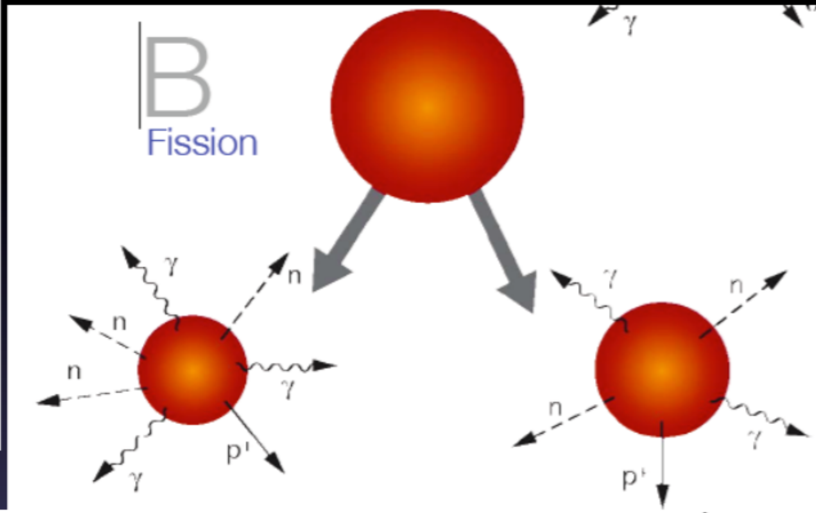
$$p + \text{Nucleus} \rightarrow p + \text{Nucleus}$$

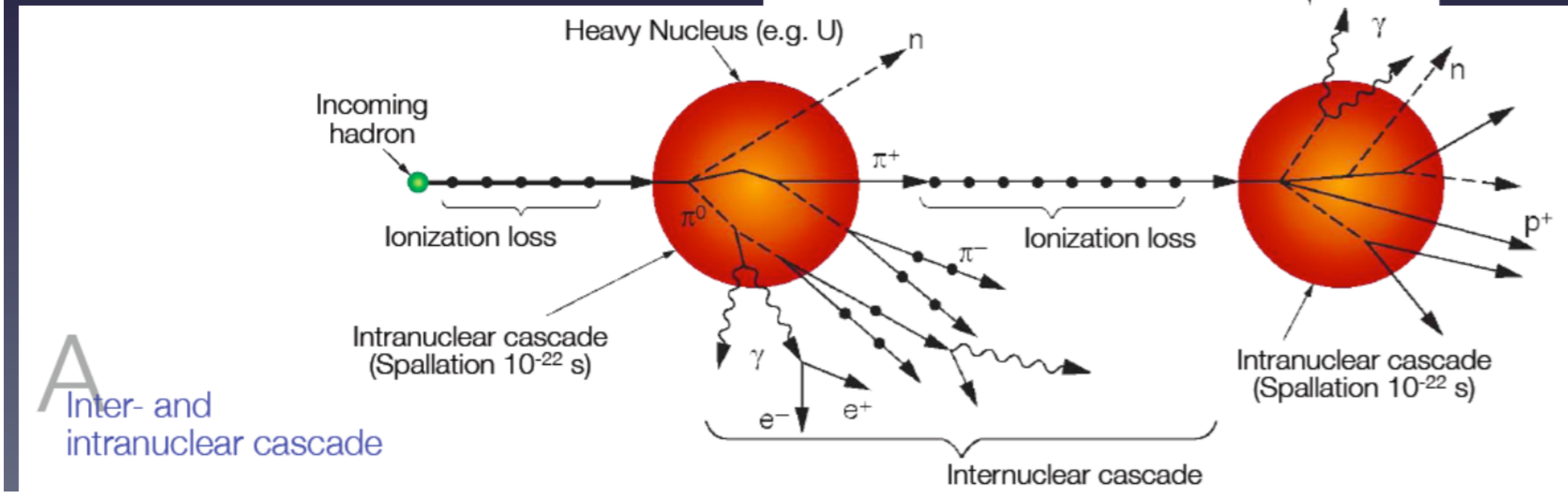
Inelastic:

$$p + \text{Nucleus} \rightarrow$$
$$\pi^+ + \pi^- + \pi^0 + \ldots + \text{Nucleus}^*$$

$$\left[\begin{array}{l} \text{Nucleus}^* \rightarrow \text{Nucleus A} + n, p, \alpha, \ldots \\ \qquad\qquad \rightarrow \text{Nucleus B} + 5p, n, \pi, \ldots \\ \qquad\qquad \rightarrow \text{Nuclear fission} \end{array}\right]$$

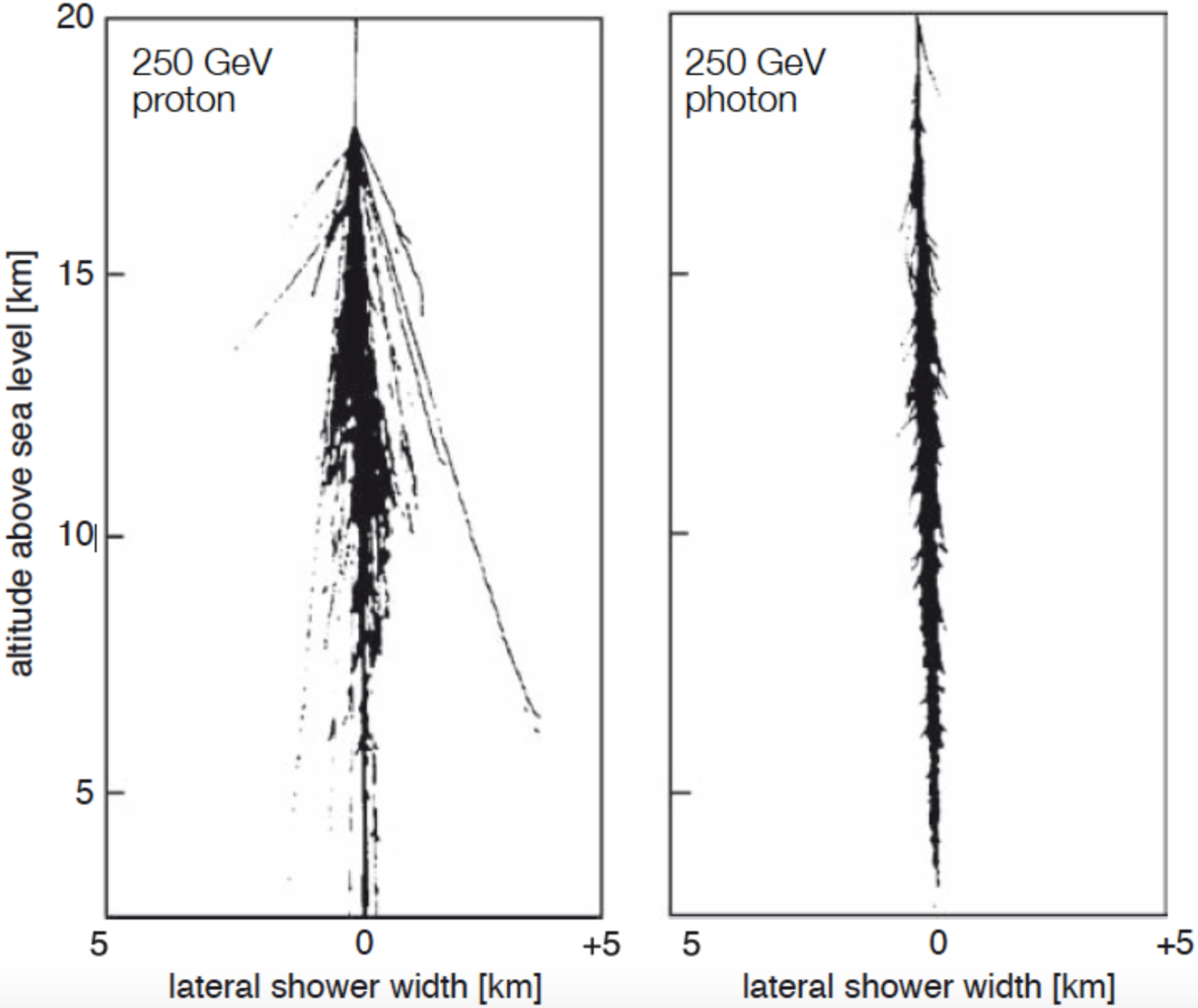






Courtesy of H. C. Schoultz Coulon

Comparison hadronic vs EM showers

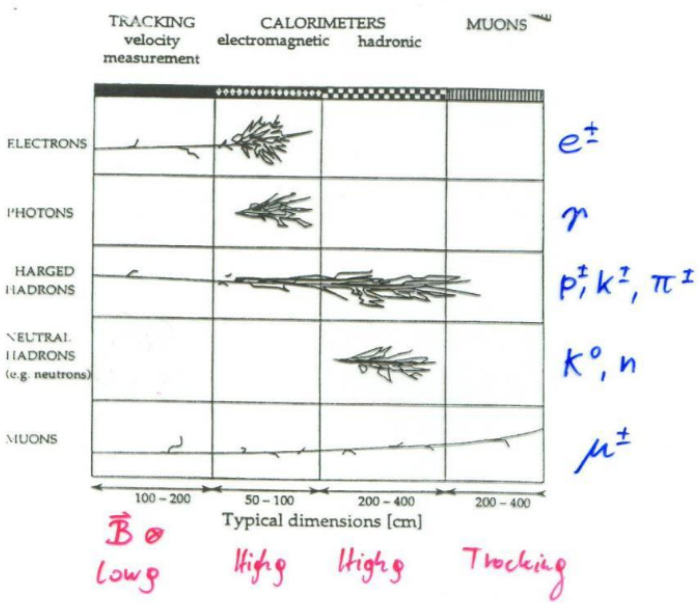


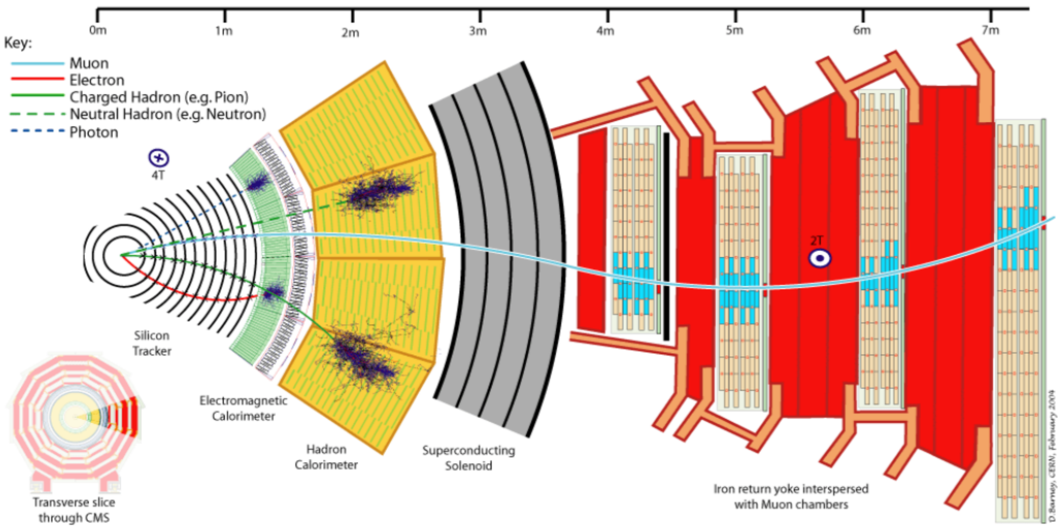
Simulated air showers

Astrofisica Nucleare e Subnucleare

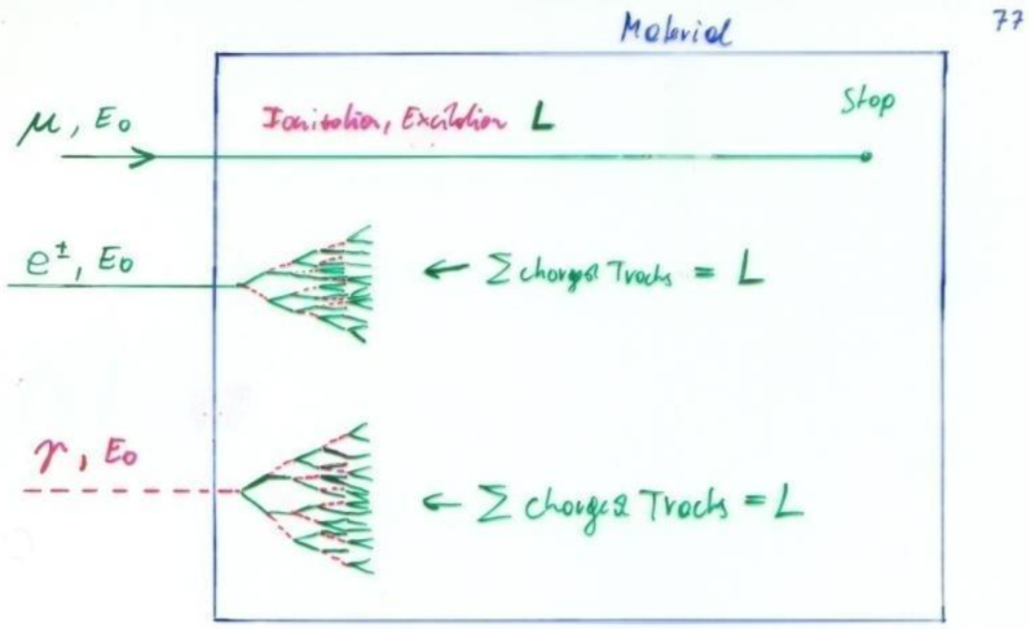
Calorimeters

Calorimetry





Calorimetry: Energy Measurement by total Absorption of Particles



The $e^\pm$ in the Calorimeter ionize and excite the material

Ionization: e^-, I^+ pairs in the Material

Excitation: Photons in the Material

Measuring the total Number of e^-, I^+ pairs or the total Number of Photons gives the particle Energy.

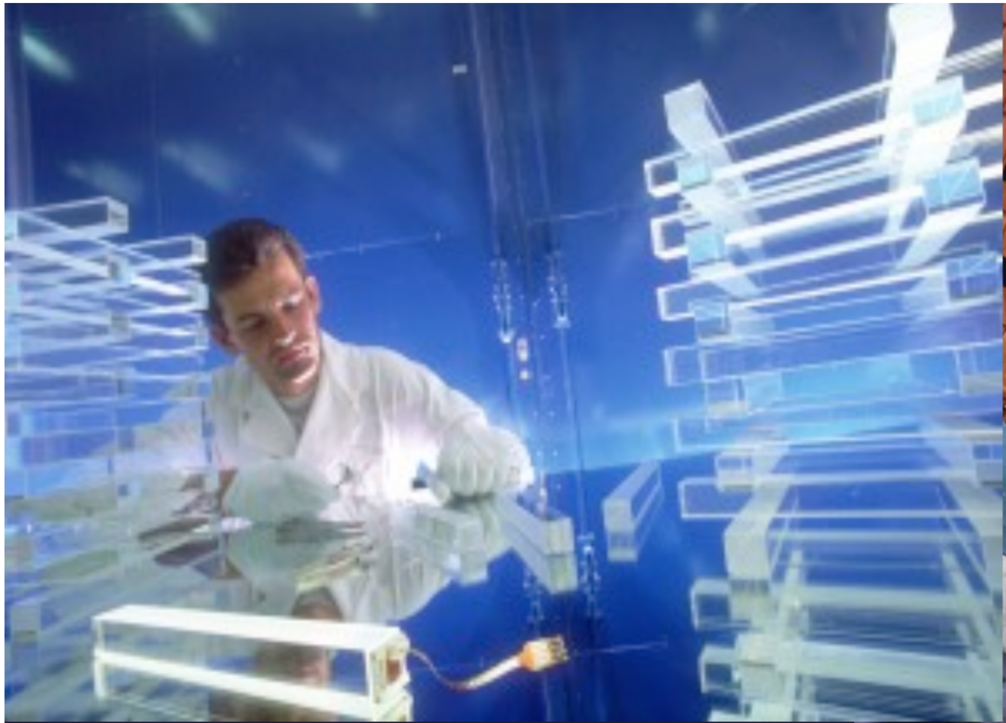
If N is the total Number of e^+, I^+ pairs or photons, or $N = c_1 E_0$:

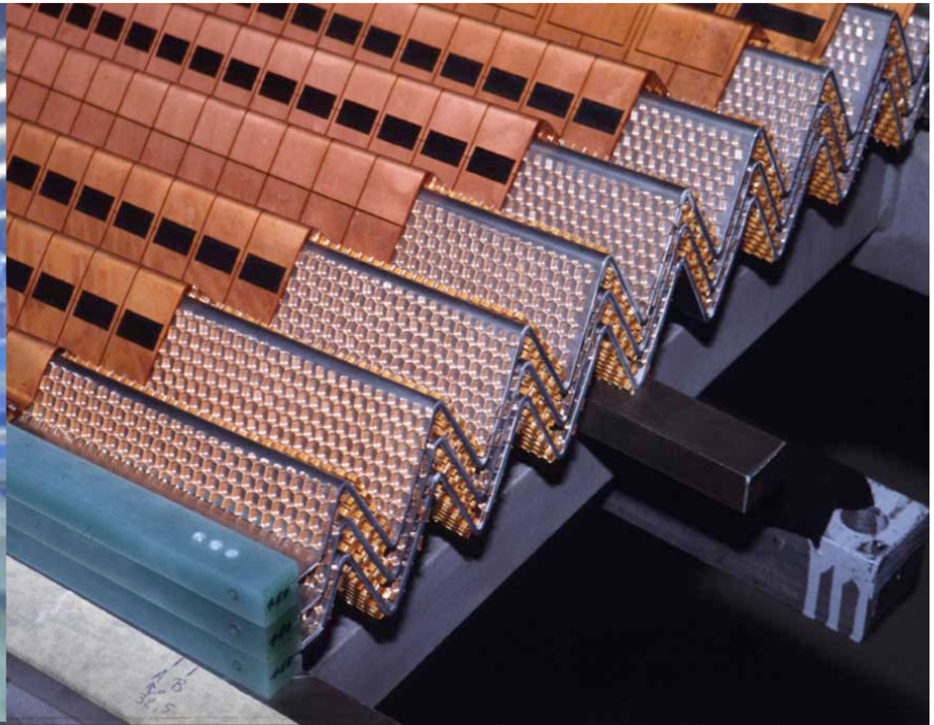
$\Delta N = \sqrt{N}$ (Poisson Statistics)

$$\frac{\Delta E}{E} = \frac{\Delta N}{N} = \frac{1}{\sqrt{N}} = \frac{a}{\sqrt{E}} \rightarrow \text{Resolution}$$

Only Electrons and High Energy Photons show EM cascades at current GeV-TeV level Energies.

Strongly interacting particles like Pions, Kaons, produce hadonic showers in a similar fashion to the EM cascade
→Hadronic calorimetry





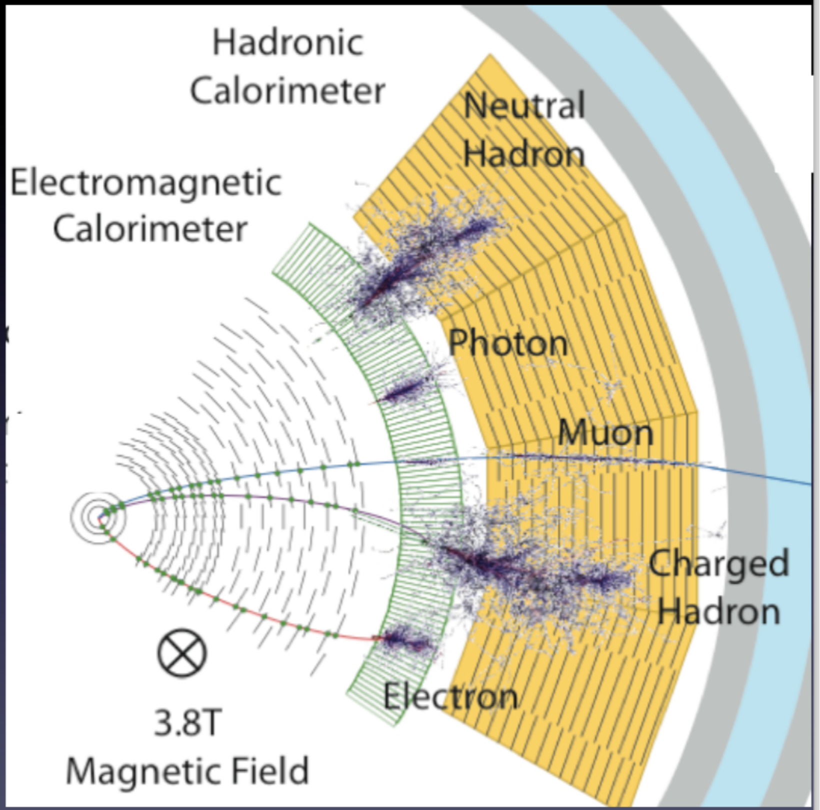
Detectors for Particle Physics

Calorimetry

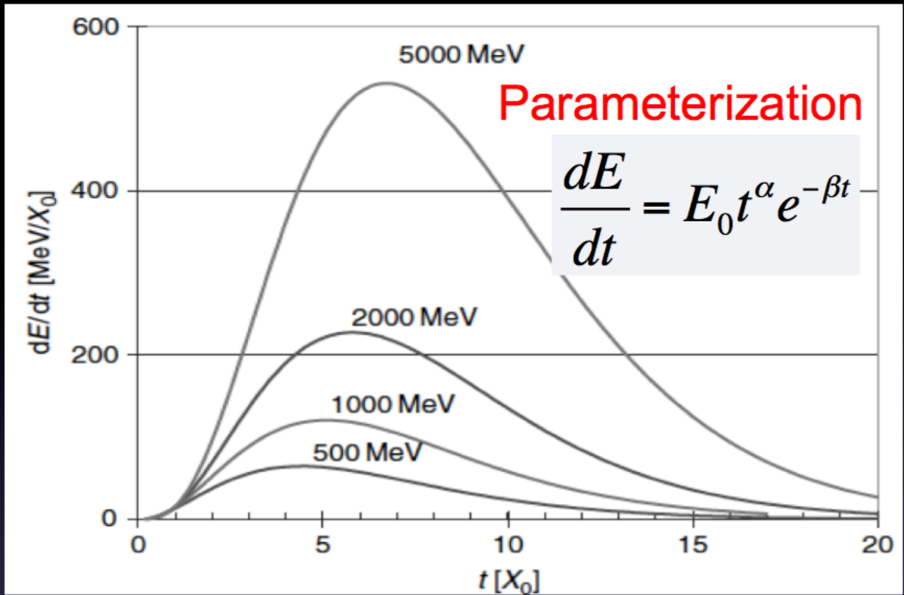
D. Bortoletto

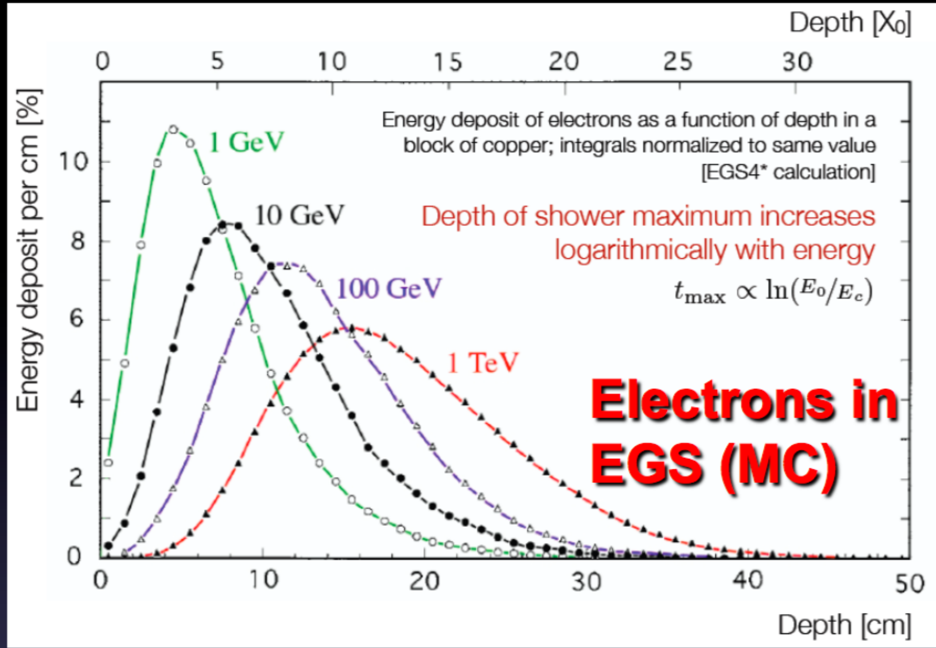
What is a calorimeter ?

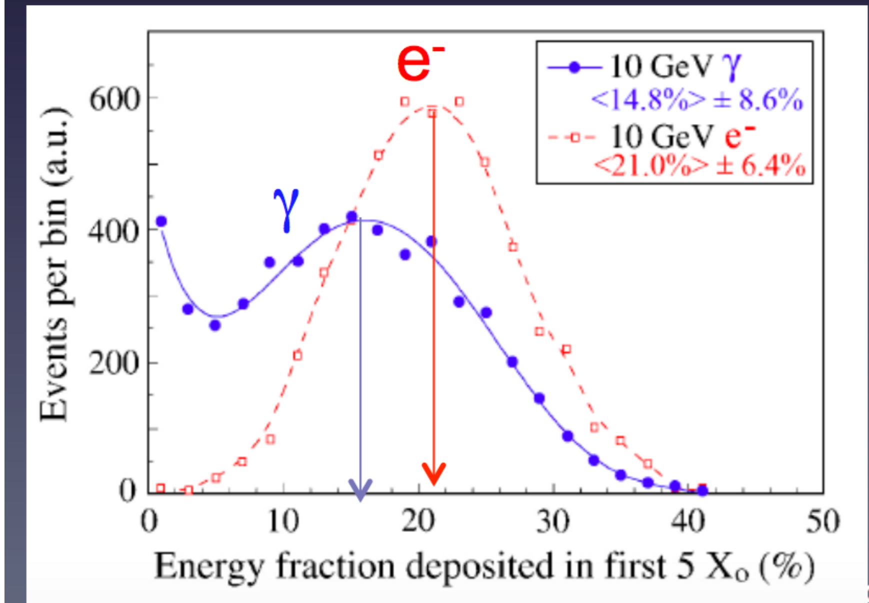
- In nuclear and particle physics calorimetry refers to the detection of particles through total absorption in a block of matter
  - The measurement process is destructive for almost all particle
  - The exception are muons (and neutrinos) → identify muons easily since they penetrate a substantial amount of matter
- In the absorption, almost all particle's energy is eventually converted to heat → calorimeter
- Calorimeters are essential to measure neutral particles



Longitudinal shower distribution







- Differences between electrons and photons generated showers
- Some photons penetrating (almost) the entire slab without interacting (peak at 0)

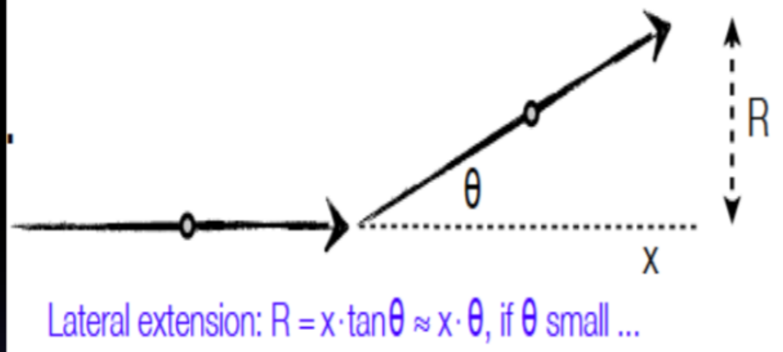
$$t_{max} = \ln\left(\frac{E_0}{E_c}\right) + C_{e\gamma}$$

$C_{e\gamma}$=-0.5 for photons
$C_{e\gamma}$=-1 for electrons

Lateral development of EM shower

- Opening angle:
  - bremsstrahlung and pair production

$$\langle \theta^2 \rangle \approx \left(\frac{m_e c^2}{E_e} \right)^2 = \frac{1}{\gamma^2}$$



  - multiple coulomb scattering [**Molière** theory]

$$\langle \theta \rangle = \frac{E_s}{E_e} \sqrt{\frac{x}{X_0}} \quad \text{where} \quad E_s = \sqrt{\frac{4\pi}{\alpha}} \left(m_e c^2 \right) = 21.2 MeV$$

- Main contribution from low energy e^- as $<\theta> \sim 1/E_e$, i.e. for e^- with $E < E_c$

- **Molière** Radius

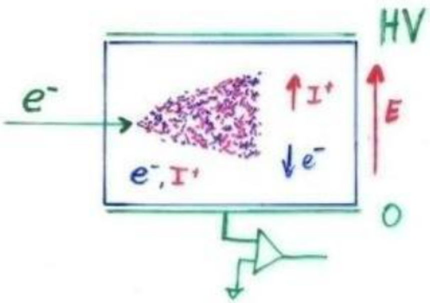
$$R_M = \frac{E_s}{E_c} X_0 \approx \frac{21.2 MeV}{E_c} X_0$$

- Assuming the approximate range of electrons to be X_0 yields $<\theta> \approx 21.2$ MeV/E_e ➝ lateral extension: $R = <\theta> X_0$

Calorimetry: Energy Measurement by total Absorption of Particles

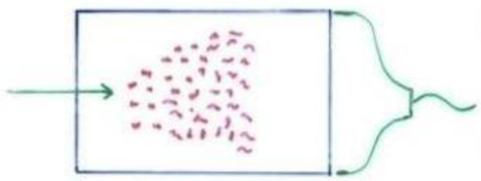
The measurement is destructive. The particle can not be subject to further study.

Energy Measurement by



Collecting the produced Charge

Liquid Nobel Gases (Nobel Liquids)



Measuring the Photons produced by the collision of the $e^{\pm}$ with atom electrons of the material.

Scintillating Crystals, Plastic Scintillators

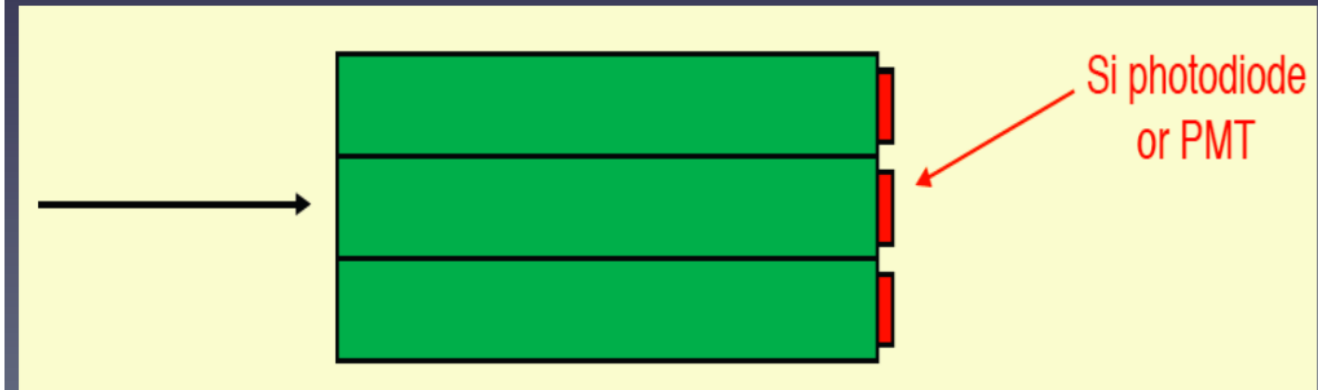
Total Amount of e^-, I^+ pairs or Photons is proportional to the total track length is proportional to the particle Energy.

EM Calorimeter configurations

- Total absorption
  - Electrons and photons stop in calorimeter
  - Scintillation proportional to energy of electron
  - Usually non-organic scintillator (BGO, $PbWO_{4,...}$) or liquid Xe
  - Advantage: Excellent energy resolution
    - see all charged particles in the shower (but for shower leakage) ➔best statistical precision
    - Uniform response ➔good linearity
  - Disadvantages:
    - cost and limited segmentation

If W is the mean energy required to produce a signal (eg an e^--ion pair in a noble liquid or a 'visible' photon in a crystal)

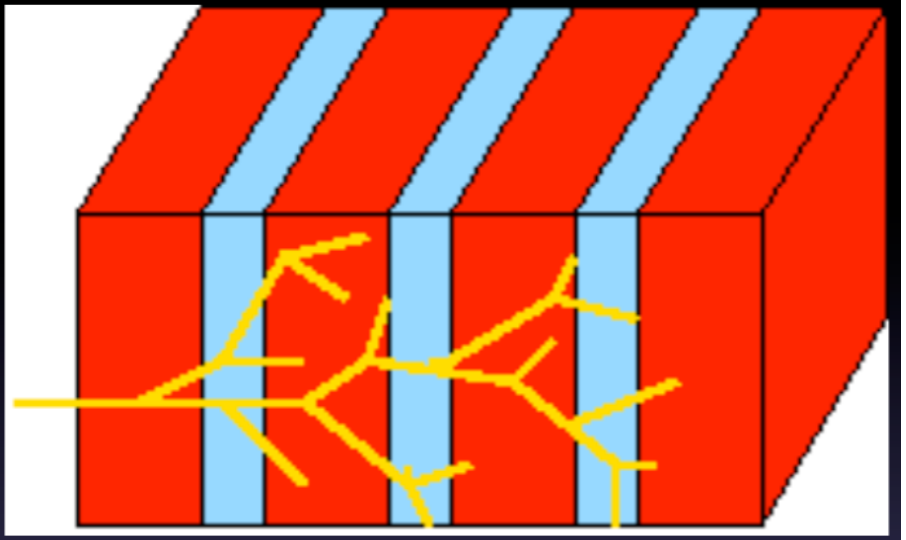
$$\frac{\sigma_E}{E} = \frac{1}{\sqrt{n}} = \frac{1}{\sqrt{E/W}}$$



- Examples:
  - B factories: small photon energies
  - CMS ECAL which was optimized for $H\rightarrow\gamma\gamma$

EM Calorimeter configurations

- Sampling Calorimeter
  - One material to induce showering (high Z)
  - Another to detect particles (typically by counting number of charged tracks)
  - Many layers sandwiched together
  - Resolution $\propto E^{-1/2}$
- Advantages
  - Depth segmentation
  - Spatial segmentation
- Disadvantages:
  - Only part of shower seen, less precise
- Examples
  - ATLAS ECAL
  - Most HCALs



- Sampling fraction

$$f_{sampling} = \frac{E_{visible}}{E_{deposited}}$$

Crystals for Homogeneous EM Calorimetry

	NaI(Tl)	CsI(Tl)	CsI	BGO	$PbWO_4$
Density (g/cm^3)	3.67	4.53	4.53	7.13	8.28
X_0 (cm)	2.59	1.85	1.85	1.12	0.89
R_M (cm)	4.5	3.8	3.8	2.4	2.2
Decay time (ns)	250	1000	10	300	5
slow component			36		15
Emission peak (nm)	410	565	305	410	440
slow component			480		
Light yield γ/MeV	4×10^4	5×10^4	4×10^4	8×10^3	1.5×10^2
Photoelectron yield (relative to NaI)	1	0.4	0.1	0.15	0.01
Rad. hardness (Gy)	1	10	10^3	1	10^5

Barbar@PEPII, 10ms interaction rate, good light yield, good S/N

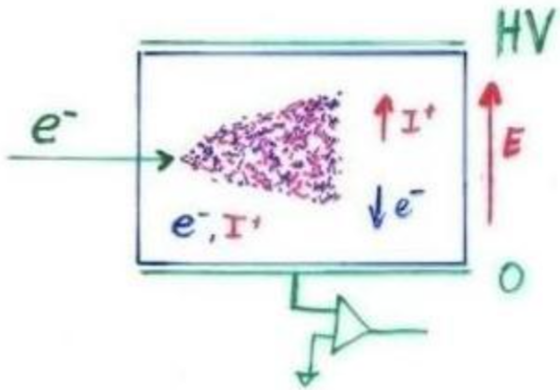
KTeV@Tevatron, High rate, Good resolution

L3@LEP, 25us bunch crossing, Low radiation dose

CMS@LHC, 25ns bunch crossing, high radiation dose

Noble Liquids for Homogeneous EM Calorimetry

	Ar	Kr	Xe
Z	18	36	58
A	40	84	131
X_0 (cm)	14	4.7	2.8
R_M (cm)	7.2	4.7	4.2
Density (g/cm^3)	1.4	2.5	3.0
Ionization energy (eV/pair)	23.3	20.5	15.6
Critical energy ϵ (MeV)	41.7	21.5	14.5
Drift velocity at saturation (mm/μs)	10	5	3



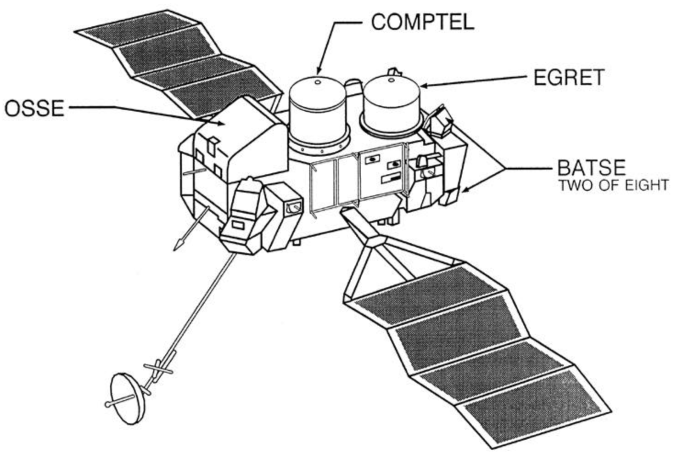
When a charge particle traverses these materials, about half the lost energy is converted into ionization and half into scintillation.

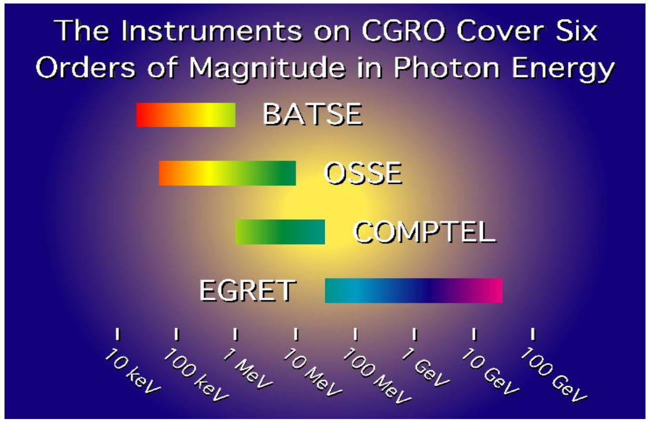
The best energy resolution would obviously be obtained by collecting both the charge and light signal. This is however rarely done because of the technical difficulties to extract light and charge in the same instrument.

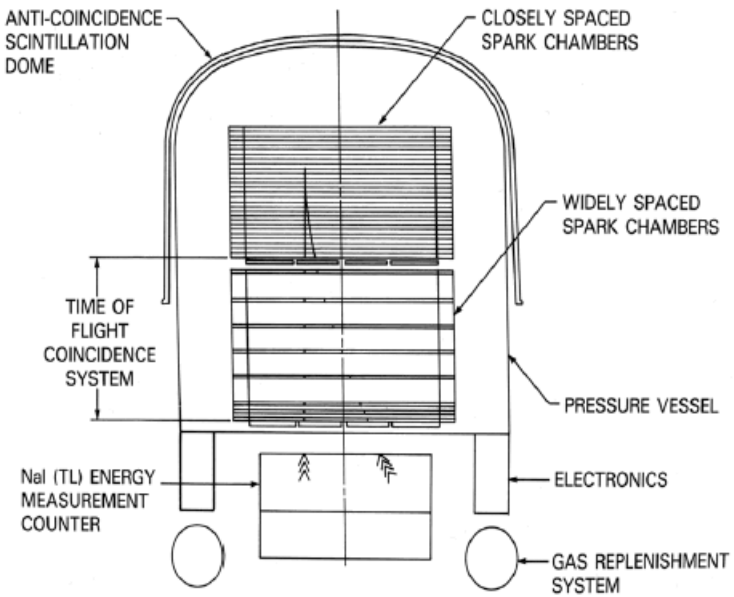
Krypton is preferred in homogeneous detectors due to small radiation length and therefore compact detectors. Liquid Argon is frequently used due to low cost and high purity in sampling calorimeters (see later).

GeV Gamma-ray Astrophysics
The EGRET legacy

EGRET



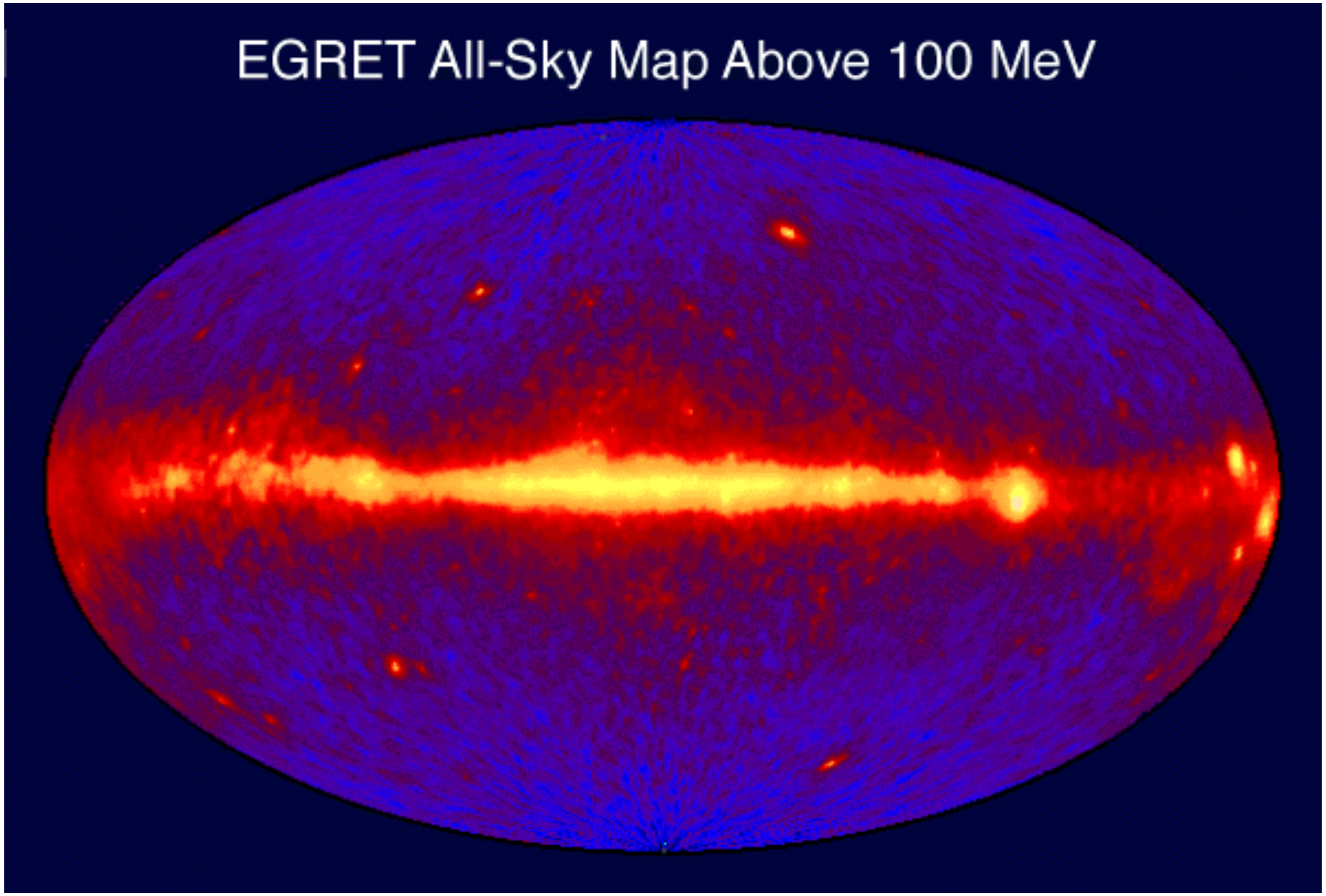




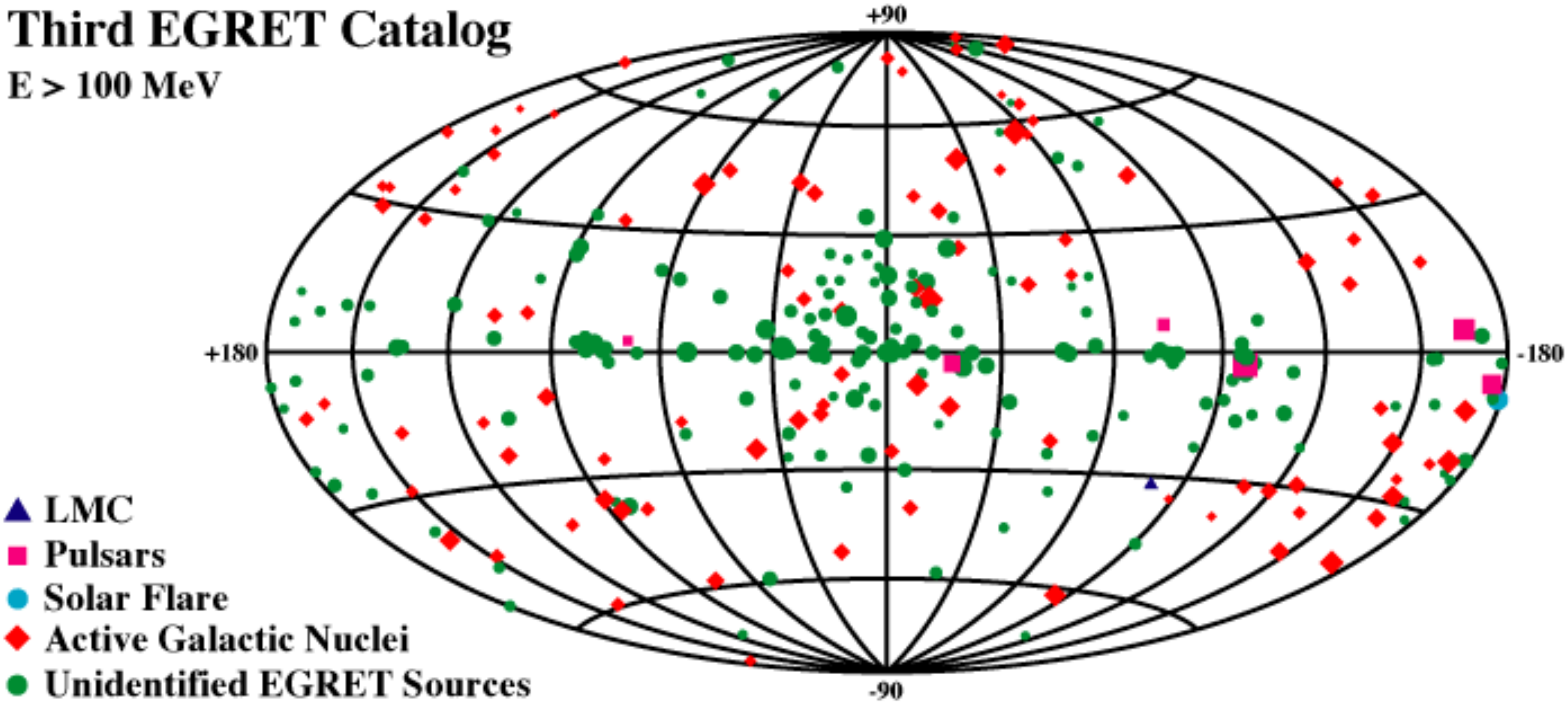
EGRET

- 1991-2000
- 30 MeV - 30 GeV
- AGN, GRB, Unidentified Sources, Diffuse Bkg

The HE sky from EGRET

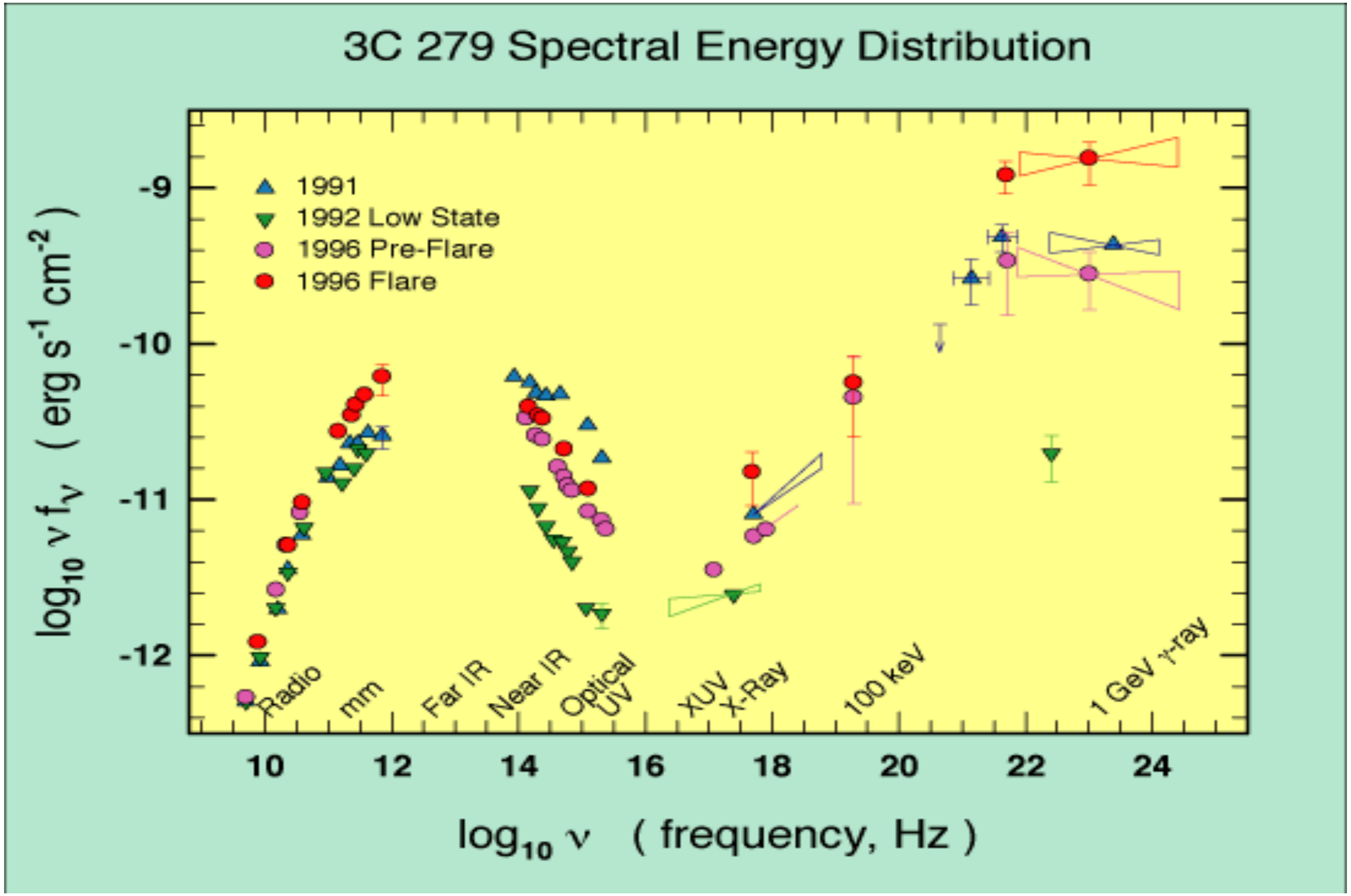


EGRET Gamma-ray Sources



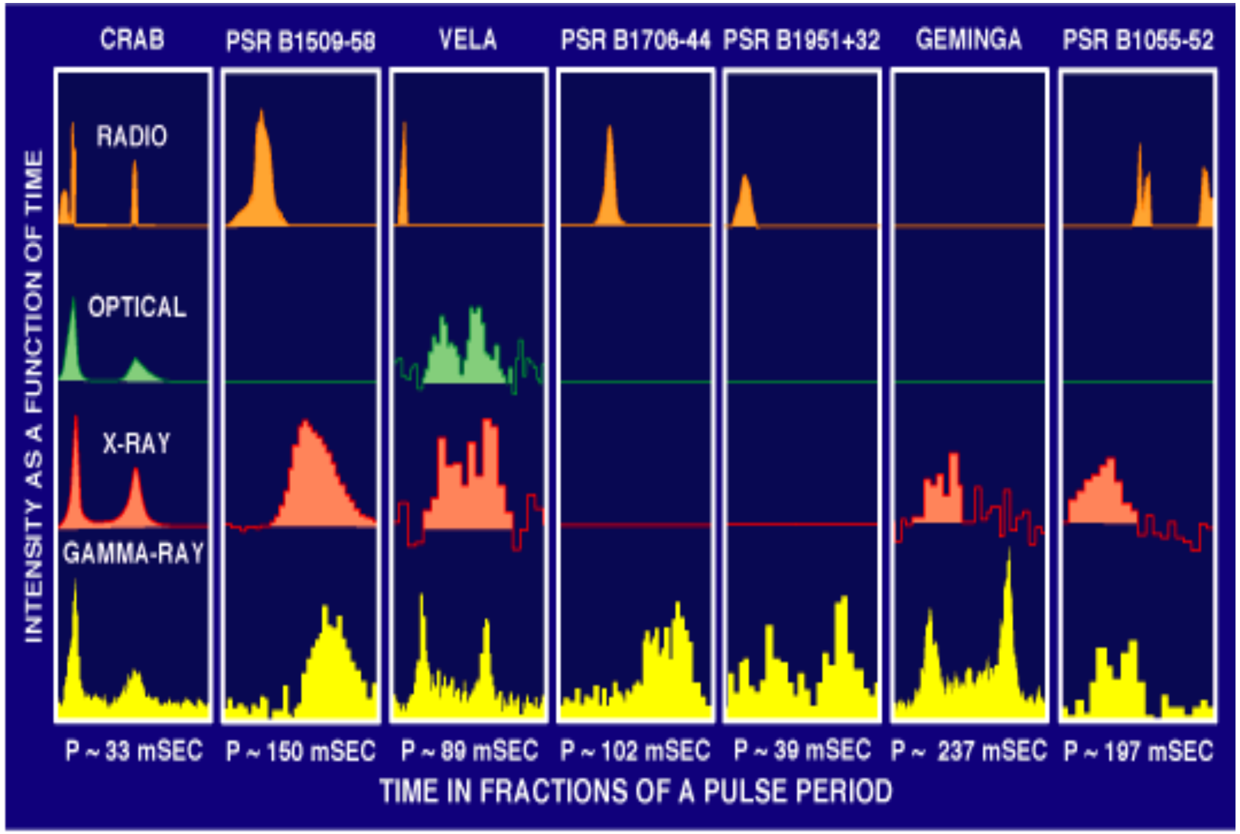
Challenge # 1

- Need simultaneous multiwavelength data to study variability and emission processes



Challenge # 2

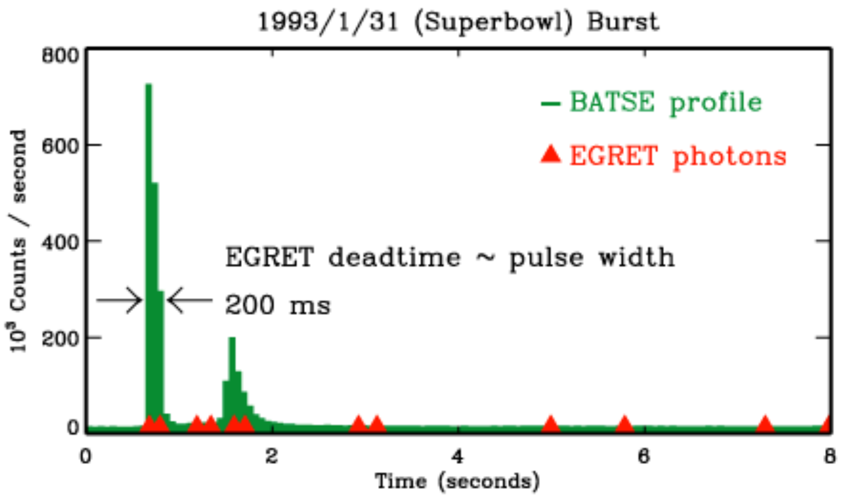
- Need more exposure and optimal timing (and radio monitoring) to discover more gamma-ray PSRs.



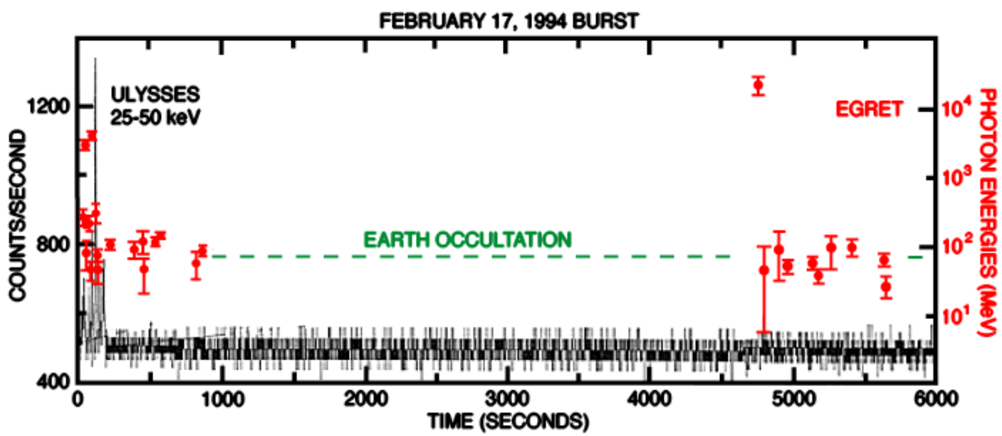
Challenge # 3

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

Prompt Emission (GRB 930131)

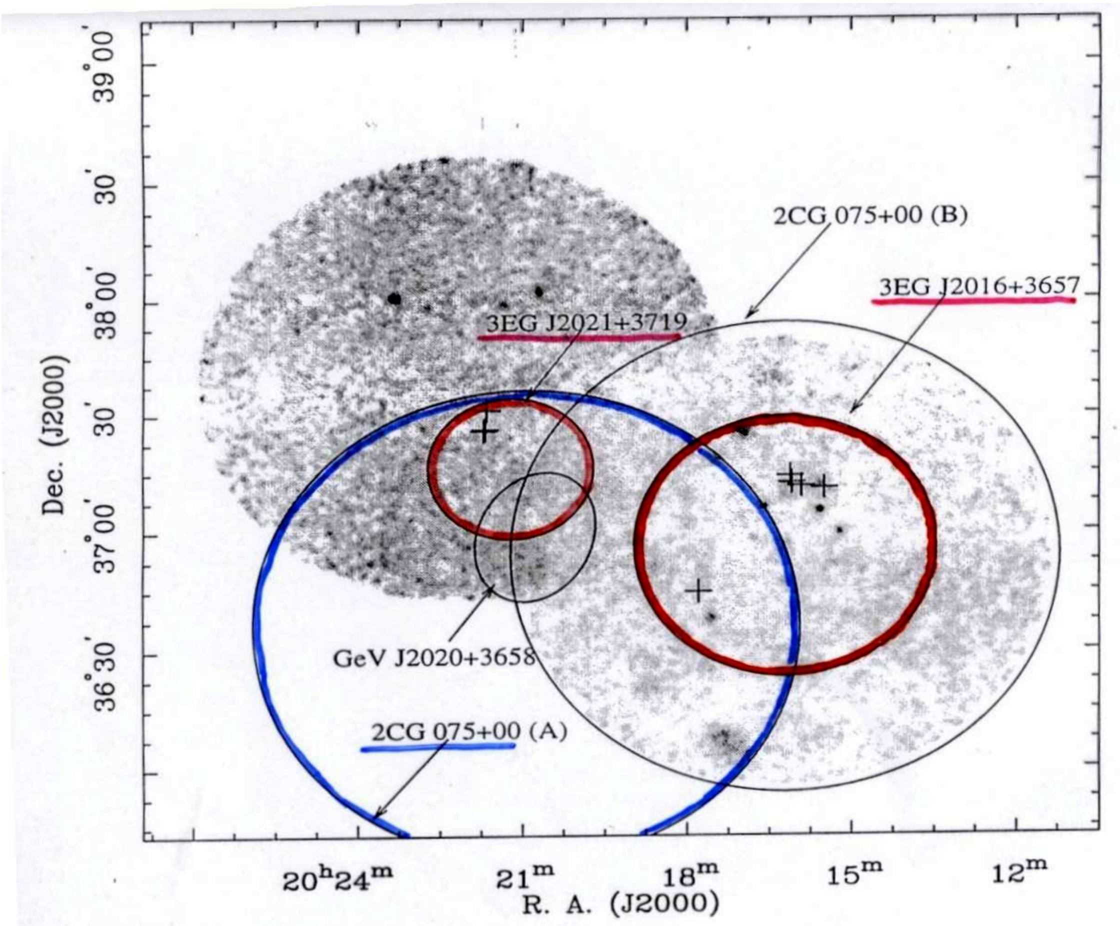


Delayed Emission (GRB 940217)



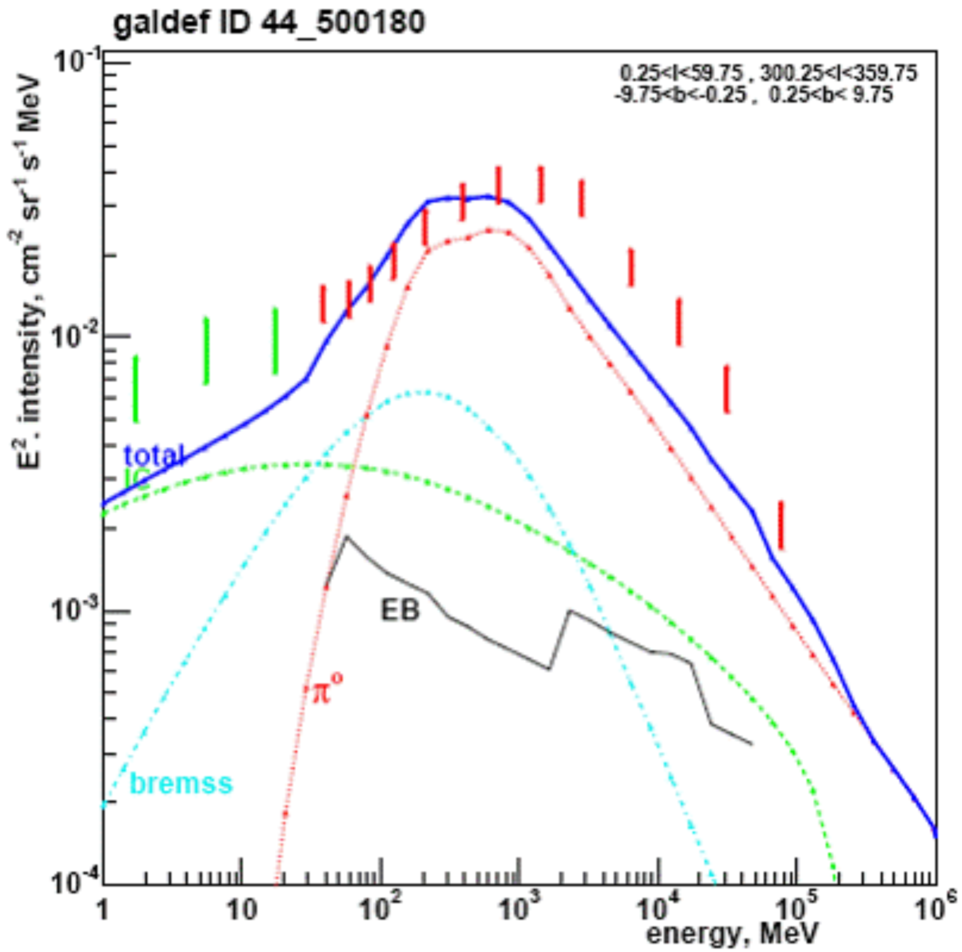
Challenge # 4

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

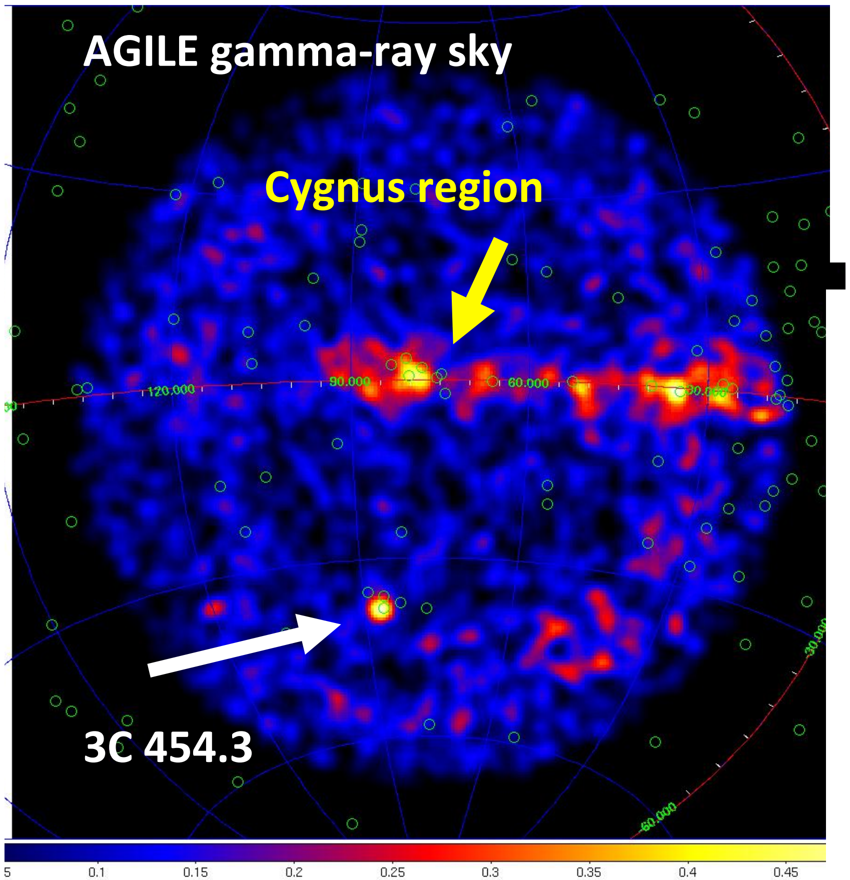


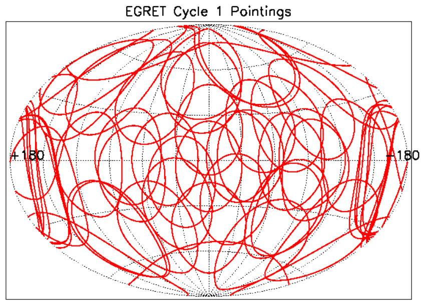
Challenge # 5

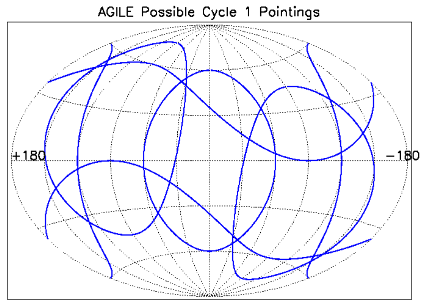
- Need improvements in Spectral Resolution fo check for DM signals

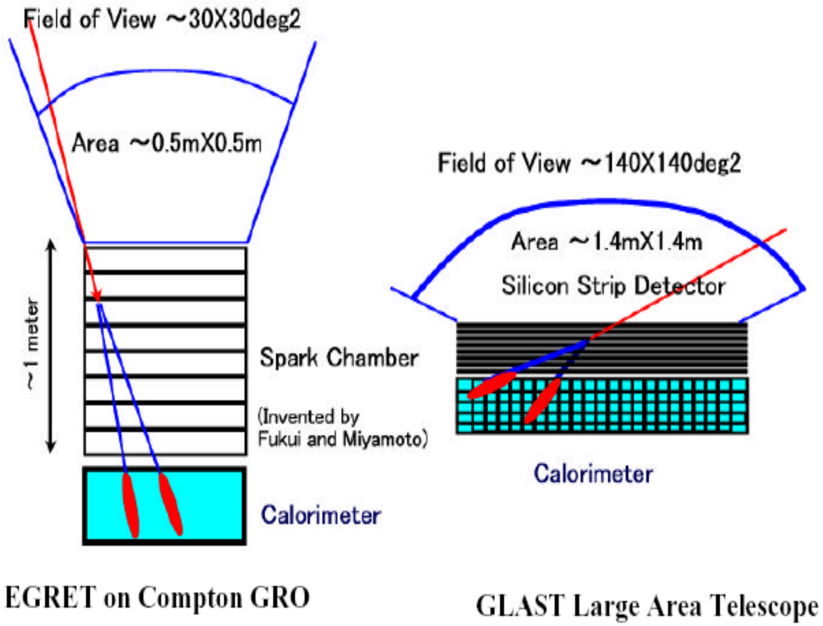


Technology impact - FoV

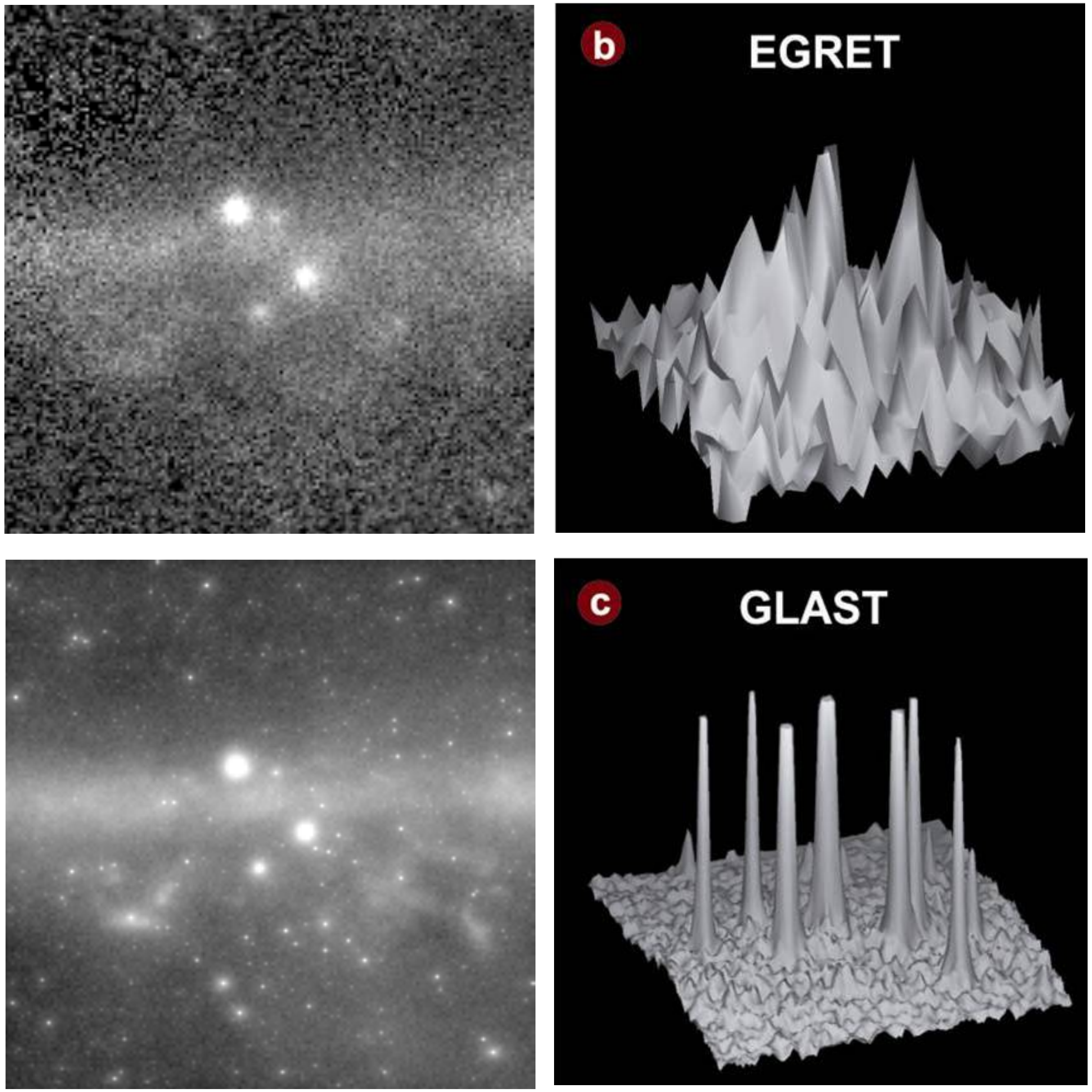








Technology impact -- PSF



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***

Multiple Scattering

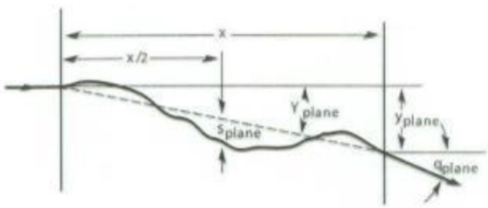
Multiple Scattering

Statistical (quite complex) analysis of multiple collisions gives:

Probability that a particle is defected by an angle θ after travelling a distance x in the material is given by a Gaussian distribution with sigma of:

$$\Theta_0 = \frac{0.0136}{\beta c p[\mathrm{GeV/c}]} Z_1 \sqrt{\frac{x}{X_0}}$$

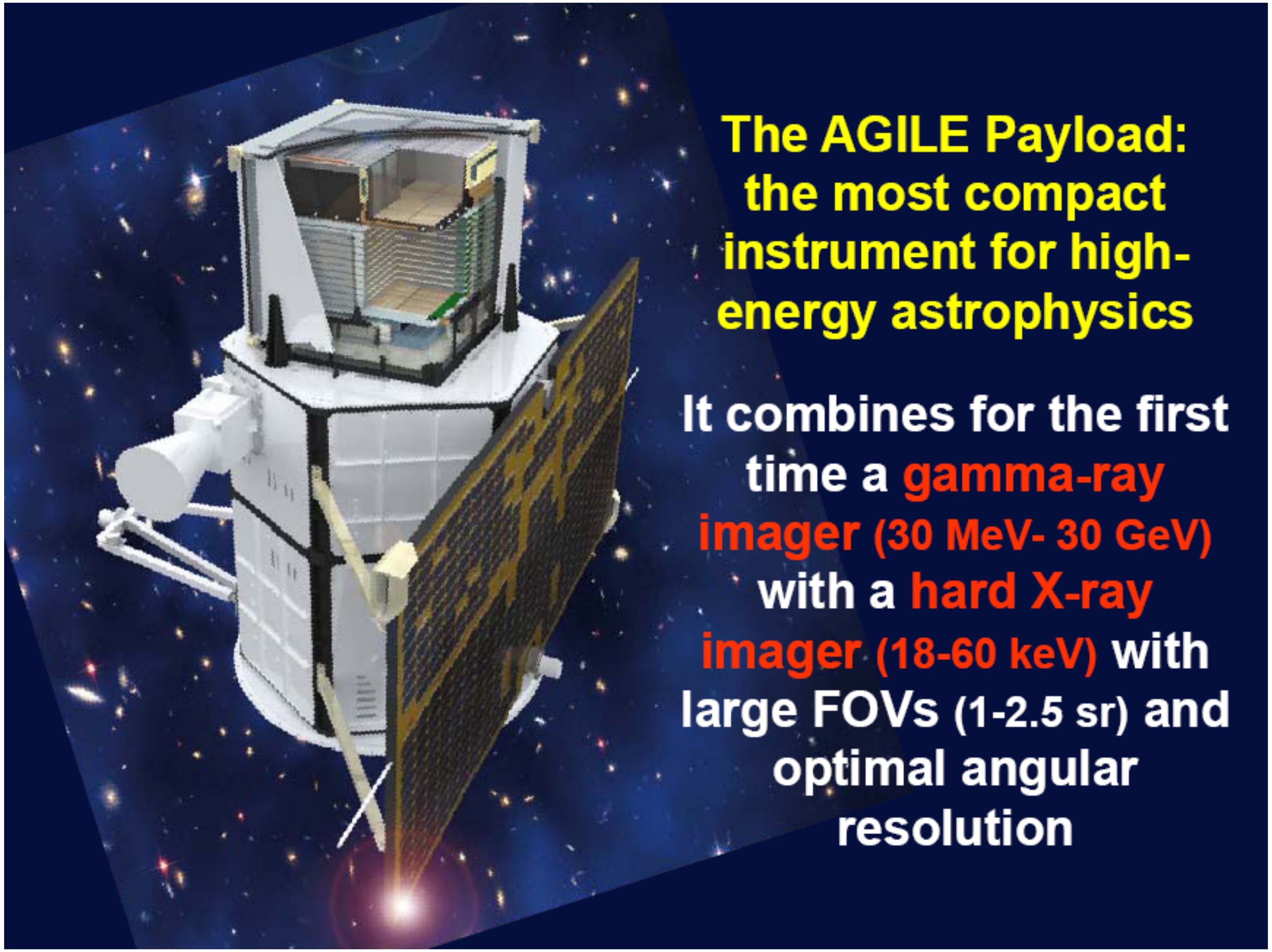
X_0 ... Radiation length of the material
Z_1 ... Charge of the particle
p ... Momentum of the particle



W. Riegler/CERN

AGILE

AGILE instrument



AGILE

agenzia spaziale italiana

INAF

INFN

CARLO GAVAZZI

Carlo Gavazzi Space SpA

OERLIKON CONTRAVES

ALCATEL ALENIA SPACE

An Alcatel/Finmeccanica company

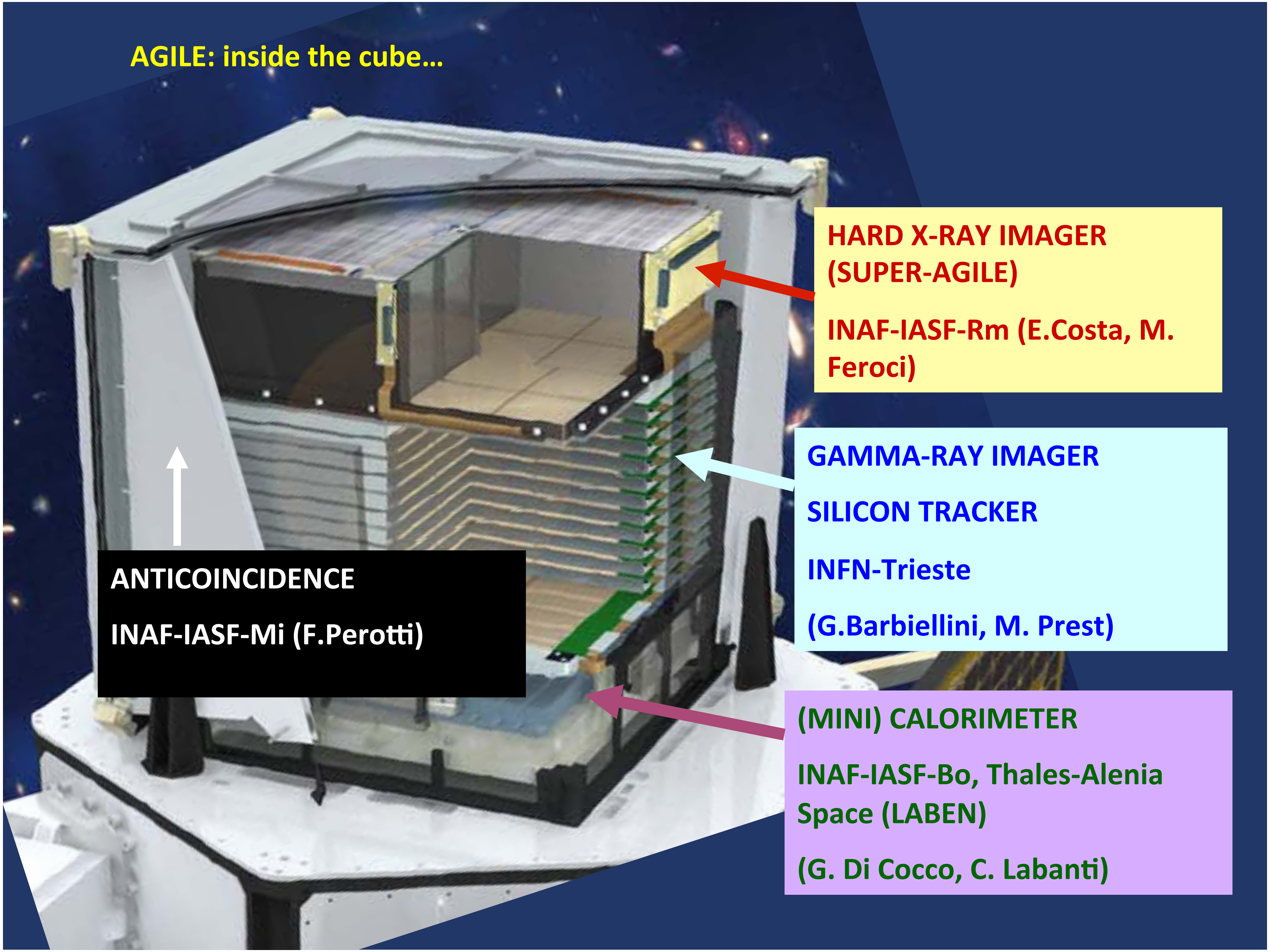
telespazio

A Finmeccanica/Alcatel company

Galileo Avionica

MIPOT

ENEA


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

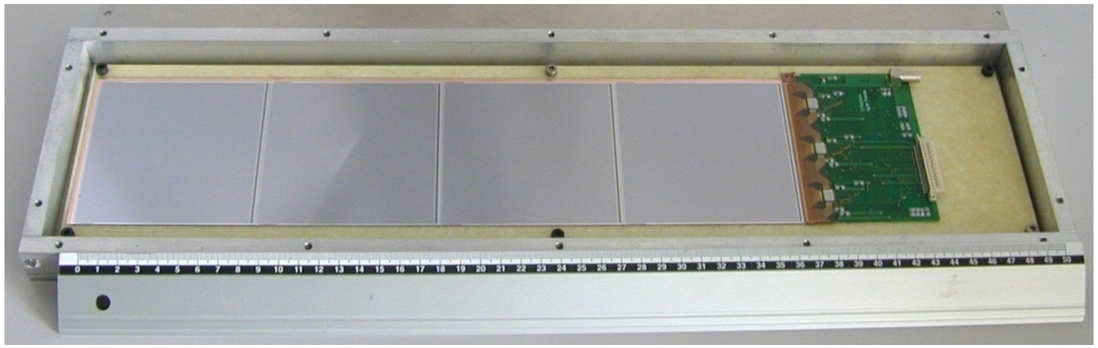
The AGILE silicon detectors

Detector specifications:

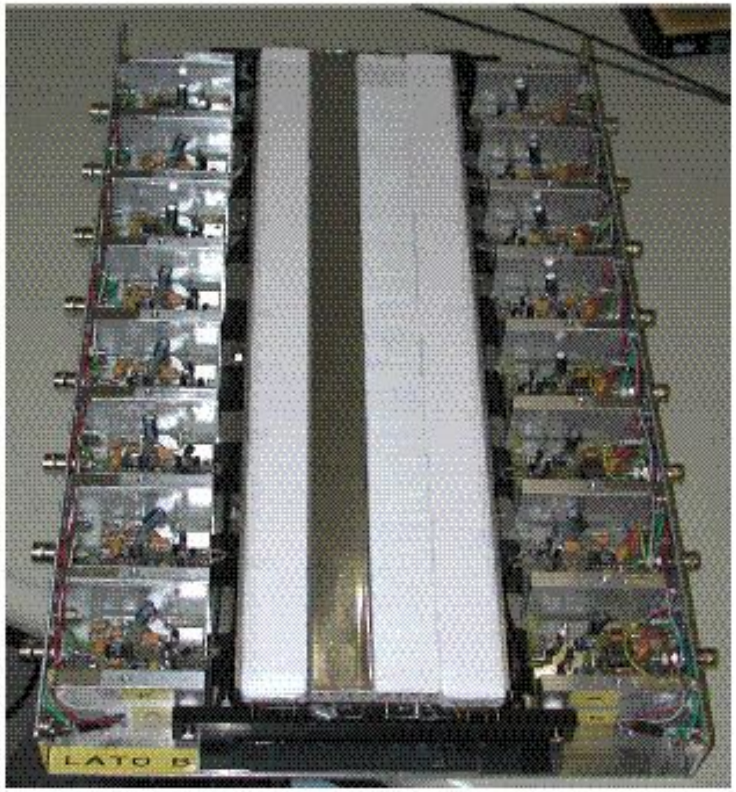
- dimension: 9.5x9.5 cm^2
- thickness: 410 μm (6 inch technology)
- readout pitch: 242 μm;
  physical pitch: 121 μm (one floating strip)
- number of strips/ladder: 384
- Single side and AC-coupled
- leakage current: 2 nA/cm^2 at Vbias=2.5*V_{FD} =200 V
- polarization resistor: 40 MΩ
- coupling capacitor: 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 $\rightarrow$ 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: $\pm$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 CsI Mini-Calorimeter



MINI-CALORIMETER

DETECTOR

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

- bar dimension: $40 \times 2.3 \times 1.5$ cm^3
- total radiation length: $1.5X_0$ (in axis)

FRONTEND ELECTRONICS

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

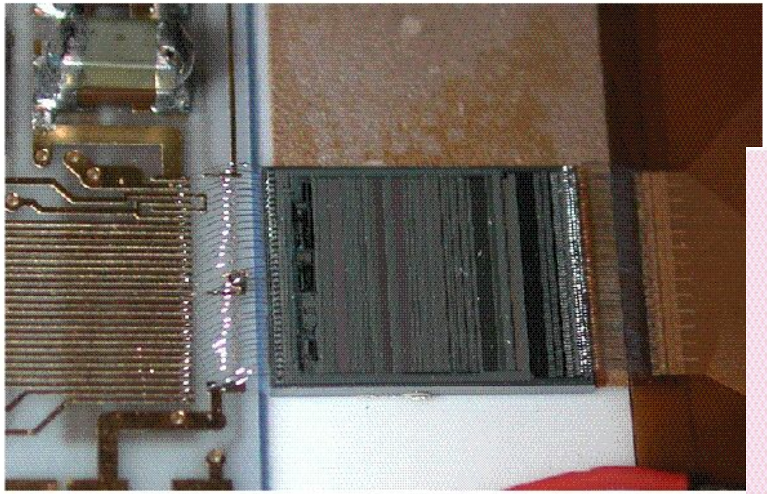
GOAL

- 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

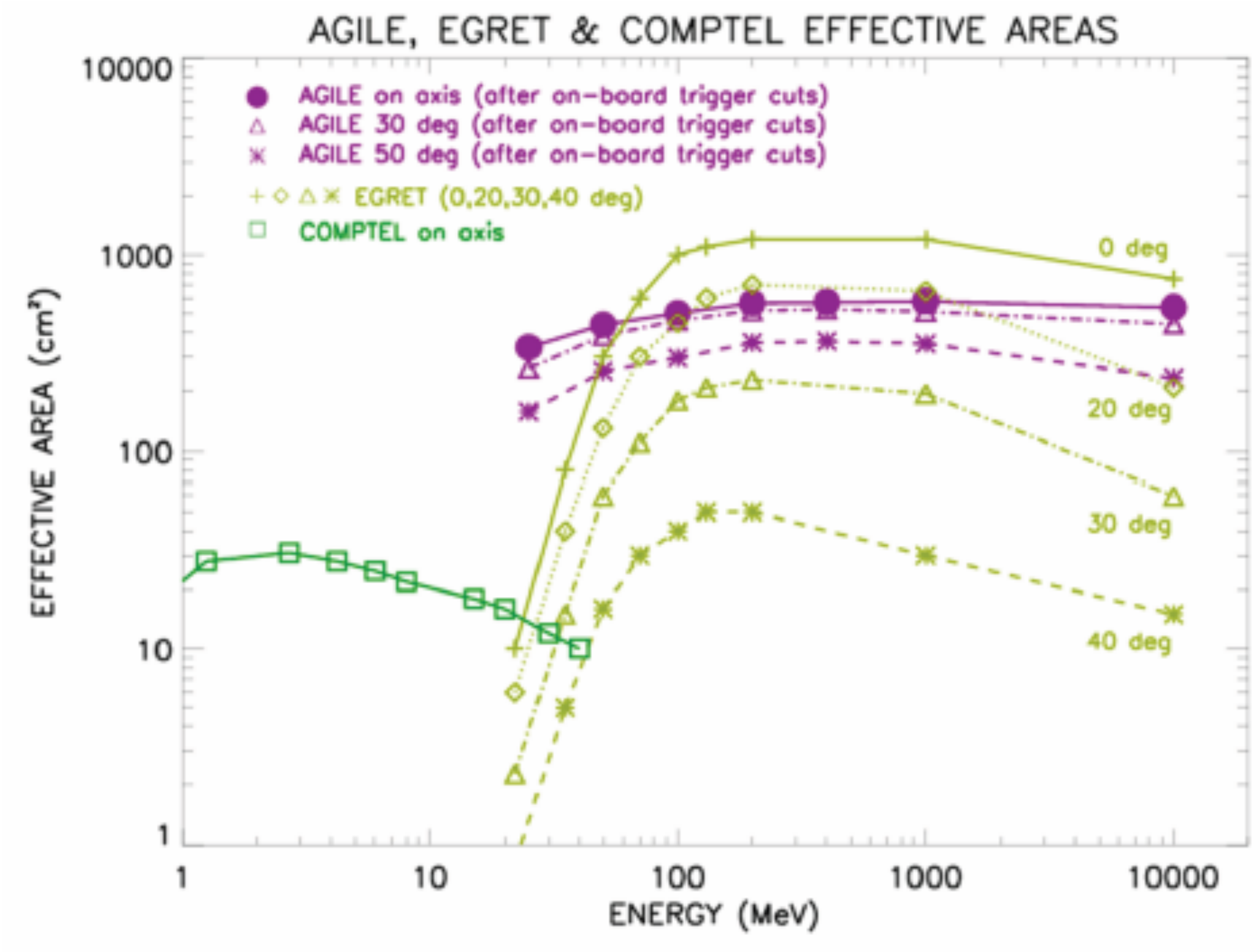
GOAL

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

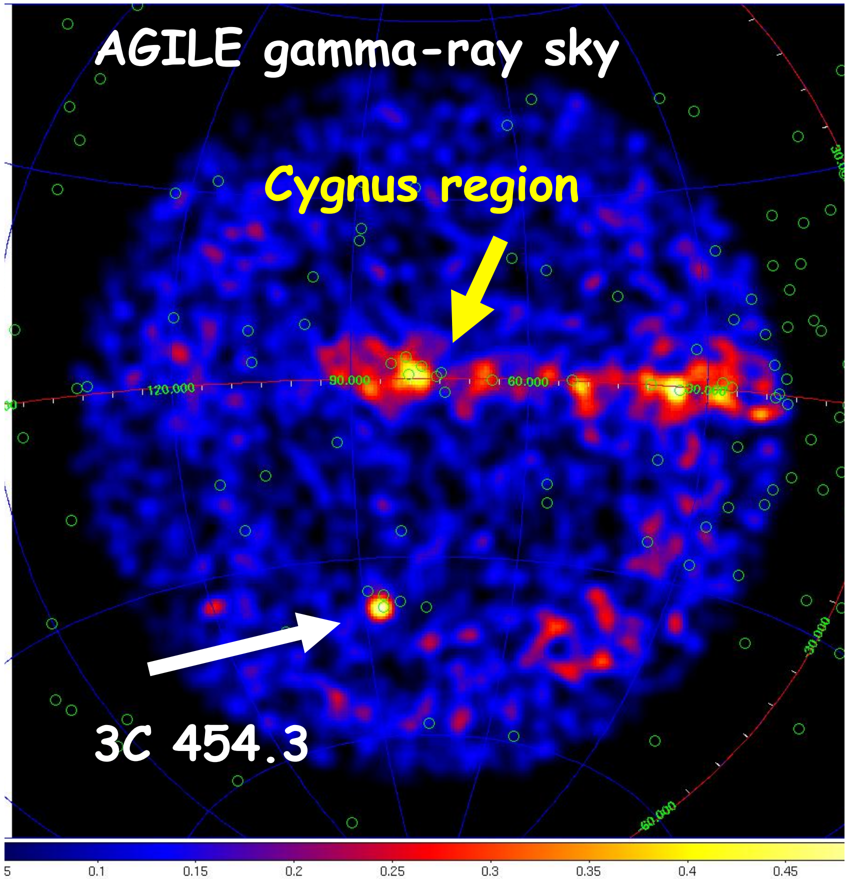
SCIENTIFIC FEATURES

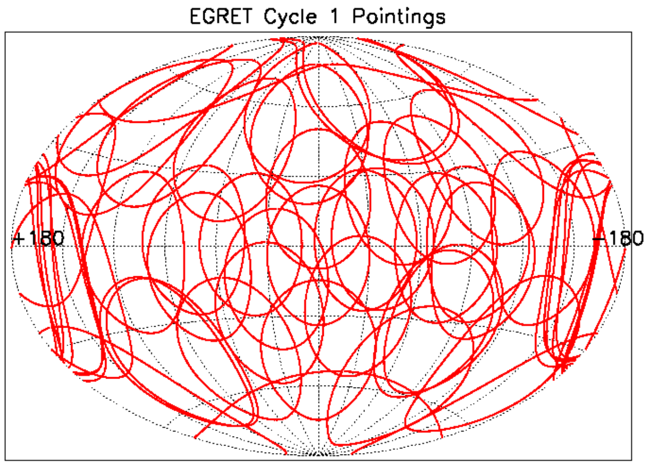
- imaging: 1'-3' at ~20mCrab
- timing resolution: $5\mu s$
- energy resolution: 4keV (FWHM)
- flux sensitivity: ~5mCrab (15keV)

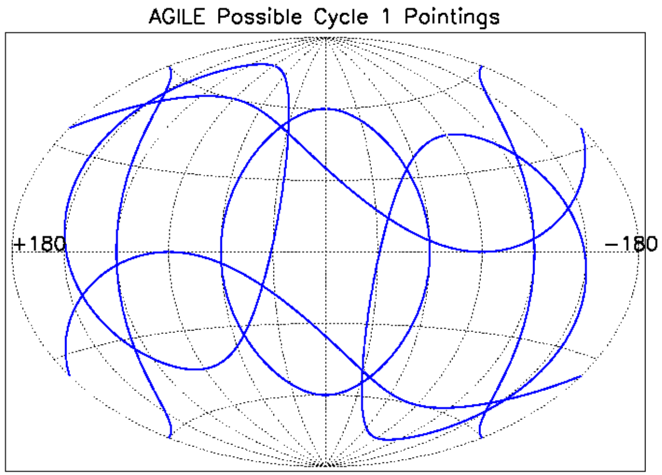
Performance



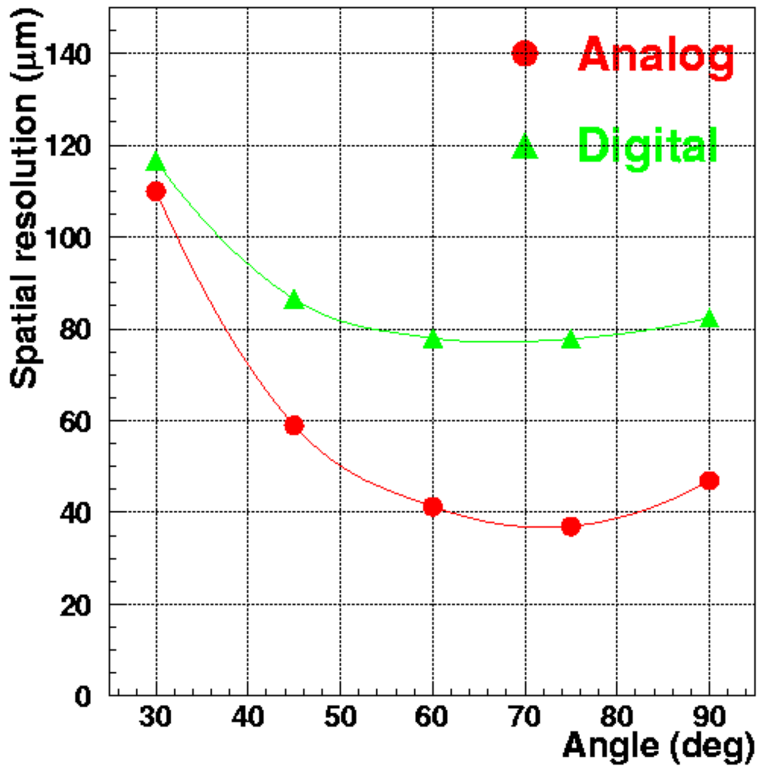
Si Self Trigger and FoV

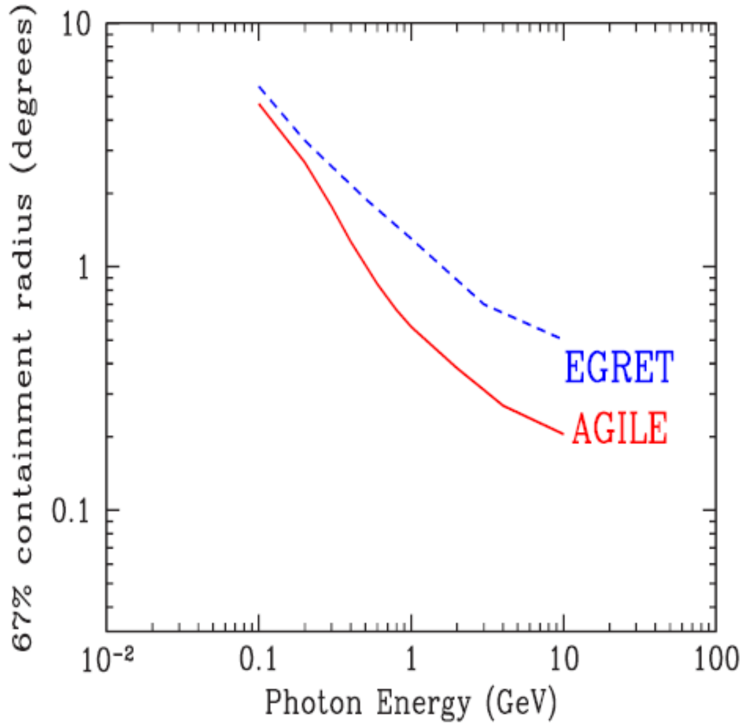






Analog readout and PSF

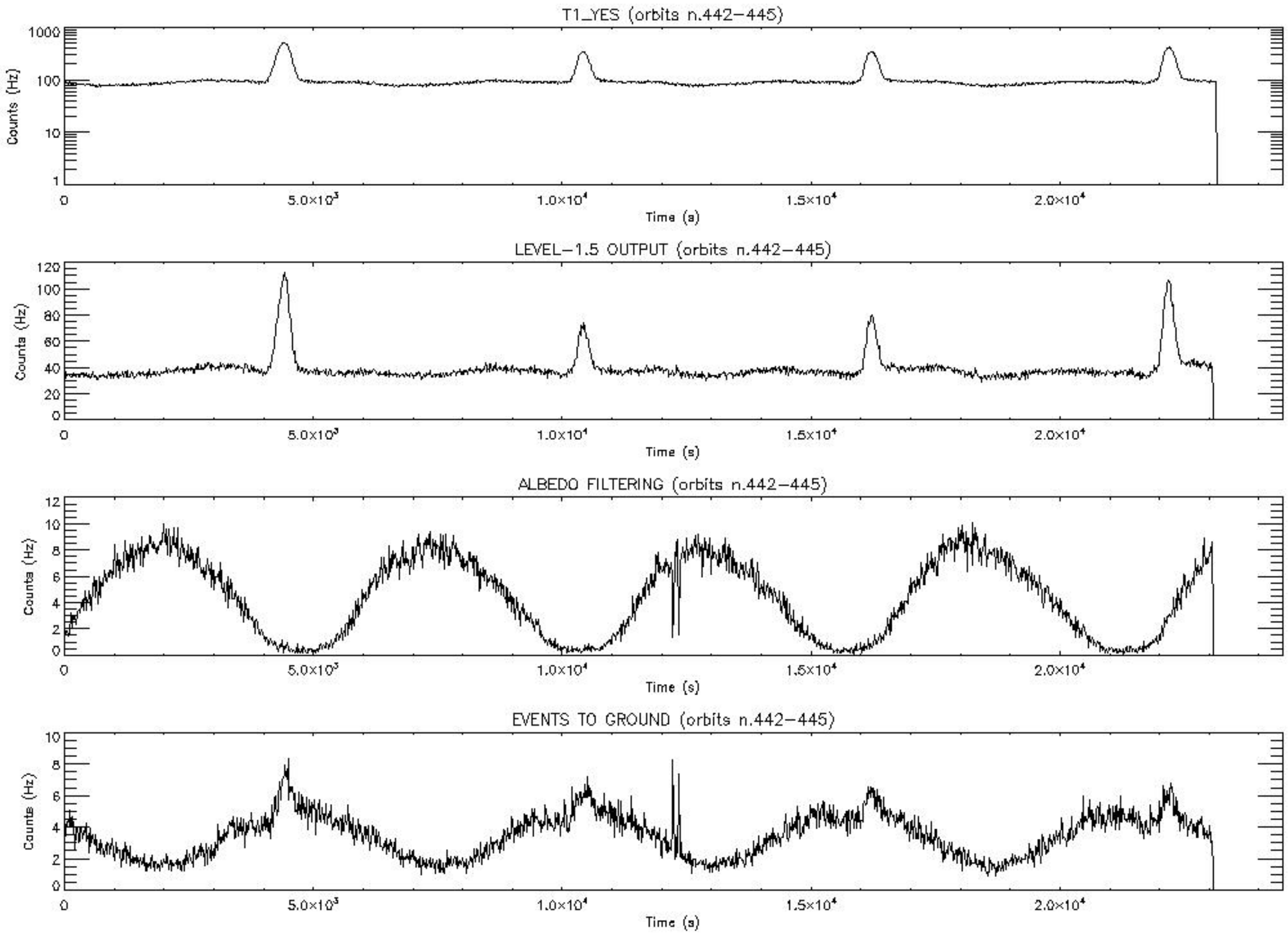




The AGILE launch

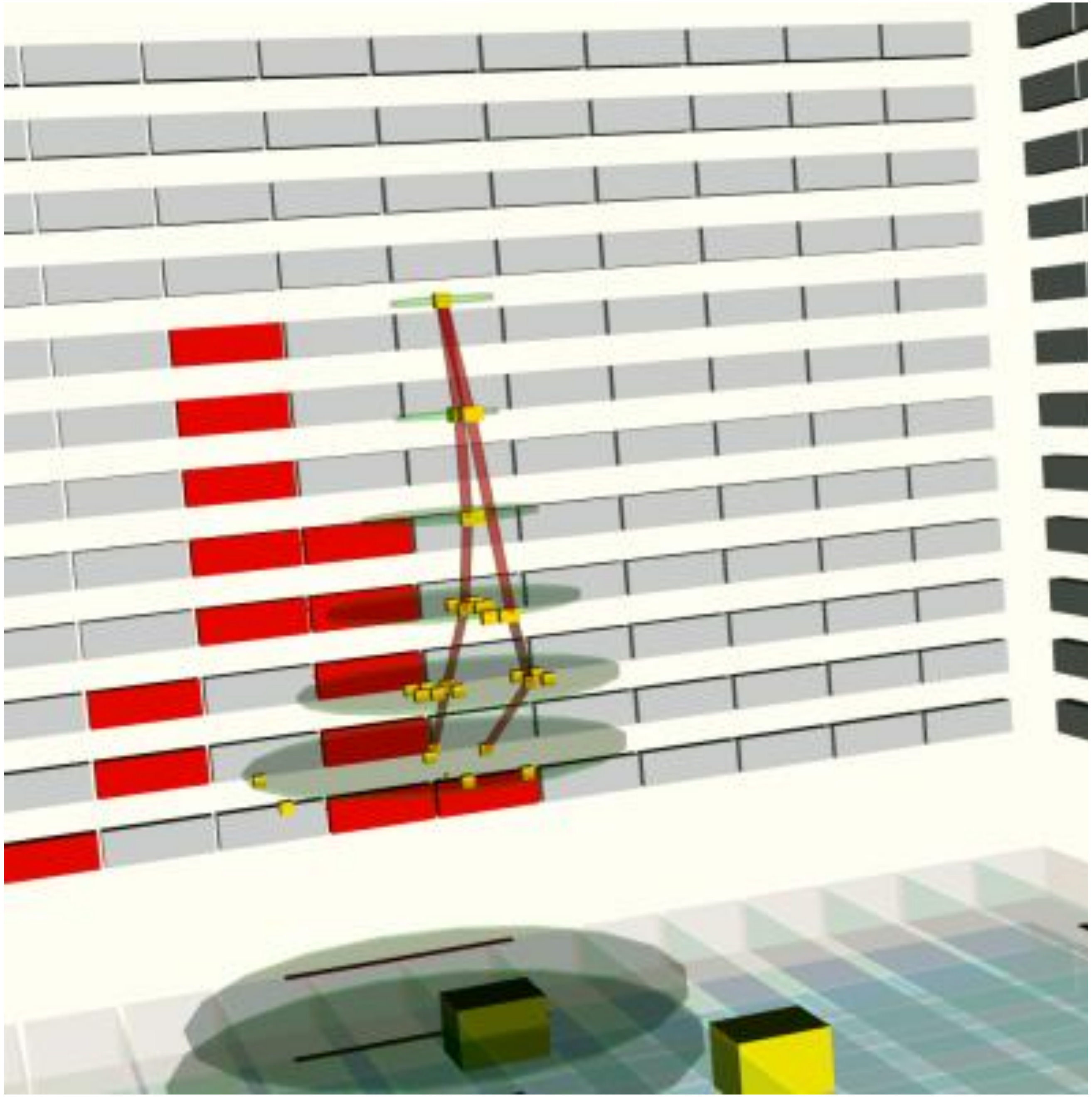
AGILE in orbit

AGILE in orbit

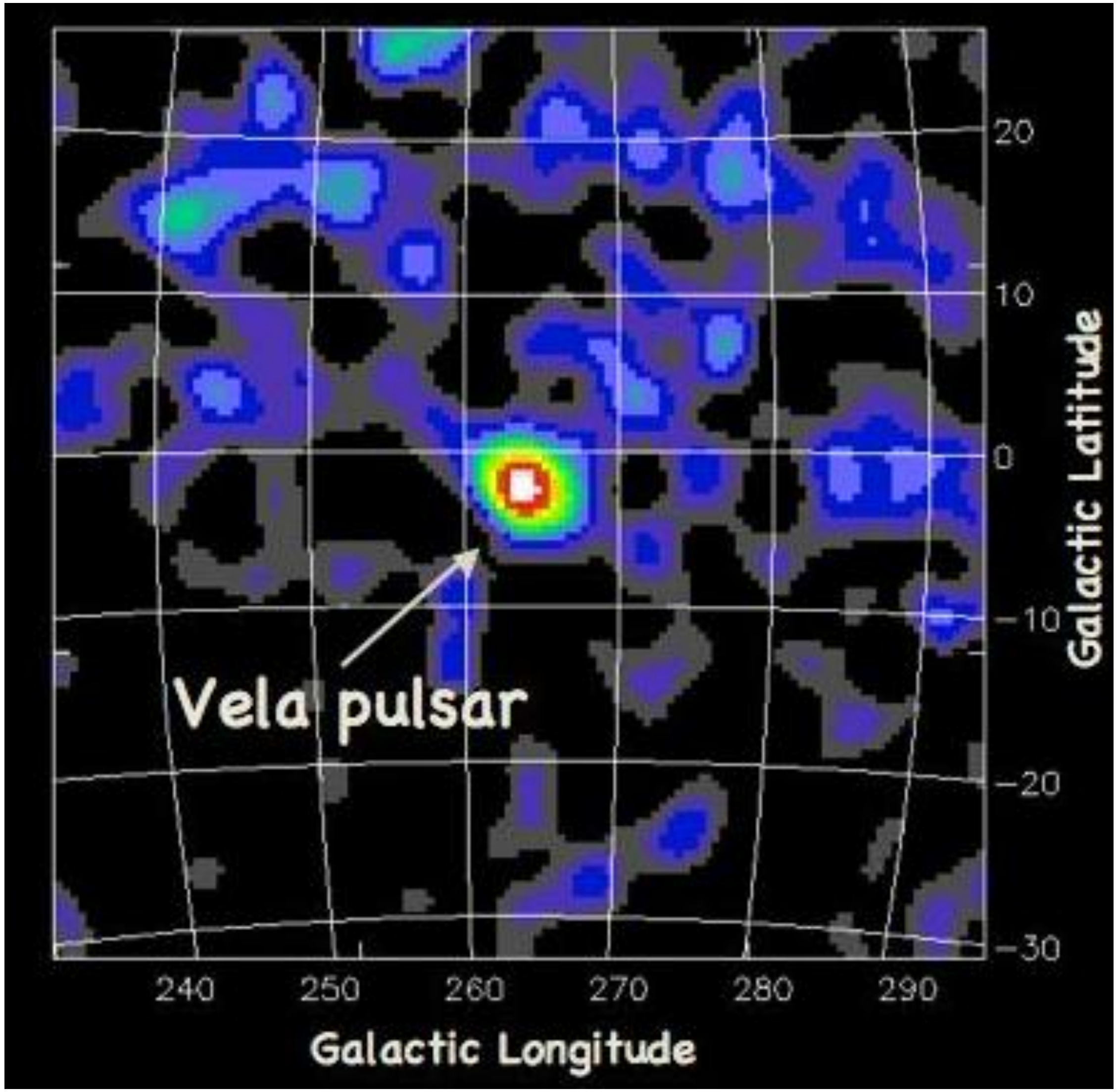


On Orbit Trigger Rates

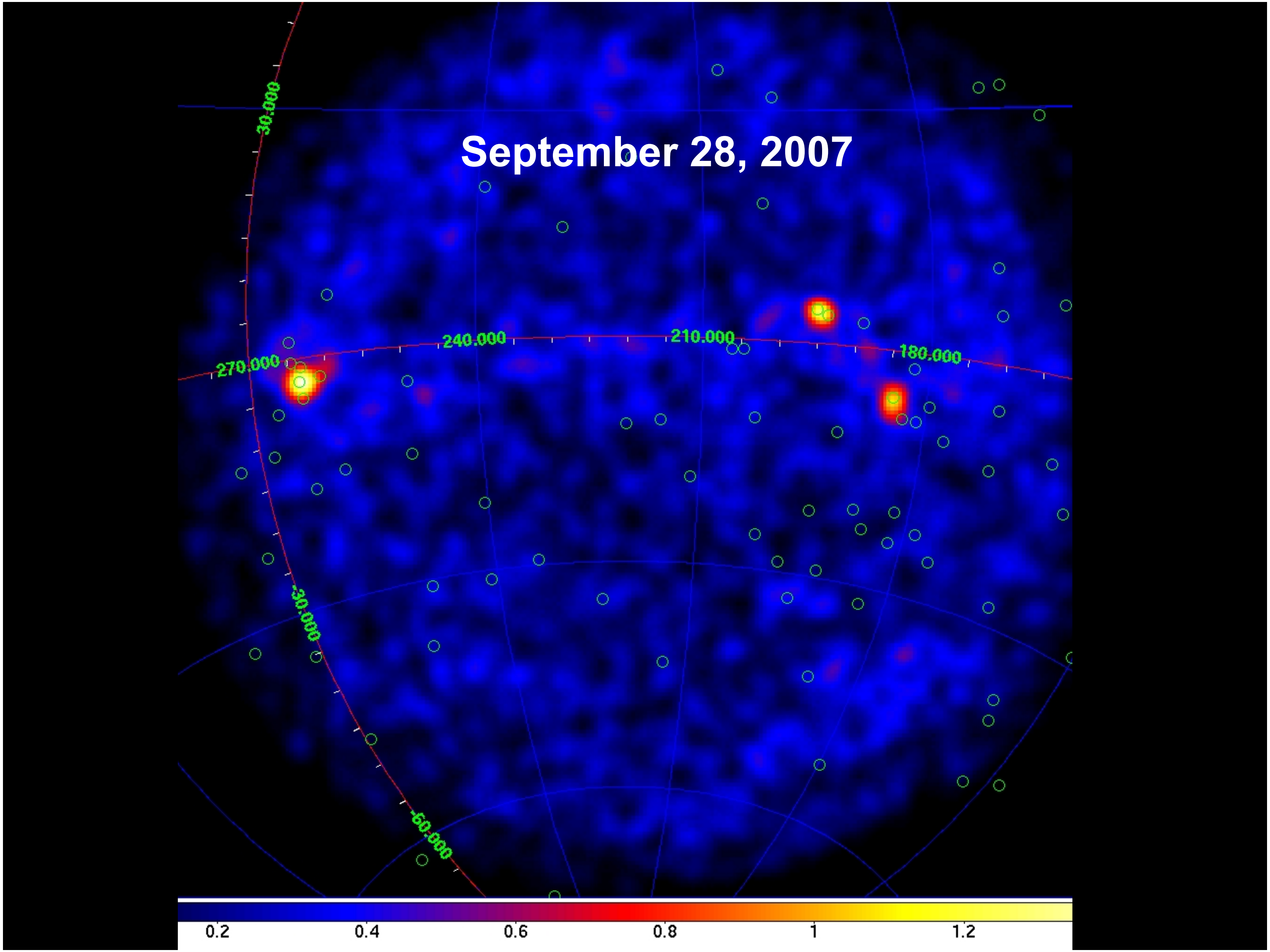
First gamma-ray detected in orbit with the nominal GRID trigger configuration (May 10, 2007)



First Light



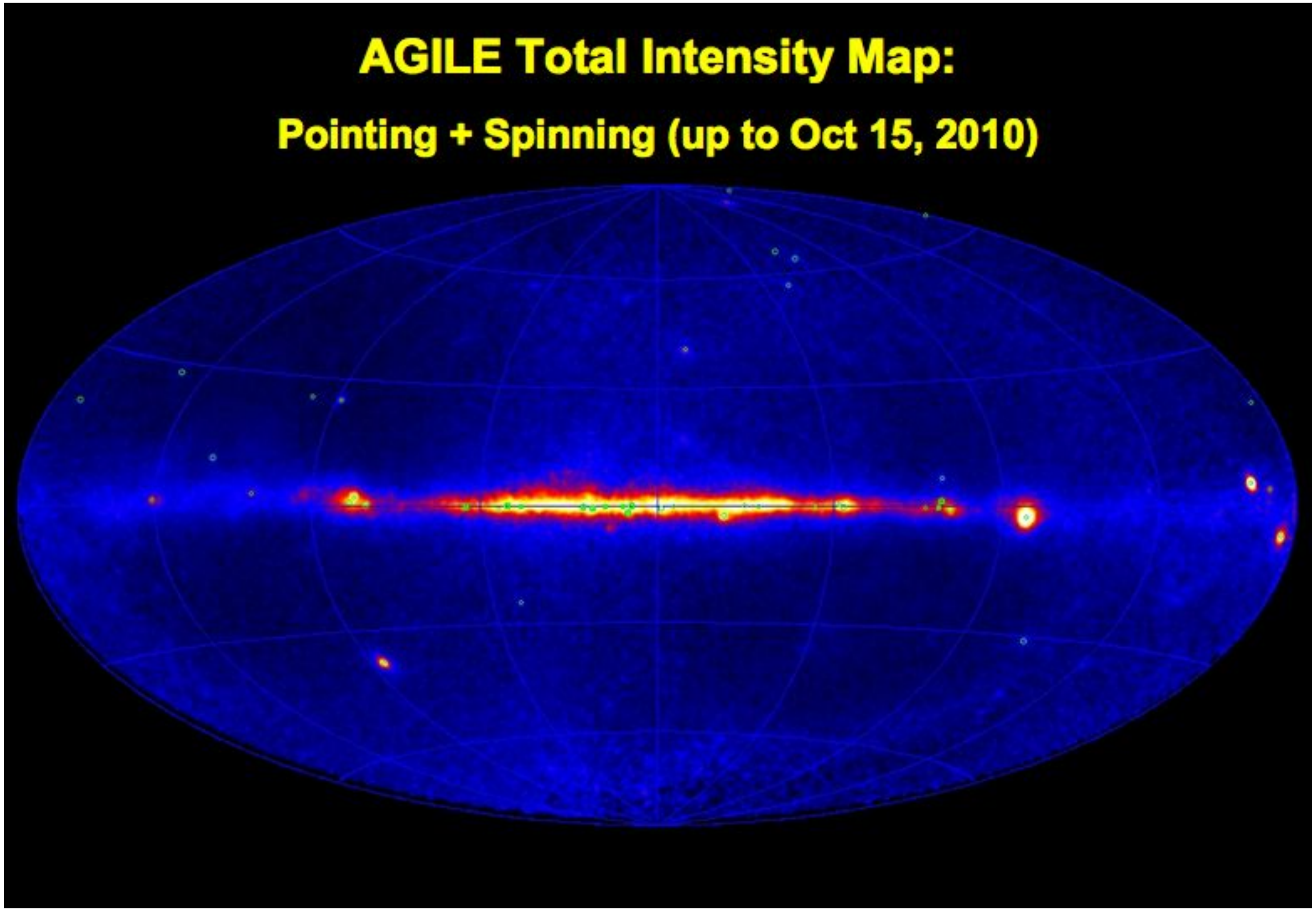
Vela pulsar
20
10
0
−10
−20
−30
Galactic Latitude
240
250
260
270
280
290
Galactic Longitude


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

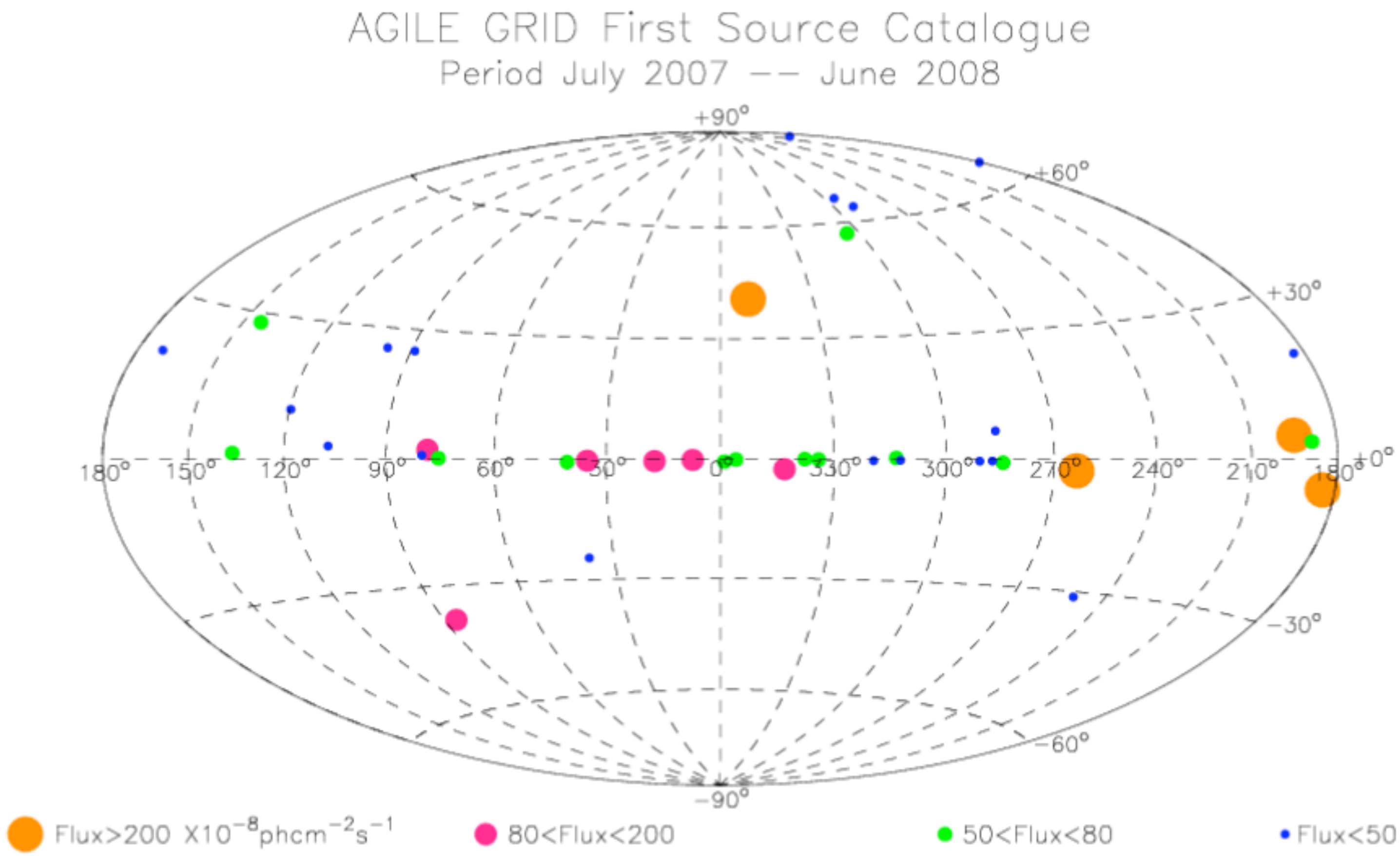
AGILE two lifes

	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

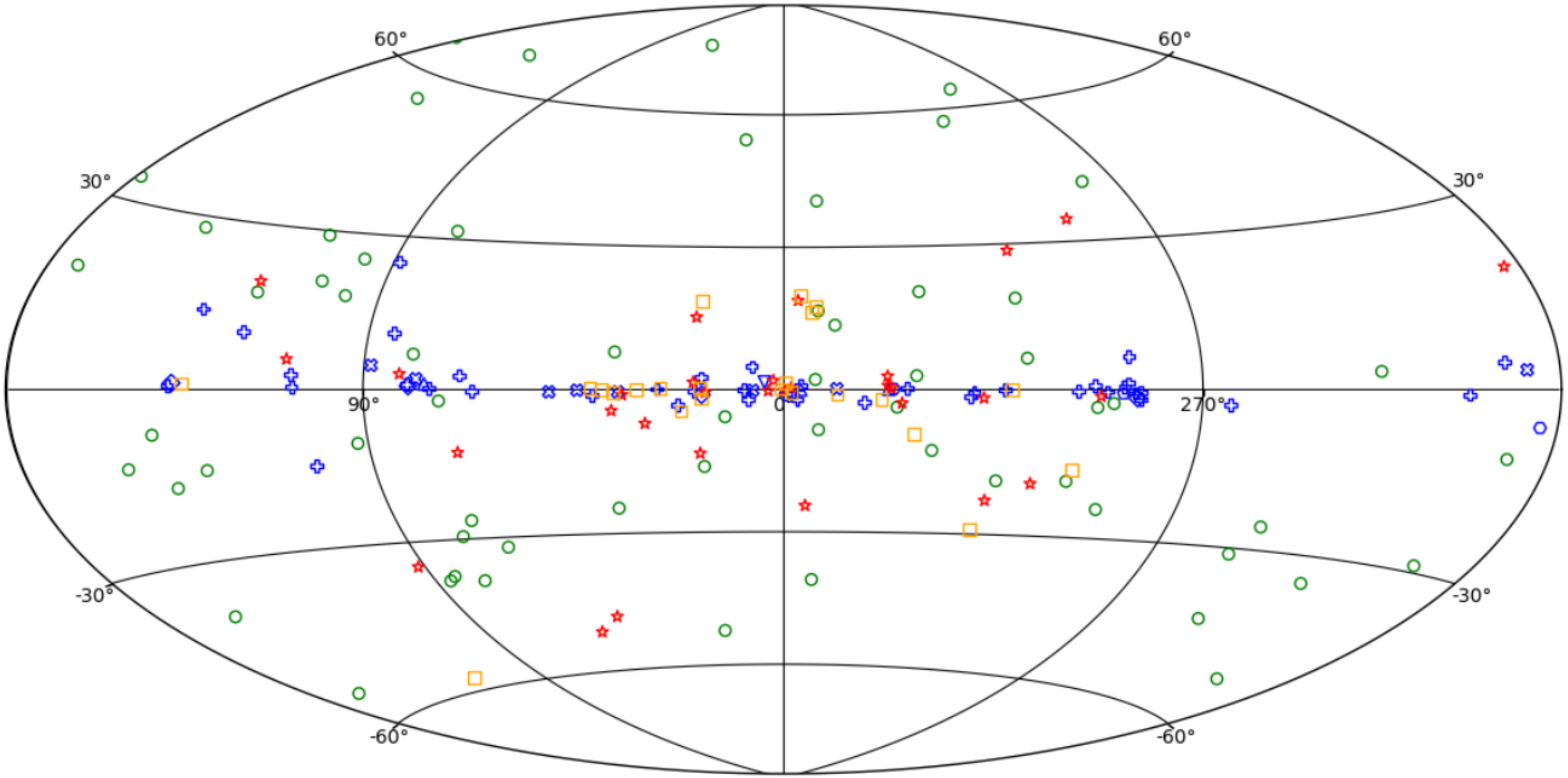


AGILE sources



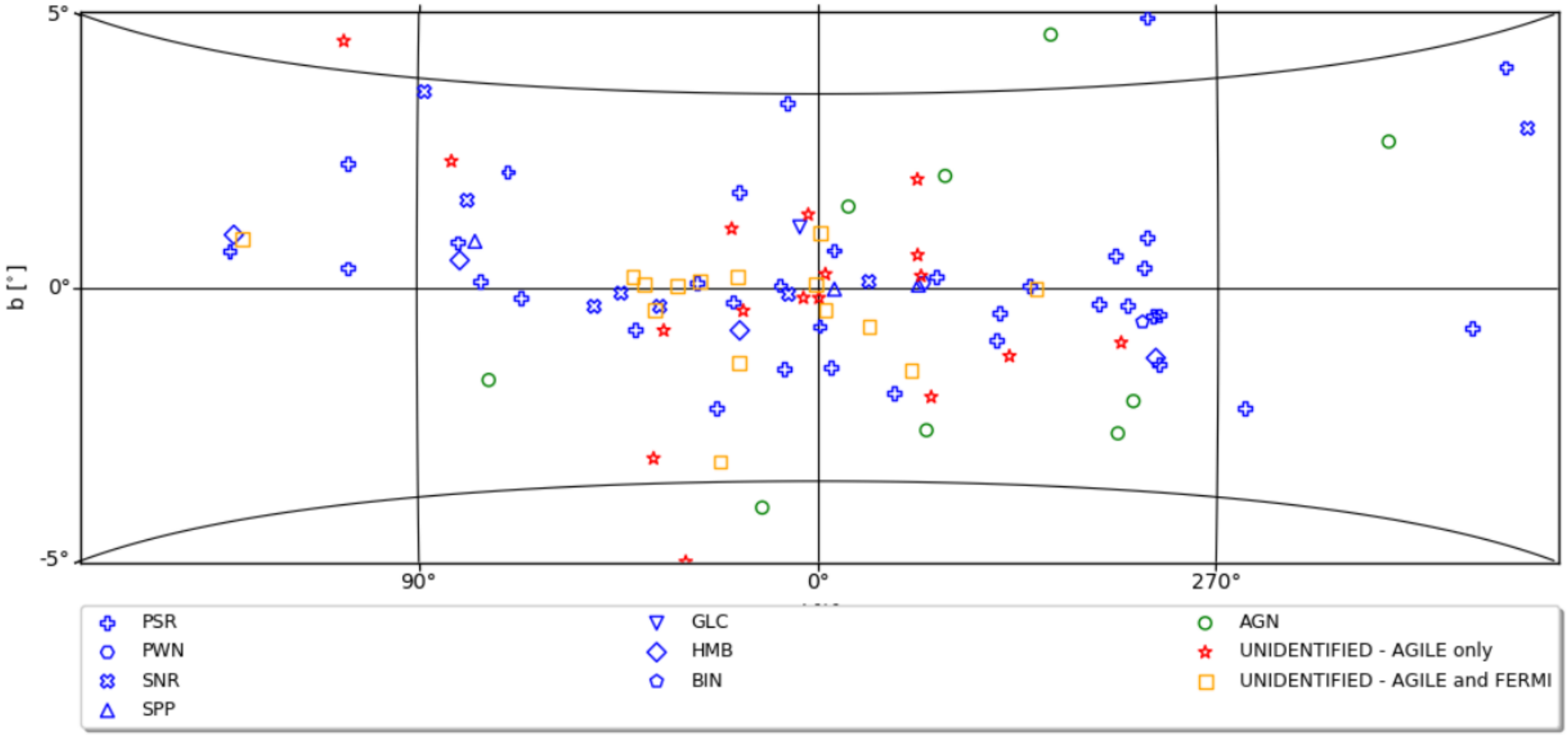
Pittori et al. 2009

AGILE sources



Bulgarelli et al. 2019

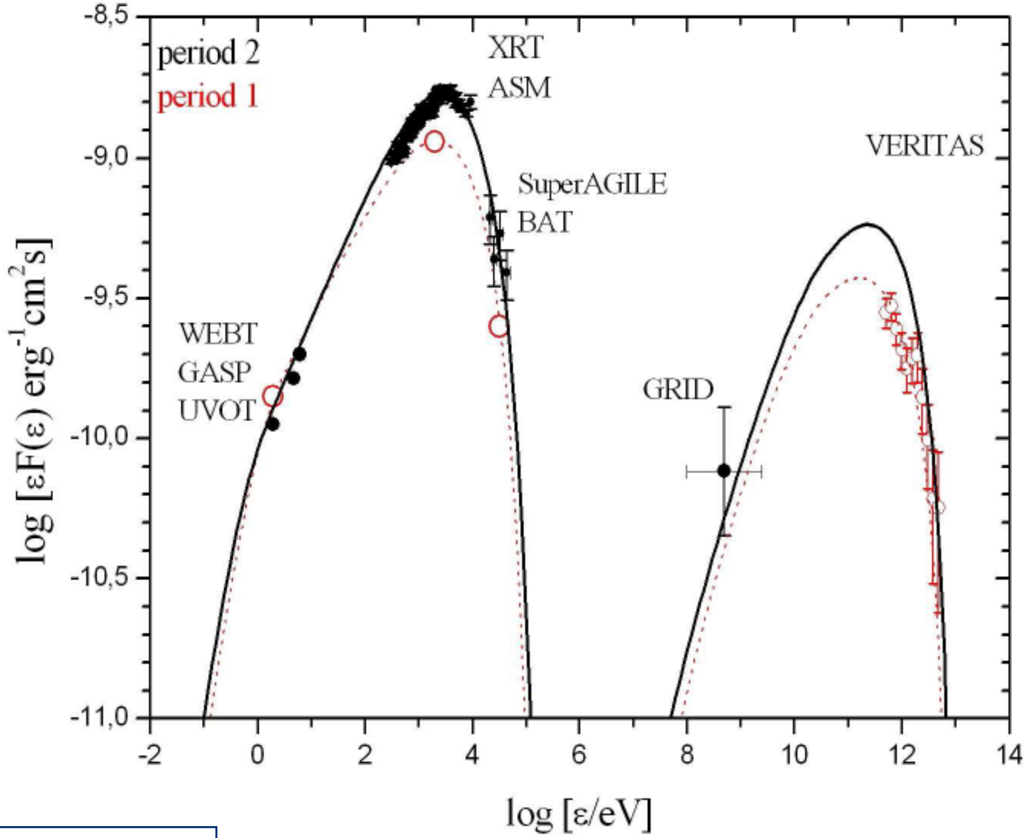
AGILE sources



Bulgarelli et al. 2019

Challenge # 1 – AGN

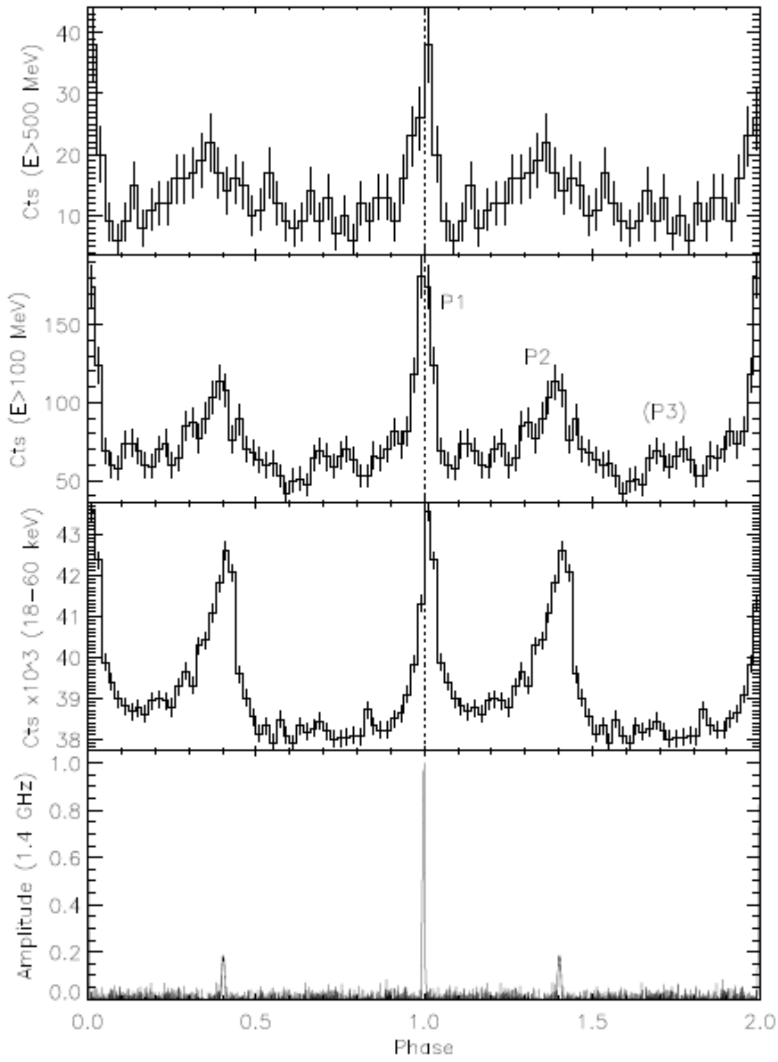
Joint campaign with MAGIC and VERITAS on Mkn 421



Donnarumma et al. 2009

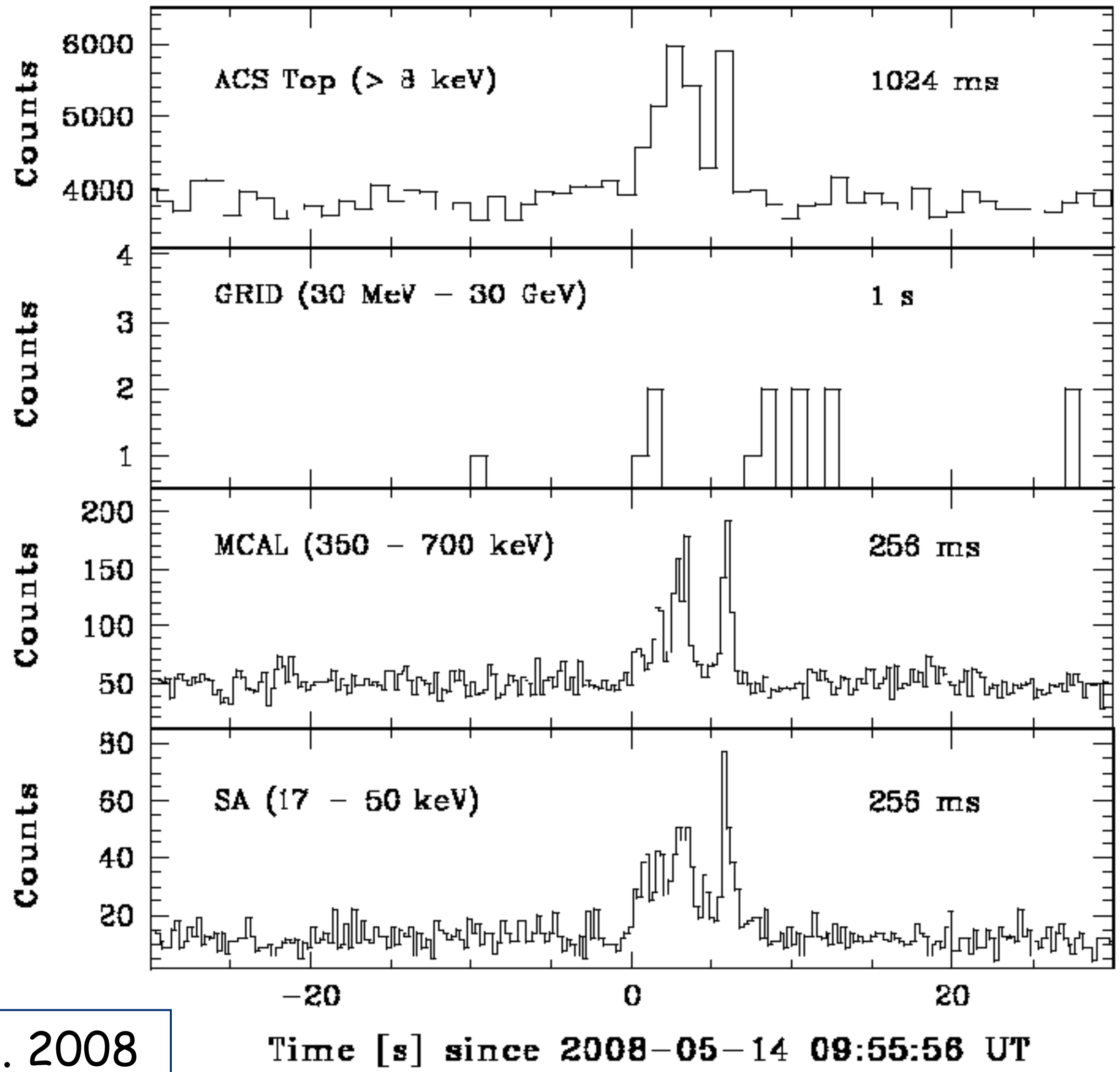
Challenge # 2 – Pulsar

High Precision Timing (eg. Crab PSR)



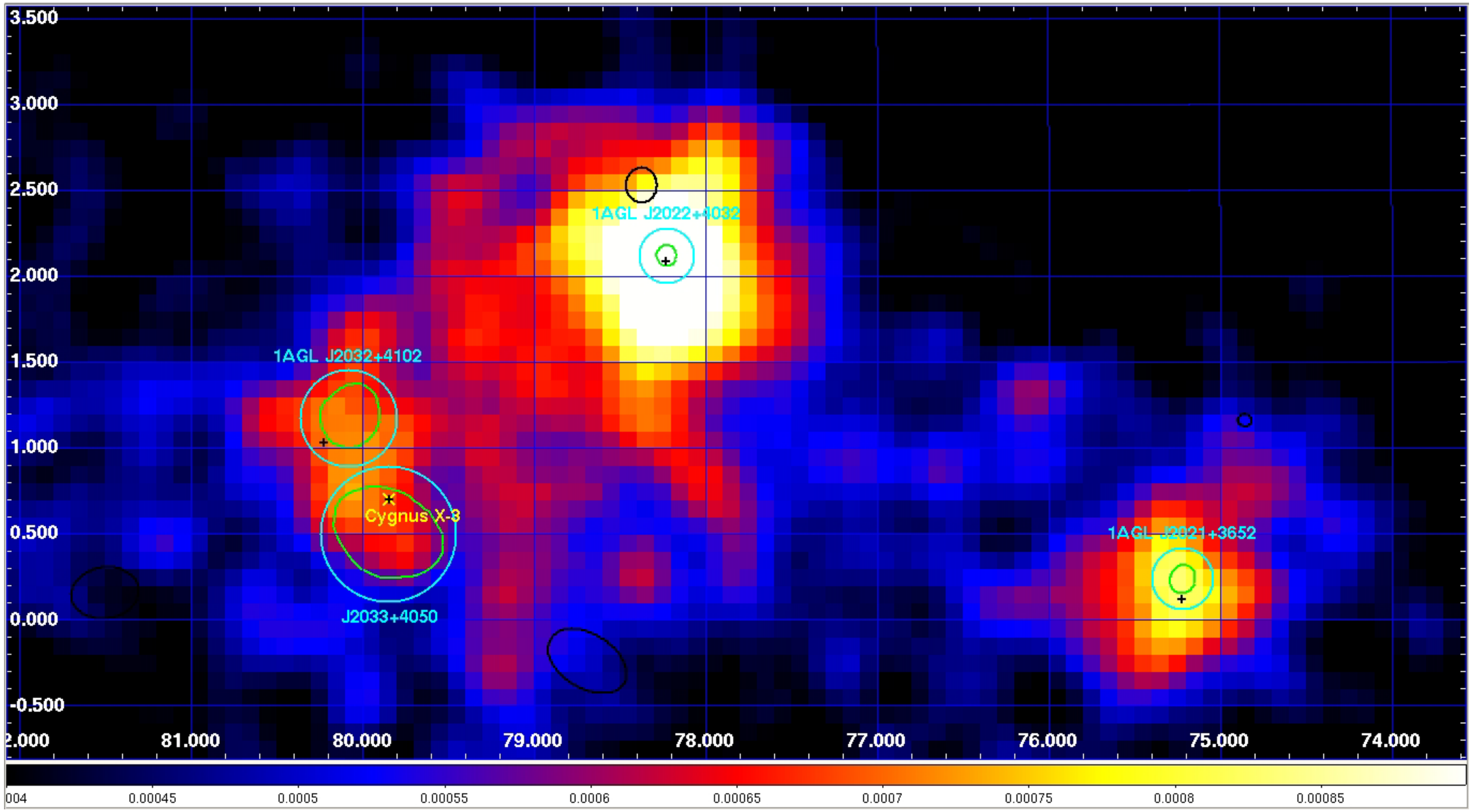
Pellizzoni et al. 2009

Challenge # 3 – GRB



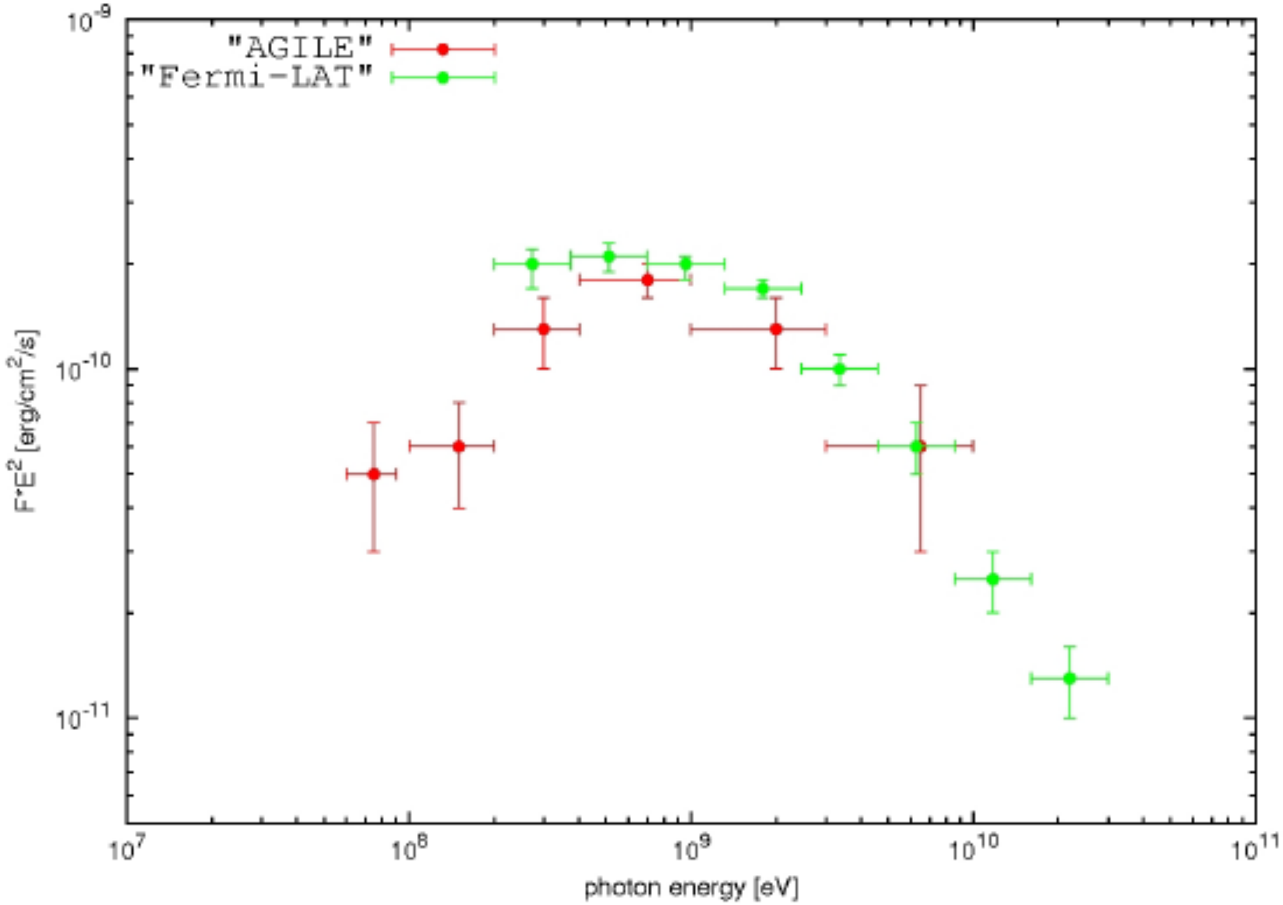
Giuliani et al. 2008

Challenge # 4 – Unidentified



Chen et al. 2011

Challenge # 5 – Spectral resolution

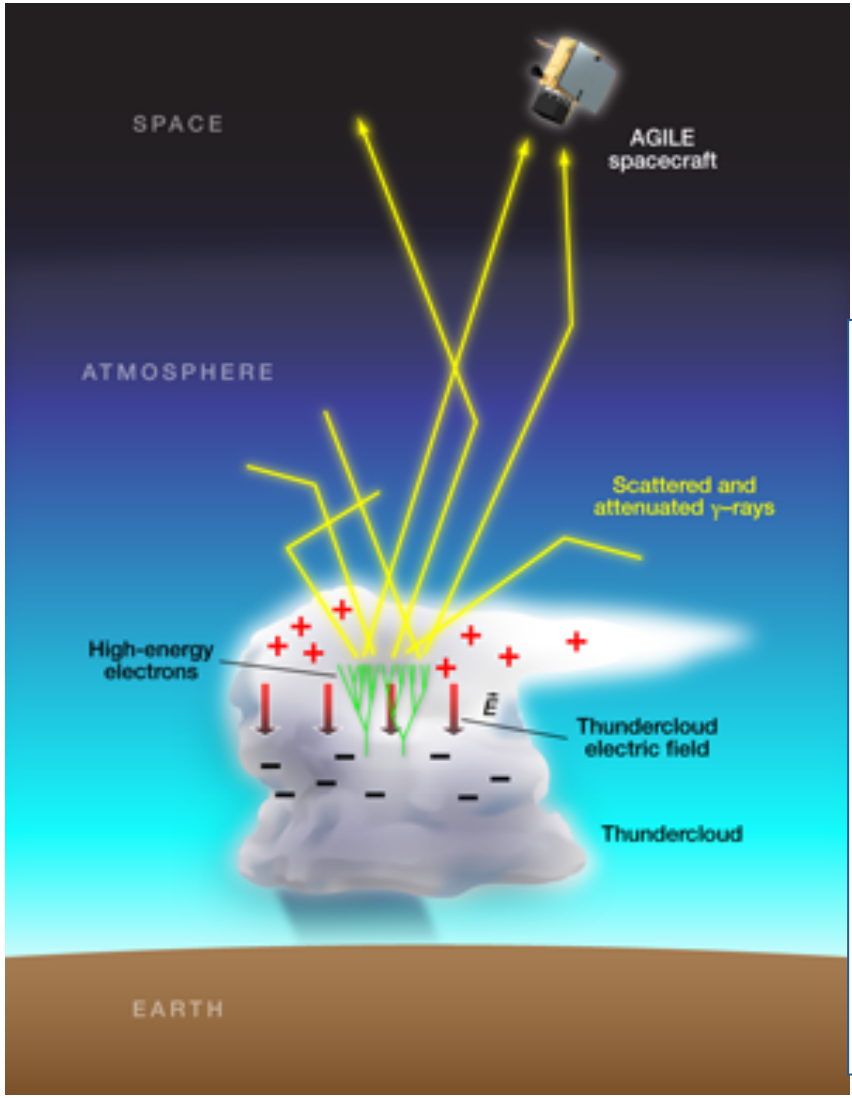


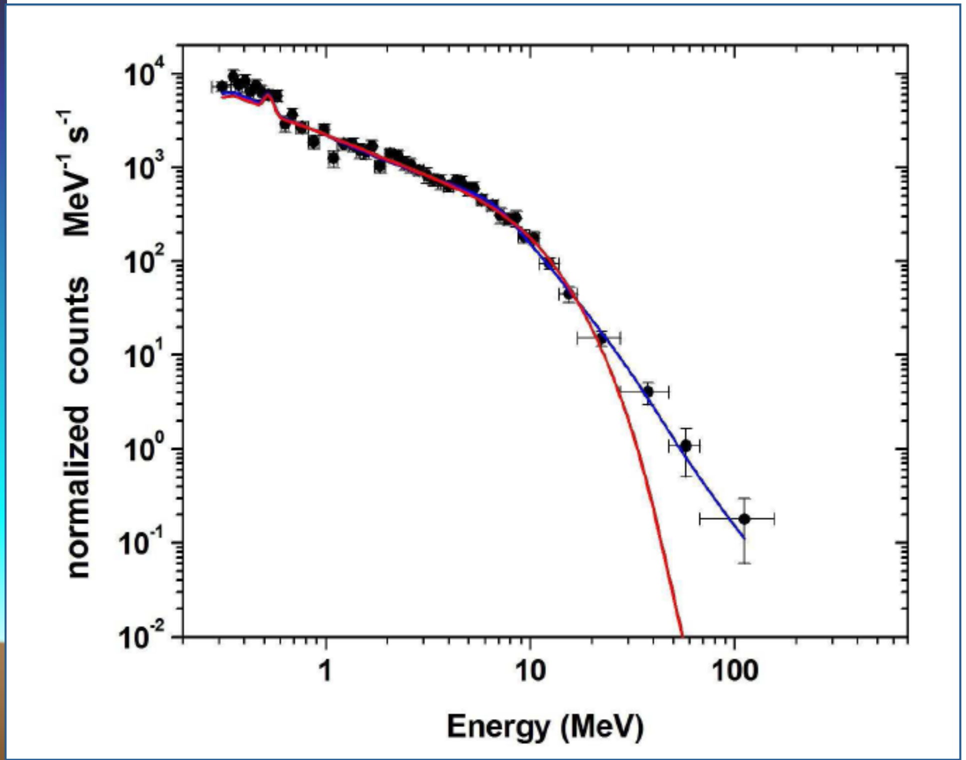
Giuliani et al. 2011

Key AGILE results

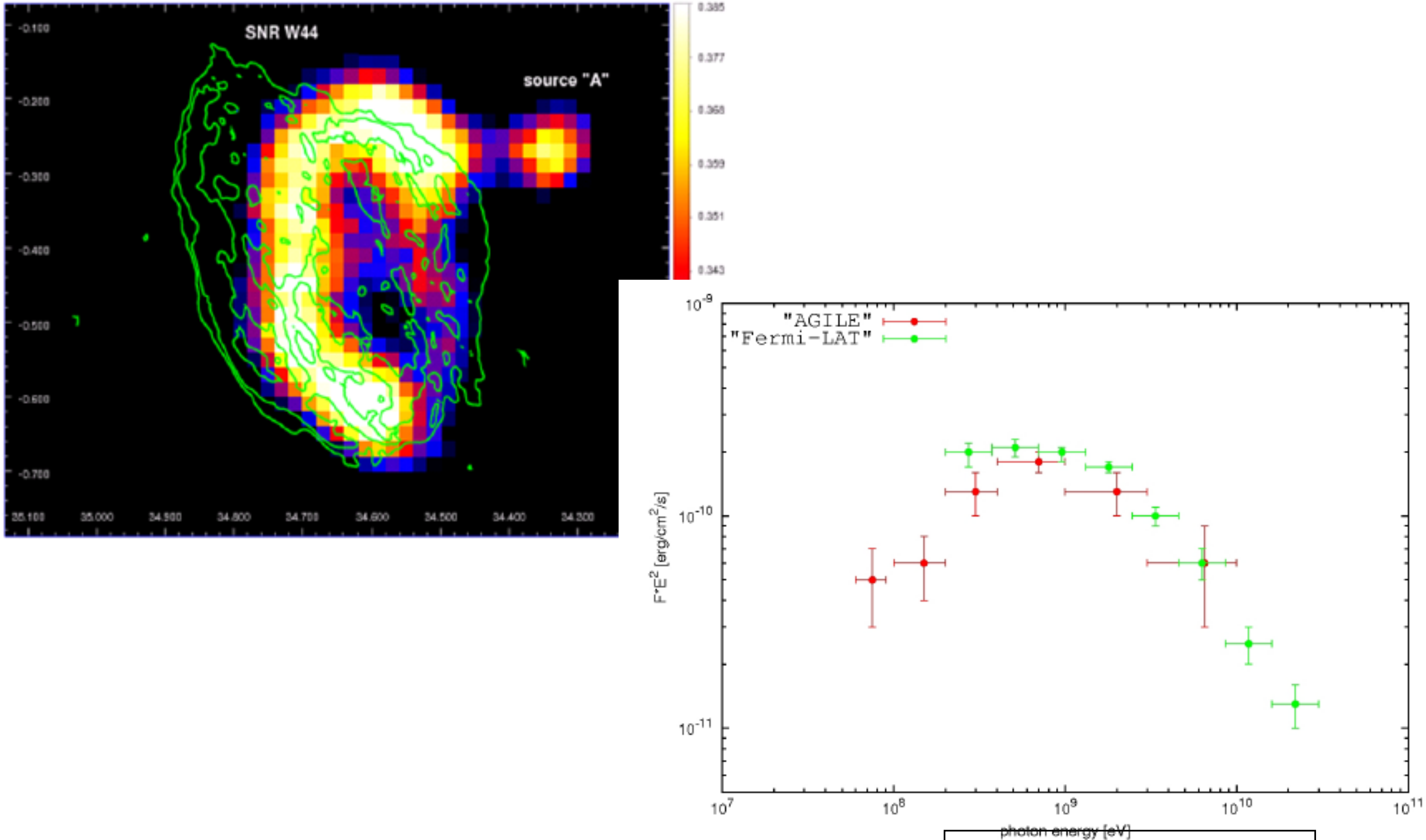
Terrestrial Gamma Ray Flashes

Marisaldi et al. 2010



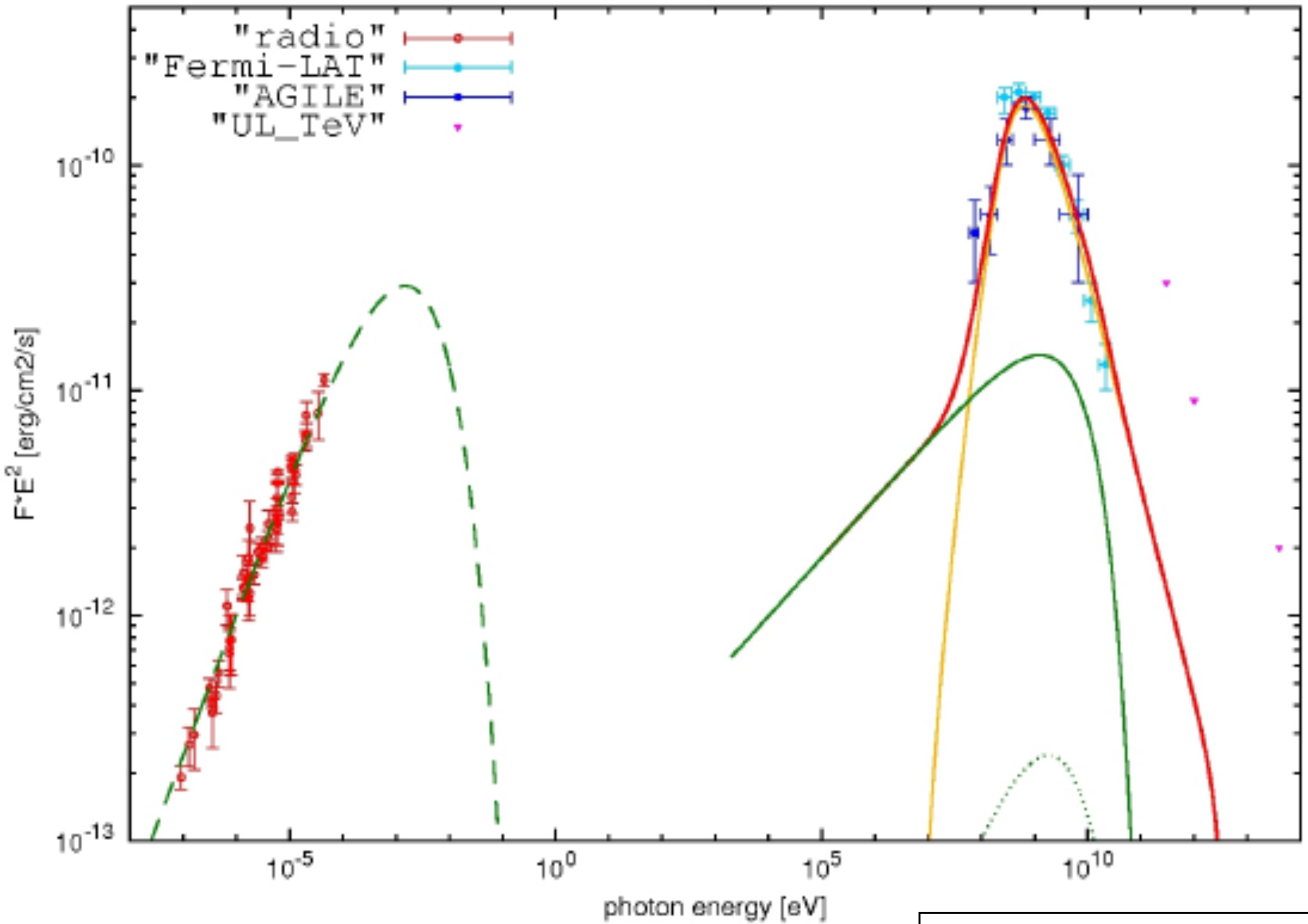


SNR W44



Giuliani et al. 2011

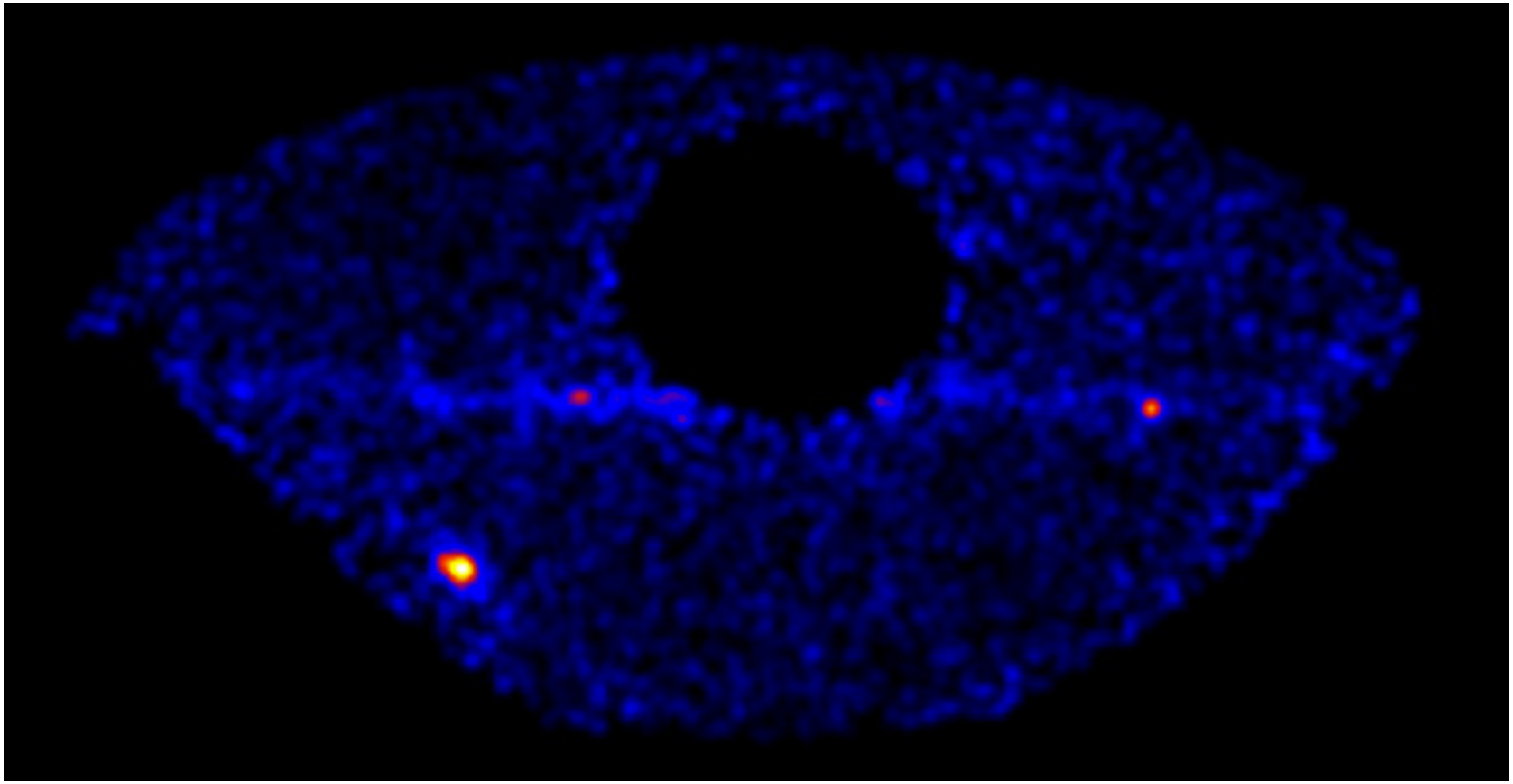
SNR W44



Giuliani et al. 2011

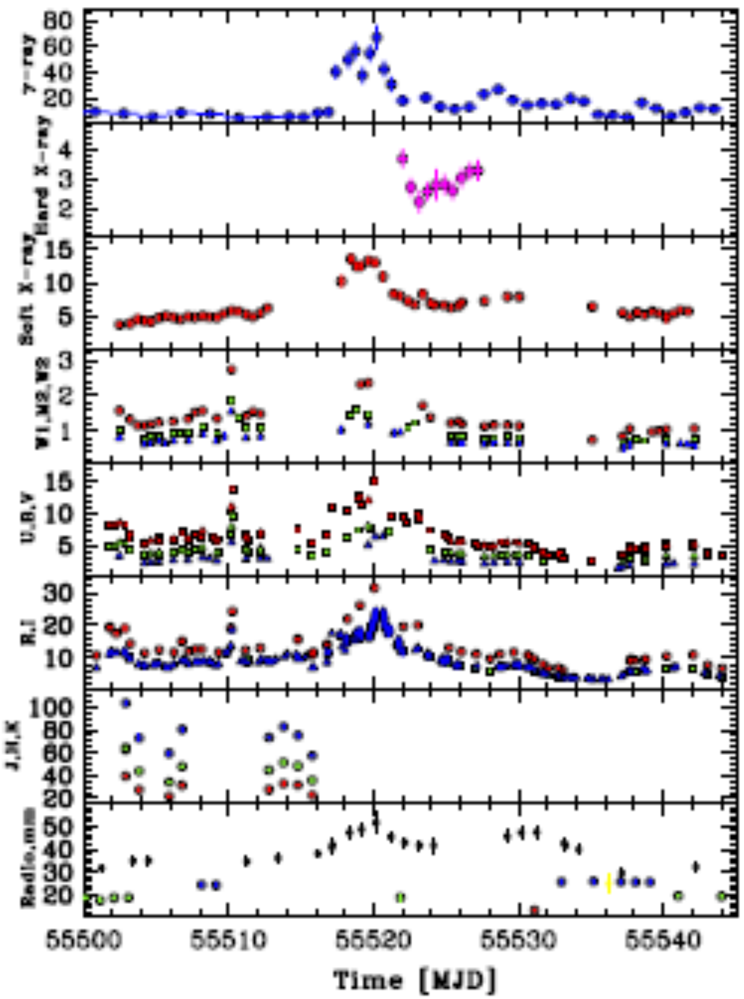
The Flaring 3C454.3

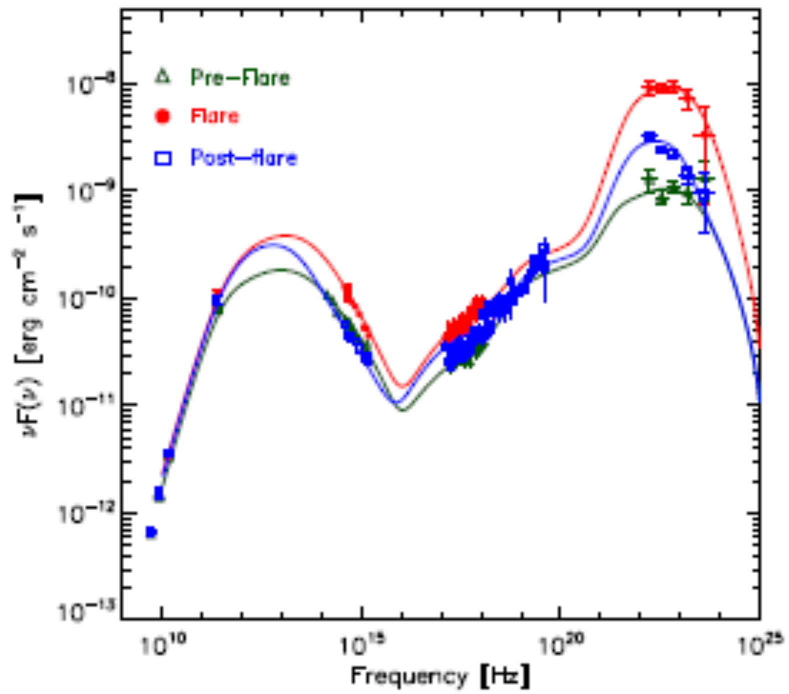
Vercellone et al. 2010



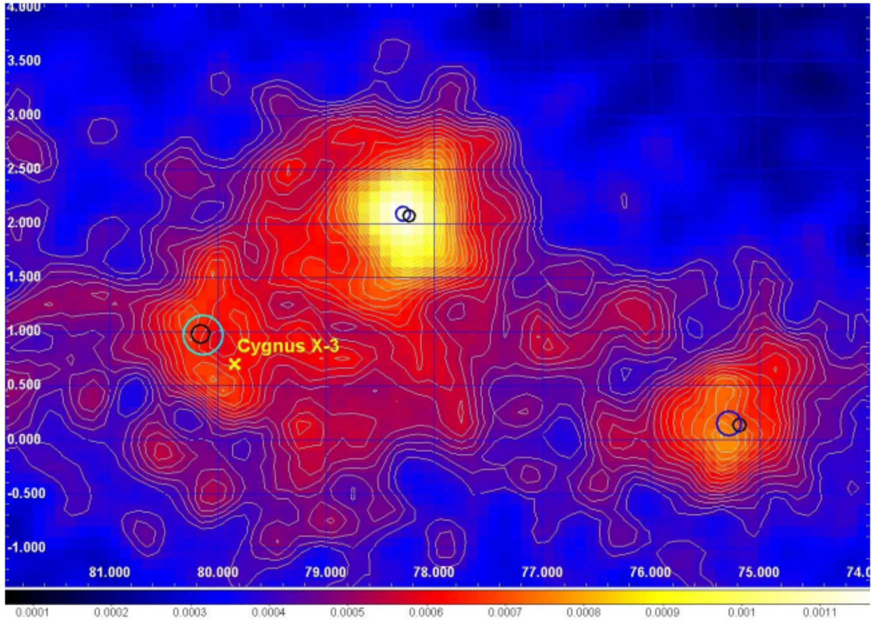
Blazar 3C454.3

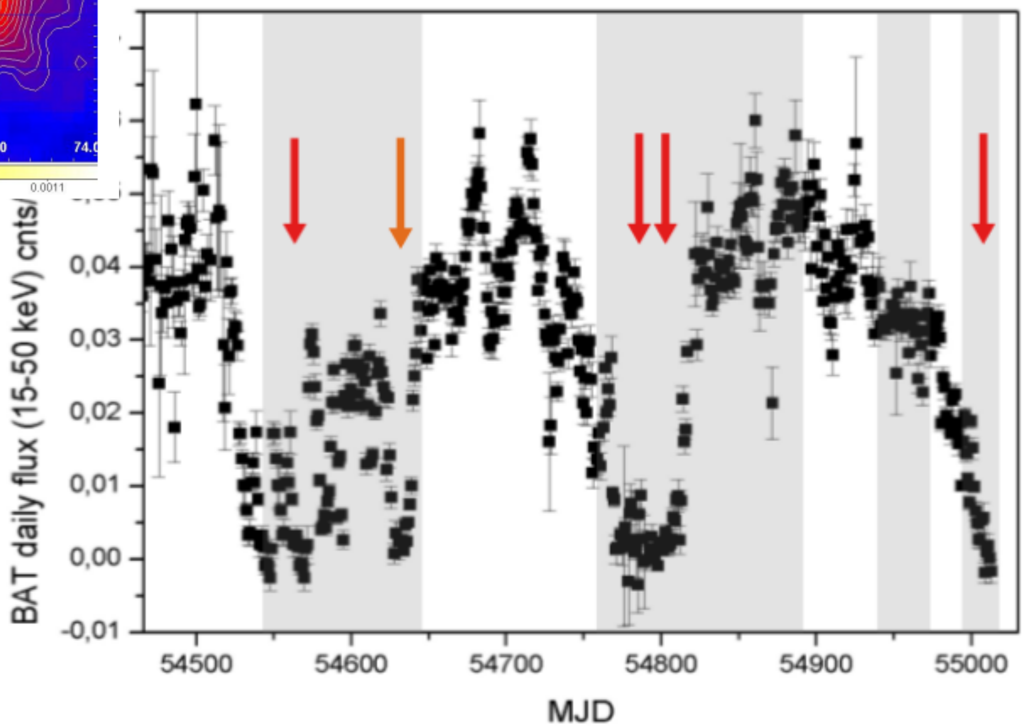
Vercellone et al. 2011





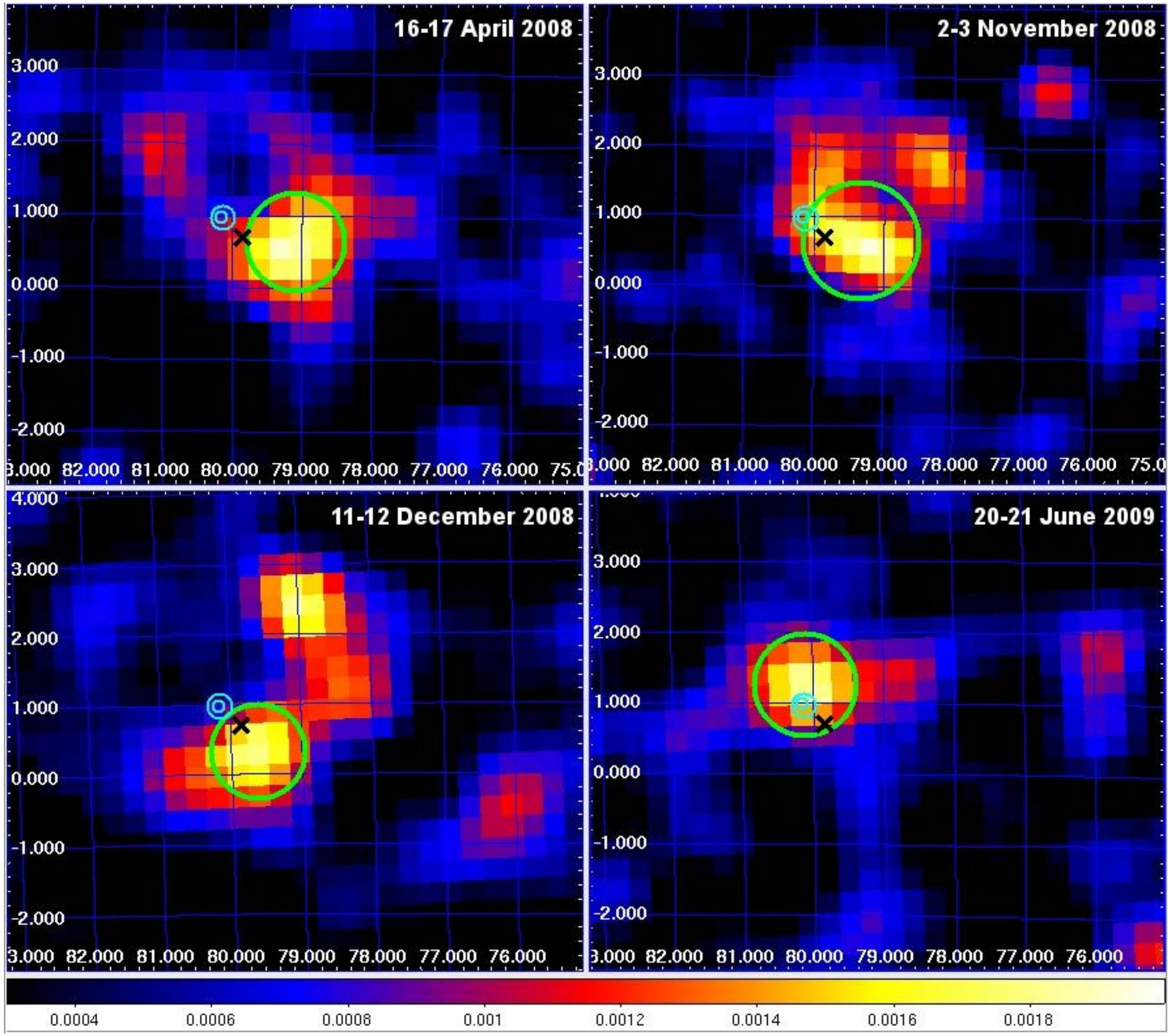
Galactic Transients: Cygnus X3





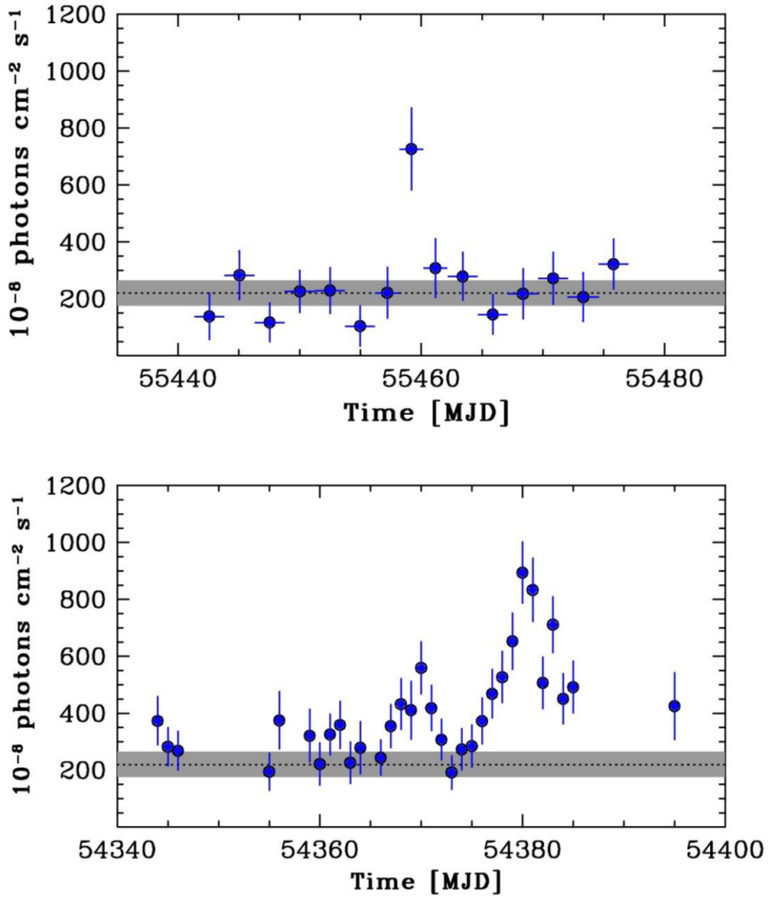
Tavani et al. 2009

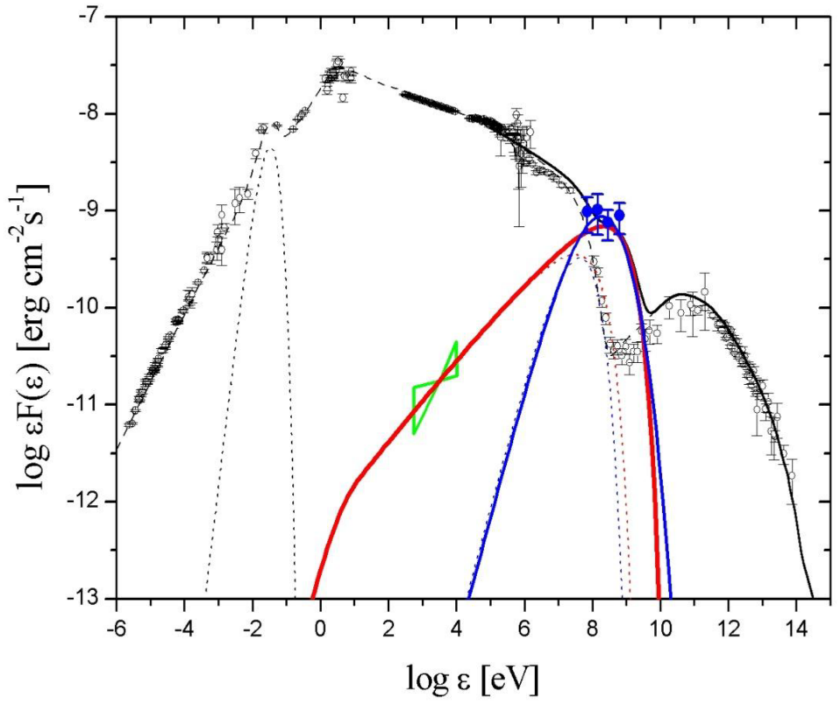
AGILE discovery of transient gamma-ray emission from Cygnus X-3



Galactic Transients: The Flaring Crab

Tavani et al. 2011

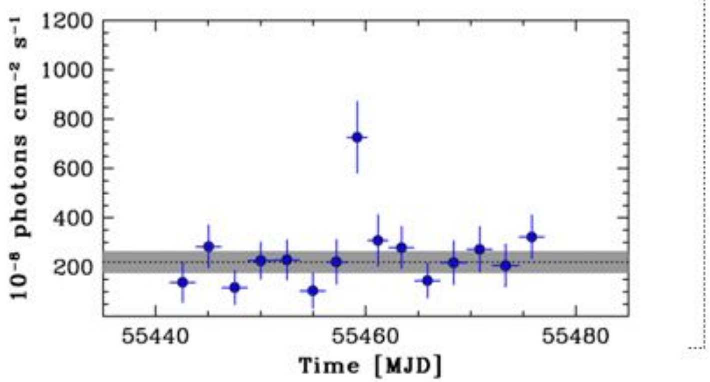


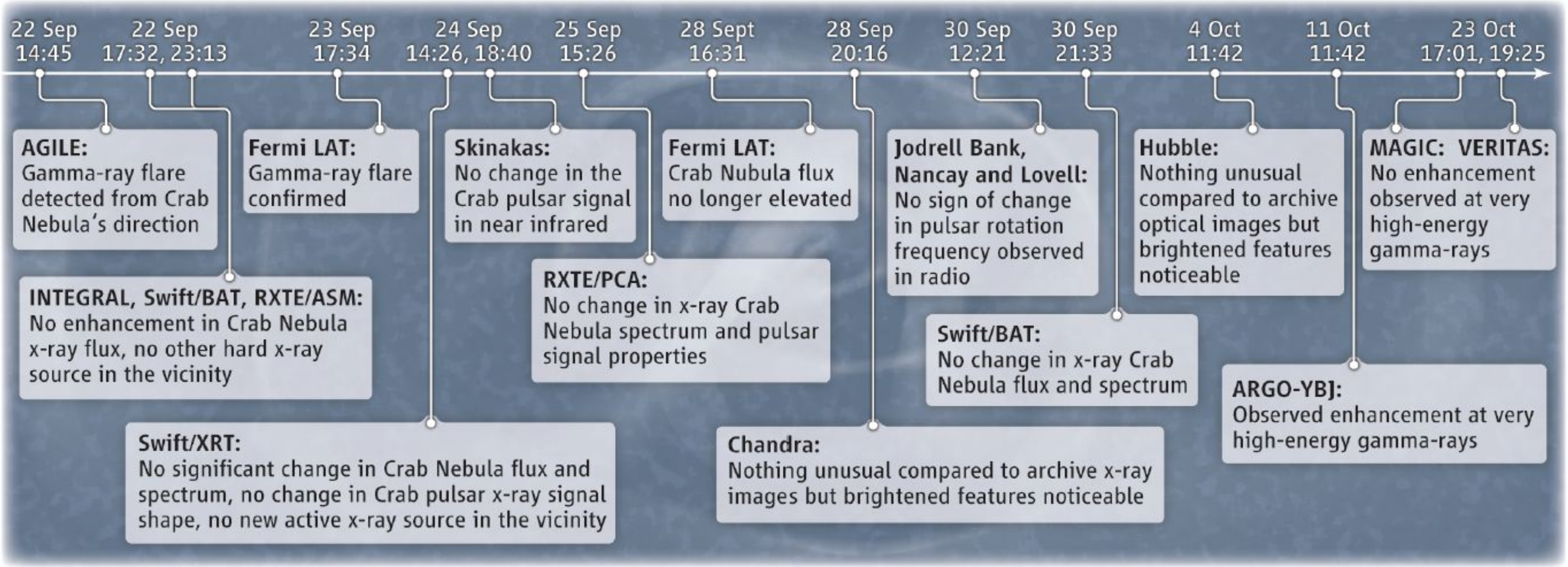


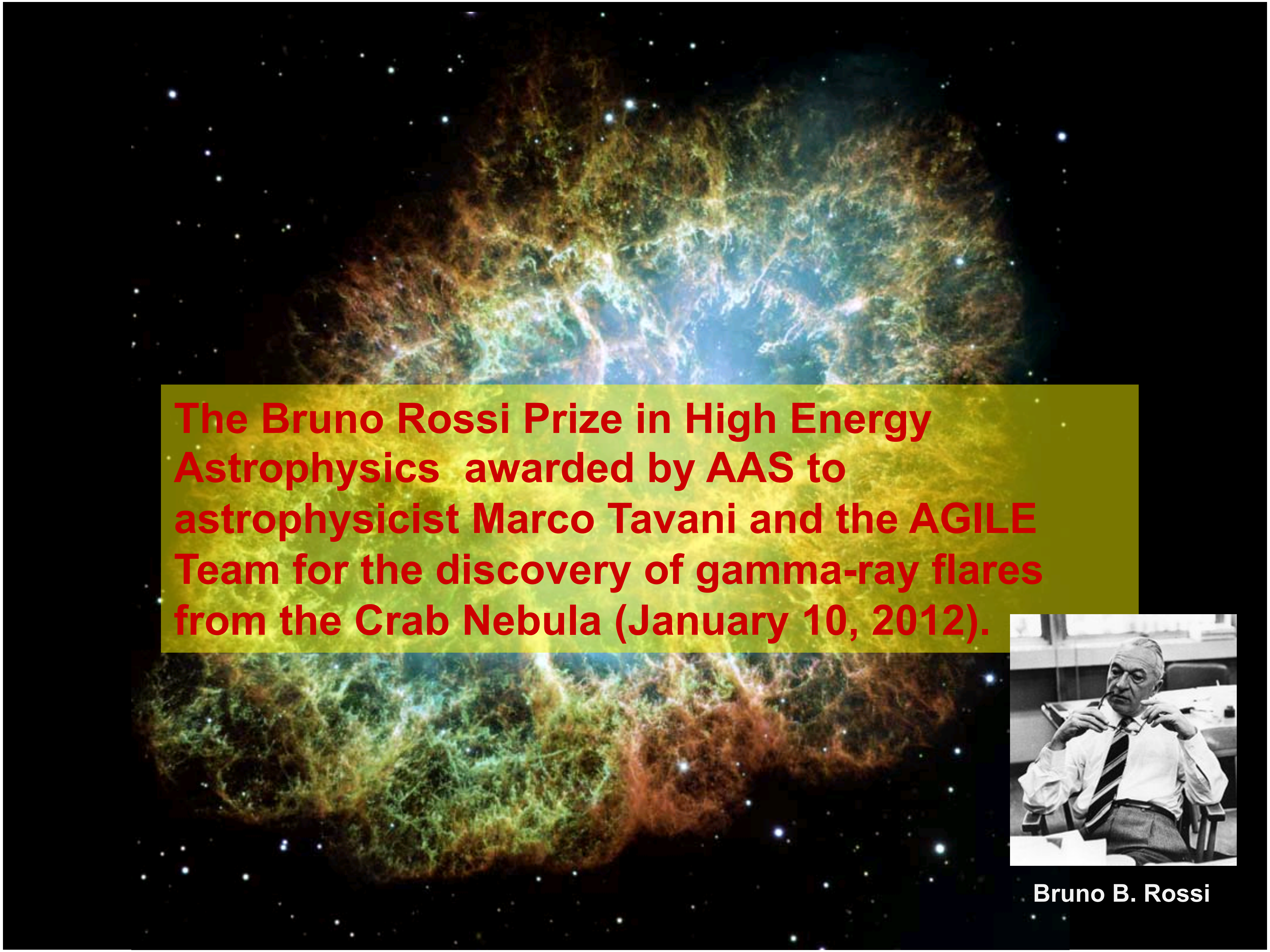
The Flaring Crab

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

ATel #2855; M. Tavani (INAF/IASF Roma), E. Striani (Univ. Tor Vergata), A. Bulgarelli (INAF/IASF Bologna), F. Gianotti, M. Trifoglio (INAF/IASF Bologna), C. Pittori, F. Verrecchia (ASDC), A. Argan, A. Trois, G. De Paris, V. Vittorini, F. D'Ammando, S. Sabatini, G. Piano, E. Costa, I. Donnarumma, M. Feroci, L. Pacciani, E. Del Monte, F. Lazzarotto, P. Soffitta, Y. Evangelista, I. Lapshov (INAF-IASF-Rm), A. Chen, A. Giuliani(INAF-IASF-Milano), M. Marisaldi, G. Di Cocco, C. Labanti, F. Fuschino,M. Galli (INAF/IASF Bologna), P. Caraveo, S. Mereghetti, F. Perotti (INAF/IASF Milano), G. Pucella, M. Rapisarda (ENEA-Roma), S. Vercellone (IASF-Pa), A. Pellizzoni, M. Pilia (INAF/OA-Cagliari), G. Barbiellini, F. Longo (INFN Trieste), P. Picozza, A. Morselli (INFN and Univ. Tor Vergata), M. Prest (Universita` dell'Insubria), P. Lipari, D. Zanello (INFN Roma-1), P.W. Cattaneo, A. Rappoldi (INFN Pavia), P. Giommi, P. Santolamazza, F. Lucarelli, S. Colafrancesco (ASDC), L. Salotti (ASI)
on 22 Sep 2010; 14:45 UT
Distributed as an Instant Email Notice (Transients)






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/

AGILE Home | About AGILE | ASI HQ AGILE | AGILE News | AGILE Data Archive | Public Software | AGILE Pointings | AGILE Catalogs | Restricted Area
Guest Observer Program | User Feedback Form | AGILE Workshops | Agile Helpdesk

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. AGILE has been operating nominally for more than 16 years, providing valuable data and important scientific results.

AGILE operations:
Launch date: 23 April, 2007 - Re-entry date: 14 February, 2024
Science observations ended on 18 January, 2024
Planned Nominal Phase: 2 + 2 extended years
Elapsed: 16 years and 10 months in orbit (6.141 days)

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

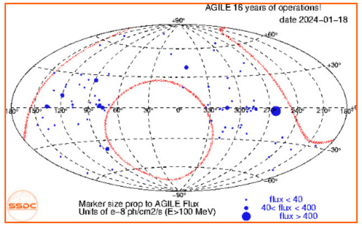
- AGILE Principal Investigator: Marco Tavani, INAF Rome (Chair)
- ASI Project Scientist: Paolo Giommi, ASI
- ASI Mission Director: Giovanni Valentini, ASI
  (Former ASI Mission Directors: Luca Salotti: Apr 2007 - Sep 2010, Giovanni Valentini: Sep 2010 - Jan 2015, Fabio D'Amico: Jan 2015 - Jun 2023)
- 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)

NEW AGILE LV3 online data analysis

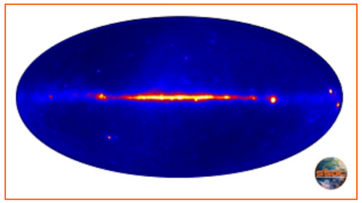
AGILE spinning sky view

(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.

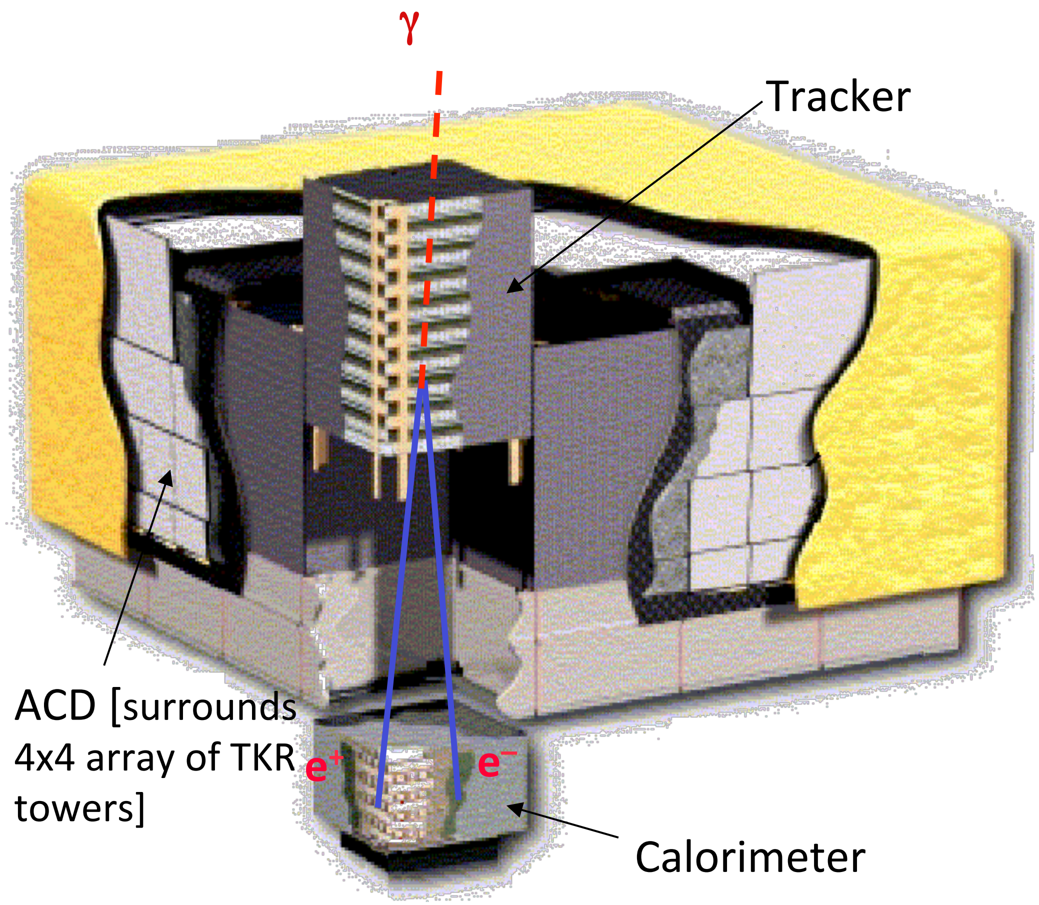
Conclusions

- 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

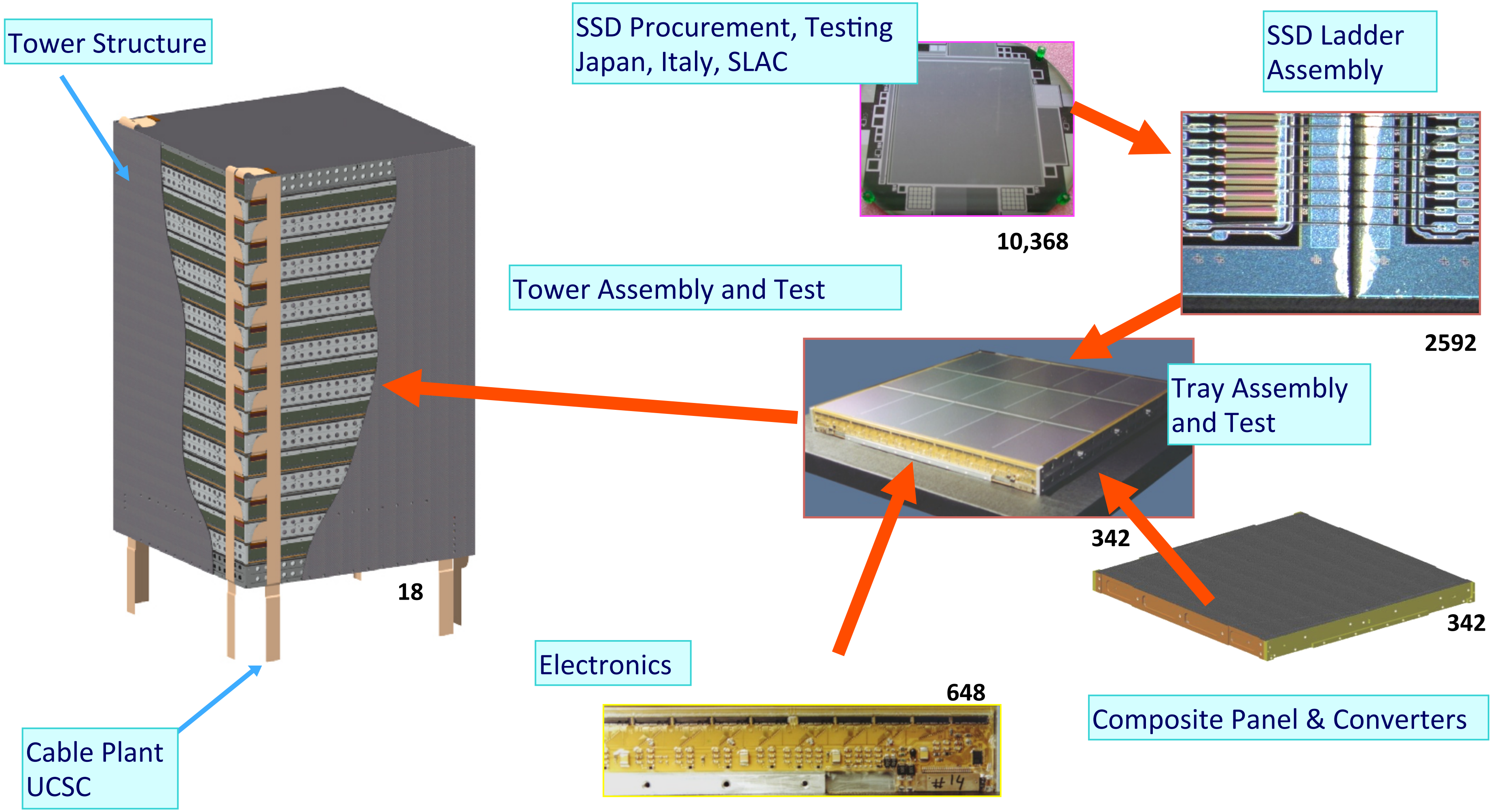
Fermi LAT

Overview of LAT

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



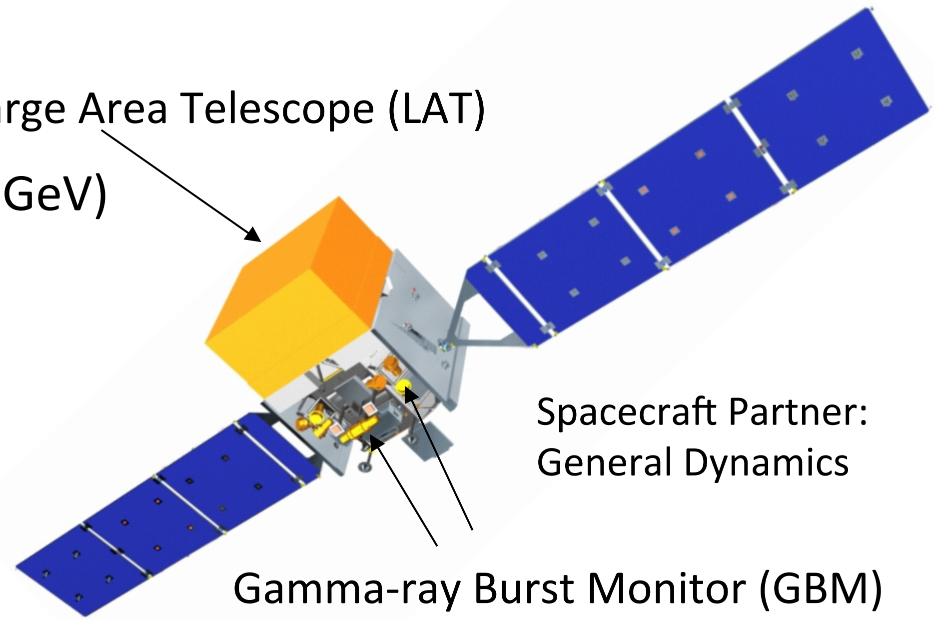
Tower Structure
SSD Procurement, Testing
Japan, Italy, SLAC
SSD Ladder
Assembly
10,368
Tower Assembly and Test
2592
Tray Assembly
and Test
342
342
18
Electronics
648
#14
Composite Panel & Converters
Cable Plant
UCSC

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.

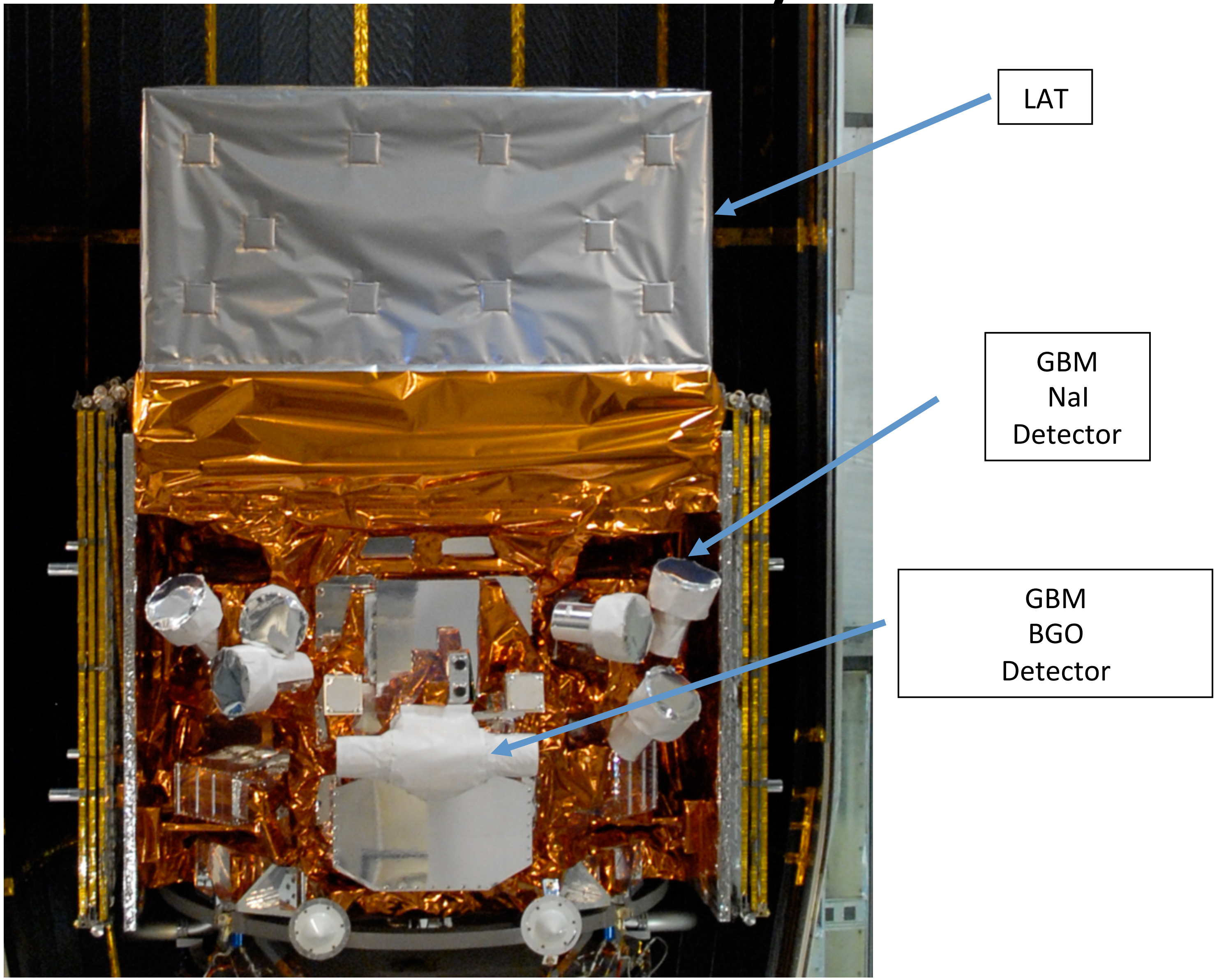
Key Features

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

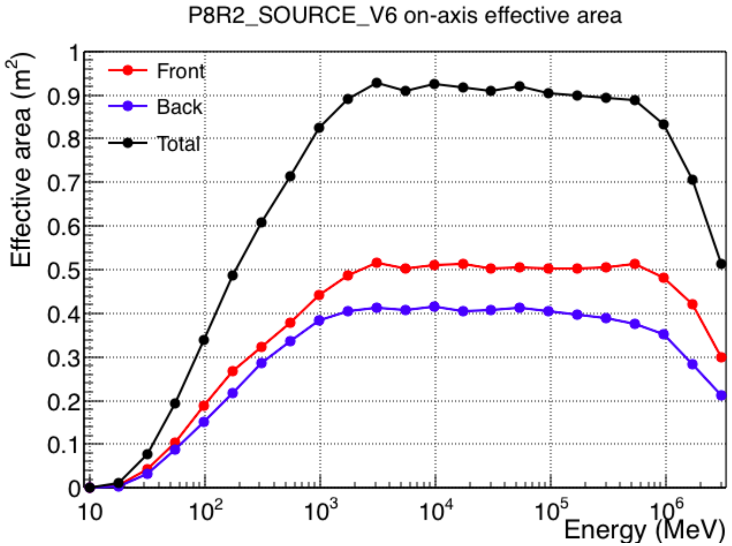


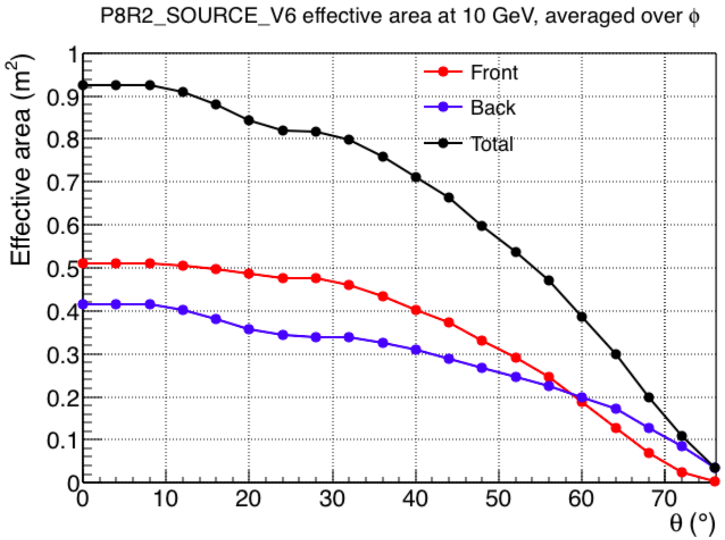
- Huge field of view
  - LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV - 100 GeV
- Large leap in all key capabilities. Great discovery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

The Observatory



Effective Area (A_{eff})





< 100 MeV limited by 3-in a row requirement

< 1 GeV limited discriminating information

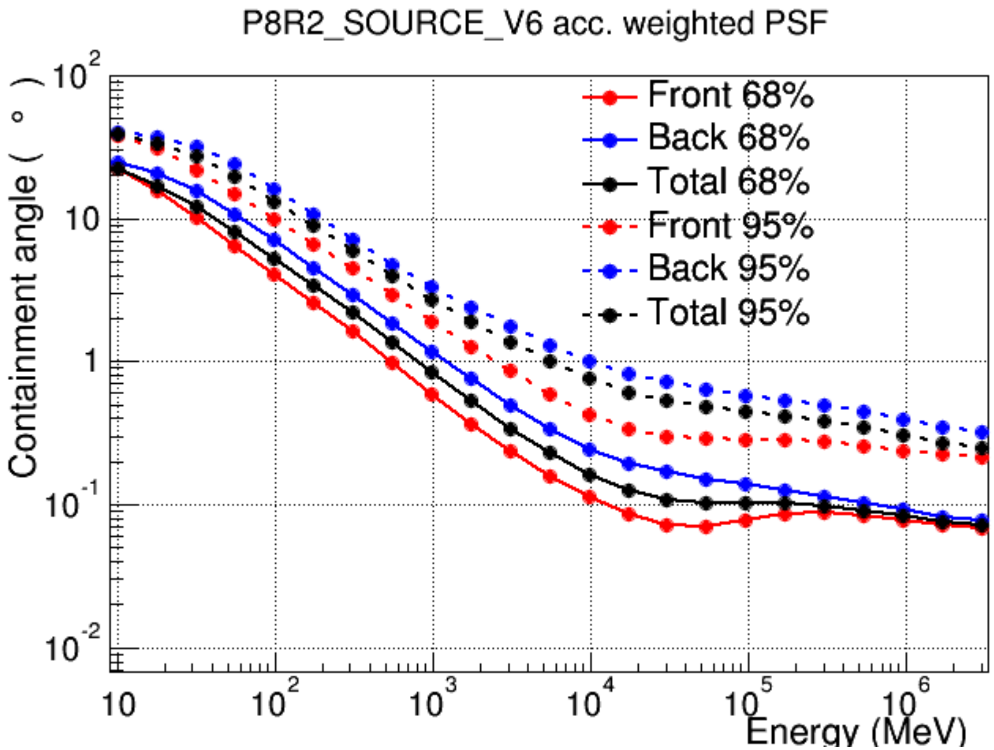
> 100 GeV self-veto from backsplash

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)

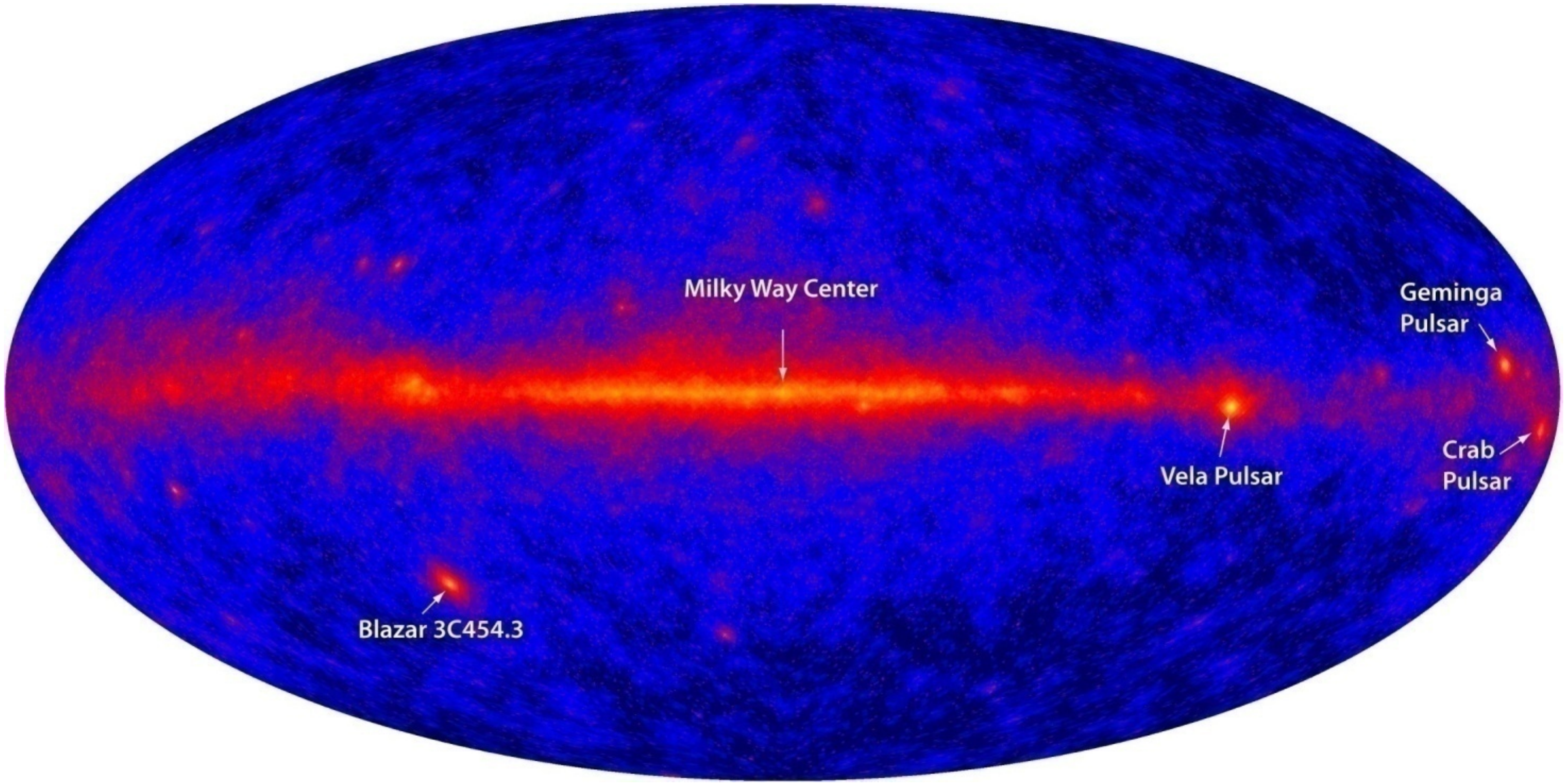


Low energy: dominated by MS

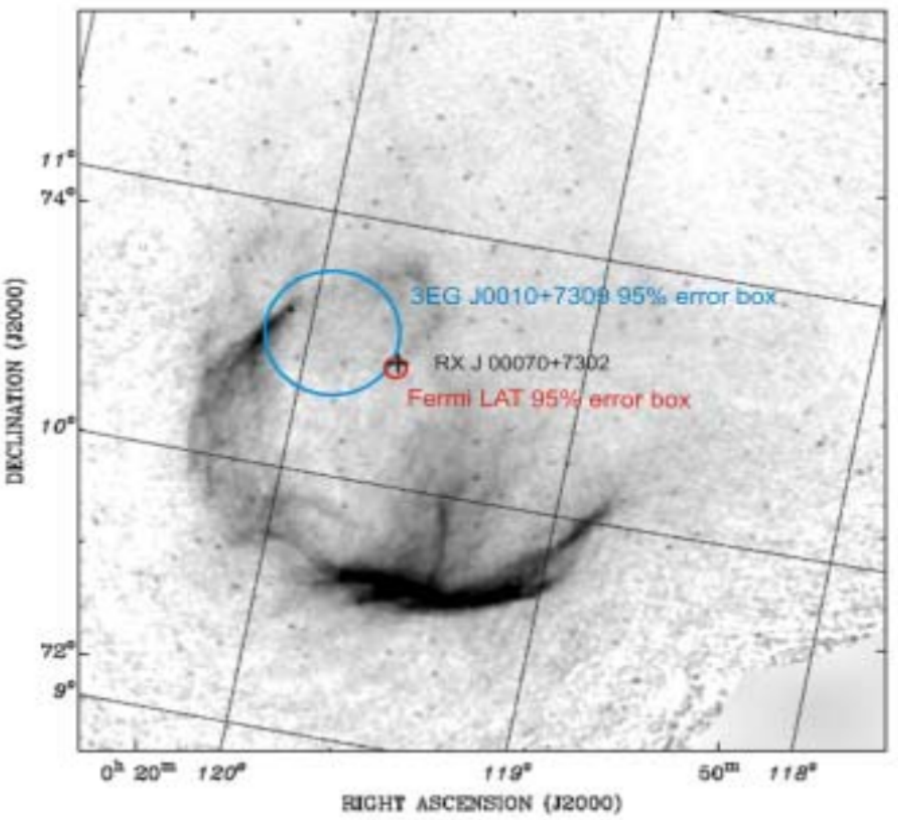
High energy: dominated by strip pitch

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

LAT first light



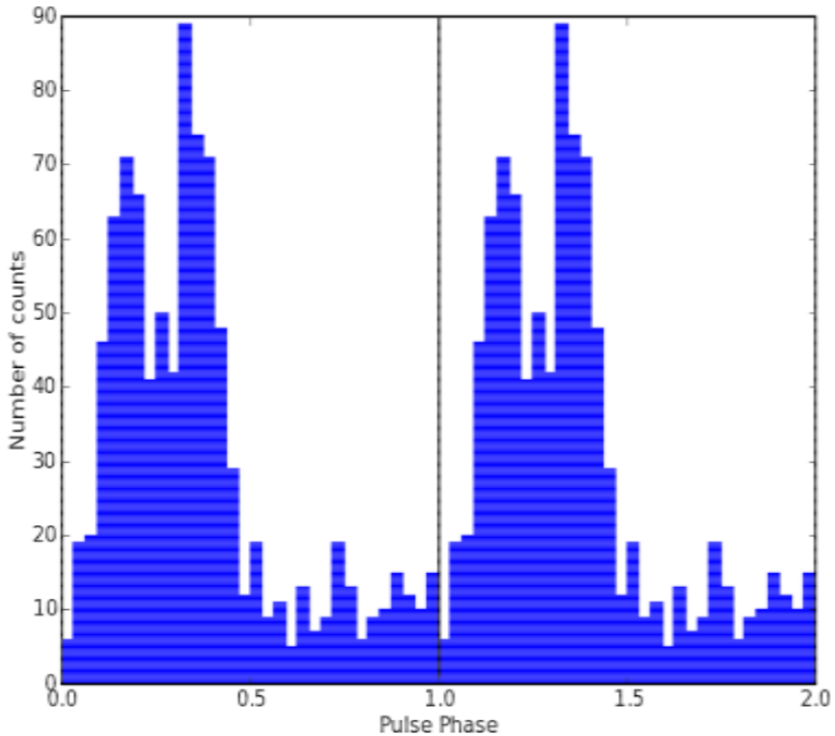
LAT discovers a radio-quiet pulsar!



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

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



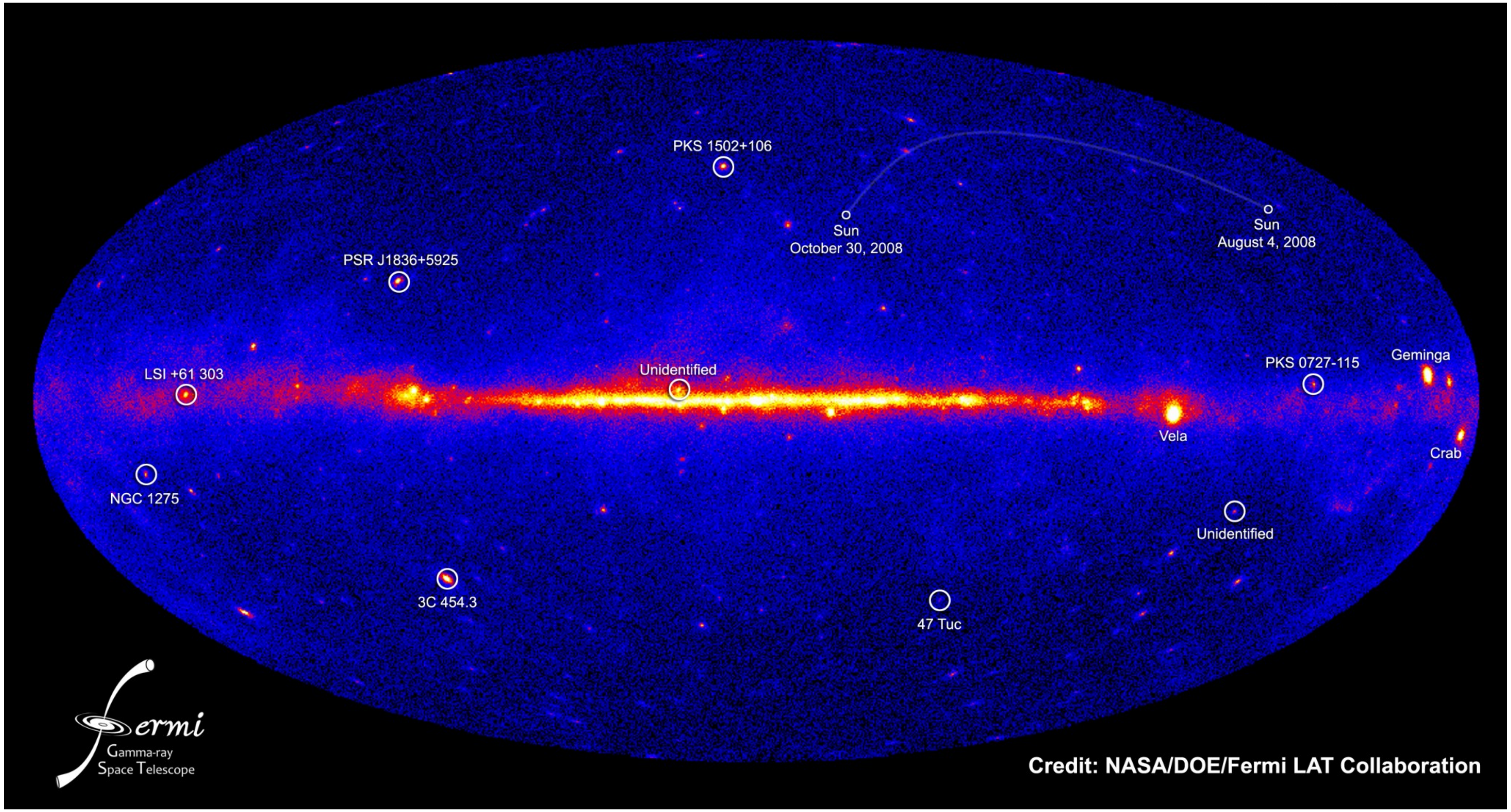
Fermi Gamma-ray Space Telescope

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

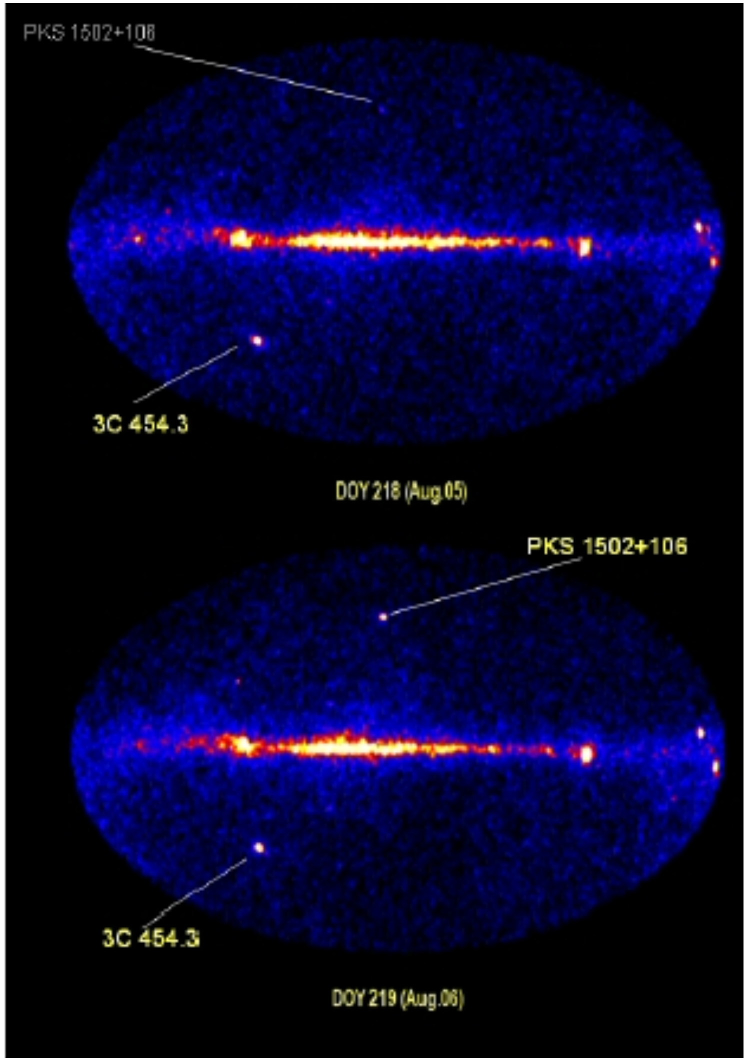
http://fermi.gsfc.nasa.gov/

“ 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. ”

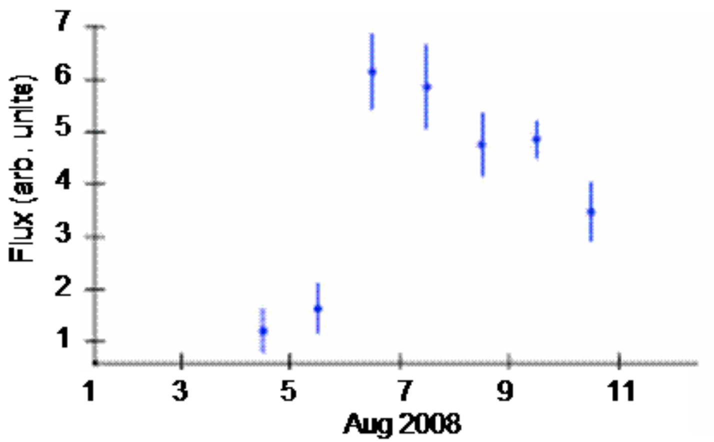
Fermi LAT 3 months sky



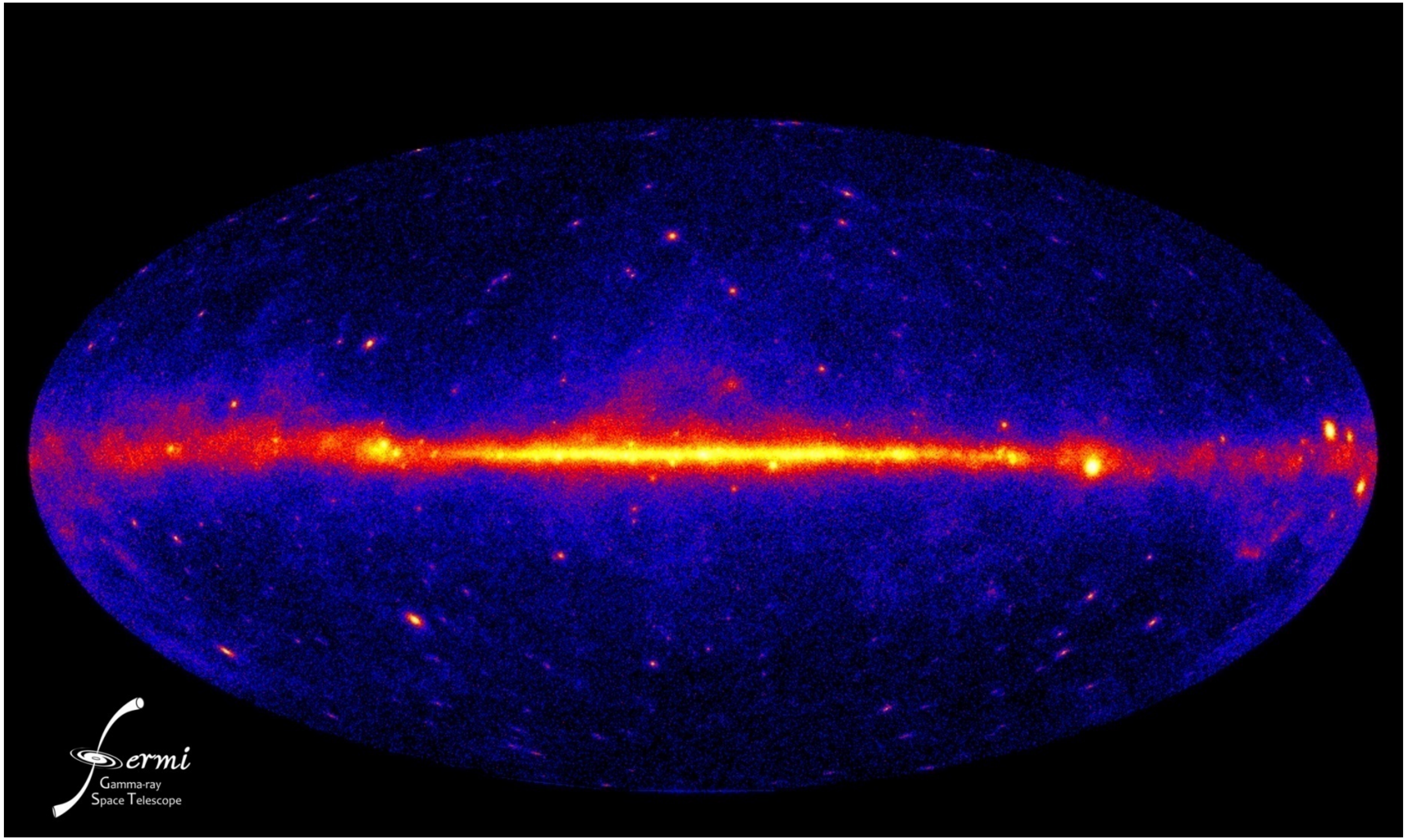
PKS 1502-106 and 3C454.3



- The sky is dynamic, Fermi is monitoring the sky, catching flaring sources over different time scales.
- Atel #1628 (3C454.3) and #1650 (PKS 1502-106) issued to announce these flares.



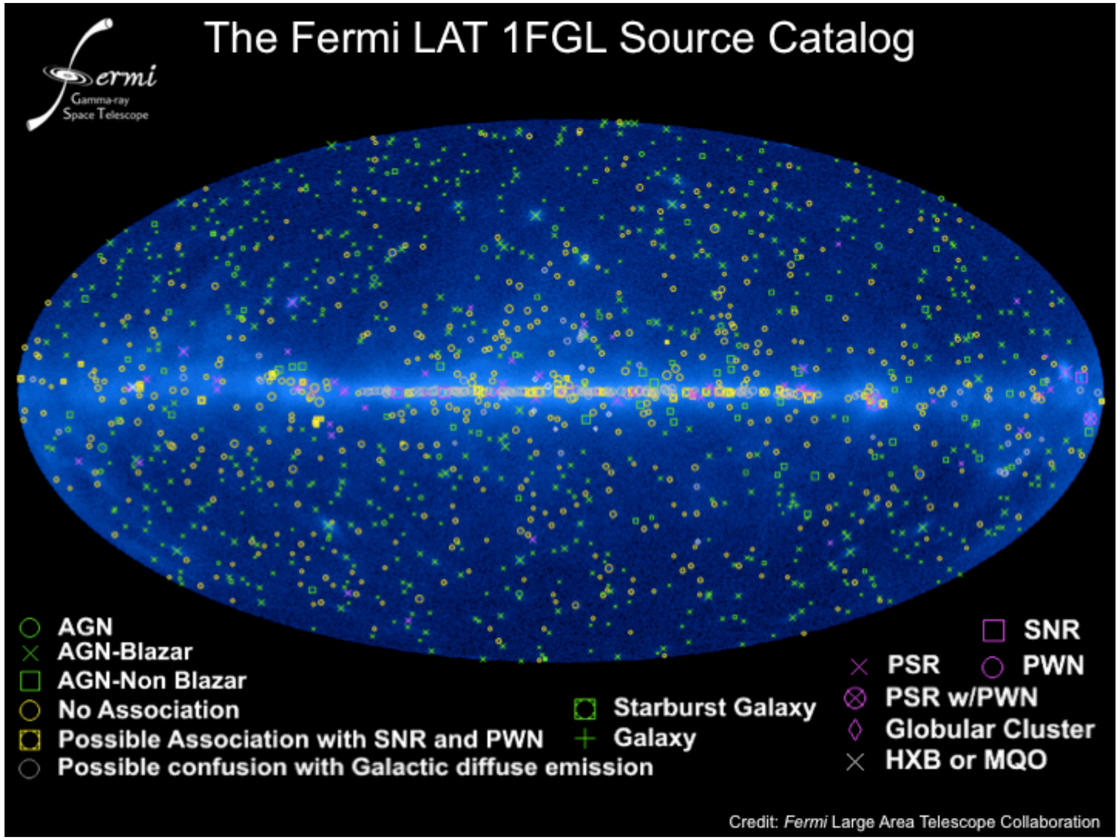
Fermi 1 yr sky



Fermi Year One Catalog

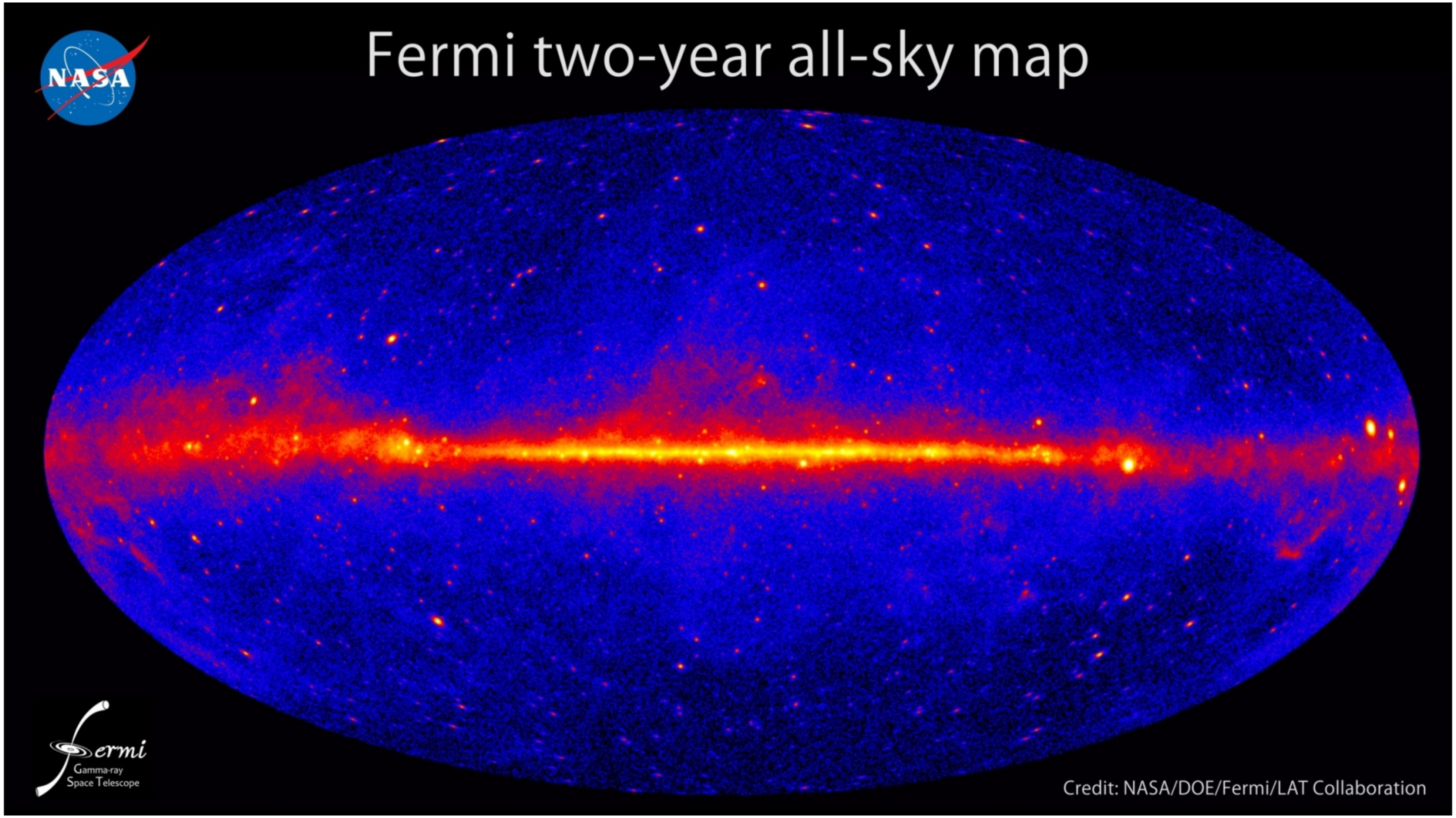
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr_catalog/

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

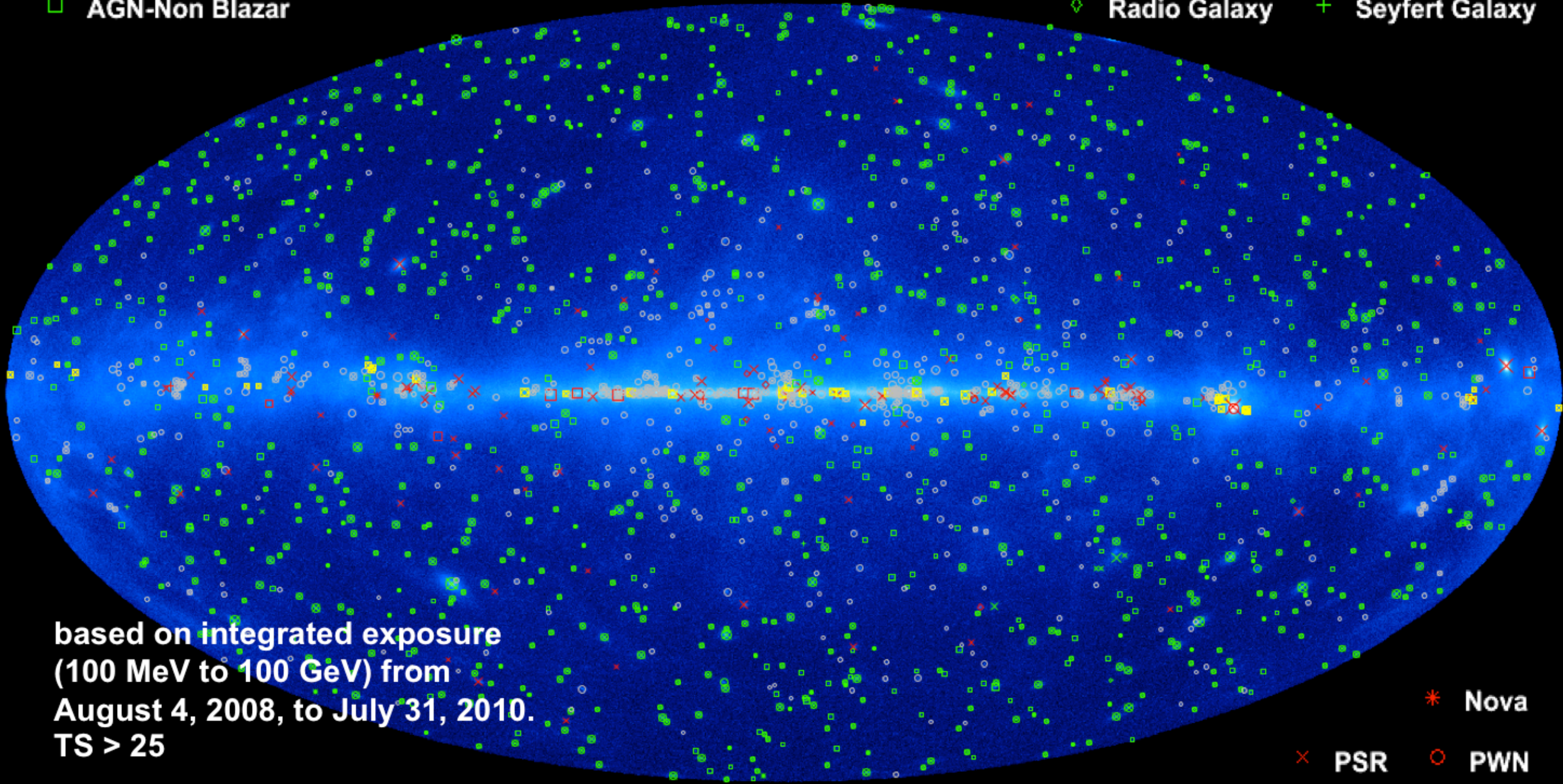

Fermi two-year all-sky map
NASA
Fermi
Gamma-ray
Space Telescope
Credit: NASA/DOE/Fermi/LAT Collaboration

2FGL Catalog

1,873 sources

○ AGN ⊗ AGN-Blazar
□ AGN-Non Blazar

× Galaxy ✳ Starburst Galaxy
◊ Radio Galaxy + Seyfert Galaxy



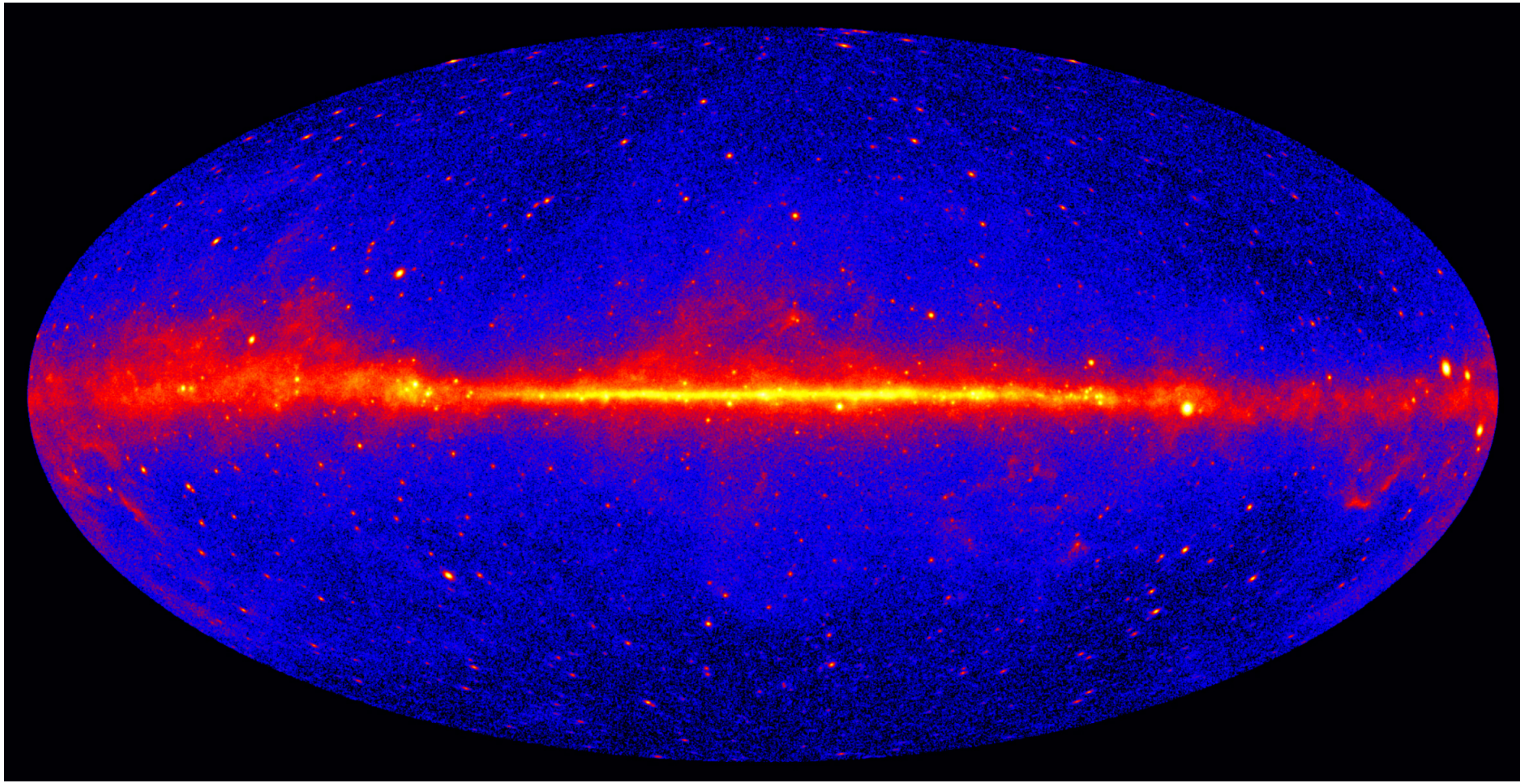
based on integrated exposure (100 MeV to 100 GeV) from August 4, 2008, to July 31, 2010. TS > 25

○ Unassociated
□ Possible Association with SNR and PWN

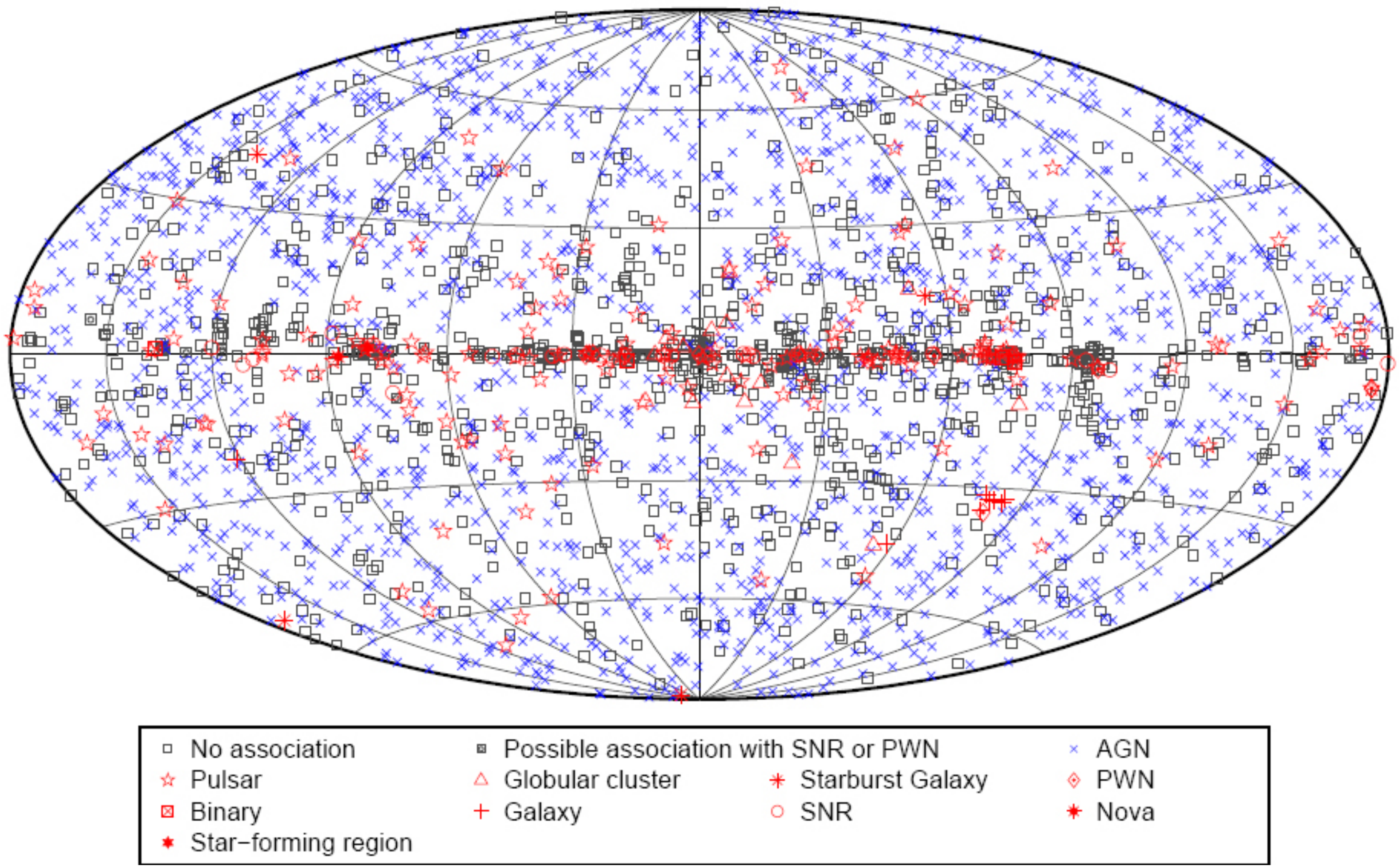
✳ Nova
× PSR ○ PWN
⊗ PSR w/PWN □ SNR
◊ Globular Cluster + HMB

Credit: Fermi Large Area Telescope Collaboration

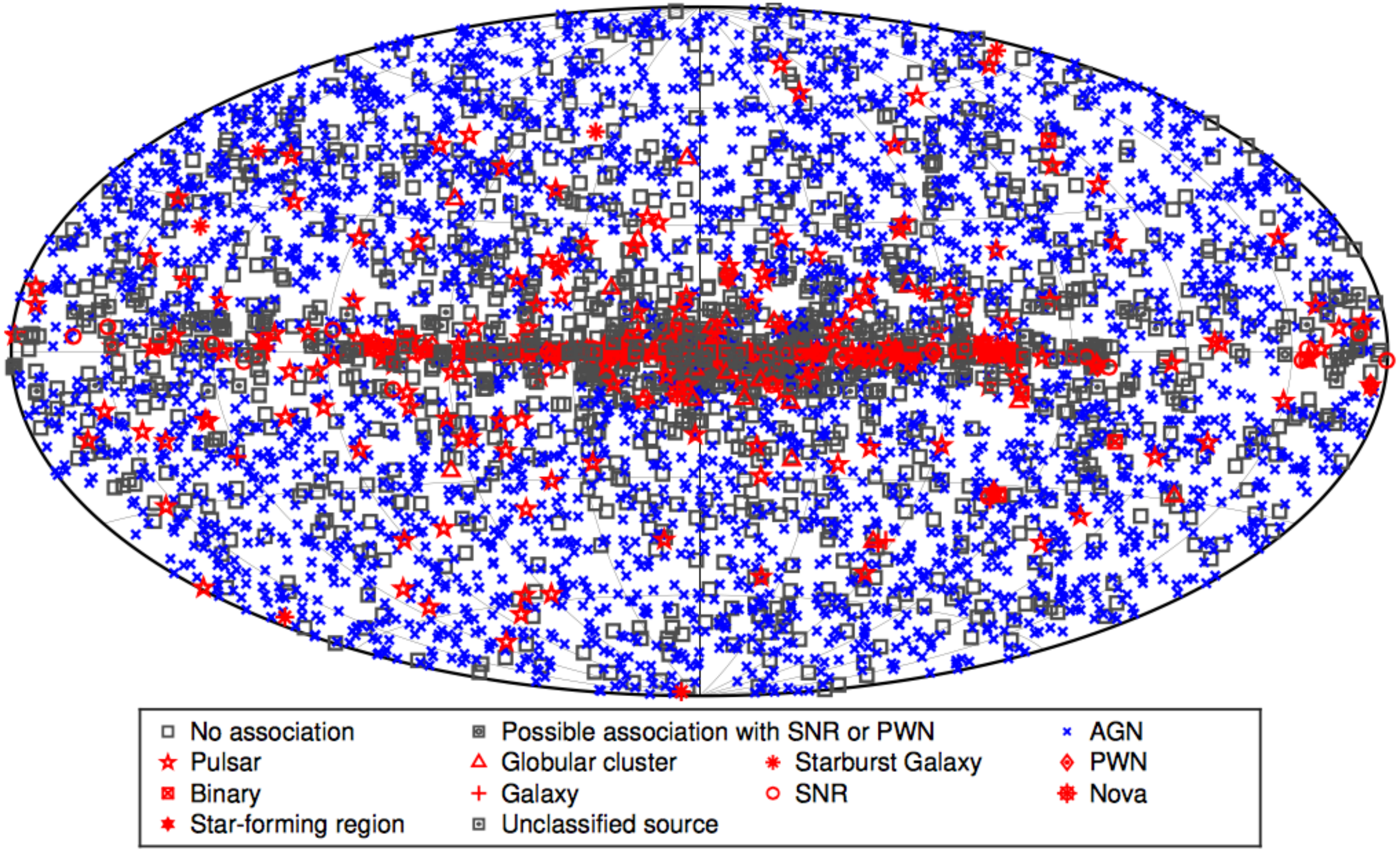
4 years sky



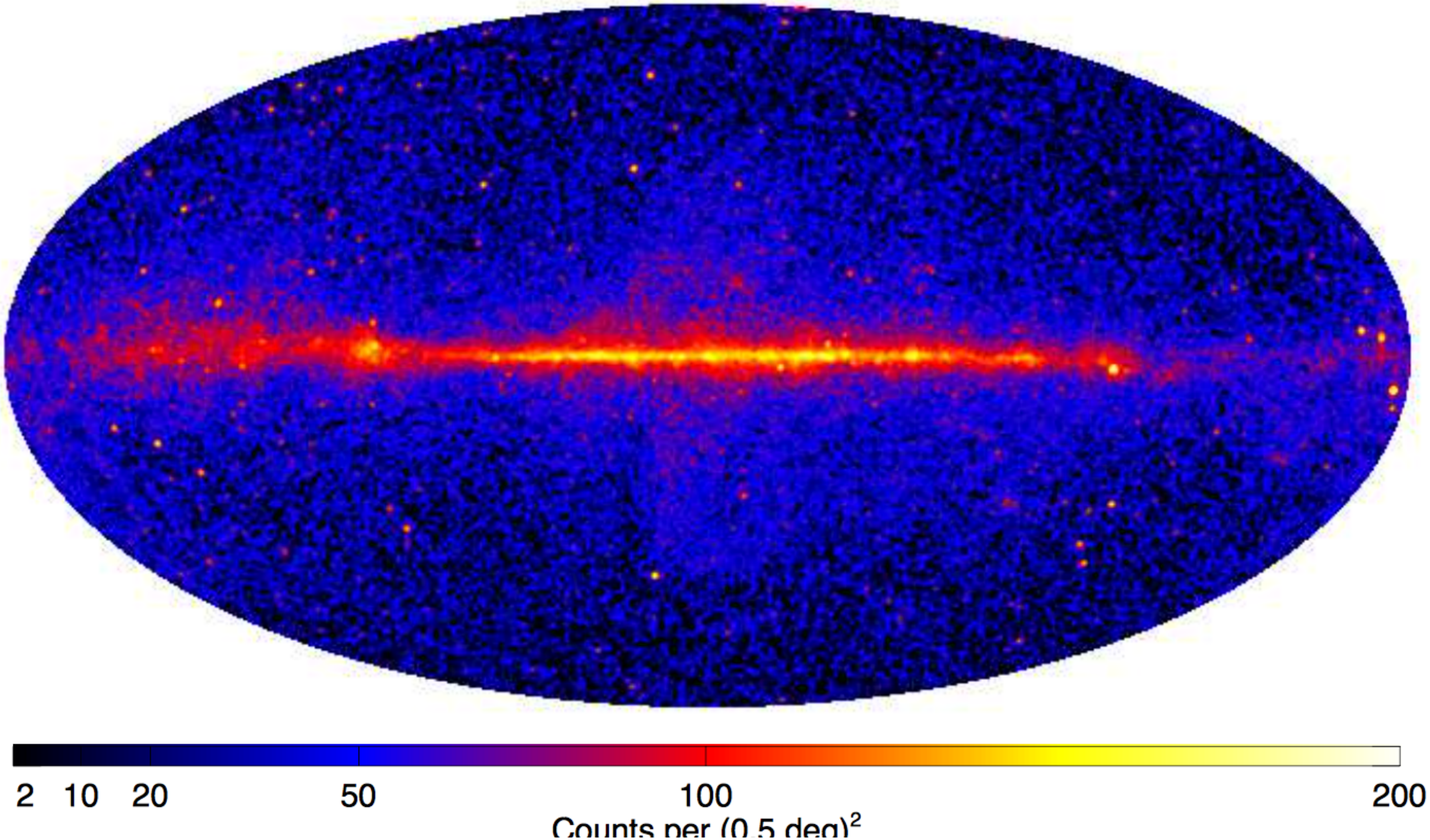
3FGL catalog – 3033 sources



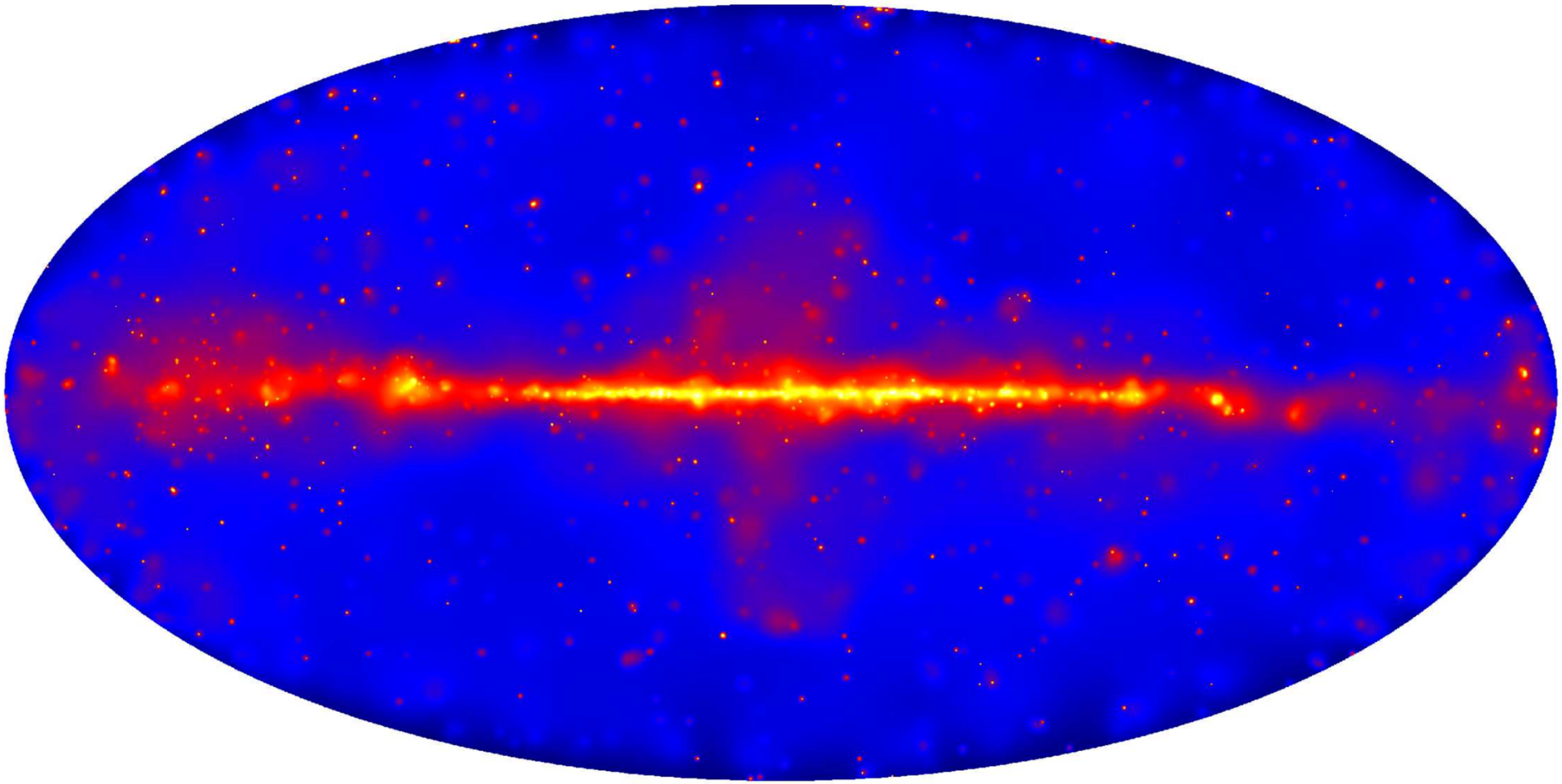
4FGL catalog



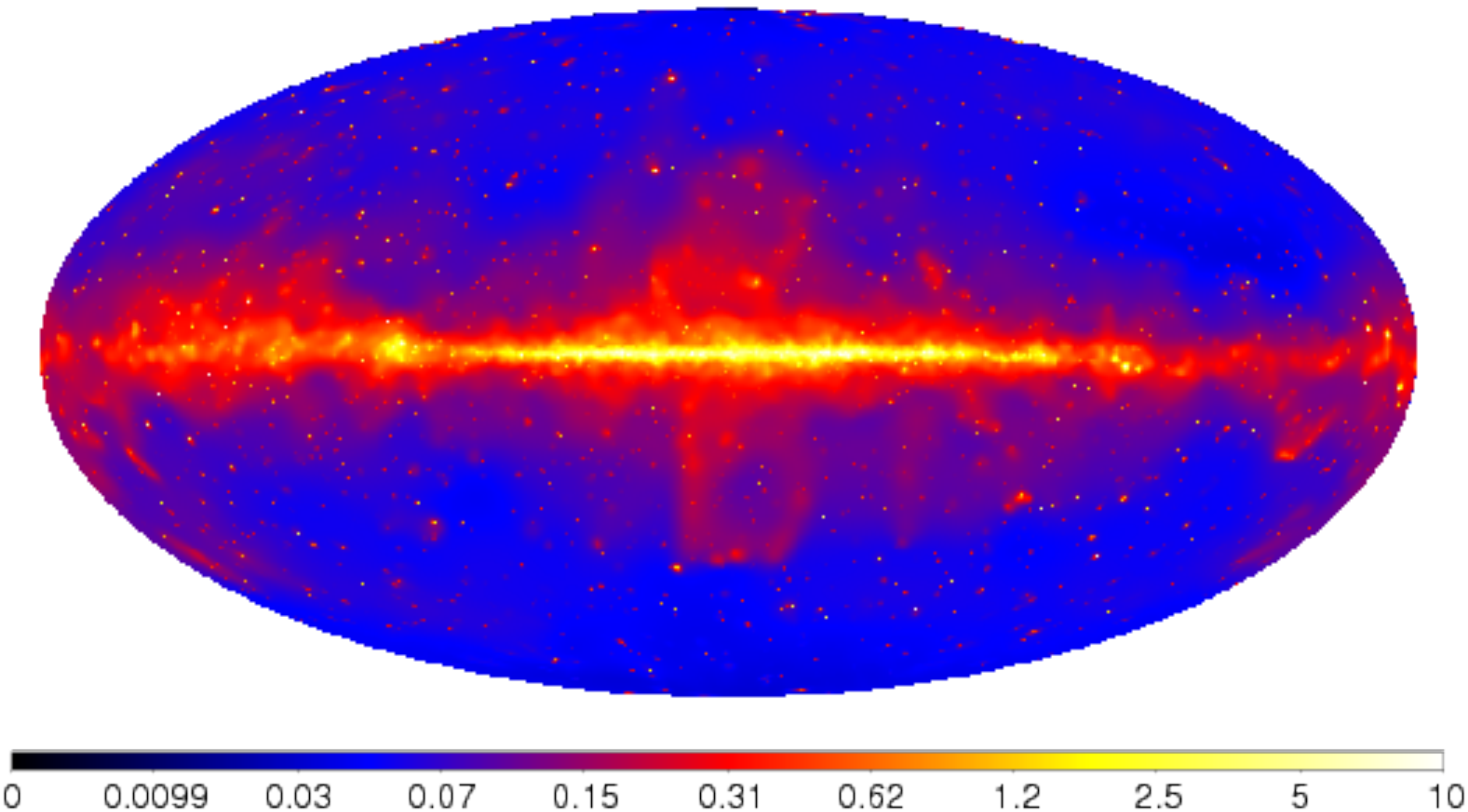
1 FHL (3 years, Pass7, E>10 GeV)



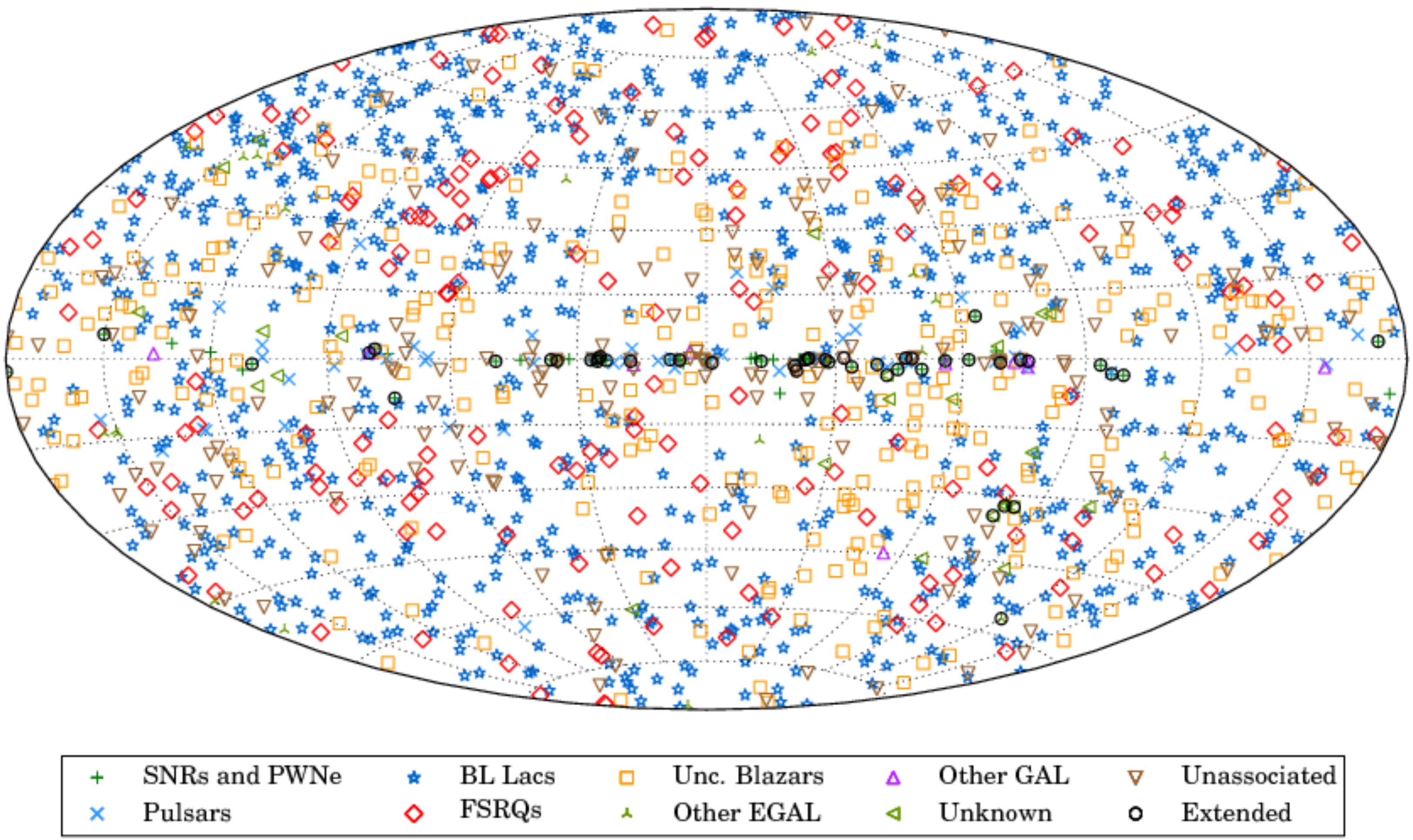
2FHL (P8 data >50 GeV) – 80 months



3FHL (E>10 GeV – P8)



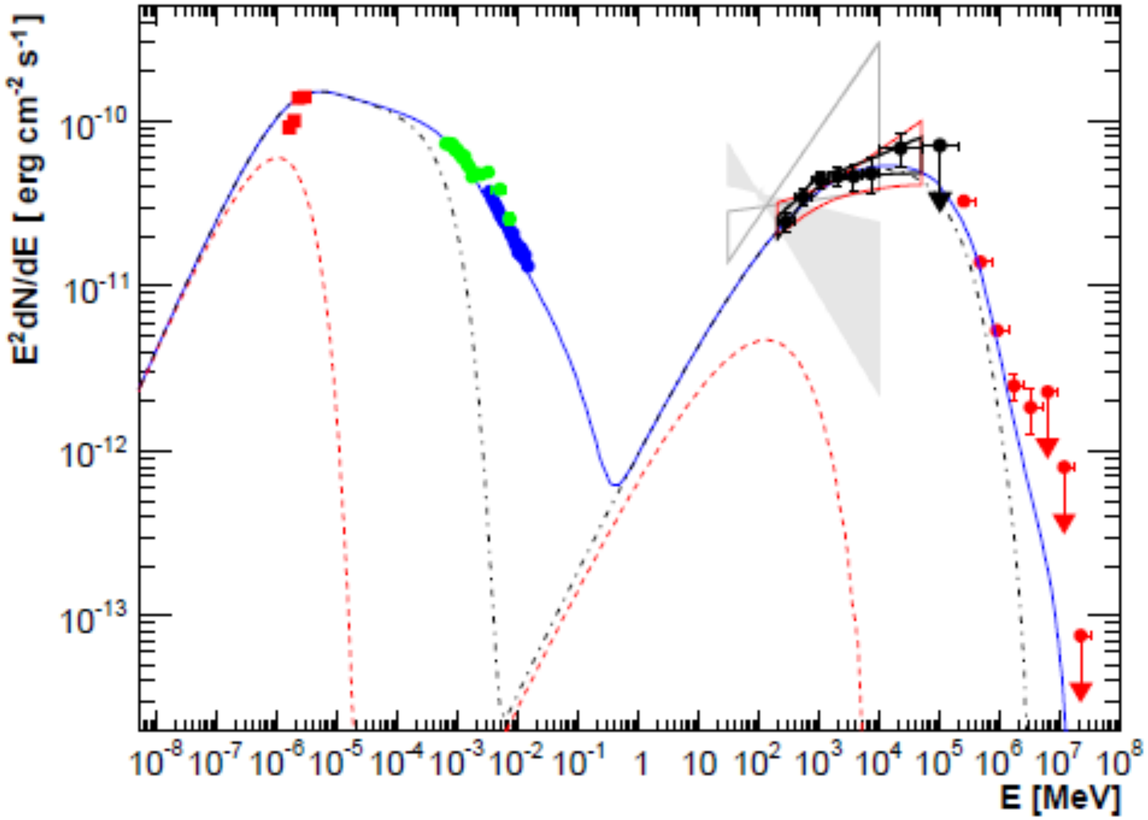
3 FHL



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

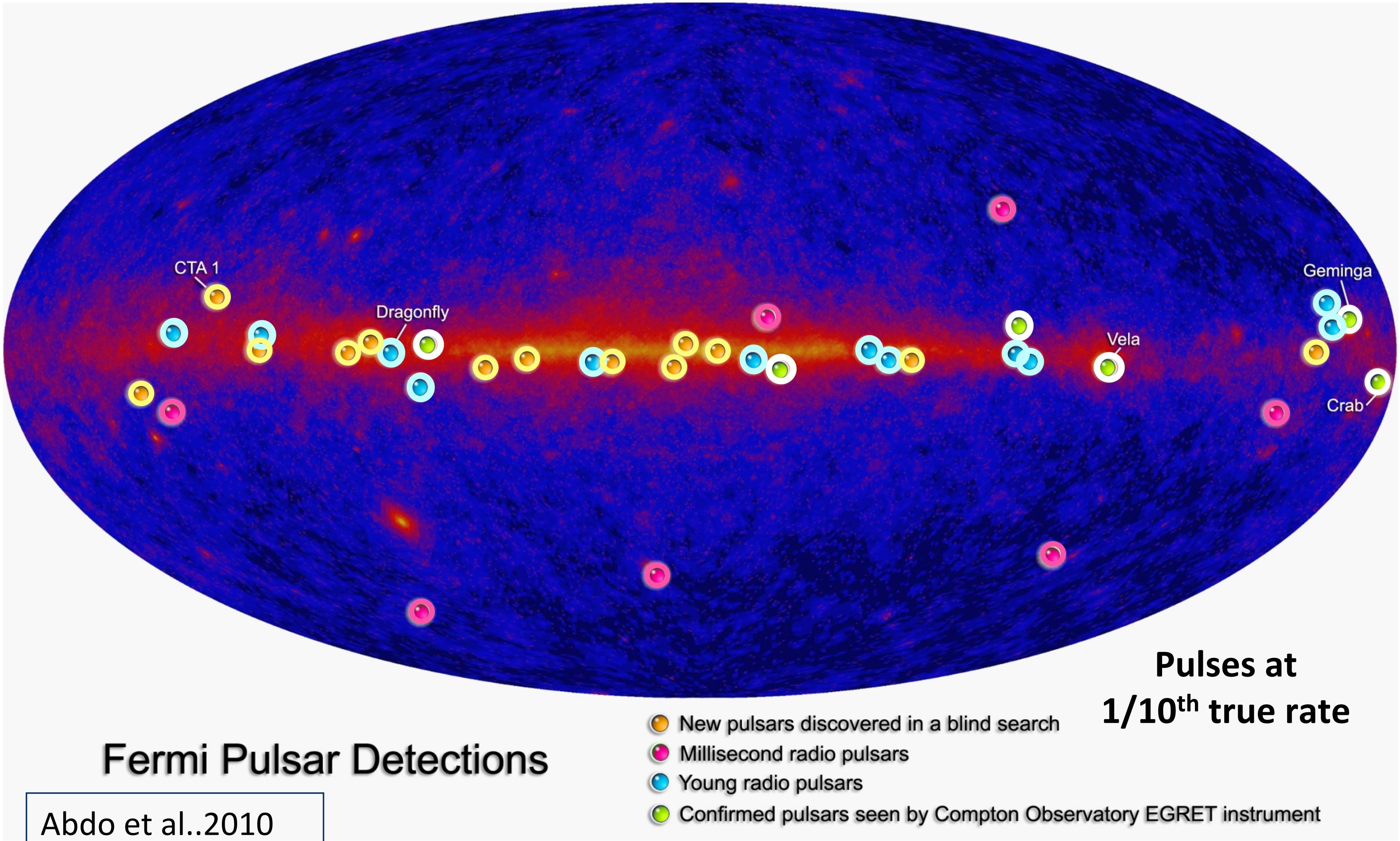
Challenge # 1 – AGN

Joint campaign on PKS 2155 with HESS



Aharonian et al. 2009

Challenge # 2 – Pulsars Blind Search



Pulses at 1/10th true rate

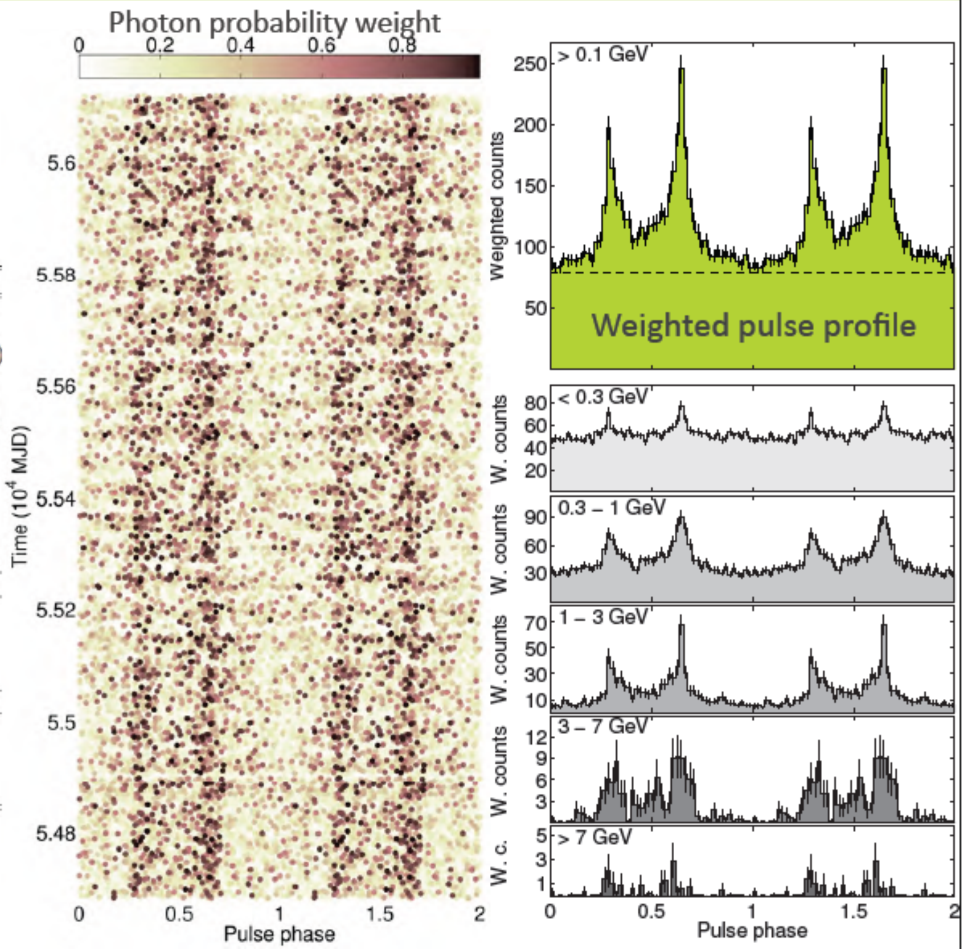
Abdo et al..2010

The first blind ms Pulsar

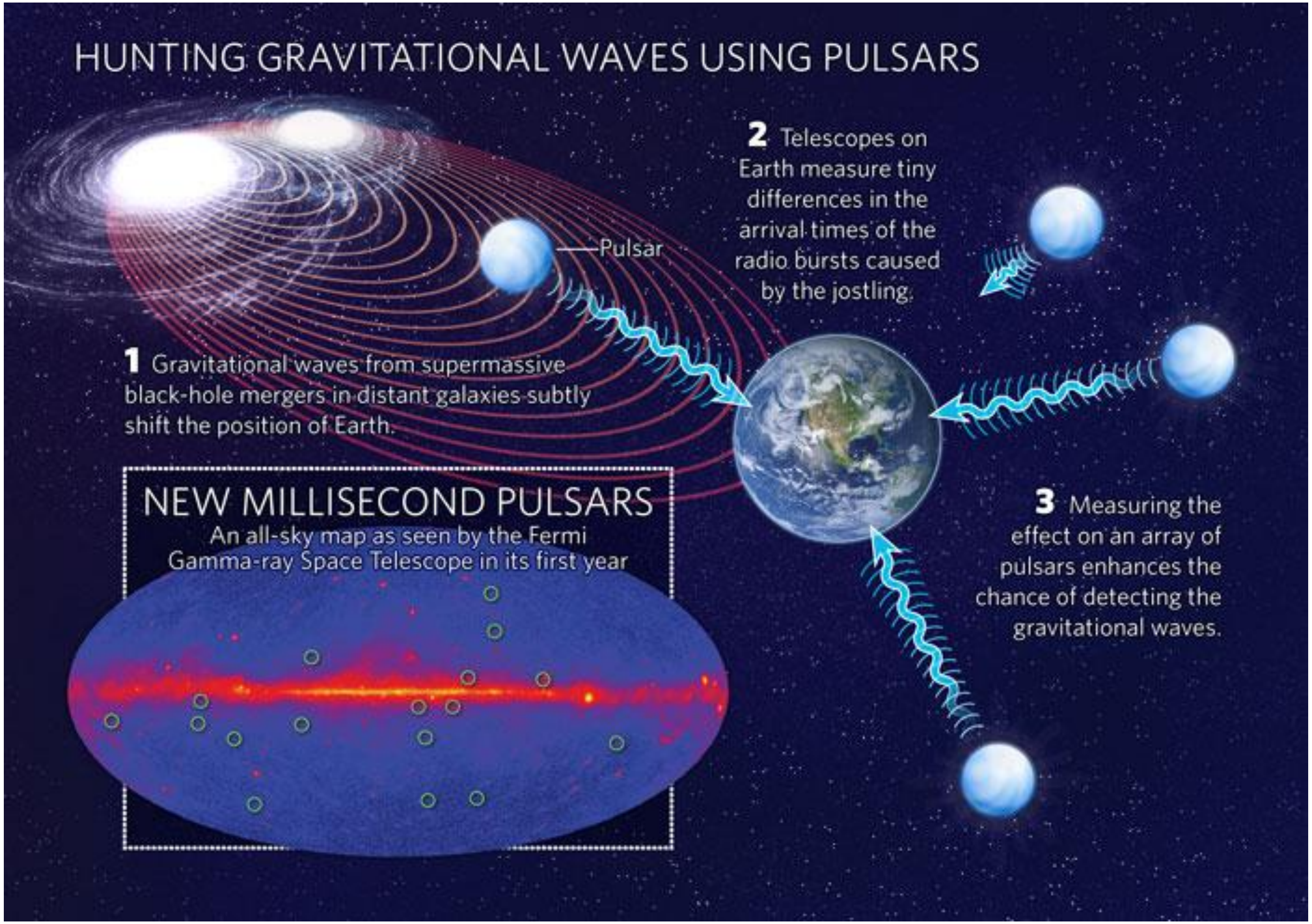
The PSR J1311-3430 system (1/2)

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

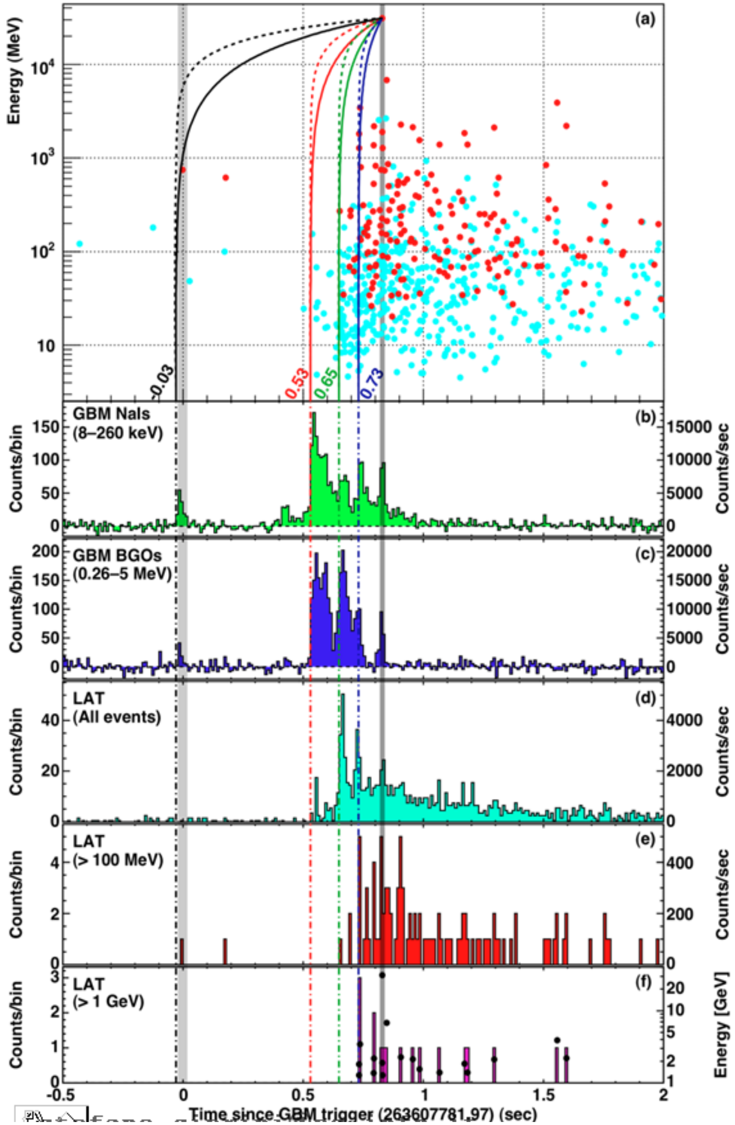
Parameter	Value
Right ascension (J2000.0) (hh:mm:ss)	13:11:45.7242(2)
Declination (J2000.0) (dd:mm:ss)	−34:30:30.350(4)
Spin frequency, f (Hz)	390.56839326407(4)
Frequency derivative, $\dot{f}$ (Hz s^{-1})	$-3.198(2) \times 10^{-15}$
Reference time scale	TDB
Reference time (MJD)	55266.90789575858
Orbital period P_{orb} (d)	0.0651157335(7)
Projected pulsar semi-major axis x (lt-s)	0.010581(4)
Time of ascending node T_{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 $\lvert\Delta t\rvert$ (ms)	Reasoning for choice of t_{start} or limit on Δt or $\lvert\Delta t/\Delta E\rvert$	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)♠	$\lvert\Delta t/\Delta E\rvert$ < 30 ms/GeV		lag analysis of > 1 GeV spikes	—	±1	> 1.22

nature

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Published: 01 October 1998

Tests of quantum gravity from observations of γ-ray bursts

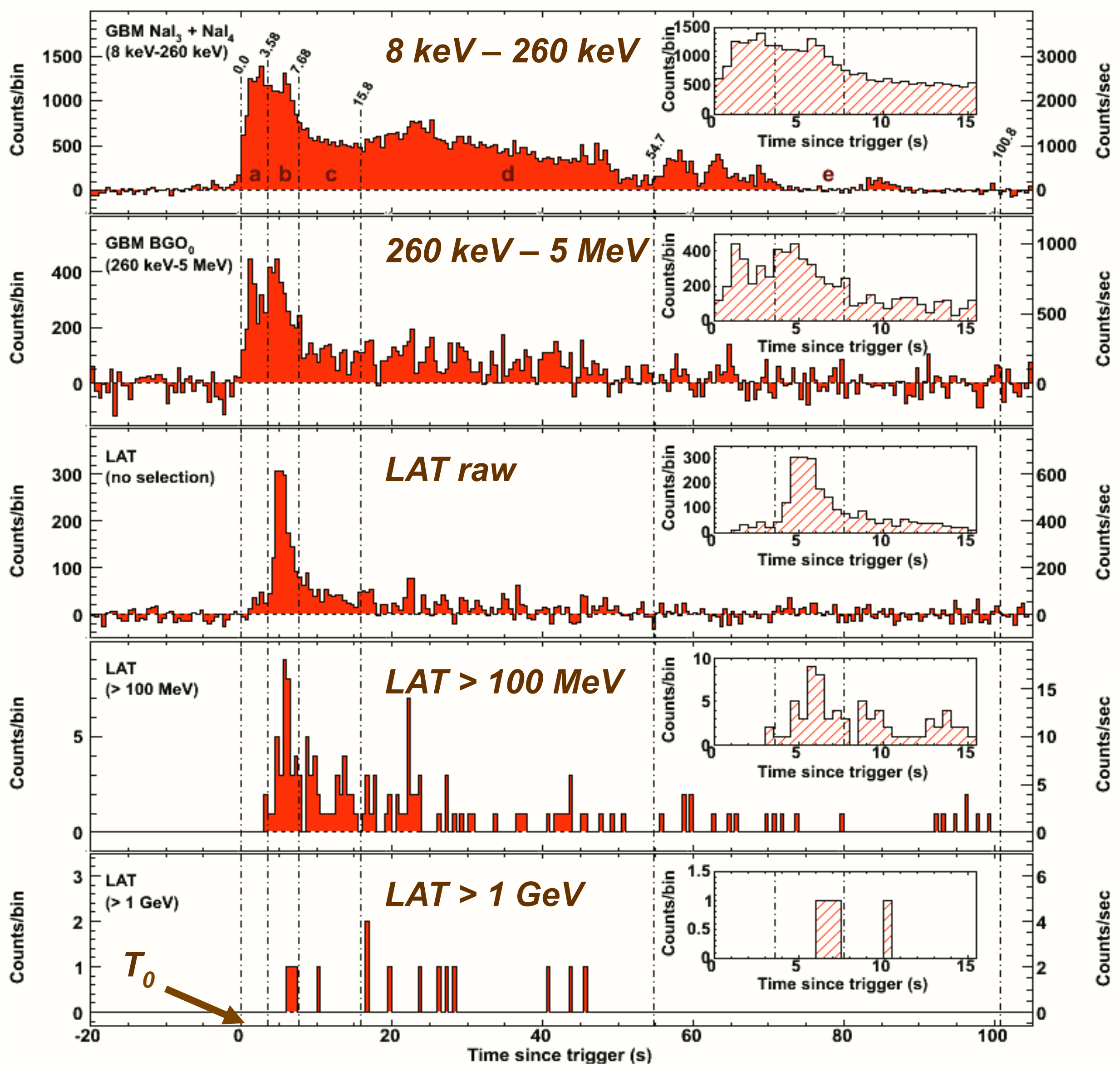
G. Amelino-Camelia, John Ellis, N. E. Mavromatos, D. V. Nanopoulos & Subir Sarkar

Nature **395**, 525 (1998) | Cite this article

The recent confirmation that at least some γ-ray bursts originate at cosmological distances[1–4] suggests that the radiation from them could be used to probe some of the fundamental laws of physics. Here we show that γ-ray bursts will be sensitive to an energy dispersion predicted by some approaches to quantum gravity. Many of the bursts have structure on relatively rapid timescales[5], which means that in principle it is possible to look for energy-dependent dispersion of the radiation, manifested in the arrival times of the photons, if several different energy bands are observed simultaneously. A simple estimate indicates that, because of their high energies and distant origin, observations of these bursts should be sensitive to a dispersion scale that is comparable to the Planck energy scale ($\sim 10^{19}$ GeV), which is sufficient to test theories of quantum gravity. Such observations are already possible using existing γ-ray burst detectors.

$$v = \frac{\partial E}{\partial p} \approx c\left(1 - \xi \frac{E}{E_{QG}}\right) \qquad \Delta t \approx \xi \frac{E}{E_{QG}} \frac{L}{c}$$

GRB080916C - Multiple detector light curve



First 3 light curves are background subtracted

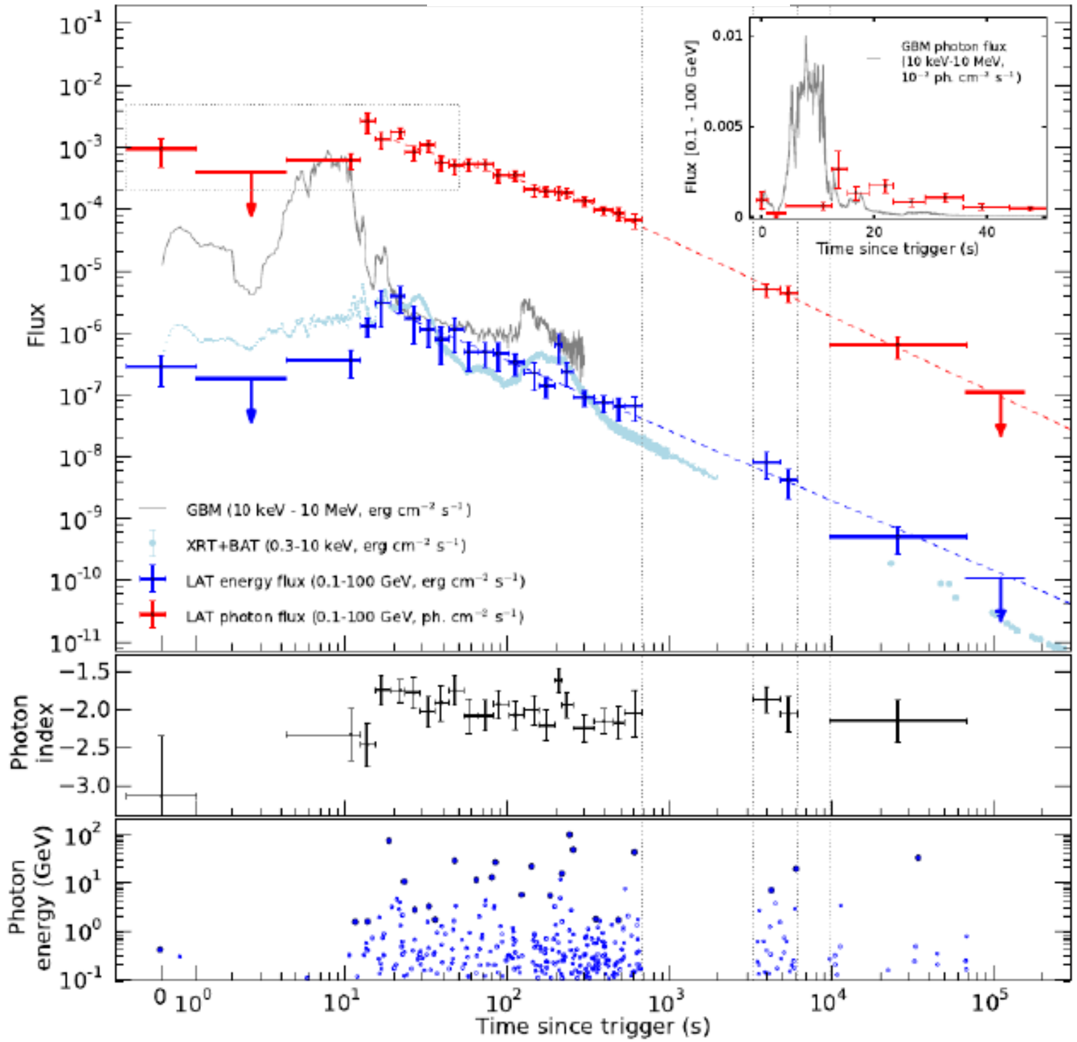
The LAT can be used as a counter to maximize the rate and to study time structures above tens of MeV

- **The first low-energy peak is not observed at LAT energies**

Spectroscopy needs LAT event selection (>100 MeV)

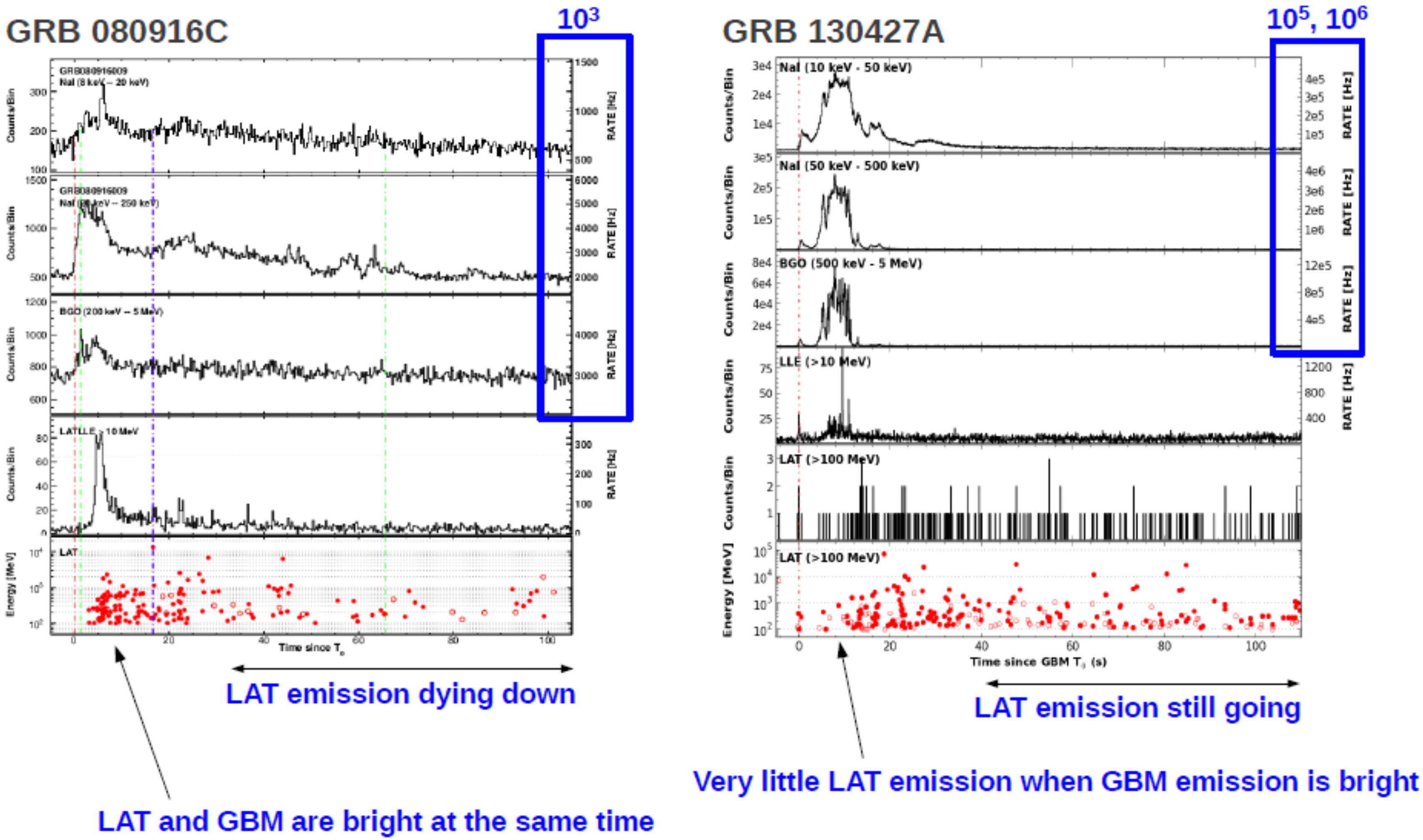
- **14 events above 1 GeV**

GRB 130427A



(Ackermann et al., Science, Vol. 343 no. 6166 pp. 42-47)

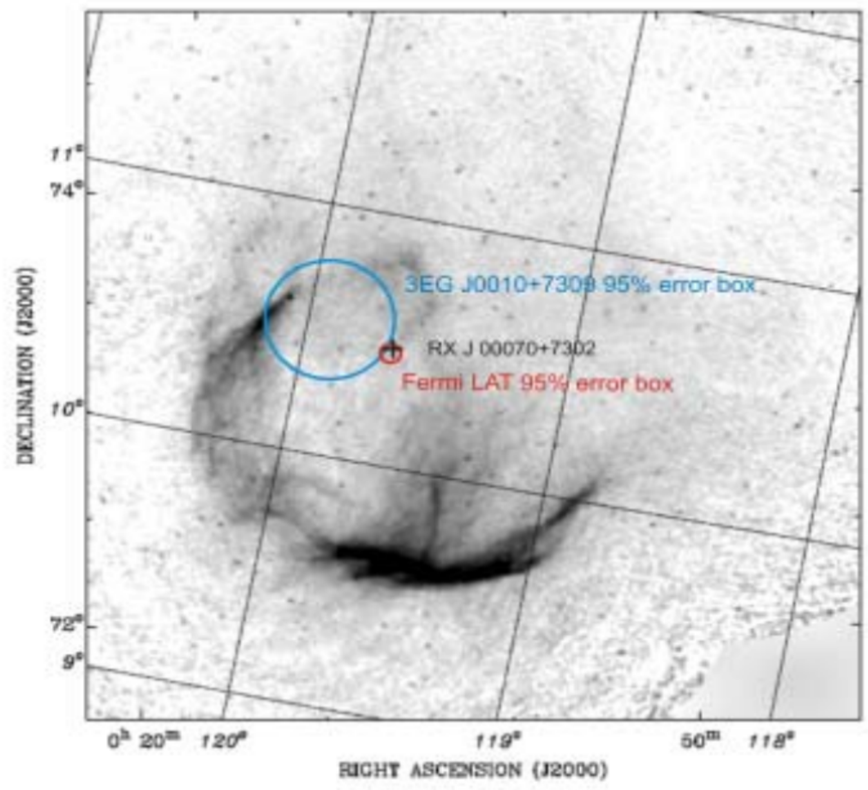
GRB 130427A

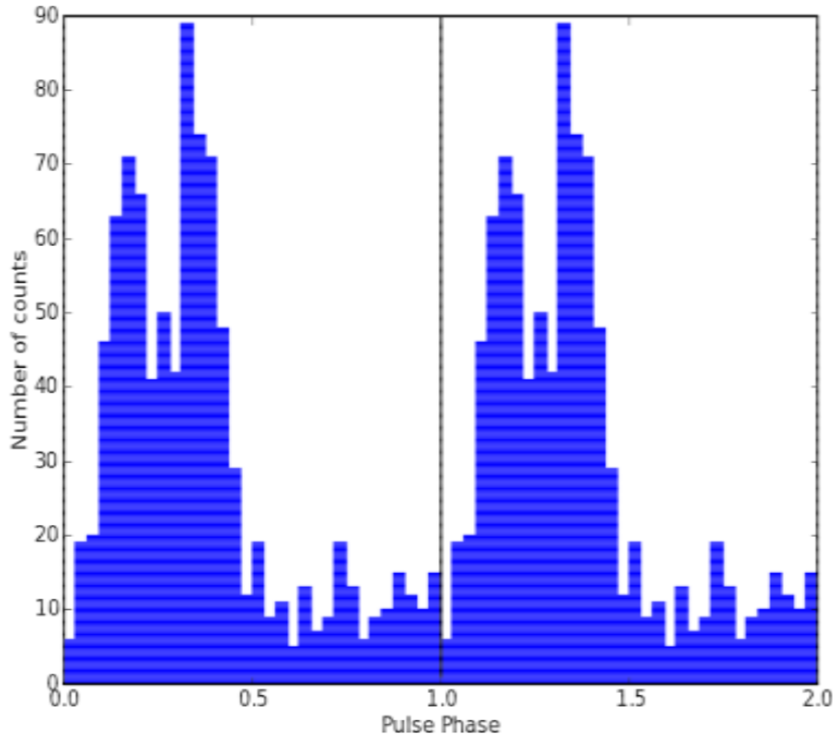


GRB 080916C
10^3
NaI (8 keV – 20 keV)
NaI (260 keV – 250 keV)
BGO (200 keV – 5 MeV)
LAT LLE > 10 MeV
LAT
Counts/Bin
RATE [Hz]
Energy [MeV]
Time since T_0
GRB 130427A
10^5, 10^6
NaI (10 keV - 50 keV)
NaI (50 keV - 500 keV)
BGO (500 keV - 5 MeV)
LLE (>10 MeV)
LAT (>100 MeV)
LAT (>100 MeV)
Time since GBM T_0 (s)
LAT emission dying down
LAT emission still going
Very little LAT emission when GBM emission is bright
LAT and GBM are bright at the same time

Challenge # 4 – Unidentified

CTA 1 Discovery

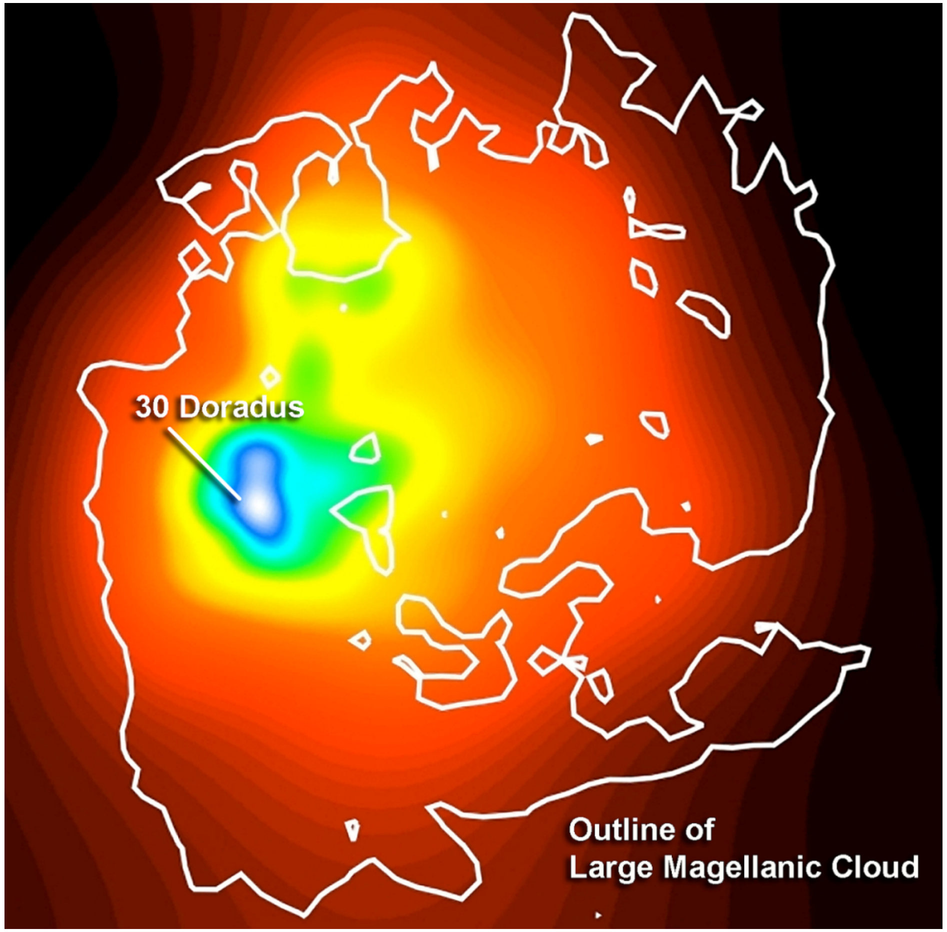




Abdo et al. 2008

Challenge # 4
Location of Gamma-ray emission

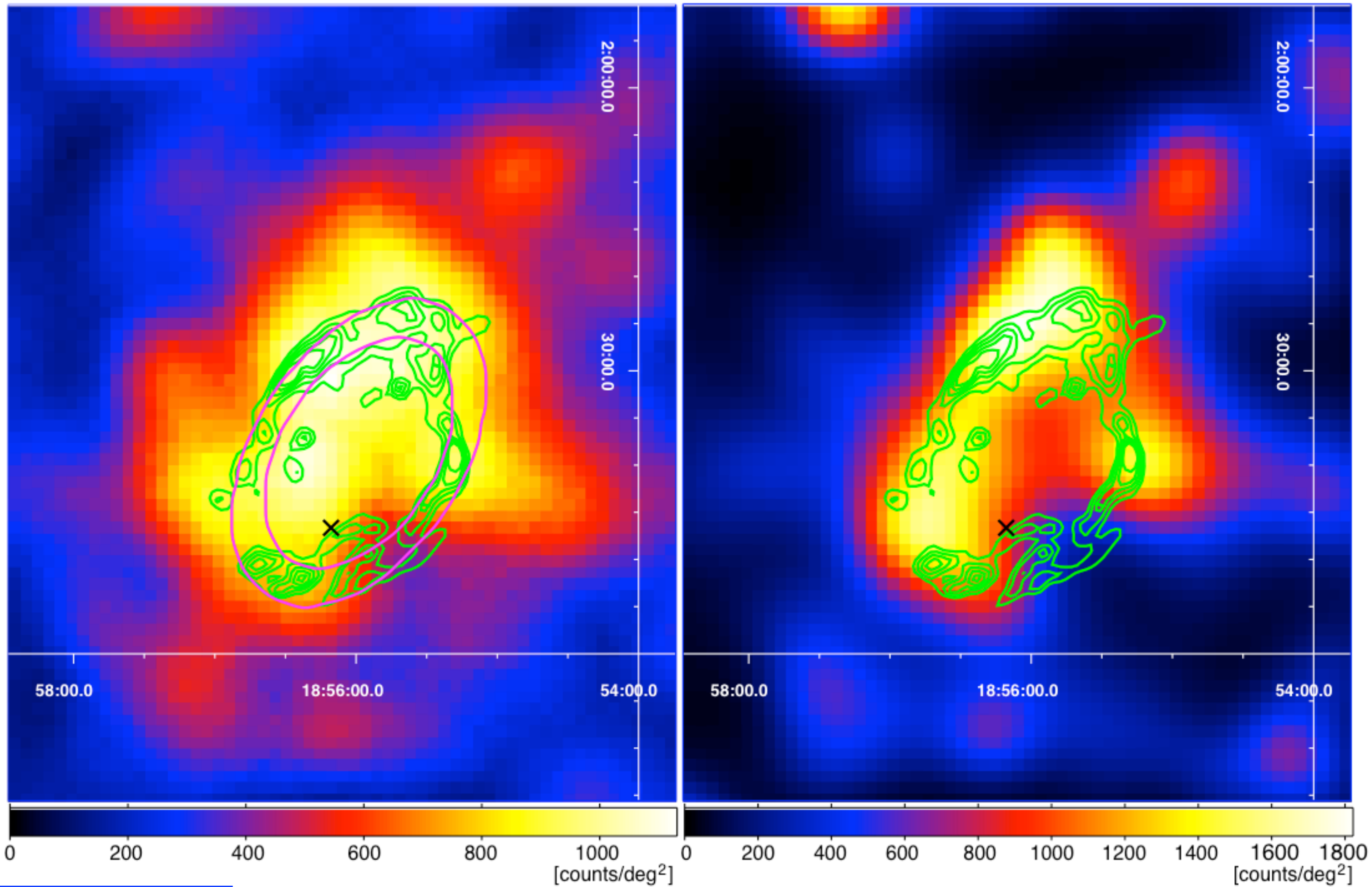
Observations of the Large Magellanic Cloud with *Fermi*



Abdo, A. A. et al. 2010

Challenge # 4
Location of Gamma-ray emission

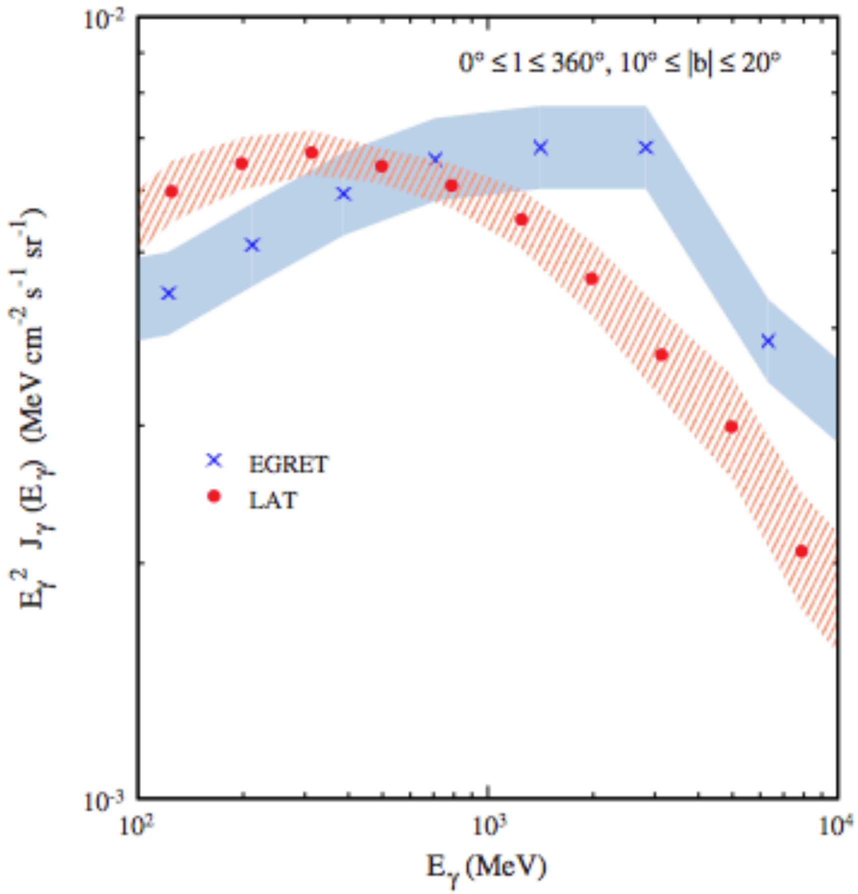
Gamma-Ray Emission from the Shell of Supernova Remnant W44 Revealed by the Fermi LAT

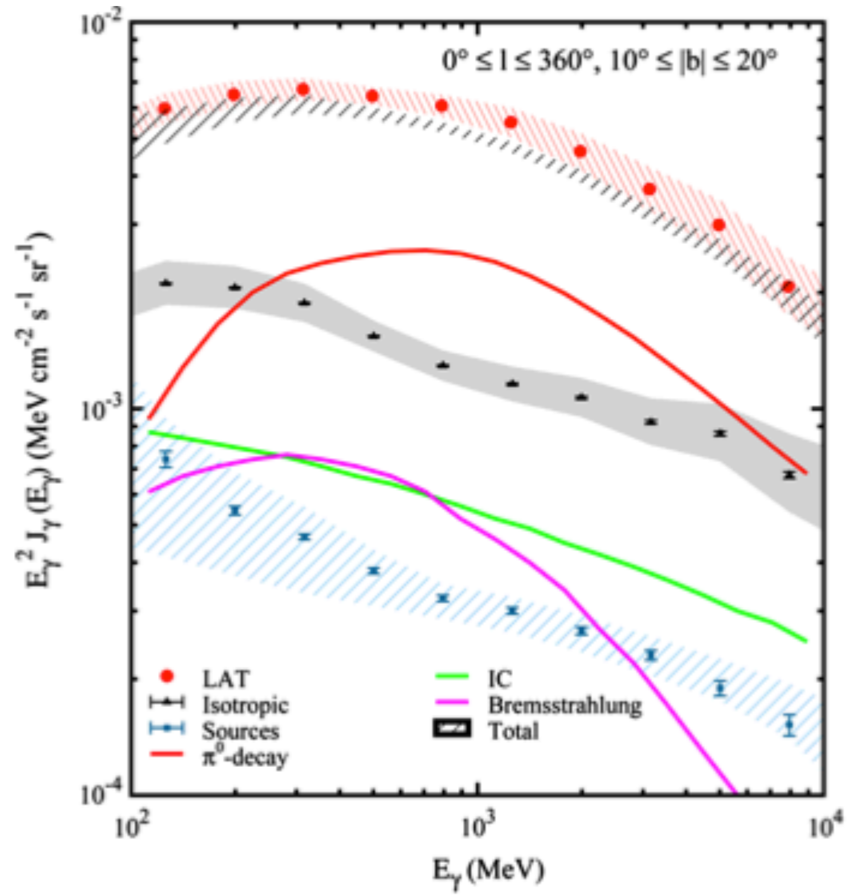


Abdo, A. A. et al. 2010

Challenge # 5 – Spectral Resolution

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

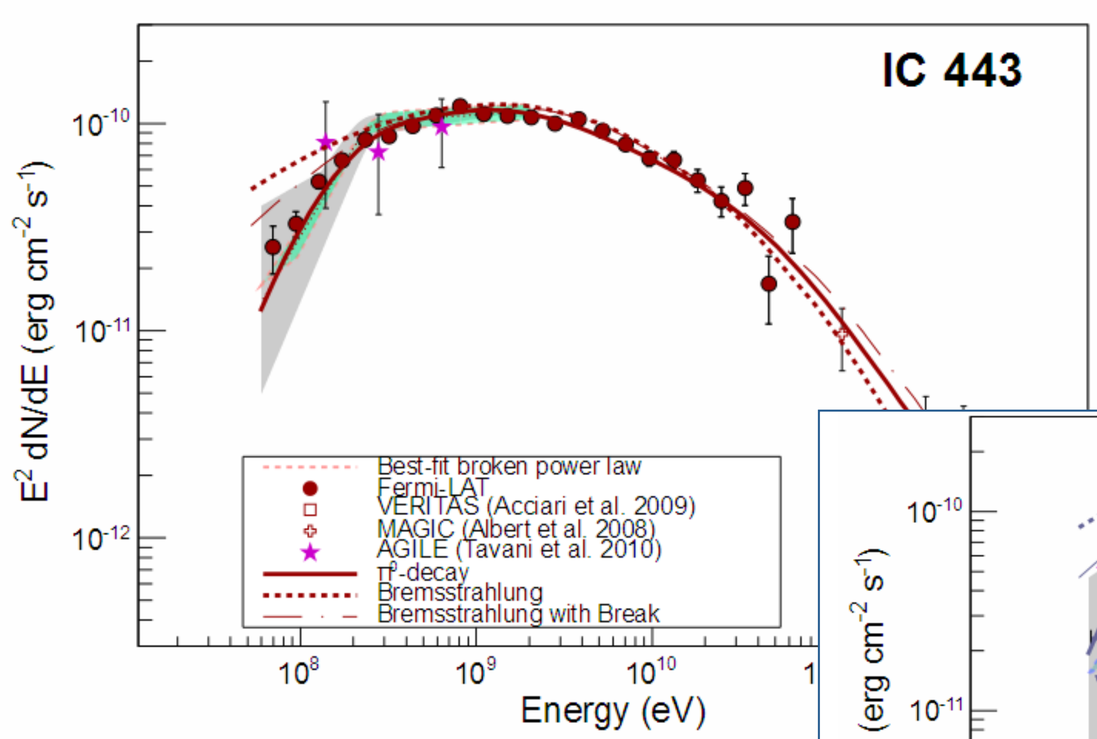


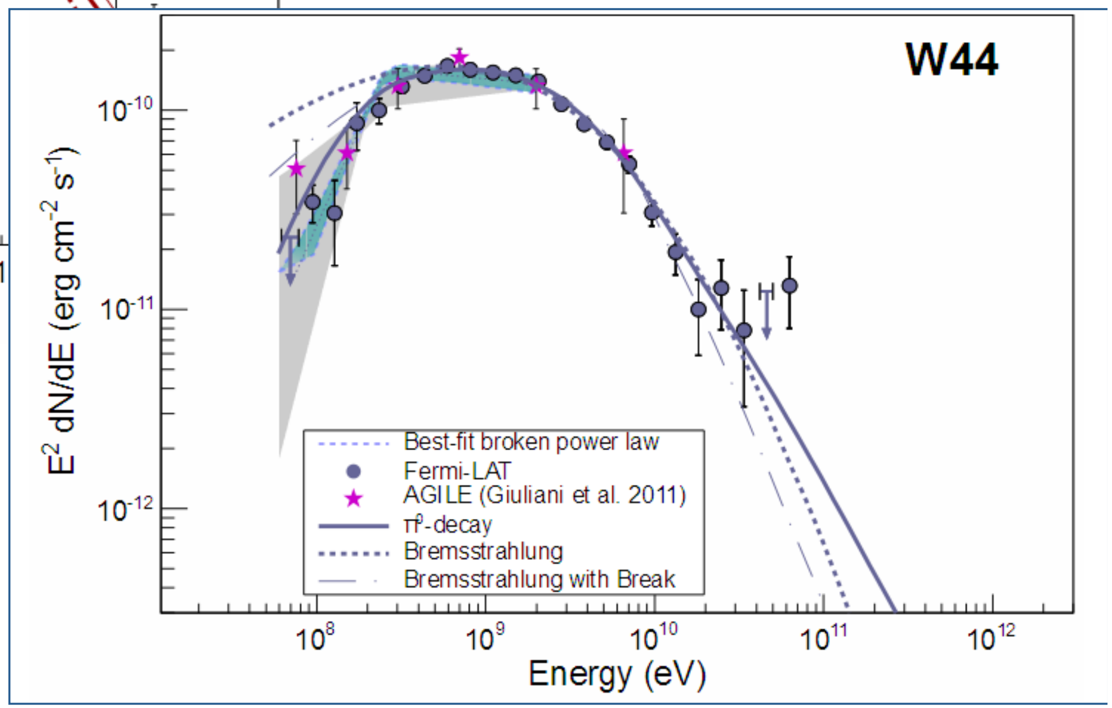


Abdo, A. A. et al. 2009

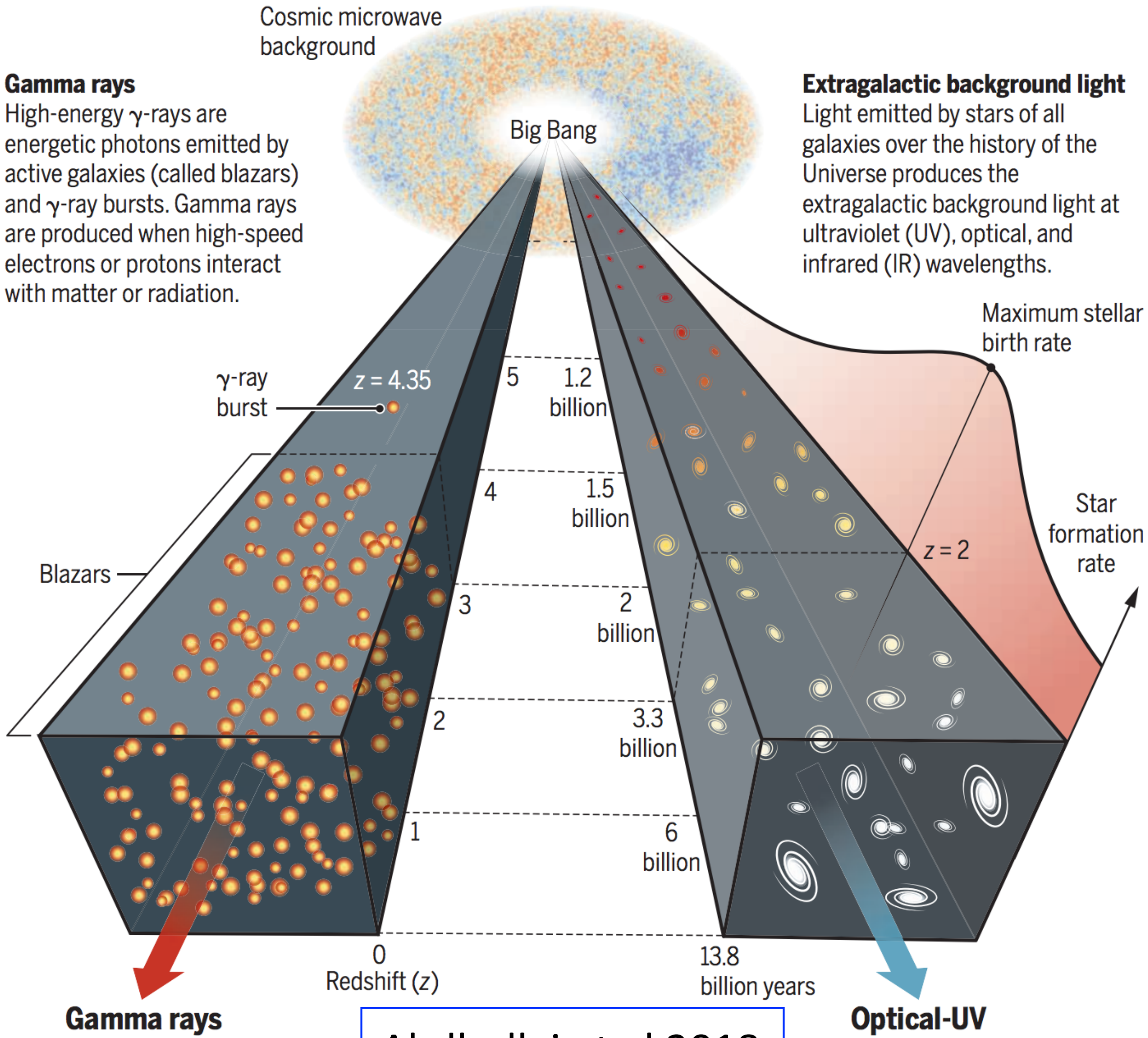
Supernova Remnants

Ackermann et al. 2013





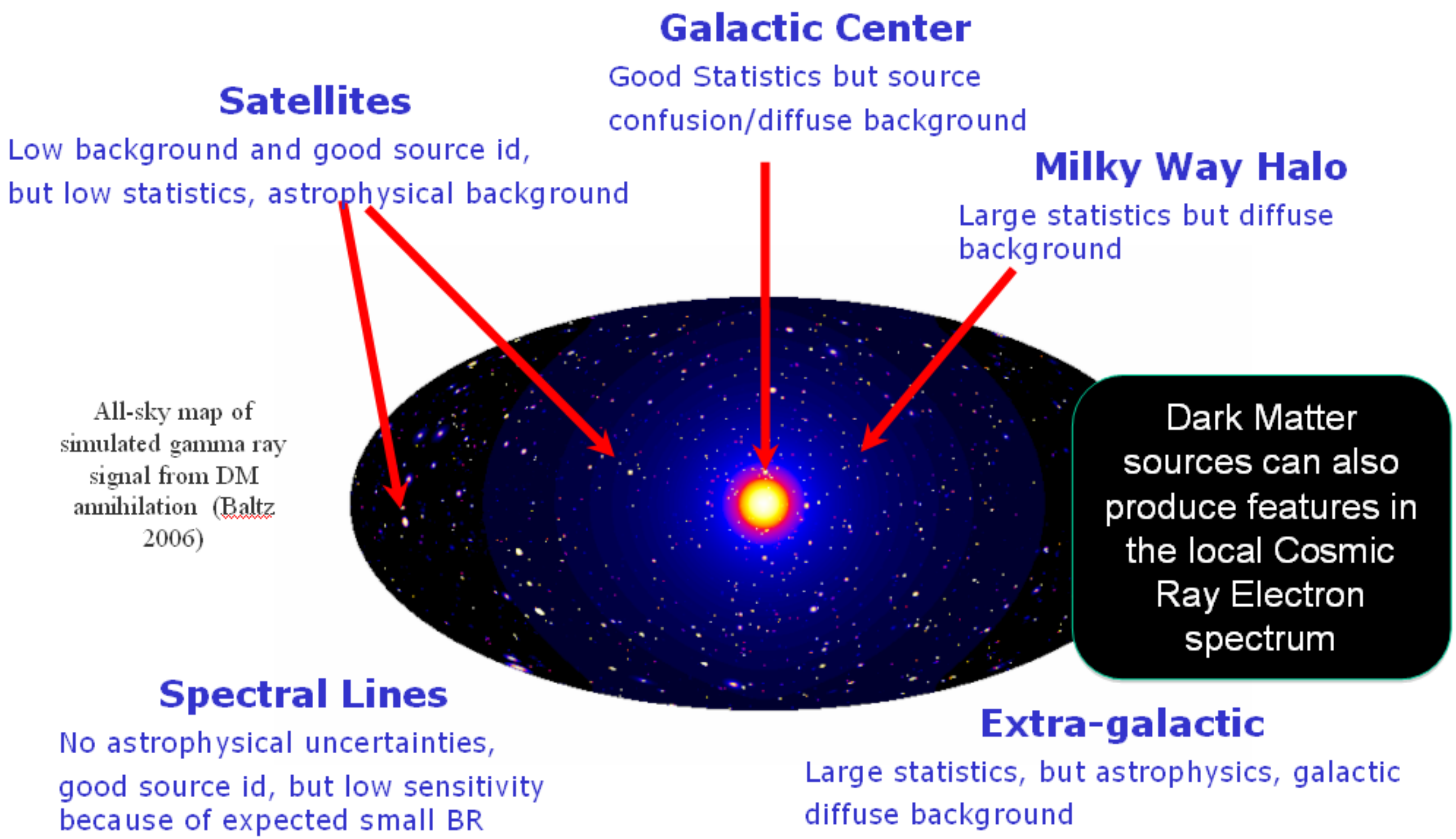
The EBL



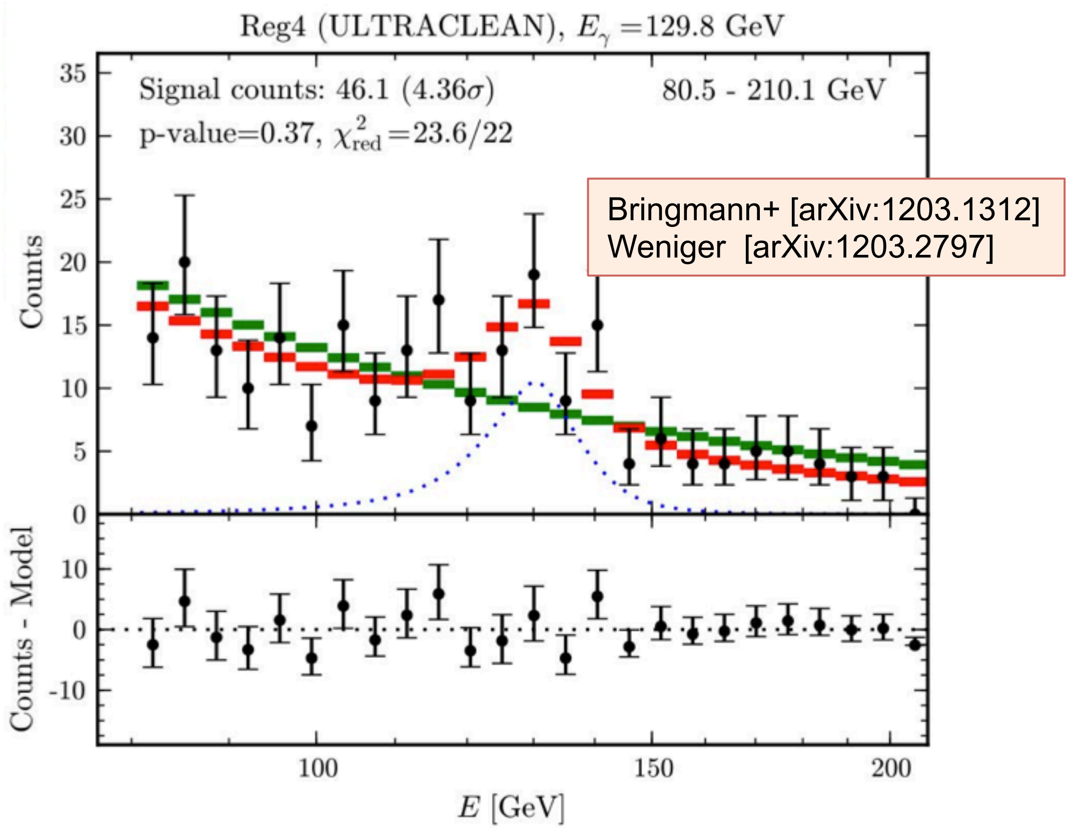
Abdhollai et al 2018

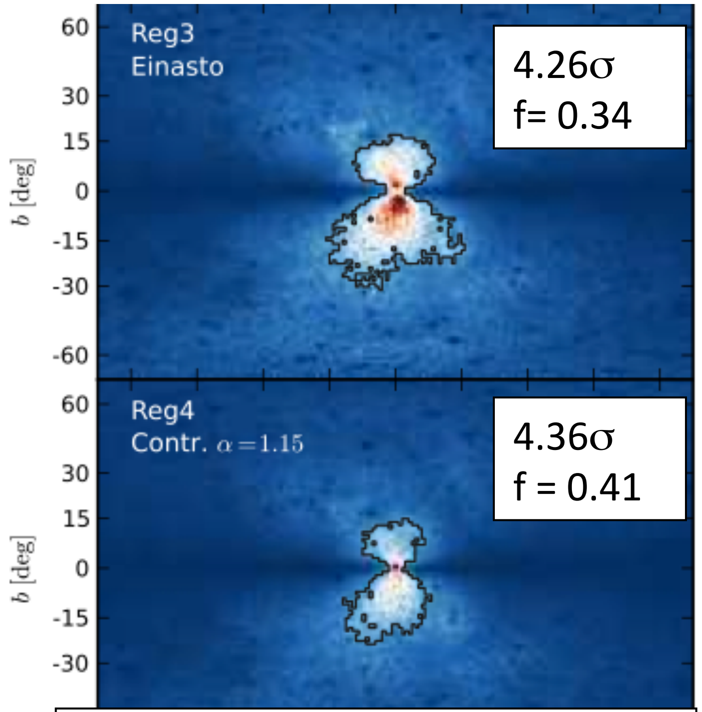
Dark Matter Searches

Gamma-ray indirect emission



Narrow Spectral Feature at 130 GeV



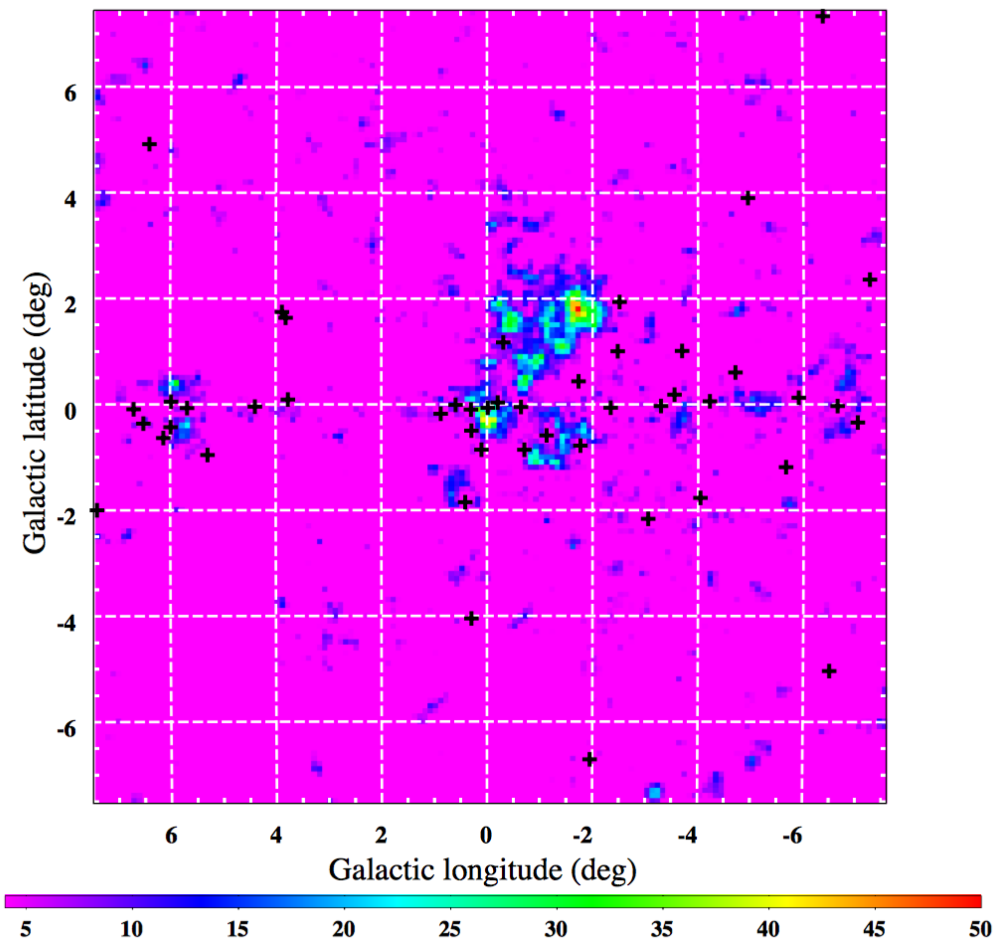


Fractional Residual (i.e., S/N):
$f = s^2 / n_s$

Bringmann et al. and Weniger showed evidence for a narrow spectral feature near 130 GeV near the Galactic center (GC) in the LAT data.

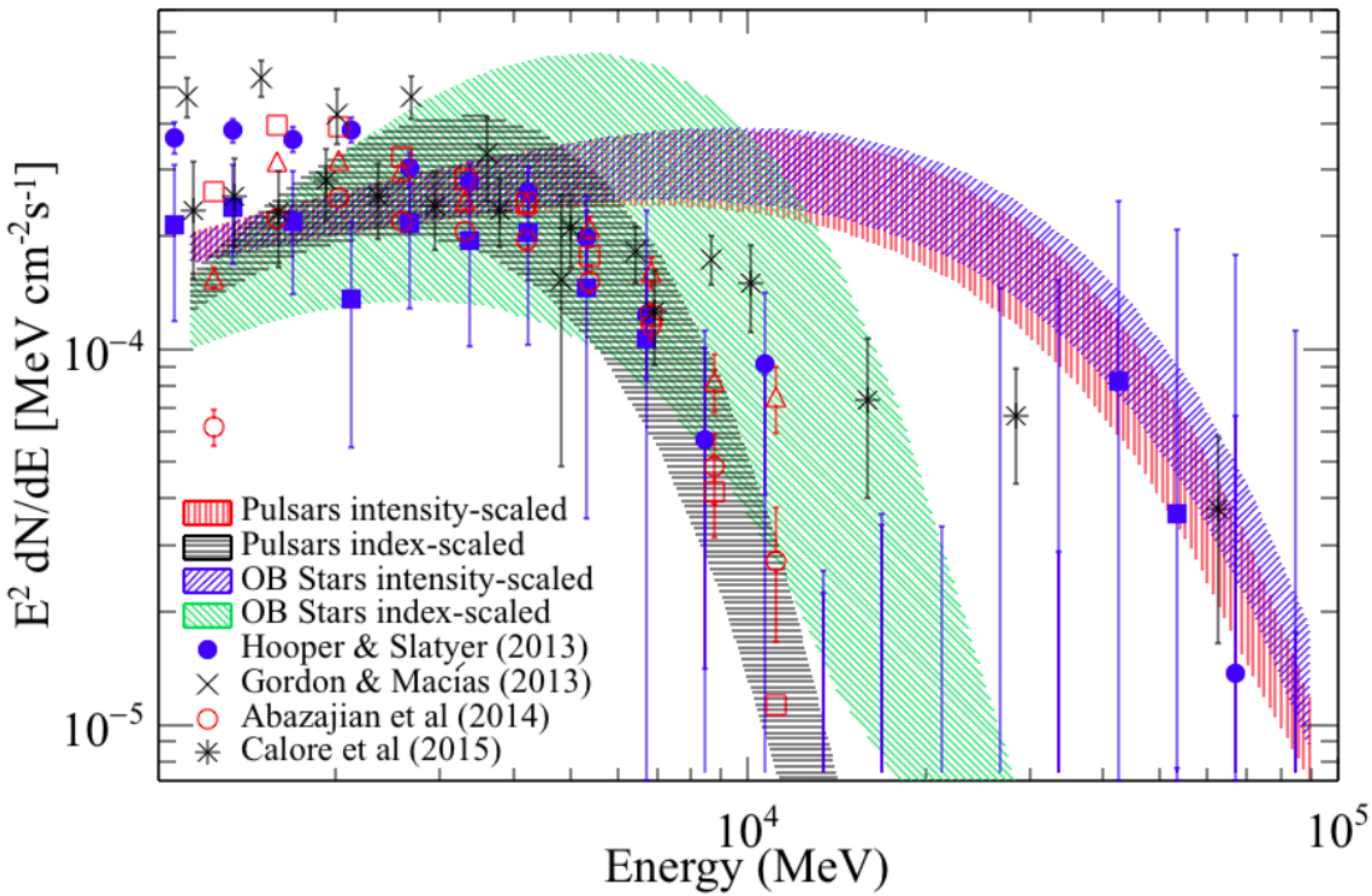
- Signal is particularly strong in 2 out of 5 test regions, shown above.
- Over 4σ local significance with S/N > 30%, up to ~60% in optimized ROI.
- Some indication of double line (111 &130 GeV).

Dark Matter searches – Galactic Center



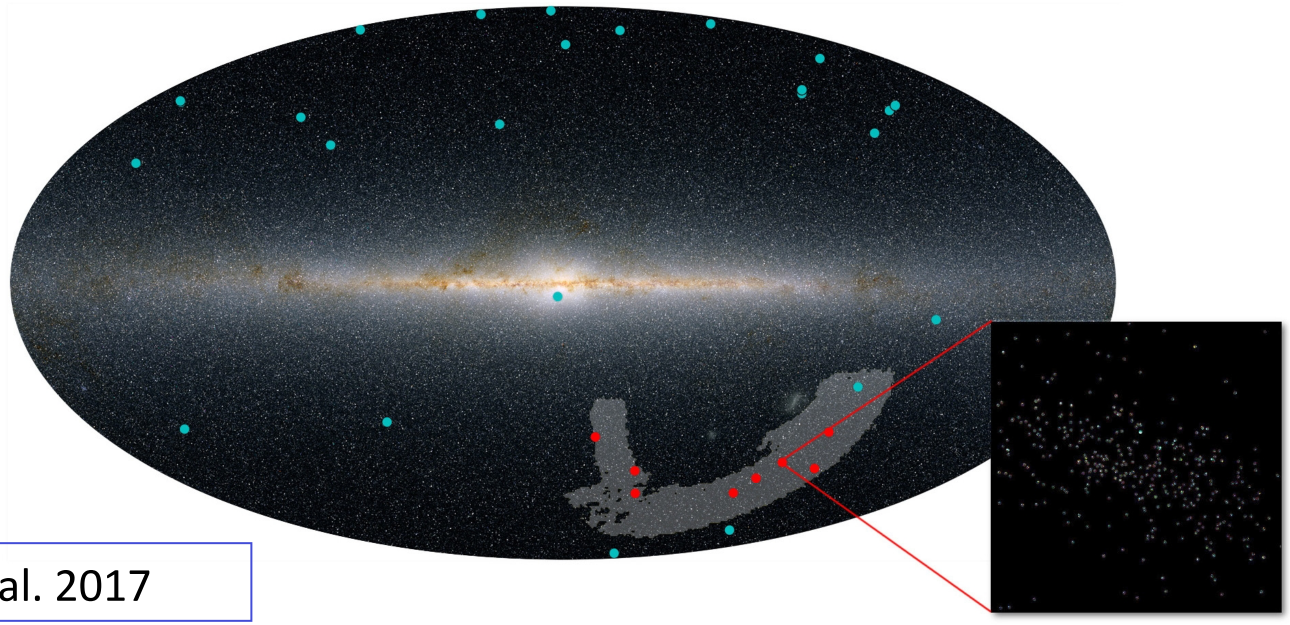
Ackermann, M. et al. 2017

Dark Matter searches – GC

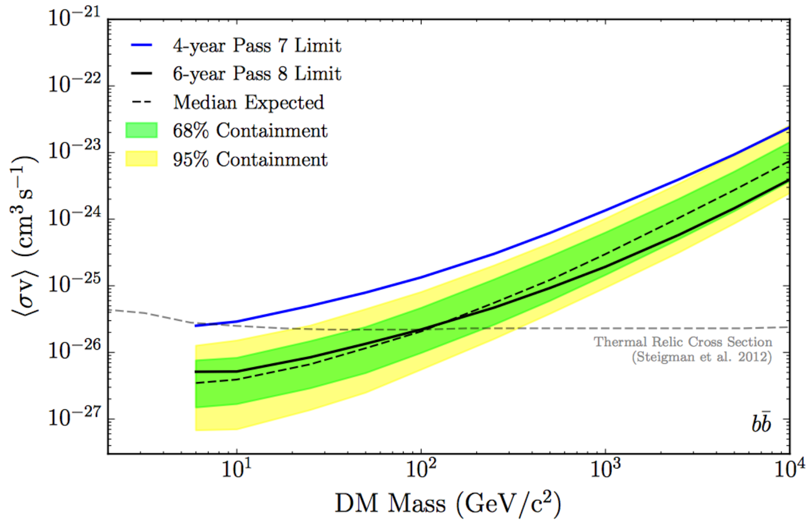


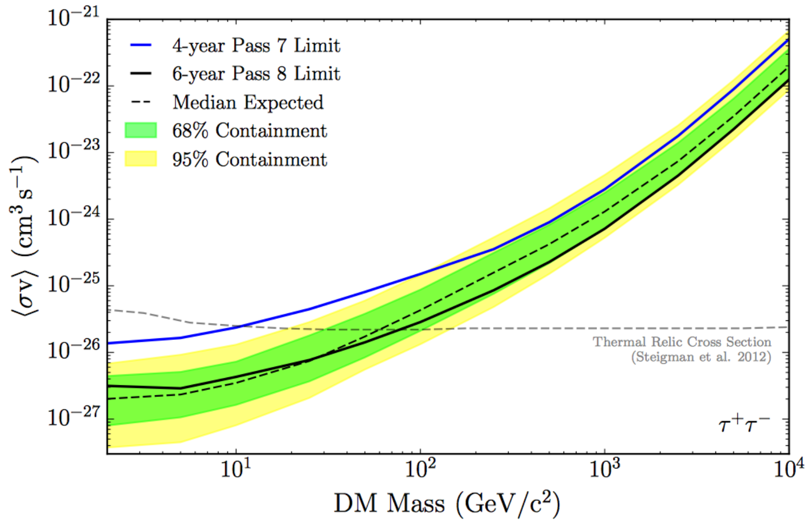
Ackermann, M. et al. 2017

Dark Matter searches – Dwarfs Galaxies

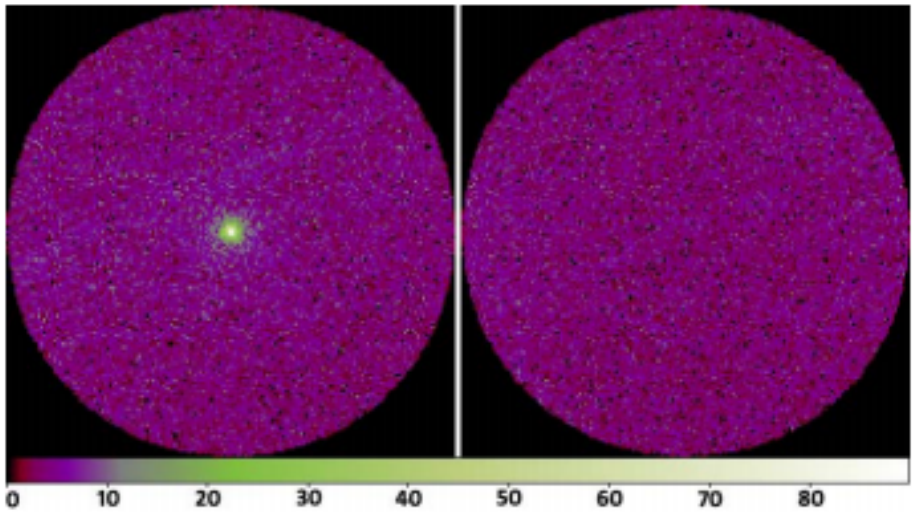


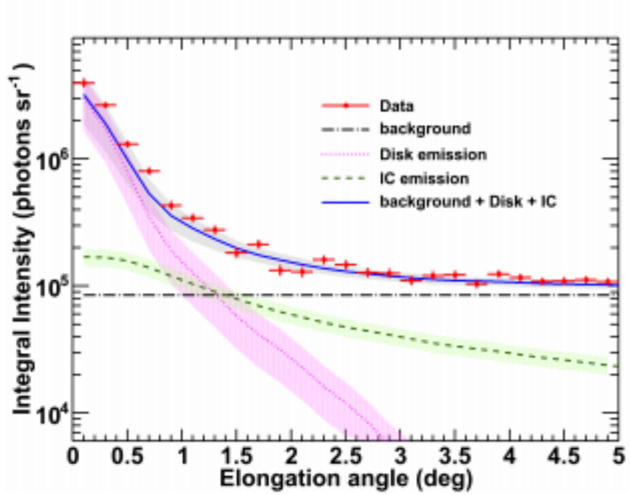
Albert, A. et al. 2017

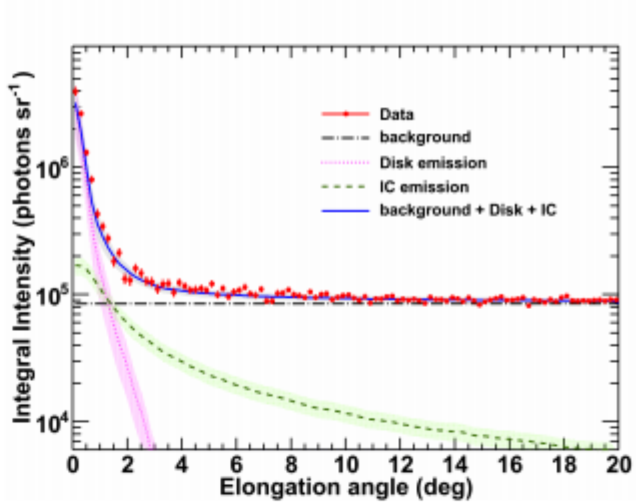




The Quiet Sun

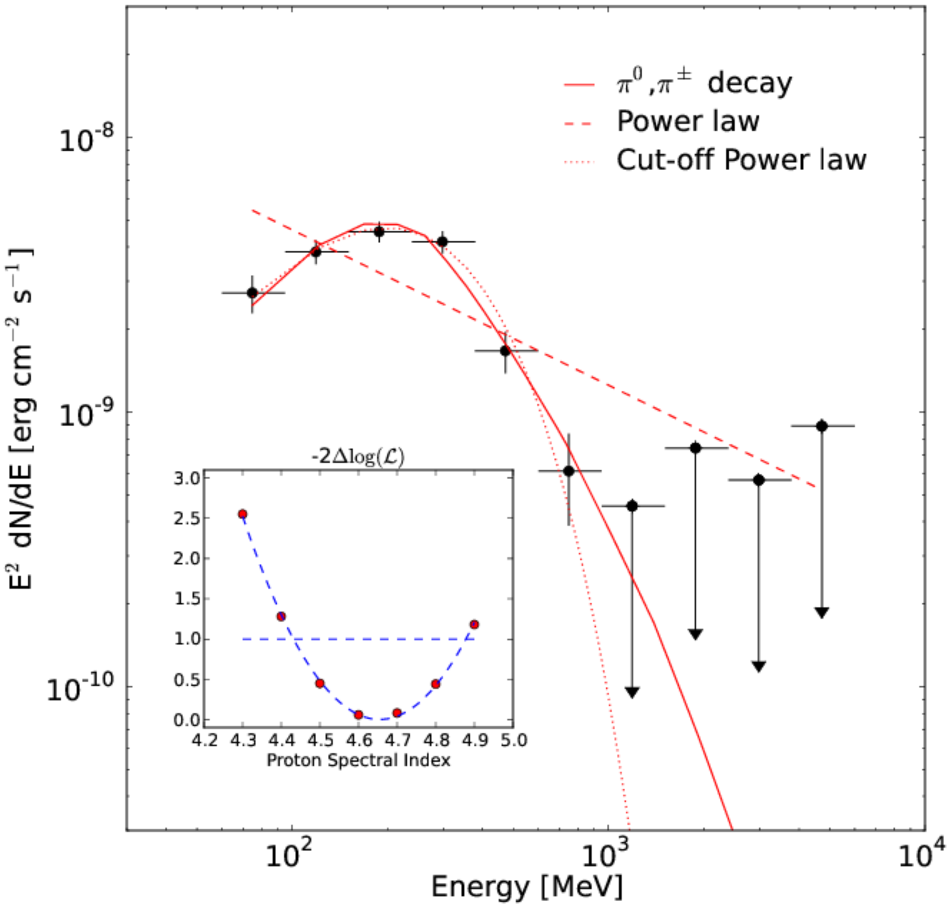


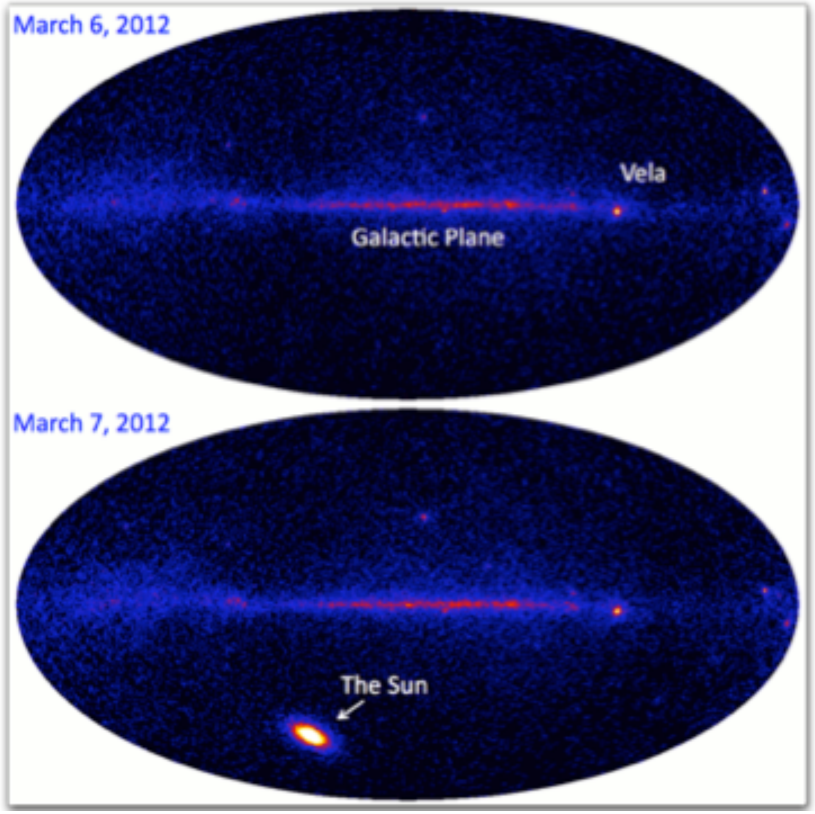




Abdo, A. A. et al. 2011

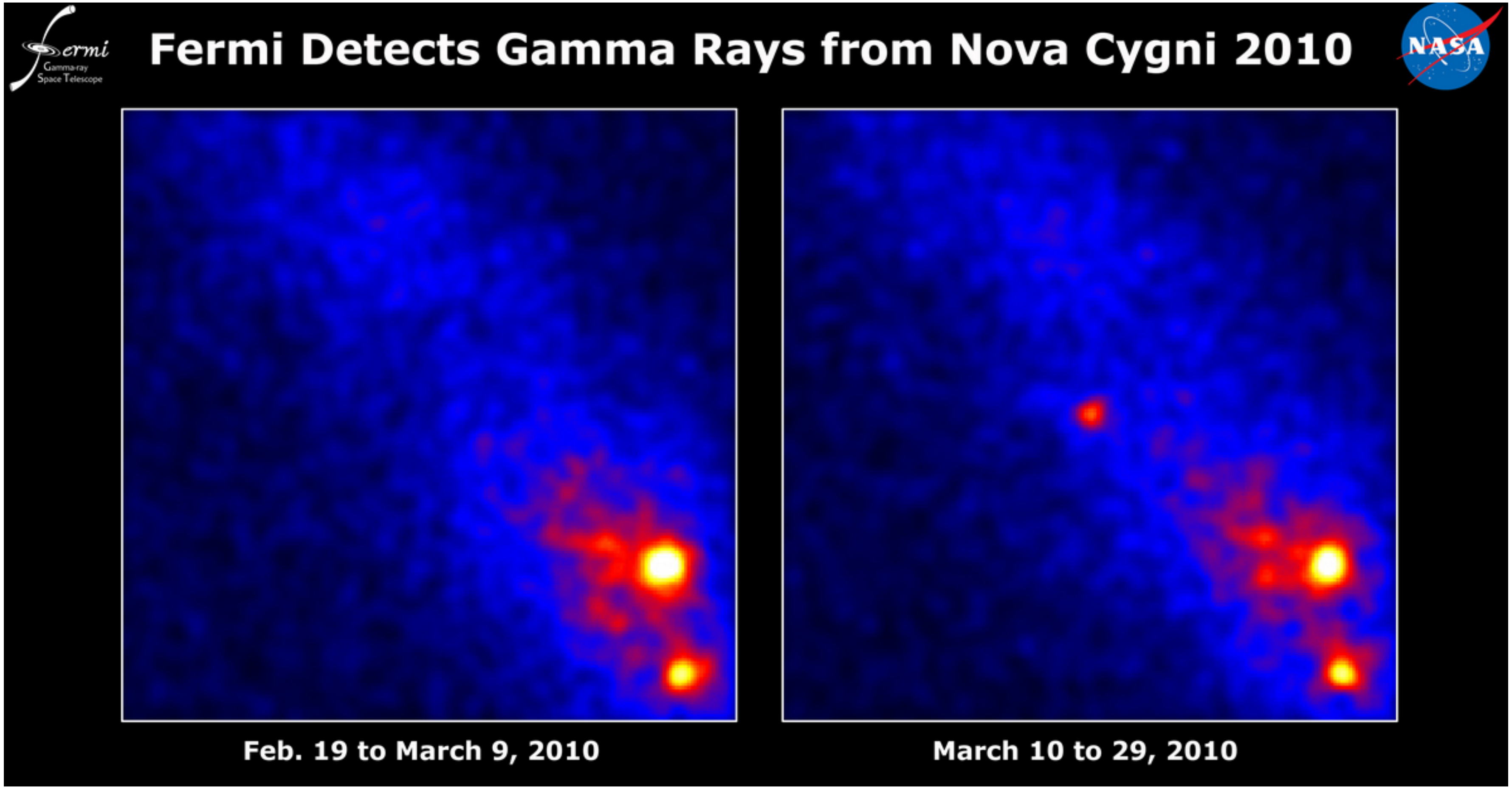
Solar Flares





Ajello, M. et al. 2014

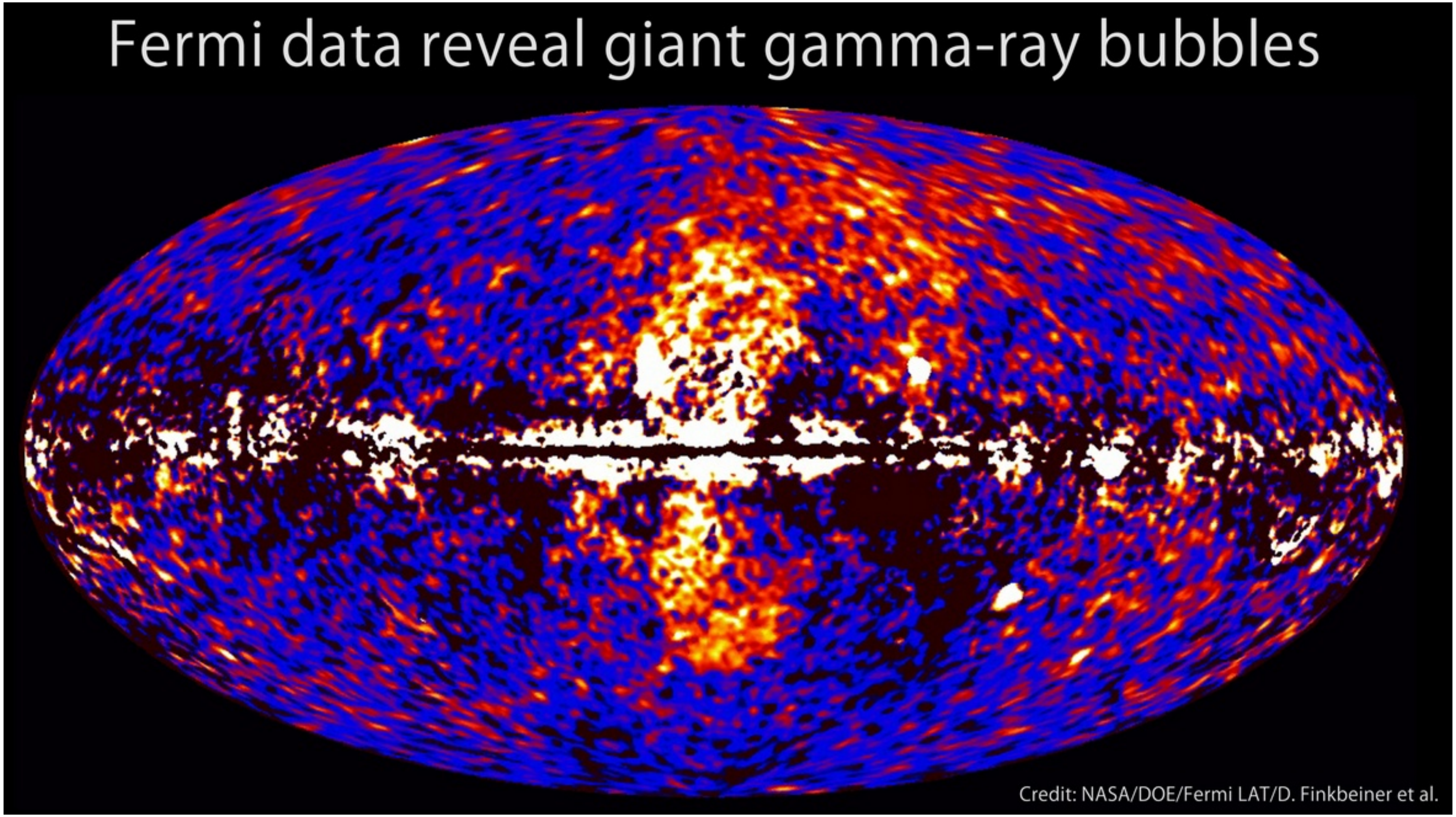
Surprise! Nova emitting in Gamma Rays!



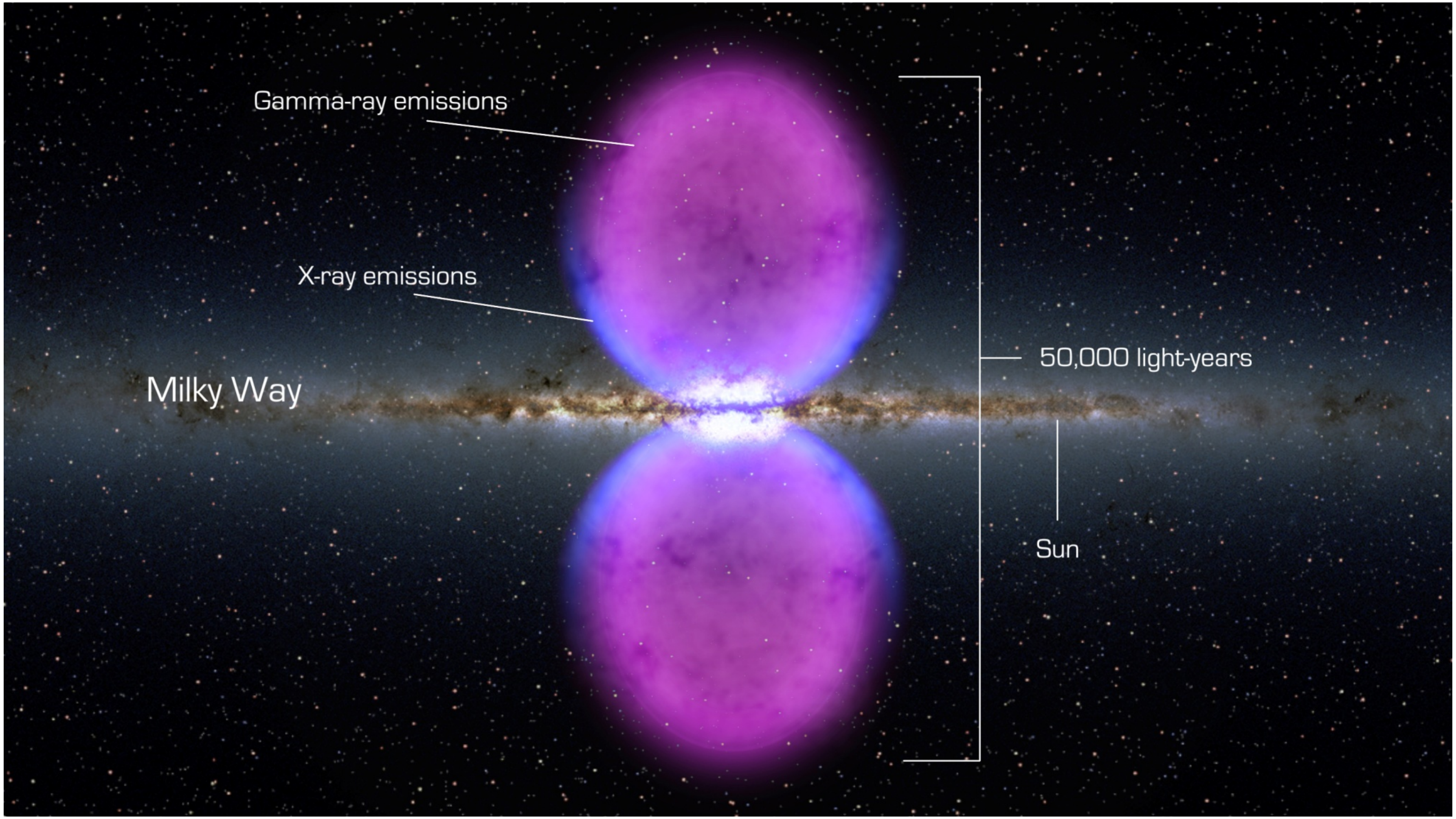
Abdo, A. A. et al. 2010

Gamma Ray Novae

Surprise! The Fermi Bubbles



Fermi bubbles



LAT team analysis: Ackermann, M. et al. 2017

Scientific Highlights of the LAT